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Solar spot influence on Earth's molecular processes

Vladimir K. Evstafyev

Institute of Applied Physics, Gagarin boulevard 20, Irkutsk 664003, Siberia
e-mail: evs@api.isu.ru

Abstract: The paper considers the two-century-old problem of how solar spots influence biological objects on the Earth. It describes the modern state of the kT-problem, which for a long time has been the most difficult obstacle in explaining solar activity effects. Based on recent advances in spin chemistry and magnetoplasticity physics, it is shown that a 'molecular target' sensitive to weak electromagnetic fields is spins in non-equilibrial states of the molecular system. A way of how solar spots can influence Earth's molecular, including biological, processes through a 'transparency window' in the Earth's atmosphere is proposed.

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Introduction

Study of solar-terrestrial links has a long history, since the famous English astronomer William Herschel found a correlation between the market prices of grain and solar spot numbers (Herschel 1801). It is still a challenging problem for natural sciences. The question is what is a primary target of the molecular system sensitive to solar spots? It must be some energy gaps between its states that are as small as weak energies influence. A number of researchers considered spin as a primary target (Vladimirskiy & Temuryants 2000). However, on this way, a hard obstacle arose, the so-called kT-problem. The physical theory stated that weak influences with much less energy than thermal fluctuations could not change the state of molecular systems because they should be thermalized. This dogma dominated researchers' thinking and so they looked for a mechanism that is able to intensify the weak influences by 10^4–10^5 times (Dmitrievskiy 1992; Bingi & Savin 2003) but failed. Recently, this problem has been solved.

The physics of crystal magnetoplasticity faced the same problem (Golovin & Morgunov 2002; Morgunov 2004). Alshits *et al*. (1987) reported that a magnetic field with an induction of 0.3 T stimulated dislocation mobility at room temperature. It seemed impossible from the view-point of equilibrium thermodynamics requiring 10^2–10^3 T. In 1991, Alshits proposed a solution to this puzzle outside equilibrium thermodynamics (Alshits *et al*. 1993, 1996). Dislocation nuclei, being paramagnetic in the triplet state, have been found not to prevent dislocation removal to a neighbouring Peierls's valley in contrast with the singlet state. It occurs when two factors take place together: first, the magnetic field stimulates the singlet–triplet conversion of a radical pair formed in the singlet state by thermal decomposition of a chemical bond and, second, duration of an elementary act of crystal plastic deformation must be less than the spin-relaxation time. In this case, thermal fluctuations have no time for mixing spin states and consequently the plastic deformation process in such a crystal becomes spin-selective. Alshits's explanation successfully overcame the kT-problem and also opened the doors to explaining solar-terrestrial links.

Now, armed with Alshits's explanation and spin chemistry theory (Buchachenko *et al*. 1978; Zeldovich *et al*. 1988), we can develop a theory of how solar spots influence molecular processes on the Earth. The first biochemical reaction of phosphorylation in mitochondria, recently revealed by Buchachenko's research group (Buchachenko *et al*. 2004; Buchachenko & Kuznetsov 2008) is a strong evidence supporting the main proposition of this paper – spins are an interface between external weak influences and the molecular system and responsible for biological effects.

Spin configurations govern chemical reactions

Chemical evolution of the molecular system strongly depends on its spin configuration. One can see it as the simplest form in an example of a radical pair (RP):

$$A\uparrow + B\downarrow = A - B \quad \text{chemical bond is formed} \tag{1}$$
$$A\uparrow + B\uparrow \neq A - B \quad \text{bond formation is banned} \tag{2}$$

In situation (1), a chemical bond is formed but in situation (2), a triplet state, the bond formation is prohibited by the law of quantity of movement momentum conservation. Hence, we see that changing the spin orientation of one electron only in a multielectronic system leads to a cardinal difference in the chemical destiny of this system. At room temperature, spin states, usually with 10^5–10^7 times less energy than thermal fluctuations, are mixed by thermalization and so there is no spin-selectivity in chemical reactions. The situation becomes different in principle when thermalization is limited. Such a situation arises where spin-lattice relaxation occurs with insufficient time for mixing spin states during an early chemical reaction and consequently the system evolves farther in a way

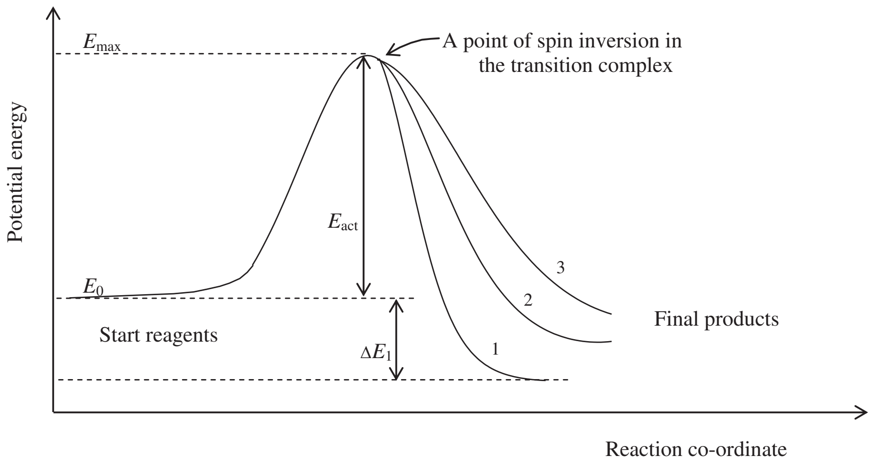

Fig. 1. Principle diagram of the chemical reaction.

directed by this early act. Here, the spin plays the role of a switchman, who directs a train onto one or the other track. It is clear that spin-selectivity may be possible in non-equilibrial conditions.

In the energy scale, all the molecular processes can be divided into two types, excitation and relaxation. The latter ones seeking the ground state liberate surplus energy and therefore do not need any additional energy for changing spin configuration. Hence, we do not need to look for the mechanism that is able to intensify the weak influences by 10^4–10^5 times as the previous researchers dogmatically thought within the framework of equilibrium thermodynamics.

Let us look at the diagram of the chemical reaction (Fig. 1). The system can slide down from the potential energy peak in different ways depending on a current spin configuration. Hence, a weak influence changing the spin state can govern the chemical reaction.

Biological objects are non-equilibrial systems

Biological organisms are recognized (Bauer 1935) as states of 'sustainable non-equilibrium' that is a principal feature of living matter. It is because, in specific conditions where thermalization is limited, spin-selective biochemical reactions under internal and external magnetic (influencing Zeeman's gap between spin states) and electromagnetic (causing resonant skips between spin states) fields change their rates, i.e. a biochemical balance, which should lead to an observable biological effect. It is easy to see as following: the spin-state saturation under an appropriate radio wave emission can be written as

$$\Delta n = \Delta n_0 \cdot e^{-2\Delta\nu \cdot t} \tag{3}$$

where Δn is the population difference $n_\alpha - n_\beta$, Δn_0 is the start population difference at the moment $t=0$, $\Delta\nu$ is a split of the spin-states. Hence

$$\lim_{t \to \infty} \Delta n = 0, \tag{4}$$

When thermalization is 'switched on', a population difference appears

$$n_\alpha = \frac{1}{2} n\left(1 + \frac{g\mu_0 H}{2kT}\right), \tag{5}$$

$$n_\beta = \frac{1}{2} n\left(1 - \frac{g\mu_0 H}{2kT}\right), \tag{6}$$

$$\Delta n = n\frac{g\mu_0 H}{2kT}, \tag{7}$$

where n_α and n_β are populations of the lower and upper levels, n is the spin number in total, g is the Lande factor, μ_0 is the Bohr magneton, H is the magnetic field, k is the Boltzmann constant and T is the ambient temperature. At room temperature, kT»$g\mu_0 H$ by 5–6 orders, therefore population differences are very small, a few thousandths or 10^{-4}%. When thermalization is almost stopped, the population of the lower n_α level is close to 100% and n_β near to empty. However, this distribution occurs when radio waves are calm. Radio EMF, corresponding to the spin-state gap, mixes spin states to zero (see equations (4) and (5)). Such a contrasting change in the spin population is impossible under thermal control, but conditions of limited or absent thermolization allow plant, animals and other living organisms to feel the Sun's radio wave 'mood'.

Radio-frequent channel of the solar activity influence on biological objects

Here, let us consider the following scheme, how does solar activity influence biological objects on Earth? As is well-known, solar flares induce intense radiation in the X-ray and radio-frequency ranges of the Sun's spectrum (Kundu 1965; Bruzek & Durrant 1977) (http://www.astronet.ru/db/msg/1188608). In the far radio-wave range, the intensity increases up to 10^5 times in comparison with the intensity of the calm Sun. The Earth's atmosphere absorbs most of the cosmic radiation but there is a 'transparency window' 0.8–30 m wide (375–10 MHz in the frequency scale), through which radio waves reach the Earth's surface.

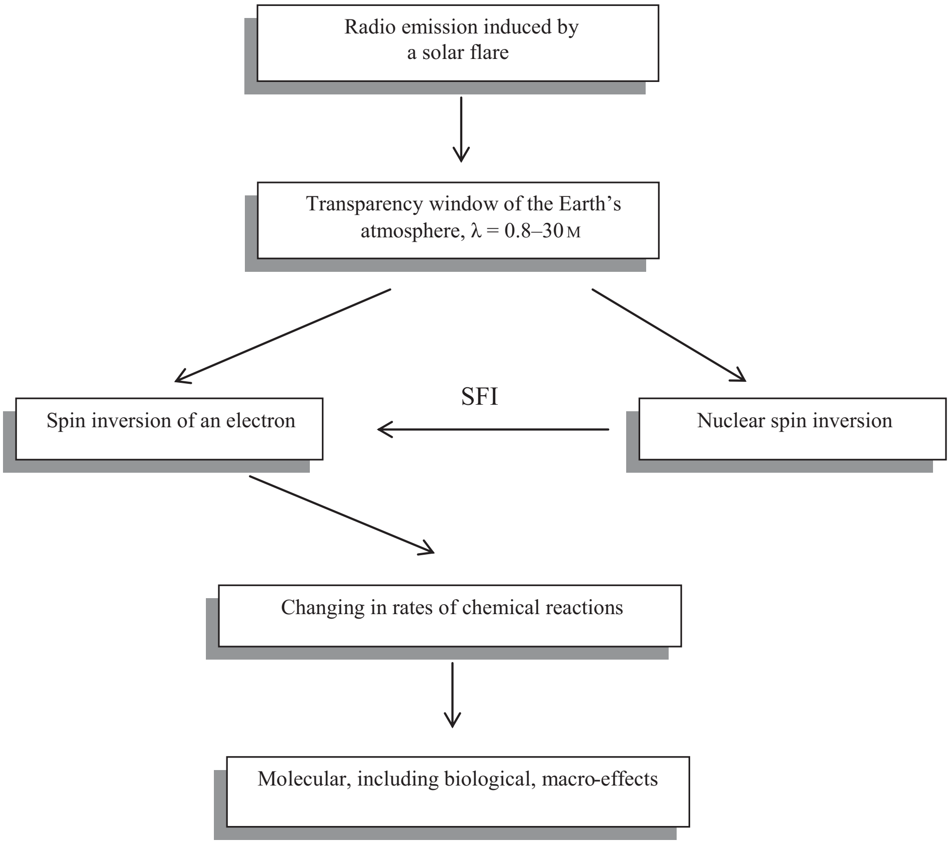

Fig. 2. A way of providing solar activity influence on Earth's molecular, including biological, processes.

Electromagnetic emission of an appropriate frequency causes a spin-inversion of some RP in a biochemical reaction and consequently changes its rate which, in turn, results in a macrobiological effect. The first reaction was found in 2004 (Buchachenko *et al.* 2004; Buchachenko & Kuznetsov 2008). The phosphorylation reaction in the mitochondria has been found to accelerate by 2–2.5 times under a radio emission of 80 MHz (non-paired electron spin-state splitting on the nucleus ^{31}P) and 1800 MHz (correspondingly on ^{25}Mg). Splitting gaps are easy calculated from the super-fine interaction (SFI) constants $a_p = 80$ MHz on ^{31}P and $a_{Mg} = 600$ MHz on ^{25}Mg using the Breit–Rabi equation:

$$E = -\frac{a}{4} \pm \frac{a}{2}\left(I + \frac{1}{2}\right), \tag{8}$$

where E is the spin-state splitting energy, a is the SFI constant and I is the nucleus spin. The first of the frequencies (wavelength = 3.75 m) is situated within this 'transparency window' and thus the 3.75 m solar emission reaches the Earth's biosphere and accelerates the mitochondrial phosphorylation reaction in biological organisms. This is a way in which solar flares influence biological processes on Earth (Fig. 2).

Of course, it is very likely that there are other biochemical reactions sensitive to the solar radio emissions reaching the Earth's surface through the 'transparency window'. Experiments (Levengood & Schikle 1962; Levengood 1965; Grechany *et al.* 2002; Kravchenko 2004) showed that growth rates of the fruit fly *Drosophila melanogaster* increased immediately after solar flares. This fact makes it clear that an active factor of Sun's radiation is its EM-radiation not corpuscular emission (solar wind) reaching the Earth's orbit in 2–3 days while light needs 8 minutes only for the same distance.

Conclusion

Thus, we can state that under conditions where thermalization is limited, spins support the transformation of external electromagnetic influence into molecular effect and spin configurations play a governing role in the evolution of chemical systems. These conditions are realized in the transition complex of chemical reactions and biological systems due to their non-equilibrium. The radio-frequency channel of solar flare influence on Earth's molecular, including biological, processes is provided through the atmosphere 'transparency window'.

Note

This is a private research of the author and not a part of the scientific programmes of the institutes he is currently working on/or worked before.

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