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Gamma ray photon interaction studies of Cr in the energy range 10keV to 1500keV

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ABSTRACT

Measurements have been made to determine gamma ray attenuation coefficients very accurately by using a narrow-collimated-beam method which effectively excluded corrections due to small-angle and multiple scattering of photons. Mass (μ/ρ) and linear attenuation coefficients (μ) of Cr in the energy range 10keV to 1500keV gamma-rays photons have been measured using the HP (Ge) photon detector. The values of μ and μ/ρ thus obtained are found to be in good agreement with the theory.

Keywords Mass and linear attenuation coefficients, Gamma-rays, HP (Ge) photon detector.

INTRODUCTION

Accurate values of photon interaction parameters like mass and linear attenuation coefficients in several materials are needed in solving various problems in radiation physics and other related areas. In the last few decades there has been an increasing interest in accurate measurements of attenuation coefficients of elements or compounds for X-rays and low-energy gamma-rays. This is mainly due to the fact that careful measurements of attenuation coefficients allow important information about the composition of materials or tissues, or at least allow discrimination between materials which have a very similar composition [1].

Although a number of experimental measurements are reported in the literature [2] , the work therein actually carried out is limited to a few energy points and materials .Further, the experimental techniques used by different workers are not identical and hence it is difficult to intercompare the experimental results. A survey of other relevant measurements [3-13] reported shows that in many of these measurements the experimental results for the same elements at the same energies are somewhat inconsistent. Appreciable discrepancies between the experimental and theoretical values were observed in some of these measurements. It was therefore decided to carry out accurate measurements of photon attenuation data covering the 10-1500 keV energy range in Cr and then determines from the attenuation data the interaction parameters like mass and linear attenuation coefficients.

In the earlier work, the photons were detected by organic scintillators and total –absorption – proportional counters. The accuracy of the final results was limited by the poor efficiency of either of these detectors. A good photon detector with high-energy-resolution characteristics as used in the present measurements is an essential requirement for higher accuracy. Solid-state detectors have the high-energy-resolution characteristics necessary for such measurements to be performed accurately. The present paper reports photon interaction parameters like mass (μ/ρ) and linear attenuation coefficients (μ) of Cr in the energy range 10 keV to 1500 keV through photon transmission measurements perform under narrow-beam counting geometry with HP (Ge) as a photon detector.

EXPERIMENTAL SECTION

The monoenergetic photon radiation required for these measurements was derived from ^{203}Hg radionuclide .The source was procured as a sealed source from BARC, Trombay, Mumbai. The photon transmission measurements were done under a narrow beam counting geometry employing high resolution HP Ge solid state detector. The HPGe detector utilized in the present work is of 30.3 cc active volume and was obtained from EG2G, ORTEC USA. The detector was operated at liquid nitrogen temperature and had a good stability of the order of 0.01 % over the entire range of photon energy. The energy resolution of the detector at 279.30 keV from ^{203}Hg was about 3.3% with full width at half maxima (FWHM) being 180 eV.

The experimental set up used in the present work as shown in figure1. The experimental system consists mainly of two aluminum collimators of about 12 cm long, having internal and external diameters of 10 and 60 mm, respectively. These collimators were internally lined with 4 mm-thick perspex so as to provide a scatter-free collimated photon beam 2mm in diameter. With the present experimental system, it was established from the photon spectrum that the energy of transmitted photons did not change appreciably due to scatter or fluorescent radiation from the collimators. A provision was made midway between the collimators to introduce absorbers which were in the form of thin foils. The entire system was arranged vertically over the HP (Ge) detector, ensuring that the central axis of the collimators coincided with the central axis of the detector.

Radioactive source of ^{203}Hg had thin beryllium windows for the exit of photon radiations. The source was kept in a lead container which was provided with an aperture for the exit of photons. The source container assembly was then kept over the collimator so as to allow a narrow, well-collimated photon beam from the collimator incident normally on the absorbers. The source and the detector were well aligned with the collimators. The incident energy of photon radiations from the source was known accurately from the photon spectrum. The chosen absorbers include thin and uniform foils of high purity of chromium.

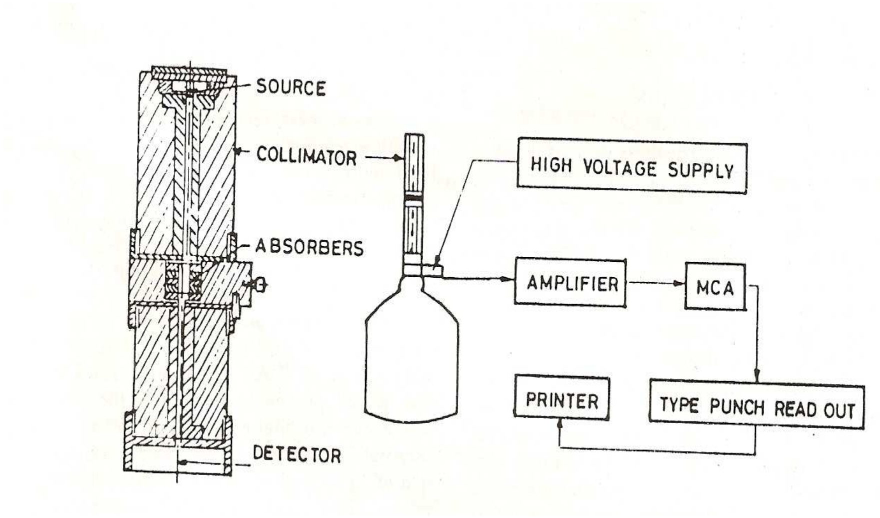
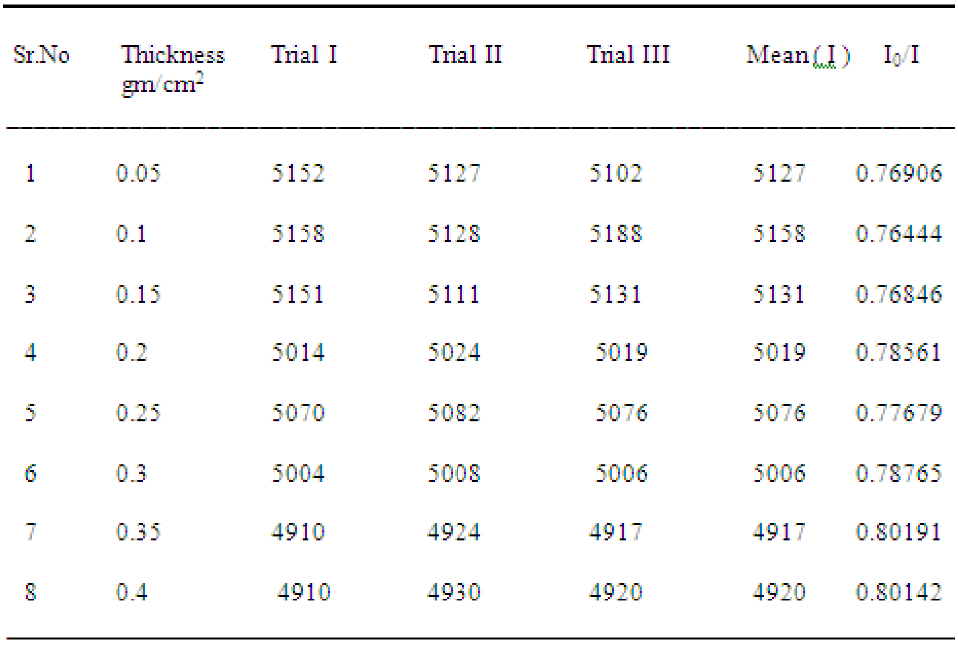


Figure. 1 Block diagram of photon counting system.

These foils were weighed accurately using a digital balance, and from their measured area the thickness proportional to the areal density in g cm^{-2} was determined. The absorbers had varying thicknesses of a few mg cm^{-2}and higher thicknesses were obtained by stacking the foils together.

Table1. Counts per 100 second for Chromium foil at 279 keV.



Sr.No	Thickness gm/cm^2	Trial I	Trial II	Trial III	Mean (I)	I_0/I
1	0.05	5152	5127	5102	5127	0.76906
2	0.1	5158	5128	5188	5158	0.76444
3	0.15	5151	5111	5131	5131	0.76846
4	0.2	5014	5024	5019	5019	0.78561
5	0.25	5070	5082	5076	5076	0.77679
6	0.3	5004	5008	5006	5006	0.78765
7	0.35	4910	4924	4917	4917	0.80191
8	0.4	4910	4930	4920	4920	0.80142

The presently used absorbers are uniform sheets of Cr, These sheets/foils were weight accurately and from their measured area, the thickness (t) in gm/cm^2 was determined in each case. The absorbers had varying thicknesses of a few mg/cm^2. The higher values of thickness were obtained by stacking required number of foils together. The absorbers used were of nuclear grade of specified purity of the order of 99.95%. No further attempts were made to ascertain the purity of these absorbers.

The schematic experimental set-up is as shown in Figure 1.

Counts recorded for various thicknesses (gm/cm^2) of Cr foils at 279, 284, 355, 362, 637, 662, 834, 1170 and 1330keV as shown in Table1 to 9 respectively.

Number of particles of radiation counted without absorber (I_0) = 3943.

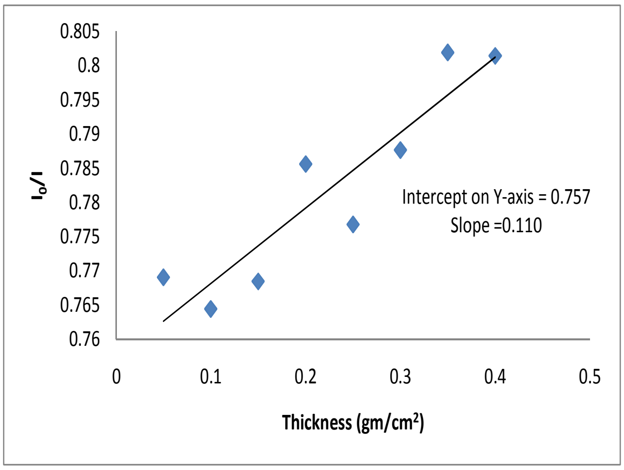


Figure 2. Thickness vs.I_0/I for the Chromium foil at 279 keV.

Table2. Counts per 100 second for Chromium foil at 284 keV.

Sr.No	Thickness gm/cm^2	Trial I	Trial II	Trial III	Mean(I)	I_0/I
1	0.05	5177	5170	5184	5177	0.7616
2	0.1	5206	5208	5210	5208	0.75710
3	0.15	5180	5182	5181	5181	0.76104
4	0.2	5071	5069	5967	5071	0.77786
5	0.25	5120	5132	5126	5126	0.76921
6	0.3	5056	5050	5062	5056	0.77986
7	0.35	4967	4965	4969	4967	0.79383
8	0.4	4965	4975	4970	4970	0.7933

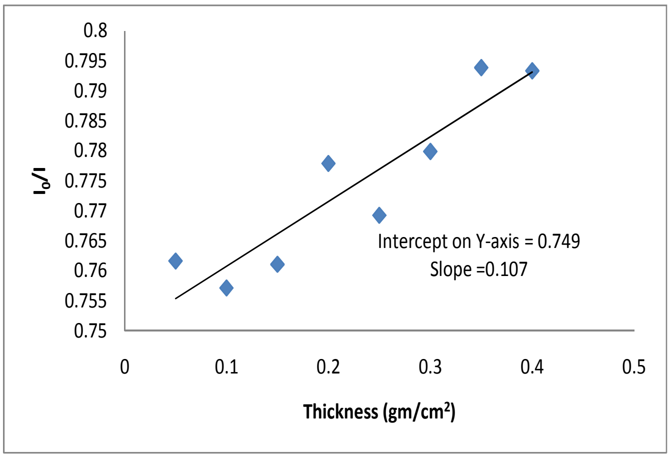
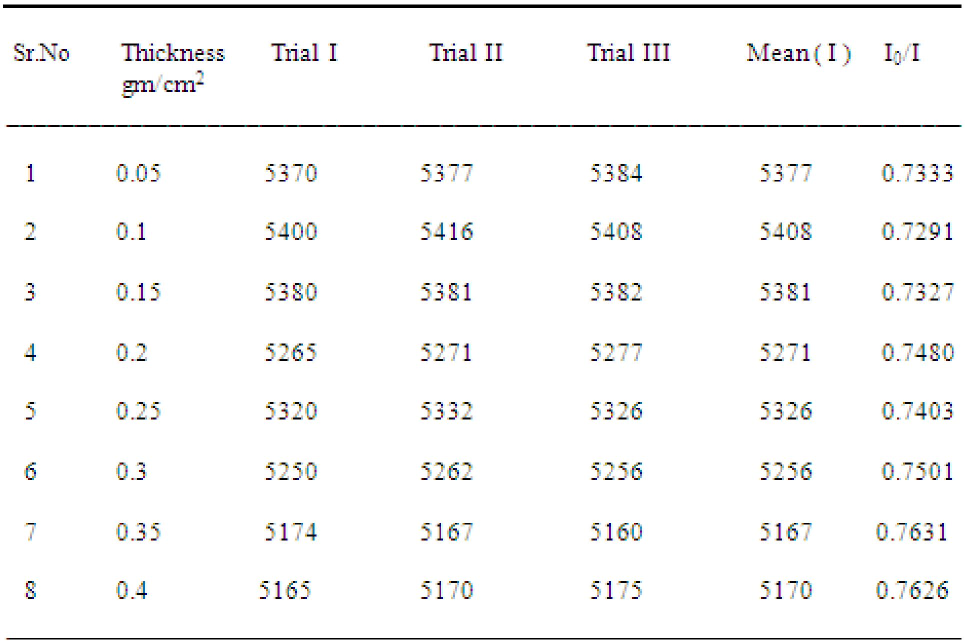


Figure3. Thickness vs.I_0/I for the Chromium foil at 284 keV.

Table3. Counts per 100 second for Chromium foil at 355 keV.



Sr.No	Thickness gm/cm^2	Trial I	Trial II	Trial III	Mean (I)	I_0/I
1	0.05	5370	5377	5384	5377	0.7333
2	0.1	5400	5416	5408	5408	0.7291
3	0.15	5380	5381	5382	5381	0.7327
4	0.2	5265	5271	5277	5271	0.7480
5	0.25	5320	5332	5326	5326	0.7403
6	0.3	5250	5262	5256	5256	0.7501
7	0.35	5174	5167	5160	5167	0.7631
8	0.4	5165	5170	5175	5170	0.7626

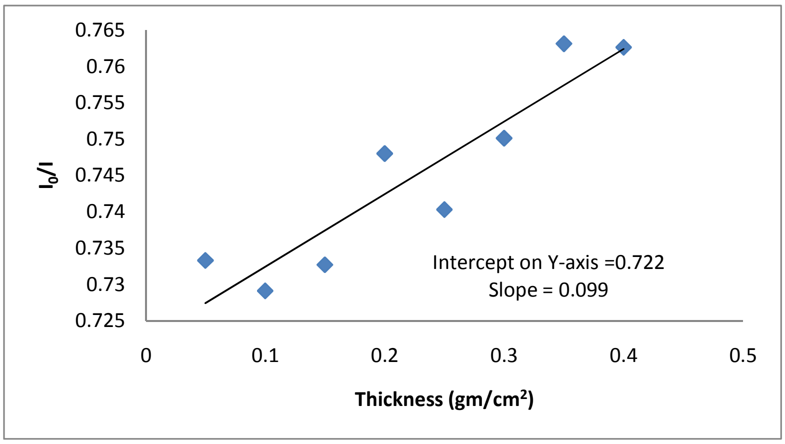


Figure 4. Thickness vs.I_0/I for the Chromium foil at 355 keV.

Table4. Counts per 100 second for Chromium foil at 362 keV.

Sr.No	Thickness gm/cm^2	Trial I	Trial II	Trial III	Mean (I)	I_0/I
1	0.05	5527	5528	5526	5527	0.71340
2	0.1	5550	5566	5558	5558	0.70942
3	0.15	5531	5530	5532	5531	0.71289
4	0.2	5423	5421	5419	5421	0.72735
5	0.25	5470	5476	5482	5476	0.72005
6	0.3	5400	5412	5406	5406	0.72937
7	0.35	5317	5310	5324	5317	0.74158
8	0.4	5530	5510	5520	5520	0.741165

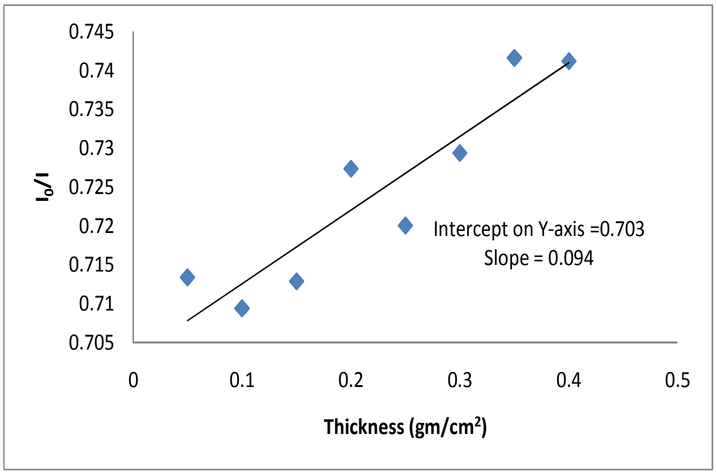


Figure 5. Thickness vs.I_0/I for the Chromium foil at 362 keV.

Table5. Counts per 100 second for Chromium foil at 637 keV.

Sr.No	Thickness gm/cm^2	Trial I	Trial II	Trial III	Mean (I)	I_0/I
1	0.05	6227	6228	6226	6227	0.6332
2	0.1	6250	6258	6266	6258	0.6300
3	0.15	6231	6232	6230	6231	0.6328
4	0.2	6121	6122	6120	6121	0.6441
5	0.25	6170	6176	6182	6176	0.6384
6	0.3	6100	6106	6112	6106	0.6457
7	0.35	6010	6017	6024	6017	0.6553
8	0.4	6010	6030	6020	6020	0.6549

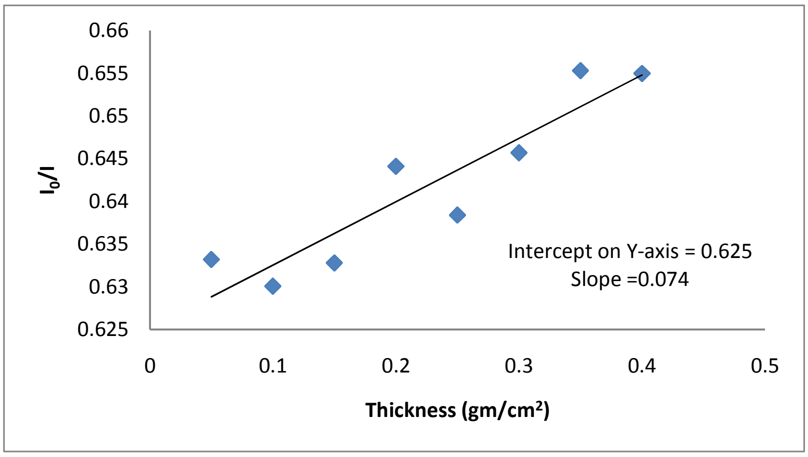


Figure 6. Thickness vs.I_0/I for the Chromium foil at 637 keV.

Table 6. Counts per 100 second for Chromium foil at 662 keV.

Sr.No	Thickness gm/cm^2	Trial I	Trial II	Trial III	Mean (I)	I_0/I
1	0.05	6327	6329	6325	6327	0.62320
2	0.1	6358	6360	6356	6358	0.62016
3	0.15	6335	6331	6327	6331	0.6228
4	0.2	6221	6220	6222	6221	0.63382
5	0.25	6276	6270	6282	6276	0.62826
6	0.3	6200	6206	6212	6206	0.63535
7	0.35	6117	6120	6114	6117	0.64459
8	0.4	6115	6120	6125	6120	0.64428

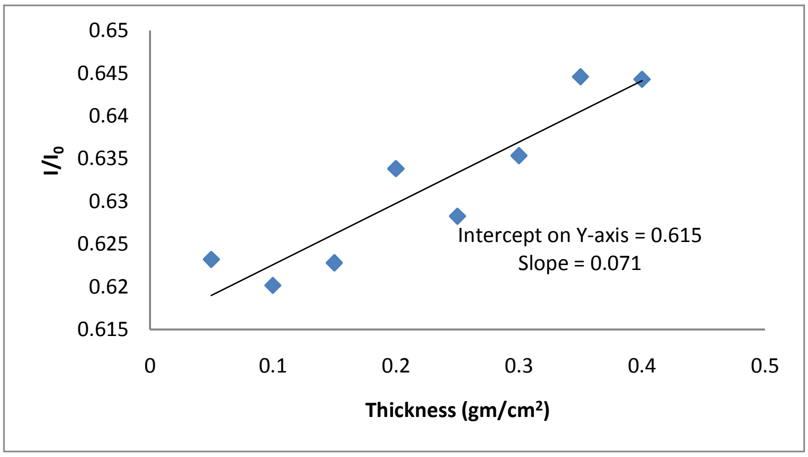


Figure 7. Thickness vs.I_0/I for the Chromium foil at 662 keV.

Table 7. Counts per 100 second for Chromium foil at 834 keV.

Sr.No	Thickness gm/cm^2	Trial I	Trial II	Trial III	Mean (I)	I_0/I
1	0.05	6727	6720	6734	6727	0.5861
2	0.1	6758	6750	6766	6758	0.5834
3	0.15	6731	6730	6732	6731	0.58579
4	0.2	6620	6621	6622	6621	0.59552
5	0.25	6676	6670	6682	6676	0.59062
6	0.3	6606	6600	6612	6606	0.59688
7	0.35	6517	6520	6514	6617	0.60503
8	0.4	6520	6515	6525	6520	0.60475

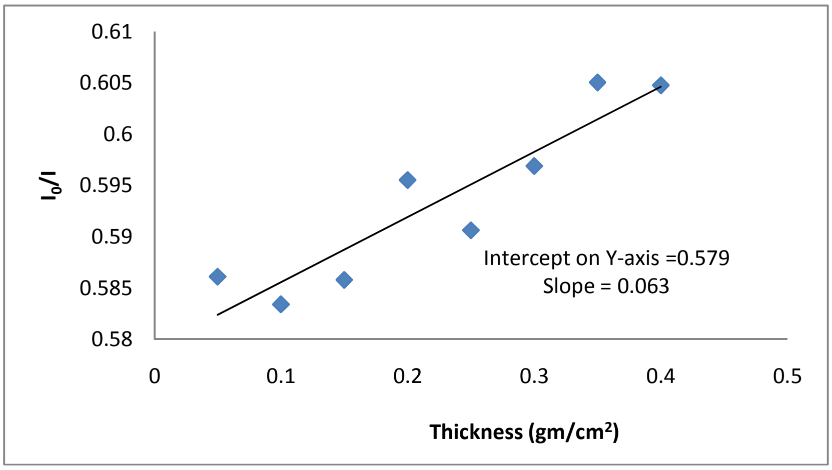
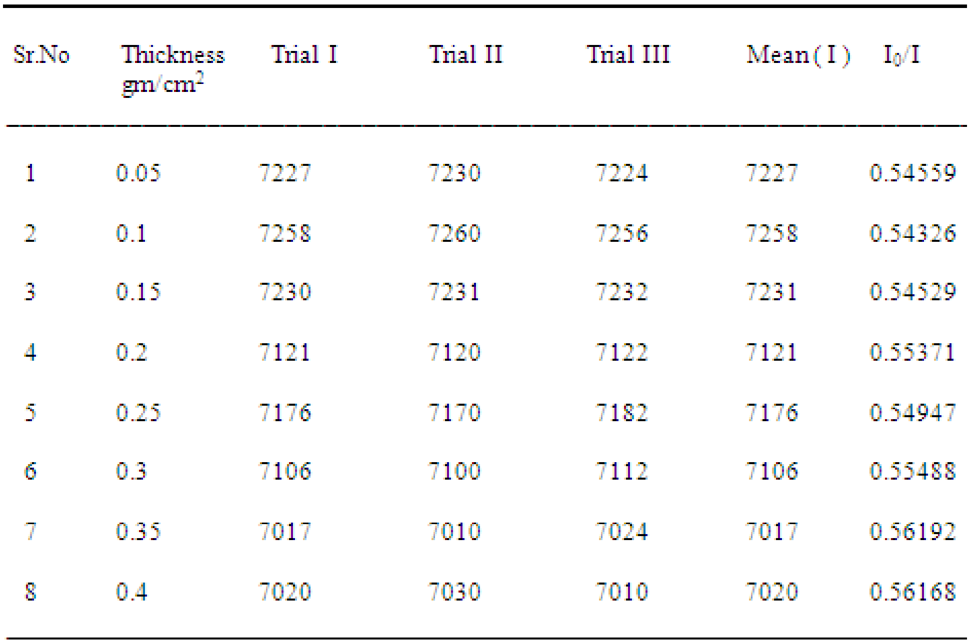


Figure 8. Thickness vs.I_0/I for the Chromium foil at 834 keV.

Table 8. Counts per 100 second for Chromium foil at 1170 keV.



Sr.No	Thickness gm/cm^2	Trial I	Trial II	Trial III	Mean (I)	I_0/I
1	0.05	7227	7230	7224	7227	0.54559
2	0.1	7258	7260	7256	7258	0.54326
3	0.15	7230	7231	7232	7231	0.54529
4	0.2	7121	7120	7122	7121	0.55371
5	0.25	7176	7170	7182	7176	0.54947
6	0.3	7106	7100	7112	7106	0.55488
7	0.35	7017	7010	7024	7017	0.56192
8	0.4	7020	7030	7010	7020	0.56168

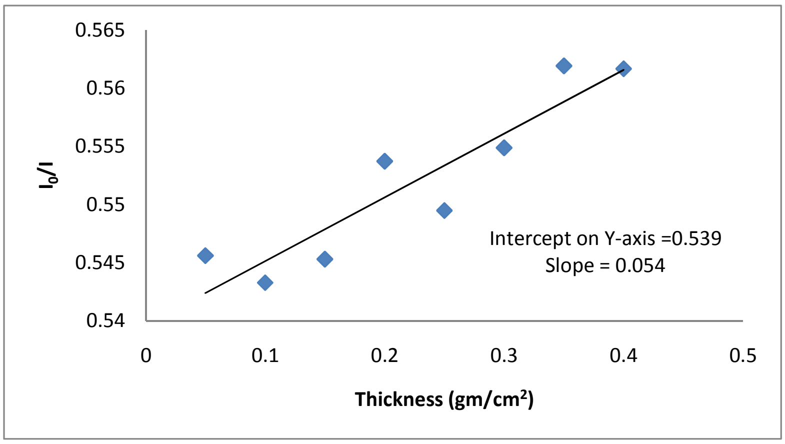


Figure 9. Thickness vs.I_0/I for the Chromium foil at 1170 keV.

Table 9. Counts per 100 second for Chromium foil at 1330 keV

Sr.No	Thickness gm/cm^2	Trial I	Trial II	Trial III	Mean (I)	I_0/I
1	0.05	7427	7426	7428	7427	0.53090
2	0.1	7458	7460	7456	7458	0.52869
3	0.15	7430	7431	7432	7431	0.53061
4	0.2	7320	7321	7322	7321	0.53858
5	0.25	7376	7370	7382	7376	0.53457
6	0.3	7306	7312	7300	7306	0.53969
7	0.35	7210	7217	7224	7317	0.54634
8	0.4	7220	7210	7230	7220	0.54612

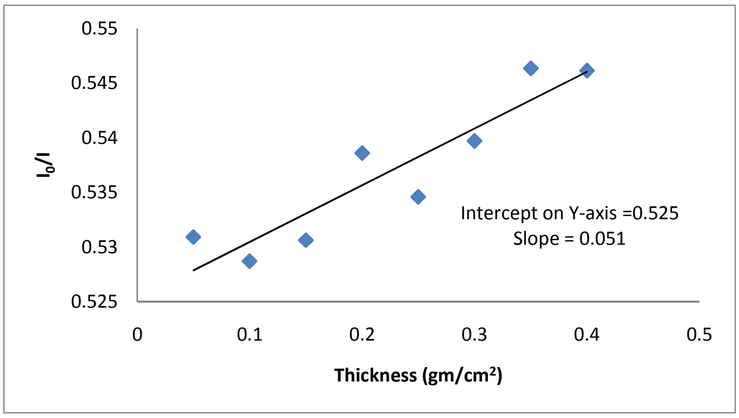


Figure 10. Thickness vs.I_0/I for the Chromium foil at 1330 keV.

Table10: Linear attenuation coefficient μ (cm^{-1}) and mass attenuation coefficient μ/ρ (cm^2/g) of Cr absorber at Photon energies 279, 284, 355, 362, 637, 662, 834, 1170 and 1330 keV.

Sr.No.	Energy keV	μ (cm^{-1})	μ/ρ (cm^2/g)
1	279	0.791a	0.110a
		0.784b	0.109b
		-0.892c	-0.917c
2	284	0.769 a	0.107 a
		0.777 b	0.108 b
		0.926 c	0.926 c
3	355	0.712 a	0.099 a
		0.690 b	0.096 b
		-3.125 c	-3.125 c
4	362	0.676a	0.094 a
		0.683 b	0.095 b
		1.053 c	1.053 c
5	637	0.532a	0.074a
		0.525 b	0.073 b
		-1.370c	-1.370 c
6	662	0.511a	0.071a
		0.515 b	0.072b
		0.838c	0.838c
7	834	0.453a	0.063a
		0.457b	0.064b
		0.875c	0.787c
8	1170	0.388a	0.054a
		0.392b	0.055b
		1.020c	0.917c
9	1330	0.367a	0.051a
		0.363b	0.0505b
		-1.102c	-0.990c

a (experimental)
b (Hubbell and Seltzer) values.
c (Percentage deviation)

RESULTS AND DISCUSSION

The linear and mass attenuation coefficients were calculated for Cr foils at various thicknesses by using gamma transmission measurements. It was observed that the experimental values of number of particles of radiation counted without absorber (I_0) per number of particles of radiation counted with absorber (I) were linearly increased with increasing thickness. Also it is observed by table 10 that as energy increases the value of linear and mass attenuation coefficients goes on decreasing.

The comparison of their measurements with the theoretical values [14] is done by calculating the Percentage deviation as:

$$\% \text{ deviation} = \frac{(\mu/\rho)_{\text{theo}} - (\mu/\rho)_{\text{exp}}}{(\mu/\rho)_{\text{theo}}} \text{ X } 100$$

These are also presented in the table 10 and the author found the deviation mostly below 2% indicating thereby excellent agreement of the author's measurements with theory. Figure 2-10 shows plot of the thickness vs.I_0/I for the Chromium foils at photon energies 279, 284, 355, 362, 637, 662, 834, 1170 and 1330keV respectively. Using this graphs, slope can be calculated and these slope is nothing but the (μ/ρ) mass attenuation coefficient of element at that particular energy. And then the linear attenuation coefficient is obtained by multiplying the mass attenuation coefficient of the element by its density.

CONCLUSION

The theoretical values of mass attenuation coefficient for element are available from [14] and the author carried out the work of their experimental measurement with excellent accuracy. The agreement of the author so measured values with theory confirms the theoretical considerations of the contribution of various processes such as photoelectric effect, the Compton scattering and the pair production. The measured mass and linear attenuation coefficients of element are useful for dosimetry and radiation shielding purpose.

From the results of the present study, it is observed that the errors quoted are due to mainly counting statistics, since the sample impurity corrections are negligible. The agreement seems to be good within experimental error. The mass attenuation coefficient μ/ρ of Chromium foils of various thicknesses have been studied by using gamma radiation in the energy range 10 keV to 1500 keV. The results have been presented in a graphical form from Figure 2-10.The increasing linear nature of graphs of number of particles of radiation counted without absorber (I_0) per number of particles of radiation counted with absorber (I) vs. the thickness of absorber are fitted by the least square method. The slope of these graphs gives the value of the mass attenuation coefficients. Then the linear attenuation coefficient (μ) is obtained by multiplying the mass attenuation coefficient of the element by its density. The results are in good agreement [15-16].

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