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Magnetic Sensitivity Report

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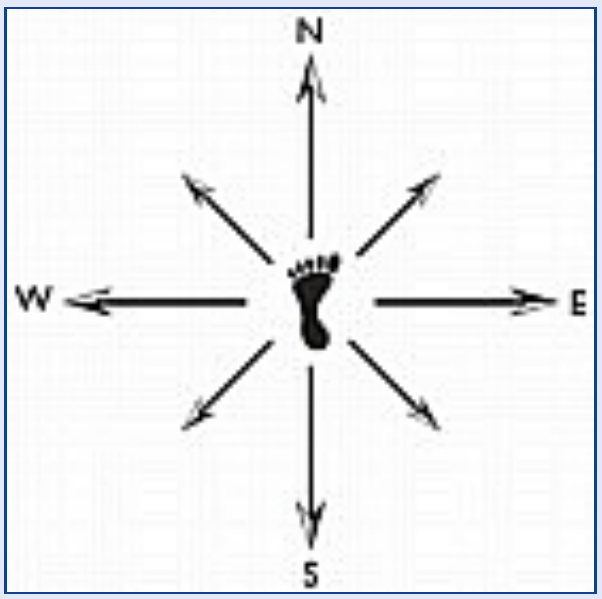

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Prepared by Halbert Katzen, J.D.
[Updated 8/15/08]

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Magnetic Sensitivity Summary

The Urantia Book states that all organisms have a biologic sensitivity to the earth's magnetic field and that this sensitivity is right on the edge of human consciousness. At the time of its publication in 1955, scientists did not generally believe that biologic organisms could have a mechanism that is sensitive to such a subtle electromagnetic field. Now many migratory and nonmigratory animals have been found to possess such sensitivity and some researchers assert that human beings also can sense the earth's magnetic field.

The Urantia Book asserts that the "bodies" responsible for this sensitivity were being discovered right around the time of *The Urantia Book's* narration, which it asserts was in the mid 1930's. In the mid 1930's scientists did discover that ampullae in a sharks snout had tiny inner ear type hairs and that there were nerves running from these ampullae to the brain. They could also tell that sharks were sensitive to electric fields. But it took until the 1960's to discover that the mechanism in these ampullae were extremely sensitive to electromagnetic fields.

Additionally, “In the 1960s, Caltech paleoecologist Heinz Lowenstam startled biologists and geologists alike with the discovery that many animals do what conventional science had considered impossible: they manufacture substances such as the iron-containing mineral magnetite [the most magnetically sensitive mineral on earth] within their bodies. Out of Lowenstam's work came the more recent finding that many migratory animals, including birds, bees, and whales, generate magnetite within their bodies and may owe their uncanny homing instincts to the presence of this "internal compass" that allows them to navigate by means of Earth's magnetic field.” Today,

various biological mechanism have been discovered that play a role in allowing many different types of animals to be sensitive to the earth's magnetic field.

Magnetic Sensitivity Review

Before addressing the particular scientific advances that having been catching up to *The Urantia Book's* statements about the sensitivity of humans and other organisms to the earth's magnetic field, some context needs to be provided regarding the assertions made by the authors of *The Urantia Book* about the limitations and permissions that were placed upon them in preparing scientific material for the book. On the one hand, *The Urantia Book* says:

> The laws of revelation hamper us greatly by their proscription of the impartation of unearned or premature knowledge. . .Mankind should understand that we who participate in the revelation of truth are very rigorously limited by the instructions of our superiors. We are not at liberty to anticipate the scientific discoveries of a thousand years. (Urantia Book 101:4.1,2)

On the other hand, *The Urantia Book* says,

> Let it be made clear that revelations are not necessarily inspired. The cosmology of these revelations is *not inspired*. It is limited by our permission for the co-ordination and sorting of present-day knowledge. . .
>
> While statements with reference to cosmology are never inspired, such revelations are of immense value in that they at least transiently clarify knowledge by:
>
> > 1) The reduction of confusion by the authoritative elimination of error.
> > 2) The co-ordination of known or about-to-be-known facts and observations.
> > (Urantia Book 101:4.2,5)

Striking a balance between not "anticipating the discoveries of a thousand years" and "the co-ordination of known or about-to-be-known facts and observations" is something that would have had to have been done regarding the issue of biological sensitivity to the earth's magnetic field. The initial phases of scientific study on this issue certainly began before *The Urantia Book* was published, and today scientific opinion on the subject still lacks a broad consensus. Nonetheless, the pattern of emerging science is well aligned with *The Urantia Book's* assertions on this topic. The early research that was done prior to *The Urantia Book's* publication has advanced significantly in the last several decades.

Whether human beings can be consciously sensitive to the earth's magnetic field is not a settled question in science. However, the ongoing research in this area is pointing in that direction the way a compass needle points north. Some researchers already conclude that sufficient evidence exists for the assertion that human beings have this capability to some degree.

Wikipedia's provides a brief encapsulation of the subject and a quick appreciation for the basic issues related to this report.

> Magnetoception (or "magnetoreception") is the ability to detect changes in a magnetic field to perceive direction or altitude and has even been postulated as a method for animals to develop regional maps. It is most commonly observed in birds, though it has also been observed in many other animals including honeybees and turtles. Researchers have identified a probable sensor in pigeons: a small (dwarf), heavily innervated region of the skull, which contains biological magnetite. Humans have a similar magnetite deposit in the ethmoid bone of the nose. Although there is no dispute that a magnetic sense exists in many avians (it is essential to the navigational abilities of migratory birds), it is a controversial and not well-understood phenomenon. . . In bees, it has been observed that magnetite is embedded across the cellular membrane of a small group of neurons; the theory is that when the magnetite aligns with the Earth's magnetic field, induction causes a current to cross the membrane which depolarizes the cell.[1]

Could it be that all we have to do to find magnetic north is follow our nose? *The Urantia Book* makes the following statements regarding a sense of direction and orientation:

> The four points of the compass are universal and inherent in the life of Nebadon [the section of the cosmos where Earth exists]. All living creatures possess bodily units which are sensitive and responsive to these directional currents. These creature creations are duplicated on down through the universe to the individual planets and, in conjunction with the magnetic forces of the worlds, so activate the hosts of microscopic bodies in the animal organism that these direction cells ever point north and south. Thus is the sense of orientation forever fixed in the living beings of the universe. This sense is not wholly wanting as a conscious possession by mankind. These bodies were first observed on Urantia [Earth] about the time of this narration. (Urantia Book 34:4.10)

The Urantia Book claims that its content was provided in the mid 1930's; however, it was not published until 1955. Though the publication date is a universally uncontenscious issue, it's claim that the content of *The Urantia Book* was provided in the mid 1930's is an issue that attracts a broader range of opinion and is not so easily verified as the book's publication date. Notwithstanding that various forms of evidence exist to support the mid 1930's date, the accuracy of this date is not what is at issue here. The date is relevant because it provides a way to investigate the internal consistency of *The Urantia Book*. Because the text refers to the "time of this narration," presumably the mid 1930's date, and not the publication date, reflects the intended meaning.

If there were no evidence of the discovery in the mid 1930's of "bodies" that are sensitive to the earth's magnetic field, this lack of evidence would have to weigh against the credibility of *The Urantia Book*. But such is not the case. However, to *The Urantia Book's* credit, the observations of the mid 1930's, as will be shown, were not at all conclusive about sensitivity to the earth's magnetic field. They simply found a mechanism in sharks that was highly sensitive to electromagnetic fields. Therefore, *The Urantia Book* authors did risk loosing credibility if the observations in the mid 1930's were not later tied to issues regarding sensitivity to the earth's magnetic field.

However, before reviewing scientific discoveries on this subject, it is important to first provide some general information on the relationship between electricity and magnetism. This is necessary in order to appreciate why the jargon in this topic switches from "electroreceptors" to "magnetoreceptors."

> Electromagnetism is the physics of the electromagnetic field: a field which exerts a force on particles that possess the property of electric charge, and is in turn affected by the presence and motion of those particles.
>
> The magnetic field is produced by the motion of electric charges, i.e. electric current. The magnetic field causes the magnetic force associated with magnets.
>
> A changing magnetic field produces an electric field (this is the phenomenon of electromagnetic induction, the basis of operation for electrical generators, induction motors, and transformers). Similarly, a changing electric field generates a magnetic field. Because of this interdependence of the electric and magnetic fields, it makes sense to consider them as a single coherent entity-the electromagnetic field.[2]

With that understanding we can now proceed with appreciating scientific developments that are harmonious with *The Urantia Book's* assertion that observations were made in the mid 1930's related to biological mechanisms that would later be discovered to be sensitive to the earth's magnetic field.

In the **History of Electroreceptors** section of Faramarz Samie's paper titled *Electroreception in Elasmobranchs* he states:

> The first evidence of electrosensitivity in elasmobranchs dates back to 1935 when Dijkgraaf, working on Scyliorhinus canicula, noticed the animal's sensitivity to a rusty steel wire (Dijkgraaf & Kalmijn, 1962). The experimenters approached the head of a blindfolded shark with such a wire. They observed that the animal escaped when the wire was closer than several centimeters from its head. They repeated the experiment with a glass rod, but the animal did not react to it. Dijkgraaf assumed that the shark was stimulated by the galvanic currents produced at the surface of the metal wire, but

had no way of proving his assumption.

> Dijkgraaf's hypothesis largely remained a speculation until Lissmann in 1958 formally suggested, based on behavioral evidence, that a group of receptors and central processes, called the ampullae of Lorenzini, aid in the detection and analysis of electric fields in the marine environment of fish. Later, experimenters verified the existence of the new class of specialized receptors through physiological experiments. They named them "electroreceptors" because their adequate stimuli were electric fields (Bullock et al. 1961, Kalmijn, 1966, 1971).[3]

The *Shark's Electric Sense* article in the August 2007 edition of Scientific American provides additional information on the history of the discovery of electromagnetic sensitivity in animals:

> The story begins in 1678, when Italian anatomist Stefano Lorenzini described pores that speckled the forward part of the head of sharks and rays, endowing them with something resembling a bad five-o'clock shadow. He noted that. . .each opening led to a long transparent tube that was filled with a crystalline gel. Some of the tubes were small and delicate, but others were nearly the diameter of a strand of spaghetti and several inches in length. . .
>
> By the late 19th century the newly improved microscope revealed that the pores on a shark's snout and the unusual structures underneath them, today called ampullae of Lorenzini, must be sensory organs of some kind. . .
>
> A thin nerve emerged from the ampulla and joined branches of the anterior lateral line nerve. Scientists traced these nerve fibers to the base of the skull, where they enter the brain through the dorsal surface of the medulla, a destination characteristic of nerves that carry sensory information into the brain. Observers discerned a single tiny hair cell, similar to those of the human inner ear and of a fish's lateral line system, inside each ampulla. The type of stimulus they might detect remained unknown, however. . .
>
> In 1938 Alexander Sand of the Marine Biological Association of Plymouth, England, succeeded in amplifying and recording nerve pulses running from ampullae of Lorenzini to the brain. . . In the early 1960s biologist R. W. Murray of the University of Birmingham in England repeated Sand's experiments with modern electrophysiological instruments and confirmed the responses to temperature changes, pressure differences and touch, but he also observed that the organs were sensitive to slight variations in salinity. Moreover, when he happened to switch on an electric field near the opening of a tube connected to an ampulla, the firing pattern changed. Further, the pattern altered according to the intensity and polarity of the field. When the field's positive pole neared the opening of an ampulla, the firing rate declined; when the negative pole came near, firing increased.
>
> Astonishingly, Murray determined that the organs could respond to fields as weak as one millionth of a volt applied across a centimeter of seawater. This effect is equivalent to the intensity of the voltage gradient that would be produced in the sea by connecting up a 1.5 volt AA battery with one pole dipped in the Long Island Sound and the other pole in the waters off Jacksonville, Florida. Theoretically, a shark swimming between these points could tell when the battery was switched on or off.

This discovery in the mid 1930's of some of the functional characteristics of the ampullae of Lorenzini is in harmony with *The Urantia Book's* statement that the "bodies were first observed on Urantia about the time of this narration." Also consistent with *The Urantia Book's* assertion that its authors "are not at liberty to anticipate . . . scientific discoveries," is that there is no mention of magnetite being present in biologic organism, as this was not discovered until after *The Urantia Book's* publication in 1955.[4] Additional discoveries were made within the ten years following publication of *The Urantia Book* that took this type of research to the next level. The conclusion regarding magnetic sensitivity is given by *The Urantia Book*, but the details are withheld. This could be the type of about-to-be-discovered knowledge that the authors indicate is within the permissible range of providing revelatory information.

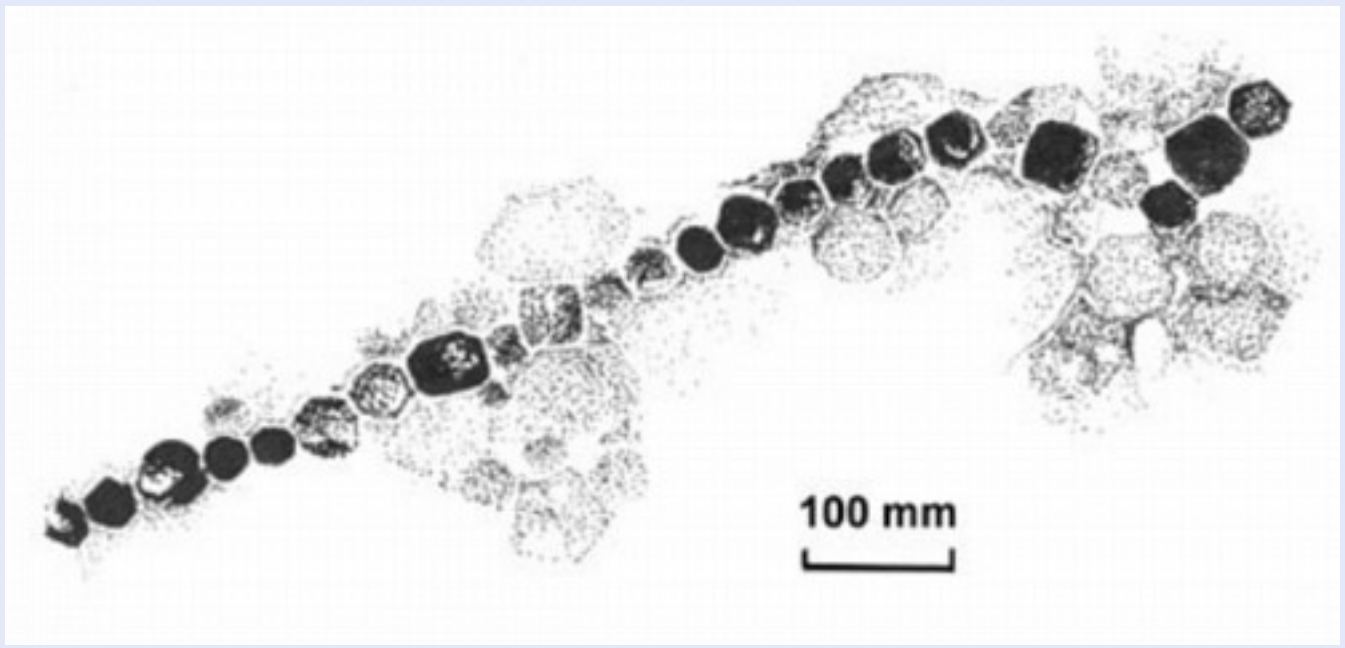
> In the 1960s, Caltech paleoecologist Heinz Lowenstam startled biologists and geologists alike with the discovery that many animals do what conventional science had considered impossible: they manufacture substances such as the iron-containing

mineral magnetite within their bodies. Out of Lowenstam's work came the more recent finding that many migratory animals, including birds, bees, and whales, generate magnetite within their bodies and may owe their uncanny homing instincts to the presence of this "internal compass" that allows them to navigate by means of Earth's magnetic field.[5]

The discovery of magnetite in numerous migrating species supports *The Urantia Book's* assertion that a general ability to detect direction exists throughout the spectrum of biological organism.

Magnetite is the world's most magnetic substance. In the article *Biomagnetism and Bio-Electromagnetism: The Foundation of Life* H. Coetzee, Ph.D. further explains the importance of this discovery.

> The discovery of a biogenic material (that is, one formed by a biological organism) with ferromagnetic properties [the ability to maintain magnetic properties without an outside electric current being applied] and found to be magnetite was the first breakthrough toward an understanding as to why some animals have the ability to detect the earth's magnetic field. Searches for biogenic magnetite in human tissues had not been conclusive until the beginning of the 1990's when work with high-resolution transmission electron microscopy and electron diffraction on human brain tissue extracts of the cerebral cortex, cerebellum, and meninges (membranes surrounding the brain and spinal cord) identified magnetite-maghemite crystals.



Magnetite Crystals under Low Magnification

These magnetite crystals were found to be organized into linear, membrane-bound chains a few micrometers in length, with up to 80 crystals per chain. Furthermore individual crystals have their magnetite-maghemite aligned along the length of the chain axes (the "easy" direction of magnetization). The magnetite-maghemite crystal alignment has been interpreted as a biological mechanism for maximizing the magnetic moment per particle, as the magnetite-maghemite direction yields approximately 3% higher saturation magnetization than do other directions. This prismatic particle shape is also uncommon in geological magnetite crystals of this size, which are usually octahedra. The crystal morphology was found to be cubo-octahedral with the magnetite-maghemite faces of adjacent crystals lying perpendicular to the chain axis.

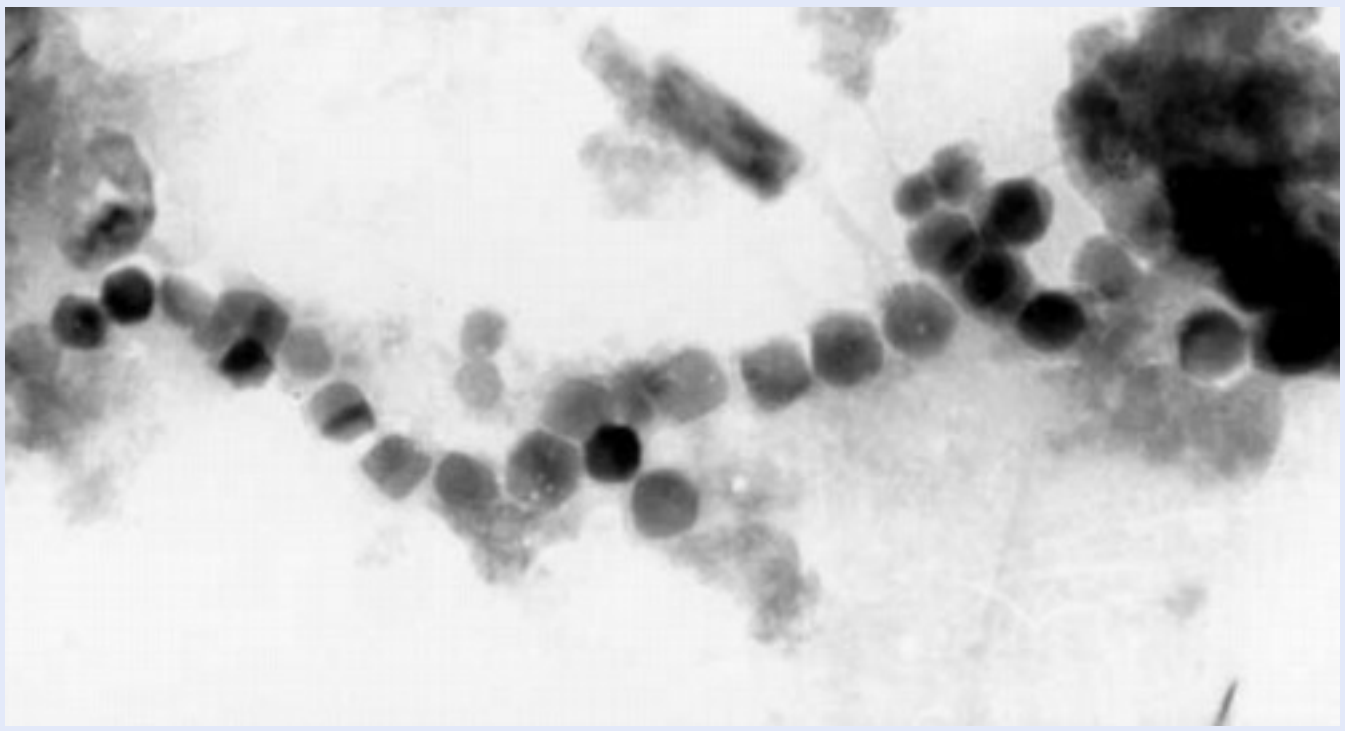
All the magnetite crystals that have been examined to date are single magnetic domains, which means that they are uniformly and stably magnetized and have the maximum magnetic moment per unit volume possible for magnetite. Elemental analysis, by energy-dispersive X-ray analysis, electron diffraction patterns, and high resolution transmission electron microscopy lattice images, showed that many of the particles were structurally well-ordered and crystallographically single-domain magnetite. This means that the production of this biomineral must be under precise biological control.

Ferromagnetic crystals interact more than a million times more strongly with external magnetic fields than do diamagnetic or paramagnetic materials (deoxyhemoglobin, ferritin, and hemosiderin). With this finding researchers were posed with a

fundamental question for biology, namely: What is the mechanism through which the weak geomagnetic fields are perceived by organisms that are able to precipitate crystals of a ferromagnetic mineral such as magnetite (Fe_3O_4)? Could these crystals use their motion in a variety of ways to transduce the geomagnetic field into signals that can be processed by the nervous system?

The presence of membrane-bound biomineral magnetite, which has been shown to have a biological origin, and the implication that some kind of mechanical coupling must take place between each compass magnetite particle and a mechanoreceptor, or at least a functionally equivalent mechanism allowing the position of the particle to be monitored by a sensory organelle in the body, is unique. Research has also found that the magnetite is produced by the cells of the organism when needed. Forms of advanced physical intelligence can directly tap into this information if they have a crystalline network within their brain cavity.

Scientists are now asking the fundamental question: What is magnetite doing in the human brain? In magnetite-containing bacteria, the answer is simple: Magnetite crystals turn the bacteria into swimming needles that orient with respect to the earth's magnetic fields. Magnetite has also been found in animals that navigate by compass direction, such as bees, birds, and fish, but scientists do not know why the magnetite is present in humans, only that it is there.[6]



Above: A linear chain of biogenic magnetite crystals, extracted from tissues in the frontal region of the sockeye salmon, *Oncorhynchus nerka,* a close relative of the rainbow trout, *Oncorhynchus mykiss*. These are also single magnetic domains, with crystal alignments similar to those in magnetotactic bacteria. *(Photo credit: S. Mann)*

Even though scientists have discovered biogenic magnetite in animals, there still remains the question of whether and how such bodies could actually stimulate the brain in order to provide directional information. In the late 1990's results began to be published out of the University of Auckland of experiments that showed nerves connecting regions in both the skull and the nose of rainbow trout where magnetite is produced.[7]

> Since magnetite had been previously found in trout's skulls, the investigators decided to record neural activity from nerves that innervate the relevant region of the skull. They discovered a population of nerve fibers that respond to changes in the ambient magnetic field in one specific nerve, called the ros V ("ros five" nerve). This is a branch of the trigeminal nerve, which supplies an innervation to the face and skull of all vertebrates, including humans. Dye was used to trace this nerve to the nose of the trout.[8]
>
> Although this may seem like more than a smoking gun, Dr. Diebel is still cautious. Although she believes these are the long sort-after magneto-receptors, she says they are yet to prove the receptors are actually connected to the nerves. That involves future more complex experiments.[9]

Indeed, some caution in jumping to conclusions may be good advice. On May 14, 2004 Science Daily published an article that brings into to question whether nerves to the brain from locations where magnetite is present are responsible for magnetoreception. An article entitled *Following Earth's Magnetic Field: Chemical Reaction In Birds Provides Sense Of Direction During Migratory Flights* indicates that magnetite is not necessary. The article, however, seems to jump to conclusions by arguing that magnetite is not involved because it is possible that animals have redundant systems so that they can continue to navigate when one of their systems may not be able to function effectively.

> Migrating birds stay on track because of chemical reactions in their bodies that are influenced by the Earth's magnetic field, a UC Irvine-led team of researchers has found.
>
> The birds are sensitive even to rapidly fluctuating artificial magnetic fields. These fields had no effect on magnetic materials such as magnetite, indicating that the birds do not rely on simple chunks of magnetic material in their beaks or brains to determine direction, as experts had previously suggested.
>
> The results are reported in the May 13 issue of Nature. The study is the first to reveal the mechanism underlying magnetoreception the ability to detect fluctuations in magnetic fields in migratory birds.
>
> In the study, Thorsten Ritz, assistant professor of physics and astronomy, and colleagues exposed 12 European robins to artificial, oscillating magnetic fields and monitored the orientation chosen by these birds. The stimuli were specially designed to allow for responses that could differ depending on whether birds used small magnetic particles on their bodies or a magnetically sensitive photochemical reaction to detect the magnetic field.
>
> We found that the birds faced in the usual direction for their migration when the artificial field was parallel to the Earth's natural magnetic field, but were confused when the artificial field was applied in a different direction," said Ritz, the lead author of the paper. "Since the artificial field's oscillations were too rapid to influence magnetic materials like magnetite, it suggests that the most likely mechanism for magnetic orientation in these birds involves tiny changes to magnetically sensitive chemical reactions, possibly occurring in the eyes of the birds we are not sure.
>
> In the experiments, the robins could walk and flutter in their cages but could not fly. The birds oriented well in the Earth's magnetic field alone, but were disoriented in the presence of a broad-band (0.1-10 megahertz) and 7 megahertz oscillating field, aligned at a 24 or 48 degree angle to the Earth's magnetic field. When the same 7 megahertz oscillating field was aligned parallel to the Earth's magnetic field, the robins showed normal migratory orientation again.
>
> Unlike our senses involving vision, hearing, smell and touch, we do not know what receptors underlie magnetoreception," Ritz said. "Migratory birds have long been known to possess a magnetic compass that helps them find the correct direction during their migratory flights. It has remained unknown, however, how birds can detect the direction of the Earth's magnetic field.
>
> Now, our study points to what we need to look for a molecular substrate for certain chemical reactions. That is, we can rule out magnetic materials in birds' beaks and elsewhere as being possible candidates. Magnetite in the beaks, however, may play a role in detecting the strength but not the direction of the Earth's magnetic field.

Though the final word is obviously not in on the subject of megnetoreception, some things have been well established. One is that many animals are sensitive to the earth's magnetic field and are able to use this sensitivity for navigation. These findings are increasingly supportive of *The Urantia Book's* assertion that all organisms have this ability to some degree. Additionally, even though human sensitivity to the earth's magnetic field still remains an open question, there is uncontroversial evidence of the presence in the human body of magnetite and other mechanisms that seem to parallel those found in animals that do exhibit sensitivity to the earth's magnetic field. As well, the way the research has been unfolding is consistent with *The Urantia Book's* assertion that the specific information it provides must be limited with respect to what has already been

discovered, even though the authors are given leeway to provide for the "co-ordination of known or about-to-be-known facts and observations."[10]

Footnotes:

1 http://en.wikipedia.org/wiki/Magnetoception

2 http://en.wikipedia.org/wiki/Electromagnetism

3 http://wrt-intertext.syr.edu/II2/samie.html

4 Urantia Book 101: 4.2

5 http://www.admissions.caltech.edu/about/milestones

6 http://www.affs.org/html/biomagnetism.html

7 http://www.abc.net.au/science/news/stories/s154625.htm

8 Howard C. Hughes: Sensory Exotica: a world beyond human experience; 1999, Ch. 10

9 http://www.abc.net.au/science/news/stories/s154625.htm

10 Urantia Book 101:4.5

Post Publication Support

Phys.org: July 10, 2012
Researchers find cells that move in response to Earth's magnetic field
For nearly half a century scientists have known that some animals are able to navigate using the earth's magnetic field and for nearly thirty years, it's been assumed that at least some of those animals that are able to "feel" the weak magnetic field are able to do so because of small amounts of iron material in their tissue. Now, a team of researchers led by Michael Winklhofera of Ludwig-Maximilians-University in Munich, have discovered a way to find individual cells that respond to a magnetic field in one species of migrating fish. As they describe in their paper published in the Proceedings of the National Academy of Sciences, all it took was the introduction of a rotating artificial magnetic field.
http://phys.org/news/2012-07-cells-response-earth-magnetic-field.html

BBC News: April 27, 2012
Magnetic fields light up 'GPS neurons', scientists say
"Researchers have spotted a group of 53 cells within pigeons' brains that respond to the direction and strength of the Earth's magnetic field. The question of how birds navigate using - among other signals - magnetic fields is the subject of much debate. These new "GPS neurons" seem to show how magnetic information is represented in birds' brains. . . ."
http://www.bbc.co.uk/news/science-environment-17855194

Reuters: February 25, 2009
Report on how magnets are used to confuse the sense of direction in crocodiles when they are being relocated.
http://www.reuters.com/article/scienceNews/idUSTRE51O08M20090225

San Diego Union-Tribune: August 25, 2008
New satellite data from all over the world reveals that cows tend to align with earth's magnetic field!
http://www.signonsandiego.com/news/science/20080825-1400-sci-cowcompass.html

Integrative and Comparative Biology: 1991
From the Abstract: "We conclude honey bees are sensitive to the geomagnetic field, that the signal processing for it is more complex than previously thought, and that a ferromagnetic transducer is compatible with all known behavioral data."
http://icb.oxfordjournals.org/cgi/content/abstract/31/1/169

Deeper and Broader

Additional Urantia Book commentary

Urantia Book: 36:5.2,5,5

> The seven adjutant mind-spirits are called by names which are the equivalents of the following designations: intuition, understanding, courage, knowledge, counsel, worship, and wisdom. These mind-spirits send forth their influence into all the inhabited worlds as a differential urge, each seeking receptivity capacity for manifestation quite apart from the degree to which its fellows may find reception and opportunity for function.
>
> . . .
>
> We are handicapped for words adequately to designate these seven adjutant mind-spirits. They are ministers of the lower levels of experiential mind, and they may be described, in the order of evolutionary attainment, as follows:
>
> 1. The spirit of intuition—quick perception, the primitive physical and inherent reflex instincts, the directional and other self-preservative endowments of all mind creations; the only one of the adjutants to function so largely in the lower orders of animal life and the only one to make extensive functional contact with the nonteachable levels of mechanical mind.

Additional Resources

American Society for Microbiology, March 2005
Habits of Magnetosome Crystals in Coccoid Magnetotactic Bacteria
Abstract: High-resolution transmission electron microscopy and electron holography were used to study the habits of exceptionally large magnetite crystals in coccoid magnetotactic bacteria. In addition to the crystal habits, the crystallographic positioning of successive crystals in the magnetosome chain appears to be under strict biological control.
http://aem.asm.org/cgi/content/full/71/8/4902

Science Daily: May 14, 2004
Following Earth's Magnetic Field: Chemical Reaction In Birds Provides Sense Of Direction During Migratory Flights
"Migrating birds stay on track because of chemical reactions in their bodies that are influenced by the Earth's magnetic field, a UC Irvine-led team of researchers has found. The birds are sensitive even to rapidly fluctuating artificial magnetic fields. These fields had no effect on magnetic materials such as magnetite, indicating that the birds do not rely on simple chunks of magnetic material in their beaks or brains to determine direction, as experts had previously suggested."
http://www.sciencedaily.com/releases/2004/05/040514030725.htm

PBS/NOVA, Animal Magnetism: November 18, 2003
Considers the question: "Would a dramatic change in the Earth's magnetic field affect creatures that rely on it during migration?"
http://www.pbs.org/wgbh/nova/magnetic/animals.html

The magnetic sense and its use in long-distance navigation by animals: 2002
Introduction: "True navigation by animals is likely to depend on events occurring in the individual cells that detect magnetic fields. Minimum thresholds of detection, perception and 'interpretation' of magnetic field stimuli must be met if animals are to use a magnetic sense to navigate. Recent technological advances in animal tracking devices now make it possible to test predictions from models of navigation based on the use of variations in magnetic intensity."
http://www.gps.caltech.edu/users/jkirschvink/pdfs/COINBWalker.pdf

Lund University: 2001
Animal Magnetoreception- Models, Physiology and Behaviour
From the Introduction: "Despite intensive research, the biophysical mechanisms of magnetoreception are not entirely known yet. Magnetobiological effects comprise processes at different hierarchical levels of a living organism, from molecular biochemical processes, leading to mutagenic, morphological and developmental effects, to complex adaptive biological processes including magnetic alignment and orientation of whole animals. In this introductory paper, I give an overview over the existing models and theories concerning the perception of magnetic fields and discuss available empirical results from physiological as well as behavioural studies in some

selected animals in relation to these models.
http://www.angel.ekol.lu.se/~rachel/publications/Introductory%20Paper%20def.pdf

Magnetite in Human Tissues: A Mechanism for the Biological Effects of Weak ELF Magnetic Fields
Bioelectromagnetics Supplement 1992
From Abstract: "A simple calculation shows that magnetosomes moving in response to earth-strength ELF fields are capable of opening trans-membrane ion channels, in a fashion sitnilar to those predicted by ionic resonance models. Hence, the presence of trace levels of biogenic magnetite in virtually all human tissues examined suggests that similar biophysical processes may explain a variety of weak field ELF bioeffects."
http://www.gps.caltech.edu/~jkirschvink/pdfs/KirschvinkBEMS92.pdf

Proceedings of the National Academy of Science: August 1992
Magnetite biomineralization in the human brain
ABSTRACT: Although the mineral magnetite (Fe3O4) is precipitated biochemically by bacteria, protists, and a variety of animals, it has not been documented previously in human tissue. Using an ultrasensitive superconducting magnetometer in a clean-lab environment, we have detected the presence of ferromagnetic material in a variety of tissues from the human brain. Magnetic particle extracts from solubilized brain tissues examined with high-resolution transmission electron microscopy, electron diffraction, and elemental analyses identify minerals in the magnetitemaghemite family, with many of the crystal morphologies and structures resembling strongly those precipitated by magnetotactic bacteria and fish. . . .
http://www.pnas.org/cgi/reprint/89/16/7683.pdf

Magnetite Biomineralization and Geomagnetic Sensitivity in Higher Animals: An Update and Recommendations for Future Study: 1989
Introduction: "Magnetite, the only known biogenic material with ferromagnetic properties, has been identified as a biochemical precipitate in three of the five kingdoms of living organisms, with a fossil record that now extends back nearly 2 billion years. . ."
http://www.gps.caltech.edu/~jkirschvink/pdfs/KirschvinkBEMS89.pdf

Princeton University: August 15, 1980
FERROMAGNETIC CRYSTALS (MAGNETITE?)IN HUMAN TISSUE
From the introductory remarks: "In recent years, a variety of animals have been found which are able to synthesize the ferromagnetic mineral magnetite (Fe3O4). Lowenstam (1962) originally recognized biogenic magnetite in the radular teeth of a primitive marine mollusc, the chiton (Polyplacophora), and since then it has been identified as a precipitate in several magnetically sensitive organisms, including honey bees (Gould, Kirschvink & Deffeyes, 1978), homing pigeons (Walcott, Gould & Kirschvink, 1979) and in magnetotactic bacteria (Frankel, Blakemore & Wolfe, 1979). Zoeger, Dunn & Fuller (1980) also report a localized concentration of magnetite in dolphin heads, although magnetosensory behavioural experiments have not as yet been done on them. Magnetite is biologically unique because it is both ferromagnetic and conducts electricity like a metal; consequently it interacts strongly with magnetic and electric fields. Due to the numerous industrial and research environments which expose people to artificially intense electromagnetic conditions, it is of importance to know whether or not this material might exist in human tissue.
http://jeb.biologists.org/cgi/reprint/92/1/333.pdf

MAGNETIC FIELDS AND THE ORIENTATION OF HOMING PIGEONS UNDER SUN
State University of New York, Stoneybook: March 1, 1977
SUMMARY: "Applying a magnetic field of 0-1 Gs (1 gauss = io~*T) to the heads of pigeons homing from unfamiliar release sites significantly increased the scatter of the birds' vanishing bearings. A magnetic field of 0-3 gauss caused no difference between the orientation of birds wearing coils with either their north or south pole up. But a field of 0-6 gauss (equal to that of the Earth) produced a small difference in the vanishing bearings of the two groups. Since an applied magnetic field has an effect on pigeon orientation under sun, it appears that pigeons do not simply switch between a magnetic and a sun compass, but that there is some interaction between the two systems."
http://jeb.biologists.org/cgi/reprint/70/1/105.pdf

Theoretical and Computational Biophysics Group website:
Magnetic Sensitivity in Animals
Introduction: "A large variety of animals possess a magnetic sense. Migratory birds use magnetic clues (in addition to light polarization, star signs, position of the sun) to find their way south in fall and north in spring. Salamanders, frogs, use the magnetic field for orientation when they have to

find the direction of the nearest shore quickly, e.g., when they sense danger. Behavioral experimentalists have used these natural movement patterns to design experiments that allow them to investigate in which way geomagnetic information is used for orientation. . ."
http://www.ks.uiuc.edu/Research/magsense/

Electroreception in Elasmobranchs by Faramarz Samie
From the introductory remarks: "According to Theodore H. Bullock, a neuroscientist, "the prediction, discovery, and establishment of electroreceptors is of extreme interest not only for the intrinsic insight into the life of some elasmobranchs that see the world through a new sense but also for the lessons it teaches about identifying and classifying receptors by function." As a response to this statement, this article will address electroreception in elasmobranchs by examining the history of electroreception, the morphology of electroreceptors, the physiological and behavioral evidence, and, lastly, the ways electroreception influences the behavior of these remarkable animals."
http://wrt-intertext.syr.edu/ll2/samie.html

Future History Volume 8 (The Academy for Future Science)
Biomagnetism and Bio-Electromagnetism: The Foundation of Life
From the introductory remarks: "Throughout the past 30 years, scientists have been extensively researching organisms that have the ability to produce the ferromagnetic mineral magnetite. . . .The discovery of a biogenic material (that is, one formed by a biological organism) with ferromagnetic properties and found to be magnetite was the first breakthrough toward an understanding as to why some animals have the ability to detect the earth's magnetic field. Searches for biogenic magnetite in human tissues had not been conclusive until the beginning of the 1990's when work with high-resolution transmission electron microscopy and electron diffraction on human brain tissue extracts of the cerebral cortex, cerebellum, and meninges (membranes surrounding the brain and spinal cord) identified magnetite-maghemite crystals."
http://www.affs.org/html/biomagnetism.html

University of Western Australia: Biophysics Department
Iron Biomineralization in the Human Brain
This link leads you to numerous abstracts from research done in this area.
http://www.biophysics.uwa.edu.au/magnetite.html

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