Engineering and Scientific International Journal (ESIJ)
Volume 9, Issue 2, April – June 2022

ISSN 2394-7187(Online)
ISSN 2394 - 7179 (Print)

A Simple Optical Method for Determination of the Dielectric Constant of Salt (%) Water using Ultraviolet Light

Prof. Samir A. Hamouda*[1], Maqboula Khamis Ibrahim[2]

[1]*Professor*, [2]*M.Sc.Scholar*

Physics Department, University of Benghazi, Libya

Corresponding Author Email id: dr_s_hamouda@yahoo.ie

Abstract — Optical constants such as refractive index, absorption coefficient, extinction coefficient and the real (εr) and imaginary (εi) components of the dielectric constant for NaCl salt water (10-50%) were determined from the UV Optical transmission data. Results of UV transmission analysis in salt water have shown that in dilute solutions the dielectric constant (real & img) is linear. The addition of dissolved Na and Cl ions above (50%) to water results in a drop in dielectric constant.

Keywords — *Optical Transmission Method; Refractive Index (N); Extinction Coefficient (K); Salt Water; Dielectric Constant.*

1. Introduction

Light is a part of electromagnetic spectrum, which comprises other regions of electromagnetic radiation such as radio, microwave, X rays, gamma-ray, and cosmic ray. The spectrum of visible light (see figure1), depending on the wavelength or frequency, consists mainly of infrared with wavelengths approximately (930nm -3200nm), visible (400-750 nm), and ultraviolet (300-400 nm) bands [1].

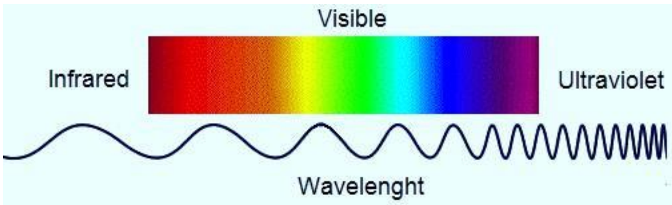

Fig.1: Shows a region of electromagnetic spectrum of experimental interest

The basic idea of applying the optical methods or optical Spectroscopies is to study how matter interacts with or emits electromagnetic radiation. However, there have been many different types of optical spectroscopy, depending on the wavelength range that is being measured. Infrared spectroscopy uses the lower energy infrared part of the spectrum and ultraviolet spectroscopy uses the higher energy ultraviolet part of the spectrum. Such optical methods are used to determine the mechanical, chemical, and electrical properties of matter. UV-Vis spectroscopy is a spectroscopy analysis technique using ultraviolet electromagnetic radiation source and visible light using spectrophotometer instrument. Spectrophotometer produces light from spectrum with certain wavelength and photometer is a measuring tool of light intensity transmitted or absorbed [2][3]. Infrared, visible, and ultraviolet radiation is widely used in scientific research, physics [4][5], astronomy [6][7], medicine [8], chemistry [9][10], biology [11][12], industry[13], and forensic science [14][15].

2. Theory of Optical Properties

The most important description of the amount of radiation penetration into the material is the Linear Attenuation Coefficient, which is a quantity that depends on the energy of the incident photon and the atomic number of the material. This quantity represents a fraction of the energy lost from the incident photon for every 1cm penetrated through the material. The unit of linear absorption coefficient μ is cm^{-1}. However, the fundamental mechanism of quantitative analysis in optical (absorption or transmission) methods is the Lambert Beer's law. According to Lambert –Beer's law [16-21], when a narrow photon beam of single energy $h\upsilon_0$ and a flux density I_0 (the number of photons per unit area and t time) falls on a homogeneous medium and penetrates it a distance (x), the flux density of the transmitted photon beam from this medium is I and is given as:

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

Applying to liquids or solutions, Lambert-Beer's law states that the amount of radiation of infrared, visible, and ultraviolet light, transmitted or absorbed by a solution is an exponent function of substance concentration and solution thickness [3]. Therefore, measurement of the amount absorption and transmission by a solution allows for the determination of electric constants, such as the absorption coefficient (α), the extinction coefficient (k), and the real and imaginary part of the dielectric constant (ε´ and ε´´) of the solution. In this paper, we report the optical and electrical properties of salt water (%) from the UV Optical transmission data. The optical property of a transmitting

DOI: **10.30726/esij/v9.i2.2022.92001**

ISSN 2394-7187(Online)
ISSN 2394 - 7179 (Print)

medium are presented as the complex dielectric constant and is given as:

$$\varepsilon = \varepsilon' + \varepsilon'' \quad (2)$$

Where ε´ is the real part and ε´´ is the imaginary part of the dielectric constant of the medium. Both parameters are calculated by the flowing formulas [22]:

$$\varepsilon' = n^2 - k^2 \quad (3)$$

$$\varepsilon'' = 2nk \quad (4)$$

Where n is the refractive index, *n* is related to the velocity of propagation of an electromagnetic wave through the medium. K is the extinction coefficient which is related to the loss of wave energy of the incident electric field to the medium. Therefore, the optical properties of the medium are governed by the interaction of the electric field of the electromagnetic wave and the medium. The refractive index (n) is related to the transmittance (T) in the medium through the relation [23]:

$$n = \frac{1}{T} + \sqrt{\frac{1}{T^2} - 1} \quad (5)$$

Transmittance is defined as ($\frac{I}{I_0}$), where I_0 is intensity of light entering the sample and I is intensity of light emerging from the medium. The absorption coefficient (α) is defined as the ratio of the incident intensity of electromagnetic waves per unit length in the direction of wave propagation in the medium and is related to the absorbance (A) and the thickness of the medium (d) as [24]:

$$\alpha = \frac{2.303A}{d} \quad (6)$$

The absorbance (A) is proportional to concentration of absorbing medium compound and is given as [25]:

$$A = -\log T \quad (7)$$

It can be seen from the relation (6) that the amount of radiation of visible light that is absorbed by a medium (solution), is proportional to the concentration and inversely to the thickness of the medium. On the other hand, the absorption coefficient (α) is related to the extinction coefficient (K) and the wavelength (λ) of the incident photons through the relation [26]:

$$\alpha = \frac{4\pi K}{\lambda} \quad (8)$$

The relation (8) states that the absorption coefficient (α) also depends on solvent, the molecular structure, temperature and the incident wavelength.

3. Materials and Methods

In considering optical methods for measurement of light absorption and transmission in NaCl salt water (concentration %), one is faced with either instrumenting new spectrophotometric equipment or improving existing equipment. The method described in this paper is the result of the second consideration. In this UV spectroscopy method, the spectrometer consists of light source, UV filter, quartz cuvette, ammeter, power supply, and photocell. Figure2 shows the main units of the optical system. Distilled water was heated to boiling temperature in order to release dissolved gases.

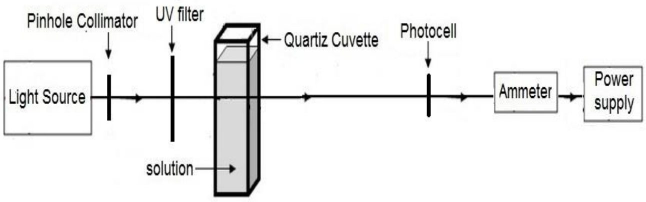

Fig.2: The experimental set-up

Salt solutions were made from distilled water with salt concentration (gram/liter) from (10-50%). However, measurements of salt solutions were taken on two consecutive days in order to achieve solution equilibrium, and average results were taken. Measurements were taken at 16^{0}C. The transmission data was recorded with ammeter in the UV wavelength range of approx. 300 nm to 400 nm and maximum transparency (366 nm).

4. Results and Discussions

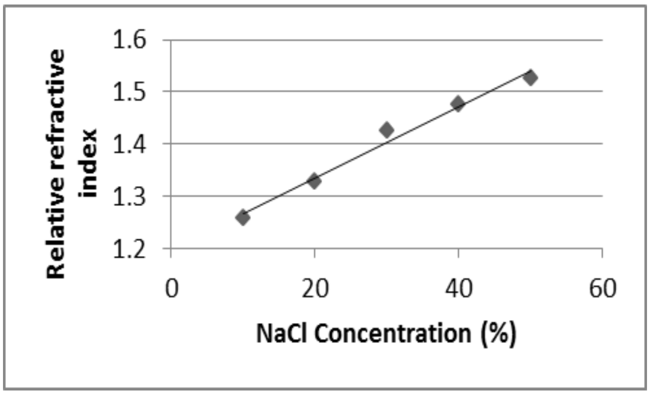

Fig.3: Shows the refractive index of salt concentration (gram/litter) from (10-50%) in water for UV wavelength (366 nm)

Figure 3 shows the refractive index of salt concentration (gram/litter) from (10-50%) in water for UV wavelength range of approx. 300 nm to 400 nm and maximum transparency (366 nm). It can be seen from

DOI: **10.30726/esij/v9.i2.2022.92001**

figure3, that the refractive index of solution increases as the concentration of solutions increases. This increase is to a certain limit. Above 50% concentration no data was obtained. This is due to the fact that, as the concentration of solutions increases its density increases, there are more molecules for the UV light to hit when it penetrates through the solutions. As a result the penetration of UV in the solution is blocked.

Figure 4 shows the real and imaginary parts of the dielectric constant of salt concentration (gram/litter) from (10-50%) in water for UV wavelength range of approx. 300 nm to 400 nm and maximum transparency (366 nm). Calculations of the (real & img) parts of the dielectric constant were carried out with UV wavelength (366 nm).

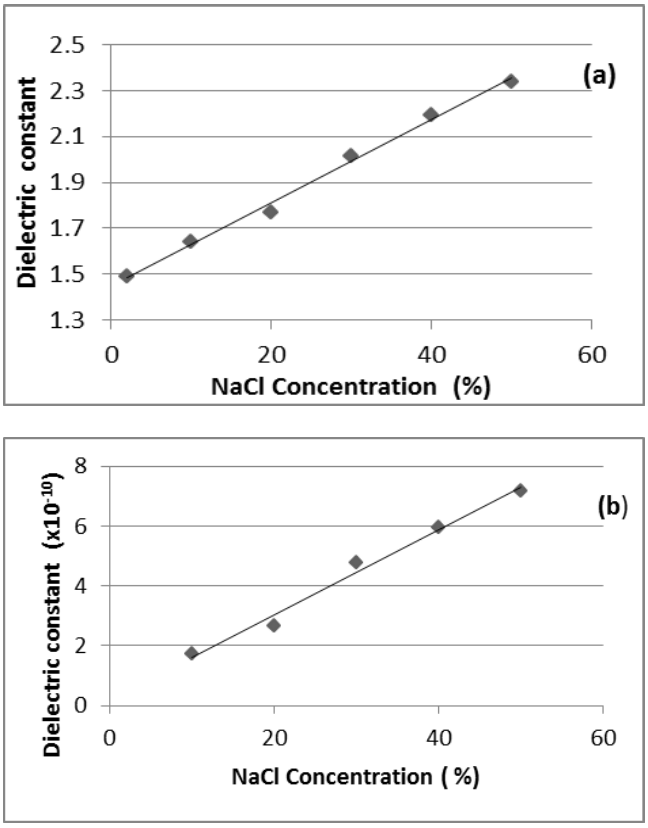

Fig.4: The effect of NaCl salt concentration on the real (a) and imaginary (b) parts of the dielectric constant for UV wavelength (366 nm).

It can be seen from figure4; that in dilute solutions the dielectric constant real (a) and imaginary (b) are linear. The addition of dissolved Na and Cl ions to water results in a drop in dielectric constant of water (~80) due to the fact that the densities of solution reach a saturation level and the solution become an electrically conductive. The dielectric constant is an indicator of how easily an insulating material can be polarized as a result of an external electric field applied to it. The dielectric constant is an indicator of how easily an insulating material can be polarized as a result of an external electric field applied to it. The NaCl ions produce electric fields that polarize the water dipoles, which is opposite to electric components of the UV electromagnetic wave.

5. Conclusion

The study of dielectric constant of NaCl salt water (%) gives important information about the nature of molecules, ions and their physical mechanisms in the solution. The optical constants of NaCl salt water, such as refractive index (n), absorption coefficient (α), extinction coefficient (k) and the real (εr) and imaginary (εi) components of the dielectric constant are important factors for optical applications. Both (n, k) were determined from the transmission (T) of UV light through NaCl water solution.

References

[1] Samir A. Hamouda and Maqboula Khamis Ibrahim., "Knowledge and Experimental Techniques", Engineering and Scientific International Journal (ESIJ), Volume 8, Issue 4, October – December 2021, pp. 156-159.

[2] Yang Sing Leong et. al., "UV-vis spectroscopy: A new approach for assessing the color index of transformer insulating oil." Sensors, Vol. 18, Issue no. 7, 2018, 6 July,, PP. 2175.

[3] Rahmi Dewi, et al., "Characterization of Optical Properties of Thin Film Ba1-xSrxTiO3 (x= 0,70; x= 0,75; and x=0,80) Using Ultraviolet Visible Spectroscopy"., The 8th National Physics Seminar, AIP Conference Proceedings vol. 2169, 2020, : 05 May, PP. 040001-1-040006.

[4] B L Diffey, "Ultraviolet radiation physics and the skin", Phys. Med. Bio., V01. 25. No. 3, 1980, PP. 405-426.

[5] Hanns Moshammer, et. al. "UV-Radiation: From Physics to Impacts ", Int. J. Environ. Res. Public Health, vol. 14, Issue 2, 2017, 17 February, PP. 200.

[6] A Vidal-Madjar, et. al. "Galactic ultraviolet astronomy", Rep. Prog. Phys, vol. 50, 1987, PP. 65-113.

[7] James Lequeux., "The Rise of Ultraviolet Astronomy in France", Journal of Astronomical History and Heritage, vol. 24, issue 1, 2021, PP. 83–97.

[8] Edwin C. McCullough., " Optical Radiations In Medicine A Survey Of Uses, Measurement And Sources"., American Association of Physicists in Medicine. AAPM REPORT NO. 3, 1977

[9] C. Bosch Ojeda and F. Sánchez Rojas, "Process Analytical Chemistry: Applications of Ultraviolet/Visible Spectrometry in Environmental Analysis: An Overview, vol.44, Issue 3, 2009, 2PP. 245-265.

[10] Robina Begum. et al., "Applications of UV/Vis Spectroscopy in Characterization and Catalytic Activity of Noble Metal Nanoparticles Fabricated in Responsive Polymer Microgels: A Review", Critical Reviews in Analytical Chemistry, vol.48, Issue 6, 2018, PP. 503-516

[11] Jessica Roberts, et.al. "The Use of UV-Vis Spectroscopy in Bioprocess and Fermentation Monitoring", Fermentation, vol. 4, Issue 1, 2018, 13 March, PP. 18.

[12] Kwan-Hoong Ng." Non-Ionizing Radiations–Sources, Biological Effects, Emissions and Exposures"., Proceedings of the International Conference on Non-Ionizing Radiation, 2017.

[13] Peter Swanson., "Advances in Light Curing Adhesives and Coatings Lead to Process and Quality Benefits in Electronics Manufacturing"., White Paper, Intertronics, 2017.

[14] Dzulkiflee Ismail, et. al." Ultra-Violet and Visible (UV-VIS) Spectroscopy and Chemometrics Techniques for Forensic Analysis

DOI: **10.30726/esij/v9.i2.2022.92001**

ISSN 2394-7187(Online)
ISSN 2394 - 7179 (Print)

of Ballpoint Pen Inks: A Preliminary Study", Malaysian Journal of Forensic Sciences, vol 5, Issue 1, 2014, January, Pp. 47-52.

[15] Mahmut Asirdizer et al., "Usage of Infrared-Based Technologies in Forensic Sciences"., Intech Open, 2016, 7 September.

[16] W. Heitler, "The Quantum Theory of Radiation", (Oxford University Press, London), England, 1944, p. 49.

[17] R. D. Evans,, "The atomic nucleus", McGraw Hill Book Company, Inc., New York.1955.

[18] C. M. Davisson and R. D. Evans, "Gamma-ray absorption coefficient". Rev. Mod. Phys, Vol.24, 1952, 79-103.

[19] Harvey Hall, "The theory of photoelectric absorpt ion for xrays and Gamma-rays", Reviews of modern physics", Vol 8, 1936, pp358-377.

[20] J. Hubbel, "Photon mass Attenuat ion and Energy- Absorpt ion Coefficients from 1keV to 20keV", Int. J. appl. radiat . isot , .vol 33 , 1982, pp1269-1290.

[21] Nat ional Bureau of Standarads "Photon Cross Sect ions, Attenuat ion Coefficient, and Energy Absorpt ion Coefficients from 10 keV to 100 GeV", U.S. Department of Commerce, 1969.

[22] S. Singh, Et Al), "Investigation Of Optical Constants And Optical Band Gap For Amorphous Se40-Xte60agx Thin Films"., Chalcogenide Letters, Vol. 14, No. 4, 2017.

[23] R Swanepoel., "Determination of the thickness and optical constants of amorphous silicon"., J. *Phys. E: Sci. Instrum,*.16, 1983, pp. 1214.

[24] Imen Ben Saad, et al., "Optical, UV-Vis spectroscopy studies, electrical and dielectric properties of transition metal-based of the novel organic–inorganic hybrid (C6h10n2) (Hg2cl5) 2.3h2o", Journal Of Advanced Dielectrics., Vol. 9, No. 5, (2019).

[25] Martin Vejražka., "Optical Methods In Biochemistry", Institute Of Medical Biochemistry, (2009).

[26] S. Singh and S. Kumar. "Investigation of Optical Constants and Optical Band Gap for Amorphous Se40-Xte60agx Thin Films", Chalcogenide Letters, Vol. 14, No. 4, April 2017, p. 139 – 146.

[27] R Swanepoel., "Determination of the thickness and optical constants of amorphous silicon", J. Phys. E: Sci. Instrum, vol. 16, 1983, p 1214.

DOI: **10.30726/esij/v9.i2.2022.92001**