Jurnal Fisika Flux
Volume 16, Number 1, Februari 2019
ISSN : 1829-796X (print); 2514-1713 (online)
https://ppjp.ulm.ac.id/journal/index.php/f/

Improved Performance of Dye-Sensitized Solar Cells With TiO_2 Nano-Particles by Using The Carrot as a Dye-Sensitized Solar Cell Applications (DSSC)

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DOI: https://doi.org/10.20527/flux.v15i2.5563
Submited: 21 November 2018; *Accepted*: 08 April 2019

ABSTRACT− The aims of the research to were know performance of Dye-Sensitized Solar Cell (DSSC) using the dye of carrots (*Daucus carota*) as a photosensitizer with a variation of dye deposition area with spin coating techniques. The structure of the samples as a sandwich consisting of the working electrode titanium dioxide (TiO_2), dye, electrodes of platinum (Pt) and the electrolyte sandwiched between two electrodes. Test absorbance dye using UV-Visible Spectrophotometer Lambda 25, using a two-point conductivity test probes El Kahfi 100 and characterization test IV using a Keithley 2602A.. DSSC fabrication has been done using dye extract of carrots (Daucus carota) with a variety of solvent technique spin coating. The results show that dye extract of carrots (Daucus carota) have an absorbance spectrum of 380-520 nm range. From the results of the test using AM Simulator 1.5G (100 mW/ cm^2) diesel simulator, it was found that the volume of TiO_2 precursors affected the performance of DSSC solar cells and the overall conversion efficiency was 0.021% for the carrots (Daucus carota) dye with ethanol solvent and 0.037% for the carrots (Daucus carota) dye by solvent acetone.
KEYWORD: *Carrot, Counter electrode, DSSC, Absorbance, Conductivity.*

INTRODUCTION

Electricity is an important factor for industrialization, urbanization, financial growth of any country (Khare, Nema, & Baredar, 2013). There are different types of conventional and non-conventional energy sources used to generate electricity. Fossil fuels such as oil, natural gas, and coal are the major sources of energy used all over the globe. Moreover, the burning of fossil fuels emits a ton of carbon dioxide that pollute the environment and also change the climate conditions (Fukurozakia, Zillesa, & Sauera, 2013).

This is what makes energy very important in meeting all the needs of life in the world, so the energy needs in the world increasingly day. Limitations of silicon solar cells are not only expensive, but the absorption spectra are too narrow (Schiffer, 2016). It is known that the energy distribution of sunlight consists of about 4% ultraviolet and 96% visible light. The main spectrum of silicon solar cell absorption is ultraviolet and purple. This shows that silicon solar cells cannot use nearly 96% of the energy from sunlight (Alharbi & Kais, 2015). Efforts to broaden the absorption spectra from the ultraviolet region to the visible light region are now applied as Dye-Sensitized Solar Cell (Lin et al., 2007) where dyes can assist DSSC to expand the absorption spectrum (Gratzel, 2006).

The absorption of light in the range 380-

520 nm and the molar extinction coefficient greater than 105 makes the carotenoids as potential sensitizers in photovoltaic solar cells and other artificial photochemical devices (Gratzel, 2003). Carrots (*Daucus carota*), melinjo (*Gnetum genemon*), and mangosteen peel (*Garcinia mangostana*) are natural ingredients that are widely consumed and contain carotenoids. But the carotenoid content may vary depending on the source.

Performance solar cells is the ability of solar cells conversion light into electrical energy. Figure 1. An I-V curve which shows Traffic cells in producing voltage and current. In the image shown in the open circuit voltage (V_{oc}), short circuit current (I_{is}), maximum voltage, maximum current and fill factor. When short circuit condition (I_{is}), the cell will produce a short circuit current. When open circuit condition no current flows so that the voltage will be the maximum, or so-called open circuit voltage. Fill factor is a measure of the quality of the performance of solar cells.

In general, Figure 1 shows the DSSC comprising dye-sensitized organic matter, a nanocrystal TiO_2 layer, an electrolyte solution containing the redox pair I^-/I^3 and the FTO glass substrate as the working electrode. The outside factor of the area and the thickness of the semiconductor layer governs the increase of dye load, then the optical density that results in the efficiency of light absorption (Meen et al., 2011).

The optical density represents the transmission size of an optical element of a certain wavelength. When connected with radiation on an object, the optical density is the ratio between the initial intensity and the intensity of the transmission. DSSC is a sandwich-shaped structure, in which two electrodes ie TiO_2 electrode with dye and a comparative electrode made of FTO-plated glass flattened by electrolyte form a photoelectrochemical cell system. The reference electrode is made of FTO glass coated with platinum because it has sufficient conductivity and heat resistance and electrocatalytic activity of triiodide reduction. TiO_2 is a photocatalyst material that has strong oxidizing power, high photostability and redox selectivity (Kalyanasundaram, 1998).

An important requirement for increasing the catalyst activity of TiO_2 is to increase the surface area of TiO_2 depending on the size of the crystal. The physical and chemical properties of TiO_2 depend on their size, morphology and crystal structure (Subbenaik, 2016). TiO_2 has three crystalline forms namely anatase, rutile, and brookite. Anatase phase TiO_2 crystals have a more active ability than rutile. Anatase is considered to be the most favorable phase of photocatalysis and solar energy conversion (Fischer et al., 2017). As shown in Figure 2.

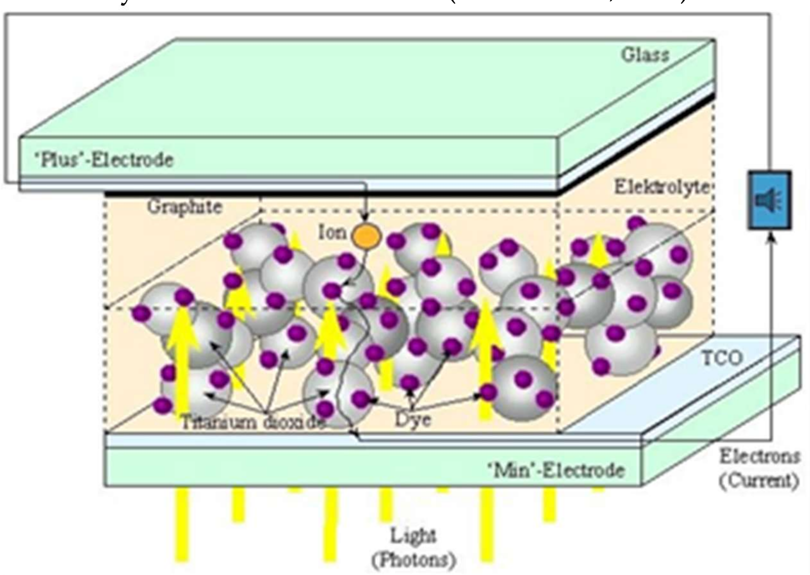


Figure 1. The structure of the Dye-sensitized Solar Cell (DSSC) (Gao, Bard, & Kispert, 2000)

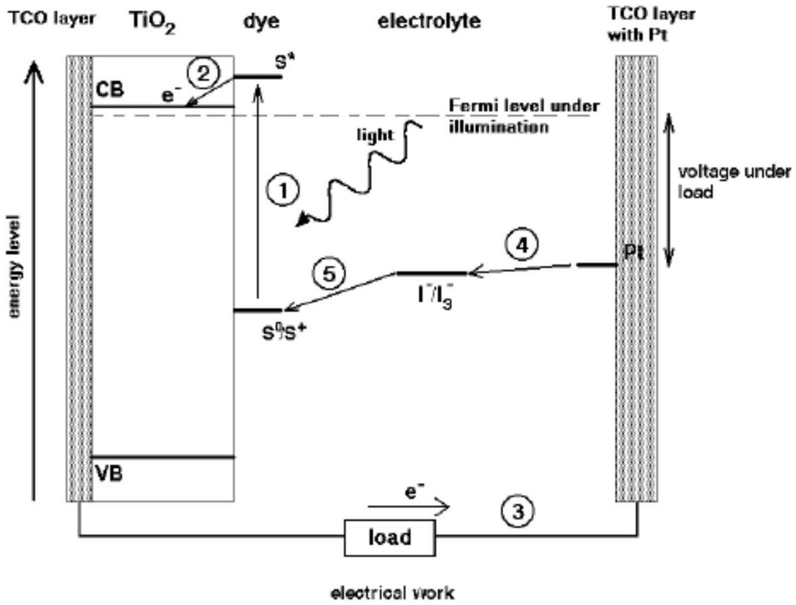


Figure 2 Working Principles of DSSC (Ma et al.,2005)

DSSC cannot be separated from Dye, therefore Dye is generally used and achieve the highest efficiency of ruthenium complex type. In addition, dye-photosintezer is an important factor in determining the performance of DSSC, such as its photosensitizer uptake properties, which directly determine the range of photoresponse of the solar cell. Dye function absorbs visible light, pumps electrons into the semiconductor, receives electrons from the redox pair in solution, and so on in a cycle, so the dye acts as a molecular electron pump. The dye must have high chlorophyll content, has strong absorption in visible areas of light, high stability and reversibility in its oxidized form. The dye used in the DSSC has a conjugated chromophore group allowing for the transfer of electrons.

Technical difficulties of developing DSSC to extend the life of the DSSC and increase the absorption of the quantity of sunlight, because organic dyes will easily decay. All questions for dye are very interesting and worthy of study (Halme, 2002). This study presents some experimental data of the carotenoid content of the Carrots that can be used as a sensitizer. The material analysis was performed on the optical and electrical properties of organic matter from Carrots. The extracts from the natural ingredients used in the study showed a similar absorbance of β-carotene in the 380-520 nm range. While the value of absorbance and optimum conductivity on the Carrots. This study aims to analyze the optical properties and to know the electrical properties of the Carrots consisting of 3 stages: the extraction of the Carrots, the measurement of the absorption of the spectrum, and the measurement of the conductivity of the extraction results. The excellence of the research than research conducted by Radwan et al., (2017) is located on the deposition technique of TiO_2 which uses techniques of spin coating thus generating a TiO_2 deposition evenly and thinly.

METHODS

Tools and Materials

The materials used in this study include glass substrate Fluorine Doped Tin Oxide (FTO), Titanium (IV) dioxide (TiO_2) nanopowder 21 nm, Polyethylene Glycol (PEG) 400, Potassium Iodide (KI), Iodine (I_2), Ethanol , Pt (Hexachloroplatinic (IV) acid 10%), Isopropanol, 70% Alcohol, and Carrots. Equipment used include digital multimeter, hot plate with a magnetic stirrer, hairdryer, ultrasonic cleaner, 10 ml, and 50 ml beaker, dropper dropped, 5 ml glass bottle, digital scales, filter paper Whatman no.42, mortar chromatography column, knife, furnace, and the spin coater.

Preparation

This preparation stage includes cleaning tools for the extraction and preparation of TiO_2 paste. The preparation process for extraction is done by cleaning the tool in the form of mortar, Fluorine Doped Tin Oxide (FTO) glass, glass bottle, beaker, and dropper with ethanol solution and using the ultrasonic cleaner to be free from materials that can not be cleaned with water only. Clean glass affects the test results of samples to be superimposed on the glass substrate.

FTO glass cleanup (Fluorine Doped Tin Oxide)

Alcohol 70% poured on the glass of chemical as much as 100 ml. The 2.5 x 2.5 cm FTO glass to be cleaned is inserted in a glass containing chemicals. Ultrasonic cleaner filled aquades to the specified limits. Chemical glass containing alcohol and FTO glass is inserted into ultrasonic cleaner at 30 minutes. After 30 minutes, the glass is dried using a hairdryer. Then measured resistance to the FTO glass using a digital multimeter.

Making of TiO_2 Nano Pasta

First step to make pasta TiO_2 is TiO_2 0.5 gram of nanopowder dissolved in 2 ml ethanol is then stirred using a stirrer vortex with a speed of 200-300 rpm for 30 minutes. The already formed TiO_2 paste is fed into aluminum foil-covered bottles and stored in a spot that avoids direct sunlight to reduce the evaporation process.

Carrots Extraction (Daucus carota)

Before to make carrots extraction, carrots cuted with small size. Then the carrots weighed using 25 grams of digital scales. Furthermore, the carrots fruit crushed and mashed using mortar. The finely ground carrots were dissolved in 125 ml of ethanol solvent with the ratio (1: 5) and then stirred for 60 minutes using a stirrer vortex with a rotation speed of 300 rpm in 60°C. After the solvent is dissolved for 24 hours and filtered with filter paper Whatman no.42. The extraction results were then chromatographed by pouring in chromatographic columns and waited until dark red extraction.

Making Working Electrode

The working electrode is made of FTO conductive glass on which the TiO_2 nano paste is deposited by the spin coating technique. In FTO glass measuring 2.5 x 2.5 cm formed an area for the deposition of TiO_2 measuring 2 x 1.5 cm above the conductive surface. The FTO side taped the tape as a barrier. The TiO_2 paste is dripped on the FTO glass that has been glued in the spinner, then in the stirrer with a speed of 200-300 rpm with a predetermined time. The coated TiO_2 FTO glass is heated using a hotplate at 500°C for 60 minutes, then cooled to room temperature. The scheme of the TiO_2 paste deposition area is shown in Figure 3.

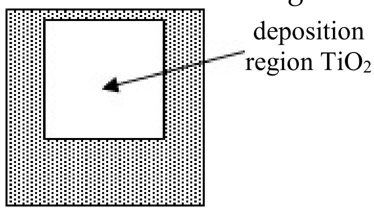


Figure 3 Schematic area of TiO_2 paste deposition

Making of Electrolyte Solution

Step making of electrolyte solution Potassium iodide (KI) of 0.8 grams (0.5 M) in solid form is mixed into 10 ml of polyethylene glycol 400 then stirred. Next to the solution was added Iodine (I_2) of 0.127 grams (0.05 M) then stirred with a stirrer vortex at 300 rpm for 30 min. The finished electrolyte solution is stored in a sealed container coated with aluminum foil.

Making of Opponent Electrode

The counter electrode is an FTO conductive glass which has been coated with a thin layer of Platinum (Hexachloroplatinic (IV) acid 10%). The steps of making the opponent electrode are 1 ml of Hexachloroplatinic (IV) acid 10% mixed with 207 ml of isopropanol and then stirred using vortex stirrer with a speed of 300 rpm for 30 minutes. The FTO glass was heated using a hotplate at 250°C for 15 minutes then spilled 3 ml of platinum solution onto the surface of the FTO glass substrate by the drop method. The glass that has been dropped platinum then cooled to reach the room temperature. The scheme of the Platinum deposition area is shown in Figure 4.

Figure 4 Platinum deposition area scheme

Dye Absorption On TiO_2 Layer

FTO conductive glass substrate which has been deposited TiO_2 layer then soaked in dye extract of Carrots for 24 hours.

DSSC Sandwich Making

The arrangement of DSSC layers of FTO glass that has been coated with TiO_2 and has been immersed in dye solution of extraction result is called the working electrode. The working electrode is dropped by an electrolyte solution and then covered with a platinum coated glass called the opposing electrode. Then the DSSC arrangement is clamped with a clamp on both sides of the right and left so as not to shift. The finished DSSC results are shown in Figure 5.

Figure 5 Results of DSSC Compilation

Natural Dye Extraction

The study used ethanol solvent to dissolve the carotenoid extracted from the natural material of the carrots. The ingredients to be extracted were cleaned with water, then as much as 25 grams of Carrots smoothed and after finely mixed 50 ml of ethanol stirred for 60 minutes 200 rpm using a magnetic stirrer at room temperature. After stirring and then stand for 24 hours and filtered using Whatman no filter paper. 42. After filtration, the solution is stored in a sealed container and protected from sunlight.

Absorption Analysis

A spectrophotometric method was used for the simultaneous determination of β-carotene (Radwan et al., 2017). The spectrophotometric method shows potential for β-carotene analysis because Pigments can absorb radiation in the visible region (Kalyanasundaram & Gratzel, 1998). The content of each extracted material was analyzed using Spectrophotometer UV Visible Shimadzu 1601 PC to determine the absorbance properties of the material. The wavelength range of absorption spectrum analysis in visible light is 300-800 nm. from the result of measurement of absorbance characteristic then known the type of dye content from natural material.

Material Conductivity

The conductivity measurements using Elkahfi 100 / IV-Meter were performed in a dark state by covering all parts of the container using aluminum foil and under irradiation using a 100 W halogen light source and an energy intensity of 680.3 W / m^2. Halogen lamps are used because they have a full spectrum that resembles visible light with sunlight. From the result of measurement of I-V then determined conductivity (σ) various material. To determine the conductivity of the organic solution can use the equation:

$$\rho = \frac{RA}{l} \quad (1)$$

$$\sigma = \frac{1}{\rho} = \frac{l}{RA} \quad (2)$$

Where σ is the conductivity ($ohm^{-1}.m^{-1}$), R is the resistance (Ohm), l is the distance between the two electrodes (m) and A is the cross-sectional surface area of the electrode (m^2).

RESULTS AND DISCUSSION

Research using natural ingredients to produce the carotenoid extract from the carrots extracted using ethanol with a fixed ratio of 1 gram of natural materials 2 ml of solvent. Then tested the absorbance using Spectrophotometer UV Visible Shimadzu 1601 PC and determined the Voltages using I-V meter / elkahfi 100 from I-V can be seen the value of dye conductivity made from the carrots.

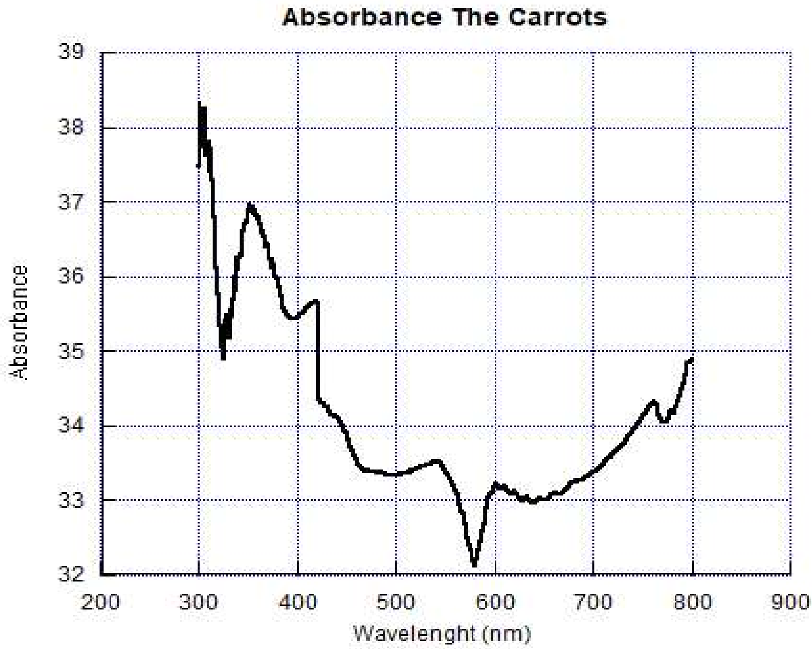
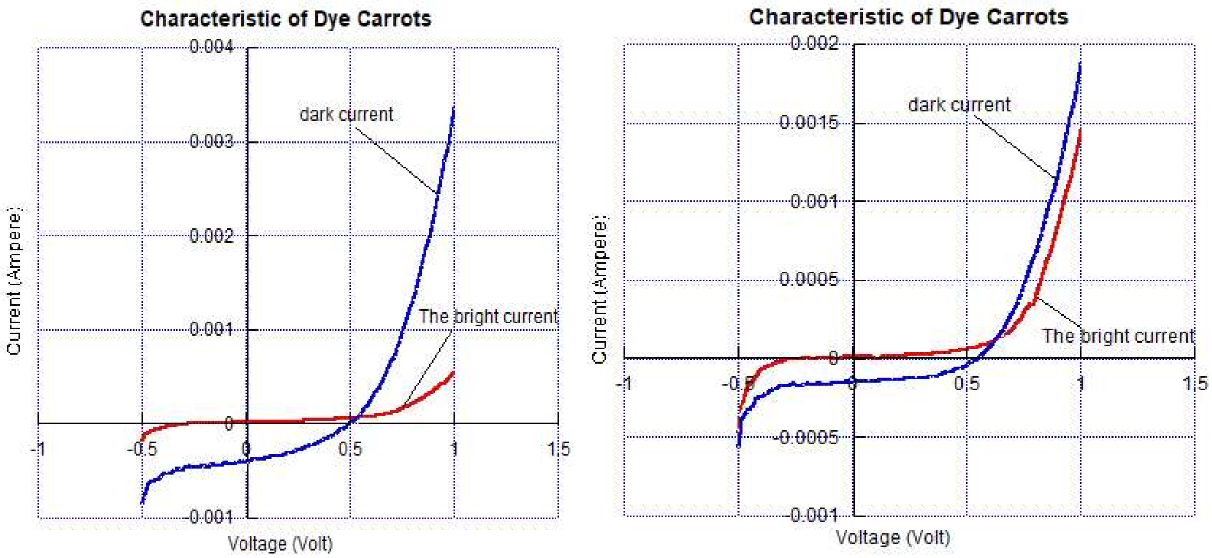


Figure 6 The absorbance of extract Carrots using Spectrophotometer UV Visible Shimadzu 1601 PC.



(a) (b)

Figure 7 Keithley test results with (a) ethanol solvent, and (b) acetone solvent

Table 1 Resistivity (Ohm), Conductivity ($Ohm^{-1}m^{-1}$), and Flow (mA) of Carrots.

Organic Materials	Condition	R(Ohm)	Σ ($Ohm^{-1}m^{-1}$)	I (mA)
Carrots	Dark	5.0×10^{9}	6.23×10^{-6}	3.27×10^{-5}
	Bright	6×10^{8}	3.54×10^{-5}	4.48×10^{-5}

Table 2 Carrots Efficiency

Method	Imax (A)	Vmax (V)	Isc (A)	Voc (V)	Fill Factor	Efficiency (%)
Ethanol solvent	0.00011	0.355	0.00014	0.565	1.02×10^{-8}	0.021
Acetone solvent	0.00047	0.160	0.00041	0.385	7.98×10^{-8}	0.037

Based on Figure 6, the absorbance of the Carrots dye shows a considerable wavelength, with a sufficiently high absorbance ability, which allows the Carrots to absorb good sunlight and maximize the performance of the DSSC (Ni et al., 2005). Figure 6 shows that a fixed ratio between Carrots extracts yields different absorbance values from both methods. Figure 6 also shows the dye spectrum of the peel of the Carrots having an absorption spectrum similar to β-carotene, which has a major absorption wave at 310-540 nm, with a successive wave peak 310 nm, 350 nm, 412 nm, and 540 nm (Supriyanto et al., 2007).

The conductivity value of the Carrots can be presented in Table 1. Table 1 can be determined that the current in the bright state is greater than in the dark. While the conductivity is greater in the dark than in the light. DSSC was tested electrically with a Keithley 2602A measurement system. The results of current and voltage tests are shown in Figure 7. Based on the graph of Keithley test results in Figures 7, we can determine the current (I_{sc}) and voltage (V_{oc}). So based on calculations that have been done the efficiency of Carrots, shown in Table 2.

From table 2, it can be seen that the efficiency produced by DSSC for Carrots with acetone solvent is greater than with ethanol solvent. This shows that with the use of solvent variation is almost equally affect the efficiency of the, where the spin coating method has a flat layer and makes the electron transfer fixed, then the resulting efficiency is greater (Hardani, Cari, & Supriyanto, 2018).

CONCLUSION

The measurement and analysis of the absorption spectra of natural dye extract of Carrots have been done with the ratio of the mass of natural materials and the volume of solvent is kept steady. The results showed that the dye extracted from the natural material has an absorption spectrum similar to that of β-carotene having absorption at wavelengths between 310 - 540 nm and a wave peak with a successive wave peak 310 nm, 350 nm, 412 nm, and 540 nm. Measurement I-V Meter / Elkahfi used the same voltage source of 9 volts produces an electric current from the extract Carrots. The current in the dark gives 3.27×10^{-5} mA, while under irradiation gives 4.48×10^{-5} mA. Measurements of the I-V meter also show the conductivity value of the extract of Carrots in the dark is 6.23×10^{-6} $Ohm^{-1}.m^{-1.}$ The conductivity under irradiation is 3.54×10^{-5} $Ohm^{-1}.m^{-1}$. Electrical current and conductivity measurements produced by Carrots extracts, this makes the Carrots necessary for further investigation as a DSSC sensitizer.

ACKNOWLEDGMENT

The researchers would like to thank the managers of the Mathematics and Natural Sciences Laboratory of UNS Surakarta and the support of the LPPM Research Grants for Beginner Lecturers (PDP) with Contract Number. T/140/E3 /RA.00 / 2019.

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