



# Luminescent Solar Concentrator Fabrication by Using a Mixture of Fluorescent Colors and Nanoparticles

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## Abstract

Zinc acetate nanoparticles were added to the organic fluorescent dye (Pyranine) to prepare three concentrations ( $3 \times 10^{-4}$ ,  $8 \times 10^{-4}$ ,  $1 \times 10^{-3}$ ) mol/L, and the dye absorbance was measured before and after the addition of the liquid Nano materials. Using (SCINCO Mega-2100 UV / Visible Spectrophotometer) as well as measuring the fluorescence of the dye before and after adding zinc acetate nanoparticles using (Spectrofluorometer F96 PRO). The Stoke displacement ( $\Delta\eta$ ), radiative life ( $\tau_{fm}$ ), fluorescence lifetime ( $\tau_f$ ), and quantum efficiency ( $Q_{fm}$ ) were calculated. The relationship between the absorption and fluorescence curves was plotted using Excel. MATLAB software was also used to measure the area under the absorption and fluorescence spectra curves. It was found that the fluorescence intensity of pyranine dye increased compared to the fluorescence intensity before adding the nanomaterial, thus increasing the quantum efficiency and thus increasing the efficiency of the solar cell significantly when adding the nanomaterial.

**Key Words:** Solar Cell, Efficiency, Fluorescence and Quantum Efficiency.

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4944

## Introduction

The electrical energy consumption is steadily increasing in worldwide and the installed traditional high power station cannot fulfill the demand. On the other hand continuous decrement of fossil fuels makes incentives to invest alternative energy sources like wind power, solar PV cell, fuel cell systematic. Use of these alternative sources of energy reduces the emission of harmful greenhouse gases which in turn reduce the amount of pollutants in the atmosphere. The field of photovoltaic has an incredible growth for past two decades with clean and environment friendly nature, non-conventional and renewable energy source, continuous reduction in system cost where regular power supply is inadequate, not reliable and costly to distribute [1].

Solar energy is the most abundant, inexhaustible and clean of all the renewable energy resources till date. The power from sun intercepted by the earth is about  $1.8 \times 10^{11}$  MW, which is many times larger than the present rate of all the energy consumption.

Photovoltaic technology is one of the finest ways to harness the solar power [2].

The leader of two days solar energy revolution is undoubtedly the silicon photovoltaic (PV) module. However, despite the immense progress in efficiency and the phenomenal drop of manufacturing and installation costs the dark blue flat panels have not found widespread use in the modern urban environment. The scarcity of available rooftop space, the high cost of land and the irregular metropolitan skyline have not allowed conventional solar technologies to supply cities with clean energy. Thus, new concepts are being investigated to integrate solar generators into new and existing buildings in the form of facades or windows.

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Luminescent Solar Concentrators (LSCs) offer a novel approach for the utilization of solar irradiation in the form of transparent glazing systems that have the potential to become functional elements of the building envelope [3].

Luminescent Solar Concentrators (LSCs) enable the creation of semitransparent glazing elements that potentially transform the so far energy passive windows and facades of metropolitan buildings into electricity power generators [4,5]. The concept of LSCs was first put forward in the early 1970s as an attempt to reduce the amount of silicon required for PV modules and to drive down the overall cost of solar energy that was prohibitively high at that time [6,7]. At present, the motivation to develop LSCs is to employ their unique optical properties to camouflage solar energy devices in the urban environment, bypassing the tight operational limitations and aesthetical inflexibility of opaque and semitransparent PV modules [8].

coated on top [9-10].

Direct or diffuse sunlight penetrating the top surface of the matrix is absorbed by the luminophores and then is isotropically re-emitted at a longer wavelength. The emitted luminescence is guided towards the perimeter of the sheet through total internal reflection where eventually it is converted into electricity by PV cells attached along the sides, see Fig. 1. As the total LSC area that is exposed to sunlight is larger than the surface area of the cells installed on the sides, the LSC device achieves light concentration. This form of light concentration is passive and low-cost, without bulky tracking equipment. Furthermore, the inherent ability to illuminate the attached PV cells indirectly, gives to the LSC device the additional benefit of being less sensitive in shading than conventional solar cells [11].

### Operational Principle of (LSC)

A typical LSC, in its simplest form, consists of a polymer or a glass sheet acting as a waveguide with luminophores either dispersed within the sheet or

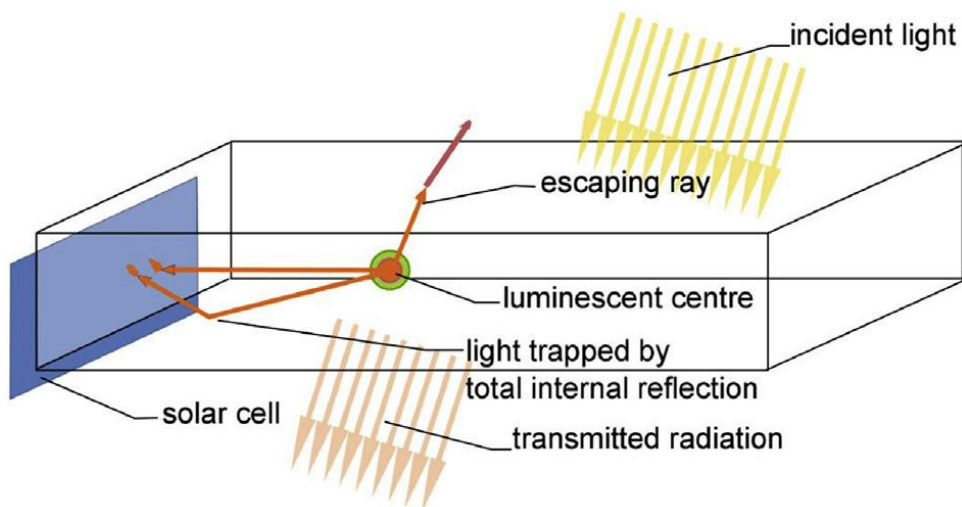


Fig. 1. Schematic representation of an LSC device under illumination [11]

### Experimental Part

In this research, Pyranine dye was used to prepare three concentrations of it after dissolving it in pure ethanol, where a quantity of the dye is weighed and then dissolved in the solvent using the dilution law to prepare the three concentrations, which is relatively low. concentrations. zinc acetate nanoparticles were added to Pyranine dye and the

same concentrations were prepared. The absorption and fluorescence spectra were calculated for use as the luminous center of the silicon solar cell.

Note: In the following figure is a picture of the solar cell used in the practical part of the research.



Figure 2. Photovoltaic cell

### 1. Pyranine Organic Dye

The arylsulfonate class of compounds includes the hydrophilic, pH-sensitive fluorescent dye known as pyranine [12]. Because pyranine dissolves in ethanol, it can be used as a dye, biological stain, optical detecting reagent, and pH indicator [13]. The measuring of intracellular pH is one illustration. Yellow highlighters also include pyranine, which gives them their distinctive fluorescence and vivid yellow-green color. Additionally, several forms of soap include it [14]. Figure (2) shows the chemical composition of the Pyranine dye and The following table shows the physical and chemical properties of Pyranine dye.

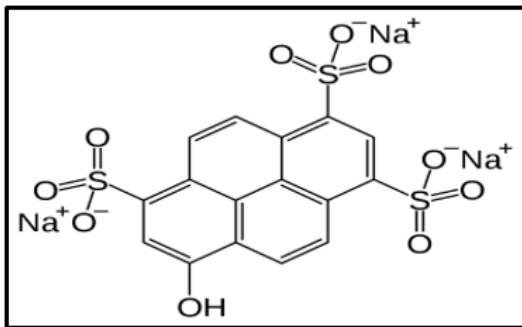


Figure 3. Chemical structure and powder of Pyranine dye [14]

Table: The physical and chemical properties of Pyranine dye [14].

Properties	
Molecular formula	C <sub>16</sub> H <sub>7</sub> Na <sub>3</sub> O <sub>10</sub> S <sub>3</sub>
Molar mass	524.37 g/mol
Physical state	yellow to greenish crystalline powder
Solubility in water	Soluble
Main hazards	XI

### 2. The Solvent (Ethanol)

It is an organic solvent whose scientific name (Ethyl Alcohol) and chemical formula (C<sub>2</sub>H<sub>5</sub>OH) and molecular weight (46.07 g/m), which solution polar base, is one of the best organic solvents. The study employments uses pure ethanol amounting purity of (99.9 %); equipped the ethanol molecule is clarified in figure (5) [15].

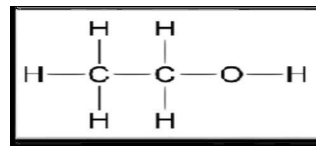


Figure 4. The structure of Ethanol molecule [16]

### 3. Zinc Acetate

Zinc acetate is a salt with the formula of Zn(CH<sub>3</sub>CO<sub>2</sub>)<sub>2</sub>, which is most usually found as Zn(CH<sub>3</sub>CO<sub>2</sub>)<sub>2</sub>•2H<sub>2</sub>O. 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. [17].

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 [18-19-20]. The zinc in zinc acetate dehydrate is octahedral, with both acetate groups being bidentate [21]

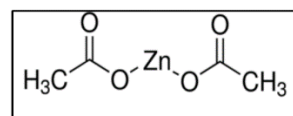


Figure 5. Chemical Zinc Acetate [18]



### Stock 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 [22-23-24]. 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 [25- 26].

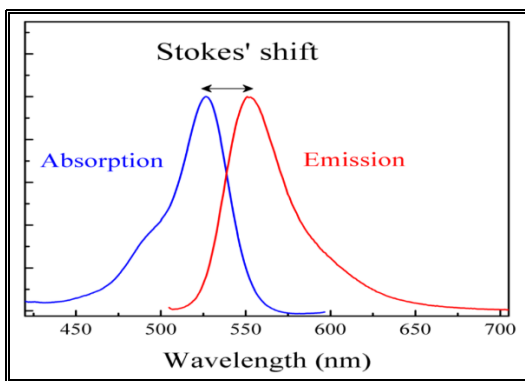


Figure 6. Stokes shift and overlap of the absorbance and fluorescence spectra [27].

### 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 [28]. 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 [29].

### The Absorbance and Fluorescence of the Pyranine Dye in Ethanol

The absorbance and fluorescence spectra of three concentrations of pyranine dye were studied ( $3 \times 10^{-4}$ ,  $8 \times 10^{-4}$ ,  $1 \times 10^{-3}$ ) mol/L. At the lowest concentration ( $3 \times 10^{-4}$ ) mol/L, the peak of absorption spectrum at wavelength was (405)nm is (0.166778), and the crest of fluorescence spectrum at wavelength was(502)nm is (58.84). Also for concentration ( $8 \times 10^{-4}$ ) mol/L, the peak of absorption spectrum was (0.518523) at wavelength was (454 )nm and highest of the fluorescence spectrum was (58) at the wavelength (502) nm. Like that for maximum the concentration ( $1 \times 10^{-3}$ ) mol/L, the peak of absorption spectrum was (0.700649) at the wavelength (454)nm, and the crest of the fluorescence spectrum was (42) at the wavelength (502) nm, as shown in figure (6,7,8)

4947

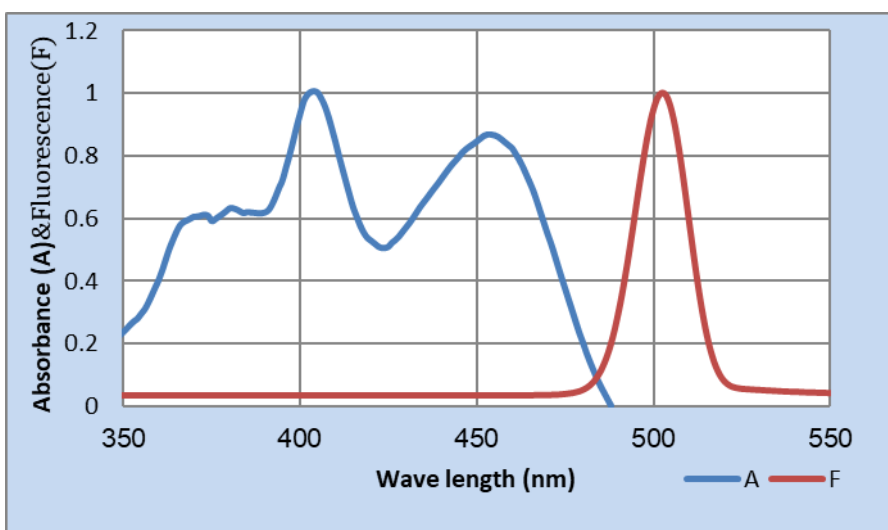


Figure 7. Absorbance and fluorescence spectra for Pyranine dye of ( $3 \times 10^{-4}$ ) mol/l



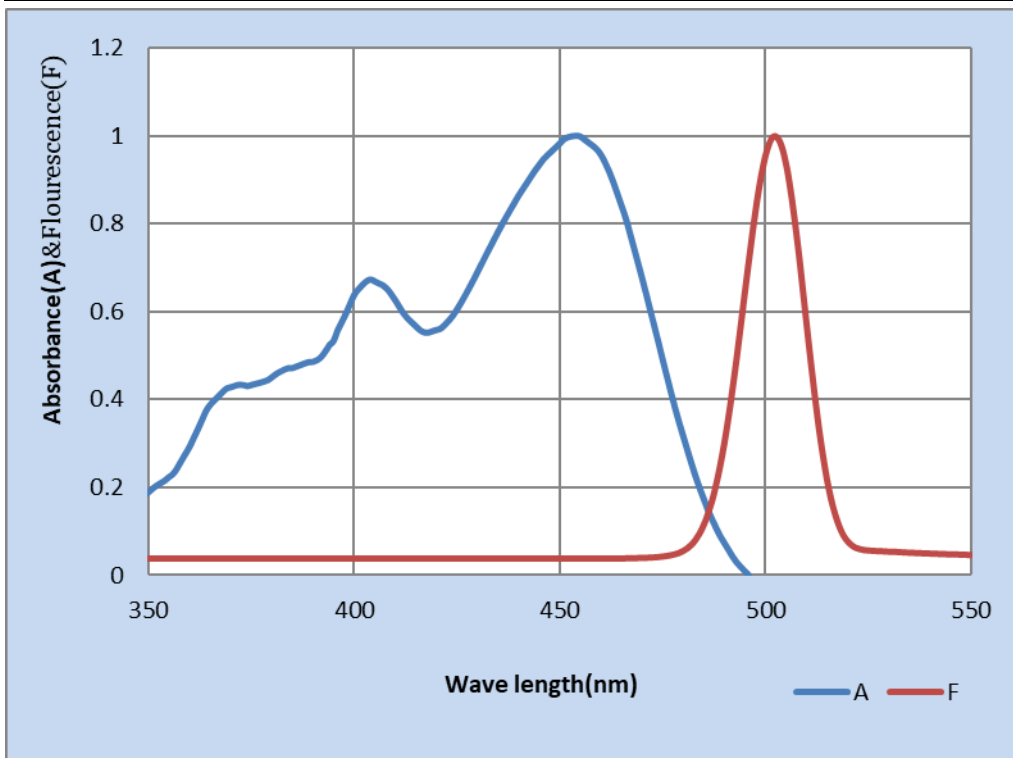


Figure 8. Absorbance and fluorescence spectra for Pyranine dye of  $(8 \times 10^{-4})$  mol/l

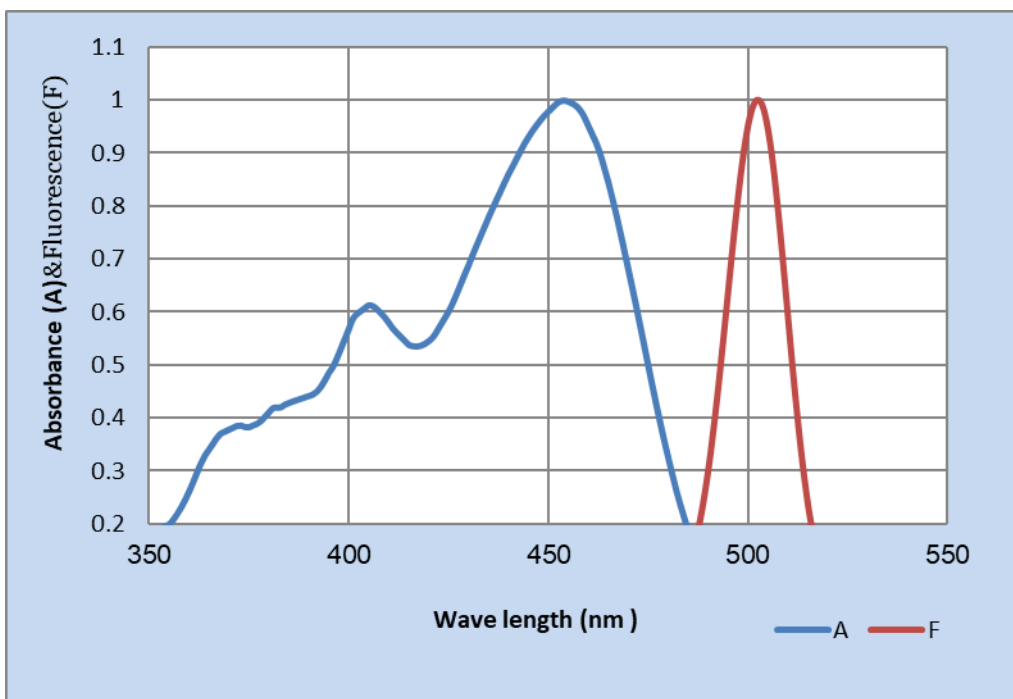
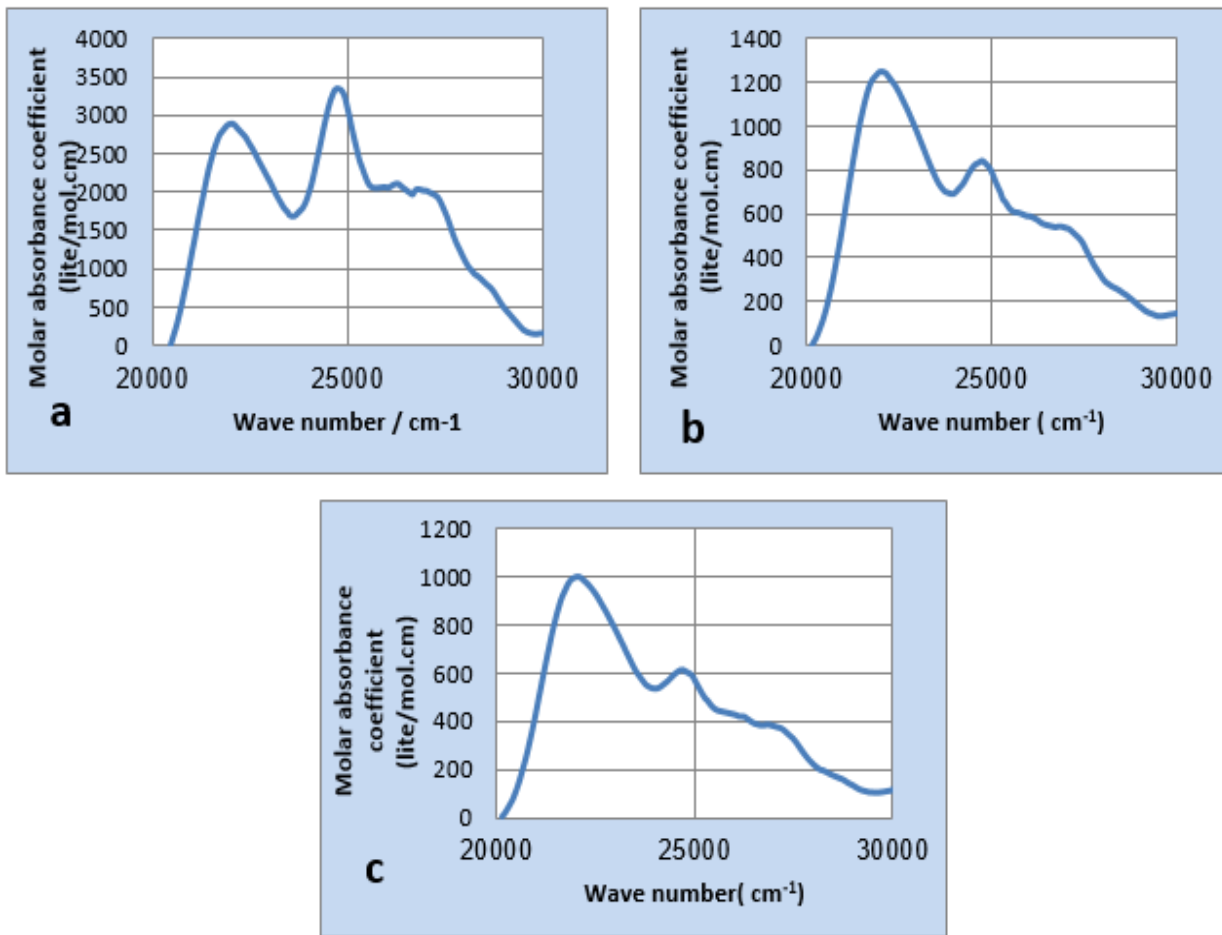


Figure 9. Absorbance and fluorescence spectra for Pyranine dye  $(1 \times 10^{-3})$  mol/l

The relationship between Molar absorption coefficient ( $L/mol^{-1}.cm^{-1}$ ) and wave number ( $cm^{-1}$ ) has been illustrated also, in figure (9), these are to calculate the area under the curve as well as nonradiative life time ( $\tau_{im}$ ) and fluorescence life time ( $\tau_f$ ).





**Fig. 10.** Spectra of molar coefficient (L/mol<sup>-1</sup>.cm<sup>-1</sup>) versus Wave number (cm<sup>-1</sup>) pyranine dye at different concentration [(a)3×10<sup>-4</sup>,(b)8×10<sup>-4</sup>(d)1×10<sup>-3</sup>] mol/L

**Table 1.** The Wavelength of maximum absorbance and maximum fluorescence, radiated life time, fluorescence life time, and quantum efficiency for Pyranine dye of different concentration.

Concentration (mol/L)	$\lambda A_{max}$ (nm)	$\lambda F_{max}$ (nm)	StokesShift $\Delta\lambda=\lambda_{fl0}-\lambda_{abs}$	The radiated Life time $\tau_{fm}$ (n sec)	The fluorescence Life time $\tau_f$ (n sec)	The quantum efficiency% $\Phi_{fm}$
$3 \times 10^{-4}$	405	502	97	6.85E-17	1.58E-17	0.23
$8 \times 10^{-4}$	454	502	48	67.21175	15.32428	0.228
$1 \times 10^{-3}$	454	502	48	86.52073	20.8515	0.241

**The Absorbance and Fluorescence of Mixture of the Pyranine Dye Zinc Acetate Nanoparticles**

The absorbance and fluorescence spectra of three concentrations of the mixture of the pyranine dye and zinc acetate nanoparticles were studied ( $3 \times 10^{-4}$ ,  $8 \times 10^{-4}$ ,  $1 \times 10^{-3}$ ) mol/L. At the lowest concentration ( $3 \times 10^{-4}$ ) mol/L, the peak of absorption spectrum at wavelength was (400)nm is (0.435559), and the crest of fluorescence spectrum at wavelength was (499)nm is (5.6). Also for concentration ( $8 \times 10^{-4}$ ) mol/L, the peak of

absorption spectrum was (0.923624) at wavelength was (403)nm and highest of the fluorescence spectrum was (8.90) at the wavelength (505) nm. Like that for maximum the concentration ( $1 \times 10^{-3}$ ) mol/L, the peak of absorption spectrum was (1.129351) at the wavelength (403)nm, and the large of the fluorescence spectrum was (14.97) at the wavelength (503) nm, as shown in figure (10,11,12)



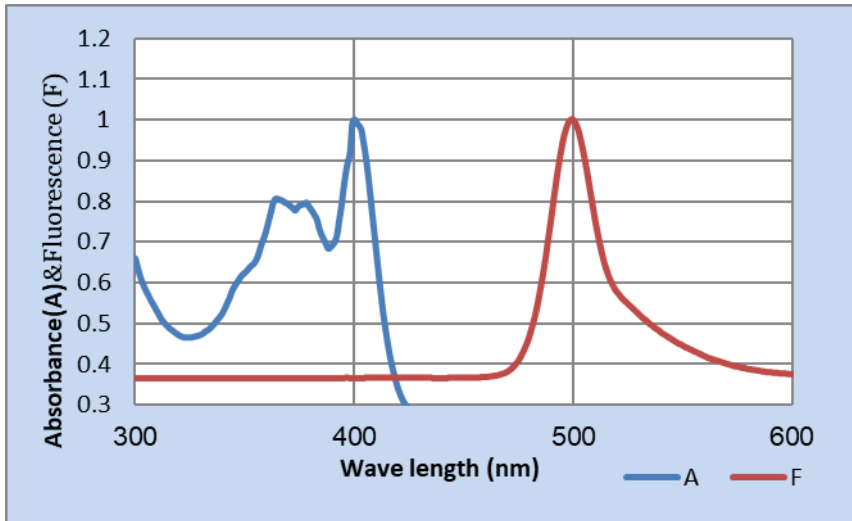


Figure 11. Absorbance and fluorescence spectra for mixture ( $3 \times 10^{-4}$ ) mol/L.

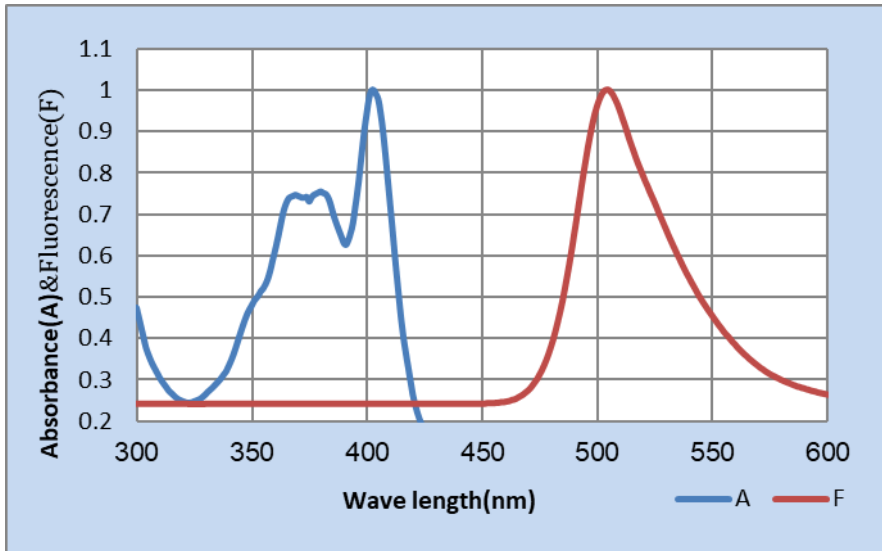


Figure 12. Absorbance and fluorescence spectra for mixture ( $8 \times 10^{-4}$ ) mol/L.

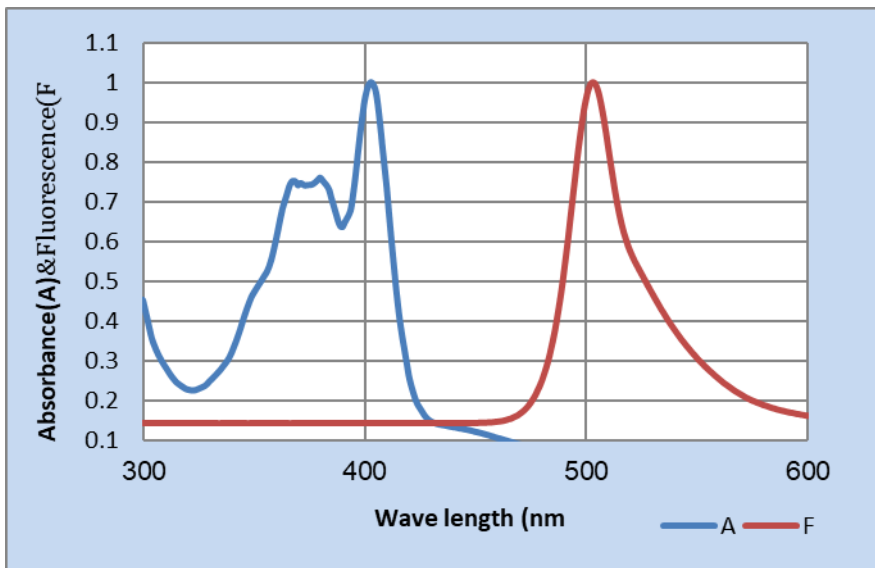


Figure 13. Absorbance and fluorescence spectra for mixture ( $1 \times 10^{-3}$ ) mol/L.



The relationship between Molar absorption coefficient ( $L/mol^{-1}.cm^{-1}$ ) and wave number ( $cm^{-1}$ ) has been illustrated also, in figure (9), these are to calculate the area under the curve as well as nonradiative life time ( $\tau_{fm}$ ) and fluorescence life time ( $\tau_f$ ).

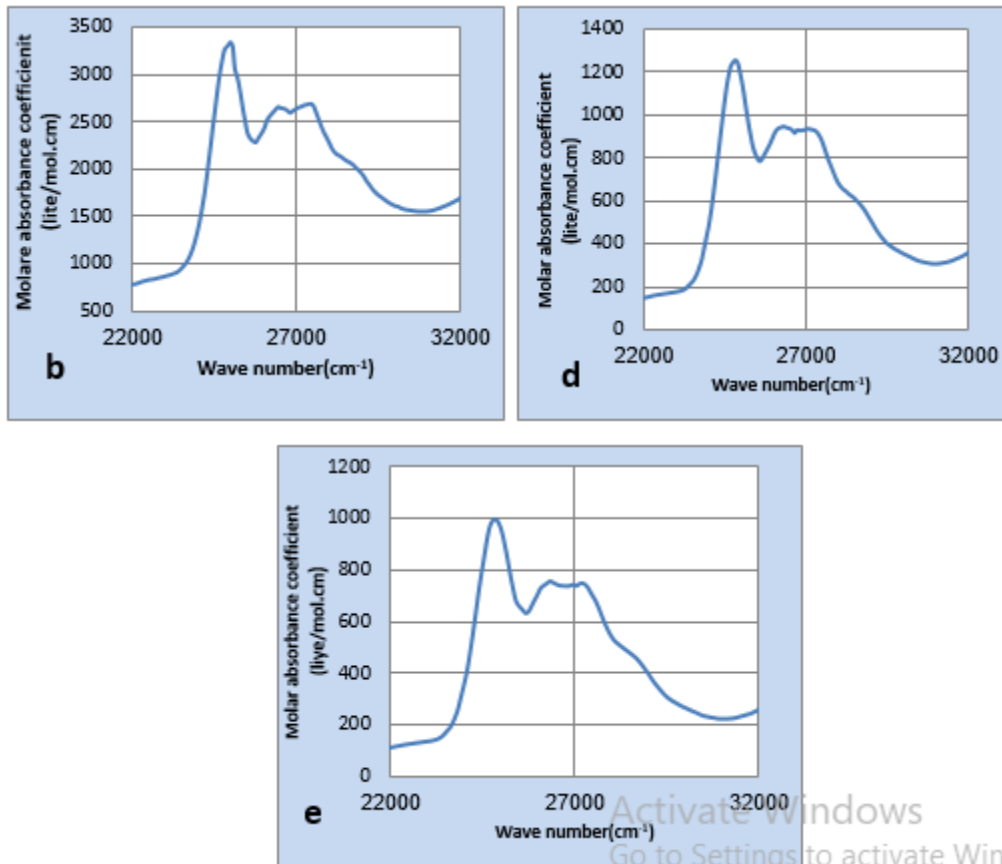


Fig. 14. Spectra of molar coefficient ( $L/mol^{-1}.cm^{-1}$ ) versus Wave number ( $cm^{-1}$ ) mixture at different concentration [(b) $3 \times 10^{-4}$ , (d) $8 \times 10^{-4}$  (e) $1 \times 10^{-3}$ ] mol/L

Table 2. The Wavelength of maximum absorbance and maximum fluorescence, radiated life time, fluorescence life time, and quantum efficiency for mixture Pyranine dye and zinc acetate nanoparticles of different concentration.

Concentration (mol/L)	$\lambda A_{max}$ (nm)	$\lambda F_{max}$ (nm)	Stokes Shift $\Delta\lambda = \lambda_{flo} - \lambda_{abs}$	The radiated Life time $\tau_{fm}$ (n sec)	The fluorescence Life time $\tau_f$ (n sec)	The quantum efficiency% $\Phi_{fm}$
$3 \times 10^{-4}$	400	503	103	0.002	0.000616	0.308
$8 \times 10^{-4}$	403	502	101	0.006502	0.002425	0.373
$1 \times 10^{-3}$	403	502	101	0.007761	0.0026	0.335

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:

$$Q_{fm} = \int F(\nu) d\nu / (\int \epsilon(\nu) d\nu) \quad (1) [30]$$

Where:  $\int F(\nu) d\nu$  : is the total area under the curve of the fluorescence and  $(\int \epsilon(\nu) d\nu)$  : is the area

under the curve of the molar absorption coefficient which is a function of the wave number ( $\nu$ -) also, the radiative lifetime is calculated according to the equation as follow:

$$\tau_{fm} = 1/K_{fm} \quad (2) [30]$$

Where:

$\tau_{fm}$  : is the radiative lifetime and its unit (s).

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

$$\tau_f = Q_{fm} \times \tau_{fm} \quad (3) [30]$$

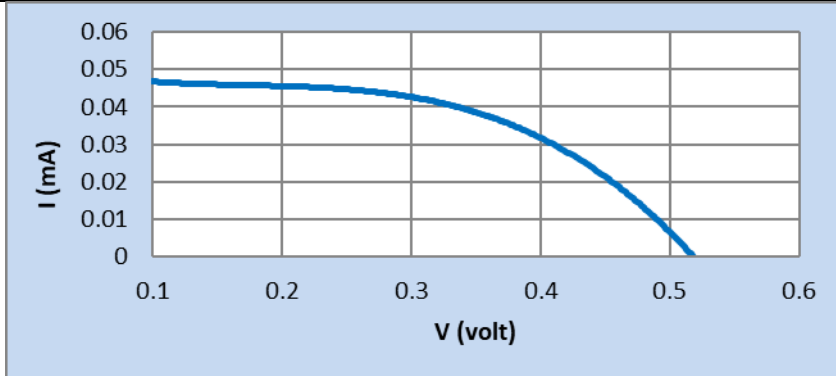


Where:

$\tau_f$ : is fluorescence lifetime and its unit (s)

**Table 3.** The measurement of the Pure solar cell efficiency.

Concentration (mol/L)	$I_{max}$ (mA)	$V_{max}$ (V)	FF	% $\eta$
Pure cell	42.00	0.336	0.519	2.016



**Figure 15.** The (I-V) curve of the pure solar cell

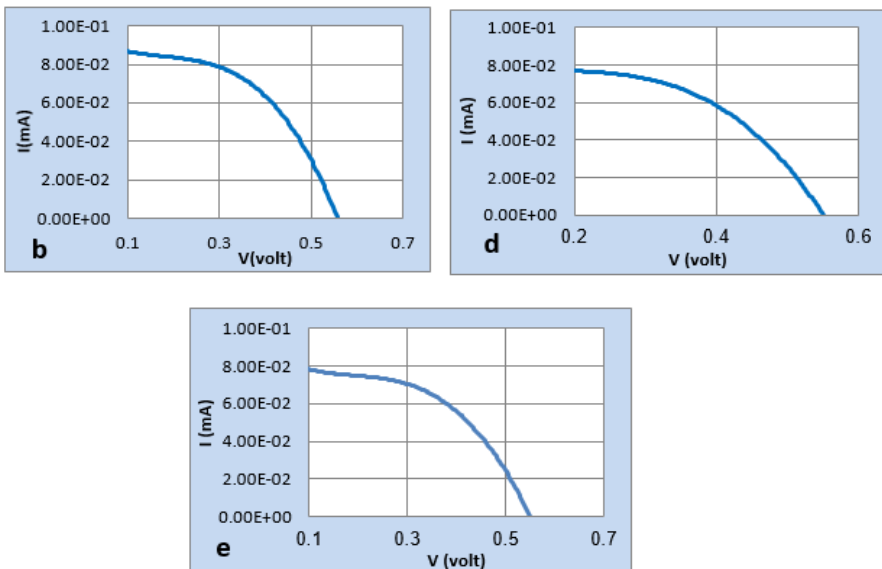
**Table:** Solar cell efficiency ( $\eta$ ) by using (LSC) panels of Pyranine dye at different concentration

Concentration (mol/L)	$I_{max}$ (mA)	$V_{max}$ (V)	FF	$\eta\%$	$\Delta\eta\%$
$3 \times 10^{-4}$	57.60	0.366	0.530	3.011	49.355
$8 \times 10^{-4}$	63.00	0.379	0.524	3.411	69.196
$1 \times 10^{-3}$	67.60	0.377	0.544	3.640	80.555

**Table 5.** Solar cell efficiency ( $\eta$ ) by using (LSC) of Mixture(Pyranine dye and nanoparticles of zinc acetate) at different concentration.

Concentration (mol/L)	$I_{max}$ (mA)	$V_{max}$ (V)	FF	$\eta\%$	$\Delta\eta\%$
$3 \times 10^{-4}$	72.89	0.375	0.517	3.905	93.7
$8 \times 10^{-4}$	67.70	0.375	0.587	3.626	79.86
$1 \times 10^{-3}$	66.40	0.366	0.507	3.471	72.17

4952



**Figure 16.** I-V characteristics curve of the solar cell with Mixture of pyranine dye and nanoparticles of zinc acetate [(b)  $3 \times 10^{-4}$ , (d)  $8 \times 10^{-4}$ , (e)  $1 \times 10^{-3}$ ] mol/L

Through Table (5), as well as the fluorescence spectra after adding zinc acetate nanoparticles, we notice an increase in Solar cell efficiency ( $\eta$ ) after adding zinc acetate nanoparticles compared with efficiency of Solar cell before addition. Explanation of this, when the concentration of the



semiconductor  $(\text{CH}_3\text{COO})_2\text{Zn}$  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. [31-32].

## Conclusion

The mixture (pyranine dye and zinc acetate nanoparticles) contribute to improving the efficiency of solar cells. The best results were obtained from a mixture of pyranine dye and zinc acetate nanoparticles at concentration of  $(1 \times 10^{-3})$  mol/l.

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