Determination of Linear Absorption Coefficient for Different Materials

IK Suleiman[1]

[1] *Department of Physics, Nigerian Defence Academy Kaduna, Nigeria.*

Author contribution.

This study was carried by Author IKS collected and prepared the field samples, participated in the laboratory procedures, performed the statistical analysis ,wrote the draft of the manuscript , designed the study and contributed to the statistical analysis.

ABSTRACT: Linear attenuation coefficient (μ) is a measure of the ability of a medium to diffuse and absorb radiation. In the interaction of radiation with matter, the linear absorption coefficient plays an important role because during the passage of radiation through a medium, its absorption depends on the wavelength of the radiation and the thickness and nature of the medium. Experiments to determine linear absorption coefficient for Lead, Copper and Aluminum were carried out in air.
The result showed that linear absorption Coefficient for Lead is 0.545cm^{-1}, Copper is 0.139cm^{-1} and Aluminum is 0.271cm^{-1} using gamma-rays. The results agree with standard values.

Keywords: Linear Attenuation Coefficient, Medium, Radiation, Copper, Lead and Aluminum.

I. INTRODUCTION

Radiation is either the process of emitting electromagnetic energy (such as heat, light, gamma-roys x-rays etc), sub-atomic particles, electrons, neutrons, protons, alpha-particles etc, or energy or particles thus emitted. Nuclear radiation cannot be seen, heard, or smelled by unaided human senses but its presence is felt by damage done to the body. The effect they produce on materials is used to quantity them. Towards the end of the 19^{th} Century a Chemist observed that salts of uranium emitted radiation which affects a photographic plate and induced electrical conductivity (ionization) in gases. It was found that, neither the quality nor the quantity of radiation emitted by a given chemical compound was in any way affected by such processes as temperature change or pressure change, and in the case of Uranium, it was found that the amount of radiation emitted did not depend in the compound, but was directly related to the quantity of Uranium in that compound. Another great Fresh physicist, Henri Becquend in 1896 was also among the first persons to observe the effect of nuclear radiation. He found that a photographic plate, sealed in complete darkness, was affected as though it had been exposed to light when placed near to Uranium source. Radiation loses energy as it transverse through matter. The higher energy of the radiation, the greater the distance it will transverse through the material. The distance the radiation having a certain amount of energy will transverse through a material depends on the density and thickness of the material.

The distance transverse is called range. From this range the thickness of the material can be measure and this give birth to thickness gauger.However, the mass attenuation is used to find the range the thickness of the materials.

The relationship between the range, thickness and energy is given as:-

$dI = Kdx$ or $I = I_{oe^{-kx}}$ ....(1)

which I: is the initial Intensity of the Alpha, Gamma, which I_{oe} is the intensity at a distance (x), thickness and k is the absorption coefficient of the particular, material[2], k depends on the type of radiation (alpha, beta, or gamma) and is directly proportional to the density (d) of the material, i.e k = μD. As Dx is infact, the mass per unit area M, of the materials, μ is referred to as the absorption coefficient of the radiation expressed in $M^2kg^{-1.}$

II. MATERIALS AND METHODS

The radioactive source $Co^{60}5\mu ci(\gamma)$, was acquired by Physics Department Nigerian Defence Academy Kaduna, Nigeria, for the purposed of experimental and research work.

The absorbers were already prepared and were also obtained from the laboratory which includes aluminum, coppers and lead. The thickness of the absorbers were measure from the absorbers using micrometer screw gauge.

The experiment to measure the linear absorption coefficient for different absorbers materials was carried out by exposing different absorbers material to $Co^{60}5\mu ci(\gamma)$ and the results obtained from the slope of the graph.

III. EXPERIMENTAL DESIGN

The detector used was sodium lodide (NaI(Ti) with 7 percent resolution, H.V of 700V, and 662 Kev energy, made by Harshaw and Filtrol. The detector allows almost 100 percent detection of gamma rays but cannot be used to detect beta – rays. The Decade sealer Counter was used during the experiment to give the counts of the radiation emitted after passing through the absorbers. The other material used includes stand with clamp for supporting sodium lodide detector and collimators. Micrometer screw gauge was used to measure the thickness of the absorbers, stopwatch for timing the number of counts.

The arraignment used during the experiment includes, material with varying thickness i.e absorbers such as Aluminum, Copper and Lead were each placed between Radioactive Source $Co^{60}5\mu ci(\gamma)$. A detector (NaI(Ti) was placed immediately after absorbers to detect the radiation passing through the absorbers. ADacade sealer was connected to the detector to give the number of counts of radiation emitted. Two collimators were used to reducethe scattering of the radiation emitted, the first collimator was placed near the radioactive source and the second collimator was placed near the detector.The detector, collimators, absorbers, radioactive source were placed on a straight line. Refer to figure (3.1).

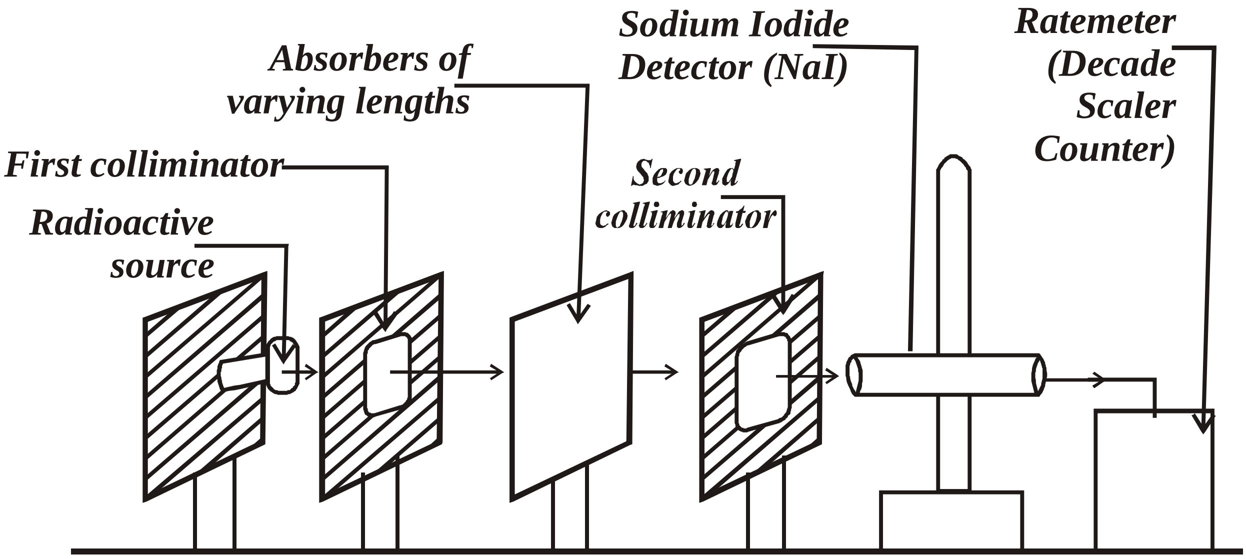

Figure 3.1: Schematic block diagram of the experimental arrangement

2.1. Experimental Se-up and Procedures to Determine Linear Absorption Coefficient for Different Absorbers Materials (Al, Cu, Pb).

The radioactive source $Co^{60}5\mu Ci(\gamma)$ was placed in the holder of the absorption apparatus as shown in Fig. (3.1). The Decade Sealer Counter and stopwatch was started simultaneously and after four minutes, the number of counts was recorded, this gives background counts, hence background countrate can be calculate from the formula in eqn. (2)

$$\text{Countrate} = \frac{\text{Numbers of counts}}{\text{Time for the counts}} \text{ (i. e 4 minutes)} \quad (2)$$

This Background countrate gives the value of I_o which is equal to Gamma-ray intensity at zero absorbers thickness.

Therefore, the absorbers (Al, Cu and Pb) were and placed one after another between the source and the detector and again the counts for four minutes was recorded and countrate calculated using the equation (2). The thickness of the absorbers were increased by insetting the absorbers one at a time, and recording the number of counts in four minutes. This experiment was repeated for several thickness and for different absorbers. The distance between the source and absorber was kept constant. The source and the absorbers plates were removed and the background count rate was recorded which is due to the cosmic-rays and the effect of small traces of radioactive isotopes in all the substances around. The countrate found were corrected by subtracting the background countrate from the countrate obtained and this value give us the value of I which is equal to the Gamma-ray intensity transmitted through the an absorber thickness (x).

Then, graphs of Log I against thickness were plotted, and the slope of the graph, which is equivalent to the linear absorption coefficient (μ) was calculated.

The mass absorption – coefficient (μm) for different absorber materials was obtained by divided the linear absorption coefficient by the density of the absorber.

i.e.

Slope of the graph = Linear absorption Coefficient (μ) an μ/ρ = μm= Mass absorption Coefficient

Whereρ is the density of the absorbers.

IV. ESTIMATION OF LINEAR ABSORPTION COEFFICIENT

The radiation from radioactive substances are to various degree absorbed by materials through which they pass. During the absorption measurement, the radiation passing through the material was weekend by an extent depending on the elementary composition, thickness and density of the substances in the radiation path, according to the equation.

$$I = I_0 \exp^{(-\mu \times X)} \text{………… ……(3)}$$

Where I_0 = Gamma – ray intensity at zero absorber thickness

I = Gamma – ray intensity transmitted through the an absorber thickness (x)

μ = Linear absorption Coefficient of the absorber

X = Thickness of the absorbers (AL, CU, and Pb)

The graph of $Log_e I$ against thickness (x) was plotted, and the slop of the graph obtained gives us the Linear absorption Coefficient of the materials (μ) which is the main aim of this work.

From equation (3.)

$$Log_e I = Log I_o - \mu x$$

$$-\mu = \frac{Log_e I - Log_e I_O}{X}$$

$$\mu = \frac{Log_e I - Log_e I_O}{X} \text{……… (4)}$$

Knowing the values of I, I_o and X, the value of μ can be calculated using the equation (4) above.

Introducing the concepts of mass absorption Coefficient (μm)

Hence

$$\mu m = \mu/\rho \text{……. ……………….(5)}$$

fromeqn (3)

$$I = I_0 \exp(-\mu m \times \rho \times X) \text{ …………..(6)}$$

whereρ is the density of the materials absorber used in g/cm^3 or Kg/m^3

According to the equation (6), the degree of radioactive radiation absorption is determined for a constant materials composition by the product of thickness and density. Using a suitable arranged measuring station, one can always ensure a constant absorption path length of radiation intensity depends exponentially only on the material density.

Therefore absorption of radioactive – radiation in matter can be calculated in general by the expression.

$$\frac{I}{I_o} = \exp(-\mu m\, d) \text{ ………………(7)}$$

which states that the intensity of radiation decreases from the original value of I_o to a value of a I_o to a value of a I after proceeding through a layer of the absorbent of thickness d, and the decreases ion the in the medium is determined by the constant of proportionality in the exponent. μmif d is taken as equivalent thickness and is given in kg/m^2 or cm^2/g with the value of d given in units length, example in metres or centimeter, the Linear absorption coefficient.

The two constants can be converted easily to each other knowing the density the absorbent, ρ (kg/m^3) by the expression in equation (5).

i.eμm = μ/p (8)

In practice, the use of μm is of advantage because the dependence of the absorption on energy can be described in such as manner in a much simpler way.

V. RESULTS

The experiment for the determination of linear absorption Coefficient for different materials (absorbers) was carried out in NDA Physics Laboratory.However, some limitations might have been encountered during the experiments. Hence, the results of this investigation is as follows:

Table 1 Background Count Rate = 150.75 Gamma – source Co^{60}5/uCi(cpm) was used on lead sheet.

Thickness of material absorbers X (cm)	Reading of Counts in front minutes (cpm)			Means counts for 4 minutes (cpm)	Countrate I^1 (cpm)	Countrate with background countrate substance	In I
	1	2	3				
0.00	5043.00	5042.00	5047.00	5044.00	1261.00	1110.25	7.01
0.10	4825.00	4823.00	4824.00	4824.00	1206.00	1055.25	6.96
0.15	4840.00	4848.00	4847.00	4847.00	1211.00	1060.50	6.97
0.25	3915.00	3916.00	39.18.00	39.18.00	978.00	827.50	6.72
0.30	3881.00	3882.00	3889.00	3889.00	971.00	820.00	6.71
0.35	4526.00	4524.00	4525.00	4525.00	1131.25	900.00	6.89
0.64	3703.00	3706.00	3703.00	3703.00	926.00	775.25	6.65
0.11	3072.00	3070.00	3071.00	3071.00	767.75	617.00	6.43
1.34	2775.00	2776.00	2777.00	2776.00	694.00	543.00	6.30
1.75	2342.00	2343.00	2347.00	2344.00	586.00	435.00	6.08
2.05	1615.00	1613.00	1614.00	1614.00	403.50	252.75	5.53
2.06	2074.00	2070.00	2072.00	2072.00	518.00	367.25	5.92
3.70	1996.00	1995.00	1994.00	1995.00	498.75	348.00	5.85

Table 2 Background Count rate = 150.75 Gamma – source Co^{60}5µCi(cpm) was used on Copper sheet.

Thickness of material (cm)	Reading of Counts in four minutes (cpm)			Means counts for four minutes (cpm)	Countrate I^1 (cpm)	Countrate with background count rate substrated	In I
	1	2	3				
0.00	5043.00	5042.00	5047.00	5044.00	1261.00	1110.25	7.01
0.15	5618.00	5623.00	5625.00	5622.00	1405.00	1254.00	7.14
0.30	5410.00	5400.00	5409.00	5409.00	1352.25	1201.60	7.09
0.45	5304.00	5300.00	5302.00	5302.00	1325.50	1174.75	7.07
0.65	5213.00	5210.00	5210.00	5211.00	1302.75	1152.00	7.05
0.80	5110.00	5110.00	5106.00	5109.00	1277.25	1126.50	7.03
0.95	5081.00	5077.00	5082.00	5080.00	1270.00	1119.25	7.02
1.10	4910.00	4912.00	4911.00	4911.00	1227.75	1077.00	6.98
1.25	4810.00	4809.00	4808.00	4809.00	1202.25	1051.50	6.96
1.45	4700.00	4699.00	4701.00	4700.00	1175.00	1024.25	6.93
1.61	4612.00	4613.00	4611.00	4612.00	1153.00	1002.25	6.91

Table 3. Background Count rate = 150.75 Gamma – source Co^{60}5µCi() was used on Aluminium sheet.

Thickness of material (cm)	Reading of Counts in four minutes (cpm)			Means counts for four minutes (cpm)	Countrate I^1 (cpm)	Countrate with background countratesubstrated I	In I
	1	2	3				
0.00	5043.00	5042.00	5047.00	5044.00	1261.00	1110.00	7.01
0.35	5420.00	5419.00	5416.00	5418.00	1354.00	1203.00	7.09
0.40	5392.00	5394.00	5396.00	5394.00	1348.50	1197.75	7.09
0.50	5240.00	5237.00	5241.00	5239.00	1309.75	1159.00	7.06

0.55	5207.00	5196.00	5194.00	5199.00	1299.00	1149.00	7.05
0.65	5040.00	5036.00	5041.00	5039.00	1259.75	1109.00	7.01
0.75	4949.00	4950.00	4948.00	4949.00	1237.25	1086.50	6.99
0.85	4809.00	4810.00	4805.00	4808.00	1202.00	1051.25	6.96

VI. DISCUSSION

The experiments to determine the linear absorption coefficient for different materials absorbers (Pb, Cu, AL) was carried out.

From Annex 1 graph 2.8, Slope = AB/BC = 6.80-5.00/ 0.40-3.70 = 1.80/ 3.30 = 0.545 = Linear Absorption Coefficient for the Lead.

From Annex 1 graph 2.9, Slope = AB/BC = 7.10 – 6.62 / 0.25 - 3.70 = 0.48 /3.45 = 0. 139 = Linear Absorption Coefficient for the Copper.

From Annex 1 graph 3.0, Slope = AB/BC = 7.12 – 6.96 / 0.30 - 0.85 = 0.16 / 0.59 = 0.271 = Linear Absorption Coefficient for the Aluminum

The results of this investigation have shown that, the linear absorption coefficient for.

(i) Lead (Pb) = 0.545 cm-1 (Refer to Graph (2.8))

(ii) Copper (Cu) = 0.139 cm-1 (Refer to Graph (2.9))

(iii) Aluminum (AL) = 0.271 cm-1 (Refer to Graph (3.0))

From this results, the mass absorption coefficient of the absorbers (Pb, Cu, and AL) can be varied using the equation (5) i.e$\mu m = \mu/p$

Whereμ = Linear absorption coefficient of the absorbers (Pb, Cu, and Al) P = Density of the absorbers

From the calculations, it was found that, the mass absorption coefficient for:-

(i) Lead with density of 11.005gcm^{-3} or 1.1x$10^3 kgm^{-3}$ is equal to 0.0495cm^2g^{-1}.

(ii) Copper with density of 9.00gcm^{-3} or 9.0 x $10^3 kgm^{-3}$ is equal to 0.0154 cm^2g^{-1}.

(iii) Aluminum with density 2.7gcm^{-3} or 2.7 x $10^3 kgm^{-3}$ is equal to 0.10040 cm^2g^{-1}.

(iv) The energies of gamma-rays from $60C_0$ (radioactive source) used during the experiment are 1.17mev and 1.mev, which given the average energy as 1.25 mev.

Comparing the values of mass absorption coefficient from standard stable for the mass absorption coefficient for several materials, in Cm^3g-1 given the Appendix (A) are, for:

(i) Lead = 0.0332 Cm^2g^{-1}

(ii) Copper = 0.0247 cm^2g^{-1}

(iii) Aluminum = 0.0259 cm^2g^{-1}

The deviations from the standard values is due to the responds of the detector used during the experiment. From the research, it was discovered that, the mass absorption coefficient and thickness of different material absorbers (Pb, Cu, Al) can be determined.

CONCLUSION

The results of this investigation shows that, the Linear Absorptions Coefficient for:

(i) Lead = 0.545 cm^{-1}

(ii) Copper = 0.139 cm^{-1}

(iii) Aluminum = 0.271 cm^{-1}

VII. ACKNOWLEDGEMENTS

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COMPETING INTEREST

There is no competing interest whatsoever that could have influenced the results of this study in any manner.

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ANNEX 1

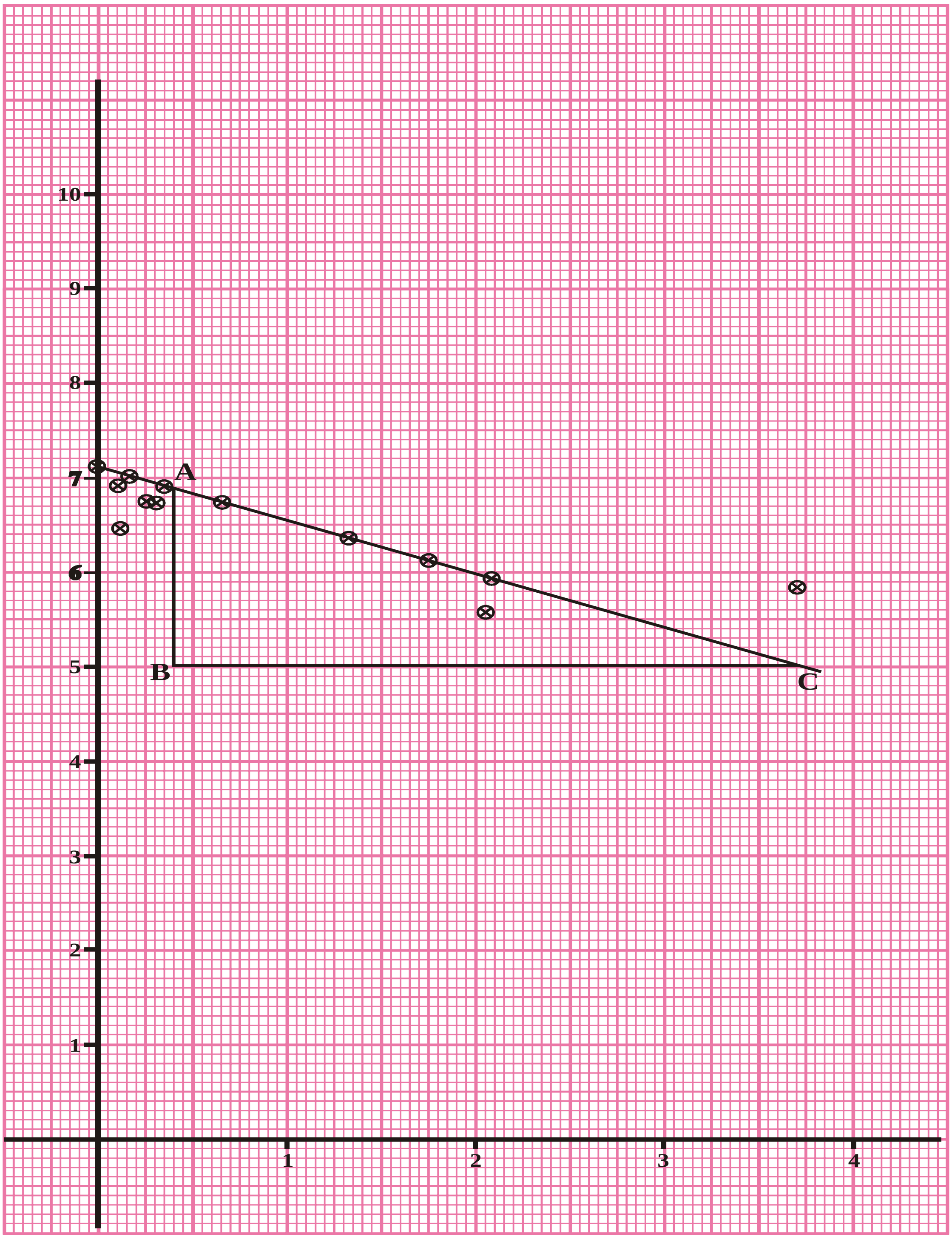

Figure 2.8

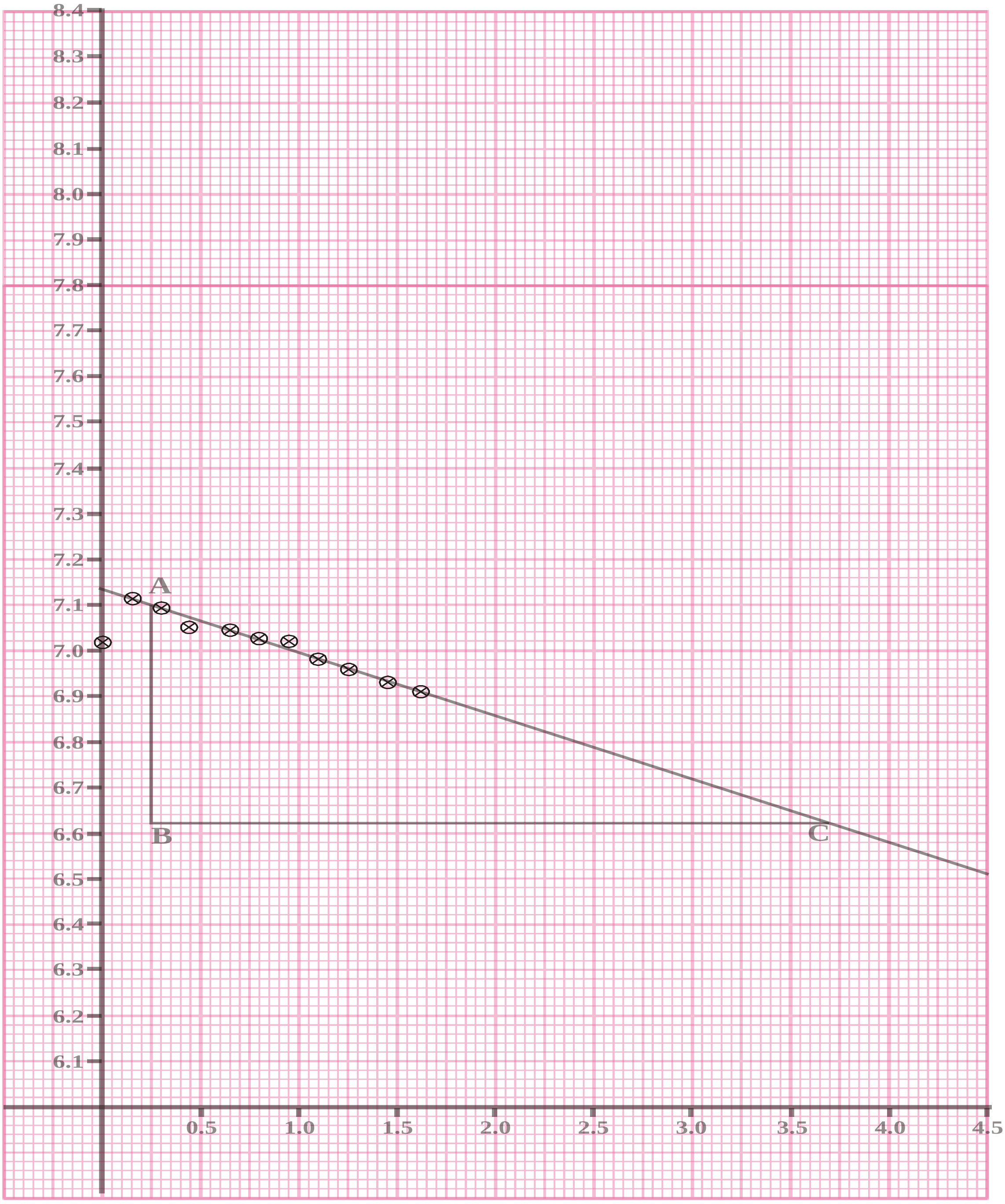
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Figure 2.9

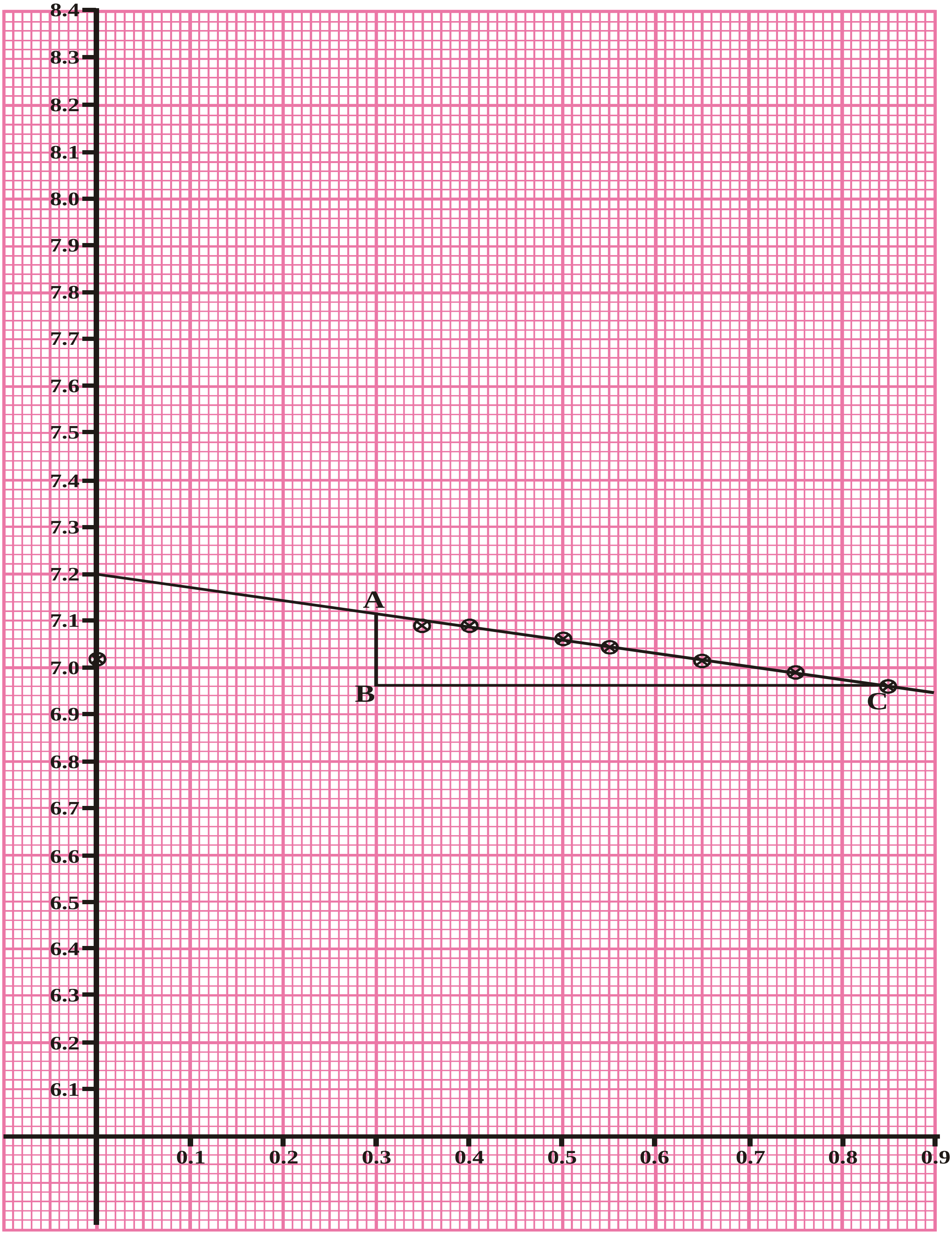
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Figure 3.0

APPENDIX A

TABLE A

The Mass Absorption Coefficient (μ_a/ρ) for several Materials, in cm^2/g^2

Material	Gamma ray energy, MeV																
	0.1	0.15	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.25	1.50	2	3	4	5	6	8	10
H	.0411	.0487	.0531	.0575	.0589	.0591	.0590	.0575	.0557	.0533	.0509	.0467	.0401	.0354	.0318	.0291	.0252	.0255
Be	.0183	.0217	.0237	.0256	.0263	.0264	.0263	.0256	.0248	.0237	.0227	.0210	.0183	.0164	.0151	.0141	.0127	.0118
C	.0215	.0246	.0267	.0288	.0296	.0297	.0296	.0286	.0280	.0268	.0256	.0237	.0209	.0190	.0177	.0166	.0153	.0145
N	.0224	.0249	.0267	.0288	.0296	.0297	.0296	.0289	.0280	.0268	.0256	.0236	.0211	.0193	.0180	.0171	.0158	.0151
O	.0233	.0252	.0271	.0289	.0296	.0297	.0296	.0289	.0280	.0268	.0257	.0238	.0212	.0195	.0183	.0175	.0163	.0157
Na	.0289	.0258	.0266	.0279	.0283	.0284	.0284	.0276	.0268	.0257	.0246	.0229	.0207	.0194	.0185	.0179	.0171	.0168
Mg	.0335	.0276	.0278	.0290	.0294	.0293	.0292	.0285	.0276	.0265	.0254	.0237	.0215	.0203	.0194	.0188	.0182	.0180
Al	.0373	.0283	.0275	.0283	.0287	.0286	.0286	.0278	.0270	.0259	.0248	.0232	.0212	.0200	.0192	.0188	.0183	.0182
Si	.0435	.0300	.0286	.0291	.0293	.0290	.0290	.0282	.0274	.0263	.0252	.0236	.0217	.0206	.0198	.0194	.0190	.0189
P	.0501	.0315	.0292	.0289	.0290	.0290	.0287	.0280	.0271	.0260	.0250	.0234	.0216	.0206	.0200	.0197	.0194	.0195
S	.0601	.0351	.0310	.0301	.0301	.0300	.0298	.0288	.0279	.0268	.0258	.0242	.0224	.0215	.0209	.0206	.0206	.0206
Ar	.0729	.0368	.0302	.0278	.0274	.0272	.0270	.0260	.0252	.0242	.0233	.0220	.0206	.0199	.0195	.0195	.0194	.0197
K	.0909	.0433	.0340	.0304	.0298	.0295	.0291	.0282	.0272	.0261	.0251	.0237	.0222	.0217	.0214	.0212	.0215	.0219
Ca	.111	.0489	.0367	.0318	.0309	.0304	.0300	.0290	.0279	.0268	.0258	.0244	.0230	.0225	.0222	.0223	.0225	.0231
Fe	.225	.0810	.0489	.0340	.0307	.0294	.0287	.0274	.0261	.0250	.0242	.0231	.0224	.0224	.0227	.0231	.0239	.0250
Cu	.310	.107	.0594	.0368	.0316	.0296	.0286	.0271	.0260	.0250	.0242	.0231	.0224	.0224	.0227	.0231	.0239	.0250
Mo	.922	.294	.141	.0617	.0422	.0348	.0315	.0281	.0263	.0248	.0239	.0233	.0237	.0250	.0262	.0274	.0296	.0316
Sn	1.469	.471	.222	.0873	.0534	.0403	.0346	.0294	.0268	.0248	.0239	.0233	.0243	.0259	.0276	.0291	.0316	.0339
I	1.726	.557	.260	.100	.0589	.0433	.0366	.0303	.0274	.0252	.0241	.0236	.0247	.0265	.0283	.0299	.0327	.0353
W	4.112	1.356	.631	.230	.212	.0786	.0599	.0426	.0353	.0302	.0281	.0271	.0287	.0311	.0335	.0335	.0390	.0426
Pt	4.645	1.556	.719	.262	.138	.0892	.0666	.0465	.0375	.0315	.0293	.0280	.0296	.0320	.0343	.0365	.0400	.0438
TI	5.057	1.717	.791	.285	.152	.0972	.0718	0.491	.0393	.0326	.0301	.0288	.0304	.0326	.0349	.0354	.406	.0446
Pb	5.193	1.753	.821	.294	.156	.0994	.0738	.0505	.0402	.0332	.0306	.0293	.0305	.0330	.0352	.0373	.0412	.0450
U	9.63	2.337	1.096	.392	.208	.132	.0968	.0628	.0482	.0383	.0346	.0324	.0332	.0352	.0374	.0394	.0443	.0474
Air	.0233	.0251	0.268	0.288	.0296	.0297	.0296	.0289	.0280	.0268	.0256	.0238	.0211	.0194	.0181	.0172	.0160	.0153
Nal	1.466	.476	.224	..889	.0542	0.410	.0354	.0299	.0223	.0253	.0242	.0235	.0241	.0254	.0268	.0281	.0303	.0325
H_2O	.0253	.0278	.0300	0321	.0328	.0330	.0329	.0321	.0311	.0298	.0285	.0264	.0233	.0213	.0198	.0188	.0173	.0165
Concrete	.0416	.0300	.0289	.0294	.0297	.0296	.0295	.0287	.0278	.0272	.0256	.0239	.0216	.0203	0.194	.0188	.0173	.0177
Tissue	.0271	.0282	.0293	.0312	0.317	.0320	.0319	.0311	.0300	.0288	.0276	.0256	.0220	.0206	0.192	.0182	.0168	.0160

TABLE B

The Mass Absorption Coefficient (μ_a/ρ) for several Materials, in cm^2/g^2

Material	Gamma ray energy, MeV																	
	0.1	0.15	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.25	1.50	2	3	4	5	6	8	10
H	.295	.265	.243	.212	.189	.173	.160	.140	.126	.113	.103	.0876	.0691	.0579	.0502	.446	.0371	.0321
Be	.132	.119	.109	.0945	.0847	.0773	.0715	.0628	.0565	.0504	.0459	.0394	.0313	.0266	.0234	.0211	.0180	.0161
C	.149	.134	.122	.106	.0953	.0870	.0805	.0707	.0636	.0568	.0518	.0444	.0356	.0304	.0270	.0245	.0213	.0194
N	.150	.134	.123	.106	.0955	.0869	.0805	.0707	.0636	.0568	.0517	.0445	.0357	.0306	.0273	.0249	.0218	.0200
O	.151	.134	.123	.107	.0953	.0870	.0806	.0708	.0636	.0568	.0518	.0445	.0359	.0309	.0276	.0254	.0224	.0206
Na	.151	.130	.118	.102	.0912	.0833	.0770	0.676	.0608	.0546	.0496	.0427	.0348	.0303	.0274	.0254	.0229	.0215
Mg	.160	.135	.122	.106	.0944	.0860	.0795	.0699	.0627	.0560	.0512	.0442	.0360	.0315	.0286	.0266	.0242	.0228
Al	.161	.134	.120	.103	.0922	.0840	.0777	.0683	.0614	.0548	.0500	.0432	.0353	.0310	.0282	.0264	.0241	.0229
Si	.172	.139	.125	.107	.0954	.0869	.0802	.0706	.0635	.0567	.0517	.0447	.0367	.0323	.0296	.0277	.0254	.0243
P	.174	.137	.122	.104	.0928	.0846	.0780	.0685	.0617	.0551	.0502	.0436	.0358	.0316	.0290	.0273	.0252	.0242
S	.188	.144	.127	.108	.0958	.0874	.0806	.0707	.0635	.0568	.0519	.0448	.0371	.0328	.0302	.0284	.0266	.0255
Ar	.188	.135	.117	.0977	.0867	.0790	.0730	.0638	.0573	.0512	.0468	.0407	.0338	.0301	.0279	.0266	.0248	.0241
K	.215	.149	.127	.106	.0938	.0852	.0786	.0689	.0618	.0552	.0505	.0438	.0365	.0327	.0305	.0289	.0274	.0267
Ca	.238	.158	.132	.109	.0965	.0876	.0809	.0708	.0634	.0566	.0518	.0451	.0376	.0338	.0316	.0302	.0285	.0280
Fe	.344	.183	.138	.106	.0919	.0828	.0762	.0664	.0595	.0531	.0485	.0124	.0361	.0330	.0313	.0304	.0295	.0294
Cu	.427	.206	.147	.108	.0916	.0820	.0751	.0654	.0585	.0521	.0476	.0418	.0357	.0330	.0316	.0309	.0303	.0305
Mo	1.03	.389	.225	.130	.0998	.0851	.0761	.0648	.0575	.0510	.0467	.0414	.0365	.0349	.0344	.0344	.0349	.0359
Sn	1.58	.563	.303	.153	.109	.0886	.0776	.0647	.0568	.0501	.0459	.0408	.0367	.0355	.0355	.0358	.0368	.0383
I	1.83	.648	.339	.165	.114	.0913	.0792	.0653	.0571	.0502	.0460	.0409	.0370	.0360	.0361	.0365	.0377	.0394
W	4.21	1.44	.708	.293	.174	.125	.101	.0763	.0640	.0544	.0492	.0437	.0405	.0402	.0409	.0418	.0438	.0465
Pt	4.75	1.64	.795	.324	.191	.135	.107	.0800	.0659	.0554	.0501	.0445	.0414	.0411	.0418	.0427	.0448	.0477
TI	5.16	1.80	.866	.346	.204	.143	.112	.0824	.0675	.0563	.0508	.0452	.0420	.0416	.0423	.0433	.0454	.0484
Pb	5.29	1.84	.896	.356	.208	.145	.114	.0836	.0684	.0569	.0512	.0457	.0421	.0420	.0426	.0436	.0459	.0489
U	10.60	2.42	1.17	.452	.259	.176	.136	.0952	.0757	.0615	.0548	.0484	.0445	.0440	.0446	.0455	.0479	.0511
Air	.151	.134	.123	.106	.0953	.0868	.0804	.0706	.0655	.0567	.0517	.0445	.0357	.0307	.0274	.0250	.0220	.0202
NaI	1.57	.568	.305	.155	.111	.0901	.0789	.0657	.0577	.0508	.0465	.0412	.0367	.0351	.0347	.0347	.0354	.0366
H_2O	.167	.149	.136	.118	.106	.0966	.0896	.0786	.0706	.0630	.0575	.0493	.0396	.0339	.0301	.0275	.0240	.0219
Concrete	.169	.139	.124	.107	.0954	.0870	.0804	.0706	.0635	.0567	.0517	.0445	.0363	.0317	.0287	.0268	.0243	.0229
Tissue	.163	.144	.132	.115	.100	.0936	.0867	.0761	.0683	.0600	.0556	.0478	.0384	.0329	.0292	.0267	.0233	.0212