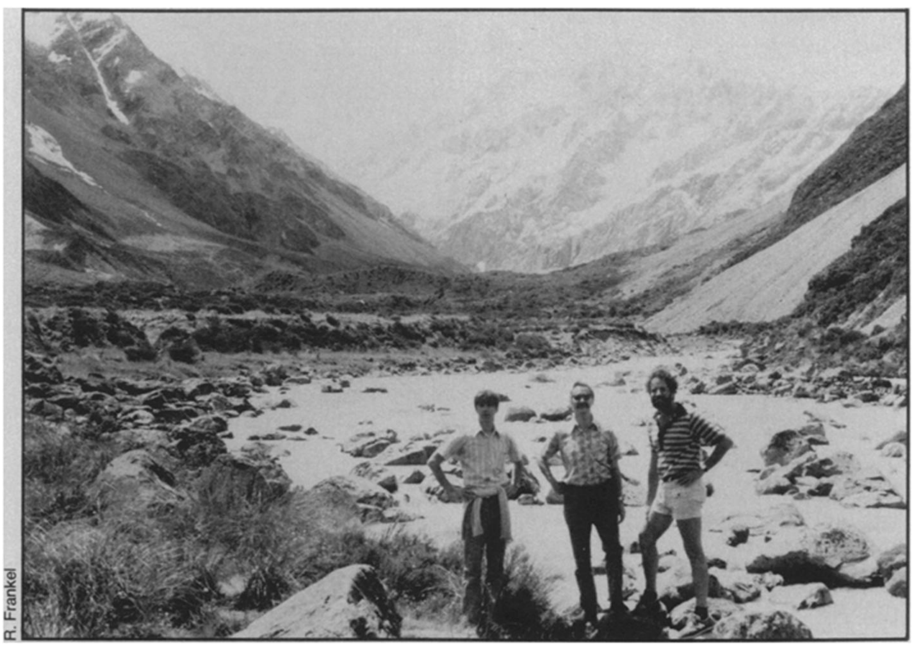
Compassed About Biologically

Magnetic bacteria are witnessed in both hemispheres. Maybe they're finding their way to something.

R. Blakemore

Chains of magnetite crystals are clearly visible along the axes of these bacteria.



R. Frankel

Expedition to the antipodes: Blakemore, Kalmijn and Frankel at Mt. Cook, New Zealand.

BY DIETRICK E. THOMSEN

Somewhere on a roof overlooking the docks a man waits for his pigeons to come home. To his joy and to the probable displeasure of his neighbors—they will. How pigeons and other well-directed organisms find their way, apart from the obvious senses of sight and smell, is one of the oldest fascinations in biology. It is rapidly becoming a question in physiology and in biophysics as investigators seek particular organs and mechanisms for such behavior.

It seems to be providential for such studies that magnetic bacteria were discovered. In investigations of this kind it helps tremendously to have a simple system to begin with. The epithet "birdbrain" is very apt; nevertheless, a pigeon's head is extremely complex compared to a single cell. And there are single, swimming cells with little magnets in them. Their existence was first reported about five years ago by Richard Blakemore, now of the University of New Hampshire (SN: 11/1/75, p. 279). Since then observation has shown that the organisms are widespread, that they manufacture these magnets, that they use them for beneficial direction finding and that the capacity to make them is inherited (SN:4/28/79, p. 278).

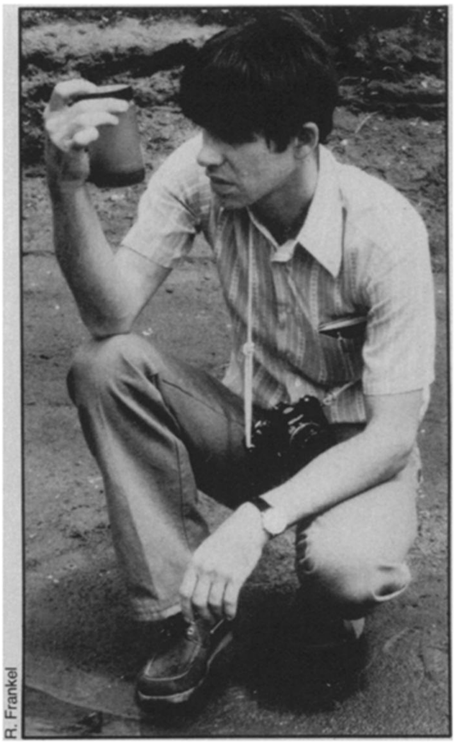
At the beginning there were just these bacteria with magnetic material in them. Blakemore's colleague Adrianis Kalmijn showed that they can sense the earth's magnetic field with a permanent magnetism of their own, and that they swim in the direction they line up. "All I had observed swam northward," Blakemore says.

There are several obvious questions: Why are these bacteria magnetic? Does it give them any advantage? And are magnetic bacteria widespread, or is magnetism a peculiarity of organisms living in Woods Hole, Mass.?

Examination showed that the bacteria had inside them chains of crystals containing iron. To determine the chemical form of the iron Richard Frankel of the Massachusetts Institute of Technology used the technique known as Mossbauer resonance spectroscopy and found that the iron is in the form of magnetite (Fe_3O_4), common lodestone. Knowledge of lodestone's magnetic properties goes back to ancient times. The amount in a bacterium was enough to account for its alignment in the earth's magnetic field, to serve as a biological compass, that is. "It was the first time that anyone had demonstrated that a living cell had a ferromagnetic compass," says Blakemore.

Furthermore, the magnetite comes in chains of crystals. The size of the crystals is just big enough to be a magnetic domain, Frankel points out. That is, they are just the amount of magnetite in which the intrinsic magnetism of the atoms naturally lines up all in the same direction. Making such domains and stringing them in a chain is a very efficient way of building a magnet. There is evidence that that configuration is not happenstance: The magnetite chain is surrounded by a sheath or membrane secreted by the organism that holds the chain in line. When the chain is taken out of the organism, the crystals do not immediately form a convoluted clump as a group of small magnets would otherwise do. In the bacterium the chain stays in line and orients itself along the organism's axis of motility.

Blakemore has a plausible hypothesis for the advantage that accrues to the bacterium for having this internal compass: food. The earth's magnetic field does not lie simply in a north-south plane. In the Northern Hemisphere it dips downward to the north as the field lines penetrate the earth's surface. Thus, to follow a north-seeking compass in the Northern Hemisphere means to go down as well as north. Down leads bacteria to the sediments where more food is. It should be stressed that the bacteria are not dragged by the geomagnetic field. "Bacteria are colloidal particles," says Blakemore. They float in water at whatever level they happen to be. They also swim by beating the water with flagella, or little tails. In these Woods Hole magnetic bacteria, the flagella are opposite the north-seeking ends of the internal magnets thus giving the organisms a preferential direction in which to swim.


R. Frankel

Blakemore probes antipodal sediments.

In the Southern Hemisphere, supposing there are any magnetic bacteria there, the preferred direction should be south. Field lines heading toward the South Pole bend downward there, and so an organism following a south-seeking compass should find bottom and the food-rich sediments.

An expedition to seek magnetic bacteria in the Southern Hemisphere was funded by the National Geographic Society, the National Science Foundation and the Office of Naval Research. The great naturalists of the past were famous for such voyages, but they are unusual nowadays. Blakemore refers to this one as "the last great butterfly hunt on the Amazon River." In fact it was a hunt for magnetic bacteria in the waters of New Zealand and Tasmania. Those places were chosen because they have just about the opposite configuration of the geomagnetic field to that of New England. Blakemore, his wife Nancy Blakemore, Kalmijn and Frankel went along.

"We went there and found a great many magnetic bacteria," Blakemore says. And they do have south-seeking internal compasses. Frankel, the magnetician, says their magnetic chains are reversed. Blakemore, the biologist, prefers to say they grow their flagella on the other end. Either description works.

The ability to grow the magnetite chains is heritable. The bacteria can be raised in strains that do it and in strains that don't. In those that do, it is observed that on cell division each daughter inherits half the mother's chain and then makes the rest from her own resources, presumably following instructions coded in her DNA. The ability to make the magnetite chains is inherited but the polarity is not. Usually a daughter's polarity follows her mother's, but there are exceptions.

An experiment was done in which a population of north-seeking bacteria was put in a bottle subject to an artificial magnetic environment that gave south-seekers the advantage in finding food. In a while south-seekers came to dominate the population. It was not that the original north-seeking population had flipped over. These were the occcasional south-seeking daughters of north-seeking mothers and their south-seeking progeny who had survived and increased while the north-seekers had died out.

And so, as Frankel sums it up, the research is able to show for the first time on a global scale that organisms use ferromagnetism to orient themselves in the earth's field. The work has had a strong influence on those seeking reasons for the orientation of more complex organisms—birds, honeybees, etc. It has been suggested that birds can somehow "see" the geomagnetic field. In fact magnetite has been found in the heads of such animals, but it should be stressed that no mechanism as simple as that of the bacteria has been found in any bird or bee brain. It will be a long time yet before we know why the pigeons come back to that roof in Hoboken where Marlon Brando is sitting □