

# Chapter 6

## Discussion and analyses of the results

From Tables 5.4 to 5.25 it is clear that the experimental values of total attenuation cross sections of amino acids and sugars are in agreement with the interpolated theoretical values of Hubbell (1982) and XCOM [Berger and Hubbell (1987)] within 3%. However at energies 30.8 and 35 keV the experimental values are higher by about 4%. At 81 keV there is good agreement within experimental errors. In the case of sugars good agreement could be observed at 661.6 keV.

In the samples used there are different sugars with identical molecular weights but with different molecular structure. For example Glucose, Galactose, Mannose and Fructose are having the same molecular weight (180.4), but their molecular structures are different. Arabinose and Ribose are having molecular weight 150.14 each. Similarly in amino acids both Leucine and Isoleucine are having the same molecular weight (131.2), *Within experimental errors, the measurement predicts the same total attenuation cross section for compounds with identical molecular weights, as expected. Keeping this fact in view the average value of mass attenuation coefficients of all the compounds is derived at each energy*

Table 6.1: Mean value of  $\mu/\rho$  for sugars ( $\text{cm}^2/\text{g}$ )

| Energy in keV | Experimental value | Hubbell (1982) | XCOM  |
|---------------|--------------------|----------------|-------|
| 30.8          | 0.329              | 0.321          | 0.317 |
| 35.0          | 0.289              | 0.278          | 0.275 |
| 81.0          | 0.178              | 0.171          | 0.174 |
| 145.0         | 0.147              | 0.142          | 0.146 |
| 276.4         | 0.120              | 0.117          | 0.117 |
| 302.9         | 0.114              | 0.114          | 0.113 |
| 356.0         | 0.109              | 0.107          | 0.107 |
| 383.9         | 0.107              | 0.103          | 0.104 |
| 661.6         | 0.081              | 0.082          | 0.082 |
| 1173.0        | 0.064              | 0.063          | 0.063 |
| 1332.5        | 0.060              | 0.059          | 0.059 |

Table 6.2: Mean value of  $\mu/\rho$  for Amino Acids ( $\text{cm}^2/\text{g}$ )

| Energy in keV | Experimental value | Hubbell (1982) | XCOM  |
|---------------|--------------------|----------------|-------|
| 30.8          | 0.310              | 0.302          | 0.299 |
| 35.0          | 0.271              | 0.265          | 0.263 |
| 81.0          | 0.174              | 0.173          | 0.173 |
| 145.0         | 0.147              | 0.144          | 0.145 |
| 276.4         | 0.116              | 0.118          | 0.118 |
| 302.9         | 0.112              | 0.114          | 0.113 |
| 356.0         | 0.106              | 0.107          | 0.106 |
| 383.9         | 0.103              | 0.104          | 0.103 |
| 661.6         | 0.082              | 0.083          | 0.082 |
| 1173.0        | 0.064              | 0.063          | 0.063 |
| 1332.5        | 0.060              | 0.059          | 0.059 |

← under consideration and are given in Tables 6.1 and 6.2, along with the corresponding theoretical values obtained from Hubbell (1982) and XCOM [Berger and Hubbell (1987)].

From Tables 6.1 and 6.2 good agreement could be observed between the experimental mean values and Hubbell (1982) & Berger and Hubbell (1987) values of  $\mu/\rho$ . It indicates the presence of a unique value for  $\mu/\rho$  for all the compounds under current investigation, at each energy of interest.

To substantiate this fact graphs were plotted with  $\sigma$  versus molecular weights of the samples, at the energies of interest and are shown in Figure 6.1. The linear nature of these curves, corresponding to each energy, shows that

1.  $\mu/\rho$  poses a unique value at each energy of interest
2. The dominant process of interaction involved at the energies of interest is Compton scattering.

However slight deviation could be observed at the lower energies, possibly due to *increase in photoeffect contribution* to the total attenuation cross sections, at these energies.

The fact that amino acid and sugar compounds used in the present investigation contain the low  $Z$  elements H, C, N and O (except Cystine, which contains S) also shows that above 145 keV the only prominent interaction is Compton scattering. Almost 99.9 % of the contribution to the total attenuation cross section is due to Compton scattering. The contribution due to all other competing processes at the energies of interest, above 145 keV is only 0.1 % or less.

## 6.1 Conclusion

In view of the mounting demand of photon attenuation cross sections of various biological compounds, due to the extensive vital applications of

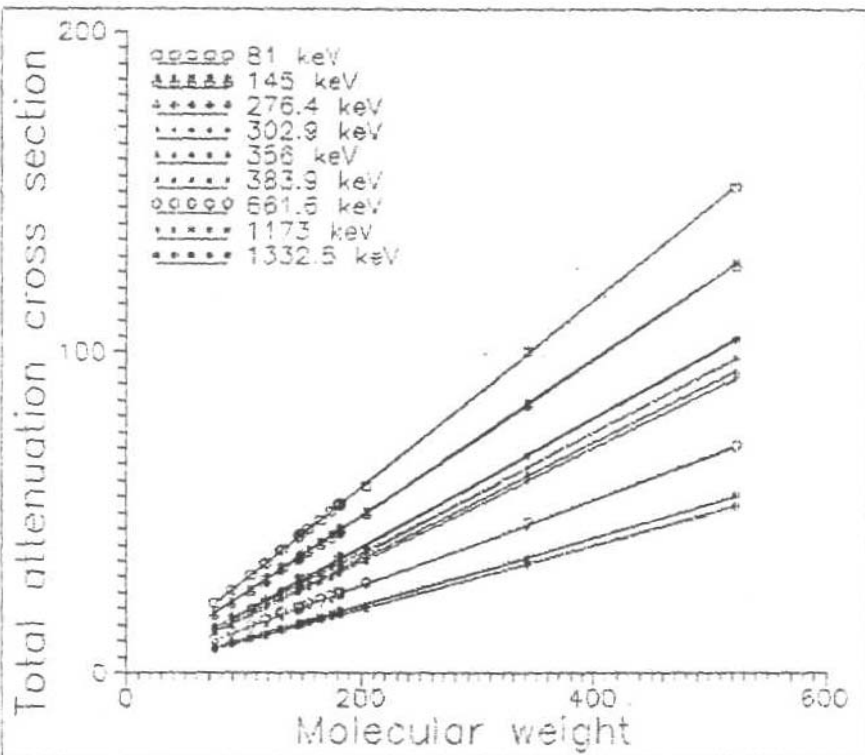
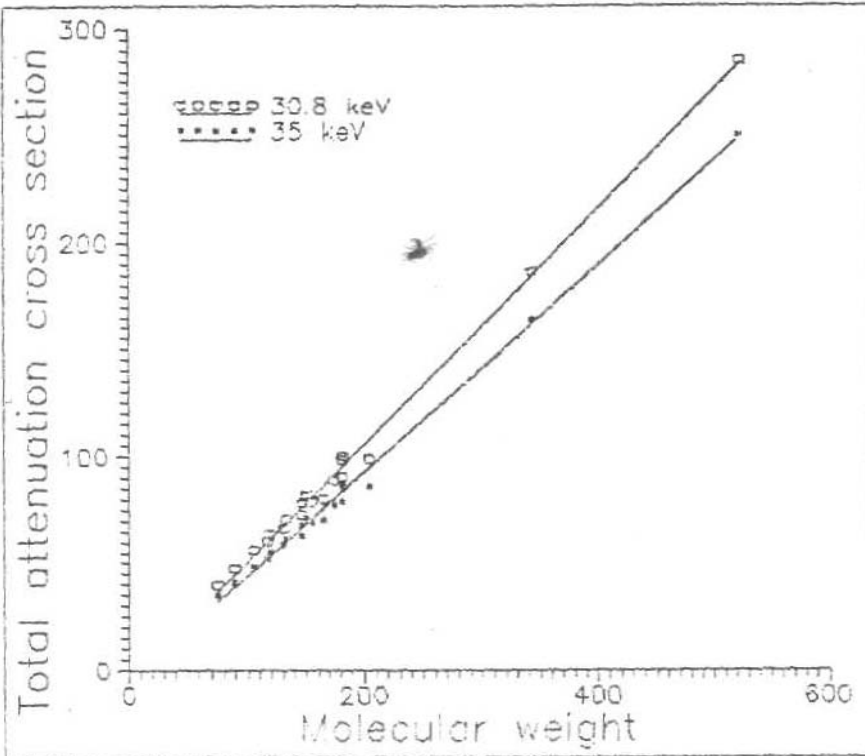


Figure 6.1: Graph showing relation of Total attenuation cross section ( $\sigma$ ) with Molecular weight (M)

← radiation, in medical and biological fields, in this study, total photon attenuation cross sections of most of the amino acid and sugar compounds have been measured at eleven energies, in the range 30.8 to 1332.5 keV, in a good geometry setup, employing a High-Purity Germanium detector.

Among different sugars and amino acids used in the present investigation, several compounds are having the same molecular weight but different chemical structure. Within the experimental errors, the measurements predict the same total attenuation cross sections for them. This clearly indicates that *the chemical structure of the compounds have little or no effect on the gamma ray attenuation in them.* And also, *there exists a unique value of mass attenuation coefficient, for all the compounds used in the investigation, at each energy of interest.* Therefore a unique value of  $\mu/\rho$  has been obtained, at each energy of interest, as the mean of the mass attenuation coefficients of all the compounds, at the corresponding energy. The values so obtained are in good agreement with the values of Hubbell (1982) and Berger & Hubbell (1987).

Further, to check the unique nature of  $\mu/\rho$  at each energy of interest, the plots of  $\sigma$  versus molecular weight of the compounds have been made (Figure 6.1). The *linear nature* of these curves confirms the existence of a unique value of  $\mu/\rho$  at each energy of interest. However at low energies (below 150 keV) little deviation could be observed. This is attributed to the increased photoeffect contribution to the total attenuation cross section, at these energies.

It is clear from the nature of the  $\sigma$  versus molecular weight curves that *the only dominant type of interaction involved (especially above 150 keV) at the energies of interest, is the Compton scattering.* The contribution to the total attenuation cross section due to all other competing processes is negligibly small. This is only to be expected due to the fact that the sugar and amino acid compounds contain low  $Z$  elements H,

C, N, and O.

Thus, the measurements made here contribute a new pool of data on total attenuation cross sections of several amino acids and sugars, at the photon energy range 30.8 to 1332.5 keV. It verifies the tabulated values of Hubbell (1982), which include the extensive atomic photoeffect calculations by Scofield (1973) and new tabulations of incoherent (nonrelativistic) and coherent (relativistic) scattering cross sections assembled by Hubbell et al. (1975), and XCOM — the computer based data base of Berger and Hubbell (1987). It is expected that, These data are of interest to physicists in the fields of medicine and biology, because they can use these results to provide them with a better sense of security while calculating total photon attenuation cross sections using tables of compiled data [Hubbell (1982), Hubbell et al. (1975) Scofield (1973)] and the computer based data base Berger & Hubbell (1987).

## Appendix

### 6.2 A semi-empirical relation for total attenuation cross sections of compounds containing H, C, N & O

The increasing use of radioisotopes in the fields of medicine and biology has necessitated a detailed knowledge of attenuation coefficients of several biological compounds in a wide energy range. In particular the energy region 50 to 1500 keV is being widely employed in medical as well as biological applications (Jackson and Hawkes, 1981). In such practical situations, rather than the extensive theoretical cross section data, a knowledge of the cross sections for the biological samples like sugars, aminoacids etc. is definitely more useful. With this end-in view, a simple semi-empirical relation has been obtained, which can be used to obtain the total attenuation cross sections of any biological compound, of known molecular weight containing any of the elements H, C, N and O, simply by substituting the values of the energy and the molecular weight of the compound of interest.

Based on the fact that the mass attenuation coefficient has a unique value at each energy of interest, the relation between total attenuation cross section  $a$  and the energy  $E$  may be written as

$$\sigma = KAE^b \quad (6.1)$$

where  $K$  and  $b$  are constants and  $A$  the atomic or molecular weight. Taking ln on both sides we get

$$\ln(\sigma/A) = b \ln E + \ln K \quad (6.2)$$

which represents a straight line of slope  $b$  and intercept  $\ln K$ . This

is the locus of all points  $[\ln E, \ln(\sigma/A)]$ . Using the least squares method, a straight line was fit using the experimental data points by performing linear regression analysis over a personal computer. The energy region was between 145 to 1330 keV. Experimental data for five typical samples of molecular weights 75.1 to 594.5 were used in the fitting procedure. The best fit values of the coefficients  $\ln K$  and  $b$  are shown in Table: A.1.

It can be seen from Table: A.1 that in the case of all the samples, the values of the respective coefficients are almost constant. Thus an average value of  $\ln K$  and  $b$  could be obtained. The mean values of  $\ln K$  and  $b$  are

$$\ln K = 0.7935 \quad \text{ie. } K = 2.2108 \quad b = -0.4296$$

$$\text{Therefore from eqn.(1)} \quad \sigma = 2.2AE^{(-0.43)} \quad (6.3)$$

Thus we have obtained a simple semi-empirical formula, for the cross sections of samples of complex molecular structure containing low  $Z$  elements. Since such samples are of immense biological interest it is felt that equation (3) can be of great practical utility particularly in situations where there is a necessity for speedier and handy interpolation of cross section data. The energy region of validity of the formula is also of relevance to the biological applications. In Figure 6.2 the values of  $\sigma$  of Alanine and Polystyrene, calculated using eqn. (3), are plotted across energy, along with the corresponding values obtained using Hubbell's data (Hubbell, 1982) for constituent elements with the aid of mixture rule. A good agreement can be noticed between the two sets of values.

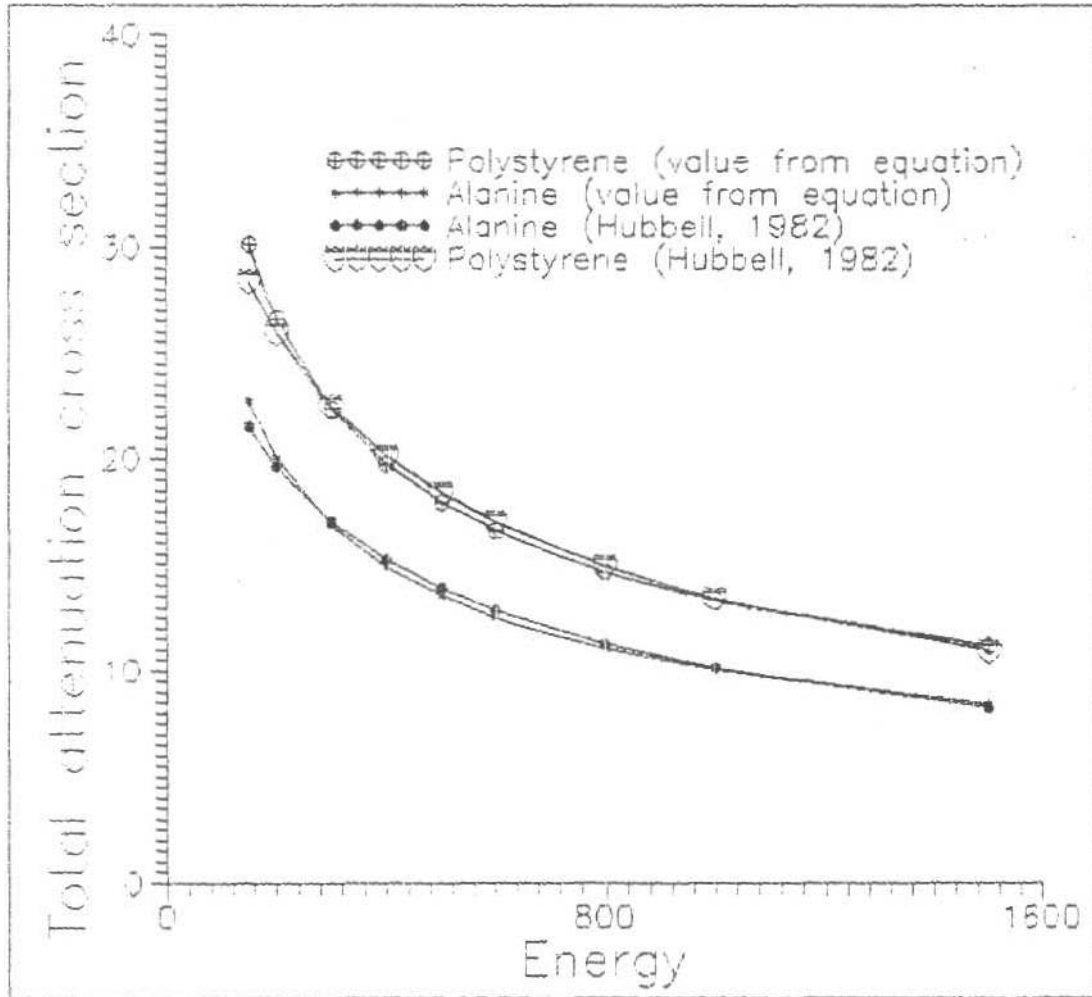


Figure 6.2:  $\sigma$  obtained from equation (3) is plotted against energy (in keV), for the compounds Alanine and Polystyrene.

Table:A.1: The best fit values of  $\ln K$  and  $b$ 

| Name of the compound | Molecular weight | $\ln K$ | $b$     |
|----------------------|------------------|---------|---------|
| Glycine              | 75.1             | 0.7761  | -0.4292 |
| Arabinose            | 150.14           | 0.7923  | -0.4296 |
| Ribose               | 150.14           | 0.7680  | -0.4246 |
| Melezitose           | 522.5            | 0.7742  | -0.4271 |
| Raffinose            | 594.5            | 0.7657  | -0.4252 |

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## Publications of the Author

1. K.P. Gopinathan Nair, Channe Gowda, J. Shylaja Kumari, S.J. Anasuya, T.K. Umesh and Ramakrishna Gowda, "Total Interaction Cross Sections of Several Sugars for  $^{133}\text{Ba}$  Photons", Nucl. Sci. Eng. 115, 300 (1993).
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3. K.P. Gopinathan Nair, T.K. Umesh and Ramakrishna Gowda, "Photon Interaction Cross Sections of Several Sugars for  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  Photons", Nucl. Sci. Eng.(to appear in Aug. 1994).
4. K.P. Gopinathan Nair, T.K. Umesh and Ramakrishna Gowda, "Total Attenuation Cross Sections of Several Amino Acids at 661.6, 1173 and 1332.5 keV", Radiat. Phys. Chem. (in press).
5. T.K. Umesh, S.J. Anasuya, J. Shylaja Kumari, Channe Gowda, K.P. Gopinathau Nair and Ramakrishna Gowda. "Photoeffect Cross Sections of Several Rare-Earth Elements for 323 keV Photons", Phys. Rev. A45, 2101. (1992).

## Papers presented in symposia/conferences

1. T.K.Umesh, S.J. Anasuya, K.P. Gopinathan Nair and Ramakrishna Gowda, "Photoeffect Cross Sections of some Rare-Earth Elements at 323 keVM, National Symposium on Radiation Physics, Hydrabad, Nov. 1991.

2. K.P. Gopinathan Nair, Channe Gowda, S.J. Anasuya, J. Shylaja Kumari, Sandiago, T.K. Umesh and Ramakrishna Gowda, "A Semi-Empirical Relation for Total Attenuation Cross Sections of Compounds Containing H, C, N and O", Sixth International Symposium on Radiation Physics, Rabat, Morocco, July, 1994.
3. S.J. Anasuya, K.P. Gopinathan Nair, Channe Gowda, J. Shylaja Kumari, Sandiago, T.K. Umesh and Ramakrishna Gowda, "Photoeffect Cross Sections of Hg and I for 661.6 keV Gamma Rays by a New Method", Sixth International Symposium on Radiation Physics, Rabat, Morocco, July, 1994.
4. Sandiago, K.P. Gopinathan Nair, Channe Gowda, S.J. Anasuya, J. Shylaja Kumari, T.K. Umesh and Ramakrishna Gowda, "Photoeffect Cross Sections of Some Low and Medium Z elements for the  $K_{\alpha}$  and  $K_{\beta}$  radiation from  $^{203}\text{Hg}$  Source", Sixth International Symposium on Radiation Physics, Rabat, Morocco, July, 1994.
5. Channe Gowda, K.P. Gopinathan Nair, S.J. Anasuya, J. Shylaja Kumari, Sandiago, T.K. Umesh and Ramakrishna Gowda, "The Total Coherent Scattering Cross Sections of Some Rare-Earth Elements at 662 keV", Sixth International Symposium on Radiation Physics, Rabat, Morocco, July, 1994.
6. J. Shylaja Kumari, Channe Gowda, S.J. Anasuya, K.P. Gopinathan Nair, Sandiago, T.K. Umesh and Ramakrishna Gowda, "Integral Incoherent Scattering Cross Sections for Some Rare-Earth Elements at 661.6 keV", Sixth International Symposium on Radiation Physics, Rabat, Morocco, July, 1994.