Magnetic Properties of Magnetotactic Bacteria

Z. Drzazga[1], Z. Dzierżewicz[2], M. Bartoszek[3], A. Cholewka[1]

[1]A. Chełkowski Institute of Physics, Department of Medical Physics, University of Silesia, Uniwersytecka 4, 40-007 Katowice, Poland
[2]Department of Biopharmacy, School of Pharmacy, Medical University of Silesia, Narcyzów 1, Sosnowiec, Poland
[3]Institute of Chemistry, Dept. of Chemistry and Technology of Environment, University of Silesia, Szkolna 9, 40-007 Katowice, Poland

Abstract

Some magnetic properties of wild strain soil and intestinal as well as cultative in laboratory conditions of *Desulfovibrio desulfuricans* bacteria were studied by means of the electron paramagnetic resonance spectroscopy (EPR) and torque method. The main wide signal in the EPR spectrum corresponds to the low spin (S=1/2) Fe^{3+} ion. The broadening of EPR lines revealed strong dipole-dipole interaction and possible misorientation of magnetic spins of magnetosomes. The sharp resonance line derived from the free radicals enclosed in the bacteria was also observed. More paramagnetic centra were found in the bacteria cultative in laboratory conditions than in the wild strains of *Desulfovibrio desulfuricans* bacteria. The torque curves had a sinusoidal shape characteristic of uniaxial anisotropy and increased almost linearly with magnetic field. The effective anisotropy coefficients for wild strains were several times larger than those grown in laboratory conditions.

Keywords: magnetotactic bacteria, EPR, torque, anisotropy, *Desulfovibrio desulfuricans bacteria*

Introduction

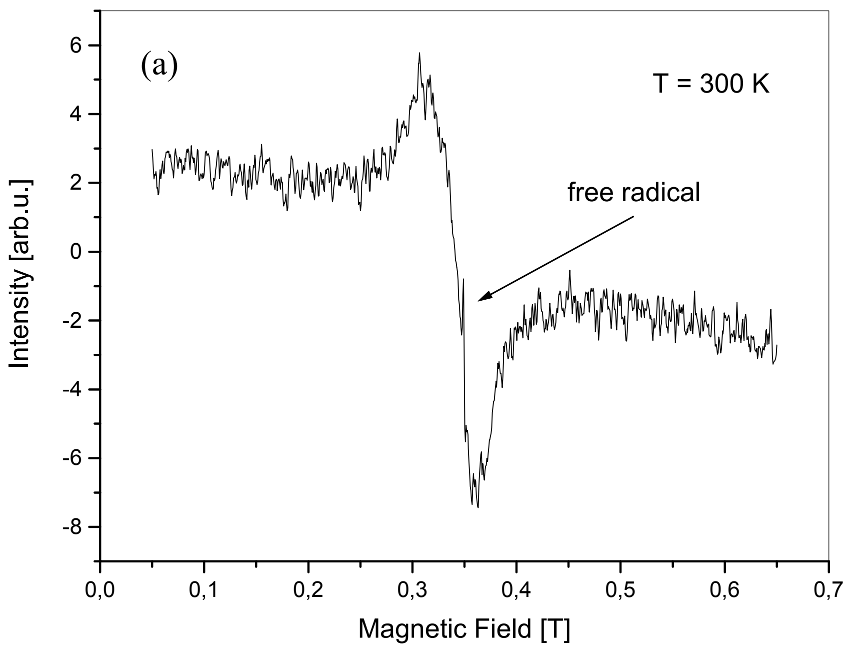
Magnetotactic bacteria are microorganisms, which contain intracellular produced crystals, usually made of magnetite (Fe_3O_4). These so-called magnetosomes are magnetic single domain particles (40-100 nm) and typically arranged in chains, which act as compass needles and so enable the bacteria to orientate in the Earth's magnetic field. The magnetotactic bacteria are Gram negative, motile, microaerophilic and aquatic. These organisms have been found in various aquatic natural environments, soil, geothermal sediments, aerobic surface and anoxic deep layers. They could be in gastrointestinal tract. Thus microbiologists as well geophysicists have been studied the magnetotactic bacteria [1-5]. Different types of bacteria magnetosomes were detected using light and electron microscope, electron diffraction patterns, magnetostatic and pulsed-field remanence measurements. Depending on the species, the bacteria contain either magnetite Fe_3O_4, iron sulphides such greigite, Fe_3S_4 or FeS. Detail studies of structure, compositions and phase transition of sulphide-producing magnetotactic bacteria indicated that only stable over time greigite crystals could be potentially useful as geological biomarkers [3]. Magnetic bacteria differ widely in their cell morphologies as well as in the morphology of their magnetosomes and number of chains per cell. These differences are reflected in the magnetic properties of individual cells. Magnetostatic interaction due to magnetization and demagnetization process in the freshwater magnetotatic bacterium *Aquaspirillum magnetotacticum* and extracted magnetosome chains were recorded in [1]. It is noteworthy that the chain-of-spheres model for coherent rotation of magnetization and non-coherent reversal mechanism could be used in analysis of the studied particles in *Aquaspirillum magnetotacticum* and *Magnetobacterium bavaricum* [2, 4]. Effects of extremely-low-frequency magnetic fields on biological magnetite were also analysed [5].

In this work some magnetic properties of wild strain soil and intestinal as well as cultative in laboratory conditions of *Desulfovibrio desulfuricans* bacteria were studied by means of the electron paramagnetic resonance spectroscopy (EPR) and torque method.

Experimental

Desulfovibrio desulfuricans bacteria of different types: wild strain soil and intestinal, isolated from excrement and from intestine as well as cultative in laboratory conditions were studied. All samples were taken from Department of Molecular Biology, Biochemistry and Biopharmacy, School of Pharmacy in Sosnowiec.

The EPR spectra of *Desulfovibrio desulfuricans* bacteria were recorded on a Bruker EMX spectrometer at the X-band. The measurements were made at room temperature.



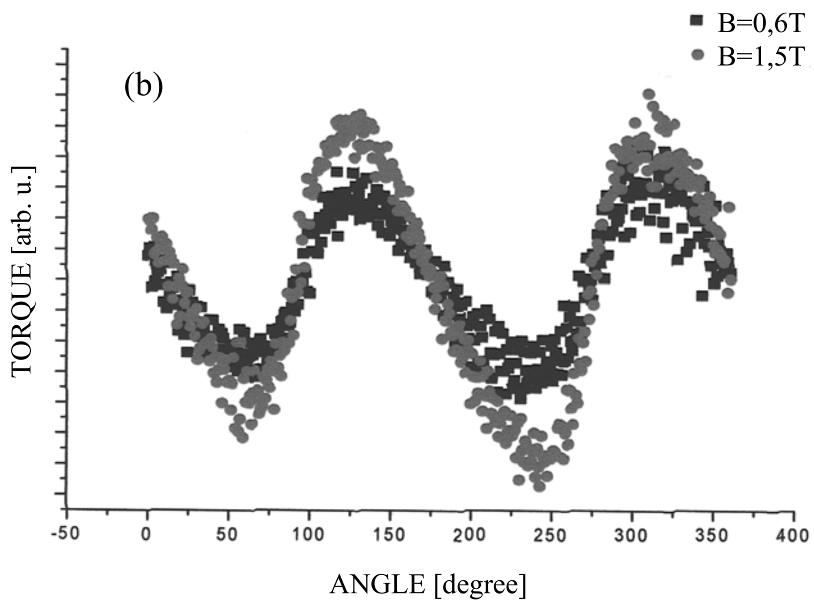


Fig. 1. (a) the EPR spectrum of wild soil strain at room temperature; (b) torque curves for aligned wild soil bacteria measured at 77 K in magnetic field B=0.6 T and B= 1.5 T

Table 1. The magnetic parameters (linewidth ΔB, g-factors, integral intensity, effective anisotropy constant K_{eff}) of studied magnetotactic bacteria

Bacteria	ΔB[mT]	Area [arb. u]	g	K_{eff} [J/kg]
Soil strain	120	21,5	2,15	1,2
Wild soil strain	61	2,2	2,00	9
Wild intestinal strain isolated from excrement	92	3,9	2,05	3
Wild intestinal strain, intestine biopsy	96	4,0	2,05	4

The relative content of paramagnetic centra in each sample was estimated by comparison of areas under the resonance curve (all samples were measured using constant mass, the same tube and position). The values of g-factor were measured relative to DPPH standard.

The magnetic anisotropy studies were carried out in magnetic field up to 1,8 T at temperature 300 K and 77 K on aligned samples. For these measurements the magnetotactic bacteria were suspended in duracryl plus and solidified at room temperature in the magnetic field of B=1,5T.

Results and Discussion

The typical EPR spectrum of *Desulfovibrio desulfuricans* bacteria in Figure 1a is presented. A single isotropic line connected with low spin form Fe^{3+} ion is observed. Relatively wide signal indicates dipol-dipol interaction of magnetic spins. The additional sharp line seems to derive from the free radicals enclosed in bacteria. The values of g-factor, the EPR line width and integrated peak areas obtained from the EPR spectra are listed in Table 1. One can see that bacteria collected from natural habitats show g-factors equal 2,0 and there are no essential differences between the other parameters of EPR spectra. The most number of paramagnetic centers is revealed in bacteria of soil strain cultative in laboratory conditions. Torque measurements showed the sin2θ curves characterizing uniaxial anisotropy. This anisotropy is generated by iron sulfides particles oriented along the chain direction in cells of bacteria aligned in magnetic field. Taken into consideration that iron accumulating is only 2-4% of bacteria dry weight it should be noted that estimated anisotropy coefficients are relatively high, especially for wild types of studied magnetotactic bacteria (Table 1). Differences in effective anisotropy constant could be connected with concentration and arrangement of magnetic particles over the chains and their randomly switching. It is interesting that value of area under the resonance curves are smaller for wild soil strain than for cultative soil strain while the effective anisotropy constant (K_{eff}) for this samples show the opposite behaviour. These facts seem to be connected with morphology of magnetosomes and number of chains per cell. The integrated peak area of EPR spectra depends on whole number of magnetosomes in strain. However the magnitude of anisotropy is a function of position and orientation of magnetosomes in the chains. Probably magnetosomes in the soil train are more disordered than in the wild strain and this fact is disclosed in anisotropy constant. There were no significant differences in magnetic anisotropy behavior at 77 K and 300 K.

Conclusions

EPR spectra show signal of Fe^{3+} ion in the low spin state in the cubic symmetry. Torque curves characteristic for shape anisotropy confirm occurrence of chains of magnetosomes magnetized in one and the same direction within the studied bacteria.

References

1. Moskowitz B.M., Frankel R.B., Flanders P.J., Blakemore R.P., Schwartz B. B.; Magnetic properties of magnetotactic bacteria. J. Magn. Magn. Mater. **73** 273 -288, **1998**.
2. Penninga I., de Waard H. Moskowitz B.M., Bazylinski D.A., Frankel R.B.: Remanence measurements on individual magnetotactic bacteria using a pulsed magnetic field. J. Magn. Magn. Mater. **149**, 279-287, **1995**.
3. Posfal M., Buseck P.R., Bazylinski D.A. and Frankel R.; Iron sulfides from magnetotactic bacteria: Structure, composition and phase transitions. American Mineralogist **83** 1469 – 181, **1998**.
4. Hanzlik M., Winklhofer M., Petersen N.: Pulsed-field-remanence measurements on individual magnetotactic bacteria. J. Magn. Magn. Mater. **248**, 258-267, **2002**.
5. Polk Ch.; Effects of extremely-low-frequency magnetic fields on biological magnetite. Bioelectromagnetics **15**, 261-270, **1994**.