Optical Properties of Tap Water Purity using He-Ne Laser with Different Power Density

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Abstract

Tap water differs from pure water, it contains more chemical contents arise in drinking water, it effect on health concern only after extended exposure of years, rather than months. The purpose of this article is to study the optical properties of tap water by using different power density from He-Ne laser beam transport through some samples. These samples of water mostly contain NaCl salts and clay .When we increasing concentration and sample length we can observed that decreasing transmittance ,(absorption and extinction) coefficients while the absorbance will be increased .At the 5 cm sample length we observed that tap water has transmittance about 17%, while NaCl (0.7) concentration has 58%,clay solute has 2%, and mixing from (0.7 NaCl and 0.15 clay) concentrations has transmittance 8%, The absorbance and absorption coefficient of tap water is greater than NaCl and less than clay alone and mixing (clay with salt) at the same sample length.

Keywords: *optical properties of water, transmittance, absorption coefficient, extinction coefficient.*

Introduction

Water is among the most abundant molecular species in nature. Water molecules are ubiquitous in the universe: the spectroscopic signature of water is found in the spectra of the sunspots, in interstellar media, in cemetery environments, and, of course, in the planetary atmospheres. Although water in the atmosphere represents only a minor admixture to more abundant constituents, the role played by water molecules in atmospheric process is inestimable. This primary concerns radiative properties of the Earth's atmospheric process is, since water vapor is recognized among the principle absorbers of radiation in the atmosphere. Atmospheric chemistry and photochemistry are also strongly affected by the presence of water [1].

The electronic properties of water due from the fact that water is composed of oxygen and hydrogen was established by *Lavoisier* and *Cavendish* at the end of the eighteenth century, as shown in Fig.(1).

Although a water molecule has an overall neutral charge (having the same number of electrons and protons), the electrons are asymmetrically distribute which makes the molecule polar. The oxygen nucleus draws electrons away from the hydrogen nuclei, leaving these nuclei with a small net positive char the excess of electron density on the oxygen atom creates weakly negative regions at the other two corners of an imaginary tetrahedron [2].

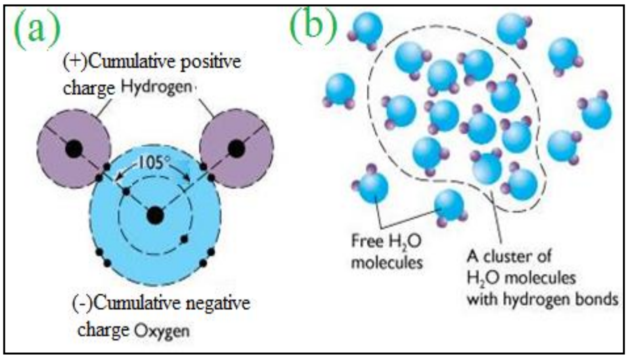

Fig. (1) Schematic view of H_2O molecule[1].

In the case for the three atoms in an H_2O molecule, there are three normal modes of vibration, as shown in Fig. (2). The first mode is a symmetrical stretching mode that ideally vibrates this translates to a transition energy of 43.7 kJ mol^{-1} which may also be manifested as a spectral absorption band at 3652 cm^{-1} .A second bending mode occurs at 1595 cm^{-1} in the IR spectrum (if absorption occurs),and a third asymmetric mode occurs at 3756 cm. Although all three of these vibrational modes are present in the H_2O molecule, the extent of IR absorption that occurs depends on the symmetry of the vibrational motion [3].

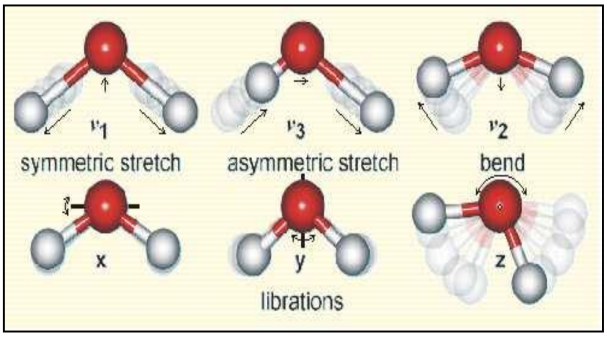

Fig.(2) The normal modes of vibrations can be observed by Infrared and / or Raman spectroscopy [2].

- **Hydrophilic Molecules:**

Substances that dissolve readily in water are termed hydrophilic. They are composed of ions or polar molecules that attract water molecules through electrical charge effects. Water molecules surround each ion or polar molecule on the surface of a solid substance and carry it into solution, as shown in Fig. (3).

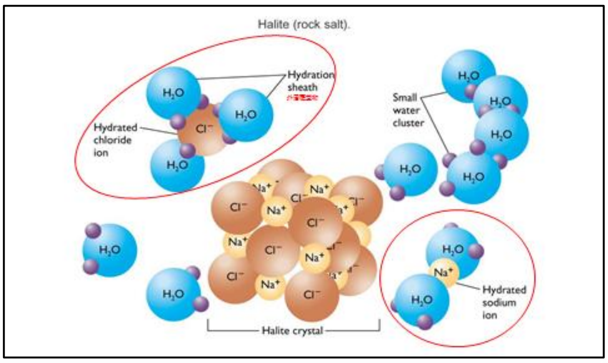

Fig. (3) Hydration: Water (as solvent) dissolves salts (as solute) by surrounding the atoms in the salt molecule and neutralizing the ionic bond holding the molecule together[4].

- **The Clay Structure Minerals:**

Are often depicted as ball-and-stick models. With such models, it is easy to envision the arrangement of oxygen and metal atoms into symmetric tetrahedral (four nearest-neighbors) or octahedral (six nearest-neighbors) coordination schemes Fig.(4). Models improve our understanding of clay-mineral atomic structure, which in turn helps us to predict the physical and chemical behavior of clay minerals. However, the atoms found in clay minerals are not fixed in space like the desktop models we hold in our hands.

Atoms are electrically charged entities that vibrate at frequencies in the range of 10^{12} to 10^{14} Hz and, in some cases, they and move from one to another structural site to within the crystal [3].

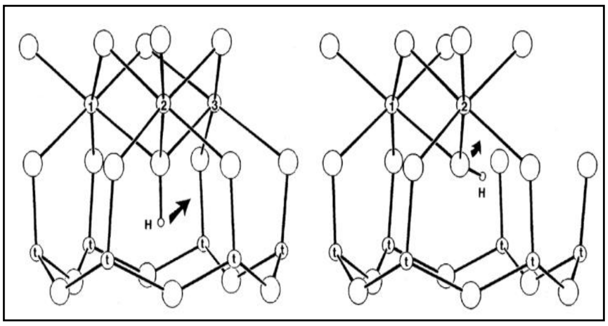

Fig. (4) Schematic diagram of trioctahedral (left) and dioctahedral (right) layer structures common to all clay minerals. Octahedral sites (1, 2, and 3), tetrahedral sites (t) and protons (H) are depicted in coordination with oxygen. Left arrow indicates the reorientation of O-H that occurs upon heating and oxidation of Fe in clay structures. Right arrow indicates the relocation of O after heating-induced hydroxylation [5].

- **Clay-Water Interaction:**

The water molecule “locked” in the adsorbed layers has different properties compared to that of the bulk water due to the strong attraction from the surface. As shown in Fig.(5).

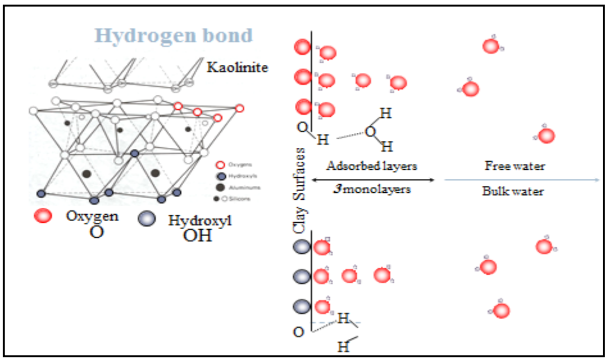

Fig. (5) Interaction of water and clay Minerals.

One prerequisite for EM radiation absorption is that a “resonance match” occurs between the vibrational energy of the bonds in clay minerals and the energy of EM radiation. In other words, IR radiation excites vibrations of the same frequency. The energy match produces an absorption phenomenon that involves an energy change or transition. The difference in energy (ΔE) for the transition is related to the wavelength of radiation as:

$$\Delta E = h \frac{c}{\lambda} \quad \text{...} (1)$$

where (h) the Planck's constant and(c) the velocity of light in a vacuum [3].

The particular coherence property of laser radiation has led in the last 20 years to new kinds of light scattering experiments not feasible with traditional light sources. These dynamic light scattering experiments have found an increasing number of applications in Physics, Chemistry, Biology, and Medicine [6].On the other hand, the high energy density, small beam divergence. and the high pointing and intensity stability of some laser beams has encouraged the use of laser sources in the traditional static light scattering experiments. Where the time averaged scattered intensities are studied [7].

The main difference between the coherent and incoherent illumination is the formation of speckles in the first case. Upon illumination of heterogeneous medium by laser radiation, a speckle structure of light field is created both on the surface and in the bulk of a body due to the interference of the scattered components with each other and with the incident light beam. This structure is characterized by sharp small-scale spatial modulation of radiation intensity, i.e., by strong spatial gradients of the light field. The gradient forces arising in this case can cause some changes in the local concentration of certain biological components of micrometer scale (erythrocytes, leukocytes, organelles, etc.), and by this means influence the biological functions of an organism [8].

Now both dynamic and static light scattering experiments can be performed with the same laser source and spectrometer [9]. One of the main applications of static light scattering experiments, i.e. the determination of molecular weights of macromolecules requires absolute intensity measurements, consequently there is an increasing demand for standards with precisely known absolute scattering power for the calibration of the light scattering photometers at laser light wavelengths [10].

In this paper, we present results of the theoretical analysis and experimental investigations of the influence of the salt (Na Cl) and clay with different concentration on the electronic and optical properties of the drinking water (tap water).

Experimental

The experimental system was consisted of He-Ne laser which used as a light source, to produce a laser beam in horizontal direction. The beam was incident on a plane mirror, at an angle of 45^0 to be reflected ends. Closed one end by both in a vertical direction. This reflecting beam supposed to pass the sample of water. At the end of the tube a power meter is placed. The glass tube of length ≈70 cm and the diameter 4cm open at both ends. Closed one end is by glass by sealing species of plane glass silicon jell. Glass tube was filled with water that has been used for the study of attenuation coefficient behavior of solutions. After the beam of intensity I_0 reflected from plane mirror. Adjusted to pass vertically the water sample in the tube then falls on the detector head at the other end of the tube as shown in the Fig.(6). The intensity of transmitted laser beam from the water solutions can be measured different reading for different depths were taken for each concentration.

After measuring optical properties of pure tap water, optical properties will be measured after adding different quantities of NaCl salt adding to distill water. Each concentration was put on magnetic stirrer for 15 min to obtain good mixing .While the optical properties for the different concentrations of clay (the material is called Kaolin Dnekla) the unalterable in distill water was prepared as follows:

In the first day 20 g of kaolin (represents W1) was taken and added to 100 ml of distill water, the suspension was left for 24 h. In the second day the suspension was separated using a filter paper, the removal overnight 24 h, in the third day the clay was dried and its weight was measured (W2) by this way and using spiral relation the concentration of the clay that still in the water was determined [11].

$$W_3 = W_1 - W_2 \quad \text{...} (2)$$

where (W_3) the weight of the clay still in the water, (W_1) the weight of origin clay, (W_2)

the weight of drying clay. Then the new concentration is represented from the relation:

$$C=\frac{W_3}{W_0}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where W_0 is the weight of the water. The size of the clay dust particles was measured the estimated rang size D=100-200µm.

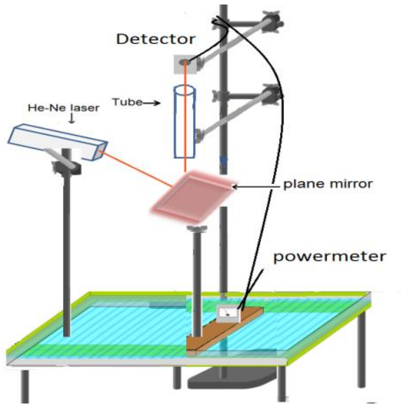

Fig. (6) Experimental system.

Result and Discussions

1- Transmittance

The ratio of transmitted intensity, I, to incident intensity, I_0, at a given frequency is called the transmittance, T, of the sample [12].

Fig.(7) shows decreasing transmission with increasing sample length at certain NaCl concentration and incident intensity is due to increasing depth length with increasing sample length so the attenuation of electromagnetic wave will be increased that lead to decrease the transmitted light intensity, other reason to interrupted that decreasing due to when the electromagnetic radiation pass through material is suffer from scattering which happened because a reflection of photons at a large number of angles from water and particulate constituents. Table (1) shows the value of transmittance with different sample length.

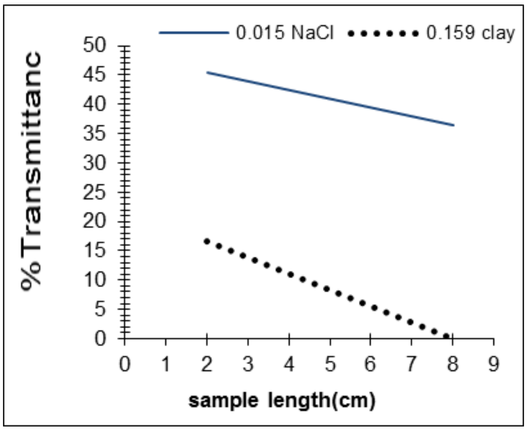

Fig. (7) The change of transmittance with sample length when I_0=5.5 mW/cm^2 of NaCl and 9 mW/cm^2 of clay.

Fig. (8) shows that decreasing of the transmitted intensity with increasing the sample length for different sample concentration The decrease of intensity of (*I*) in this case doesn't due to absorption only, but result from the fact that some light is scattered by pollutants and thus removed from the direct beam. When salt and water are combined, a mixture is created. Compounds in mixtures retain their individual properties.

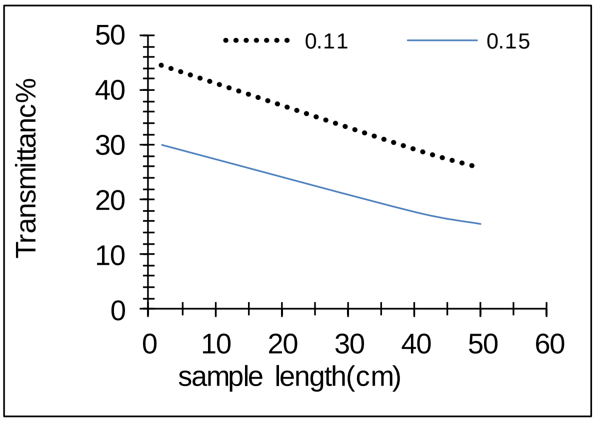

Fig. (8) Shows the relationship between transmittance and sample length when the incident intensity is constant.

When it will be using clay as could be shown in Table (3). It can be observed that the intensity decreases with increasing sample length, that due from the colors of an object typically arise because materials selectivity absorbs light of certain frequencies while freely scattering or transmitting light of other frequencies. Thus if an object absorbs light of all visible frequencies, it is black.

When mixing NaCl salt with clay ,we can observed that the transmittance is increased that due to when we add salt to the clay the dissolution will be happen which make to decrease the solution density and that able laser light to transmitted with low attenuation.

2-Absorbance (A)

Light absorption occurs when atoms or molecules take up the energy of a photon of light, thereby reducing the transmission of light as it is passed through a sample. Light attenuates exponentially as it passes through clear materials or solutions. So, naturally the reduction of transmitted light is exponentially related to the concentration of the sample and path length of light traveled, the absorbance related with transmittance according to [12]:

$$A = -\log(T) = 2.00 - \log(\%T) \quad ....(4)$$

Fig.(9) shows that the relation between absorbance and sample length, we can see that increasing absorbance with increasing sample length that due from photons of light may interact with the electron shell of molecules and be absorbed. Those Photons of light may interact with the electron shell of molecules and be absorbed, the photon energy is transferred to the molecule that absorbed it. This energy is utilized to transition electrons from the ground state to higher energy levels. Molecules can have very distinct absorption spectra because the energy content of some photons. The energy of absorbed photons may be utilized to break chemical bonds or generate electrons (in the case of photosynthesis). However, due to requirements for conservation of energy, the energy of all absorbed photons is eventually released in aquatic ecosystems as heat.

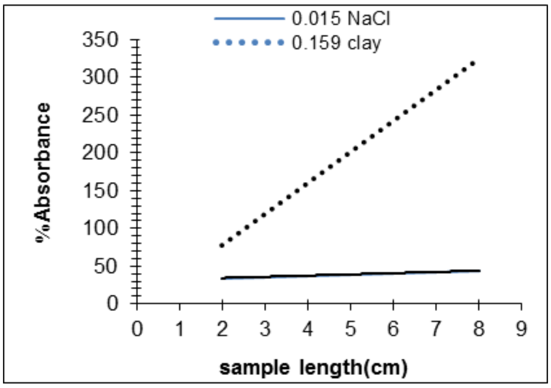

Fig. (9) The change of absorbance with sample length when I_0=5.5 mW/cm^2 of NaCl and 9 mW/cm^2 of clay.

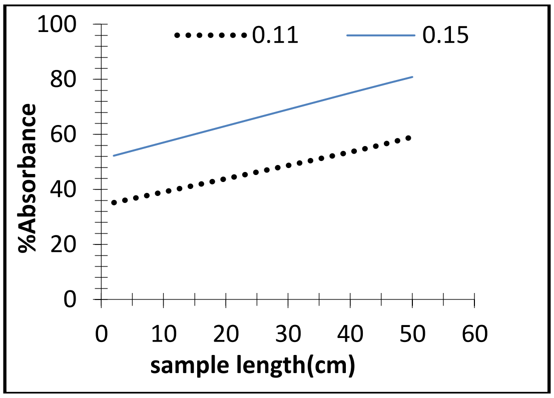

Fig. (10) Shows the relation ship between absorbance and concentration when the incident intensity is constant.

When mixing NaCl with clay as could be shown in Table (3). The absorbance will be increased rather than NaCl alone but it remains smaller than the clay alone that due from the dissolution will be happen when add salt to the clay the number of molecular will be decreased subsequent decrease the solution absorption.

Table (1)
The effect of NaCl and clay sample length on transmittance and absorbance at laser power density of NaCl 5.5 mW/cm^2 and 9 mW/cm^2 of clay.

Concentration (g/100ml)	*Sample thickness (cm)*	*Transmitted Intensity(mW/cm^2)*	*Transmittance (T)*	*Absorbance (A)*
NaCl 0.015	2	2.5	0.46	0.34
NaCl 0.015	40	2	0.36	0.44
NaCl 0.015	50	1.8	0.33	0.49
Clay 0.159	2	1.5	0.17	0.78
Clay 0.159	8	0.005	0.001	3.26

Table (2)
The effect of NaCl concentration on transmission and absorbance at incident laser power density 9 mW/cm^2.

Concentration NaCl (g/100ml)	*Sample thickness*	*Transmitted Intensity(I)*	*Transmission (T)*	*Absorbance (A)*
0.11	2	4	0.44	0.35
0.11	40	2.62	0.29	0.54
0.11	50	2.31	0.26	0.59
0.15	2	2.7	0.3	0.52
0.15	40	1.6	0.18	0.75
0.15	50	1.4	0.16	0.81

Table (3)
The transmittance and absorbance of clay and NaCl and mixing at incident laser power density 4.5 mW/cm^2 and sample length 5 cm.

Concentration (g/100ml)	*Transmitted Intensity(I)*	*Transmission (T)*	*Absorbance (A)*
Tap water	0.805	0.18	0.74
Clay0.15	0.1	0.02	1.65
NaCl 0.7	2.6	0.58	0.23
NaCl (0.7)+ Clay (0.15)	0.4	0.09	1.05

3-Optical Coefficients

1-3.Absorption coefficient

To determine the absorption coefficient (a) of the medium [12]:

$$\alpha = 1/t \ ln\, {}^{1}\!/_{T} \quad \text{...} (5)$$

Or

$$\alpha = 2.303\frac{A}{t} \quad \text{..} (6)$$

where (t) is the path length of the medium. The absorption coefficient is typically given in units of cm^{-1}.

Fig. (11) shows the absorption coefficient of light by tap water is lower than when we using NaCl salt and it decreases substantially with increasing sample length. That because in aquatic ecosystems photons may be absorbed by the water itself, dissolved substances, and particulate material. Pure water is not a colorless liquid. As is obvious by observing very deep, clear systems, water is a blue liquid. This color implies that there is significant spectral variation in absorption over the visible region. As see in Fig.(12), absorption coefficient increased markedly with increasing NaCl concentration at the same sample length., this may actually be an artifact of small amounts of dissolved organic carbon contamination present in even the most carefully purified water.

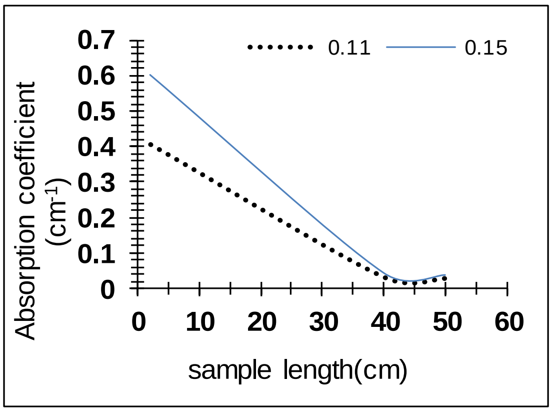

Fig. (11) The change of absorption coefficient with sample length when I_0=5.5 mW/cm^2 of NaCl and 9 mW/cm^2 of clay.

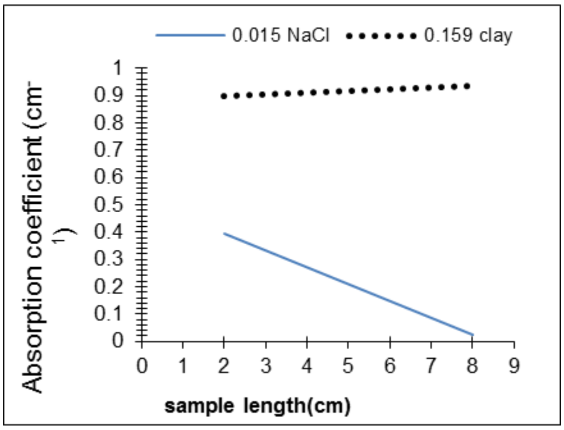

Fig. (12) The relation between sample length and absorption coefficient.

When we using clay as could be shown in Table (6) the absorption coefficient will be increased with increasing sample length that due from (Dissolved Organic Matter) (DOM) plays the most critical role in influencing the absorption spectrum of natural waters. This material consists mainly of hemic and folic compounds originating from the decomposition of terrestrial plant material under anaerobic conditions. As seen in Table (4), we can observe that the observation coefficient is increased rather than NaCl salt that due from the presence of CDOM.

When we add NaCl to Clay where the sample length remains constant we can observed increasing in absorption coefficient that due from CDOM strongly affects the absorption of visible light ,also these cells often contain a variety of accessory pigments (e.g. carotinoids, chlorophyll b, and chlorophyll c, etc.) as well as chlorophyll a. The author *Atkins* [13] sees that the absorbance peaks of chlorophyll a (425 and 665 nm) are often apparent in the spectral analysis of session over and above that of accessory pigments. Systems with high concentrations of CDOM may also have significant amounts of suspended organic colloids composed of humid matter.

2-Extenction Coefficient

The extinction coefficient is a measure of the amount of radiation absorbed per unit concentration per unit length and dependents' upon the wavelength of the incident radiation and is greater where the absorption is more intense [13].

The extinction coefficient (sometimes still called the “molar absorption coefficient”), when transmitted intensity varies with the length, L, of the cell, and the molar concentration, c, according to the Beer-Lambert Law:

$$I = I_0 10^{-\varepsilon(\bar{v})cl} \quad \text{..} (8)$$

where ε ($\bar{\upsilon}$) is dependent upon the wave number (or frequency). Its dimensions are 1/ (concentration × length), normally written in L mol^{-1} cm^{-1}. An alternative set of units is cm^{2}mol^{-1}, which means that ε ($\bar{\upsilon}$) can be thought of as a molar cross-section for absorption: the greater the cross-sectional area of the molecule for absorption, the better its ability to block the passage of the incident radiation.

Radiation density depends on the total quantity of the absorbing compound in the radiation pat and is linearly dependent on the concentration of the absorbing species. This is most commonly expressed as the following equation:

$$\varepsilon = \frac{A}{cl} \quad \text{..} (9)$$

where *L* (cm) is the path length of the cell, (c) (mol/L) is the molar concentration (number of moles of the solute dissolved per liter of the solution) of the absorbing species in the solution and ε the molar absorptivity.

Table (6) shows that the molar coefficient of water don’t have any value that because the water don’t have concentration and the molar coefficient depends on concentration according to relation (9), also it shows that the deceasing of extinction coefficient with increasing sample length when the NaCl concentration is remain constant that due from the fact that inversely preparation between ε and sample length according to relation (9), when different concentration will be used the molar absorption coefficient will be increased with increasing concentration at the same sample length that due from the linear relationship between extinction coefficient and concentration.

The molar absorption coefficient of clay will be increased with increasing sample length that due from the fact that the molar absorption coefficient of clay gets added to the molar coefficient of the previous sample and get ε for the next member of the series. The molar absorption coefficient of clay is greater than of NaCl that due from that NaCl salt all most consisted from two compound Na and Cl while clay consisted from many compounds and the molar absorption of it is the sum of it all. The extinction coefficient of mixing is greater than NaCl and clay alone.

Table (4)
Absorption coefficient and molar absorption coefficient at different sample lengths.

Concentration (g/100ml)	*Sample thickness*	*Absorption coefficient*	*Molar absorption coefficient(cm^{-1})*
NaCl 0.015	2	0.39	1 .41
NaCl 0.015	40	0.03	0.73
NaCl 0.015	50	0.02	0.65
Clay 0.159	2	0.9	2.45
Clay 0.159	8	0.93	2.56

Table (5)
Absorption coefficient and molar absorption at different sample concentration.

Concentration (g/100ml)	*Sample thickness*	*Absorption coefficient*	*Molar absorption coefficient*
0.11	2	0.41	1.60
0.11	40	0.03	0.12
0.11	50	0.02	0.11
0.15	2	0.60	1.74
0.15	40	0.04	0.13
0.15	50	0.04	0.11

Table (6)
The absorption and extinction coefficients of clay and NaCl.

Concentration (g/100ml)	*Sample thickness*	*Absorption coefficient*	*Molar absorption coefficient*
Tap water	5	0.34	-
Clay 0.15	5	0.11	0.07
NaCl 0.7	5	0.76	2.20
Na+ Clay	5	0.48	0.25

Conclusions

The tap water has transmittance 3 times as less as of NaCl salt, it is grater 8 times than transmittance of clay, and 2 times greater than mixing of NaCl with clay, the absorbance and absorption coefficient of water is grater 3times than NaCl and 2 times than clay and less 2 times rather than mixing from NaCl with clay.

References

[1] Barrow G. M. (McGraw-Hill Companies. Inc., Sixth Edition, Phase Diagrams of Water, pp. 245, 1996.

[2] Brimblecombe P., "Air composition and chemistry", Cambridge: Cambridge University press", p.p. 267, 1996.

[3] Schroeder P. A. ,"Infrared Spectroscopy in clay science": In CMS Workshop Lectures, Teaching Clay Science, A. Rule and S. Guggenheim, eds., The Clay Mineral Society, Aurora, CO ,Vol. 11, 181-206, 2002.

[4] Li B., "Density-Functional Theory and Quantum Chemistry Studies on “dry” and “wet” NaCl (001)", Thesis M. Sc., Berlin, pp. 34-50, 2009.

[5] Schroeder P. A., "Far infrared-ray diffraction and chemical investigation of potassium micas": American Mineralogist, Vol.75, pp. 983-991, 1990.

[6] Pecora R., "*Dynamic Light Scattering*", Plenum New York, pp. 10-13, 1985.

[7] Tsunashima Y., Moro K., Chu B., Liu T. Y., "Characterization of group C meningococcal polysaccharide by light-scattering spectroscopy. III. Determination of molecular weight, radius of gyration, and translational diffusional coefficient" Biopolymers, Volume 17, Issue 2, pp 251–265, February 1978.

[8] Rubinov A. N., Katarkevich V. M., Afanas'ev A. A., Efendiev T. S., "Interaction of interference laser field with an ensemble of particles in liquid", Optics Communications, Vol. 224, pp. 97-106,August 2003.

[9] Thurn A., Burchard W., Niki R., "Structure of casein micelles II. α s1-casein",Colloid and Polymer Science, Volume 265, Issue 10, pp 897-902, 1987.

[10] Moreels E., De Ceuninck W., and Finsy R., "Measurement of the Rayleigh ratio of some pure liquids at several laser light wavelengths", J. Chern. Phys. Vol. 86, No.2, pp. 618 -632, 1987.

[11] Amarasinghe A.D., Tharanga M.A., Alwis T.T., Anuradha H.B. and Dasanayaka D.R., "Annual Transactions of IESL", The Institution of Engineers, Sri Lanka Study the Factors Influencing Coir Pith Drying, pp. [9-13], 2012.

[12] Singh K.,Sandhu G.K., and Lark B.S., "Molar extinction coefficient of solutions of some organic compounds", J. Pramana of physics,Indian,vol.62, No.5, pp.1139-1145, 2004.

[13] Aksoy S., Caglar Y., Ilican S., Caglar M., "Effect of Sn dopants on the optical and electrical properties of ZnO films", J.Optical Application, Vol. XL, No.1, pp.8-14, 2010.

الخلاصة

يختلف ماء الحنفية عن الماء النقي، انها يحتوي على محتويات كيميائية أكثر تظهر في المياه الصالحة للشرب، وتأثر على اضطراب الصحة بعد التعرض الطويل لسنوات، وليس شهورا. غرض هذا البحث دراسة الخصائص البصرية لماء الحنفية باستعمال شعاع ليزرالهليوم_نيون قدرة وبكثافات مختلفة لبعض العينات. تحتوي هذه العينات على املاح كلوريد الصوديوم والغرين بتراكيز مختلفة. عندما نزيد تركيز وطول العينات نلاحظ نقصان النفاذية ومعاملا الامتصاص و التوهين بينما زيادة بالامتصاصية. عندما يكون طول العينة ثابت حوالي ٥ سم نلاحظ ما يلي، ماء الحنفية يحتوي على نفاذية تقريبا ١٧%، بينما ملح كلوريد الصوديوم بتركيز ٠,٧ يمتلك ٥٨%، محلول الغرين بتركيز ١,٥ يمتلك نفاذية ٢%، بينما كانت نفاذية ٨% لخليط بتركيز ٠,٧ من ملح الطعام مع محلول الغرين بتركيز ١,٥، الامتصاصية ومعامل الامتصاص لماء الحنفية اكبر من ملح كلوريد الصوديوم واقل من الغرين لوحده وعند الخليط (الغرين مع الملح) عندما يكون طول العينة ثابت.