**Re-exam Photosynthesis & Bio Energy (PBE) 2017**

July 4, 2017, 14:00 – 17:00, zaal C7

Lecturer: Dr. Anjali Pandit

**Instructions:**

- **For this exam it is <u>not</u> 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!!

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

a) The process of photosynthesis consists of the light reaction (from light absorption to energy stabilization in chemical form) and the dark reaction (leading to carbon fixation). The energy efficiency of the whole process is maximal ~5%. Give three important loss factors for the light reaction and one for the dark reaction.

(*20 points*)

b) Describe how the quinone pools in photosynthetic membranes contribute to transfer of protons across the membrane.

(*10 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.

Consider the photosynthetic apparatus of plants. Give for each phase an important membrane protein and describe its function in 2 sentences.

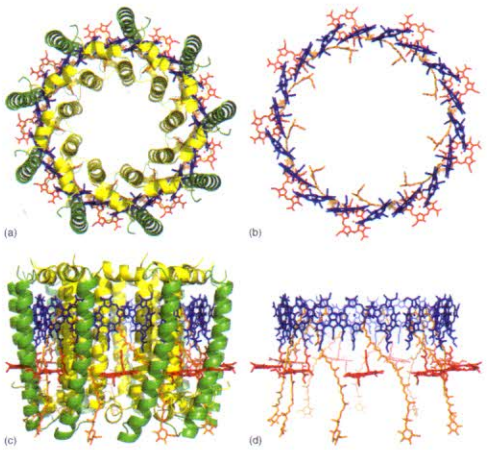
(*20 points*)

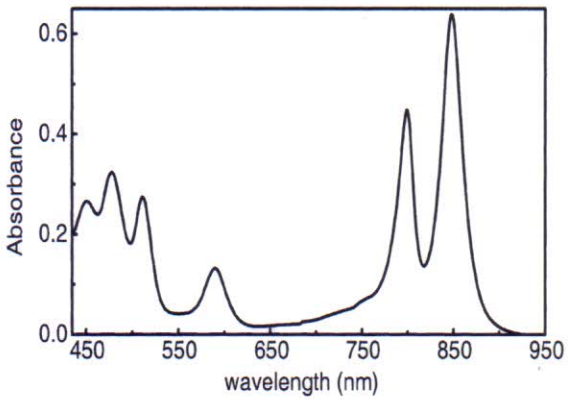
d) Give the difference between C3 and C4 plants, explaining why C4 plants have a higher photosynthetic efficiency.

(*10 points*)

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

2.1. The figure below shows the oligomeric structure of the light-harvesting complex 2 (LH2) in purple non-sulfur bacteria. The right side shows the LH2 absorption spectrum.






a) The LH2 bacteriochlorophyll (BChl) absorption in the $Q_y$ region is shown between 750-950 nm. Explain why the absorption spectrum has two peaks in this region.

(*10 points*)

b) The red BChls are called the B800 BChls and the blue BChls are called the B850 BChls. Give the dominant mechanisms for excitation transfer among B800 BChls and for excitation transfer among B850 BChls.

(*10 points)*

c) The orange pigments in the structure above are carotenoids. Give two important roles of carotenoids in purple-bacterial antenns, and mention the energy-transfer processes that are associated with those roles.

(*10 points*)

2.2 The photosynthetic membranes of purple non-sulfur bacteria contain LH1 ring-shaped antenna complexes that circumvent the photosynthetic reaction centers, and peripheral LH2 antenna ring complexes. One LH1 ring contains 32 BChls (16 BChl dimer units). One LH2 ring contains 27 BChls (9 subunits that each bind two B850 BChls and 1 B800 BChl).

At 1.5 Air Mass solar irradiance (B)Chls will approximately absorb 10 photons per second. Consider that purple non-sulfur bacteria have reaction-center turnover rates of about 1 $(ms)^{-1}$.

a) Show with a calculation why purple non-sulfur bacteria need LH2 antennas in addition to LH1 for efficient photosynthesis.

(*10 points*)

b) When purple non-sulfur bacteria are grown in low-light conditions with light intensities of ~4 photons per second, their photosynthetic membranes have larger LH2/LH1 ratios. Explain why this is the case and estimate the optimal LH2/LH1 ratio for efficient photosynthesis under those low-light conditions.

(*10 points*)

In photosynthetic units of purple non-sulfur bacteria, excitations are transferred from the 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 $\tau_F = 17$ nanoseconds

c) Calculate the fluorescence quantum yield of a photosynthetic unit in the purple membrane.

(*10 points*)

2.3. In the following study, LH2 B800 BChls were replaced by chemically modified (B)Chl pigments, that were reconstituted in the B800 protein-binding pocket. The graph below shows the absorption spectrum of native LH2 (a) and of the modified complexes (b-h).

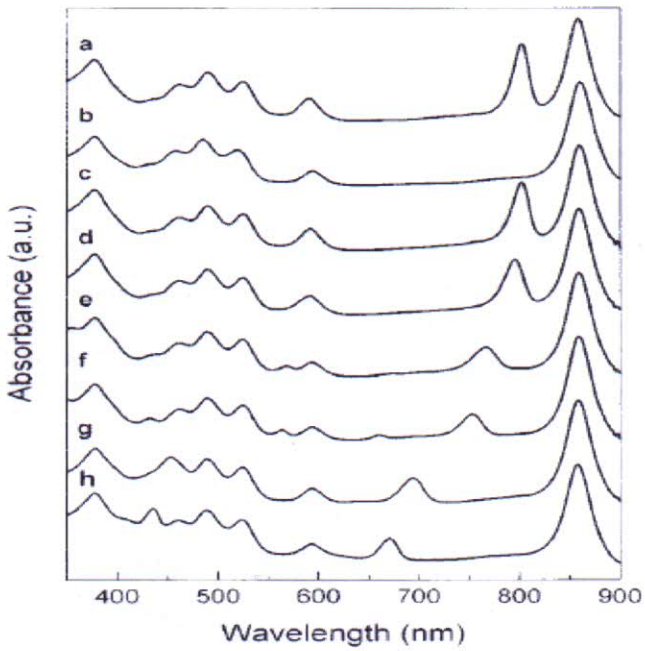
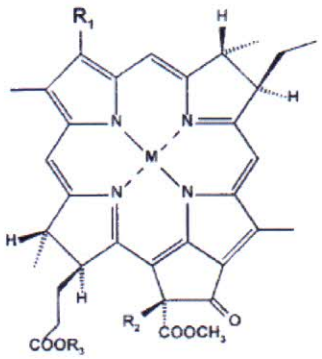



FIGURE 2 Absorption spectra of the (*a*) native, (*b*) B850-only, and (*c*) BChl-, (*d*) Zn-Bphe, (*e*) 3-vinyl-BChl-, (*f*) $3^1$-OH-Bchl-, (*g*) 3-acetyl-Chl-, and (*h*) Chl-B800 reconstituted complexes.

a) The picture next graph shows some of the modifications. Draw the axis of polarization for the $Q_x$ and $Q_y$ transition in the figure. Can you explain why 3-vinyl-BChl (spectrum e) has blue-shifted B800 absorption compared to native BChl?

(*10 points*)



| | $R_1$ | $R_2$ | $R_3$ | M |
|---|---|---|---|---|
| BChl | $COCH_3$ | H | $C_{20}H_{39}$ | Mg |
| $BChl_{gg}$ | $COCH_3$ | H | $C_{20}H_{33}$ | Mg |
| $13^2$-OH-BChl | $COCH_3$ | OH | $C_{20}H_{39}$ | Mg |
| Zn-Bphe | $COCH_3$ | H | $C_{20}H_{39}$ | Zn |
| 3-vinyl-BChl | $C_2H_3$ | H | $C_{20}H_{39}$ | Mg |
| $3^1$-OH-BChl | CHOH- | H | $C_{20}H_{39}$ | Mg |

b) Give three parameters that determine the rates of excitation energy transfer between B800 and B850 chromophores in native LH2. Which of the parameter(s) are affected by the modifications?

(*10 points*)

c) Pump-probe experiments were performed on the native LH2 and on the substituted complexes. For native LH2, the pump pulse was set at ~ 800 nm, and for the B800-substituted complexes the pump pulses were set at their respective absorbance maximum. The graph below shows the transient-absorption changes around 850 nm (note the negative axis!). The time-resolved ΔA signals were fit with a single-exponential function. Explain which process is observed in transient absorption kinetics for native LH2 and explain the slower kinetics for the B800-substituted complexes.

(*10 points*)

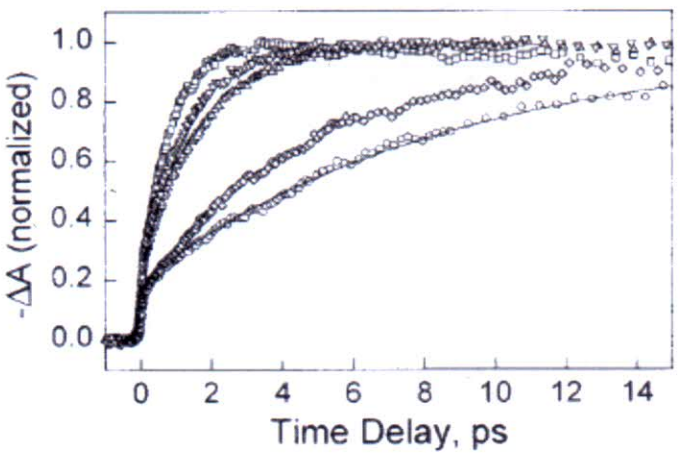



FIGURE 3 The rise in bleaching of the $Q_y$ absorption band of the BChl-B850 molecules with time in native and selected reconstituted complexes. The excitation wavelengths are recorded in Table 2. B850 bleaching was probed at 870 nm.

*Key:* □, native; ▽, 3-vinyl-BChl- ; △, $3^1$-OH-BChl- ; ◇, 3-acetyl-Chl- ; and ○, Chl-B800-reconstituted complexes.