Exam Photosynthesis & Bio Energy (PBE)

April 12, 2017, 14:00 – 17:00, Havinga zaal

Lecturer: Dr. Anjali Pandit

Instructions:

- **For this exam it is not allowed to use books or lecture notes. It is allowed to use a calculator.**
- **The exam consists of 4 questions on 8 pages, including first page.**
- **Write your answers on the supplied exam sheets. Do not forget to write your name and student number on the sheets!**
- **Numbers of points for each question are indicated.**
- **Please write clear! If your answers are unreadable, we cannot give credits for it**

Good luck!!

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Question 1: Photosynthesis and energy efficiency (*60 points total*)

a) The light reaction of photosynthesis from sunlight absorption to stabilization of energy in chemical form takes place in photosynthetic membranes. List four important membrane protein complexes that are responsible for this process in plants (multiple answers possible) and explain their function in 1-2 sentences.

(*20 points*)

b) Plants, algae and cyanobacteria perform oxygenic photosynthesis, whereas other species such as purple bacteria perform anoxygenic photosynthesis. Give three important differences between the two types of photosynthesis.

(*15 points*)

c) The four major phases of energy storage in photosynthesis are

(i) light capture and energy transfer;
(ii) charge separation and primary electron transfer in the reaction center;
(iii) stabilization by secondary reactions;
(iv) carbon fixation and export of stable products.

The energy efficiency of the whole process is maximal ~5%. Give for each phase an important loss factor

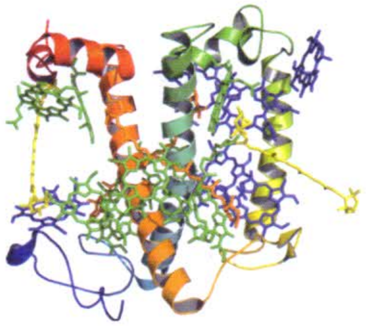
(*20 points*)

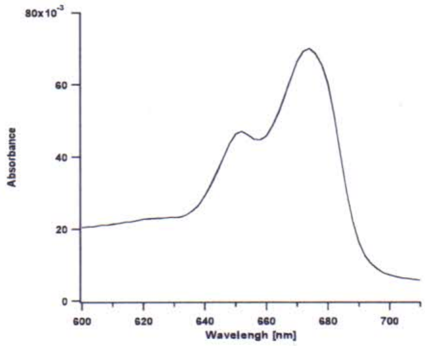
d) To optimize micro-algae for oil production, stress conditions are induced, of which a common one is nitrogen starvation. Explain why nitrogen starvation is effective for this purpose.

(*5 points*)

Question 2: Photosynthetic light-harvesting antennas ***(90 points total)***

1. The figure below shows the monomer structure of the major light-harvesting complex in plants (LHCII), with the different types of pigments colour coded: green, chlorophyll a; blue, chlorophyll b; yellow and orange, carotenoids. The LHCII nearest-neighbour chlorophylls have inter-distances between 1 and 2 nm. The right side shows the LHCII absorption spectrum in the chlorophyll Q_y region.





a) Explain why the absorption spectrum of LHCII is broadened compared to the spectrum of isolated chlorophylls a and b.

(10 points)

b) Give three factors that determine the rate of excitation transfer among the chlorophylls within LHCII.

(10 point)

c) Consider LHCII in a fluorescent state. From which pigment type will fluorescence be emitted upon white light illumination? Explain your answer.

(10 points)

2. At 1.5 Air Mass solar irradiance chlorophylls will approximately absorb 10 photons per second. Green sulfur bacteria, however, live deep in the sea where their bacteriochlorophylls will absorb only one photon per half an hour. They have no photoprotective mechanisms. To compensate for the low irradiance, their photosystems are connected to large assembled bacteriochlorophyll antennas, called chlorosomes that contain ~250000 bacteriochlorophylls. Their reaction centers have turnover rates of ~100 s^{-1}.

a) Are the photosynthetic units of green sulfur bacteria designed for optimal photosynthetic performance (i.e. each absorbed photon leads to a charge-separated state) considering their natural habitat? Give a calculation with your answer.

(10 points)

Excitations are transferred from the chlorosome antenna to the reaction center within 50 picoseconds. Excited states reaching the reaction center are trapped, i.e. transfer to the reaction center is irreversible and always leads to charge separation.

Given are the following characteristics of bacteriochlorophyll:

- internal conversion rate $k_{IC} = 1.7*10^8$ s^{-1}
- triplet rate $k_T = 1.0*10^8$ s^{-1}
- intrinsic fluorescence lifetime $t_F = 17$ nanoseconds

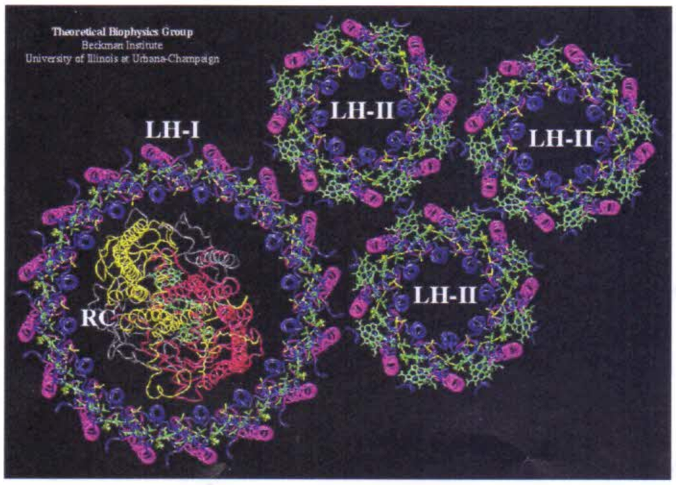
b) Calculate the quantum yield of triplet formation.

(10 points)

c) A researcher with a lab based at a location at 1.5 Air Mass conditions wants to culture green sulfur bacteria on a window bench, under local sunlight conditions. What will happen with the photochemical quantum efficiency, compared to green sulfur bacteria in their native habitat? Estimate the quantum yield of triplet formation under these lab conditions.

(10 points)

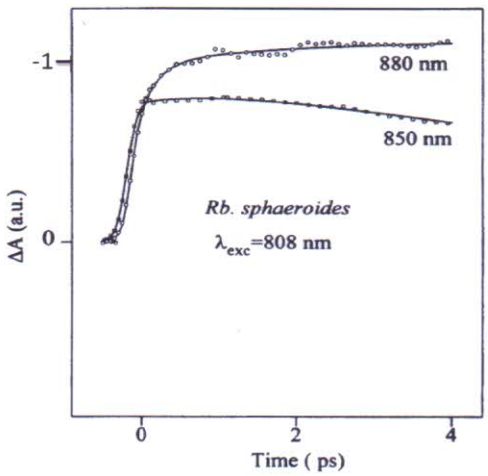
3. This question addresses two pump-probe studies on entire, functional, photosynthetic membranes of purple non-sulfur bacteria. The photosynthetic unit of this bacterium is shown here below. The bacteriochlorophyll dimer rings in LH-II and LH-I are excitonically coupled with redshifted Q_y absorption maxima at 850 nm, resp. 880 nm.



In the first pump-probe study, the pump pulse consisted of a laser pulse at 808 nm. The time-dependent recorded absorption changes at 850 nm and at 880 nm are presented in the graph below. Note the sign of the ΔA scale, i.e. after t=0 the ΔA values at 850 nm and 880 nm become *negative*. The t=0 offset is slightly shifted because of instrument-response effects that are not further discussed here.

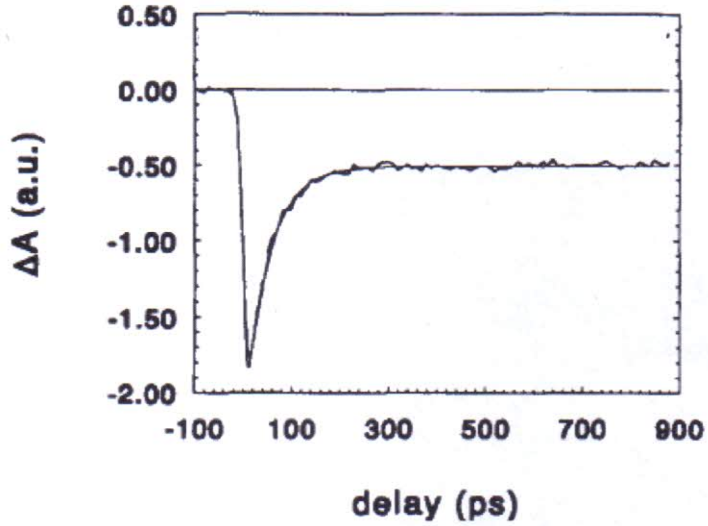
a) Consider the recorded absorption changes in the graph. Explain the processes that are observed within 1-4 picoseconds after the pump pulse.

(10 points)



b) The graph below shows another pump-probe experiment on entire purple-bacterial membranes, where the pump pulse was set at 880 nm, and absorption changes were recorded at 890 nm. (here the ΔA scale is drawn from negative to positive!). Explain the process that is observed in the curve below.

(*10 points*)



c) Give two reasons why exciton coupling between bacteriochlorophylls in the purple-bacterial photosynthetic unit contributes to the energy-transfer efficiency.

(*10 points*)