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Improving the Efficiency of Silicon Solar Cells Using Photo-Luminescent Solar Concentrators Based on Plant Dyes Solutions Doped with Nanoparticles

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ABSTRACT

In this research, natural dyes were used as luminous solar concentrates to improve the efficiency of solar cells. In this study, natural dyes (kujrat , saffron and raisins) were used after dissolving them in pure water as a solvent because it does not affect the properties of the dyes by (0.001, 0.002, 0.003) grams per 100 ml of pure water. After dissolving the dyes in water and preparing the concentrations used in the research, zinc oxide nanomaterials were added, and the absorbance and fluorescence were calculated for each concentration, The optical properties were studied over a wavelength range (200-800) nm. The results showed that increasing the concentration of the dyes leads to an increase in the intensity of the absorbance and a decrease in the fluorescence, but when adding the nanomaterials zinc oxide, the absorbance increases and the fluorescence decreases with an increase in the concentration of the dyes. and the solar concentrator efficiency was calculated for each concentration highest efficiency of a solar cell using Kujrat dye was (η=1.670%) . Calculation of cell efficiency without dye(η=0879%) .

1. Introduction

Nearly all of the energy on earth comes from the sun. Solar energy is the most readily available, endless, silent, and scalable of all the renewable energy sources. use cases [1,2] A photovoltaic (PV) device is one that transforms sunlight directly into electricity without the use of noise, moving parts, or pollutants, making it trustworthy and long-lasting. PV is a sophisticated technique that makes use of the sun's energy [3,4]. The charge notion that separates at the interface of two materials with various conduction methods is the foundation of PV device mechanisms [5]. Charles Fritts created the first photovoltaic cell in the 19th century, which was made of selenium and a thin film of gold [6, 7]. At AM 1.5 G, the sun's spectral distribution includes photons with wavelengths ranging from the ultraviolet (UV) to the infrared (280-2500 nm, 0.5-4.4 eV). External quantum efficiency (EQE) is a measure of a PV cell's spectral responsiveness [8]; it is the ratio of electron-hole pairs produced to the number of incident photons striking the front surface of the device. Luminescent solar concentrator s (LSC) commercialisation has not been extensively accepted because of its low efficiency. As the radiation the cell produces gets closer to the band gap of the PV materials, the cell's external quantum efficiency rises and it generates more current [9,10]. The Luminescence solar concentrator (LSC) shown in figure(1) requires luminescent materials with the following photo physical characteristics: (i) broad absorption that covers the solar spectrum before the band gap of the edge-attached solar cells; (ii) long-wavelength emission centered at the strongest spectral response region of the edge-attached solar cells; and (iii) large Stokes shift with minimal spectral overlap that can minimize the probability of self-absorptive[11].

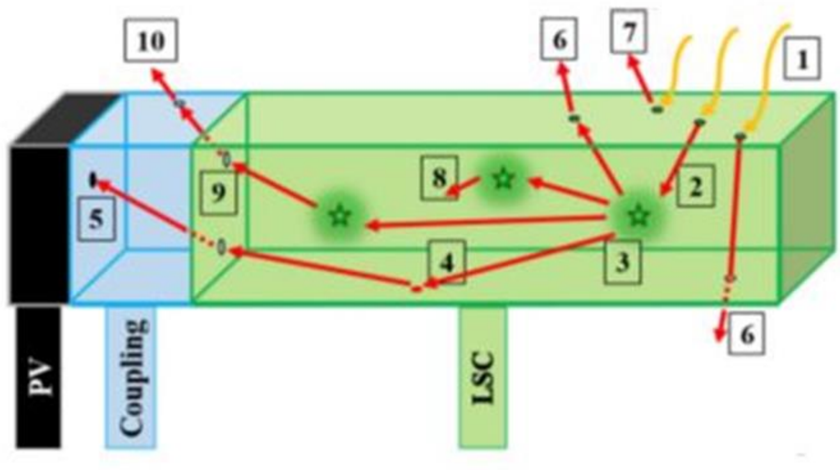

Figure 1: : Configuration of an LSC[12]

Fig 1 shows: 1- photon enters the LSC and is 2- absorbed by the luminescent material, then 3- re-emitted at longer wavelength and waveguided by Total Internal Reflection (TIR) and 5- reaches the PV cell through the optical coupling. Losses include: 6- the fraction of light which is lost through the bottom and other surfaces (escape cone loss), 7- front surface reflection and 8- the emitted photon which is re-absorbed by another luminescent molecule and its energy is decreased. 9- a fraction of radiation striking the optical coupling, might be 10- deviated and lost due to non-optimal optical coupling and refractive indices differences. Note that, the radiation may also be scattered or attenuated by the host or coupling material which are not shown here [12].

In this research, the optical properties (absorbance, fluorescence, and efficiency of the solar cell) of natural dyes (saffron, Kujrat, and raisins) are studied, and their effect on improving the efficiency of the solar cell, and their measurements are compared after adding nanomaterials to it.

1.1.Experimental

Natural dyes were used extracted from the saffron plant , kujrat tea, and the raisins fruits, which were prepared after washing them well and soaking them with water, then putting them on a low heat and boiling them at 75 degrees Celsius, and eliminating 20 percent of the water to preserve its fragrance. Finally, drying was completed by a dryer at 75 degrees Celsius. for 10 hours, resulting in a dry paste that was crushed to generate dye powder, where 1g, 2g, and 3g of each dye were dissolved in one liter of distilled water,The absorbance was calculated by the he fluorescence was calculated by the fluorescence device for all absorbance device, as well as t the dyes after dissolving them with water in the figure (2,3)and then the zinc oxide , nanomaterials (Zno) who is certified Sky Spring Nanomaterials is an ISO 9001, Which was purchased from international company with value 10-30 nm , were added after mixing them with pure water at a rate of 1.6 grams according to the application of the concentration equation [21] .

$$C = \frac{WX1000}{MwXV} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where: C : the Zno concentration

W : is the weight of the Zno (in gram) measured using sensitive weighting balance,

Mw : Molecular weight of the Zno

V : the volume of the solvent (ml)

pure water and then mixing the mixture of the nanomaterial and mixing them with 200 ml of rate of 10 ml to 100 ml for eac with the dye solution at aconcentration of each dye, and both the absorbance and fluorescence were calculated for each mixture as in the figure (4,5)e and then th , cell efficiency was also calculated for the dye solution Before adding the nanomaterials and after As shown in Tabl adding the nanomaterialse (1,2,3) where The illuminating solar concentrator was manufactured using four silicon solar cells placed at the edge of the basin containing the prepared dyes. The parameters of the solar cell were calculated for the three concentrations prepared in the presence and absence of the nanomaterial zinc oxide (zno) , and the efficiency of the solar cell was calculated and the amount of increase and decrease in the amount of this efficiency. Also calculated The solar cell efficiency without dyes (η= 0.869) .

1.2. Measurements

1.2.1. Absorbtion

The electrons in molecules can receive photon energy (hf) when photons strike them, allowing them to transition from the ground state to higher (excited) electronic states. This is feasible given that the energy of the photons, E, and the energy difference between the excited state and the ground state, E, are equivalent . A molecule's total energy is typically written as the product of its electronic energy (Ee), vibrational energy (E_V), and rotational energy (Er), as shown in the formula [14]:

$$E_{total} = E\,e + E\,v + E\,r \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Because multiple transitions with various energies (vibrational and rotational) can occur with electronic transitions, the bands of the absorption spectra are widened.

1.2.2.Fluorescence

A primer on luminescence is beneficial. A visible photon illuminates a molecule, which it absorbs, excites to move to a high level, and then emits photons to return to a low level. This phenomenon is known as fluorescence. The molecule changes the excited electrical state to one of its vibrational modes after taking in light from an outside source. It descends to the lowest vibrational level and, after colliding with surrounding molecules and losing some of its vibrational energy, is radioactively transferred from this level to one of the ground vibrational levels. This happens rather quickly [15] . Photoluminescence begins with the absorption of photons (A) . The ground state electrons (S_o) are given energy by this process, allowing them to move to higher energy state (S_1, S_2,...) so a state of vibrational excitation (ν).They perform vibrational relaxation (VR) there to the lowest vibrational state of the stimulated electronic state, they lose part of their energy without radiation. Additionally, they lose energy nonradiatively through internal conversion (IC).

1.2.3. Photovoltaic Parameter

The power output, short-circuit current, open-circuit voltage, The combined fill factor and efficiency of a solar cell are referred to as photovoltaic parameters.

1.2.4 Fill Factor (FF)

The sharpness of the current-voltage curve in a solar cell is measured by the filling factor.It is referred to as the curve factor and it demonstrates how well the PV cell's series resistance and connection were constructed. When there is no series resistance, it can be higher, thus Voc needs to be high [16,17]:

$$FF = \frac{V_{max} I_{max}}{V_{oc} I_{sc}} = \frac{P_{max}}{V_{oc} I_{sc}} \dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

The solar cell properties are best clarified by use of a current-voltage curve (or an I-V curve). As shown in figure(2), the voltage is represented by the horizontal axis and the current is represented by the vertical axis.

The cell solar can produce the highest current at zero voltage. At the increase of the external load, the voltage is increasing as the current decreases to the point of Voc . At Voc all excess carriers are recombined within the cell and no current is there to power the load. Two other parameters are employed in this dissertation, maximum power (Pmax) and efficiency (η). Pmax is the point of at which maximum power is produced by the solar cell Vmp and Imp can then be determined for use in the design of a solar array [18].

1.2.5. Solar Cell Efficiency (η)

The electrical output power of the solar cell at the maximum power of the current-voltages divided by the input power is known as the solar cell's efficiency . The PV-cell power conversion efficiency, η, can be given [19]:

$$\eta = \frac{V_{max} I_{max}}{P_{in}} = \frac{P_{max}}{P_{in}} = \frac{V_{oc} I_{sc} FF}{P_{in}} \dots\dots\dots\dots\dots\dots\dots\dots (4)$$

The most popular metric used to compare the effectiveness of solar cells is solar cell efficiency. As a result, the equation provides the improvement ratio of solar cell efficiency given by [20]:

$$\Delta\eta = \frac{(\eta\%)_{LSC} - (\eta\%)_{bare}}{(\eta\%)_{bare}} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where (η%)_LSC is the conversion efficiency when installing luminescent solar concentrator on the solar cell and (η%)_bare is the bare solar cell efficiency .

2. **Results and discussion**

The absorbance of each dye solution was plotted through the UV device as shown in fig.(2) .

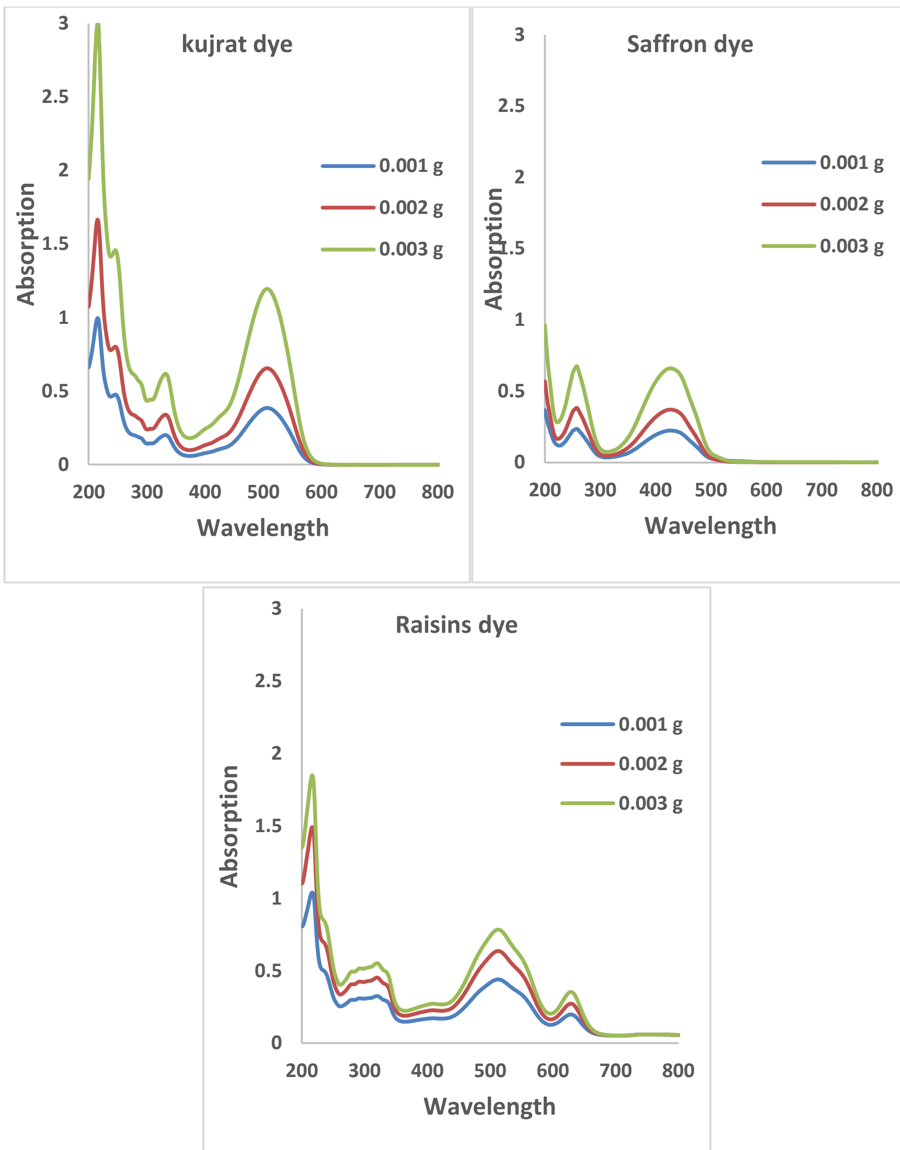

Figure (2) curve Absorbance of dyes nature (kujrat, saffron and raisins dyes) .

Figure 2: shows the Absorbance of nature dyes extension .Section (a) shows the Absorbance curve of kujrat dye type where a peak at wavelength (500 nm)

(b) shows the Absorbance curve of Saffron dye at wavelength (450 nm) (c) shows the Absorbance curve of Raisins dye at wavelength (516 nm) . We notice in figure (2) that the absorbance increases with increasing dye concentration.

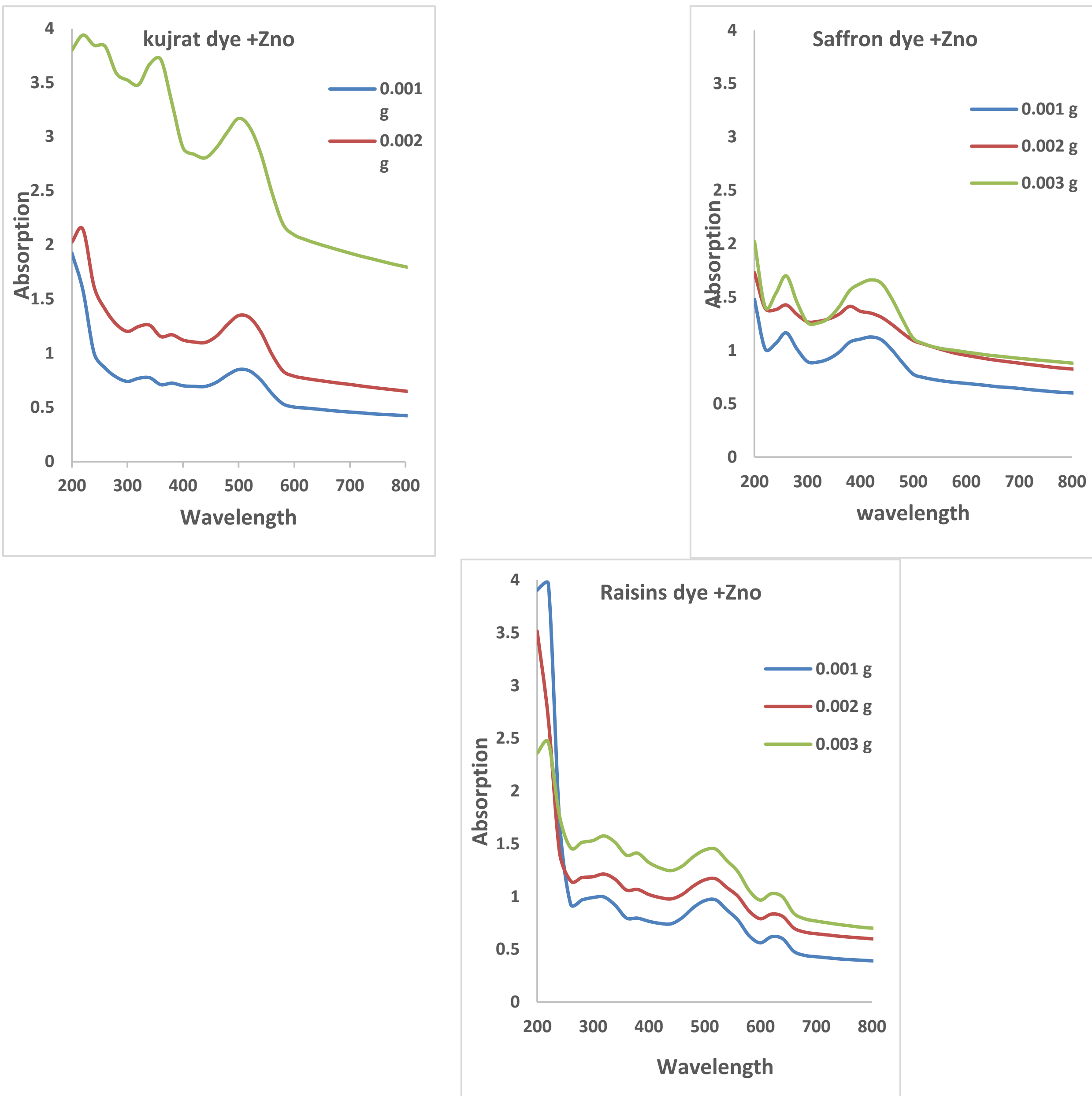

Figure (3) Absorption spectrum of each of Kujrat ,Saffron and Raisns dyes mixed with nanomaterial zno (zinc oxid).

We notice an increase in the absorbance when the nanoparticles are added, and it increases with the increase in the dye concentration According to Beer-Lambert's law [22].

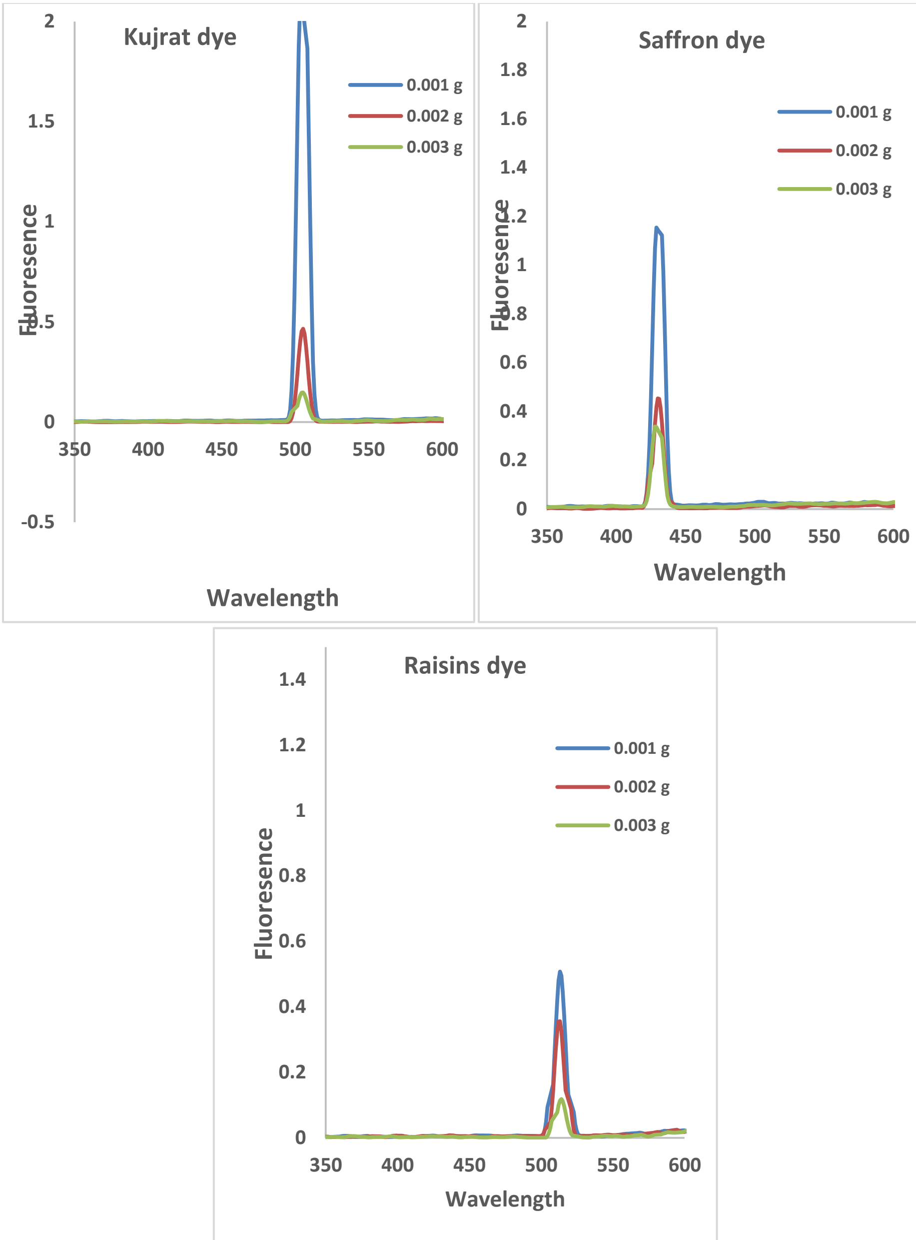

Figure (4) fluorescence spectrum of each of Kujrat ,Saffron and Raisins dyes .

We notice in figure (4) that the fluorescence decreases as the dye concentration increases .

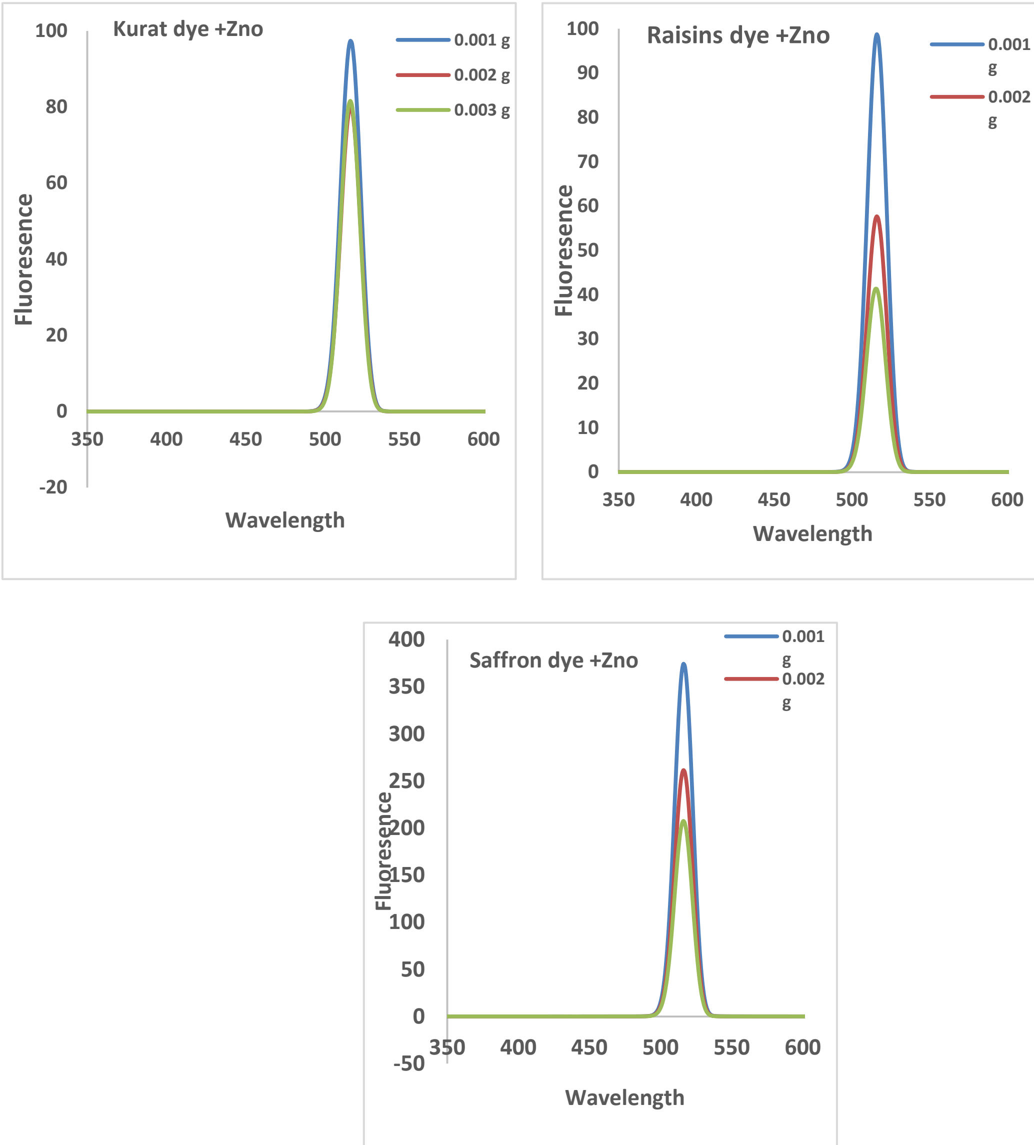

Figure (6) fluorescence spectrum of each of Kujrat , Saffron and raisins dyes mixed with nanomaterial Zno (zinc oxide) .

We notice in figure (6) a high increase in fluorescence when adding the nanomaterial due to a decrease in the energy gap due to the formation of local levels, where the electron is picked up in two stages from the valence band to the local levels and then from the local levels to the conduction band.

Table (1) Solar Cell Efficiency (η) of Mixture (Kujrat dye and zinc oxide) at Different Concentrations.

Concentration (g)	Nanomaterials	I_{max}	V_{max}	F.F	η%	Δη%
0.001		278.0	0.489	0.788	0.871	0.002
0.001	Zno	521.3	0.496	0.706	1.657	0.906
0.002		222.7	0.484	0.658	0.690	-0.205
0.002	Zno	515.9	0.505	0.806	1.670	**0.921**
0.003		220.3	0.489	0.840	0.690	-0.205
0.003	Zno	501.9	0.489	0.780	1.573	0.810

Table (2) Solar Cell Efficiency (η) of Mixture (Saffron dye and zinc oxide) at Different Concentrations.

Concentration (g)	Nanomaterials	I_{max}	V_{max}	F.F	η%	Δη%
0.001		333.0	0.469	0.749	1.001	0.151
0.001	Zno	473.1	0.494	0.738	1.498	**0.723**
0.002		261.7	0.505	0.747	0.847	-0.025
0.002	Zno	423.7	0.506	0.843	1.374	0.581
0.003		291.3	0.488	0.709	0.911	0.048
0.003	Zno	368.7	0.514	0.865	1.214	0.397

Table (3) Solar Cell Efficiency (η) of Mixture (Raisins dye and zinc oxide) at Different Concentrations.

Concentration (g)	Nanomaterials	I_{max}	V_{max}	F.F	η%	Δη%
0.001		226.5	0.480	0.808	0.696	-0.199
0.001	Zno	509.6	0.498	0.793	1.626	0.871
0.002		276.2	0.479	0.756	0.848	-0.024
0.002	Zno	484.4	0.512	0.733	1.589	0.828
0.003		219.1	0.476	0.806	0.668	-0.231
0.003	Zno	506.3	0.504	0.504	1.635	**0.881**

The higher increase in the efficiency of the solar cell in the kujarat dye mixed with zno nanometrail .

The reason for increasing the efficiency of the solar cell by adding the nanomaterials is the scattering of the photons of light due to the presence of the nanomaterials in different directions, and due to the distribution of the solar cells in four directions, all the scattering photons were obtained . This is because the scattering depends on the wavelength, where the dimension of the nanoparticle ranges from (10-30)nm , according to the information of the company from which the purchase was made, and the wavelength of light absorption is (200-800)nm , which is greater than the dimension of the nanoparticle, and thus the scattering is done according to the Rayleigh scattering [23] .

3. **Conclusion**

We conclude from the research study that improving the efficiency of the solar cell by using natural dyes in addition to the presence of nanomaterials that work to improve the optical properties, where the highest value of the efficiency of the solar cell was obtained in the dye of Kujrat dye($\eta\Delta$=0.921%) while the efficiency of the solar cell without a light center was(η=0.869 %) .

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