How birds see magnetic fields – an interview with Klaus Schulten

« On jargon, and why it matters in science writing How birds see magnetic fields – an interview with Thorsten Ritz »
By Ed Yong | November 24, 2010 6:14 pm

It's now winter in Europe and many small birds are well on their way to warmer climes, migrating over large tracts of land in search of better weather. Along the way, they keep their course with a remarkable supersense – the ability to sense magnetic fields.

This sense is known as magnetoreception. It sounds like a party for an X-Men villain, and it's also the subject of my latest feature, out in this week's issue of New Scientist. I talk about how birds sense magnetic fields, using a compass in the eye and a map in the beak. I look at why the magnetic sense has been so fiendishly difficult to study and why it has taken five decades to unravel some of its details.

For the full details, you'll have to read the feature, but this is the quick version: when light enters the eyes of birds, it excites a molecule called cryptochrome, shunting it into a state when it can be affected by the earth's magnetic field. The upshot is that you can 'blind' a bird to magnetic fields by covering its eyes (and sometimes, just the right one). It's possible that they may even be able to *see* the fields as patterns overlaid on top of their normal vision.

One of the reasons that magnetoreception is such a tricky topic (for scientists as well as science writers!) is that it straddles incredible diverse fields of research, including quantum physics, neuroscience and animal behaviour. Only a few scientists can bridge such divides, and I had the pleasure of interviewing two of them for my piece: Klaus Schulten and Thorsten Ritz. Both gave eloquent, insightful and funny interviews that were inevitably pared down into a few short quotes for the feature. Fortunately, I have all the space I need to make that material publicly available.

First up is Schulten, who talks with marvellous clarity about the early days of the research and where it expects it to go. He was warm and jovial, and gave a great insight into how discoveries are made – by connecting dots that no one else can see. I've edited it very gently for length, but the words are all his.

Talk to me about the early days of the research. How did you get involved?

That goes a long time back all the way to 1975 when I was a post-doc at the Max Planck Institute. It started with some basic chemistry experiments that could be influenced by weak magnetic fields. I developed a theory that explained the behaviour. You could follow a rapid chemical reaction that involved absorption of light by one of two molecules and transfer of electrons between them. One could influence this reaction with a simple door magnet.

Immediately, I thought about the open problem of magnetoreception in behavioural biology. It had been discussed for decades earlier and I thought maybe this reaction, which was entirely feasible in living cells, could explain magnetoreception in birds and other animals. So I submitted a 1978 paper to Science that made this suggestion. I got the paper back with a rejection note saying, "A less bold scientist may have designated this idea to the waste paper basket". I scratched my head and thought, "This is either a great idea or entirely stupid." I decided it was a great idea and published it quickly in a German journal!

Then I gave a lecture at Harvard, where I had been a graduate student. The Nobel-prize-winner Dudley Hershbach listened to it and said, "In a test tube, you need light. Where is the light in the bird?" I knew this was a good question and thought that magnetoreception would likely be in the eye and actually involve the visual system of birds. The behavioural biologists, who were really quite desperate about finding where the magnetic compass was located in animals, immediately took up this suggestion and added light to the experiments. Very quickly, they saw there was a very strong light effect. That is how it all started.

Your website suggests that birds could actually see magnetic fields and that the fields appear as light or shade on their field of vision. How solid is that idea?

The problem is that I'm not Doctor Doolittle! I can't talk to the animals and I would love to ask them. Magnetoreception seems to be involved in their visual system because they need light. If you cap the eyes – actually, if you cap just one eye, you can influence it. So one eye is more involved. How that actually works, I have no clue except that one could imagine how it could be for humans. The idea is simply that the eye is a great sensor to be participating in magnetoreception because magnetoreception is about orientation and the eye is about orientation.

Any kind of visual pattern that depends on the Earth's magnetic field that you could impose on the normal visual pattern could help the bird. Now you don't want this magnetic-field dependent pattern too strong because the bird has to find food, it has to orient, it has to avoid the eagle that might want to catch it. And so you have a subtle kind of effect.

It turns out that whenever some shade or some bit of discolouration in the visual field moves, humans and other animals – but particularly birds – can pick it up easily. So I thought that there is some sort of pattern that when the bird moves its head, the pattern moves and the bird can actually see this pattern that's due to the Earth's magnetic field quite easily. So I would imagine some type of shade that is superimposed by the bird. I made this suggestion in 1978.

Who came up with the cryptochrome idea? Was it something you yourself realised?

I waited until I really had some concrete ideas about which molecule in the eye might actually be responsible for magnetoreception. It took me until 2000, when it was shown that cryptochrome is present in the eye of many animals, that I published my paper. I knew from my knowledge as a physicist and a biochemist that cryptchrome realises exactly this light-induced electron-transfer reaction that I had been dealing with in the test tube in 1975. [*When light hits cryptochrome, it nudges an electron over to a partner molecule called FAD. The two molecules become what's known as a 'radical pair', which can be influenced by magnetic fields. – Ed*]

When I heard cryptochrome and eye, I just fell of my chair and realised this was exactly what was needed. I realised it within a split-second. So I published in 2000 a paper about how birds can see the Earth's magnetic field using cryptochrome. That was the starting point.

Cryptochrome is an interesting signalling molecule that's involved in the daily rhythm of people and the biological clock. I knew this and I knew that the clock is light-triggered. It's in a part of the brain where some reptiles actually receive light from the outside through a hole in the skull. In other animals, light goes from the eye to the brain centre where cryptochrome is. And one day there was an article – I can't remember in which journal – where people discovered that there was cryptochrome in the eye. Before it was only in the brain and now suddenly they showed that there is cryptochrome in the eye!

And that for me was the breakthrough. I thought that bird eyes were involved in magnetoreception and suddenly I had a molecule that could do the job. It was exactly capable of carrying out this magnetic field effect that I had discovered in 1975. Today, people are very convinced – it's not 100% proven, one should say that – but people are very convinced that cryptochrome is involved in magnetoreception.

Cryptochrome is very interesting because it's found throughout many animal groups. If it's so common, why can't more animals sense magnetic fields? Why can't humans do it, for example?

So now I'm getting a little crazy and I'm not sure if this is really… <chuckles>. Okay, so I'll go a little bit to the edge. I wrote a paper two years ago where I suggested that there are actually two magnetic field-dependent reactions in cryptochrome. There is a second reaction that involves superoxide, a negatively charged oxygen molecule. This is a molecule that's quite common in our metabolism – you cannot avoid it. [*Superoxide is incredibly reactive and rather destructive – Ed*] This is why you eat antioxidants like blueberries to keep health. The body checks the concentrations of superoxide very well. A molecule called superoxide dismutase is like a vacuum cleaner that takes away all superoxide but obviously leaving a little bit because it can't find every molecule.

We showed in this publication that very low concentrations of superoxides could really add to the magnetic sensitivity of cryptochrome. I made this tongue-in-cheek suggestion that maybe some animals like humans are more interested in longevity than good orientation; so we'd rather lower our superoxide concentrations so our cryptochrome can't really utilise it. Other animals that are more short-lived can afford a higher concentration so they can use superoxide with their cryptochrome.

But I think this is a little crazy. The simple answer might be that like everything else, having magnetoreception has a cost. Every sense has a cost. Maybe for humans and other animals, magnetoreception is not so important but for birds and other animals that are migratory, it's very important. They have bad weather conditions where you can't see your hand in front of your eyes but you still need to know where is north and where you are because if you drift away too far, you're dead. So for them, it's more important but for animals that live more locally or get experience for where they are through other means, it's less important.

Do you think the behavioural studies using live birds are starting to run out of answers? Will we start to need contributions from genetics, neuroscience and other disciplines?

Absolutely. A sense that we do not share depends on the behavioural biologists because you have to somehow talk to the animals – that's a science that can do that. At the end of the day, we must prove in very clear terms that the sense that is being postulated exists and what its properties are. We don't debate that there is a visual sense because we share it and we know it's there. But still there are many scientists who study in detail the sensitivity of the visual sense, how many photons we need, how we're adapted in the dark, how we distinguish so many colours. These are studied genetically.

The same is true for the magnetic sense; just as we study the visual sense atom by atom, literally going down the level of the individual proteins that are involved in the visual sense, we have to go down to the individual protein in the cryptochrome in magnetoreception. We definitely now have to go beyond the behavioural biology. In vision, there is no debate. In magnetoreception, we need lots of careful biochemical and cellular biology studies. I would be only intellectually happy if we're doing the same kind of careful, detailed analysis right back to the atomic level for magnetoreception. The field is very clearly moving towards going to the microscopic level, finding the molecules involved and what their physical properties are. It's a lot of fun!

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