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ScienceDirect
Journal of Magnetism and Magnetic Materials 320 (2008) e204–e206
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Oriented magnetic material in head and antennae of *Solenopsis interrupta* ant

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Available online 21 February 2008

Abstract

Ferromagnetic resonance (FMR) has been used to study the magnetic material in the antennae, head, thorax and abdomen of *Solenopsis interrupta* ants. The measurements were performed at room temperature (RT). The ferrimagnetic broad lines associated to magnetite/maghemite isolated nanoparticles (high field, HF) and to large nanoparticles or aggregates (low field, LF) in insect spectra are present in the *S. interrupta* body part spectra, although they slightly differ in resonant fields and lineshapes. The spectral absorption areas show $(32\pm3)\%$, $(24\pm2)\%$, $(21\pm2)\%$ and $(23\pm1)\%$ of magnetic material average fractions in antennae, head, abdomen and thorax, respectively. Only the resonance field of the head and antennae showed angular dependence. This work shows that head and antenna of *S. interrupta* ant present organized magnetic material, indicating a biomineralization process.

PACS: 76.50.+g; 75.50.Gg; 61.46.Df; 87.90.+y

Keywords: Fire ant; FMR; Magnetoreception; Magnetic sensor; Nanoparticle

Ants have an orientational system for homing after foraging. A magnetic compass response has been shown for *Formica rufa* [1] and *Oecophylla smaragdina* foraging [2]. *Atta colombica* ants respond to magnetic reversal in the absence of sunlight cues [3] and the time for trail formation of *Solenopsis invicta* ants is influenced by the magnetic field [4]. These results stimulate further magnetic and behavioral studies on *Solenopsis* ants.

Ferromagnetic resonance (FMR) studies of insect body parts yield interesting results on magnetic material amounts, volume and magnetic anisotropy estimative. Orientational information on the magnetic material can be useful in distinguishing biomineralized from ingested material and it contributes for the developing of magnetoreception models. In this paper the FMR technique is applied to the intact and oriented body parts of the *Solenopsis interrupta* ant (Santschi, 1916).

About 50 *S. interrupta* ants were collected one by one, keeping the nest intact, in Citrolândia, Rio de Janeiro, Brazil. The ants were carefully washed with distilled water to clean the nest soil, dried and separated in: pair of antennae, head, thorax with feet and abdomen with petiole. Each sample was composed of 20 ant body parts and only workers ants were used.

No preservation protocol was used. There is no change in natural diet and measurements were performed in the collecting day (March 10, 2005) to avoid degradation of the magnetic and biological materials.

Measurements were performed at room temperature (RT), in a X-band EPR spectrometer (Bruker ESP300E) operating at a microwave power of 4 mW with a 100 kHz modulation frequency and a ~2 Oe modulation field in amplitude, with the magnetic field applied perpendicular to the long body axis of the ant around which the sample is rotated. Microcal origin 6.0 Software was used to fit the spectra to a sum of a Gaussian (low field (LF) component) and a Lorentzian (high field (HF) component) lines. The fitting parameters are the peak-to-peak linewidth (ΔH_{pp}) and the resonance field (H_R). The FMR absorption spectra areas, S, were calculated as the second integrals of the derivative spectra starting at HF values where the baseline

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0304-8853/$ - see front matter © 2008 Published by Elsevier B.V.
doi:10.1016/j.jmmm.2008.02.048

is better defined, with a software developed using the graphic language LabVIEW®.

The area, S, is proportional to the number of FMR resonant spins [5,8]. The magnetic material percentages of each body part were obtained through S. The highest magnetic material fraction was found in the *S. interrupta* antennae, as previously observed in *Pachycondyla marginata* ants [9] and *Schwarziana quadripunctata* bees [8]. The magnetic material average of $(32\pm3)\%$, $(24\pm2)\%$, $(21\pm2)\%$ and $(23\pm1)\%$ were found in antennae, head, abdomen and thorax, respectively. The sum of antennae and head magnetic material percentage gives a total of $(56\pm5)\%$. The largest magnetic material amount in head with antennae is in good agreement with the result in the smashed body parts of *Solenopsis substituta* ants [5], for which at least 55% of the magnetic material was found in head with antennae. Similar results between species point to the possibility of systematizing the magnetic material study in this genus.

The ferrimagnetic broad lines associated to magnetite/maghemite isolated nanoparticles HF and to large nanoparticles or aggregates LF in insect spectra [5–7] are observed in the spectra of the four *S. interrupta* body parts (Fig. 1), although they slightly differ in resonant fields and lineshapes one from each other. The LF component is observed only by the non-zero baseline at LFs (Fig. 1b). Under a reliable association of the HF line with magnetite-isolated nanoparticles [5–7] added to its possible biological function, this study was focused in this line. The line associated to free radicals ($g=2$) is observed in head, abdomen and thorax spectra [10].

The HF component linewidth spectrum is (650 ± 100) Oe. The HF H_R of abdomen and thorax spectra is (3050 ± 100) Oe, with no significant angular dependence.

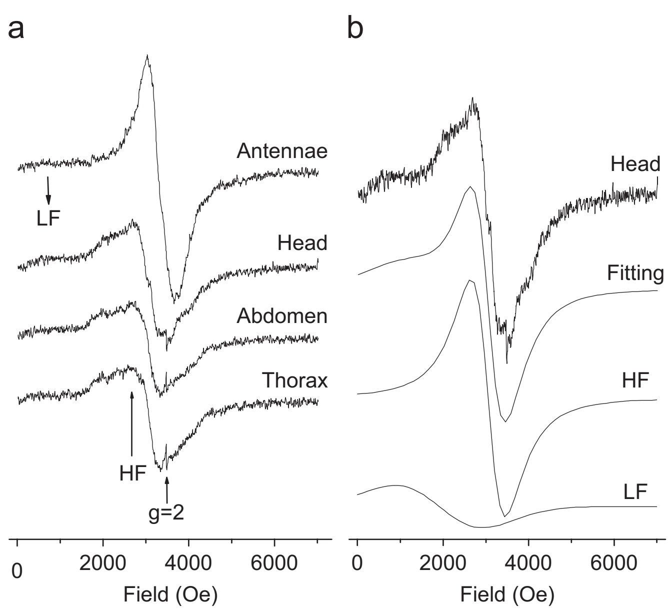

Fig. 1. (a) Ferromagnetic resonance (FMR) spectra of *S. interrupta* body parts, with the long body axis oriented perpendicular to the magnetic field at RT and (b) head fitted spectra and components.

However, head and antennae FMR spectra show an angular dependence (Fig. 2).

The H_R angular dependence of the HF component is shown in Fig. 3, where the angles are the rotation around the long body axis. The curves present a $180\pm10°$ period. Two local maxima are observed, shifted $90\pm10°$, one from the other. HF curves of head and antennae are $55\pm5°$ displaced one from each other.

The angular dependence of H_R of field cooled (5000 G) manganese ferrites ferrofluids is characterized by a 180° period [11] and the amplitude, associated to the anisotropy constant K_1 depends on the temperature and particle diameter [12]. This typical H_R angular dependence resonance was also observed in ionic magnetic fluids based

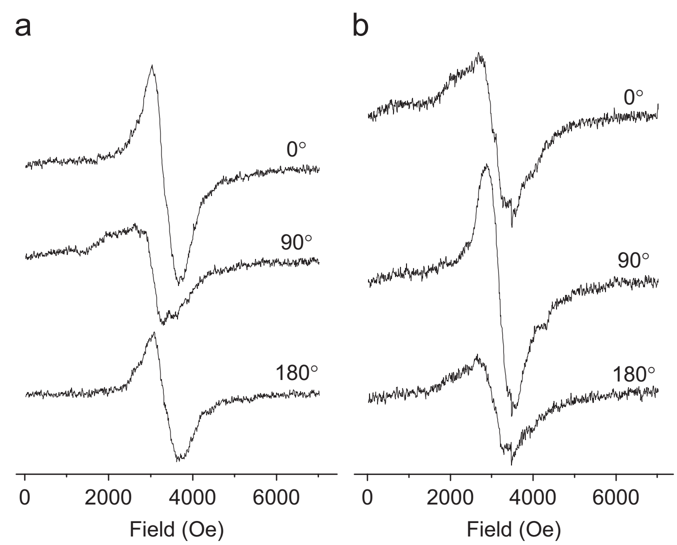

Fig. 2. FMR spectra angular dependence with the magnetic field perpendicular to the long body axis around which the sample is rotated: (a) antennae and (b) head

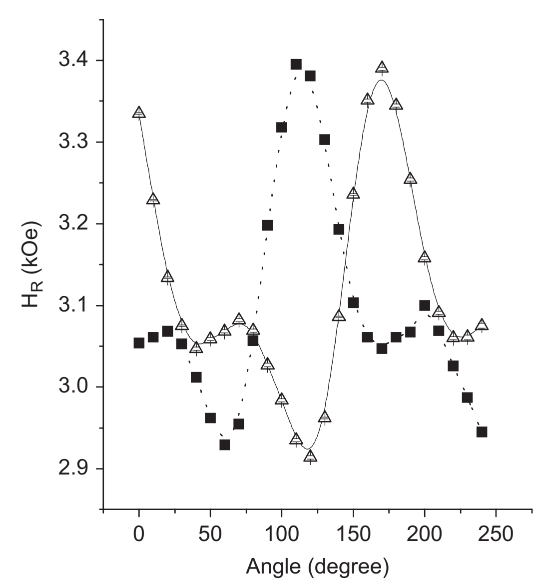

Fig. 3. H_R angular dependence of the HF component of head (■) and antennae (Δ). The solid and dot lines are guide to the eyes.

in $ZnFe_2O_4$ and $CuFe_2O_4$ nanoparticles [13] and fitted with an expression based on an axial magnetic anisotropy.

The H_R angular dependences of ant head and antennae samples cannot be analyzed based on an axial magnetic anisotropy. A second-order approach, supported by the complementary experimental data should be considered for the determination of magnetic material orientation relative to the ant long body axis. It should be considered that this organized material, because of the body sectioning, could have been modified. Nevertheless, these results showing an organization of this material can be an indicative of a biological specific function.

The abdomen and thorax may contain ingested material that is not oriented and would not be appropriate, as magnetic sensor or it does not allow the magnetic sensor orientation to be revealed. Although magnetic material exact localization and organization in head and antennae are still unknown, the evidence of magnetic oriented material orientation supports the possibility of a magnetic sensor in these ant body parts. This magnetic sensor should have specific characteristic associated to its function that can be achieved by a biological-controlled process, as observed in these parts.

The antenna is primary an olfactory and tactile sensor organ [14]. Under a reliable function of the biomineralized particles in head and antennae, added to the consideration of antennae sensory functions, it is a good candidate for magnetic sensor organ.

Although many animals have the ability to detect earth magnetic fields, the neural mechanisms that underlie this sensory modality have remained not described in insects. One of the major difficulties to elucidate magnetoreception mechanism has been the lack of an appropriate social insect to these studies.

The characterization of each magnetic system is important to understand the function of these natural sensors. However, for a more detailed analysis, FMR results must be considered together with other magnetic techniques as well as electron microscopy. The occurrence of magnetic material is necessary but not sufficient to clarify animal magnetic sensitivity. Behavior experiments, neurophysiological, histological and ethological investigations are also relevant.

Due to ant ecological importance, high diversity, numerical majority, taxonomy knowledge, facility in collecting and ambient changes sensitivity [15], the Formicidae family can be adequate for these studies. In particular, the oriented magnetic material in the antennae, an olfactory and tactile sensor organ, confirms *Solenopsis* ants for future studies in magnetoreception.

L.G.A. thanks CNPq for the fellowship.

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