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APPROACH OF TEACHING ABOUT PHOTOVOLTAIC CELL IN HIGH SCHOOL*

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Abstract. Nowadays, an imperative problem is to improve the use of green energy. We are considering that the students from high school must be familiarized with renewable energy sources and devices that use green energy. That is why we present here some aspects concerning the study, in the high school, of the photovoltaic cells as alternative to produce energy by directly conversion of the solar light in electricity.

Key words: solar cells, photovoltaic effect, education, solar radiation, green energy, conversion efficiency, solar devices.

1. INTRODUCTION: WHY TO TEACH ABOUT THE SOLAR CELLS ?

The world's population uses 14 TW of power today and we will need ~ 30 TW of power in 2050. But, much of the extra 16 TW must be provided without releasing carbon dioxide into the atmosphere [1].

On the other side, a few hundred years ago it was found that the electricity is produced if sunlight falls on a thin layer of selenium. But the conversion efficiency was low (as low as 0.6 %). Solar cells were not popular for a long time because of its low efficiency.

They were developed for special use in the 1950s as part of the space program. They converts solar energy directly into electrical energy, which is stored in the rechargeable battery and used for various applications as lights, appliances, street lights, sine boards, and others. The battery can also be used to feed the motor which runs the vehicles.

Today, the mankind efforts are being made to obtain more and more renewable energy in order to reduce our dependency on the fossil fuels and the pollution created by them [2]. The Sun radiates energy in the form of heat and

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light. We utilize these forms of energy either directly or indirectly, after conversion into some other forms. Besides the primary role of the Sun's energy, it is now believed that elements have been formed from hydrogen by the process of nuclear fusion occurring in stars, similar to the sun. In that sense, everything that we see around us, including ourselves and the uranium used as nuclear fuel are products of the star-dust. Hence, stars in general and our sun in particular, are the ultimate source of energy.

The light could be converted in electric energy by using photovoltaic (PV) cells. If one examines the operating principle of the solar cells, the processes found resemble photosynthesis and are almost as old as the Earth itself [3].

The plants convert the light in chemical energy during the photosynthesis. This is a complex process by which the cells containing chlorophyll in green plants convert incident light to chemical energy and synthesize organic compounds from inorganic compounds, especially carbohydrates from carbon dioxide and water, accompanied by the simultaneous release of oxygen. Photosynthesis, meaning “putting together by light”, is the process by which almost all plants, and some bacteria harness the energy in sunlight to produce sugar (and oxygen as a byproduct). The conversion of light energy into chemical energy is dependent on the substance chlorophyll, a green pigment that bestows upon plant leaves their green appearance. Not all plants have leaves, but the ones that do are very efficient at converting solar into chemical energy. As such, leaves can be thought of as biological solar collectors, equipped with numerous tiny cells that carry out photosynthesis on a microscopic level [3].

The PV cells generate electricity directly from the solar energy, an important type of renewable energy source, without needing any intermediary device. Is there any similarity between a green leaf and a solar cell? [4] We have enough sun to study them!

Because of the global warming and its geographic location, Romania has a good solar potential of 210 sunny days per year and an annual solar energy flux between 1,000 kWh/ m^2/year and 1,300 kWh/ m^2/year [5].

2. HOW TO TEACH ABOUT THE SOLAR CELLS?

The Physics teacher has to answer the following challenge: how the fundamentals of photovoltaic (PV) can be taught at a general level, to students who might have minimum (or even zero) background in semiconductor physics or electronics. Indeed, it is shown that PV effect mechanism can be explained in similar terms as the photochemical conversion mechanism, including photosynthesis and the dye-sensitized solar cell [4].

The Romanian Physics curriculum contains the fundamentals of semiconductors in the 12-th grade, with no reference to the PV cells. We are considering that such devices have to be studied in high school. There are

European projects which developed a teaching module suitable for 16-18 year olds studying Physics at advanced level in the area of Renewable Energy, principally photovoltaics [6]. We have tried also to teach about solar cells within an experiment suitable for 16-18 year olds studying and performed at the Grigore Moisil High School, from Bucharest. We have to mention that they have a real formation with the informatics specialization. And also, we have to say that the students from the 10-th grade have studied the conduction in metallic conductors, the Current-Voltage (I-U) characteristics of the resistors, light bulbs and direct current sources. Students are familiar with the PV cells used in most calculators. In fact some students may wish to try some innovative applications of the PV cells. More possible future PV applications can be discussed with students.

We have treated the PV cell as an electric source and we proceed to obtain its I-U characteristics. The two PV cells, buy from a specialized store (Fig. 1), were linked together in series with a variable load resistor as one can see in Fig. 2. The ammeter and the voltmeter were connected as usual.

Fig. 1– The solar cells.

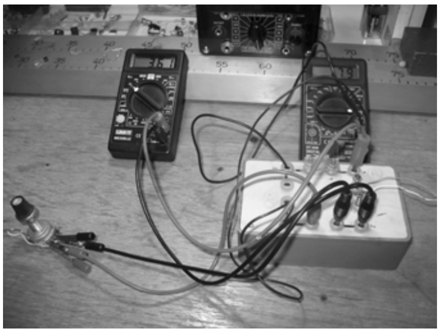


Fig. 2 – The resistor and the meters.

This experimental set-up was introduced in an electronic lesson from the AeL (Electronic assistant for high schools), as you can observe in Fig. 3. The name of the lesson was Power of the home appliances. We have considered that we already have solar home appliances as recharges, solar cookers. It is a good reason to explain the students how the solar cells are working. We will begin by reading the meters indications, the current and the potential, for each value of load resistor, drawing then the I-U characteristics in fourth quadrant where the cells run in regime of a photo element.

3. EXPECTED OBSERVATIONS FROM THE STUDENTS

Students should see the effects of the light intensity and of the different light wavelengths on the PV cell and of the cell temperature. Voltage readings will be larger when more light is absorbed. Readings should be smaller when the PV cell is cold, though this temperature effect may be too minor to observe on a small scale. The PV cell should remain dry. The decreasing angles from the sun (light source) result in lower readings.

Puterea celulei fotovoltaice

Celulele fotovoltaice generează curent continuu.

Puterea electrică a celulelor fotovoltaice se calculeaza ca produs dintre tensiunea U si intensitatea curentului electric I,

P=U·I

Pentru o valoare a tensiunii U=0,5V si o intensitate a curentului electric generat I=2A, puterea asigurată de o celulă din Si de 100cm va fi:

P=0,5·2=1W.

Această valoare redusă a puterii, subliniază necesitatea de a lega mai multe celule fotovoltaice în serie, pentru a se obţine panouri fotovoltaice capabile să asigure o putere electrică semnificativă.

Clic pe butonul Play pentru a vizualiza următorul cadru din experiment.

Fig. 3 – The electronic lesson AeL.

The data was gathered in a datasheet as the one from the Fig. 4. The *I*-*U* characteristic for a PV cell based on an ideally p-n junction in the light is given by the Shockley equation [7, 8]:

$$I = I_0[\exp(qU/k_BT) - 1] - I_L, \tag{1}$$

where: I_0, q, k_B, T and I_L, are the reverse saturation current, electronic charge, Boltzmann constant, absolute temperature and photocurrent, respectively.

The dark *I*-*U* characteristic for the linked PV cells is shown in Fig. 4. The cells where placed in a dark box and they where connected with a DC power supply. The conclusion is that the solar cell in the dark is acting like a diode. It is non-linear, highly asymmetric, and completely different from the linear *I*-*U* characteristic of a resistor, well known by the students from the 8-th and the10-th grade.

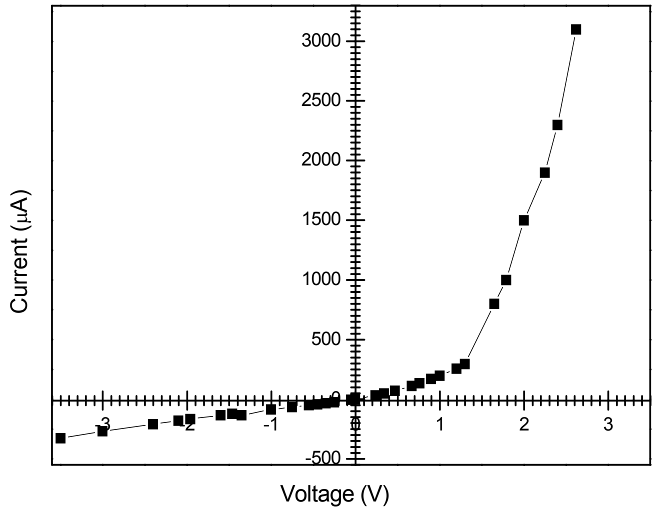


Fig. 4 – The dark *I-U* characteristic of the linked PV cell at room temperature.

According with equation (1), the current under illumination is in opposite direction than the current flowing through the p-n junction in forward bias (Fig. 5).

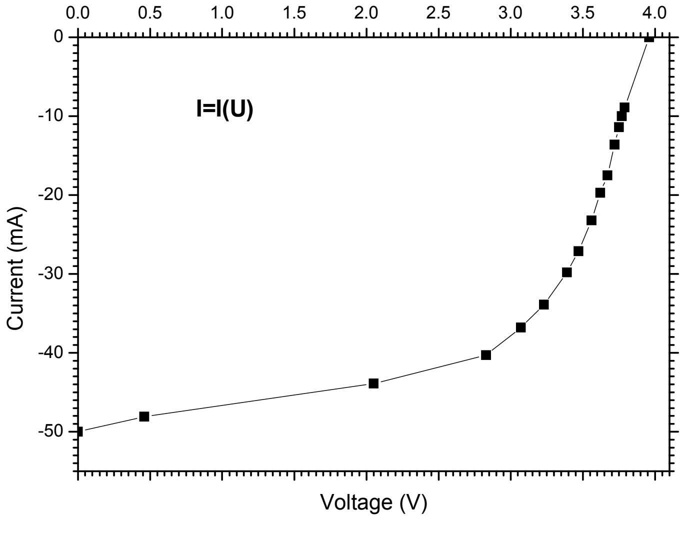


Fig. 5 – The *I-U* characteristic of the linked PV cell under illumination at room temperature.

The students can see that this characteristic is very different from the other one they know. This is the usually plot if they want to extract the cell parameters as photo element: open-circuit photo voltage (U_{oc}), short-circuit photocurrent, fill factor (*FF*) and integral conversion efficiency η [9].

In Fig. 5, the students recognize the open circuit voltage, U_{oc} =3.96V and the short circuit current I_{sc} =50 mA. The attempt to represent the generated power *versus* potential illustrates the graphic in Fig. 6.

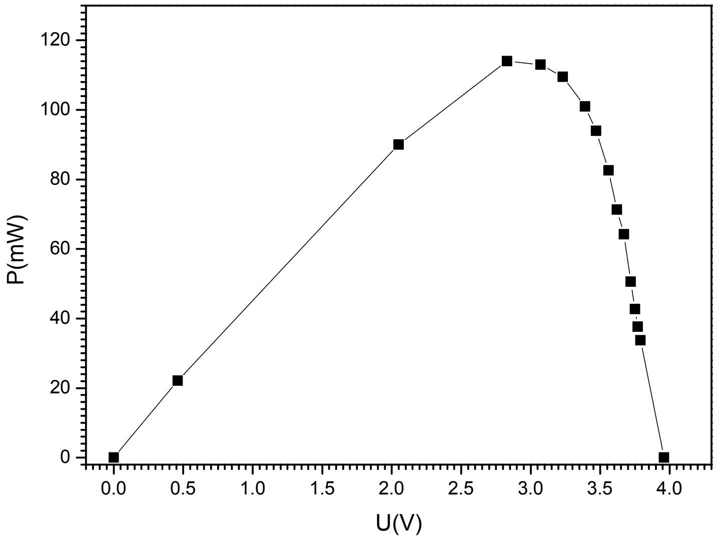


Fig. 6 – The power of the solar cells.

One can see that the increase of the resistive load on an irradiated cell continuously from zero, which means the short circuit, to a very high value, that means an open circuit, we can determine the maximum-power point. This represents the load for which the cell can deliver maximum electrical power at that level of irradiation. The output power is zero in both the short circuit and open circuit extremes. The value of the maximum generated power is P_{max}= 114.05mW. The fill factor *FF*, is the ratio of the maximum power point divided by the open circuit voltage U_{oc} and the short circuit current I_{sc} [10]:

$$FF = \frac{P_{\max}}{U_{oc} \cdot I_{sc}} \tag{2}$$

The calculated fill factor *FF*, of our group of solar cells is ~0.6.

4. THE EXPERIMENTAL ACTIVITY OF THE STUDENTS

The students can use a data acquisition system for registering the current and the potential of the PV cells extracted from a battery charger under illumination. The experimental set-up is shown in Figs. 7 and 8.

Fig. 7 – The experimental set-up.

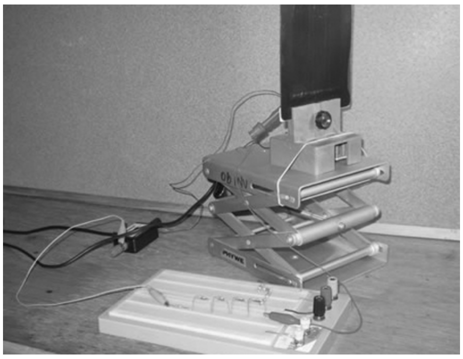
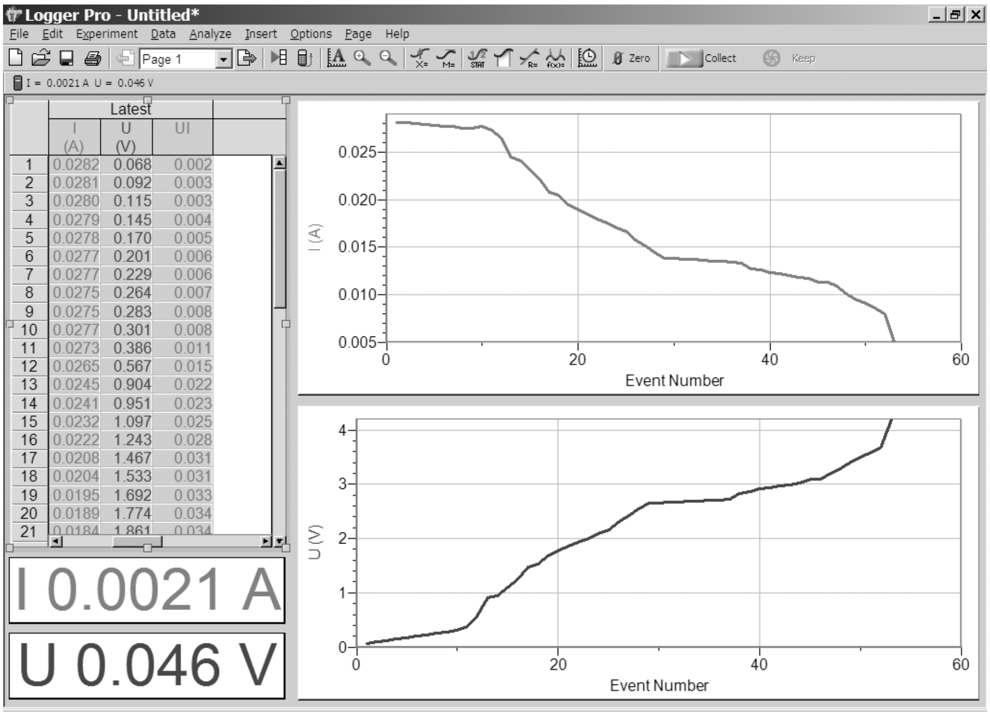


Fig. 8 – The resistive load.

The data acquisition board is LabPro from Vernier and the ready-made software is Logger Pro [10]. The registered values for current and voltage, at different load of the solar cell are illustrated in Fig. 9.



I = 0.0021 A U = 0.046 V

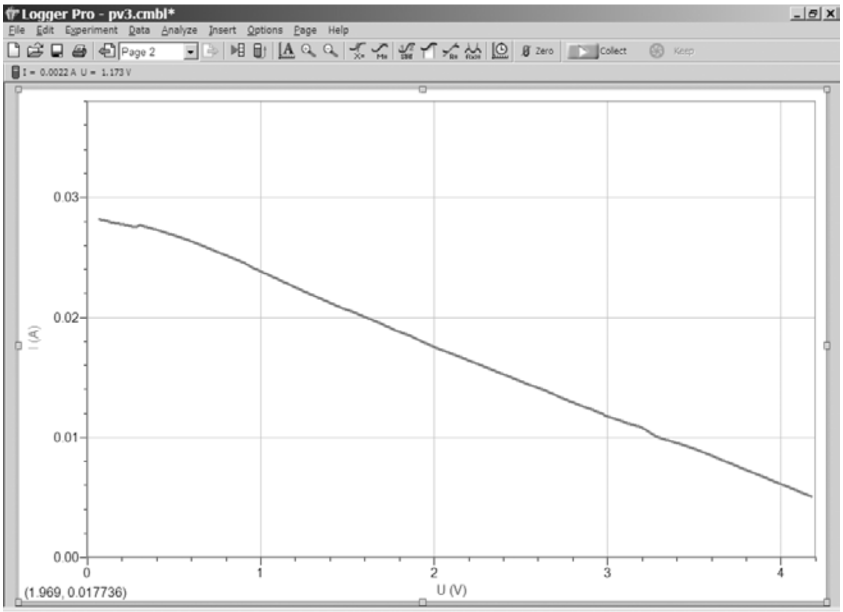
	Latest		
	I (A)	U (V)	UI
1	0.0282	0.068	0.002
2	0.0281	0.092	0.003
3	0.0280	0.115	0.003
4	0.0279	0.145	0.004
5	0.0278	0.170	0.005
6	0.0277	0.201	0.006
7	0.0277	0.229	0.006
8	0.0275	0.264	0.007
9	0.0275	0.283	0.008
10	0.0277	0.301	0.008
11	0.0273	0.386	0.011
12	0.0265	0.567	0.015
13	0.0245	0.904	0.022
14	0.0241	0.951	0.023
15	0.0232	1.097	0.025
16	0.0222	1.243	0.028
17	0.0208	1.467	0.031
18	0.0204	1.533	0.031
19	0.0195	1.692	0.033
20	0.0189	1.774	0.034
21	0.0184	1.861	0.034

I 0.0021 A

U 0.046 V

Fig. 9 – The registered values for the current and the voltage, for the different load.

Using this software, the students represent the *I-U* characteristics of the solar cell as it is illustrated in Fig. 10.

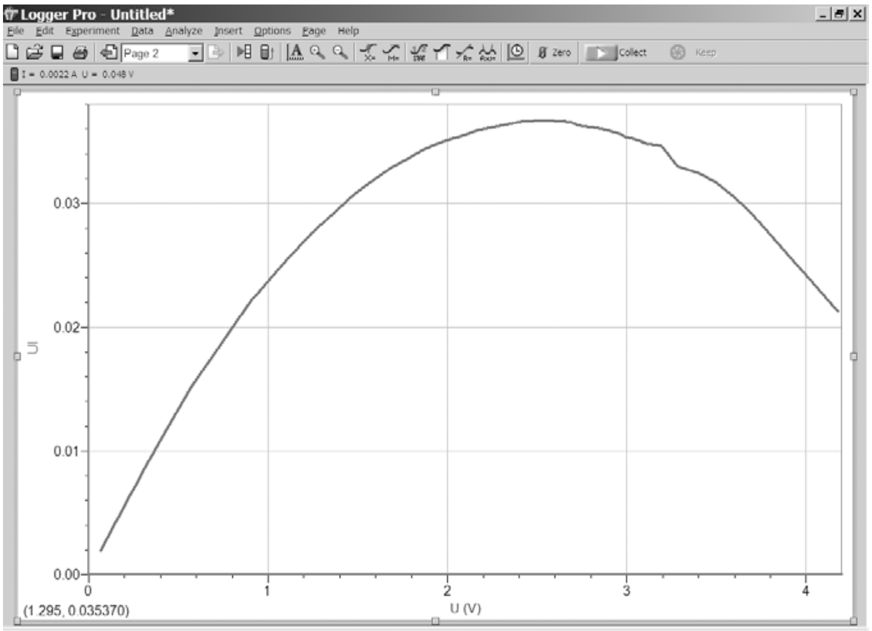


I = 0.0022 A U = 1.173 V

(1.969, 0.017736)

Fig. 10 – The *I-U* characteristic for the solar cell.

The generated power *versus* the voltage is represented in Fig. 11.



I = 0.0022 A U = 0.048 V

(1.295, 0.035370)

Fig. 11 – The generated power *vs*. voltage.

A new challenge is to find the conversion efficiency of light in electricity. A PV cell energy conversion efficiency η is calculated using the ratio of the maximum power point, P_{max}, divided by the input light irradiance E [W/m^2] under standard test conditions (STC means a temperature of 25°C and an irradiance of 1,000 W/m^2) and the surface area of the solar cell S [m^2], [11]:

$$\eta = \frac{P_{\max}}{E \cdot S}, \tag{3}$$

For this action we need to measure the input light irradiance *E*. This is the aim of another lesson.

5. WHAT HAPPENS INSIDE THE SOLAR CELL?

Solar cells are composed of various semiconductor materials, which become electrically conductive if they are supplied with light or heat, but which operate as insulators at low temperatures [12].

In order to produce a solar cell, based on a p-n junction, a semiconductor wafer must be doped to change its conductivity at last one time. Doping is the intentional introduction of chemical elements, in order to obtain a surplus of either positive charge carriers (p-type conductivity semiconductor where the majority charge carriers are the holes) or negative charge carriers (n-type conductivity semiconductor where the majority charge carriers are the electrons). At the interface between the two regions with different conductivities across of the semiconductor wafer, appears a so-called p-n-junction.

At this junction, a depletion layer is built and across it appears an internal electric field which leads to the separation of the photo generated charge carriers. When the cell is illuminated, electron-hole pairs are produced by the interaction of the incident photons with the atoms of the cell. The internal electric field separates the electron – hole pairs, the electrons moves in opposite direction of the internal electric field in n- part of the junction, and the holes moves in same sense with the internal electric field being collected to p-part of the junction. Due to this polarization, during the illumination an open circuit voltage could be measured between the terminals of the cell. If the outer circuit is closed, by a load resistor, then a direct current flows through it [13, 15]. The next image is a print screen from an animation introduced in the AeL lesson. The students could see what happens in the semiconductor if the light hit it.

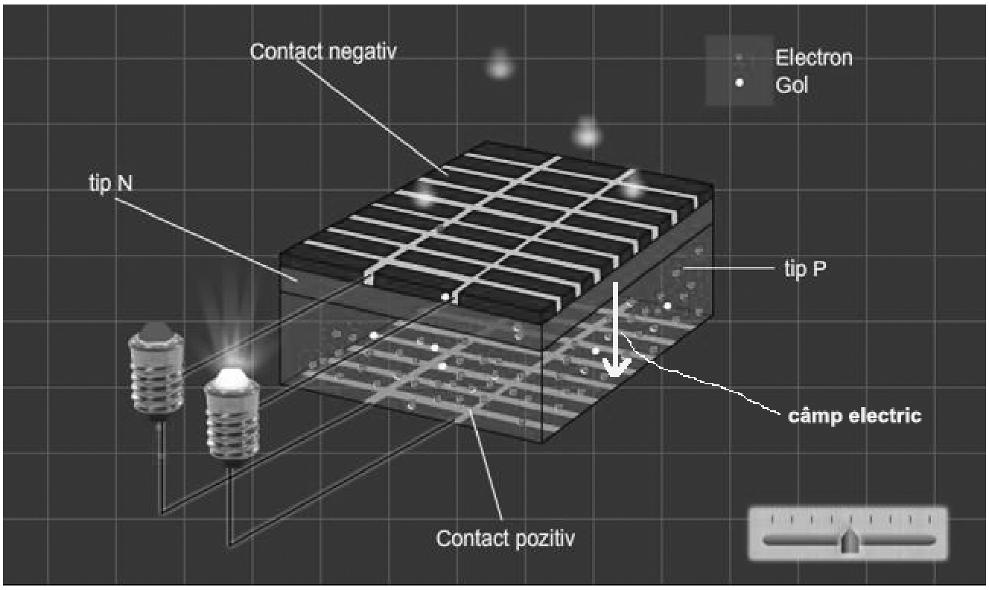


Fig. 12 – The inside of the photovoltaic cell.

6. WHAT ARE THE BENEFITS OF THE SOLAR POWER USING?

The students have to find some important benefits of the solar cells (SC). One important area is the cars industry. The electricity generated by solar cells is used to run the motor. In the next future we will see on roads the cars running only on solar energy, an important form of renewable energy available abundantly and freely.

Some solar devices as: electric cars with a recharge station, solar houses, solar elevators, solar fans, etc will be soon encountered in our daily life. We have to mention that these solar devices can be made mostly with recycled materials, excepting perhaps the solar cells.

Figures 13 and 14 illustrate some of these devices.

7. ASSESSMENT

We have tried to be objective, so we have choose to test our students by using an adapted Multiple Choice Questioner made for the grade 9 by some colleagues from Texas [14]. The 10 items of this test were grouped to serve the educational objectives that will prove the opportunity of this act of teaching. At the end of the lesson the students will be able to:

1. explain how the photovoltaic works.

2. investigate, describe, and compare the impact of the technological innovations.
3. collect, gather, record and represent the experimental data.
4. make wise decisions in order to conserve the resources and to preserve the Nature.

Fig. 13– The solar car.

Fig.14 – The eco-house.

After the evaluation of the tests, the ratio of touching the objectives was (Table 1):

Table 1

The results of the accomplishment of the educational objectives

No	Educational Objective	Number of correct answers from total	Ratio	Accomplishment
1	Obj1	19/26	73%	yes
2	Obj2	16/26	67%	yes
3	Obj3	19/26	73%	yes
4	Obj4	21/26	80%	yes

The practical test for the students was to study themselves, the dependence on the distance from the light source of the voltage generated by the group of four PV cells, linked in series. The experimental device is illustrated in Fig. 15.

Fig. 15 – The students during the practical test.

The students have accomplished the Educational Objective no 3. The graphical representation of the voltage *vs*. the distance between the PV cells and the light bulb is illustrated in Fig. 16.

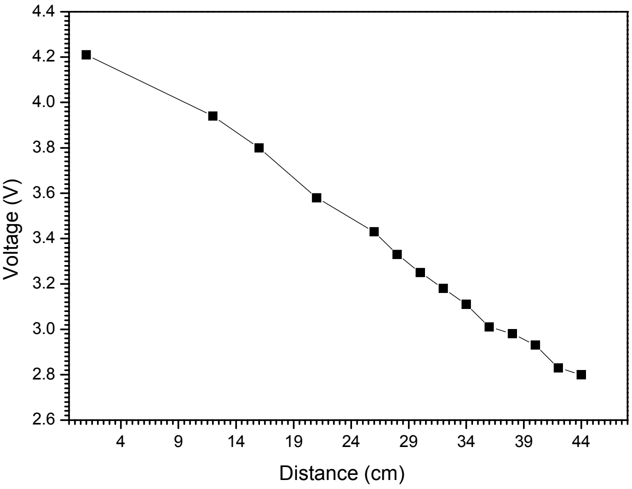


Fig. 16 – The voltage *vs*. distance.

8. CONCLUSIONS

We have to mention that our work referring to the opportunity of introduction the PV cells study in high school was developed outside the school program. The students agreed to participate in this special project and we know they do all the best for succeed to learn about PV cells.

The great challenge for a Physics teacher is to motivate the students themselves. Consequently, we consider that our students were very motivated to learn and to work with PV cells. They have many eco-ideas developed during this special activity. They were also materialized by using recycled materials.

Our initiative is accordingly to the European policies referring to the photovoltaic education [6], so we hope that the National Committee for Physics will do the best for restructure the National Curriculum for Physics.

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