Geomagnetism

Reversals: Magnetic Flip

What do we mean by a magnetic reversal or a magnetic 'flip' of the Earth?

The Earth has a magnetic field, as can be seen by using a magnetic compass. It is mainly generated in the very hot molten core of the planet and has probably existed throughout most of the Earth's lifetime. The magnetic field is largely that of a dipole, by which we mean that it has one North pole and one South pole. At these places, a compass needle will point straight down, or up, respectively. It is often described as being similar in nature to the field of a bar (e.g. fridge) magnet. However there is much small-scale variation in the Earth's field, which is quite different from that of a bar magnet. In any event, we can say that there are currently two poles observed on the surface of the Earth, one in the Northern hemisphere and one in the Southern hemisphere.

By magnetic reversal, or 'flip', we mean the process by which the North pole is transformed into a South pole and the South pole becomes a North pole. Interestingly, the magnetic field may sometimes only undergo an 'excursion', rather than a reversal. Here, it suffers a large decrease in its overall strength, that is, the force that moves the compass needle. During an excursion the field does not reverse, but later regenerates itself with the same polarity, that is, North remains North and South remains South.

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How often do reversals occur?

As a matter of geological record, the Earth's magnetic field has undergone numerous reversals of polarity. We can see this in the magnetic patterns found in volcanic rocks, especially those recovered from the ocean floors. In the last 10 million years, there have been, on average, 4 or 5 reversals per million years. At other times in Earth's history, for example during the Cretaceous era, there have been much longer periods when no reversals occurred. Reversals are not predictable and are certainly not periodic in nature. Hence we can only speak about the average reversal interval.

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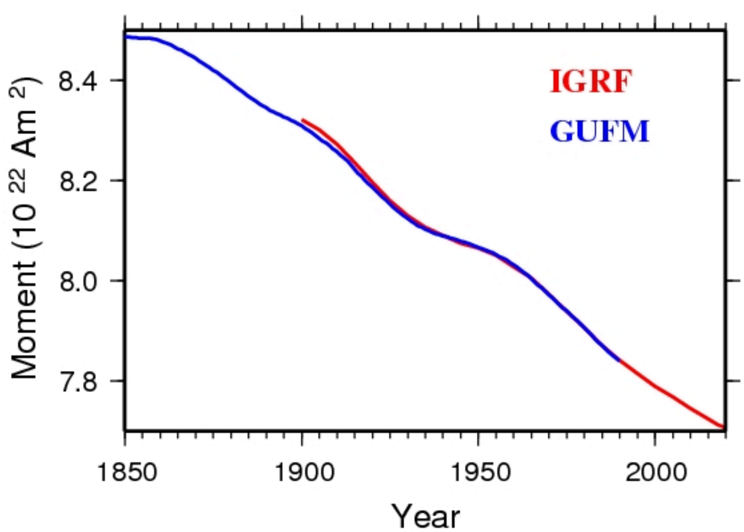
Is the Earth's magnetic field reversing now? How do we know?

Measurements have been made of the Earth's magnetic field more or less continuously since about 1840. Some measurements even go back to the 1500s, for example at Greenwich in London. If we look at the trend in the strength of the magnetic field over this time (for example the so-called 'dipole moment' shown in the graph below) we can see a downward trend. Indeed projecting this forward in time would suggest zero dipole moment in about 1500-1600 years time. This is one reason why some people believe the field may be in the early stages of a reversal. We also know from studies of the magnetisation of minerals in ancient clay pots that the Earth's magnetic field was approximately twice as strong in Roman times as it is now.



Even so, the current strength of the magnetic field is not particularly low in terms of the range of values it has had over the last 50,000 years and it is nearly 800,000 years since the last reversal. Also, bearing in mind what we said about 'excursions' above, and knowing what we do about the properties of mathematical models of the magnetic field, it is far from clear we can easily extrapolate to 1500 years hence.

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How quickly do the poles 'flip'?

We have no complete record of the history of any reversal, so any claims we can make are mostly on the basis of mathematical models of the field behaviour and partly on limited evidence from rocks that retain an imprint of the ancient magnetic field present when they were formed. For example, the mathematical simulations seem to suggest that a full reversal may take about one to several thousand years to complete. This is fast by geological standards but slow on a human time scale.

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What happens during a reversal? What do we see at the Earth's surface?

As above, we have limited evidence from geological measurements about the patterns of change in the magnetic field during a reversal. We might expect to see, based on models of the field run on supercomputers, a far more complicated field pattern at the Earth's surface, with perhaps more than one North and South pole at any given time. We might also see the poles 'wandering' with time from their current positions towards and across the equator. The overall strength of the field, anywhere on the Earth, may be no more than a tenth of its strength now.

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Is there any danger to life?

Almost certainly not. The Earth's magnetic field is contained within a region of space, known as the magnetosphere, by the action of the solar wind. The magnetosphere deflects many, but not all, of the high-energy particles that flow from the Sun in the solar wind and from other sources in the galaxy. Sometimes the Sun is particularly active, for example when there are many sunspots, and it may send clouds of high-energy particles in the direction of the Earth. During such solar 'flares' and 'coronal mass ejections', astronauts in Earth orbit may need extra shelter to avoid higher doses of radiation. Therefore we know that the Earth's magnetic field offers only some, rather than complete, resistance to particle radiation from space. Indeed high-energy particles can actually be accelerated within the magnetosphere.

At the Earth's surface, the atmosphere acts as an extra blanket to stop all but the most energetic of the solar and galactic radiation. In the absence of a magnetic field, the atmosphere would still stop most of the radiation. Indeed the atmosphere shields us from high-energy radiation as effectively as a concrete layer some 13 feet thick.

Human beings and their ancestors have been on the Earth for a number of million years, during which there have been many reversals, and there is no obvious correlation between human development and reversals. Similarly, reversal patterns do not match patterns in species extinction during geological history.

Some animals, such as pigeons and whales, may use the Earth's magnetic field for direction finding. Assuming that a reversal takes a number of thousand years, that is, over many generations of each species, each animal may well adapt to the changing magnetic environment, or develop different methods of navigation.

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I'm interested in a more technical description. Can you tell me more?

The source of the magnetic field is the iron-rich liquid outer core of the Earth. This liquid moves in complex ways as a result of the convection of the heat deep within the core and of the rotation of the planet. The motion of the core fluid is continuous and never stops, even during a reversal. It can only stop when the energy source fails. Heat is produced at least partly because of the solidification of the liquid core onto the solid inner core that sits at the centre of the Earth. This process has operated continuously over billions of years. At the top of the liquid core, some 3000 km beneath our feet and below the rocky mantle, the fluid may travel at horizontal speeds of tens of kilometres per year. The motion of this metal fluid across existing magnetic field lines of force produces electrical currents and these, in turn, generate more magnetic field. This is a process known as advection. To balance any growth of the field, and thus stabilise what we call the 'geodynamo', we need diffusion, where field 'leaks' away from the core and is destroyed. Ultimately, the core fluid flow produces a complicated magnetic field pattern at the Earth's surface with a complicated time variation.

Simulations of the geodynamo on supercomputers have demonstrated the complex nature of the field and its behaviour over time. Simulations have also revealed reversals in the polarity, where the magnetic North pole is replaced by a South pole, and vice versa. In such simulations, the strength of the main dipole appears to weaken, perhaps to about 10% of its normal value (but not vanish) and the existing poles may wander across the globe and be joined by other temporary North and South magnetic poles (the 'non-dipole field').

The solid iron inner core of the Earth has been shown in these simulations to be important in controlling the reversal process. Because it is a solid, the inner core can't generate magnetic field by advection, but any field that is generated in the fluid outer core can diffuse, or spread, into the inner core. The field generation process (advection) in the outer core seems to regularly attempt to reverse. But unless the field locked into the inner core first diffuses away, a true reversed field cannot become established throughout the core. Essentially the inner core resists any 'new' field diffusing in and perhaps only one in every ten such reversal attempts is successful.

It is worth stressing that these results, while fascinating in themselves, are not known to be strictly true of the 'real' Earth. However, we have mathematical models of the Earth's magnetic field for the last 400 years, with early models based largely on observations made by mariners engaged in merchant and naval shipping. From these models and extrapolating down into the Earth, it is known that regions of reversed flux at the core-mantle boundary have grown over time. In these regions the compass points in the opposite direction, in or out of the core, compared to that of surrounding areas. It is the growth in area of such a reversed flux patch under the south Atlantic that is primarily responsible for the decay in the main dipolar field. This reverse patch is also responsible for the minimum in field strength called the South Atlantic Anomaly, now centred over south America. In this region energetic particles can approach Earth more closely, causing increased radiation risk to low Earth orbit satellites.

There is much work yet to be done in understanding the properties of the deep Earth. This is a world where the crushing forces and core temperatures similar to that of the surface of the Sun take our scientific understanding to the limit.

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Links to other descriptions of the Earth's magnetic field.

1. Non-Specialist
Geomagnetism FAQ
'When North Goes South'
Exploration of the Magnetosphere
'The Great Magnet, the Earth'

2. More Technical
Deep Earth Research Group, School of Earth and Environment, University of Leeds
'Earth: Magnetic Field and Magnetosphere'

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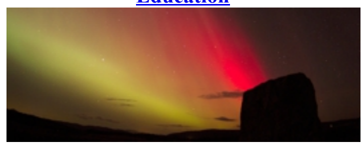

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