Transient mesoscopic stucture: Nanoscopic order of nuclear spins

Bela E. Bode, University of St Andrews, Scotland
Jörg Matysik, Leiden University, The Netherlands

'Nano structures' are generally understood in terms of stable atomic or molecular arrangements in the space. Nano structures, however, might also be transient, occurring for micro- or nanoseconds, and then vanish into unstructured heat-driven movement. Particles as electrons and several atomic nuclei exhibit magnetism because they carry a small magnet, called 'spin'. Can these spins transiently form magnetic nano structures? Yes, they do under certain conditions.

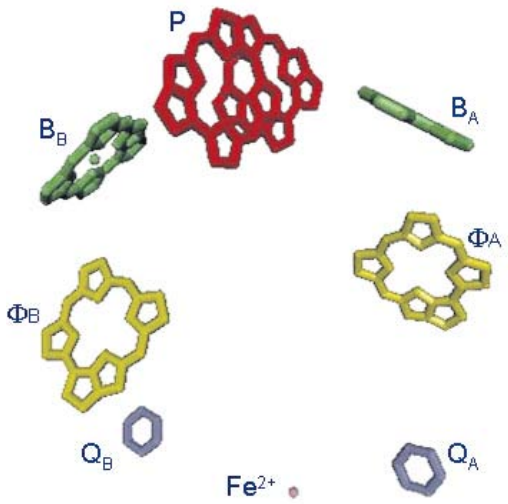

Fig. 1: The structure of the photosynthetic apparatus. Upon illumination, photosynthetic proteins separate charges by transferring electrons form the chlorophylls acting as primary electron donor (red) to the quinone cofactors (blue). This electron pumping process is unidirectional under natural conditions.

It is photosynthesis (Fig. 1), one of the key processes for live on earth, that produces large pools of electronic and nuclear spin order in its first step. Photosynthesis actually is an ordering process. It is generally recognized that photosynthesis uses light energy to separate the negative charge of electrons to one side of a membrane, and the positive charge of protons to the other. As result, the membrane is charged like an electric battery having a certain voltage which can be used for driving processes of live. Electrons and some atomic nuclei have not only charges but, as we have mentioned, spins, too.

In 1994, McDermott and Zysmilich from Columbia University have shown experimentally, that the photosynthetic primary reaction not only leads to charge order, but can also produce nuclear spin order (Fig. 2). At that time, the occurrence and

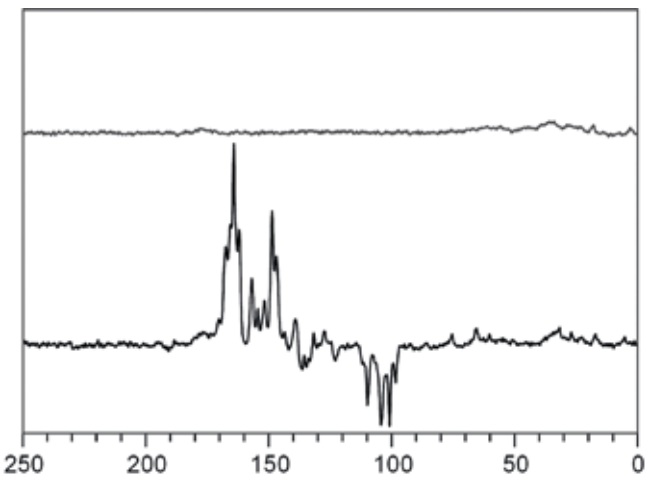

Fig. 2: ^{13}C NMR spectroscopy on a photosynthetic protein without (top) and under illumination (bottom). The dramatic increase of signal is direct proof for high nuclear spin order. That demonstrates that photosynthetic charge ordering is also spin ordering on nano scale.

observation of this spin ordering appeared as lucky coincidence. Samples were treated at low temperature and high magnetic field. Isolation of photosynthetic proteins from the organisms and special chemical treatment appeared to be necessary. In the meanwhile, we know that spin order is observable at ambient temperatures without freezing the sample and in entire photosynthetic membranes, cells and even plants. A new theory predicts this effect to occur also at the earth's magnetic field. Recently, even in electron transfer proteins other than photosynthetic systems, this spin order has been shown. Although difficult to detect, it thus seems to be a quite widespread phenomenon in natural electron transfer systems under entirely natural conditions which has been conserved in evolution, as evidenced from its presence in species whose last common ancestor lays back three billion years.

One can assume that such mesoscopic pools of ordered nuclear spin occur simply as a by-product. On the other hand, effects are known stabilizing the flow of electrons in one direction and blocking it in the opposite direction. By such a mechanism the transient magnetic nano structure would become a spin valve enforcing efficient electron transfer. Obviously, R&D in spintronics and artificial photosynthetis would profit form implementation of such nano valves.