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Research Article

Analysis and Development of a Visible Spectrophotometer for Identification of Nanoparticles in Chemical Solutions

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Abstract: Nowadays, the knowledge and technology in the nanotechnology domain are quickly developing and research, industrial, and service centers require more efficient instruments for the identification of the nanomaterial. Recently, some deviations have been observed within patterns and samples which make us understand that the more nanotechnology science will be developed, the more physical phenomena would be prominent and visible. In other words, the more we approach small and smaller scales, i.e. nano dimensions, new pieces of physical knowledge will be developed. These developments can be applied for future technological achievements. Nanotechnology developments are a matter of measurement, development, fabrication, and manipulation of individual structures on a nanometer scale. All these procedures have been made possible only through the development of scanning probes, optical tweezers, electron microscopy with high dissociation power and lithographic tools, focused ion beam milling system, and many other tools. An important category of tools in material identification is spectrophotometers or spectrometers. Accordingly, various kinds of spectrometers have been investigated in this study and a spectrometer for nanoparticles' scattering has been developed and fabricated. The wide range of applications of visible optical instruments made the authors of this study limit their efforts to visible range spectroscopy. The research and experiment results conducted on the newly-manufactured instrument have been compared with those from commercially available spectrometers.

Keywords: scattering; scattering cross-section; nanoparticle; scattering spectrometer (nephelometer)

1. Introduction

Nowadays, and in modern physics, scientific arguments are to be proved through indirect assessments, and basic and infrastructural rules are mostly based upon indirect observations. The advances and discoveries made in contemporary science make the results and knowledge to get more naturally unbelievable. In this study, the application of optical instruments has been proved to be the best way to study and investigate nature. That's because due to our potential in the perception of electromagnetic waves in optical frequencies, our brain is accustomed to interpretation and processing light-related phenomena, even if we magnify the structure to be studied thousands of times more. This perceptual potential is considered as one of the most significant aspects which makes it interesting to study optics and optical processes just in the same way as physical relations and equations. The fact that optical energy resides in the spectrum of electron transition and material vibration energy, makes us apply light to acquire exclusive information regarding material's structural and dynamic properties and intricate and favorable manipulations for material's quantum mode. These exclusive spectroscopic capabilities have gained significance in the study of biological nanostructures as well as the solid-state besides prevalent optical procedures [1].

Visible spectrometers consist of two parts, namely optical and electronic. Generally, ready-made electronic components are commercially available; however, the optical pieces must be assembled based on optical equations. Optical spectrometers are composed of four or five main components. Besides stimulation resources for diffusion, sample containers, wavelength selection tools, and supervisors of radiation power, the optical spectrometer includes some other optical elements to parallelize, focus, and orient the electromagnetic radiation. There are some basic rules in optics science, based on which many other significant equations are derived. In an assessment of optical constituents and spectroscopic systems, different rules are applied. They namely are the survival rule, reflection and diffraction rules, and absorption rules [2].

2. Theoretical Foundations and Equations

2.1. Ray optic and wave optics

The consistency principle obliges us to transform the pervasive theory into a limited one. Therefore, under conditions in which no definite wave phenomena such as diffraction and interference are involved, the ray optic must be practically transformed into wave optic. We already know that if and only if the dimensions of the object or the gate to be exposed by the light, would be comparable with light's wavelength, then diffraction and interference are easily identified. When $\lambda \ll d$, then the wave behavior would give us the same results as the ray behavior. In terms of symbols, it can be rewritten as:

$$\lim_{\frac{\lambda}{d}\to 0}(wave\ optics) = ray\ optics \qquad (1)$$

2.2. Scattering by dipoles induced in small scatterers [3]

A monochrome flat wave would be incident at a scatterer under normal conditions. For simplicity, the surrounding circumstances would be considered as ε_r=μ_r=1. In case the incidence direction would be defined by n unit vector, and the incident polarization vector would be ε, then, the incident fields are defined as the following:

$$E_{inc} = \varepsilon_0 E_0 e^{ikn.X} \qquad (2)$$

$$H_{inc} = n_0 \times E_{inc}/Z_0 \qquad (3)$$

Where $k = \frac{\omega}{c}$ and a temporal dependence is perceivable as $e^{-i\omega t}$. These fields would induce p and m dipolar moments in small scatterers and these dipoles would radiate the energy in all directions. In regions away from the scatterers, the scattered field would be obtained as follows:

$$E_{sc} = \frac{1}{4\pi\varepsilon_0} k^2 \frac{e^{ikr}}{r} \left[(n \times p) \times n - n \times \frac{m}{c}\right] \qquad (4)$$

$$H_{sc} = n \times E_{sc}/Z_0 \qquad (5)$$

Where n is the unit vector in the direction of observation and r is the distance from the scatterer. The incidence (radiation) power in n direction with ε polarization in the unit of spatial angle and the unit of incident flux (power per surface unit) in n direction with ε polarization, would be a quantity with surface dimensions in the unit of spatial angle which is called as the scattering differential cross-section:

$$\frac{d\sigma}{d\Omega}(n, \varepsilon; n_0, \varepsilon_0) = \frac{r^2 \frac{1}{2Z_0} |\varepsilon^*.E_{sc}|^2}{\frac{1}{2Z_0} |\varepsilon_0{}^*.E_{inc}|^2} \qquad (6)$$

By substituting E_{sc} and E_{inc} in (6), we have:

$$\frac{d\sigma}{d\Omega}(n, \varepsilon; n_0, \varepsilon_0) = \frac{k^4}{(4\pi\varepsilon_0 E_0)^2} \left|\varepsilon^*.p + (n \times \varepsilon^*).\frac{m}{c}\right|^2 \qquad (7)$$

2.3. Scattering at short wavelengths

The opposite limit of scattering in long wavelengths proportionate to the scatterer would be obtained from classic ray theory, just like Kirchhoff's diffraction domain and screen diffraction, and zero-order approximation. Through limiting scattering to an angular domain which a little above geometrical optics routes, the fields' wave aspects would verify these theories. For a thin flat obstacle, one can apply diffraction theory; however, for other kinds of obstacles, our calculations of scattering domains would be based upon E_s and B_S scattering fields. Accordingly, the following equation would be applied:

$$\varepsilon^*.F(k, k_0) = \frac{i}{4\pi} \oint_{s1} e^{-ik.x'} [\omega\varepsilon^*.(n' \times B_s) + \varepsilon^*.(k \times (n' \times E_s))] da' \qquad (8)$$

Due to the generality of the shadow region's share, it is better to consider it individually. Thus, it can be rewritten as:

$$\varepsilon^*.F = \varepsilon^*.F_{sh} + \varepsilon^*.F_{ill} \qquad (9)$$

In case the incident (radiation) wave would be a flat wave with k wave vector and polarization, then Equation (10) and (11) hold:

$$E_i = E_0 \varepsilon_0 e^{ikx} \qquad (10)$$

$$B_i = k_0 \times E_i/k \qquad (11)$$

Considering

$$\varepsilon^*.F(k, k_0) = \frac{i}{4\pi} \oint_{s1} e^{-ik.x'} [\omega\varepsilon^*.(n' \times B_s) + \varepsilon^*.(k \times (n' \times E_s))] da' \qquad (12)$$

And

$$\begin{cases} E_s \cong -E_i \\ B_s \cong -B_i \end{cases}$$, the share of the shadow (dark) region is:

$$\varepsilon^*.F(k, k_0)_{sh} = \frac{E_0}{4\pi i} \oint_{sh} e^{i(k_0 - k).x'} [\varepsilon^*.(n' \times (k_0 \times \varepsilon_0)) + k \times (n' \times \varepsilon_0)] da' \qquad (13)$$

Where integration would be applied on the S shadow region only. Through rearrangement of vector multiplication, we have:

$$\varepsilon^*.F(k, k_0)_{sh} = \frac{E_0}{4\pi i} \oint_{sh} e^{i(k_0 - k).x'} \varepsilon^*.[(k + k_0) \times (n' \times \varepsilon_0) + (n'.\varepsilon_0) k_0] da' \qquad (14)$$

For short-wavelength limits, the sizes of $k.x'$ and $k_0.x'$ are relatively larger than one. The exponential factor in the above equation would quickly oscillate and would make the integrator would have a small mean, except for its forward type in which $k \cong k_0$. In the forward region of $\theta \leq \frac{1}{kR}$, the second sentence is negligible in comparison to the first sentence because $\frac{\varepsilon^*.k_0}{k}$ is from $\sin\theta \ll 1$ order. Because $\varepsilon^*.k \equiv 0$, then:

$$\varepsilon^*.F_{sh} \cong \frac{iE_0}{2\pi}\varepsilon^*.\varepsilon_0\int_{sh} e^{i(k_0-k).x'}(k_0.n')da' \qquad (15)$$

2.4. Polarization Current [4]

The polarization problem plays a fundamental role in the spectroscopy of atoms and molecules. That's because the identity of disturbing levels lies within the polarization problem.

Atoms find their way into Maxwell equations through polarization current. i.e.:

$$\nabla \times H = i_c + n^2\varepsilon_0\frac{\partial E}{\partial t} + \frac{\partial P_a}{\partial t} \qquad (16)$$

Where i_c is the conduction current that is carried by load carriers. $n^2\varepsilon_0\frac{\partial E}{\partial t}$ is the displacement current which includes the vacuum value and is affected by other atoms of the host network in which active atoms are immersed, and $\frac{\partial P_a}{\partial t}$ is the polarization current for activated atoms.

In case the environment's refractive index would be homogenous and we would neglect the conduction current, we have:

$$\nabla.(\nabla \times H) \equiv 0 = n^2\varepsilon_0\frac{\partial}{\partial t}(\nabla.E) + \frac{\partial}{\partial t}\nabla.P_a \qquad (17)$$

Accordingly:

$$\nabla.E = -\frac{1}{n^2\varepsilon_0}\nabla.P_a \qquad (18)$$

From combining the first Maxwell equation with another Maxwell equation, the following wave equation would be obtained:

$$\nabla \times [\nabla \times E] \equiv \nabla(\nabla.E) - \nabla^2 E = -\mu_0\frac{\partial}{\partial t}\nabla \times H = -n^2\mu_0\varepsilon_0\frac{\partial^2 E}{\partial t^2} - \mu_0\frac{\partial^2 P_a}{\partial t^2} \qquad (19)$$

And finally:

$$\nabla^2 E - \frac{n^2}{c^2}\frac{\partial^2 E}{\partial t^2} = \mu_0\frac{\partial^2 P_a}{\partial t^2} - \frac{1}{n^2\varepsilon_0}\nabla(\nabla.P_a) \qquad (20)$$

2.5. Lasers

Lasers are radiation resources that are capable of disseminating monochromatic, coherent, aligned, and bright light. That's why their highly applicable in spectroscopy. Laser radiation is made possible through "Stimulation Emission". For a stimulated emission from a higher n energy level in a two-level system to dominate the absorption, there must be population inversion occurred between the two levels. Disturbing the normal population distribution requires energy consumption, this process is called pumping. An activated environment is a system that exists in the solid, liquid, or gas phase, and which includes population inversion. In lasers, this action is facilitated by the activated environment existing between the two mirrors. Both mirrors have a high reflection capacity, but one of them has a little radiation leakage. The region between the two mirrors is called the "laser cavity". The distance between mirrors must be an integer multiple of half wavelength. The reflector surfaces of the mirrors are particularly coated with strong and weak dielectric materials including SiO_2 and TiO_2. This is done to make sure regarding the nearly full reflection of mirrors for a particular wavelength. The reflectance capacity of normal aluminium, silver, or gold coatings is not sufficiently high. One of these mirrors would be coated such that %1-10 of the incidence (radiation) would be emitted as a light beam .

2.6. Scattering Spectroscopy

"Scattering Spectrometer" or "Nephelometer" is an instrument for measuring the optical waves scattered from a sample. This instrument may work either with laser or lamplight. The detectors included in these types of spectrometers are solid-state detectors. These spectrometers are highly applicable in wastewater management organizations for detecting materials and pollutants whose existence in water may work as pathogens. The costs involved in the development and manufacturing of these detectors seem to be affordable for small research and development centers. Multiple series of semi-automatic scattering spectrometers have been used in the present study.

2.7. The instrument used for measuring the scattered lights from solutions [5]

We can apply classic electromagnetic theory for calculating light scattering from a single molecule.

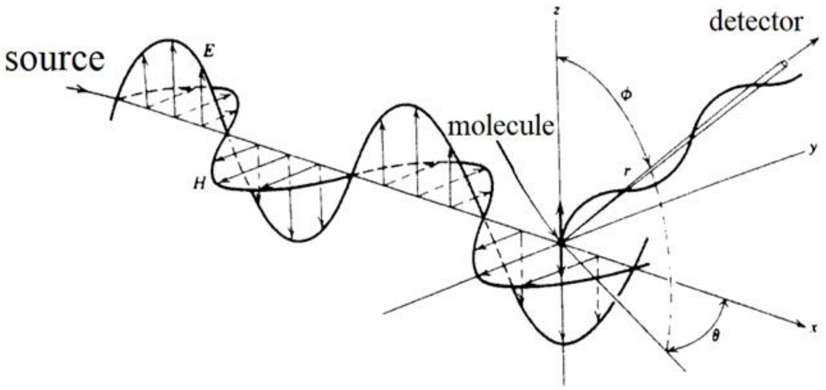


Figure 1: the scattering of flat polarized light by a single molecule. For an isotropic, induction dipole moment in direction of the z-axis. Thus, no light would be scattered in the z-axis direction.

The dependence of polarized incident light scattering in the z-axis direction is displayed in Figure 1. Scattering in Z-axis direction is zero.

Most often, unpolarized light is used in scattering experiments. The angular dependence of a small isotropic molecule (in comparison with light's wavelength) can be obtained through the increase in scattering intensities of two perpendicular polarized light waves. This results in the scatterer intensities just as follows:

$$\frac{i}{I_0} = \frac{\pi^2 a^2}{2{\varepsilon_0}^2 r^2 \lambda^4}(1+\cos^2\theta) \qquad (22)$$

Where θ is the angle between the incident light beam and the observation direction. This angular dependence is displayed in Figure 3-5-b. this illustrates that the scattering intensities in direct and inverse directions are equal. The intensity of the scattered light is inversely equal to the biquadratic of the applied wavelength. Thus, the blue light would be scattered more than the red light and accordingly, the light passing the suspended particles' space would be inclined to red [6].

To calculate scattering using polymer molecules in solution, we must consider concentration fluctuations in small portions of pollution, smaller than a cube with dimensions equal to wavelength, such that it could include a sufficient amount of molecules. The calculation manual is included in advanced guides on light scattering. Here, in this paper, we make use of a simpler procedure that is less concerned with statistical averaging but would result in more accurate values. The polarization of α polymer can be related to solution's refractive index, n, refraction index of the pure solvent, n_0:

$$n^2 - {n_0}^2 = \frac{N\alpha}{\varepsilon_0} \qquad (23)$$

Where N is the number of polymer particles in unit volume. This equation can be related to some form in which it expresses the polarization equation based on the development of a special refractive index, i.e. $\frac{dn}{dc} = \frac{n-n_0}{c}$.

Where c is the concentration per mass in unit colume and M is the molar mass of the polymer.

$$\alpha = \frac{n^2-{n_0}^2}{N}\varepsilon_0 = \cdots = 2n_0\frac{dn}{dc}\frac{M\varepsilon_0}{N_A} \qquad (24)$$

Where the last form of the equation is to be obtained through substituting $n+n_0$ for $2n_0$. That's because, in dilute solutions, c/N can be substituted by M/N_A. through substituting this phrase for the scattering of a polymer molecule, we have:

$$\frac{i}{I_0} = \frac{2\pi^2 {n_0}^2\left(\frac{dn}{dc}\right)^2 M^2(1+\cos^2\theta)}{\lambda^4 r^2 {N_A}^2} \qquad (25)$$

Through multiplying it in $N = \frac{cN_A}{M}$, the scattering of N particles in volume unit would be obtained:

$$\frac{i}{I_0} = \frac{2\pi^2 {n_0}^2 \left(\frac{dn}{dc}\right)^2 Mc(1+\cos^2\theta)}{\lambda^4 r^2 N_A} \qquad (26)$$

This equation suggests that the extra scattering of the solution to the scattering of the solvent is proportionate to the concentration of the soluble based on mass in unit volume and molar mass of the soluble.

In a simple experiment, the intensity of the passing beam light from a polymer solution would be measured. In case a minor portion of the light would be absorbed, the loss of intensity would be related to scattering. The total scattering intensity is obtained from I integer on all angles. The intensity of passing light would be obtained from the following equation:

$$I = I_0 e^{-\tau x} \qquad (27)$$

Where τ is the turbidity and x is the cell thickness in the direction of the incident beam. This is one form of Beer Law for light weakening. The calculations result in the following:

$$\tau = \frac{32\pi^3 {n_0}^2 (\frac{dn}{dc})^2 Mc}{3N_A\lambda^4} = HMc \qquad (28)$$

Where

$$H = \frac{32\pi^3 {n_0}^2 (\frac{dn}{dc})^2}{3N_A\lambda^4} \qquad (29)$$

Which is a constant value for a particular wavelength and solvent. That's why τ turbidity is proportionate to molar mass. This procedure is more beneficial for higher molar masses compared with the osmosis pressure procedure, which is negatively reduced through increased molar mass.

Instead of measuring the intensity of passing light, τ is calculated from the following equation:

$$\tau = \frac{32\pi^3 {n_0}^2 (\frac{dn}{dc})^2 Mc}{3N_A\lambda^4} = HMc \qquad (30)$$

From an experimental perspective, the measurement of scattering intensity, y the instrument, displayed in Figure 4-5 has a higher sensitivity.

2.8. Polar Nephelometers

A nephelometer is an instrument used for measuring lights scattered at different angles. The light source and the detector can both revolve around the sample (scattering cell) and proportionate to coordinates of the polarized instrument.

The light source may be a lamp (e.g. tungsten-hallogenic, mercury pressure, or xenon) alongside an ideal collimator or it may happen that a laser would be used on its own.

Although lasers are easy to use, they don't seem to be cost-effective. A 300-200 W halogen-tungsten lamp present in old overhead projectors, not only is cheap but also is available in most of the photographic equipment stores. though a minor portion of the energy is transformed into visible light but is preferred over continuous-wave lasers in terms of efficiency and price.

2.9. Light scattering [6]

The amount of light loss in the Extinction sample is due to absorption and scattering agents.

Considering the proportion between particle's dimensions with wavelength λ, different approximation orders of the Bessel function are applied for modeling in which the scattering properties of the sample are studied. These properties are to be estimated from the following equation:

$$S_{scattered}(I_v, I_h, U, V)_{4\times1} = F_{4\times4}.S_{incident}(I_{v_0}, I_{h_0}, U_0, V_0)_{4\times1}/{k_0}^2 r^2 \qquad (31)$$

Where the zero subscripts are for input rays. In addition, h subscript is related to light's vertical polarization and v is related to horizontal polarization of light. Here, F is a 4*4 matrix, based on S_i and S_i^*, that i=,

$$\begin{cases} I_v = E_v {E_v}^*; \\ I_h = E_h {E_h}^*; \\ U = E_v {E_h}^* + E_h {E_v}^*; \\ V = i(E_v {E_h}^* - E_h {E_v}^*); \end{cases} \qquad (32)$$

Thus:

$$\begin{cases} I_v = |S_1|^2 I_{v_0} / {K_0}^2 r^2 \\ I_h = |S_2|^2 I_{h_0} / {K_0}^2 r^2 \end{cases} \qquad (33)$$

S_1 and S_2 in Equation (33) depend upon the morphology of scatterer, which are to be obtained from May Theory. In case the particle's dimensions would be larger than being a dipole, then S_1 and S_2 would be obtained concerning scattering factor:

$$\begin{pmatrix} S_1 & 0 \\ 0 & S_2 \end{pmatrix} = \frac{i{k_0}^3(m-1)V}{2\pi}\sqrt{P(x)}\begin{pmatrix} 1 & 0 \\ 0 & \cos\theta \end{pmatrix} \qquad (34)$$

Where k is the wavenumber, and V is the sample volume and we have:

$$m = \frac{n-ik}{n_0} \qquad (35)$$

Through multiplying Equation (34) by its complex, we have:

$$\begin{pmatrix} |S_1|^2 & 0 \\ 0 & |S_2|^2 \end{pmatrix} = -{k_0}^6\left(\frac{(m-1)V}{2\pi}\right)^2 P(x)\begin{pmatrix} 1 & 0 \\ 0 & \cos^2\theta \end{pmatrix} \qquad (36)$$

Through substituting Equation (33) in 936) we have:

$$\begin{pmatrix} \frac{I_v}{I_{v_0}} & 0 \\ 0 & \frac{I_h}{I_{h_0}} \end{pmatrix} = \frac{{k_0}^4}{r^2}\left(\frac{(1-m)V}{2\pi}\right)^2 P(x)\begin{pmatrix} 1 & 0 \\ 0 & \cos^2\theta \end{pmatrix} \qquad (37)$$

By considering r as a constant distance and having known the intensities arriving at the detector at different angles, scattering factor would be easily obtained.

2.10. Experimental procedures

The criteria for measuring the intensity of scattered light from silver nanoparticles were different polarization modes. In the first stage, a lamp with a full visible wavelength range has been used here, the intensity of the light absorbed by the silver nanoparticles was intended. Thus, the detector has been placed in line with the light source sample and different wavelengths have been individually inserted into the sample container upon displacement of the dispersion device. This has been once administered with sample solvent as well. There are several available procedures for the assembly of optical pieces required for fabrication of scattering visible spectrometer:

a) Displacement of the light source in array spectrometer
b) Displacement of polychromator and detector in array spectrometer
c) Displacement of the light source and polychromator in the non-array spectrometer
d) Displacement of the detector in non-array spectrometer

These modes are evident in Figure 2.

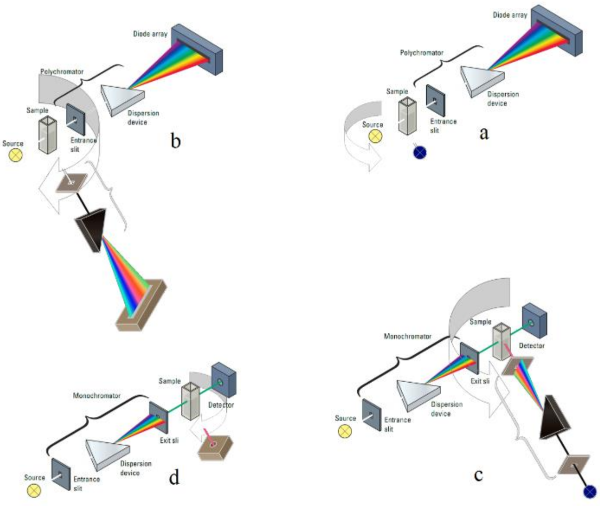


Figure 2: four different alternatives for development and fabrication of scattering spectrophotometer

2.11. Different components of the developed devices:

a) Light source

The visible light source produces all visible wavelengths (300-700 nm) with high intensity. This light source is a high-voltage halogen lamp including a incandescent metal. This incandescent lamp would produce a high amount of light as a result of being heated to a temperature near 500 ℃. This lamp works through a current-increasing trans. The input for this trans is urban electricity. To prevent burning or being blown out, three individual fans are inserted to cool it down. The light produced by this lamp would be focused to a point outside the lamp casing through a concave mirror included at its back and a set of lenses which are included at its front.

b) Diffraction grating and its operator:

1200 line diffraction grating, would separate the focused and intense light produced by the lamp to wavelengths between 300-700 nm. The grating operator would help different wavelengths to arrive at the sample at the right time. This operator is a clock engine.

c) Cylindrical detector casing:

In one type of these casings which is a hollow cylinder, 31 rows of detectors cover the whole casing wall, and four-light-sensitive sensors are included in any row. The sample which is contained within a glass container would be inserted exactly in the middle of this cylindrical casing and would be exposed to incident wavelengths. Right after the incidence of light photons to the sample, the sample would either pass the photons, absorbs them, or would scatter them. The detectors would record all the scattered light from the surroundings in terms of their angle. Moreover, the opposite detector would record the passing light and these pieces of information would be finally transferred to the computer through a digital multimeter. In another category of detectors, the photovoltaic cells are applied to define the incidence energy in any direction.

In case we consider the direct direction of the light entering the detector casing, this light line would separate the detector into two-cylinder halves until it arrives at the final point. We consider the final point as the reagent of the zero angles and the right entrance light (optical gap) as the reagent of 180 degrees angle. Then, we would divide both cylinder halves into 180 degrees and sign them. In case the device would be in the first mode (i.e. the application of photo-resistance), the zero angle detector would record the light emitted from the sample. In case it would be in reference sample position, the shadowgraph would be recorded by zero angle detector and in case we immediately place silver nanoparticles in the same place as the sample, another shadowgraph would be recorded based on the wavelength. Through deducing the silver solution-induced darkness from the reference-induced darkness, the graph for visible absorption of silver nanoparticles would be depicted. The difference between these two graphs displays the lights which couldn't arrive in the detector due to the presence of silver nanoparticles. In the second mode, when the photodiode would be in zero angle position, in case reference would be in sample location, the graph would display the intensity of passing light in terms of wavelength. Through inverting the graph, the reference-induced darkness distance would be obtained. Doing so for silver nanoparticles and deducing its darkness graph from the reference darkness graph, would give us the absorption graph of silver nanoparticles.

As it has been stated previously, each half-cylinder would be divided into 180 degrees (using a protractor). In the first mode, any 10 degrees is capable of dispatching a signal to the multimeter. This operation is handled manually. In other words, after visible analysis of the first 10 degrees, we go to the next 10 degrees and displace the cables until all 170 degrees would be recorded in the computer (the last 10 degrees don't belong to photo-resistance due to the input gap).

d) Polarizer filter:

A polarizer filter is inserted before and after the sample to develop polarized light. This filter is capable of flexible and precise rotation on the ballbearing using an engine.

e) Prism components:

To reflect the incoming and outgoing ray beams, rotating prisms have been used as well.

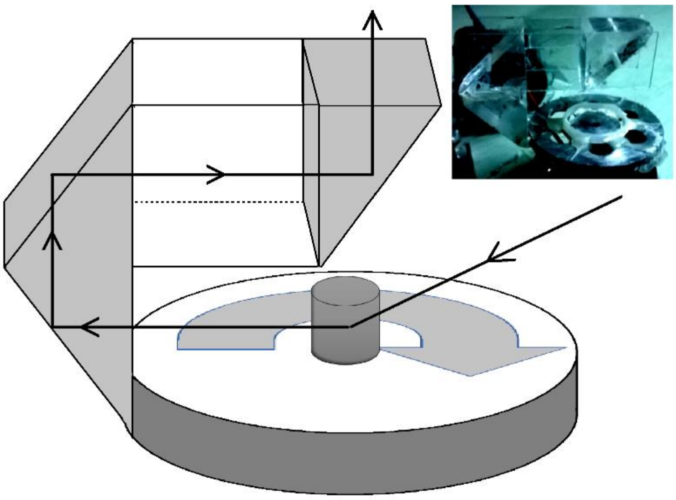


Figure 3: Three pieces of rotating prisms that collect scattering beams in different angles, then direct collected beams to the detector. The sample is putted in the centre of the system.

2.12. Integration of scattering spectrophotometer

- At the first setup attempt, an old video projector device has been used for light generation and 1200 diffraction mesh was used to separate the wavelength and a photocell has been used as a detector.
- For the second setup attempt, an urban tungsten lamp has been used as a light source inside a metal cavity. The beams scattered from the spectroscope have been decomposed into different spectrums and have been analyzed through the Ziman experiment's CCD in the modern laboratory after passing the sample.
- In the third attempt, all the components stay unchanged, except for the detector, for which 360-degrees array photo-resistance has been used for sample analysis.
- In the fourth attempt, a photodiode has been used for sample analysis besides a photo-resistance analyzer.
- Finally, a spectroscope device has been used for 360 degrees rotation around the sample and a light meter has been used as a detector. The mentioned light meter was capable of being connected to the computer. Besides, some kind of electrical engine has been exploited for the displacement of the detector arm.

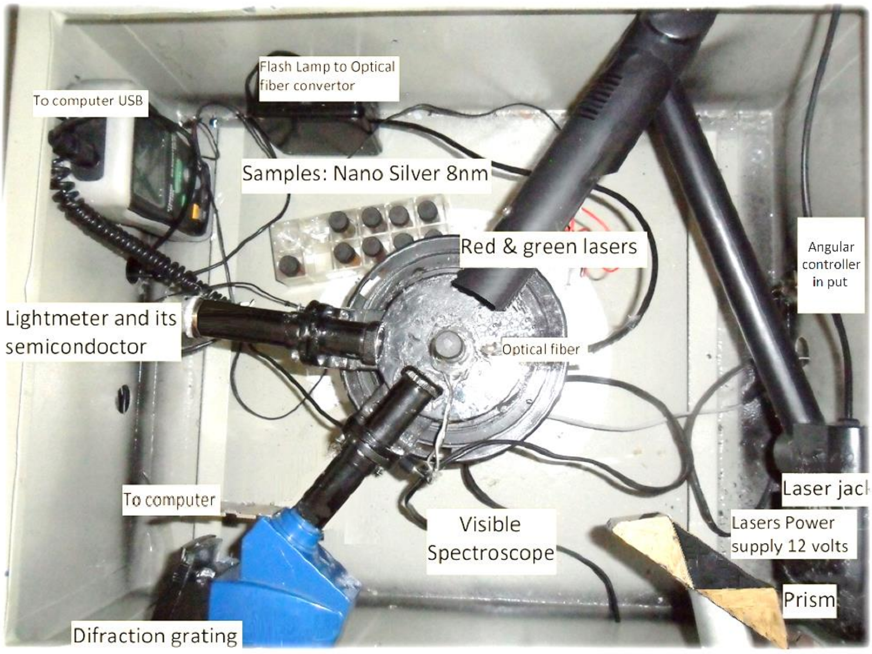


Figure 4: fifth developed device equipped with green and red laser and LED white light

3. Results

The method followed for measurement is to obtain the difference between the intensity arrived at the sensor (when the sample is inserted inside the casing) and the arrived intensity (just when the sample solvent, e.g. distilled water, which is also known as a reference, is located inside the casing). Doig so, all the errors originating from the sample container, sensors, etc. would be wholly eliminated. Besides, the results for different angles and wavelengths would be obtained.

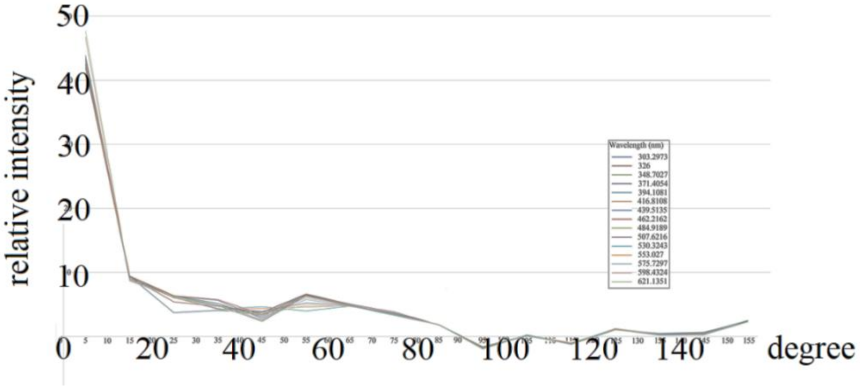


Figure 5: the results obtained from the scattering spectroscope under 15 different wavelengths and 155 different angles

For this analysis to be completed, we first place the reference, develop the matrix, and then, we would place the nanoparticle and would obtain another matrix. Since our objective is to assess the scattering, we must deduce the intensity of scattered light by the nanoparticle, i.e. a matrix whose arrays are the inverse of the second matrix's elements, from a matrix whose elements are the inverse of those within the first matrix. The results would be symmetrized and depicted in Excell Software.

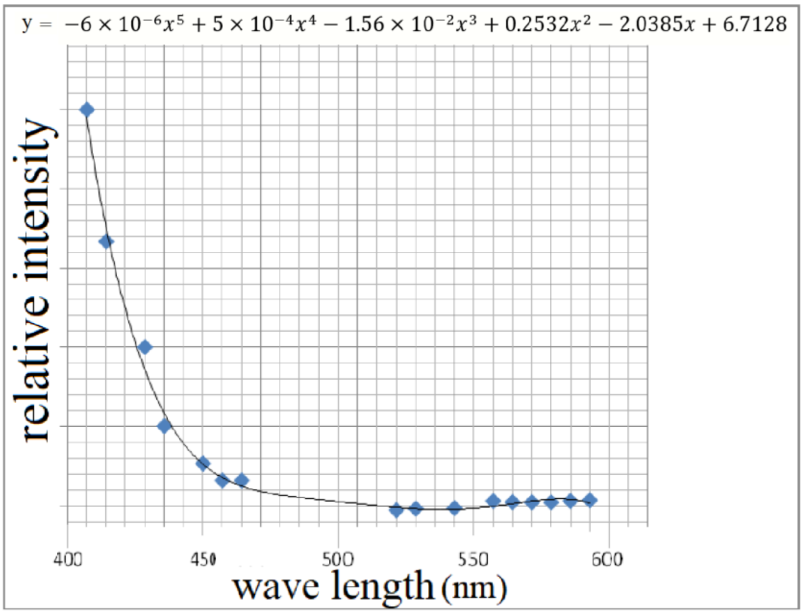


Figure 6: the image for the difference of the intensities arrived from silver nanoparticles and water under zero degrees angle

In case the same sample would be placed in a calibrated spectrophotometer, the following diagram would be obtained:

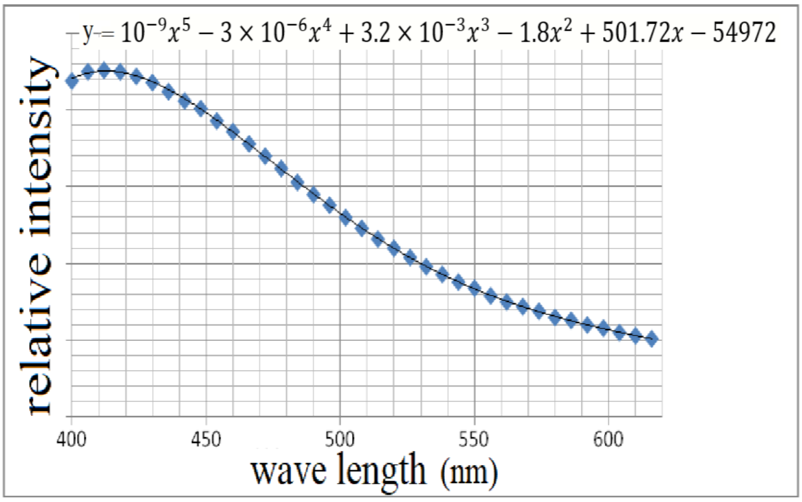


Figure 7: silver nanoparticles absorption by a UV-Vis calibrated spectrophotometer

By dividing the two algebra sentences obtained from Excell software for the resultant diagrams, a sentence would result which is considered as the calibration agent of our spectrophotometer.

$$G = \frac{10^{-9}x^5 - 3 \times 10^{-6}x^4 + 3.2 \times 10^{-3}x^3 - 1.8x^2 + 501.72x - 54972}{-6 \times 10^{-6}x^5 + 5 \times 10^{-4}x^4 - 1.56 \times 10^{-2}x^3 + 0.2532x^2 - 2.0385x + 6.7128}$$

In the second stage, the light emitted from green and red laser diode has passed among silver nanoparticles and the intensity of the scattered light has been depicted in Excel software in different directions and based on Lux.

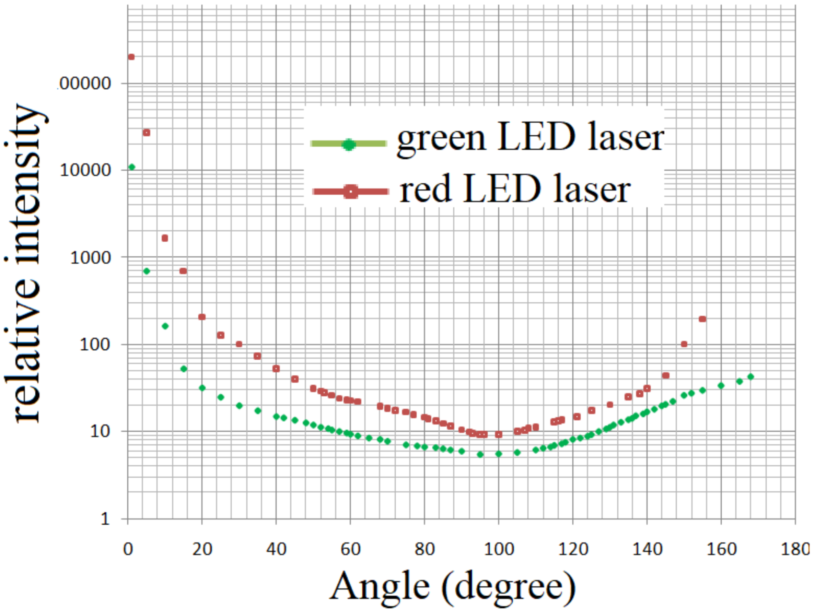


Figure 8: the intensity of green and red laser diode lights scattered in different directions by silver nanoparticles

In another study, polarization has been investigated. In other words, polarized light has directly entered the sample and after light polarization scattering, a polarizer blade has been inserted in the sample's path once again.

The final intensity has been depicted based on various wavelengths in Excell software when the second polarizer has been rotating at different angles.

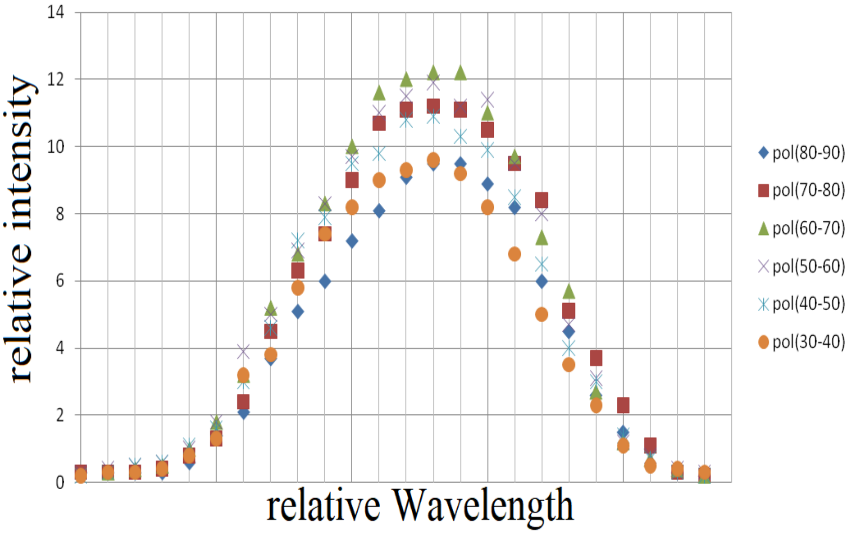


Figure 9: an investigation of the arrived light intensities under zero angle in six polarizations. The horizontal axis displays the wavelength

4. Discussion

In the end, a comparison with other similar studies is attempted. Figure 10 studies the cytoplasm using a polarized nephelometer under 12 different polarization and 180 degrees rotation. The advantages of a polarized nephelometer are evident for the study of membraneous materials compared with a simple nephelometer at 180 degrees angle.

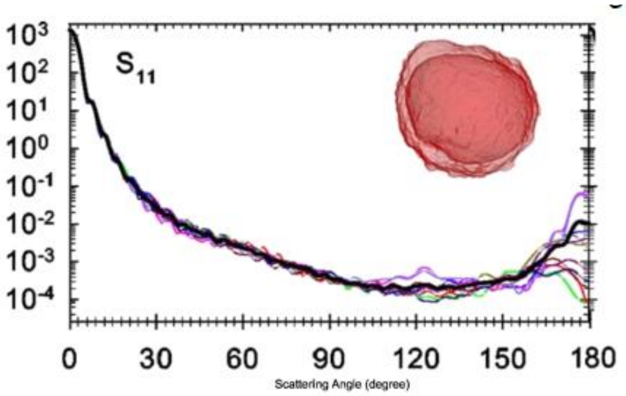


Figure 10: the scattering curve obtained from cytoplasm under 12 different polarizations of 1000 nm light, for which the black line is the mean [7].

Figure 11 displays the dependence of the scattering spectrum to the incident wavelength in angles more than zero degrees. Figure 12 displays the scattering spectrum obtained from hexagonal nanoparticles to predict their dimensions.

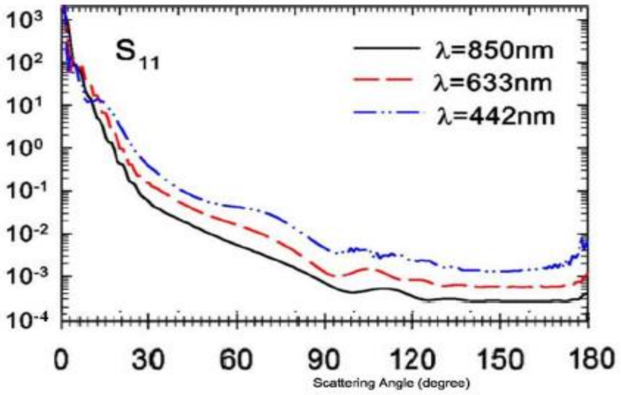


Figure 11: the scattering spectrum obtained from globes with a radius of 13.4 μm, summing up to 14.5 μm by considering the crust, under different wavelengths [7].

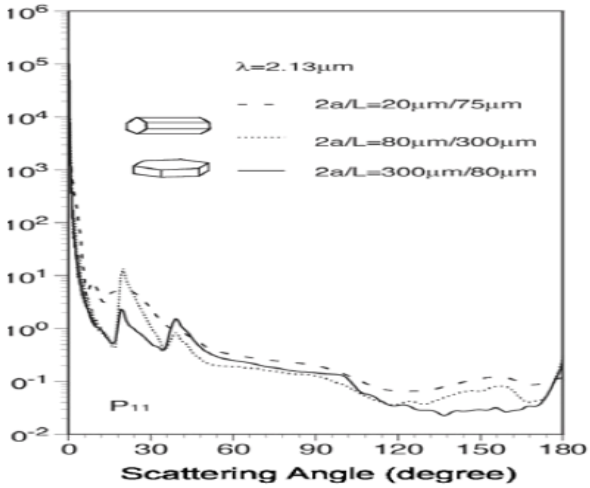
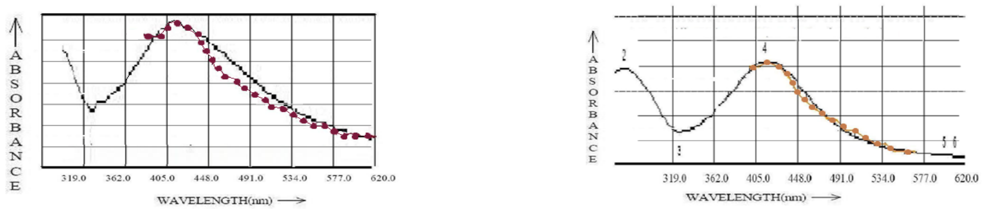


Figure 12: the scattering curve obtained from three nanoparticles with different hexagonal morphologies [8]

5. Conclusion

Visible spectrophotometry of the chemical solutions would give us information regarding the type and concentration of chemical solutions. In addition, information can be obtained regarding the nanoparticles' size within nano-scale solutions. Upon the extension of theories regarding the fluctuations in surface loadings of nanoparticles, such as "May Theory" and "Muhler's Scattering Matrix" as well as the experiments conducted in this regard, the scholars have found that through recording the intensity of light passing the nanoparticle solution, nanoparticles size can be estimated in different angles considering their morphology and structure. According to most of the resultant three-dimensional diagrams, one can predict the morphology and constituent materials of the nanoparticles included within a solution. Since this approach is a cheaper alternative compared with other available morphology determination procedures, I hope it would be a substitute for electron microscopy procedures. The device being developed in this study acts like a 3-D scanner, with the minor difference that the sample under study is liquid, not solid, and would deliver results for external models with high precision. Just like a 3-D scanner, visible light would be radiated at the sample. the reflection of light from the sample would be recorded in the computer considering its wavelength and finally, the researcher obtained the required information about nanoparticles.



20 nm nanoparticles

8 nm nanoparticles

Figure 13: the compatibility of experimental results obtained from the developed device (dashed lines) and available reference values for Vis spectrum of 8 nm and 20 nm silver nanoparticles

The detection of scattered rays from the nanoparticles being stimulated through visible light and are electromagnetically intensified would impact the direction of primary intensity, the incident light's wavelength, and primary polarization. This will provide the researchers with invaluable information such as the material, morphology, and dimensions of the nanoparticles. Not all these capabilities are present in UV-Vis absorption spectrophotometers.

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