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# Photon Cross Section Studies of Nickel Based Alloys and Special Alloys at Energies 42.0 Kev - 59.54 Kev And 145.4 Kev – 661.6 Kev.

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**ABSTRACT :**
The Photon cross section studies of nickel based alloys and special alloys are measured using gamma ray spectrometry based NaI (TI) scintillation detector with four energies, i.e., 42.0 KeV, 59.54 KeV and 145.4 KeV, 661.6 KeV respectively. The samples, such as nickel based alloys and special alloys are collected from various manufacture companies in INDIA. Photon cross section values are measured from the experiment and compared with theoretical values of Strom-Isreal and Veigele by the using of XCOM programme. Experiment values are very good agreement with theoretical values.

**Keywords :** Photon cross section studies, Special alloys, energies 42.0 KeV, 59.54 KeV and 145.4 KeV, 661.6 KeV.

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## I. INTRODUCTION :

Because of having various uses in the fields like Industry, Education, Agriculture, Health etc., the study of the interaction of photons with matter has gained more important role in recent years. In the involvement of researchers around the globe we have got literature about many of effective atomic numbers ($Z_{eff}$) for total and partial photon interactions. The effective atomic numbers ($Z_{eff}$) for the total and partial gamma ray interactions in alloys is having equally important. The absorption and scattering of gamma-rays in all materials are related to value of $Z_{eff}$ of materials and the energy of photons. In this all interactions, there will have a energy transfer from photon to matter. Theoretical and experimental studies have been reported in a wide range of energies from a few KeV up to several GeV. Although, the several researchers have been carried out good research in this interaction study, still there is many interactions have to study. In the present study we have reported the results of Scattering cross sections and Incoherent scattering cross sections of special alloys (barns/atom) at two energies, i.e., 145.4 KeV and 661.6 KeV. Along with the study of Scattering cross section (of barns/atom), we have studied Nickel based alloys, photoelectric & Interpolated total effective atomic numbers ($Z_{eff}$) at energies 42.0 KeV and 59.54 KeV.

## II. EXPERIMENTAL METHODS :

Using gamma ray spectrometer, in order to carry out systematic studies on the aspects which are mentioned above, it is required to conduct transmission experiments, for the measurement of total photon cross sections in elements, alloys and mixtures with an aim to estimate photoelectric and scattering cross sections and effective atomic numbers. Transmission experiments using a good geometry setup in conjunction with a PC based multi-channel analyser was conducted in this laboratory. The incoherent scattering cross section and scattering cross section values are measured from experiment and compared with theoretical values of Strom-israel and Veigele by the using XCOM programme.

In the present experimental investigation scintillation spectrometer consists of a thallium activated sodium iodide thin crystal. Optically coupled to photomultiplier along with a preamplifier, a linear amplifier and PC based multi-channel analyser is employed for the detection of X- and Gamma Rays. Gamma rays are well collimated using collimators of cylindrical shape and a circular aperture of 6mm diameter between the source and the detector. The detector was shielded by a lead screen to reduce the radiation coming directly from the source and scattered from the surroundings. The attenuation measurements were made with multichannel analyser. The experimental setup is shown in fig.1.

Figure.1: Block Diagram of Gamma-Ray absorption setup

The radioactive isotopes used in the present investigation are listed in the Table 1, along with their energies and half-lives. These radioactive isotopes Barium ($^{133}$Ba), Cesium ($^{137}$Cs), Europium($^{152+154}$Eu), Cerium ($^{141}$Ce), were obtained from the BRIT, Bhabha Atomic Research Centre, Trombay, Mumbai, India and Americium ($^{241}$Am) of strength 30mCi source obtained from isotope division, Americium Laboratories, Americium, Buckinghamshire, England, U.K.

| Sl.No: | Radioisotope | Half-life Time | Energy of the Photons selected in KeV[a] | |
|---|---|---|---|---|
| | | | X-Rays | Y-Rays |
| 1 | $^{241}$Am | 433 Years | -- | 59.54 |
| 2 | $^{133}$Ba | 10.7 Years | 30.85 | 81 |
| 3 | $^{(142+154)}$Eu | 16.0 Years | 42 | -- |
| 4 | $^{141}$Ce | 32.5 Days | -- | 145.4 |
| 5 | $^{137}$Cs | 30.17 Years | 32.1 | 661.6 |

( [a] C.M. Leadere and V.S. Shirly. Tables of Isotopes Wiley New Yark )

**Table 1:** Radio Isotopes and photon energies used in the present work

The linearity of the spectrometer was studied separately with thick and thin NaI (TI) crystal detectors, the spectral distribution between the pulse height and the photon energy using the standard source are shown in figure.2. The results plotted in figure.2, shown an excellent linearity over the photon energy region of interest.

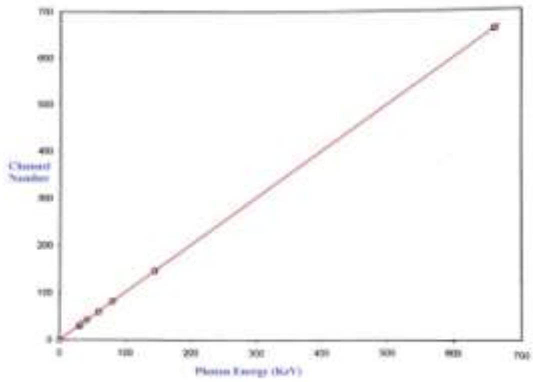

Figure.2 : Energy-Linearity of the [ NaI (TI) detector ] Spectrometer

In the present study as a samples we have taken Nickel based alloys, i.e., Superimphy, Inconel, Anhyster-DS, Invar and Telphy and the special alloys SuperniC-274, MDN-174, MDN-250, Super Heat-80, Soft Mag-48B, BT-9, Titan-31, BT 5-1, OT 4-1, BT 3-1, Titan 12, Titan 15. These alloys were obtained as gift samples from Mishra Dhatu Nigam Limited, super alloys projects, Hyderabad, India. And Nimonic-90 and S.Steel are the gift samples from D.M.R.L., Hyderabad, India. For the experiment the sample alloy was cold rolled under uniform pressure and uniform foils were obtained. These uniform foils were cut into rectangular pieces of various sizes and thicknesses. The mass of the foils was determined by the same microbalance and was corrected to third decimal place. The thickness was measured using a micrometre whose least count is 0.001 cm. After knowing the mass and thickness of the foil the mass per unit area was computed. Alloy foils of various thicknesses (gm/cm$^2$) used in the present investigation ranges from 50 mg/cm$^2$ to 1000 mg/cm$^2$, such that the transmission ($I/I_0$) lies between 0.1 to 0.6.

## III. ANALYSIS OF DATA :

In this work the data obtained from experimental procedure were analysed by using the standard formulations. The mass attenuation coefficients for wrought Nickel Base alloys at different energies were determined by performing scattering experiments, and by using semi empirical relations were the experimental values are compared.

$$I = I_0 \exp(-\mu_m t) \qquad (1)$$

Where $I_0$ and I are the un-attenuated and attenuated photon intensities and the sample thickness is t(g/cm$^2$)and the linear mass attenuation coefficient is $\mu_m = \mu/\rho$ (cm$^2$/g).

For any chemical compound or mixture of elements, the mixture rule will give the total mass attenuation coefficient $\mu_m$.

$$\mu_m = \Sigma_i W_i (\mu_m)_i \qquad (2)$$

where, $W_i$ is the weight fraction ( the proportion by weight ) $(\mu_m)$ is the mass attenuation coefficient of $i^{th}$ element.

For a material composed of multi element the fraction by weigh is given by,

$$w_i = \frac{n_i A_i}{\sum_i n_i A_i} \qquad (3)$$

Where $A_i$ is the atomic weight of the $i^{th}$ element and $n_i$ is the number of formula units.

The total atomic cross-section ($\sigma_t$) for materials can be obtained from the measured values of µm using the following relation

$$\sigma_t = \frac{\mu_m N}{N_A} \qquad (4)$$

Where $N = \sum_i n_i A_i$ atomic mass of materials, $N_A$ is the Avagadro's number.

The total electronic cross-section ($\sigma_e$) for the element is expressed by the following equation

$$\sigma_e = \frac{1}{N_A} \sum \frac{f_i N_i}{Z_i} (\mu_m)_i = \frac{\sigma_i}{Z_{eff}} \qquad (5)$$

Where $f_i$ denotes the fractional abundance of the element I with respect to the number of atoms such that f1+f2+f3+f4+….fi =1 $Z_i$ is the atomic number of $i^{th}$ element

The total atomic cross-section ($\sigma_t$) and total electronic cross-section ($\sigma_e$) are related to the effective atomic number ($Z_{eff}$) of the material through the following relation

$$Z_{eff} = \frac{\sigma_t}{\sigma_e} \qquad (6)$$

Finally, the average distance between two successive interactions, called the photon mean free path ($\lambda$), is given by

$$\lambda = \frac{\int_0^\infty x \ \exp(-\mu x) dz}{\int_0^\infty \exp(-\mu x) dx} = \frac{1}{\mu} \qquad (7)$$

Where ($\mu_l$) is the linear attenuation coefficient and x is the absorber thickness.

In the present Measurement the statistical error is limited to less than 1% by collecting a sufficient number of counts under the photo peak for the selected region of interest (ROI). The percentage deviation due to the non-uniformity of the absorbers was estimated using the relation. This has been minimized by following the counting sequence of Conner et all.(1970). The errors due to this method will be almost of the order of 0.5%. The extrapolation technique described earlier eliminates the error due to multiple scattering. The overall errors introduced on the total photon mass attenuation coefficients are thus around 2%.

## IV. RESULTS AND DISCUSSION :

Utilising the good geometry setup and employing the methods already discussed, the mass attenuation coefficients were measured in twelve special alloys at two energies 145.5 KeV and 661.6 KeV are represented in table 2a, and nine nickel based alloys at two energies 42.2 KeV and 59.54 KeV are presented in the table 3a, where also, the experimental results are compared with Strom &Isreal, Vegele and Hubbels theoretical values.

### 1.1. Scattering and Incoherent scattering cross-sections:

The scattering and Incoherent scattering cross sections by subtracting the minor contribution of photoelectric cross section and photoelectric plus coherent scattering cross sections respectively from the total experimental cross sections, where the photoelectric plus coherent scattering contribution is less than 20% of the total cross section.

| Sl.No | Name of the alloy | Scattering Cross Sections | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Hubbell et.al | | Strom&Isreal | | Vegele | | Experimental | |
| | | 145.4 KeV | 661.6 KeV | 145.4 KeV | 661.6 KeV | 145.4 KeV | 661.6 KeV | 145.4 KeV | 661.6 KeV |
| 1 | Supernic 274 | 14.55 | 7.626 | 15.49 | 7.610 | 15.63 | 7.623 | 15.69 | 7.678 |
| 2 | MDN 174 | 12.78 | 6.661 | 12.73 | 6.648 | 12.90 | 6.656 | 12.94 | 6.853 |
| 3 | MDN 250 | 13.71 | 7.045 | 13.66 | 7.038 | 13.84 | 7.031 | 13.66 | 7.096 |
| 4 | Super Heat 80 | 13.64 | 7.035 | 13.63 | 7.021 | 13.74 | 6.922 | 13.55 | 6.807 |
| 5 | Soft Mag 48B | 12.31 | 6.421 | 12.30 | 6.410 | 12.38 | 6.418 | 12.33 | 6.436 |
| 6 | BT – 9 | 10.90 | 5.954 | 10.91 | 6.044 | 11.00 | 5.752 | 10.94 | 5.581 |
| 7 | Titan 31 | 10.39 | 6.041 | 10.39 | 5.810 | 10.48 | 5.541 | 10.51 | 5.536 |
| 8 | BT 5-1 | 11.15 | 5.892 | 11.14 | 5.857 | 11.19 | 5.861 | 11.08 | 5.851 |
| 9 | OT 4-1 | 10.60 | 5.732 | 10.58 | 5.752 | 10.64 | 5.638 | 10.52 | 5.629 |
| 10 | BT 3-1 | 10.75 | 5.957 | 10.76 | 5.940 | 10.85 | 5.693 | 11.10 | 5.688 |
| 11 | Titan 12 | 10.65 | 5.684 | 10.65 | 5.667 | 10.69 | 5.671 | 10.63 | 5.663 |
| 12 | Titan 15 | 10.64 | 5.672 | 10.64 | 5.666 | 10.69 | 5.670 | 10.71 | 5.631 |

**Table 2a:** Scattering cross section of special alloys (barns/atom) at energy (145.4 KeV) and (661.6 KeV).

Thus the scattering cross-sections ($\sigma_{sca}$) and incoherent scattering cross sections ($\sigma_{incoh}$) were obtained in all the twelve special alloys at 145.4 KeV and 661.6 KeV photon energies. The Scattering Cross sections values are presented in Table 2a, along with theoretical values of Hubbell et al.(1968) and Storm and Israel (1970).

And the incoherent scattering cross sections values are presented in Table 2b, along with theoretical values of Hubbell et al.(1968) and Storm and Israel (1970).

| Sl.No | Name of the alloy | Incoherent Scattering Cross Sections | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Hubbell et.al | | Strom&Israel | | Veigele | | Experimental | |
| | | 145.4 KeV | 661.6 KeV | 145.4 KeV | 661.6 KeV | 145.4 KeV | 661.6 KeV | 145.4 KeV | 661.6 KeV |
| 1 | Supemic 274 | 12.494 | 7.461 | 12.550 | 7.458 | 12.544 | 7.430 | 12.594 | 7.484 |
| 2 | MDN 174 | 11.093 | 6.572 | 11.071 | 6.563 | 11.150 | 6.258 | 11.185 | 6.444 |
| 3 | MDN 250 | 11.683 | 6.938 | 11.682 | 6.932 | 11.745 | 6.665 | 11.594 | 6.727 |
| 4 | Super Heat 80 | 11.675 | 6.931 | 11.713 | 6.923 | 11.713 | 6.923 | 11.555 | 6.808 |
| 5 | Soft Mag 48B | 10.785 | 5.336 | 10.731 | 6.330 | 10.731 | 6.330 | 10.686 | 6.357 |
| 6 | BT – 9 | 9.641 | 5.688 | 9.651 | 5.684 | 9.646 | 5.682 | 9.597 | 5.512 |
| 7 | Titan 31 | 9.321 | 5.488 | 9.324 | 5.482 | 9.324 | 5.481 | 9.351 | 5.477 |
| 8 | BT 5-1 | 9.816 | 5.794 | 9.826 | 5.790 | 9.824 | 5.788 | 9.724 | 5.778 |
| 9 | OT 4-1 | 9.478 | 5.583 | 9.482 | 5.77 | 9.482 | 5.557 | 9.372 | 5.549 |
| 10 | BT 3-1 | 9.553 | 5.633 | 9.561 | 5.628 | 9.559 | 5.625 | 9.783 | 5.630 |
| 11 | Titan 12 | 9.533 | 5.616 | 9.537 | 5.610 | 9.538 | 5.609 | 9.480 | 5.602 |
| 12 | Titan 15 | 9.530 | 5.614 | 9.535 | 5.609 | 9.535 | 5.608 | 9.557 | 5.570 |

**Table 2b**: Incoherent Scattering cross section of special alloys (barns/atom) at energy (145.4 KeV) and (661.6 KeV).

The theoretical values of Hubbellet al. are almost consistent with theoretical values of Storm and Israel (1970) except in few cases. There is good agreement between the theory and experiment as evident from the tables. The experimental values are also good agreement with the compiled values of Vegele (1973).

### 1.2. Total and partial effective atomic numbers:

The$Z_{eff}$ and $Z_{poto}$values of Nickel Based alloys at two photon energies 42.0 KeV and 59.5 KeV and the scattering values of special alloys at energies at 145.4 KeV and 661.6 KeV are presented in table 3a, and table 3b, respectively. $Z_{photo}$values for nickel based alloys at two energies 42.0 and 59.54 KeV calculated from Hine's relations along with interpolated values. Similarly $Z_{scat}$ the effective atomic umber for scattering is given by Hine (1952).

| Sl. No | Name of the alloy | 42.0 KeV | | 59.54 KeV | | Photoelectric effect Hine's Relation |
|---|---|---|---|---|---|---|
| | | Interpolated ($Z_{eff}$) | Photoelectric ($Z_{photo}$) | Interpolated ($Z_{eff}$) | Photoelectric ($Z_{photo}$) | |
| 1 | Superimphy | 27.15 | 27.16 | 27.22 | 27.22 | 27.3 |
| 2 | Anlyster – M | 27.25 | 27.47 | 27.56 | 27.38 | 27.59 |
| 3 | Inconel | 27.16 | 27.18 | 27.20 | 27.12 | 27.29 |
| 4 | Nimonic - 90 | 26.37 | 27.36 | 26.87 | 27.27 | 27.42 |
| 5 | Anlyster – DS | 26.57 | 26.96 | 26.96 | 26.87 | 27.01 |
| 6 | Invar | 26.62 | 26.67 | 26.72 | 26.62 | 26.76 |
| 7 | Delivery – P | 26.75 | 25.72 | 26.75 | 26.64 | 26.78 |
| 8 | Telphy | 25.42 | 25.92 | 25.95 | 25.85 | 25.95 |
| 9 | S.Steel | 25.57 | 25.83 | 25.80 | 25.79 | 25.84 |

**Table 3a:** Interpolated total effective atomic numbers ($Z_{eff}$) and Photoelectric effective atomic numbers ($Z_{photo}$) of Nickel based alloys at 42.0 Kev and 59.54 KeV.

| Sl.No | Name of the alloy | Experimental Results | | | | |
|---|---|---|---|---|---|---|
| | | Scattering effective atomic numbers ($Z_{scatt}$) | | Incoherent effective atomic numbers ($Z_{incoh}$) | | Hines relation for $Z_{incoh}$ |
| | | 145.4 KeV | 661.6 KeV | 145.4 KeV | 661.6 KeV | |
| 1 | Supemic 274 | 29.20 | 29.24 | 29.36 | 29.35 | 29.38 |
| 2 | MDN 174 | 25.64 | 25.68 | 25.78 | 25.74 | 25.86 |
| 3 | MDN 250 | 27.10 | 27.15 | 27.26 | 27.24 | 27.31 |
| 4 | Super Heat 80 | 27.05 | 27.21 | 27.29 | 27.28 | 27.27 |
| 5 | Soft Mag 48B | 24.74 | 24.81 | 24.86 | 24.82 | 24.94 |
| 6 | BT – 9 | 22.19 | 22.26 | 22.36 | 22.36 | 22.38 |
| 7 | Titan 31 | 21.38 | 21.42 | 21.54 | 21.52 | 21.62 |
| 8 | BT 5-1 | 22.62 | 22.70 | 22.79 | 22.78 | 22.83 |
| 9 | OT 4-1 | 21.81 | 21.89 | 21.92 | 21.90 | 21.97 |
| 10 | BT 3-1 | 22.01 | 22.07 | 22.18 | 22.18 | 22.18 |
| 11 | Titan 12 | 21.87 | 21.92 | 21.96 | 21.94 | 21.98 |
| 12 | Titan 15 | 21.84 | 21.89 | 21.94 | 21.94 | 21.96 |

**Table 3b:** Scattering effective atomic numbers ($Z_{scatt}$) and Incoherent effective atomic numbers ($Z_{incoh}$) of special alloys at 145.4 KeV and 661.6 KeV.

In fact, $Z_{eff}$ value decreases as energy increases and is supposed to reach to a constant value (Partha Sarathi 1974), But the above statement cannot be confirmed from the present results in view of the experimental errors. This may be due to narrow range of atomic numbers constitute the alloys selected in the present investigation. However from the present experimental results there appears to be a decreasing trend in $Z_{eff}$ value with increasing energy. From these tables it can also be seen that $Z_{pho}$ is near to $Z_{eff}$ at low photon energies where, photoelectric effect is dominant and as energy increases the $Z_{incoh}$ value slowly approaches the $Z_{eff}$ value. This trend occurs, as at low energy photoelectric cross sections dominate and at higher energies incoherent scattering cross sections dominate the photoelectric effect plus coherent scattering. This effect can be observed from the present result. However, as the variation in not much and is within the range of experimental errors, definite conclusions cannot be drawn in this regard. But, according to Hine any partial effective atomic number is independent of energy. In order to observe this, systematic studies are to be conducted with alloys having different elements with wide range of atomic numbers.

## V. CONCLUSIONS :

The total photoelectric cross sections that were obtained by subtraction method are in very good agreement with the theoretical values of Storm and Israel. They are also in agreement with the compilation data of Veigele within the range of errors. However, there is general agreement between various theoretical, compiled and available earlier investigations.

The extracted total photon cross sections of special and nickel based alloys are in good agreement with the theoretical predictions of Strom and Israel. The total photoelectric cross sections derive from total photon cross sections at 42.0 KeV and 59.54 KeV photon energies for nickel based alloys are in good agreement with theoretical prediction of Scofield. Similarly the total scattering and incoherent scattering cross section derived from the total photon cross section at photon energies 145.4 KeV and 661.6 KeV, for special alloys are in good agreement with the theoretical values of Hubbell et al. And Storm and Israel.

The interpolated values of partial effective atomic numbers $Z_{pho}$, $Z_{sea}$ and $Z_{incoh}$ are almost energy independent. The calculated values of $Z_{pho}$ and $Z_{incoh}$ from Hine's relations are in good agreement with the interpolated values. The references listed below have completed their work with different low energies with different samples.

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