JOURNAL OF KUFA−PHYSICS
www.uokufa.edu.iq/journals/index.php/jkp | ISSN: 2077−5830

Performance Enhancement of Luminescent Solar Concentrator by using Mixing Fluorescent Colors and Nanoparticles

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ARTICLE INF

Article history:
Received: 11 MAY, 2022
Revised: 20 JUN, 2022
Accepted: 26 JUN, 2022
Available Online: 12 AUG, 2022

Keywords:

Solar cell
Efficiency
Fluorescence
Quantum efficiency

ABSTRACT

Liquid zinc acetate nanoparticles were added to a fluorescent organic dye (fluorescein sodium) to prepare three concentrations (2 × 10^{-5}, 7×10^{-5}, 1×10^{-4}) moI/L, and the absorbance of the dye was measured before and after adding Liquid nanomaterial by using two devices (SCINCO Mega-2100 UV/visible Spectrophotometer.) as well as measuring the flux of the dye before and after adding zinc acetate nanoparticles using the (Spectrofluorometer F96 PRO). The Stoke displacement (Δη), the radiative age (τfm), the fluorescence lifetime (τf), and the quantitative efficiency (Qfm) were calculated. Absorption and fluorescence curves were drawn using the Excel program. The MATLAB program was also used to measure the area under the absorption and fluorescence spectra curves. It was found that the fluorescence intensity of fluorescein sodium dye has increased compared to the intensity of fluorescence before adding the nanomaterial and thus increasing the quantitative efficiency, which in turn helps in improving the performance of the photovoltaic concentrator, resulting in an improvement in the efficiency of the solar cell.

DOI: http://dx.doi.org/10.31257/2018/JKP/2022/140106

تحسين أداء المكثف الشمسي المضيء باستخدام خلط الألوان الفلورية والجسيمات النانوية

أحمد عبد لرضا حسين عدنان فالح حسن

كلية العلوم جامعة الكوفة

الكلمات المفتاحية:

الخلايا الشمسية
الكفاءة
الفلورة
الكفاءة الكمية

الـــخُــلاصــة

لقد تم اضافة جسيمات أسيتات الزنك النانوية السائلة الى صبغة عضوية متفلورة (فلورسين صوديوم) لتحضير ثلاث تراكيز $(2\times10^{-5}, 7\times10^{-5}, 1\times10^{-4})mol/L$ ، وقد تم قياس امتصاصية الصبغة قبل وبعد اضافة المادة النانوية السائلة من خلال استعمال جهازي(*SCINCO Mega-2100 UV/visible Spectrophotomete.*)وكذلك قياس

الفـــورة للصـــبغة قبـــل وبعـــد اضـــافة اســـيتات الزنـــك النانويـــة باســـتعمال جهـــاز (*Spectrofluorometer F96 PRO*) . وقد تم حساب كل من ازاحة ستوك ($\Delta\eta$) و العمر الإشعاعي (τ_{fm}) و عمر الفلورة (τ_f) والكفاءة الكمية (Q_{fm}) ، وتم رسم منحنيات الأمتصاصية والفلورة بوساطة برنامج الأكسل كذلك تم استخدام برنامج *MATLAB* لقياس المنطقة الواقعة تحت منحنيات أطياف الامتصاص والفلورة. وجد أن شدة الفلورة لصبغة فلورسين صوديوم قد ازدادت مقارنة بشدة الفلورة قبل اضافة المادة النانوية وبالتالي زيادة الكفاءة الكمية التي تساعد بدورها في تحسين أداء المركز الشسي الأضائي فينتج عن ذلك تحسين كفاءة الخلية الشمسية.

1. INTRODUCTION

Renewable energy is energy that is derived from unlimited sources. There is made hot debate these days about the proper use of energy sources, it is necessary to know which of these sources to use and why. Most of the factors such as cleanliness, stability, cost and efficiency as well as environmental impacts should be taken into account. Many industries around the world still rely mainly on fuel This is a painful fact. There is no doubt that these types of fuels are very effective in terms of the quality of the energy production involved, but they are not beneficial in the long run. It is necessary and as soon as possible to shift the adoption of industries to renewable energy sources. In addition, fossil fuels are one of the main causes of many environmental risks, which represent a major threat to the ecological balance [1].

Renewable technologies are regarded as clean energy sources, and optimal utilization of these resources minimizes environmental impacts, produces minimal secondary waste, and is sustainable based on current and future economic and social societal needs. The sun is the source of all energies [2]. Solar energy is classified into two types based on its application: photoelectric and photo thermal. The photoelectric effect is the conversion of sunlight directly into electricity.

Photovoltaic cells (PV) or solar cells are devices that take advantage of this effect Solar radiation is converted into thermal energy by photo thermal systems. [3] Concentrated solar energy systems are classified into geometric solar concentrators (GSC) and luminescent solar concentrators , respectively. GSC systems concentrate solar energy using mirrors or lenses and are used in large and small scale generation applications, but they are currently less competitive due to the requirement of solar tracking (heliostat) and the low manufacturing tolerance of the optical components. [4]A Luminescent Solar Concentrator (LSC) is a transparent host material optical waveguide doped with luminophores.

LSC technology works by capturing incident solar radiation, converting the spectrum to the wavelength band of interest, and concentrating the light through total internal reflection (TIR) to the edge of the LSC where a photovoltaic (PV) solar cell is attached [5] The primary motivation for implementing an LSC is to replace the large area of expensive solar cells required in a standard flat-plate PV panel with an inexpensive polymeric collector, lowering the cost of the module (in dollars per watt) as well as the cost of solar power (in dollars per kilowatt hour). LSC technology has a significant advantage over other concentrating systems in that it can collect both direct and diffuse solar radiation. [6]

2. EXPERIMENTAL PART

In this research, fluorescein sodium dye was used to prepare three concentrations of it after dissolving it in pure ethanol, where a quantity of the dye was weighed and then dissolved in the solvent using the dilution law to prepare the three concentrations, which are relatively low concentrations. Zinc acetate nanoparticles were added to the fluorescein sodium dye and the same concentrations were prepared. The absorption and fluorescence spectra were calculated to be used as a luminous center for the silicon solar cell. Figure 1shows a picture of the solar cell used in the practical part of the research.

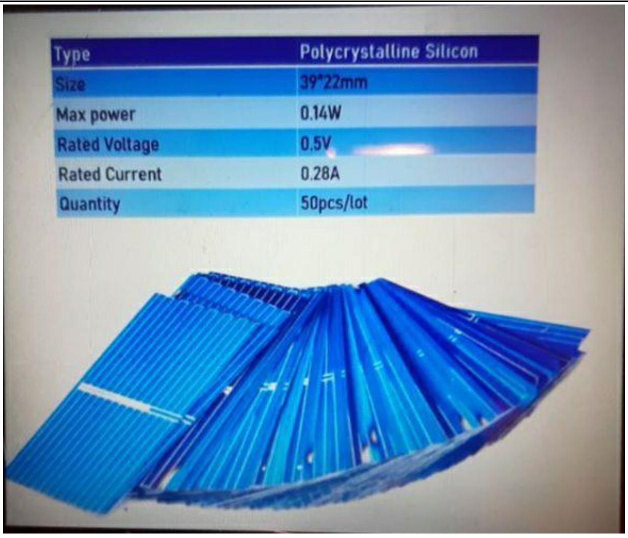

Figure 1: Photovoltaic cell.

2.1 . Fluorescein sodium dye

Fluoresce in Sodium dye belongs to the Xanthine class dye family, which is distinguished by efficient manufacturing and high chemical stability of the type of solvent (polarity), as well as the degree of acidity (PH) of the solvent. Figure 1 depicts the dye structure (2). Fluorescein Sodium dye has the chemical formula; (C20H10Na2O5), Molecular weight; (376.3), and is an orange-red to dark red crystalline powder that was dissolved in alcohol. [7].

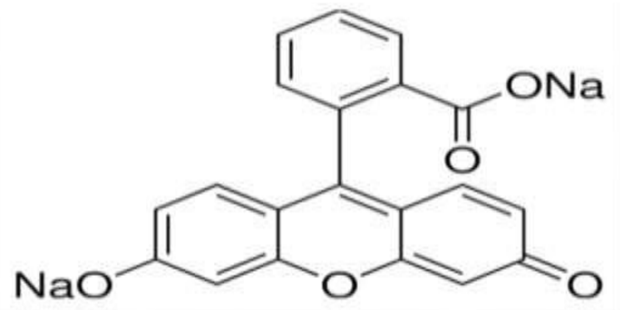

Figure 2: The structure of Fluorescein sodium [8]

2.2. The Solvent (Ethanol)

It is an organic solvent with the scientific name Ethyl Alcohol, its chemical formula is(C2H5OH), and a molecular weight of 46.07, making it one of the best organic solvents. The study makes use of pure ethanol with a purity of 99.99 percent; the ethanol molecule is seen in Figure (3) [9].

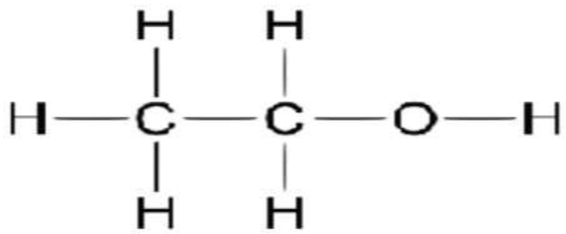

Figure 3: The structure of Ethanol molecule [9].

2.3. Zinc acetate

Zinc acetate is a salt with the formula of $Zn(CH_3CO_2)_2$, which is most usually found as Zn(CH3CO2)2•2H2O. Colorless solids, both the hydrate and anhydrous versions, have been utilized as nutritional supplements. Acetic acid reacts with zinc carbonate or zinc metal to produce zinc acetates. It bears the E number of E650 when used as a food additive. [10]. As seen in figure (4), zinc is coupled to four oxygen atoms in anhydrous zinc acetate, forming a tetrahedral environment. These tetrahedral polyhedral are subsequently joined by acetate ligands to form a variety of polymeric forms[11-12-13]. The zinc in zinc acetate dehydrate is octahedral, with both acetate groups being dentate [14-15].

3. STOKES SHIFT

Stokes shift can be defined as the difference in wavelength or frequency units in the position of the large absorbance and emission spectra of the same electronic transitions. Stokes shift is the result of oscillatory relaxation or attenuation in the solvent rearrangement [16-17-18]. Figure (4) depicts the difference (Stokes shift) between the absorbance and emission spectra fluorescence. The Stokes Rule states that the wavelength of a fluorescence emission should be several times greater than the wavelength of absorbance. Because of the loss of energy in the excited state owing to vibrational relaxation, the fluorescence spectrum is located at lower energy (longer wavelengths) than the absorbance spectrum. However, in most circumstances, the absorbance and emission spectra have partial overlaps, i.e. fraction of light is emitted at shorter wavelengths than the absorbed light [19- 20].

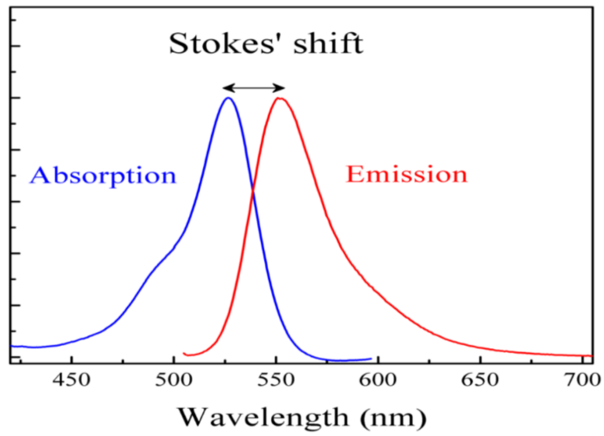

Figure 5: Stokes shift and overlap of the absorbance and fluorescence spectra [21].

4. QUANTUM EFFICIENCY

It is the number of carriers captured by the solar cell divided by the number of photons of a particular energy incident on the solar cell [22].

If all photons of a particular wavelength are absorbed and the ensuing minority carriers are collected, the quantum efficiency at that wavelength is unity. The (Q.E) can be thought of as the probability of collecting photons due to a single wavelength's generation profile, integrated over the device thickness and normalized to the incident quantity of photons [23].

5. RESULTS AND DISCUSSION

The absorbance and fluorescence spectra of three concentrations of fluorescein sodium dye were studied $(2 \times 10^{-5}), (7 \times 10^{-5}), (1 \times 10^{-4})$ mol/L. The dye has the highest absorption spectrum at (1.36243) at the wave length of (497nm) for all concentrations ,the highest absorbance intensity of the maximum concentration is (1×10^{-4}) mol/L , and at the minimum concentration(2×10^{-5}) mol/L, the highest of absorption spectrum was (0.349433) at the wavelength(493)nm as shown in figure (6) .We used Ethanol as solvent of fluorescence sodium dye and it have a zero absorbance in visible rang (greater than 400 nm) that means the Ethanol did not contribute to absorption as show in figure (5).

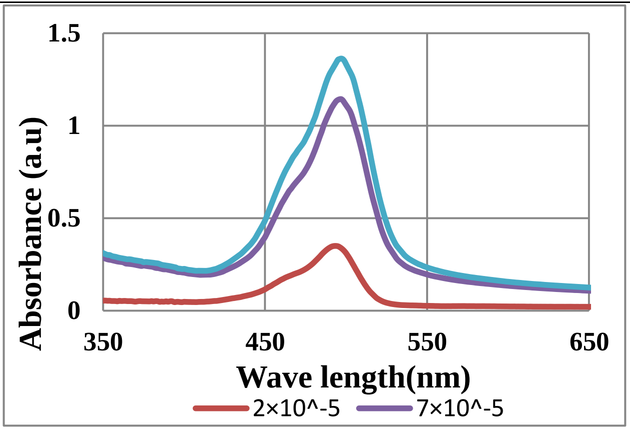

Figure 6: Absorption spectrum of fluorescein sodium dye at different concentrations.

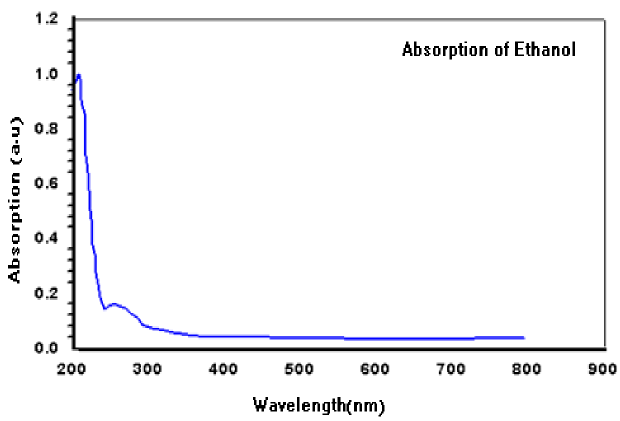

Figure 7: Absorption spectrum of Ethanol.

The highest fluorescence intensity is in the wavelength of (516nm) with the concentration of(2×10^{-5}) mol/L and , the minimum fluorescence intensity is in the wavelength(521nm) with the concentration (1×10^{-4}) mol/L as shown in figure (8).

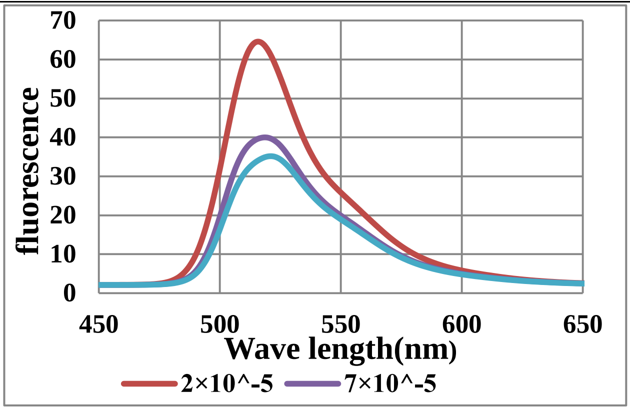

Figure 8: fluorescence spectrum of fluorescein sodium dye at different concentrations.

Also the absorption and fluorescence spectra studied for three concentrations,(2×10^{-5}),(7×10^{-5}),(1×10^{-4}) mol/L of mixed (Fluorescein sodium dyes and zinc acetate nanoparticles) . The mixture(fluorescein sodium and zinc acetate nanoparticles) had the highest absorption spectrum at (0.517836) with a wave length of (483) nm for all concentrations, the highest absorbance intensity of the maximum concentration is(1×10^{-4}) mol/L, the highest of absorption spectrum is (0.175861) at the wave length (484) nm at the minimum concentration $(2\times 10^{-5}$mol/L) the highest of absorption spectrum is at the wavelength (484) nm. figure (9) shows the effect of concentrations on absorptivity.

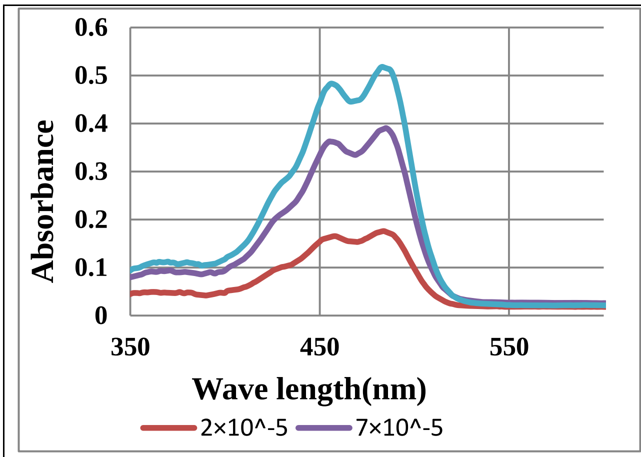

Figure 9 : Absorption spectrum of mixture dye and nanoparticles of zinc acetate at different concentrations.

The highest fluorescence intensity is in the wavelength (516)nm with the concentration of (1×10^{-4}) mol/L and , the minimum fluorescence intensity is in the wavelength of (513 nm) with the concentration(2×10^{-5}) mol/L , as shown in figure (10)

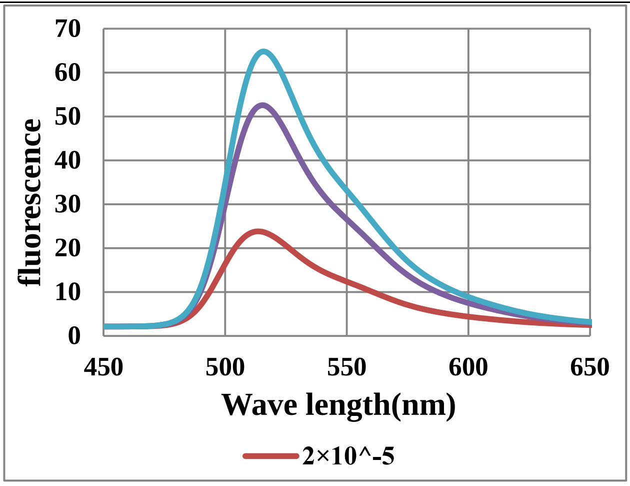

Figure 10: fluorescence spectrum of mixture dyes and nanoparticles of zinc acetate at different Concentrations.

The values of absorbance intensity of mixture Fluorescein sodium dyes and zinc acetate nanoparticles at different concentration shown in table (1).

Table (1): The absorbance intensity of fluorescein sodium dye before and after the addition of the nanomaterial at different concentrations**.**

Concentrations (Mol /L)	Absorbance (fluorescein sodium dye)	Absorbance mixture of dye and nanoparticles of Zink acetate
2×10^{-5}	0.3494	0.1758
7×10^{-5}	1.1430	0.3904
1×10^{-4}	1.3624	0.5178

From this table, we can notice that the absorbance decreases after adding nanomaterial's. , where at a concentration of (1×10^{-4}) mol/L , the absorbance before adding nanomaterial's is 1.3624 and after adding it is 0.5178 as example .

The table (2) show the values of fluorescence intensity of of mixture Fluorescein sodium dyes and zinc acetate nanoparticles at different concentration

Table(2): The fluorescence intensity of fluorescein sodium dye before and after adding the nanomaterial at different concentrations.

Concentrations (Mol /L)	fluorescence (fluorescein sodium dye)	Fluorescence mixture of dye and nanoparticles of zinc acetate
2×10^{-5}	**64.59**	**23.8**
7×10^{-5}	**39.99**	**51.93**
1×10^{-4}	**35.17**	**64.81**

According to this table it can be noticed that the fluorescence increases after the addition of nanomaterial's, for example, the concentration of (1×10^{-4}) mol/L ,where the fluorescence before adding the nanomaterial's was (35.17) and after the addition become (64.81) This increase causes an increase in the quantitative efficiency of the concentrator and we calculate the values of stocks shift, radiated lifetime, fluorescence lifetime and quantum efficiency of fluorescence of Zinc acetate at different concentrations as shown in table (3).

Through Table(2), as well as the fluorescence spectra after adding zinc acetate nanoparticles, we notice an increase in the fluorescence of the dye after adding zinc acetate nanoparticles compared to the fluorescence of the dye before addition Explanation of this, when the concentration of the semiconductor$(CH_3\ COO)_2Zn$ nanoparticles increases, the energy gap is modified and decreased, and thus the adsorption of the dye molecules on the surface of the zinc acetate nanoparticles occurs.[24,25]. The values of the stock shift between absorption and fluorescence spectra are given in table (3), were calculated by taking the different between maximum fluorescence and absorption which are measures by UV-Visible spectrophotometer, and the values quantum efficiency measures by an equation:

$$Q_{fm}=\int F(\bar{v})\, d\bar{v} / \left(\int \varepsilon(\bar{v})\, d\bar{v}\right) \quad \ldots\ldots\ldots(1)\ [26]$$

Where : $\int F(\bar{v})\, d\bar{v}$: is the total area under the curve of the fluorescence and ($\int \varepsilon(\bar{v})\, d\bar{v}$) : is the area under the curve of the molar absorption coefficient which is a function of the wave number ($\bar{v}$) also, the radiative lifetime is calculated according to the equation as follow:

$$\tau_{fm} = 1/K_{fm} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)\ [26]$$

Where: τ_{fm} : is the radiative lifetime and its unit (s).

K_{fm} : is the rate of disappearance of the unit(s^{-1}).

$$\tau_f = Q_{fm} \times \tau_{fm} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)\ [26]$$

where : τ_f : is fluorescence lifetime and its unit (s).

Table (3): The wavelength for maximum absorbance, maximum fluorescence, stoke displacement, average radiative life, average fluorescence lifetime, and quantum efficiency.

Concentration mol/L	λ_{max} nm	λ_{max} nm	Stokes Shift $\lambda\Delta = \lambda_{flo} - \lambda_{abs}$	The radiated Life time τ_{fm} $n\ sec$	The fluorescence Life time $\tau_f n$ **sec**	The quantum efficiency % ϕ_{fm}
1×10^{-4}	483	516	33	1.22	1.16	0.95
7×10^{-5}	485	515	30	5.61	4.77	0.85
2×10^{-5}	484	513	29	2.30	1.82	0.79

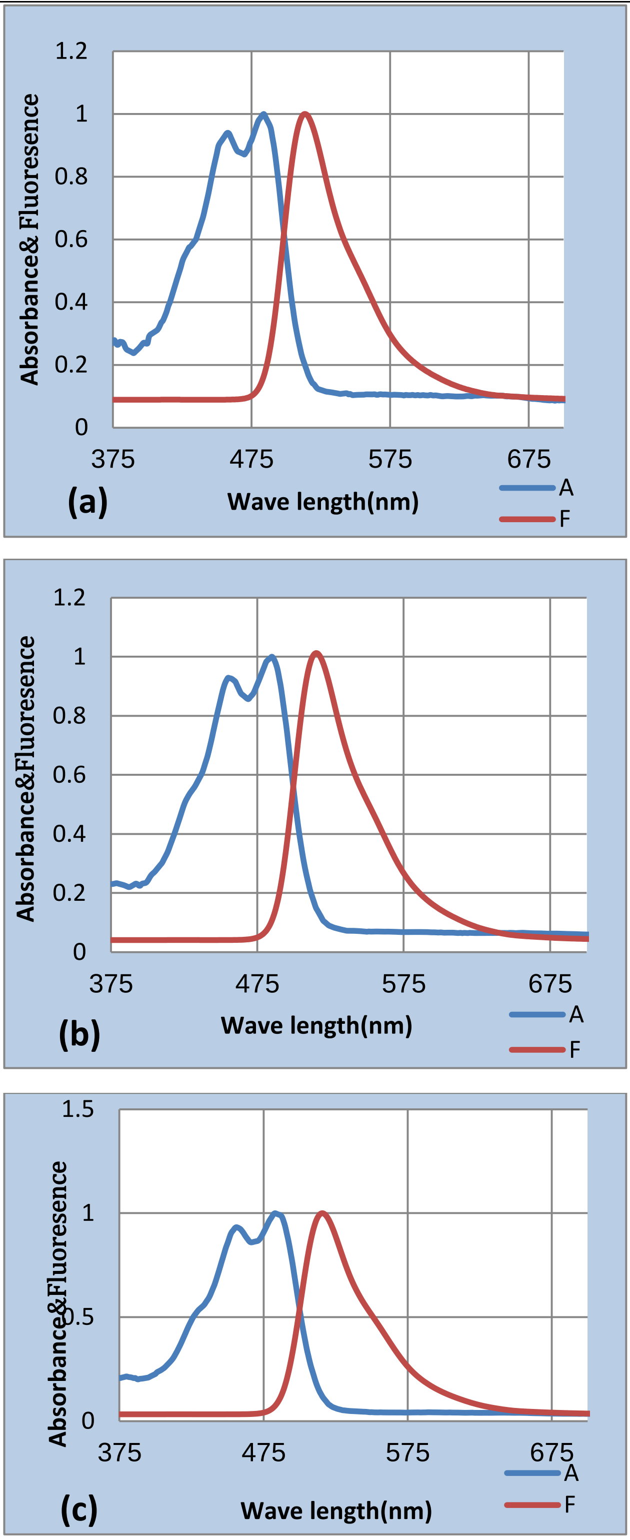

Figure 11: Spectra of absorption (A) and fluorescence (F) of the mixing fluorescein sodium dye and nanoparticles of Zinc acetate at different concentrations[(a)(2×10^{-5}) (b)(7×10^{-5}) (c)(1×10^{-4})]mol/L.

The relationship between Molar absorption coefficient (L/mol^{-1}.cm^{-1}) and wave number (cm^{-1}) has been illustrated also, in figure (12), these are to calculate the area under the curve as well as nonradioactive life time(τ_{fm}) and fluorescence life time(τ_f).

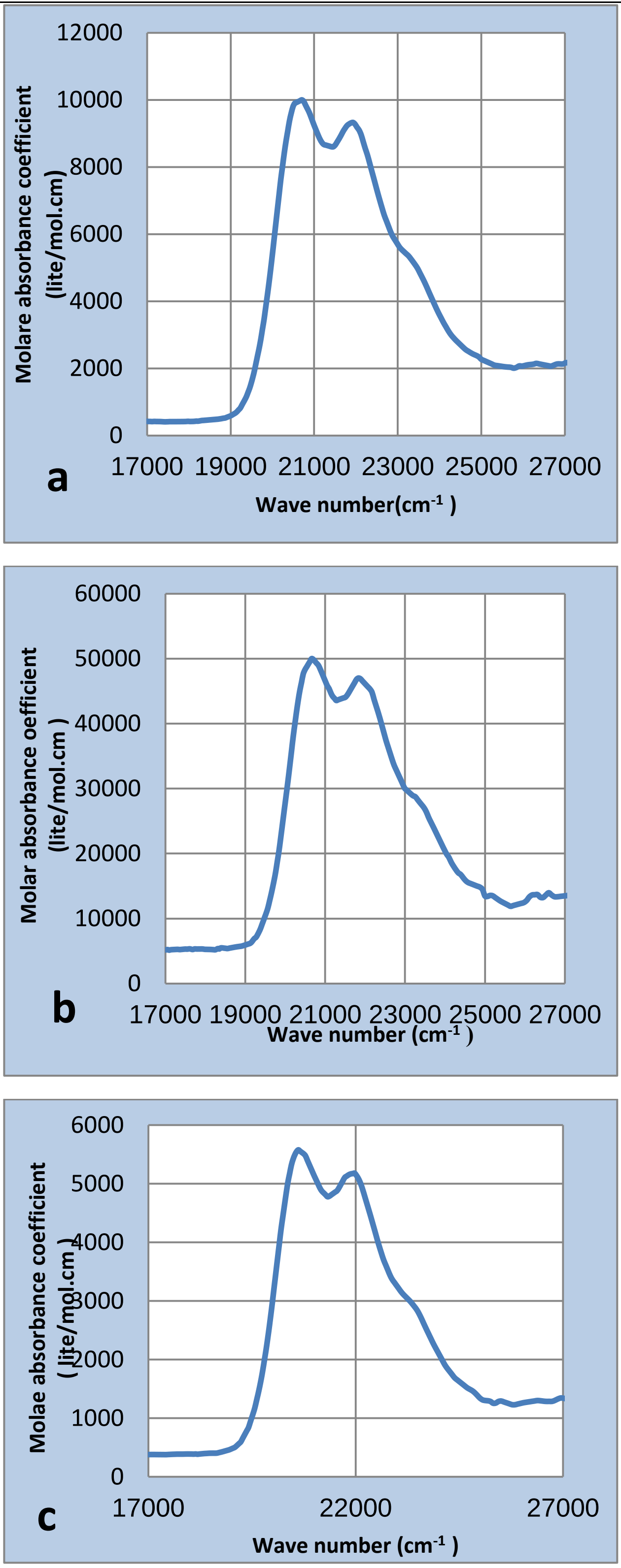

Fig 12: Spectra of molar coefficient (L/mol.cm) versus Wave number (cm^{-1}) fluorescein sodium dye at different concentration [(a)1×10^{-4},(b)2×10^{-5},(c)7×10^{-7}] mol/L.

6. CONCLUSION

The mixture (fluorescein sodium dye and nanoparticles of Zinc acetate)

contributed improve the efficiency of the solar cell. The best results were obtained by mixture fluorescein sodium dye and nanoparticles of Zinc acetate at concentration of (1×10^{-4})mol/L.

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