INSTITUTE OF PHYSICS PUBLISHING PHYSICAL BIOLOGY

Phys. Biol. **1** (2004) 135–136 www.iop.org/Journals/PhysBio PII: S1478-3967(04)82937-1

NEWS ARTICLE

Birds use physical chemistry to find north

Behavioral biologists have demonstrated that migratory birds, among other animals, possess a physiological magnetic compass that helps them to find the right direction on their migratory flights. Although this fascinating ability was known as early as 1972, the underlying biophysical mechanism and receptors remained elusive.

Light-dependent magnetic compass

In the early 1970s, the physicist Klaus Schulten noted that a light-induced electron transfer between two photopigment molecules results in the generation of a radical pair intermediate that will either exist in a singlet or a triplet state and subsequently decay in chemically different singlet or triplet products. Theoretical calculations and *in vitro* experiments showed that the ratio between singlet and triplet products from radical-pair reactions can be modulated by an earth-strength magnetic field, thereby potentially providing the basis for a magnetic compass.

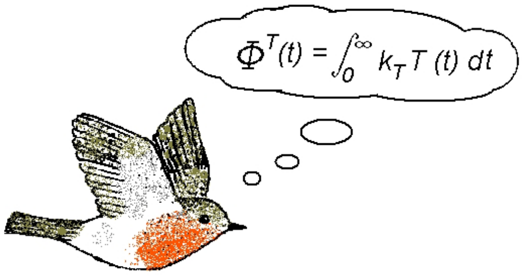
This hypothesis was initially greeted with skepticism since it suggested that the magnetic compass of birds requires light for its function. However, the hypothesis was ultimately put to the test when the group of Wolfgang Wiltschko investigated magnetic orientation of birds under monochromatic light of different wavelengths. They found that European robins in the local geomagnetic field oriented in the expected migratory direction under blue (424 nm), turquoise (510 nm), and green light (565 nm), but were disoriented under yellow (590 nm) and red light (635 nm). A very similar wavelength dependency pattern of avian magnetoreception has been demonstrated in several other migratory birds when using low light levels (corresponding to dusk); however, more complex patterns emerge in studies of wavelength dependencies for different light intensities.

Interestingly, the influence of light on the magnetic compass of birds is processed in a lateralized fashion: When European robins were tested with an eye cap covering their left eye, their magnetic compass responses were unchanged from control conditions, but when their right eye was covered, they became disoriented. While all of these results were consistent with a radical-pair based magnetic compass activated by a blue-green photopigment, they fell short of providing conclusive evidence for a chemical sensing mechanism underlying the avian magnetic compass.

Physics theory guides key experiment

In principle, physics theory can yield accurate predictions about the effects of weak magnetic fields through different magnetoreception mechanisms. Could it be possible to infer the nature of the magnetoreception mechanism and receptors from the behavior of animals, by using a complex, theory-guided stimulus as a probe? One immediate theoretical prediction is that oscillating magnetic fields at broad resonance frequencies in the low radio frequency range (1–100 MHz) will disrupt a physiological compass based on radical-pair reactions because they will mask the effects of an earth-strength static field on radical-pair reactions.

1478-3967/04/020135+02$30.00



On the other hand, such fields will not affect magnetic compasses based on other mechanisms, such as magnetite-based compasses. Moreover, in a radical-pair-based compass system, the alignment of the oscillating field with respect to the static field will determine whether oscillating fields lead to disruption or not, whereas a non-specific disturbing effect of oscillating fields should occur regardless of angle between static and oscillating fields.

The magnetic compass orientation behavior of birds in oscillating magnetic fields is thus a good test to identify the underlying biophysical mechanism. Such a test was performed in a collaborative project between the physicist Thorsten Ritz and the behavioral biology group of Wolfgang Wiltschko reported in the journal *Nature* on May 13. European robins were tested for magnetic orientation in the geomagnetic field only (control condition) and in conditions in which an additional weak oscillating field was applied. In the control condition, the robins exhibited seasonally appropriate northerly orientation. In the presence of an additional 7.0 MHz oscillating field presented at 24° and 48° relative to the geomagnetic field, the birds were disoriented. In contrast, when the 7.0 MHz oscillating field was parallel to the geomagnetic field, the birds oriented in the migratory direction and their response was indistinguishable from the control condition.

These results indicate a resonance effect on singlet–triplet transitions and provide the first, albeit indirect, evidence that the biophysical mechanism underlying the magnetic compass of birds is a radical pair mechanism. The identification of the mechanism now puts the spotlight on the eye of birds to search for the molecular basis of magnetoreception with genetic and molecular approaches and represents a milestone in the now more than forty-year old quest of explaining the magnetic sense.

What about the role of magnets in avian magnetoreception? Magnetite, a biogenic magnetic material, in the form of single domains and super-paramagnetic particles has been found in the beak of birds. Behavioral and electrophysiological studies suggest that the discovered magnetite is not involved in magnetic compass orientation, but instead forms the basis of a magnetic-intensity sensor, potentially used in a magnetic 'map' sense for determining geographic position. Birds thus appear to have a gaussmeter in their beak and a magnetic compass in their eye.

References

Ritz T, Thalau P, Phillips J, Wiltschko R and Wiltschko W 2004 *Nature* **429** 177
Wiltschko R and Wiltschko W 1995 *Magnetic Orientation in Animals* (Berlin: Springer)
Wiltschko W, Munro U, Ford H and Wiltschko R 1993 *Nature* **364** 525
Wiltschko W, Traudt J, Güntürkün O, Prior H and Wiltschko R 2002 *Nature* **419** 467
Wiltschko W and Wiltschko R 1972 *Science* **176** 62

doi:10.1088/1478-3967/1/2/N01
Online at stacks.iop.org/PhysBio/1/135