Absorption Parameters for Glucose Solution for Gamma Ray at 59.54 keV

Maan S. Al-Arif[1] and Diyaree O. Kakil[2]

[1]School of Medicine, Koya University
Daniel Mitterrand Boulevard, Koya KOY45, Kurdistan Region – F.R. Iraq

[2]Department of Physics, Faculty of Science and Health, Koya University
Daniel Mitterrand Boulevard, Koya KOY45, Kurdistan Region – F.R. Iraq

***Abstract*—Photon absorption parameters for glucose solution at different concentrations such as linear attenuation coefficient, mass attenuation coefficient, effective atomic number, electron density and density determined at 59.54 keV photon energy. The mass attenuation coefficient is calculated using the mixture rule and a correction factor to approximate the experimental model is added. Accordingly, the effective atomic number and electronic density appears to decrease with increasing glucose concentration. Moreover, the measured linear attenuation coefficient and the density for the solution are linearly increased with concentration. We can conclude that the electrical conductivity of the solution depends on the physical nature of the electrical charge carrier in the solution, concentration of the solute material, and the electronic density of the solution at the same time.**

***Index Words*—Atomic number, attenuation coefficient, density, photon absorption.**

I. Introduction

Solution density is often used as a point of identification in the determination of an unknown substance. When a substance is dissolved in pure water, the density of the solution will be different from that of the water itself. The determination of the density of certain physiological liquids is often an important screening tool in medical diagnosis. The method used in density determination depends on the type of sample and on the level of precision desired (Zamyatin, and Burkov, 2012; Terwilliger, 2002). The general method to determine the density involves measurement of the mass and the volume of the sample using different techniques. On the other hand, with the extensive use of gamma-active isotopes in medicine, industry and agriculture, the study of absorption of gamma rays in the composite materials has become an interesting and exciting field of research. The photon attenuation coefficient, effective atomic number, electron density are basic quantities required in determining the absorption of x-rays and gamma photons in matter. The knowledge of the absorption parameters such as mass attenuation coefficient (μ/ρ), linear attenuation coefficient (μ), total atomic cross-section (σ_a), electronic cross-section (σ_e), effective atomic number (Z_{eff}), and electron density (N_{eff}) play an important role in understanding the physical properties of composite materials. They are invaluable in many applied fields, such as nuclear diagnostics, radiation protection, and radiation dosimetry.

Some material when dissolve in solution has certain dosimetric properties after exposed to photon radiation (Soppe, 1993; Marzouguia, et al., 2008; Hamzaoui, et al., 2009). The effective atomic number of such solution becomes of high importance especially at low photon energies where the energy dependency increases.

Since the solution density is varied with solute concentration, the present work aims to determine the density of glucose in distilled water by measuring the photon attenuation coefficient. This technique tends to establish the relationship between glucose concentration and the density. Moreover, the effective atomic number, electronic density of the solution calculated using the measured density and linear attenuation coefficient. The linear attenuation coefficient for some chemical solutions have been studied which shows a linear relationships with concentration (Mitkar, and Dongarge, 2012a; Mitkar, and Dongarge, 2012b; Baldha, et al., 1997). Similar method will be used to establish the relationship between concentration of the solution and density, effective atomic number, and electronic density.

II. Theoretical Background

The intensity of gamma radiation after traversing the thickness, $\boldsymbol{x}$, of chemical solution is given by:

$$I = I_0 e^{-\mu x} \quad (1)$$

μ represent the linear attenuation coefficient. The intensity of radiation can also be written in terms of the mass attenuation coefficient such as:

$$I = I_0 e^{-(\mu/\rho)x\rho} \quad (2)$$

ARO-The Scientific Journal of Koya University
Volume IV, No 2(2016), Article ID: ARO.10103, 04 pages
DOI: 10.14500/aro.10103
Received 09 June 2016; Accepted 08 August 2016
Regular research paper: Published 09 September 2016
Corresponding author's e-mail: maan.safa@koyauniversity.org

(μ/ρ) is the mass attenuation coefficient, and ρ is the density of the material. The total mass attenuation coefficient (μ/ρ) for chemical mixture at any reference photon energy is related to the (μ/ρ) of the constituent elements in the mixture (Baldha et al., 1997; Teli, and Chaudhari, 1995; Chaudhari, and Teli, 1996; Teli, and Chaudhari, 1996; Wang, et al., 1995; Singh et al., 2002) and is given by:

$$(\frac{\mu}{\rho})_{solution} = \sum_i w_i \, (\frac{\mu}{\rho})_i \tag{3}$$

Where, w_i, is the mass fraction of component i, $(\frac{\mu}{\rho})_i$ is the mass absorption coefficient of component i, and the summation is over all components of the mixture.
The density of the solution can then be determined as;

$$\rho_{solution} = \frac{\mu_{solution}}{\sum w_i (\mu/\rho)_i} \tag{4}$$

Where, $\mu_{solution}$, represent the experimental linear attenuation coefficient, and $\sum_i w_i (\frac{\mu}{\rho})_i$ is the calculated solution mass attenuation coefficient.

The mass attenuation coefficient values of the materials have been calculated using the WinXCom program (Gerward, et al., 2004). This well-known and widely used program provides the total mass attenuation coefficient and total attenuation cross-section data for approximately 100 elements, as well as the partial cross-sections for incoherent and coherent scattering, photoelectric absorption and pair production at energies from 1 keV to 100 GeV. For materials composed of multiple elements, the fraction by weight is given by:

$$w_i = \frac{n_i A_i}{\sum_i n_i A_i} \tag{5}$$

A_i represents the atomic weight of the i-th element and n_i is the number of formula units. The total atomic cross-sections σ_a for the sample can be obtained from the value of (μ/ρ) using the following relation (Baltej, et al., 2012):

$$\sigma_a = \frac{1}{N_A}\left[\frac{(\mu/\rho)_{compound}}{\sum_i \frac{w_i}{A_i}}\right] \tag{6}$$

N_A represents the Avogadro's number. The total electric cross section (σ_e) is given by the following formula [Nil et al., 2013]:

$$\sigma_e = \frac{1}{N_A}\left[\sum_i \left(\frac{f_i A_i}{Z_i}\right)(\mu/\rho)_i\right] \tag{7}$$

Where f_i is the number fraction of the atoms of element (i) relative to the total number of the atoms of all elements in the mixture, and Z_i is the atomic number of the i-th elements in the mixture. σ_a and σ_e are related to the Z_{eff} of the material through the following expression (Baltej, et al., 2012; Nil et, al., 2013):

$$Z_{eff} = \sigma_a/\sigma_e \tag{8}$$

The N_{eff} (number of electrons per unit mass) can be written as following:

$$N_{eff} = \left(\frac{N_A}{A_i}\right)(Z_{eff})\sum_i n_i = \frac{(\frac{\mu}{\rho})s}{\sigma_e} \tag{9}$$

III. Materials and Method

The extent of gamma ray penetration depends upon several factors including energy of radiation and nature of intervening material. Since $70\,ml$ of distilled water is used in the present work, the energy of the gamma source is selected so that significant intensity attenuation should occur throughout the sample. Therefore, ^{241}Am gamma source with energy of 59.54 keV and activity of $0.34\,MBq$ is selected to be use in the present work. The ^{241}Am source has low penetration power which reduces the amount of shield needed. The ^{241}Am source have a linear attenuation coefficient of about $0.206\,cm^{-1}$, and a half value thickness of about $3.25\,cm$ in distilled water. The alpha particle emitted with gamma ray from the ^{241}Am source is easily absorbed by $1.0\,mm$ thick piece of paper placed in the direction of the beam.

The experimental arrangement for measuring the attenuation coefficient of glucose solution is shown in Fig. 1. The Attenuation coefficient measurement is performed using NaI (TI) scintillation detector connected to a multi-channel analyzer (MCA) with an energy resolution of 7.5% at 662 keV.

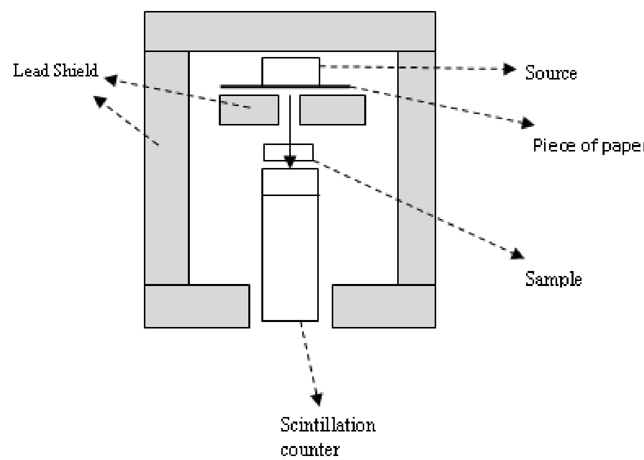

Fig. 1. Arrangement for measuring the attenuation coefficient.

The volume of liquid in the polyethylene container, with an inner diameter of $4.5\,cm$, increases from $10\,ml$ to $60\,ml$ in $10\,ml$ steps, and the fraction of the intensity transmitted are recorded. The temperature of the solution is kept at $20°C$ throughout the measurements. The actual height of the solution in the container is calculated by dividing the volume by the inner cross-sectional area. The transmission ratio for each solution height is recorded and used to calculate the linear attenuation coefficient according to (1).

The absorption coefficient for gamma rays is available for mixture of solid materials and solutions using various calculation techniques (Mitkar, and Dongarge, 2012a; Mitkar, and Dongarge, 2012b; Baldha, et al., 1997; Baltej, et al., 2012; Nil, et al., 2013; Singh, 2000). Most of them claim a good agreement with the well known mixture rule.

In the present work, the mixture rule is also used to calculate the mass attenuation coefficients for the solution at different glucose concentrations. In practice radiation suffers from attenuation in passing through the solution, the base of the polyethylene container, and the aluminum layer covering the crystal of the scintillation detector. Since calculation based on mixture rule consider only the attenuation by the solution, therefore the attenuation of the $1\,mm$ thickness of the polyethylene base, and the attenuation of the 0.4 mm aluminum layer covering the crystal must be added to the calculation. The linear attenuation coefficient for aluminum layer is $0.7506\ cm^{-1}$ which attenuates the radiation beam intensity by 3%, and the attenuation coefficient for the polyethylene layer is $0.18518\ cm^{-1}$ which attenuates the radiation beam by 1.85%, at 60 keV (Hubbell, and Seltzer, 1995; NIST, 1996). Density of the solution at different glucose concentrations are then calculated according to (4).

Different concentrations of glucose solution expressed in terms of percent composition by mass (*% w/w*) are prepared and used in this work. The percent composition by mass is the mass of the solute divided by total mass of the solution (mass of solute plus mass of solvent), multiplied by 100. Table I shows the amount of glucose dissolved in distilled water corresponding to each arbitrary chosen concentration used in this investigation.

TABLE I
THE AMOUNT OF GLUCOSE DISSOLVED IN 70 ML OF DISTILLED WATER

glucose mass (g)	*% w/w*
4.66	6.66
6.99	9.09
13.99	16.66
17.50	20.00
27.99	28.57
34.94	33.30
48.98	41.17
70.0	50.00
105.0	60.00

IV. RESULTS AND DISCUSSION

The measured linear attenuation coefficient, the calculated mass attenuation coefficient (before and after correction) according to (3) is shown in Table II.

Solution density is gradually increases from $1.0\ g/cm^3$ at 0 % (*w/w*) concentration to a value of $1.393\ g/cm^3$ at 60 % (w/w) concentration.

The solution densities corresponding to each glucose concentration as a function of glucose concentration is shown in Fig. 2.

The variation of the effective atomic number and the effective electron density with glucose concentrations are shown in Fig. 3 and Fig. 4.

The effective atomic number and the effective electronic density of the solution decrease linearly and smoothly with increasing glucose.

TABLE II
EXPERIMENTAL AND CALCULATED ATTENUATION COEFFICIENTS AS A FUNCTION OF SOLUTION CONCENTRATION

Concentration (% w/w)	(μ) (cm^{-1})	(μ/ρ) Before Correction (cm^2/g)	(μ/ρ) After Correction (cm^2/g)
0	0.228	0.2057	0.2161
6.66	0.231	0.2048	0.2152
9.09	0.242	0.2045	0.2147
16.66	0.254	0.2036	0.2137
20	0.257	0.2032	0.2133
28.57	0.260	0.2021	0.2116
33.3	0.262	0.2015	0.2115
41.17	0.270	0.2006	0.2106
50	0.276	0.1995	0.2094
60	0.290	0.1982	0.2081

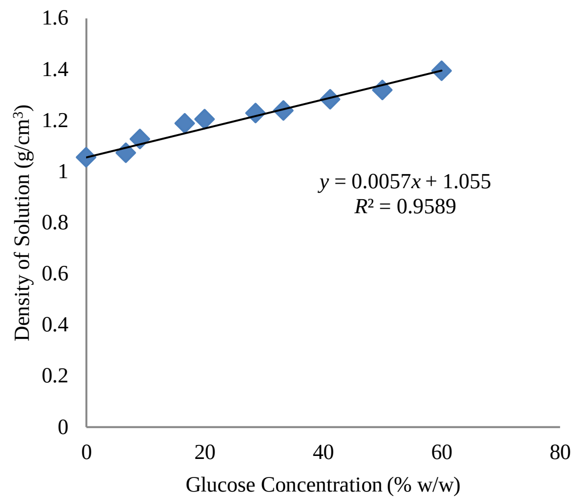

Fig. 2. Variation of the solution density with glucose concentration

V. CONCLUSION

A smooth linear relationship between concentration and density for the solution is obtained by means of measuring the linear photon attenuation coefficient. The density of the solution increases as the concentration increases.

The effective atomic number of the solution decreases with increasing the concentration. This indicates that as concentration increases, the solution physical property becomes approximately a tissue equivalent solution.

The electronic density for the solution decreases with increasing concentration. This trend of sugar solution agrees with some researchers (Marzouguia, et al., 2008). They found that higher electrical conductivity for sucrose solutions occur at concentration of $20\%\,(w/w)$ and tend to decrease with increasing concentration. Other researchers (Riyadh, and Abul-Hail, 2011) found that the electrical conductivity for sodium chloride solution increase with increasing concentration and was attributed to the ionic nature of the electrical charge carrier in the solution and not to the

 http://dx.doi.org/10.14500/aro.10103

electronic density. We suggested that the electrical conductivity of the solution depends on the physical nature, concentration of the solute material, and the electronic density of the solution. Moreover, higher value of the electronic density would indicate an increase in the probability of a photon-electron energy transfer and an energy deposition into the material. The present result indicates that the attenuation method is an excellent method to determine the unknown solution density, effective atomic number, and the electronic density. This method can be used with high accuracy in industry and research in cases where those photon absorption parameters are vital.

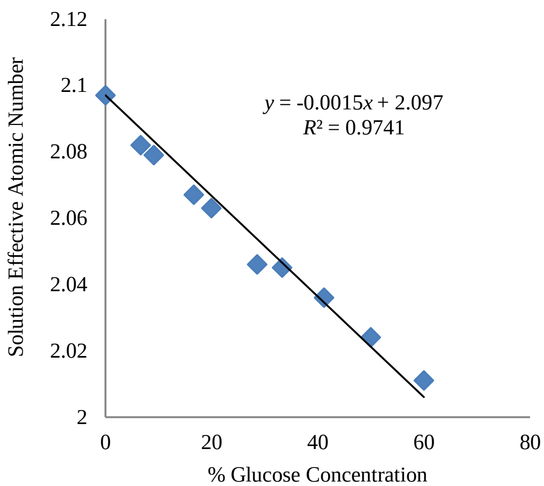

Fig. 3. Variation of the effective atomic number with glucose concentration.

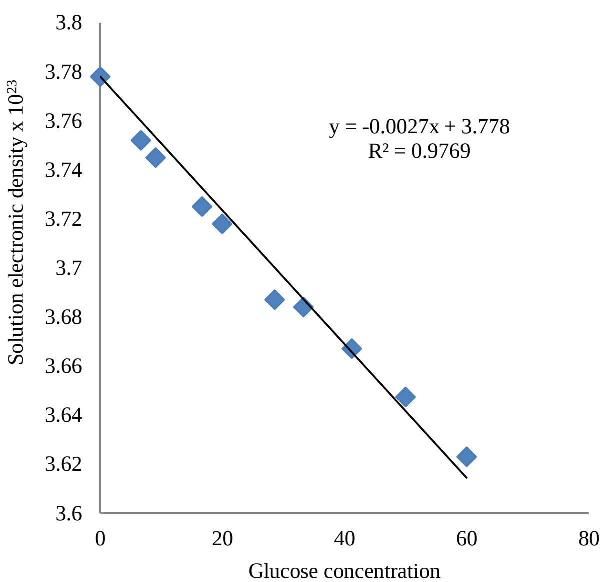

Fig. 4. Variation of the effective electronic density with glucose concentration.

REFERENCES

Zamyatin, I.V. Burkov, K.A., 2012. Determination of solutions density by the dilatometric titration method. *Russian Journal of General Chemistry*, 82(4), pp.639-642.

Terwilliger, T. C., 2002. Automated structure solution, density modification and model building. *Acta Cryst.* D58, 1937-1940, pp.3519-3540.

Soppe, W. J, 1993. Computer simulation of radiation damage in NaCl using a kinetic rate reaction model. *Journal of Physics: Condensed Matter*, 5 (22), pp.3519.

Marzouguia, K., Hamzaoui, A.H., Farah, K. and Ben Nessib, N., 2008. Electrical conductivity study of gamma-irradiated table sugar for high-dose dosimetry. *Radiation Measurements*, 43, pp. 1254–1257.

Hamzaoui, A.H., Farah, K., Marzougui, K., Horchani, S. , Ben Nessib, N. and M'Nif, A., 2009. PH-Metric study of gamma-irradiated table sugar for dosimetry purpose. *Radiation Measurements*, 44, pp.374–377.

Mitkar, S.R. and Dongarge, S.M., 2012a. Measurement of Linear and Mass Attenuation Coefficient of Alcohol Soluble Compound for Gamma Rays at Energy 0.511 MeV‖. *Archives of Applied Science Research*, 4(4), pp.1748-1752.

Mitkar, S.R. and Dongarge, S.M., 2012b. Study the Linear and Mass Attenuation Coefficient of Alcohol Soluble Compound for Gamma Rays at Energy 662 KeV. ***J****. Chem. Pharm. Res.*, 4(8), pp.3944-3949.

Baldha, G.J., Raval, D.A., Subbarao, M.V., and Kulkarni, R. G., 1997. Attenuation Coefficient of Various Gamma Radiations by Solutions of Cobalt Sufate. *Applied Radiation and Isotopes*, 48(8), pp.1121–1124.

Teli, M.T.e and Chaudhari, L.M., 1995. "Attenuation Coefficient of 123 KeV Gamma-Radiation by Dilute- Solution of Ferrous Sulfate". *Indian Journal of Pure & Applied Physics*, 33(7), pp.395-397.

Chaudhari, L. M. and Teli, M.T., 1996. Linear Attenuation (or Absorption) Coefficient of Gamma Radiation For dilute-Solutions of Potassium-Chloride. *Applied radiation and isotopes, 47(3), pp. 365-367.*

Teli, M.T.e and Chaudhari, L.M., 1996. The Attenuation Coefficient of Ammonium-Chloride for 662 KeV Gamma-Radiation, Measured for Dilute –solutions‖. *Radiation physics and chemistry*, 47(4), pp. 531-534.

Wang, D.C., Ping, LA. and Yang, H., 1995. Measurement of the mass attenuation coefficients for SiH4 and Si. *Nucl Instrum Meth B*; 95, pp.161-165.

Singh, K., Singh, H. and Sharma, V et al., 2002. Gamma-ray attenuation coefficients in bismuth borate glasses. *Nucl Instrum Meth B;* 194, pp.1-6.

Gerward, L., Guilbert, N. and Jensen, KB et al., 2004. WinXCom–a program for calculating X-ray attenuation coefficients. *Radiat Phys Chem,* 71, pp.653-654.

Baltej, S.S. Dhaliwal, A.S. Mann, K.S. and Kahlon, K.S., 2012, Study of mass attenuation coefficients, effective atomic numbers and electron densities for some low *Z* compounds of dosimetry interest at 59.54 keV incident photon energy. *Annals of Nuclear Energy*, *(*42), pp.153–157.

Nil, K., Zeynal, T. and Merve, C., 2013. Determining photon energy absorption parameters for different soil Samples. *Journal of Radiation Research*, 54, pp.578–586.

Singh, G. K. Lark, B. S. and Sahota, H.S., 2000. Attenuation Measurements in Solutions of Some Carbohydrates‖. *Nuclear Science and Engineering*, 134 (2), pp.208-217.

Hubbell, J.H and Seltzer, S.M., 1995. Tables of X-Ray Mass Attenuation coefficients and Mass Energy Absorption Coefficients, 1 keV to 20 MeV for Elements Z=1 to 92 and 48 Additional Substances of Dosimetric Interest. *Radiation Physics Division, PML, NIST.*

The National Institute of Standards and Technology (NIST) is an agency of the U.S. Department of Commerce 1996. Available at: http://www.nist.gov/pml/data/xraycoef/index.cfm.

Riyadh, Ch. Abul-Hail, 2011. Electrical conductivity dosimetric characteristics of gamma-irradiated food salt. *Journal of Basrah Researches (Sciences)*, 37(4) A, pp.25-29.