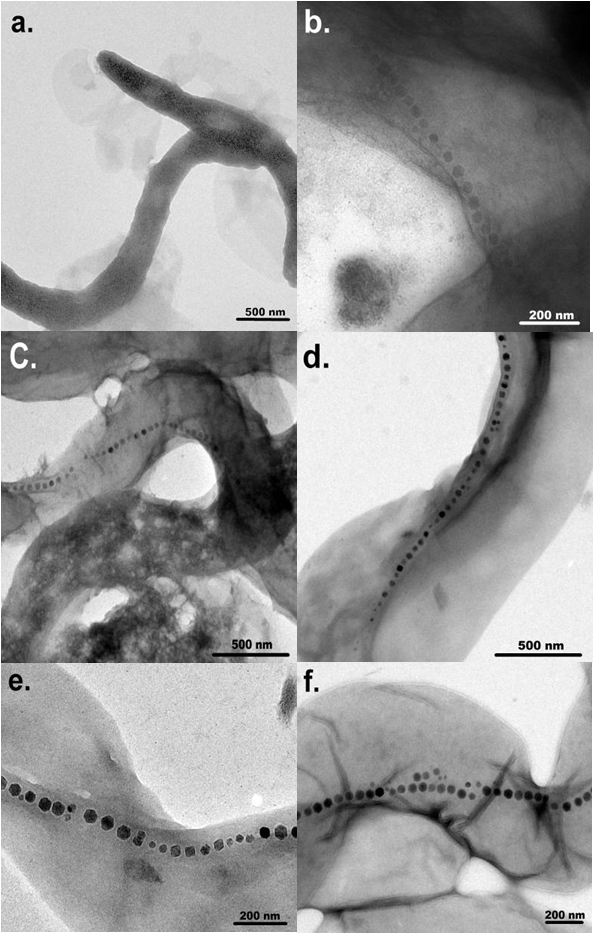
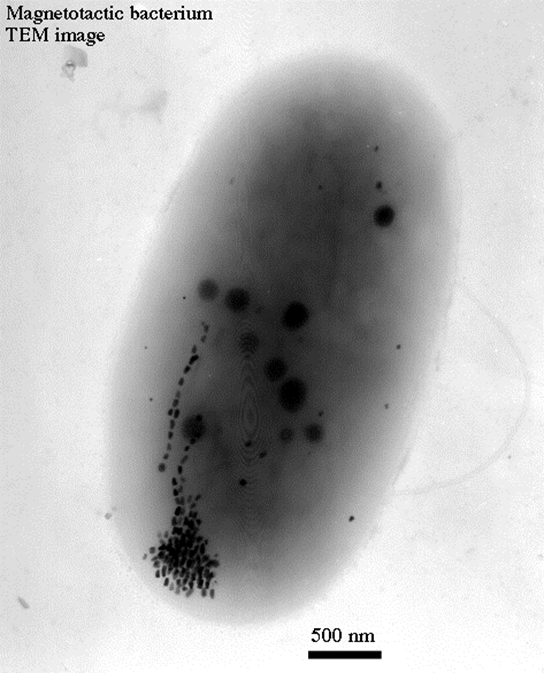
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| **Magnetotactic bacteria** (or **MTB**) **Dr.Neihaya Heikmat**  Magnetic Bacteria are known to synthesize fine crystalline particles of magnetite (Fe3O4) or [greigite](file:///F:\wiki\Greigite) (Fe3S4) known **as bacterial magnetic particles (BMPs).** These naturally synthesized BMPs are enveloped by a thin lipid bilayer and are uniform in shape and size ranging from 50 to 100 nm in diameter.  The first description of magnetotactic bacteria appeared in 1963 by **Lowenstam**,  and hence called them **"magnetosensitive bacteria".**The first peer-reviewed article on magnetotactic bacteria appeared in a 1975 by **Blakemore**, who had similarly observed bacteria capable of orienting themselves in a certain direction: Blakemore realized that these microorganisms were following the direction of Earth's magnetic field, from south to north.  To perform this task, these bacteria have [organelles](file:///F:\wiki\Organelle) called [magnetosomes](file:///F:\wiki\Magnetosome) that contain magnetic crystals. The biological phenomenon of microorganisms tending to move in response to the environment's magnetic characteristics known as [**magnetotaxis**](file:///F:\wiki\Magnetotaxis) . In contrast to the [magnetoception](file:///F:\wiki\Magnetoception) of animals, the bacteria contain fixed magnets that force the bacteria into alignment — even dead cells align, just like a compass needle. The alignment is believed to aid these organisms in reaching regions of optimal oxygen concentration. |

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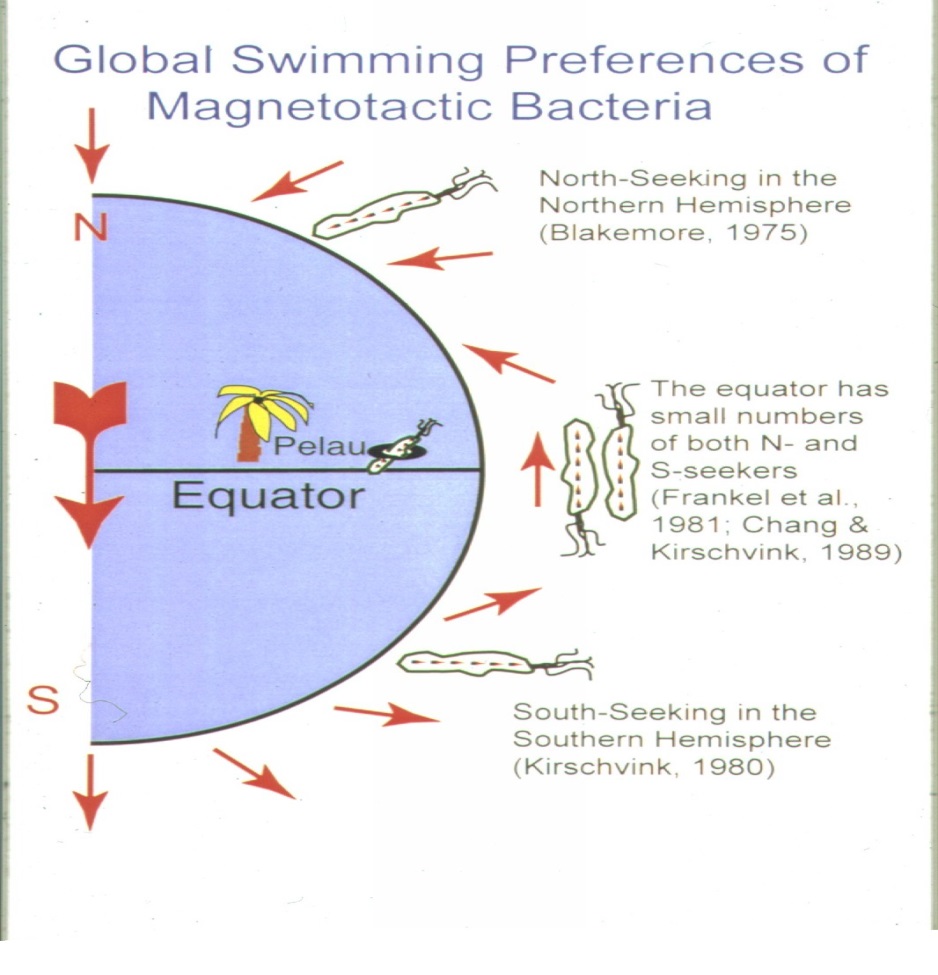
**Types of Magnetotatic bacteria**

The sensitivity of magnetotactic bacteria to the [Earth's magnetic field](file:///F:\wiki\Earth%27s_magnetic_field) arises from the fact these bacteria [precipitate](file:///F:\wiki\Precipitate) chains of crystals of magnetic minerals within their cells; to date, all magnetotactic bacteria are reported to precipitate either [magnetite](file:///F:\wiki\Magnetite) or [greigite](file:///F:\wiki\Greigite).

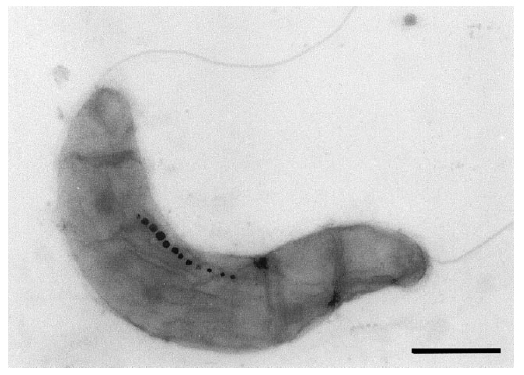
**Biology of MTB**

MTB- a [polyphyletic](file:///F:\wiki\Polyphyletic) group of [bacteria](file:///F:\wiki\Bacteria) exhibited several different morphologies (shapes) of MTB exist, differing in number, layout and pattern of the bacterial magnetic particles (BMPs) they contain. The MTBs can subdivided into two categories, according to whether they produce particles of [magnetite](file:///F:\wiki\Magnetite) (Fe3O4) or of [greigite](file:///F:\wiki\Greigite) (Fe3S4), although some species are capable of producing both. Magnetite possesses a [magnetic moment](file:///F:\wiki\Magnetic_moment) three times that of greigite.

**Characteristics of MTB:** Various morphological types exist, Gram-negative prokaryote, Magnetic nanoparticles present in magnetosomes, Found in sediments in diverse aquatic environment. All are either obligate microaerophiles, or strict anaerobes. Motile, aquatic bacteria. Direction of motility is affected by the Earth’s geomagnetic field. Strains are either north- or south-seeking depending upon oxic conditions



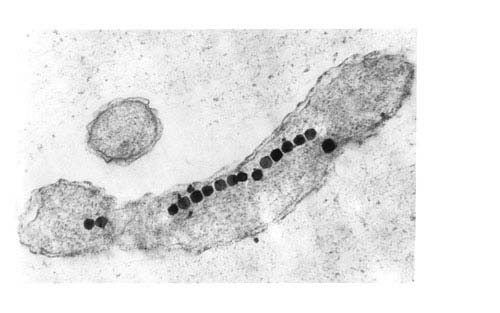
Current hypothesis states that these bacteria use the geomagnetic field to locate lower O2 or anaerobic habitats. Magnetite-producing magnetotactic bacteria are usually found in an [oxic-anoxic transition zone](file:///F:\wiki\Anoxic_waters) (OATZ), the transition zone between oxygen-rich and oxygen-starved water or sediment. Many MTB are able to survive only in environments with very limited oxygen, and some can exist only in completely anaerobic environments. Some types of magnetotactic bacteria can produce magnetite even in [anaerobic](file:///F:\wiki\Hypoxia_(environmental)) conditions, using [nitric oxide](file:///F:\wiki\Nitric_oxide), [nitrate](file:///F:\wiki\Nitrate), or [sulfate](file:///F:\wiki\Sulfate) as a final acceptor for [electrons](file:///F:\wiki\Electron). The greigite mineralising MTBs are usually strictly anaerobic.



**Magnetotactic bacteria**

The diversity of MTB reflected by the high number of different morphotypes found in environmental samples of water or sediment. Commonly observed morphotypes include spherical or ovoid cells ([cocci](file:///F:\wiki\Coccus)), rod-shaped ([bacilli](file:///F:\wiki\Bacilli)), curved bacteria ([vibrio](file:///F:\wiki\Vibrio)) and helical ([spirillum](file:///F:\wiki\Spirillum)) of various dimensions. One of the more distinctive morphotypes is an apparently multicellular bacterium referred to as the **many-celled magnetotactic prokaryote (MMP)**. Regardless of their morphology, all MTB studied so far are motile by means of [flagella](file:///F:\wiki\Flagella), the arrangement of flagella differs and can be polar, bipolar, or in tufts. they are [Gram-negative](file:///F:\wiki\Gram-negative) bacteria of various phyla: Despite the majority of known species' being [proteobacteria](file:///F:\wiki\Proteobacteria), e.g. [*Magnetospirillum magneticum*](file:///F:\wiki\Magnetospirillum) an alphaproteo- bacterium.

***Magnetospirillum*** is a [Gram-negative](file:///F:\wiki\Gram-negative), [microaerophilic](file:///F:\wiki\Microaerophilic) genus of [magnetotactic bacterium](file:///F:\wiki\Magnetotactic_bacteria), first isolated from pond water by Blakemore in 1975. It is characterized by a spirillar, or helical, morphology. It is also a motile bacterium owing to the presence of a polar [flagellum](file:///F:\wiki\Flagellum) at each end. Four species have been described: *Magnetospirillum magnetotacticum strain MS-* (originally classified as *Aquaspirillum magnetotacticum*;) *Magnetospirillum magneticum strain AMB-1*; *Magnetospirillum gryphiswaldense*; and *Magnetospirillum bellicus*.



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| The typical [habitat](file:///F:\wiki\Habitat_(ecology)) of *Magnetospirillum* consists of shallow fresh water and sediments, characterized by low concentrations of [oxygen](file:///F:\wiki\Oxygen) for growth (microaerophilic) where it lives in the upper portion of the sediment (oxic/anoxic interface). It prefers an oxygen gradient of approximately 1-3%. *Magnetospirillum* also resorts to [aerotaxis](file:///F:\wiki\Aerotaxis), in order to remain in favourable O2 concentration conditions. When the bacteria ingest iron, proteins inside their bodies interact with it to produce tiny crystals of the mineral [magnetite](file:///F:\wiki\Magnetite), the most magnetic mineral on Earth. Due to the high quality of the [single-domain](file:///F:\wiki\Single_domain_(magnetic)) magnetic crystals there is also a commercial interest in the bacteria. The crystals are thought to have the potential to produce magnetic tapes and magnetic target drugs. |

**The MTB polarity model**

Various experiments have clearly shown that [magnetotaxis](file:///F:\wiki\Magnetotaxis) and [aerotaxis](file:///F:\wiki\Aerotaxis) work in conjunction in the magnetotactic bacteria. Aerotaxis is the response by which bacteria migrate to an optimal oxygen concentration in an oxygen gradient. The behaviour that has been observed in these bacterial strains has been referred to as [magneto-aerotaxis](file:///F:\w\index.php?title=Magneto-aerotaxis&action=edit&redlink=1).

Two different magneto-aerotactic mechanisms — known **as polar and axial** — are found in different MTB strains.

## Magnetosomes

## It have linear dimensions of 40 to 50 nm and are separated from adjacent particles in the chain by approximately 4 to 10 nm, and the particles are well crystallized with truncated octahedral morphology and are oriented so that [111] faces are perpendicular to the magnetosomes chain axis. The number of magnetosomes per cell is variable within a population, but the average number is typically 10 to 20 magnetosomes per cell, and the average number of magnetosomes also varies with culture conditions, especially chelated iron concentration and disolved oxygen tension.

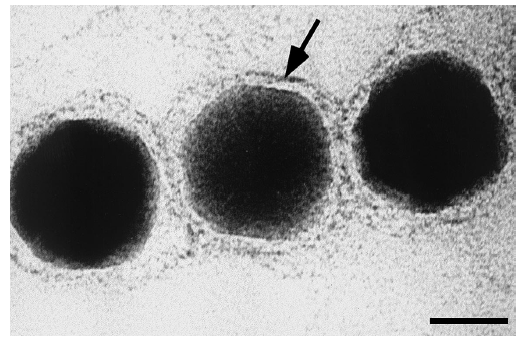
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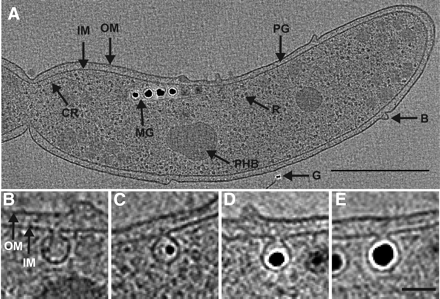
## Another trait that shows considerable diversity is the arrangement of magnetosomes inside the bacterial cell. In the majority of MTB, the magnetosomes are aligned in chains of various lengths and numbers along the cell's long axis, which is magnetically the most efficient orientation.

## Three general crystal morphologies appeared: roughly cuboidal, elongated prismatic, and tooth-bullet shaped. However, dispersed aggregates or clusters of magnetosomes occur in some MTB, usually at one side of the cell, which often corresponds to the site of flagellar insertion.

## Membrane and proteins of Magnetosomes

The biomineralisation of the magnetite is brought about by the regulating mechanisms of the concentration of iron, by the [nucleation](file:///F:\wiki\Nucleation) of crystal, of the potential redox and of the [pH](file:///F:\wiki\PH). The compartmentalization in magnetosomes permits the biochemical control of such processes. After the sequencing of the [genome](file:///F:\wiki\Genome) of certain species of MTB, a comparative analysis of the [proteins](file:///F:\wiki\Protein) involved in the formation of BMP became possible. These proteins of the magnetosomial membrane (MM) beyond the [serine proteases](file:///F:\wiki\Serine_protease) domain contain PDZ domains. Other MM proteins contain TPR domains (Tetratric Peptide Repeat).





**Formation of the magnetosome**

The formation of the magnetosome requires at least three steps.

1. The invagination of the magnetosome membrane (MM)

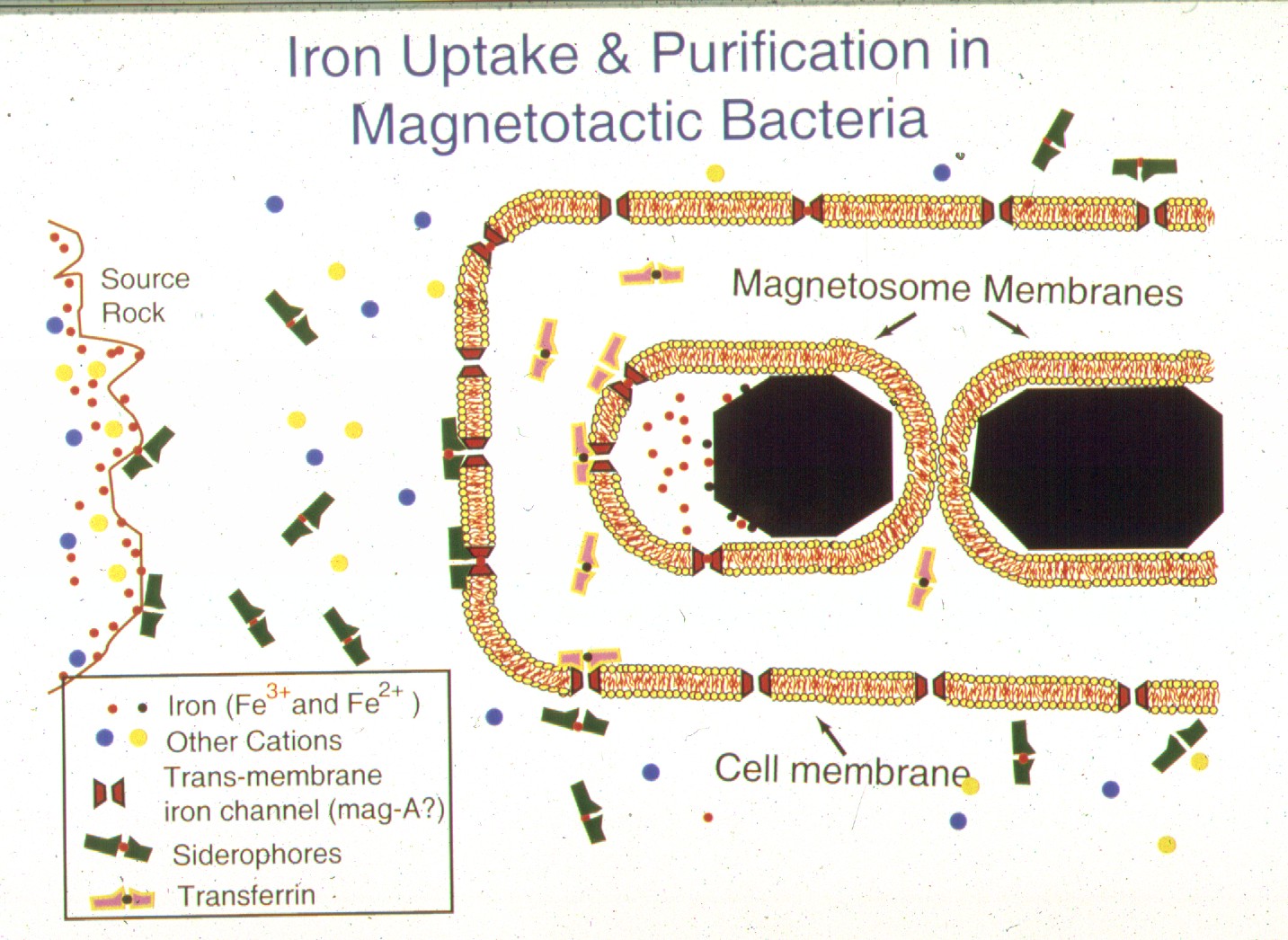
2. The entrance of magnetite precursors into the newly formed vesicle.

3. The nucleation and growth of the magnetite crystal.

During the first formation of an [invagination](file:///F:\wiki\Invagination) in the cytoplasmic membrane is triggered by a [GTPase](file:///F:\wiki\GTPase). It is supposed this process can take place amongst [eukaryotes](file:///F:\wiki\Eukaryote), as well.

The second step requires the entrance of ferric [ions](file:///F:\wiki\Ion) into the newly formed [vesicles](file:///F:\wiki\Vesicle_(biology)) from the external environment. Even when cultured in a Fe3+ deficient medium, MTB succeed at accumulating high intracellular concentrations of this ion. It has been suggested that they accomplish this by secreting, upon need, a [siderophore](file:///F:\wiki\Siderophore), a low-[molecular-weight](file:///F:\wiki\Molecular_weight) ligand displaying an elevated affinity for Fe3+ ions. The "Fe3+-siderophore" complex is subsequently moved in the [cytoplasm](file:///F:\wiki\Cytoplasm), where it is cleaved. The ferric ions must then be converted into the ferrous form (Fe2+), to be accumulated within the BMP; this is achieved by means of a transmembrane transporter, which exhibits sequence homology with a Na+/H+ [antiporter](file:///F:\wiki\Antiporter). Furthermore, the complex is a H+/Fe2+ antiporter, which transports ions via the [proton gradient](file:///F:\wiki\Proton_gradient). These transmembrane transporters are localised both in the cytoplasmic membrane and in the MM, but in an inverted orientation; this configuration allows them to generate an efflux of Fe2+ ions at the cytoplasmic membrane, and an influx of this same ion at the MM.

During the final stage of the process, the magnetite crystal nucleation is by action of transmembrane proteins with acidic and basic domains. One of these proteins, called Mms6, has also been employed for the artificial synthesis of magnetite, where its presence allows the production of crystals homogeneous in shape and size.

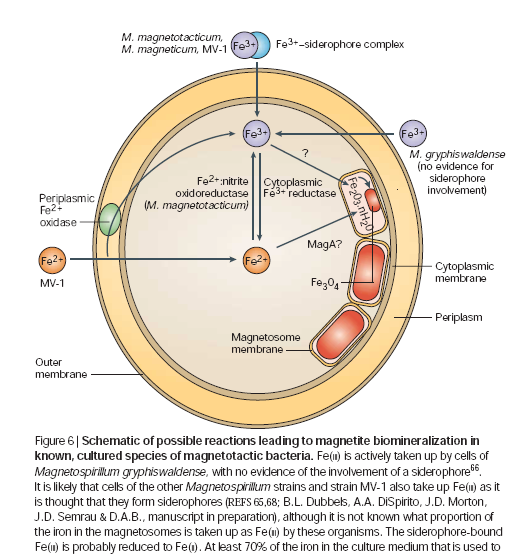


**Biomineralisation**

Several clues led to the hypothesis that different genetic sets exist for the biomineralisation of magnetite and greigite. In cultures of *Magnetospirillum magnetotacticum*, iron can not be replaced with other transition metals (Ti, Cr, Co, Cu, Ni, Hg, Pb) commonly found in the soil. In a similar manner, [oxygen](file:///F:\wiki\Oxygen) and sulfur are not interchangeable as nonmetallic substances of the magnetosome within the same species.

From a [thermodynamic](file:///F:\wiki\Thermodynamics) point of view, in the presence of a neutral pH and a low redox potential, the inorganic synthesis of magnetite is favoured when compared to those of other [iron oxides](file:///F:\wiki\Iron_oxide). It would thus appear [microaerophilic](file:///F:\wiki\Microaerophile) or [anaerobic](file:///F:\wiki\Hypoxia_(environmental)) conditions create a suitable potential for the formation of BMPs. Moreover, all iron absorbed by the bacteria is rapidly converted into magnetite, indicating the formation of crystals is not preceded by the accumulation of intermediate iron compounds; this also suggests the structures and the [enzymes](file:///F:\wiki\Enzyme) necessary for biomineralisation are already present within the bacteria.

**Fe3+**→**Fe2+**→ **amorphous ferrous oxyhydroxide (ferrihydrite?) → oxidise [2Fe3+Fe2+(O)x(OH)y]n+** →**Fe3O4 + H+ + H2O**

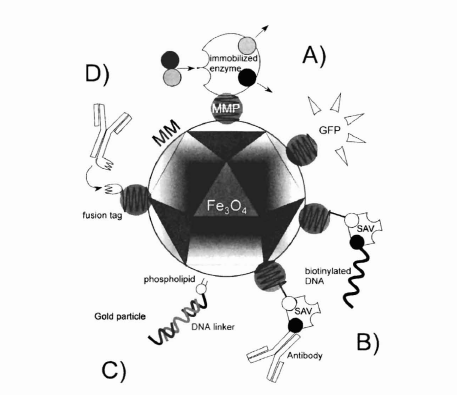


**Biotechnology applications**

In certain types of applications, bacterial magnetite offers several advantages compared to chemically synthesized magnetite. Bacterial magnetosome particles, unlike those produced chemically, have a consistent shape, a narrow size distribution within the single [magnetic domain range](file:///F:\w\index.php?title=Magnetic_domain_range&action=edit&redlink=1), and a membrane coating consisting of [lipids](file:///F:\wiki\Lipids) and [proteins](file:///F:\wiki\Protein). The magnetosome envelope allows for easy couplings of bioactive substances to its surface, a characteristic important for many applications.

Magnetotactic bacterial cells have been used to determine south magnetic poles in meteorites and rocks containing fine-grained magnetic minerals and for the separation of cells after the introduction of magnetotactic bacterial cells in to  [granulocytes](file:///F:\wiki\Granulocyte)  and [monocytes](file:///F:\wiki\Monocyte)  by [phagocytosis](file:///F:\wiki\Phagocytosis). Magnetotactic bacterial magnetite crystals have been used in studies of [magnetic domain analysis](file:///F:\w\index.php?title=Magnetic_domain_analysis&action=edit&redlink=1) and in many commercial applications including: the immobilisation of [enzymes](file:///F:\wiki\Enzymes); the formation of magnetic [antibodies](file:///F:\wiki\Antibodies), and the quantification of [IgG](file:///F:\wiki\IgG); the detection and removal of [Escherichia coli](file:///F:\wiki\Escherichia_coli) cells with a fluorescein [isothiocyanate](file:///F:\wiki\Isothiocyanate) conjugated monoclonal antibody immobilised on magneto-tactic bacterial magnetite particles; and the introduction of genes into cells, a technology in which magnetosomes are coated with DNA and "shot" using a particle gun into cells that are difficult to transform using more standard methods.

Using this special characteristic, a sandwich chemiluminescence enzyme immunoassay using antibody-conjugated to BMPs permits the development of highly sensitive assays for insulin, HbA1c, glycated albumin and IgG. In addition, the development of a competitive chemiluminescence enzyme immunoassay allows us to detect small molecules, such as environmental pollutants, hormone and toxic detergents.



**Biological applications**

* a potential biomarker for geobiologists
* an ideal system for studying biomineralization
* magnetosomes have been also used for the generation of magnetic antibodies as components of medically important biosensors e.x. Brain tumor sensing
* were also used as carriers for the introduction of DNA into cell as contrast agents for magnetic resonance imaging and tumor-specific drug carriers based on intratumoral enrichment
* Treatment of AIDS

**Environmental chemistry and technology**

* Waste water and potable water purification using magnetite microparticles to the removal of heavy metals and radionuclides from it.
* Magnetically modified microbial cells for xenobiotics removal.
* Magnetically modified enzymes for the detection of their inhibitors (heavy metals, pesticides etc…)
* the used of „Microbial magnetometer” .