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INTERDISCIPLINARY TEACHING OF A LIGHT-BASED BIOLOGICAL PROCESS: PHOTOSYNTHESIS

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The interdisciplinary study of light propagation and interaction with different environments can be performed to Physics classes and also in related disciplines such as Science discipline classes. The interdisciplinary approach ask the teacher to have knowledge of both specialized disciplines and related fields, very well mastered, to observe and explain complex phenomena of nature that lends itself to such studies.
Keywords: light, interdisciplinary, photosynthesis, physics, sciences

Studiul interdisciplinar al propagării luminii şi interacţiunii acesteia cu diverse medii poate fi realizat la orele de fizică, dar şi la discipline înrudite din liceu, cum ar fi disciplina Ştiinţe. Abordarea interdisciplinară a subiectului solicită profesorului să aibă cunoştinţe din aria mai multor discipline şi domenii înrudite, pe care să le stăpânească foarte bine pentru a observa şi explica fenomenele complexe ale naturii ce se pretează la acest mod de abordare.
Cuvinte-cheie: lumină, interdisciplinar, fotosinteză, fizică, ştiinţe

INTRODUCTION

In middle school, in biology classes, only a a few simple concepts about photosynthesis are introduced because students do not have chemistry concepts necessary to address this complex process.

In high school, also to Biology discipline, students meet the concept of photosynthesis in the Xth class, chapter "fundamental structure and functions of living organisms", when to the Autotrophic nutrition section they study the following aspects of photosynthesis process: chemical equation, the stages of photosynthesis (without the intimate mechanism of photosynthesis); highlighting photosynthesis (by CO_2 absorbed, by organic matter produced and by O_2 produced); importance; role of assimilating pigments (chlorophyll a and chlorophyll b) [1].

From the analysis of contents related to photosynthesis taught in the classroom at Biology, is noted that at the Xth classroom level does not enter into details on the mechanism of this process and is only specified stages of process progress and main issues, the photosynthesis taking place in two phases, interdependent: one to light and another in the dark.

THEORETICAL AND METHODOLOGICAL ASPECTS ON INTERDISCIPLINARY STUDY OF PHOTOSYNTHESIS

Under the action of light, plants convert minerals from water and carbon dioxide from atmosphere into organic matter and the oxygen is released. In the process of photosynthesis is used only 1% of incident light on the leaves (Fig. 1).

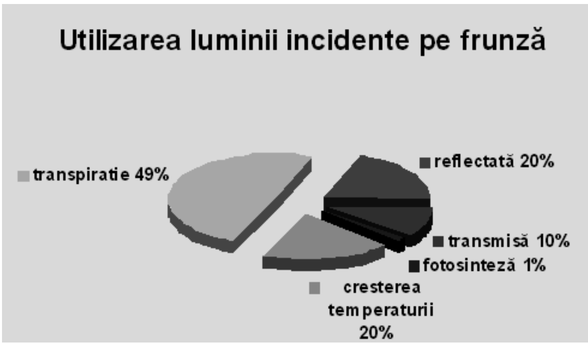

Fig. 1. Percentage of using of incident light on the leaves

In order to approach in the interdisciplinary manner the photosynthesis mechanism, should be examined in more detail the light and dark phases of process and the teacher should state that:

- the light phase – called Hill phase, is the process where reactions take place under the incident light and assimilating pigments, processes taking place in the chloroplast granum and assuming: entering CO_2 into chloroplasts; absorption of light energy; converting light energy into chemical energy;

- the dark phase - Blakman phase, is the phase that occurs in the absence of light, depending on the temperature and a number of enzymes involved in chloroplast stroma.

The interdisciplinary study class of XII^{-th} requires only describing the processes occurring in the light phase. For this, based on the literature, it is considered that there are two photosystem inside of thylakoid membranes, I and II, which operate in series connection, each containing about 300 pigment molecules called photoreceptors antennas that are designed to receive electromagnetic radiation and transmit incident photon energy to the reaction center represented by the *chlorophyll molecule* a_{700} so called because it has absorption maximum radiation in the wavelength range of 700 nm and respectivelly *chlorophyll molecule* a_{680} that absorbs radiation in the wavelength range of 680 nm [2, 3].

The processes suffered by the chlorophyll molecules from the photosystems I and II are:

- After absorption of a single photon energy, *chlorophyll molecule* a_{700} of photosystem I reaction center passes in excited state;
- Chlorophyll molecule a_{700} of the photosystem I reaction center undergoes an oxidation process, releasing the electron from the excited state, the electron finally reach ferredoxin molecule that reduced.
- Ferredoxin releasing the electron to the $NADP^+$, which, in the presence of protons resulting from photolysis of water, forms a strong reducing substance (nicotinamide adenine dinucleotide diphosphate):

$$2H^+ + 2e^- + NADP^+ \rightarrow NADPH + H^+ .$$

- Chlorophyll a_{680} from photosystem II, absorbing one incident photon energy, passes in the excited state, then gives up the electron in the excited state out of the chlorophyll molecule a_{700} via a chain of electron-transporting substance and finally recover an electron from the water which is decomposed by photolysis [4, 5].

It should be made clear that at the high school, can not analyze in detail such a complex process as is photosynthesis. From the analysis of the mechanism of photosynthesis process is observed that it can be easily explained and understood at the XII^{-th} class, after students have assimilated a series of physics notions (hypothesis of Planck, Bohr's model, energy levels and excitation-relaxation processes, emission spectra and absorption) and a series of Chemistry knowledges about the processes of oxidation and reduction. To facilitate the understanding of the mechanism of light phase of photosynthesis process described above, can use a series of sketches and drawings in which suggestive images, shown the steps described above (fig. 2).

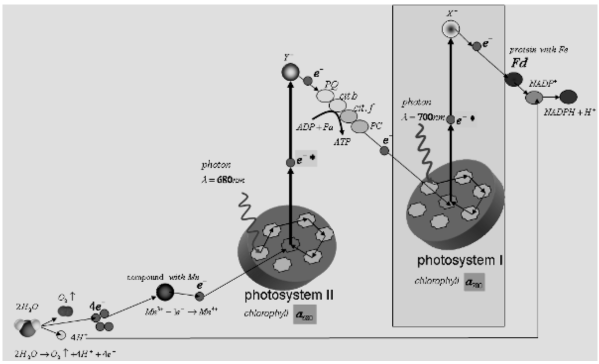

Fig. 2. The light phase of photosynthesis

This mechanism can be implemented in a specific schematic diagrams of XII^{-th} Physics course, the transitions experienced by different systems or molecules are represented by with energy levels [6] (Fig. 3).

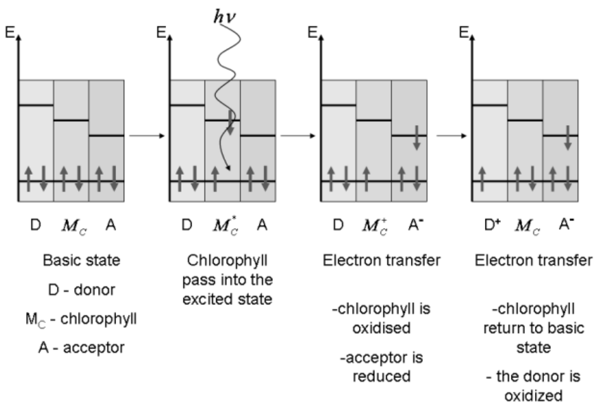

Fig. 3. Explication of photosynthesis using energy level schematic diagrams

As regards the the intimate mechanism of the process of photosynthesis, it consists of a series of reactions that occur under the action of light, which are called photochemical reactions, molecules passing from the ground state to higher energy states, called excited states, naming the activation process. Such reactions can be described by the following diagram (fig. 4) [7].

$$M_1 + \gamma \rightarrow M_1{}^*$$
$$\downarrow$$
$$M_1{}^* \rightarrow M_1^+ + e^{-*} \qquad oxidation$$
$$\downarrow$$
$$M_1^+ + e^- \rightarrow M_1 \qquad reduction$$
$$M_2 + \gamma \rightarrow M_2{}^* \qquad \Uparrow$$
$$\downarrow \qquad \Uparrow$$
$$M_2{}^* \rightarrow M_2^+ + e^{-*} \qquad oxidation$$
$$\downarrow$$
$$M_2^+ + e^- \rightarrow M_2 \qquad reduction$$
$$\Uparrow$$
$$\Uparrow$$
$$compound \quad with \quad Mn$$
$$\Uparrow$$
$$2H_2O \rightarrow O_2\uparrow + 4H^+ + 4e^-$$

Fig. 4. Mechanism of photochemical reactions

In fig. 4:
M is the ground state;
M^* is the activated chlorophyll molecule, in excited state;
$e^-{}^*$ is an electron with high energy potential;
γ is the photon producing excitation of molecule, photon energy calculated with relation: $\varepsilon = h\nu$,
where $h = 6{,}6\cdot 10^{-34}\, J\cdot s$ - Planck constant,
ν - the frequency of the incident electromagnetic radiation.

The above scheme is also found in the XII-th classroom manual, below shows the interaction of electrons with atoms (

Fig. 5) or photon-atom interaction (fig. 6) [8].

$$e^- + A \rightarrow e^- + A \qquad elastic \quad collision$$
$$e^- + A \rightarrow e^- + A^* \qquad excitation$$
$$\downarrow$$
$$A^* \rightarrow A + photons \qquad spontaneous \quad deexcitation$$
$$e^- + A \rightarrow A^+ + e^- + e^- \qquad ionisation$$
$$A^+ + e^- \rightarrow A + photons \qquad capture \quad of \quad an \quad e^-$$

Fig. 5. The interaction of electrons with atoms

$$\gamma + A \rightarrow \gamma + A \qquad elastic \quad collision$$
$$\gamma + A \rightarrow \gamma + A^* \qquad excitation$$
$$\downarrow$$
$$A^* \rightarrow A + fotoni \qquad fluorescent \quad deexcitation$$
$$A^* \rightarrow A + \gamma \qquad resonant \quad fluorescent \quad deexcitation$$
$$\gamma + A \rightarrow A^+ + e^- \qquad ionisation$$
$$A^+ + e^- \rightarrow A + fotons \qquad capture \quad of \quad an \quad electron$$

Fig. 6. The interaction of photons with atoms

After absorption of a photon, an electron from the molecule of chlorophyll moves on a higher energy level.

In the study of chlorophyll molecule excitation are taken into account two excitation energy levels, which determine the presence of two main lines of absorption.

Ground state is the state denoted S_0 where the e molecule is in thermal equilibrium with the environment, and pairs of electrons into occupy the lowest energy orbitals in its atoms.

Under the influence of radiation in the red area of the visible spectrum, electrons can pass onto the level S_1 and under the influence of higher energy blue radiation can pass on S_3 level, or otherwise chlorophyll molecule passes into excited states (Fig. 7).

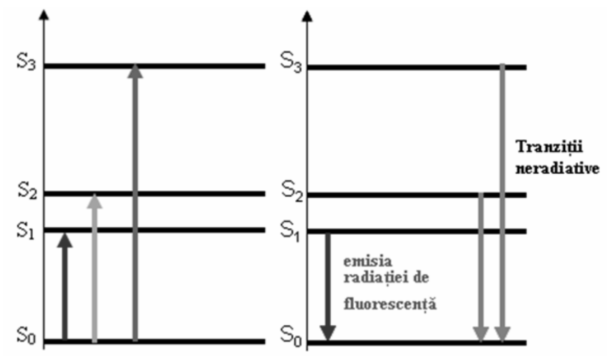

Fig. 7. Processes of excitation and relaxation

After expiring time in the excited state, the molecule of chlorophyll is relaxated and go in the ground state, a process that may or may not be accompanied by emission of light:

- transition $S_1 \rightarrow S_0$ is followed by fluorescence radiation emission;
- in transitions $S_3 \rightarrow S_0$ or $S_2 \rightarrow S_0$, given energy disperses off as heat, or is transferred to another molecule of chlorophyll.

It should be noted that if the transition $S_1 \rightarrow S_0$ occur, some of the transferred energy is wasted as heat and the rest by fluorescence emission, photon is emitted with less energy than that of the absorbed photon, and therefore, the fluorescent light has a wavelength higher.

At Physics discipline, of the particular interest, the experiences underline the absorption spectrum of chlorophyll fluorescence phenomenon, so the laboratory experiments can be made at the XII-th grades, to the study of the Atom and Molecule concepts.

In the XII-th class, Chapter Atomic physics, in addition to observing continuous spectrum and discrete spectrum (of lines) which are typically studied, could be studied also the absorption spectrum of chlorophyll, so students becomme familiar with the practice.

As regards the phenomenon of chlorophyll fluorescence, it can be revealed by a simple experiment, observing in light from the Sun a test tube containing an extract of chlorophyll (fig. 8).

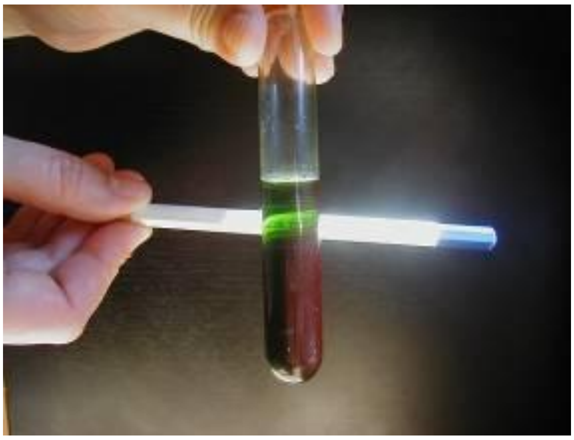

Fig. 8. Observing fluorescence in solar light. The entire sample tube is red, excepting area observed by transparency which is green

Looking chlorophyll solution, it was found that through transparency it appears green because it absorbs blue and red radiation, leaving to pass the yellow and green if the tube is observed from the side - reflection - appear colored red, because of red light emission - fluorescence phenomenon [9]. This phenomenon becomes more pronounced in the dark, if the tube is illuminated with an ultraviolet light source or a continuous emission spectrum (Fig. 9, Fig. 10).

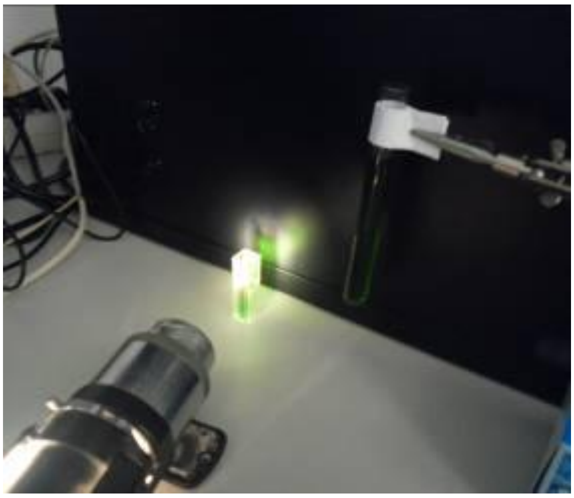

Fig. 9. Experimental setup for fluorescence observation

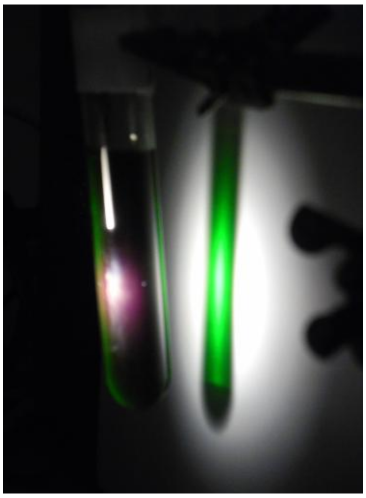

Fig. 10. Observing transmitted light and fluorescence (tube is red, image on the screen is green)

It should be noted that chlorophyll pigments exhibit powerful fluorescence when the extraction of chlorophyll is made with polar organic solvents.

The non-polar organic solvents, such as benzene, do not show the phenomenon of chlorophyll fluorescence, this occurring if trace quantities of water or polar solvent are added [10]. The explanation for this phenomenon is related to the presence of magnesium atom in the molecule of chlorophyll.

CONCLUSIONS

The interdisciplinary approach of complex topics such as is photosynthesis, request form teacher training, additional depth study of materials comprising theoretical concepts related to phenomena addressed, specific language acquisition and handling, formation of specific work skills, subject to certain rules and norms.

These additional efforts are aimed by a better understanding of the concepts taught and studied phenomenon by students.

Studiul experimental al fenomenelor abordate interdisciplinar contribuie la creşterea interesului elevilor pentru disciplinele cu caracter ştiinţific, la trezirea dorinţei de cunoaştere a lumii înconjurătoare şi de explicare a fenomenelor obsevate, doar pe baze ştiinţifice.

Experimental study of phenomena approached interdisciplinary helps to increase pupils' interest in scientific disciplines, to instill the desire for knowledge of the surrounding world and to explain the observed phenomena based only scientifically tools.

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