The relationship between state II to state I transitions and cyclic electron flow around photosystem I*

KAZUHIKO SATOH¹ and DAVID C. FORK

Carnegie Institution of Washington, Department of Plant Biology, 290 Panama Street, Stanford, CA 94305, USA

(Received: 18 January 1983; in revised form: 15 March 1983)

Key words: State I-state II transitions, blue-green alga, cyanobacterium, photosynthesis, energy transfer, cyclic electron flow, phase transitions, Synechococcus

Abstract. The effects of electron acceptors, inhibitors of electron flow and uncouplers and inhibitors of photophosphorylation on a state II to I transition were studied. 3-(3,4-dichlorophenyl)-1,1-dimethylurea (DCMU) did not inhibit the state II to I transition. By contrast, 2,5-dibromo-3-methyl-6-isopropyl-p-benzoquinone (DBMIB), methyl viologen and antimycin A inhibited the transition indicating that the cyclic electron flow around photosystem I, but not the oxidation of electron carriers (such as plastoquinone), induced the state II to I transition. Uncouplers, but not inhibitors of photophosphorylation, inhibited the state transition suggesting that the proton transport through the cyclic electron flow was related to the transition.

Introduction

State I-state II transitions are known to be important ways by which plants can adapt to changes in light quality in their natural habitat [5, 17]. It has been proposed that excess illumination of photosystem I causes the plants to go into state I where the transfer of light energy from pigment system II to I is restricted. By contrast, excess illumination of photosystem II causes the plants to pass into state II where the transfer of light energy from system II to I is enhanced [5, 17, 22]. Therefore, the intensity of fluorescence at room temperature is high in state I while it is low in state II.

Recently, a new hypothesis has been proposed to explain the mechanism of state transitions [1, 2, 12, 14]. According to this hypothesis, the redox level of plastoquinone changes with the light quality used and phosphorylation of LHCP occurs in proportion to the amount of reduced plastoquinone. The

*CIW-DPB Publication No. 790

¹ On leave from the Department of Pure and Applied Sciences, College of General Education, University of Tokyo, Meguro-ku, Tokyo 153, Japan

Abbreviations: DCMU, 3-(3,4-dichlorophenyl)-1,1-dimethylurea; DBMIB, 2,5-dibromo-3-methyl-6-isopropyl-p-benzoquinone; CCCP, carbonylcyanide m-chlorophenylhydrazone; DCCD, N,N'-dicyclohexylcarbodiimide; PMS, N-methylphenazonium methosulfate; LHCP, light-harvesting chlorophyll a/b proteins

245 PR168
phosphorylation of LHCP induces a state I to II transition and, therefore, a
decrease of the intensity of chlorophyll fluorescence. In order to check
whether this hypothesis is true, it was necessary to compare the characteristics
of fluorescence changes produced by phosphorylation of LHCP in vitro with
those produced by state transitions in vivo. Unfortunately, in spite of the
importance of this phenomenon, little is known about state transition in vivo.
For example, not many papers have dealt with the effects of inhibitors of
electron flow or of uncouplers of phosphorylation on the state transitions.
DCMU is the only one known to inhibit the state I to II transition but
not the state II to I transition [7, 15]. In the preceding paper [10] we
showed using the blue-green alga, *Synechococcus lividus* that the dark
adapted state is state II and that the light-requiring step is the state II to I
transition.

In this work, we examined the effects of electron acceptors, inhibitors of
electron transfer and uncouplers and inhibitors of photophosphorylation on
the state II to I transition, in *Synechococcus lividus*, and we found that the
state II to I transition was induced by the turnover of the cyclic electron
transfer system around photosystem I and not by redox changes of
plastoquinone. The results also demonstrate that a slow fluorescence increase
in the presence of DCMU represents the state II to I transition.

**Materials and methods**

The thermophilic blue-green alga *Synechococcus lividus* (strain SY-4 from
Mercedes Edwards) was grown at 55°C as described previously [9].

Time courses of chlorophyll fluorescence and fluorescence spectra were
measured using a fiber optic system to excite and collect the fluorescent light
[8]. For light II, 632.8 nm light from a He-Ne laser (Spectra-Physics Stabilite
Model 124B) was used and for light I, a blue light was obtained by passing the
light from a 150W, 21.5 V projector lamp (type DLS) through two Corning
glass filters (4–96) and a Calflex C heat reflecting filter (Balzers). If not
otherwise mentioned, the light intensities of light II and light I were 124 and
980 μwatts/cm², respectively. For measurements of fluorescence induction in
the msec time range, a Nicolet Signal Averager Model 1010 was used as a
transient time converter.

For measurements of fluorescence produced by low intensity excitation
light, we used a rotating sector and lock-in-amplifier. The fluorescence pro-
duced by a continuous, low intensity beam was chopped (at a rate of 0.8 ms
light and 5.1 ms dark) and led to a photomultiplier (Hamamatsu TV, R-928)
by one branch of the fiber optic. High intensity actinic illumination was given
to the sample during the periods when the chopper blade shielded the
photomultiplier.