Avian magnetoreception:

The cryptochrome and magnetite models

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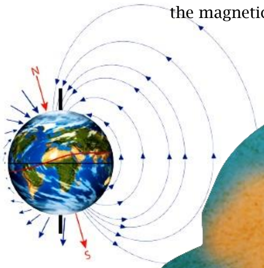
ABSTRACT

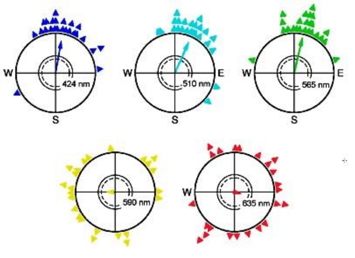
Magnetoreception is the ability to **perceive the magnetic field**. A few species of birds can use the magnetic force to orientate themselves and **navigate during migrations**. In the last decades, at least two magnetosensory systems have been discovered in birds. Thus, the aims of this report are:

- Describe the three main models proposed
- Review the behavior and physiology of some migrant birds
- Compare briefly this avian sense with other animal taxa

EARTH'S MAGNETIC FIELD

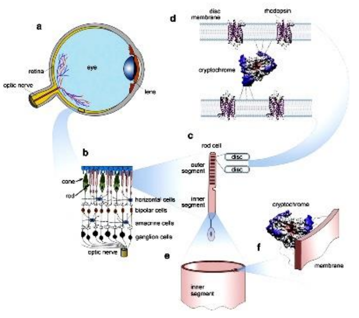
The geomagnetic field is a huge magnet, a dipole whose poles are in the vicinity of the geographic poles. It is originated inside the Earth, due to the movement of the external fluid layer of the nucleus. The magnetic field lines leave the surface of the planet at the Antarctic pole, follow a curve around the globe and return to the surface at the Arctic pole. The magnetic vectors point upward on the southern hemisphere, run parallel to the Earth's surface at the magnetic equator and point downward on the northern hemisphere.





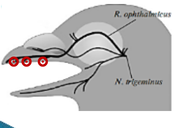
HOW BIRDS CAN DETECT MAGNETIC FIELDS?

The first species in which the magnetoreceptive sense was revealed was the **European robin**, a nocturnal migrant bird. Individuals from migrating populations were taken and it could be seen that they preferred to stay at the side of the jail which pointed towards the direction of migration. When the magnetic north was modified birds changed their directional preferences according to the change in the magnetic north. If they were tested under monochromatic yellow or red light, the birds were disoriented, as the diagrams on the left exemplify.



1 RETINA

Chemical reactions in the retina of birds are supposed to be the basis of avian magnetoreception. The **cryptochromes** (d, f) are flavoproteins associated with the outer membrane of photoreceptors cells. The **radical pair model (RPM)** proposes that photons of certain wavelength can induce the electron transference from the cryptochrome to an acceptor as FAD. This would result in a pair of molecules with radicals. According to the disposition of the spins, the radical pair can be in a singlet or in a triplet state and its inter-conversion rate, that responds to the magnetic field, could affect different cell reactions as the normal rhodopsin-based visual process.



2 UPPER BEAK

Magnetite and **maghemite** are a set of independent biogenic iron oxide crystals that may operate as a compass needle. They are located inside dendrites and arranged in the cell membrane of the **trigeminal nerve's ophthalmic branch**. The figure on the left illustrates six characteristic bilateral locations that are proposed to be aligned for detecting magnetic vectors. The magnetic field could induce changes in particles of magnetite, thus press or elongate the cell membrane, which induces mechanosensitive ion channels to lead an action potential.

CONCLUSIONS

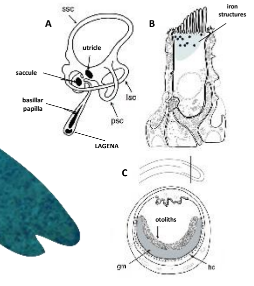
For magnetoreception, two hypotheses are currently discussed, one proposing a chemical compass based on a radical pair mechanism, the other postulating processes that involve magnetite particles. The experimental evidence suggests that birds use both mechanisms.
The vestibular system model, in which lagena takes part, has not yet been completely verified. It is necessary to promote more researches for the discovering of the precise mechanism of these three magnetic organs. Nevertheless, it has not to be forgotten the existence of strong evidences supporting the olfactory map hypothesis, or at least in certain species of birds. In the same way, there are other theories less studied such as stellar or geological maps, among others.

A WIDESPREAD SENSE

Systematics	No. of orders	No. of families	No. of species	Type of compass
Mollusks				
Snails	1	1	1	?
Arthropods				
Crustacean	3	3	5	Polarity compass
Insects	6	7	9	Polarity compass?
Vertebrates				
Cartilaginous fish	1	1	1	?
Bony fish	2	2	4	Polarity compass?
Amphibians	1	2	2	Inclination compass
Reptilians	1	2	2	Inclination compass
Birds	**3**	**11**	**20**	Inclination and polarity compass
Mammals	2	2	3	Polarity compass

3 INNER EAR

In the bird's inner ear, hair cells hold calcium carbonate **otoliths**, that detect linear accelerations. They are thought to be involved in magnetoreception, because they contain abundant quantities of **ferrihydrite**, and due to the fact that lagena's ablation alters the orientation abilities of pigeons.



NEURONAL INTEGRATION

The cryptochrome's type receptors (1) could act as inclination compass, while magnetite's type receptors (2) probably receive quantitative information as well as polarity. Hence, each one of these magnetoreceptors enhance different regions of the brain:

1) - Cluster N, in the visual Wulst
2) - Hindbrain's vestibular nuclei
- Lateral hyperpallium
- Dorsal thalamus,
- Hippocampus

REFERENCES

- Kishkinev, D. A., & Chernetsov, N. S. (2015). **Magnetoreception systems in birds: A review of current research**. *Biology Bulletin Reviews*, 5(1): 46-62.
- Ritz, T., Adem, S., and Schulten, K., (2000). **A model for photoreceptor-based magnetoreception in birds**. *Biophysical Journal*, 78(2): 707–718.

FIGURES

All pictures and diagrams were taken and **modified** from different publications:

- Robin silhouette: Franklin, F.; CC by SA, 3.0
- Earth globe: O'Neill, P. (2013). **Magnetoreception and baroreception in birds**. *Development Growth and Differentiation*, 55(1), 188–197.
- Diagrams and table: Wiltschko, W., & Wiltschko, R. (2005). **Magnetic orientation and magnetoreception in birds and other animals**. *Journal of Comparative Physiology A*, 191(8): 675-693.

1) **Retina:** Solov'yov, I. A., Mouritsen, H. & Schulten, K. (2010). **Acuity of a cryptochrome and vision-based magnetoreception system in birds**. *Biophysical Journal*, 99: 40–49.
2) **Upper beak:** Fleissner, G., Stahl, B., Thalau, P., Falkenberg, G. & Fleissner, G. (2007). **A novel concept of Fe-mineral-based magnetoreception: histological and physicochemical data from the upper beak of homing pigeons**. *Naturwissenschaften*, 94: 631–642.
3) **Vestibular system:** Lauwers, M., Pichler, P., Edelman, N.B., Resch, G.P., Ushakova, L., Salzer, M.C., Heyers, D., Saunders, M., Shaw, J., & Keays, D.A., (2013). **An iron-rich organelle in the cuticular plate of avian hair cells**. *Current Biology*, 23(10): 924–929.