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Magnetoreception

Animal navigation is an ancient phenomenon. It is due to the fact that the resources on earth are not evenly distributed – and the distribution of resources changes with the season. Additionally, one must take the conditions of the environment into account along with the change of resources. For example, many animals in the world migrate due to changes in temperature of the seasons. One must also take into account that these 2 factors – resources and temperature – are linked, along with the seasons.

Migration distances are very widely distributed. Some animals migrate only a short distance – across islands for example, while other animals traverse entire oceans or landmasses (or multiple!). The initial mechanism for animal navigation was proposed by Charles Darwin in 1873, that of dead reckoning. However, this seems unlikely since animals must travel long distances correctly year after year. Eventually, many different mechanisms for migration were found – honeybees used the sun, polarization of the sky, and magnetic field of the earth to navigate. This was shown by Karl von Frisch in the 20th century. Homing pigeons also use scent, the sun, and earth's magnetic fields to navigate (shown by William Keeton). The cores of these findings is the conclusion that animals utilize many different methods for navigation.

The specific mechanism in question for this discussion is that of magnetoreception. This describes a sense which allows living creatures to detect magnetic fields. This lets them discover their altitude and location – assisting their navigation and development of regional maps. This phenomenon exists in bacteria, arthropods, and in major groups of vertebrates. The bacteria in question are called magnetotactic bacteria. The bacteria are called this because they exhibit magnetotaxis – orientation and migration along the earth's magnetic field lines. This is due to magnetosomes, tiny particles of magnetite or iron sulfide. The magnetosomes are bundled together, forming aligned chains in the presence of a magnetic field. Each of these groups of magnetosomes act as a magnetic dipole, allowing bacteria to detect the magnetic fields around them.

This simple model of magnetoreception in bacteria lets us hypothesize the methods of magnetoreception in animals – as the exact mechanism is unknown. There exist two main hypotheses for magnetoreception in animals. The first is the use of cryptochrome – a molecule that forms two radicals when it is exposed to blue light. The spins of the two electrons in the radicals are correlated. The time that the cryptochrome exists in its activated state depends on the nature of the magnetic field surrounding it, as different strengths and orientations will cause the dynamics of the two electrons to change and affect the relaxation time. Cryptochrome is posited to affect the sensitivity of retinal neurons to light, allowing any eyes with this molecule to “see” magnetic fields which shift the colors of the surroundings. Since the magnetic field of earth is only 0.5 Gauss, phase shift seems like the only likely noticeable change arising from its changes in orientation. The second mechanism proposed for magnetoreception is basen of iron oxide (magnetite – Fe_3O_4. This oxide is permanently magnetized as a ferromagnet once it becomes large enough to have significant domain size (~50 nm). This would also allow for animals to navigate with magnetic fields.

There is an additional mechanism for sensing magnetic fields in animals, using induction. This mechanisms has been most thoroughly explored in sharks and stingrays. These species have a specialized organ called the ampullae of Lorenzini which can detect slight variations in electric potential. The organ in question is simply a mucus-filled sac connected to the pores in the skin with a canal. These organs are posited to detect currents in the surroundings – effectively understanding the electric nature of the world around them. Through Faraday’s law, as the animal moves through a magnetic field, current will be generated which can be detected by the aforementioned ampullae of Lorenzini. Specifically, increases in the electric potential decrease the rate of nerve activity. They are located at the mouth and nose.

Invertebrates have also shown to orient themselves in magnetic fields. The nematode Caenorhabditis elegans was shown to posess the first described magnetosensory neurons. These worms us the magnetic field of earth to orient themselves vertically to dig through soil. The specific response is due to the satiety of the worm – inverting the signal and causing the worm to dig upwards. Additionally, the mollusk Tochuina tetraquetra has shown to orient themselves on magnetic north-east prior to a full moon. The pedal 5 and pedal 7 neurons have no known function – but have exhibited changes in firing over time after being exposed to magnetic stimulation. The fly Drosophila melanogaster has shown to be magnetosensory as well – as specific gene knockouts will affect whether the fly prefers magnetic field line directions or not. Control flies with type 1 Cry, the only cryphochrome gene they posess, were trained to follow magnetic fields. However, a mutation of the Cry gene prevented flies from recognizing the magnetic field, or prevented the learning of the correct field. Additionally, magnetoreception is well-documented in honey bees, ants, and termites.