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Animal magnetism: how magnetic fields can influence chemistry in living cells

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ABSTRACT

In recent years, scientists have discovered that many animals can sense the weak magnetic field of the earth and use it to help them navigate. Other studies suggest that weak magnetic fields in our environment may be harmful to our health. Here, we look at a mechanism by which weak magnetic fields might influence biology and demonstrate direct magnetic effects on the chemistry of living cells.

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Ever since human beings first discovered the magical attractive effect of lodestones in the ancient world, we have been fascinated by the power of invisible magnetic fields and in particular how they can affect us and our bodies. For example, the Sushruta Samhita, an ancient Hindu medical text, describes how magnetite was used to remove arrows trapped inside the body. However, magnetic fields and biology have a chequered history, with many seeking to tap into the mysterious nature of the fields to exploit the public. The past is full of examples of miracle magnetic cures like Elisha Perkins "tractors" that could use the power of magnets to "draw off the noxious electrical fluid" that led to pain in patients, and the "King of the magnetic quacks", Dr. C. J. Thacher, who believed his "magnetic shields" could cure any condition, including paralysis!

Today our interest in these mysterious fields and their possible effects on biology remains undiminished. There are two important phenomena that continue to attract the attention of biologists and medics, but which are still far from being understood. The first is that we now know that many animals are capable of sensing the very weak Earth's magnetic field and using it for navigation. Arctic Terns, for example, use their built-in magnetic compass to help them navigate worldwide round trips of up to 90'000 km every year. The second is that epidemiological studies suggest a weak association between environmental electromagnetic fields and childhood leukemia, meaning that since 2001, the World Health Organization classifies extremely low frequency magnetic fields as possibly carcinogenic to humans.

These observations require us to explain the underlying physical mechanism by which a very weak magnetic field might be able to influence biological processes. In recent years, the so-called "radical pair mechanism" has become the frontrunner for explaining the magnetic compass ability of animals. This mechanism involves chemical reactions that proceed through short-lived (typically a few hundred billionths of a second) intermediates known as radical pairs (RPs). Radicals possess a quantum mechanical property known as spin, which makes them behave like tiny magnets, and remarkably, when these pairs of radicals come together, their possibility of reacting together depends on the relative orientation of these tiny magnets. Applying even a weak magnetic field can influence how the RPs change these orientations and can lead to the reaction going faster or slower. Thus, through this mechanism, chemical reactions involving RPs can be altered by the application of magnetic fields. Such effects were first demonstrated in the 1970s and have been studied continuously ever since.

Returning to the bird magnetic compass, the idea is that reactions that generate magnetically sensitive RPs can take place inside cells in the eyes of migratory birds. The current hypothesis is that these reactions take place inside proteins known as cryptochromes, which report changes in the radical pair reaction to the brain through the optic nerve, essentially allowing the birds to "see the magnetic fields" in their environments.

Until now, there has been no direct evidence for the radical pair mechanism operating in real living systems. Recently, we were able to directly demonstrate the effect of a magnetic field on the chemical reactions of RPs in living cells for the first time. To do this, we exploited a property possessed by all cells, known as autofluorescence, which is the emission of light by certain molecules naturally present in the cells. We studied the tiny amount of natural light emitted by individual cells when exposed to blue light, using a specially built microscope. We suspected that the autofluorescence in our measurements was due to molecules called flavins, which we already knew from our earlier work show magnetically sensitive chemical reactions when exposed to blue light. Our idea was to use this autofluorescence to find out if the flavin molecules were undergoing RP based chemical reactions in the cells. Fluorescence and RP chemistry are basically competing processes for flavins and so one can be used to observe the other. We were able to successfully and repeatedly demonstrate a clearly measurable effect in which applying a magnetic field caused a reduction in the amount of light emitted by the cells. Furthermore, we were able to confirm that the effect came from naturally occurring flavin molecules in the cells and determine some magnetic properties of the RPs involved. This discovery has thus now firmly established the connection between the radical pair mechanism and biological magnetoreception, taking us a step closer to really understanding how those magical and mysterious magnetic fields affect biology.