Journal of Magnetism and Magnetic Materials 226–230 (2001) 2040–2041

Journal of magnetism and magnetic materials

www.elsevier.com/locate/jmmm

Induced remanent magnetization of social insects

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Abstract

The induced remanent magnetization (IRM) of honeybees *Apis mellifera* and ants as *Pachycondyla marginata*, a migratory species, and *Solenopsis* sp., a fire ant, was obtained using a SQUID magnetometer from 10 to 300 K. An anomalous sharp change of the remanent magnetization is observed at 67 ± 0.2 K for migratory ants. The IRM at room temperature indicates the presence of at least 10 times lower concentration of magnetic material in the whole fire ant as compared to the migratory ant abdomen ($0.22 \pm 0.33 \times 10^{-6}$ emu/ant, and $2.8 \pm 1.2 \times 10^{-6}$ emu/abdomen, respectively). Our results in honeybee abdomen ($4.6 \pm 0.9 \times 10^{-6}$ emu/abdomen) agree with other reported values. IRM at room temperature in ants and honeybees indicates the presence of single domain (SD) or aggregates of magnetite nanoparticles. The loss of remanence from 77 to 300 K can be related to the stable-superparamagnetic (SPM) transition of small particles (less than ca. 30 nm). From these values and considering their estimated volumes an upper limit 10^{10} SPM and 10^9 SD or aggregate particles are obtained in these insects. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Social insects; Remanence curves; Biomineralization

The magnetic orientation behaviour has been studied in insects [1], however the number of insect species observed is still small. Social insects, as bees, ants, wasps and termites, live in colonies establishing a well-organized society in breeds. Magnetic measurements have been performed to characterize biomineralized magnetic material as a magnetoreceptor sensor [2–4]. Magnetite is the most common biomineralized magnetic material [5]. *Pachycondyla marginata* (*P.m.*) is an interesting ant to study magnetoreception for its migratory and well-organized predatory raids only on a termite species [6]. As geomagnetic influence was observed in *Solenopsis invicta* ants [7] and *Apis mellifera* (*A.m.*) honeybees [2], they are also attractive insects for this study. *A.m.* honeybees were collected at the entrance of the hive in São Paulo University apiary. The honeybees were dried for 10 h at 35°C and for 21 h at 39°C and kept in a desiccator. Sample consists of 12.3 mg of 2–3 smashed bee abdomens. *P.m.* ants were collected in a small urban forest in Campinas, São Paulo and ants *Solenopsis* sp. (*S.* sp.) in Citrolândia, Rio de Janeiro. Ants were extensively washed with ethanol 80% and conserved in this solution. *P.m.* abdomens and *S.* sp. ants were smashed and desiccated. 37 mg (about 45 whole ants) of *S.* sp filled the sample holder while about 3 *P.m.* abdomens were fixed to the sample holder with vacuum grease. All samples are from Brazil, in the South Atlantic Magnetic Anomaly region, where the geomagnetic field is about 0.22 Oe.

Fig. 1 shows IRM warming results obtained using a SQUID magnetometer from 4 to 300 K with a field cooling (FC) of 3 kOe, except for migratory ants (40 kOe). A sharp decrease is easily observed for the migratory ant at about 67 K as in the identification of magnetite multidomains from stingray [8]. IRM at 300 K indicates the presence of at least 10 times lower concentration of magnetic material in the whole *S.* sp. ant as compared to the *P.m.* ant abdomen ($0.22 \pm 0.03 \times 10^{-6}$ emu/ant, and $2.8 \pm 1.2 \times 10^{-6}$ emu/abd, respectively). Our honeybee results at room temperature agree with Takagi's [4] value using an 8 kOe FC and with Kirschvinck's [9] ones. The recent IRM results for two termite species in samples presenting ultrafine and clusters of magnetite

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PII: S0304-8853(00)00832-5

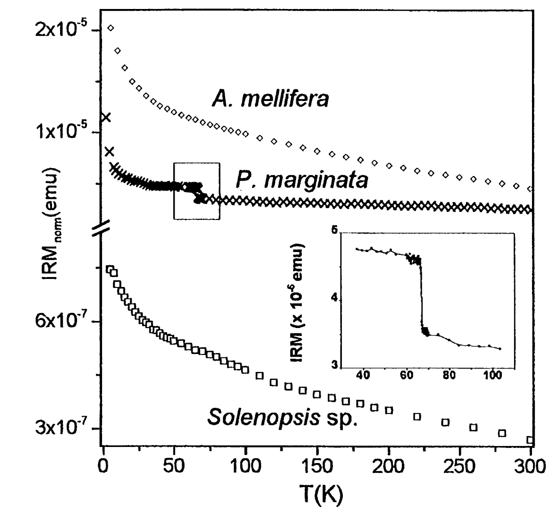

Fig. 1. IRM temperature dependence of honeybee and migratory ant abdomens and whole fire ants. *Y*-axis is normalized as IRM per abdomen of migratory ant and honeybee, and per whole fire ant. The inset shows details of the 67 K transition in the migratory ants curve.

particles with a 5 kOe FC at room temperature [3] are also of this order. From our measurements the numbers of SPM and SD/aggregate particles are estimated considering magnetite as the magnetosensor material with 470 emu/cm^3 saturation magnetization value, and particles sizes of 130 Å diameter [11] for SPM and 390 × 260 × 260 Å for SD [10] *P.m.* particles and for *A.m.*, 120 Å diameter for SPM and aggregate with 5 particles for SD [12]. Volumes from electron microscopy data [10] are higher than the magnetic ones estimated from EPR data [11,12]. The use of EPR volumes to obtain the particle numbers results then in upper limit values. The *A.m.* and *P.m.* SPM numbers and the *A.m.* SD number are then higher limit numbers. The room temperature (RT) IRM values yield SD and aggregate particle numbers while the 77 K to RT IRM loss, the superparamagnetic (SPM) particles. The numbers of SPM particles, 1.8×10^9 (*P.m.*) and 1.4×10^{10} (*A.m.*), and of SD/aggregates, 2.3×10^8 (*P.m.*) and 2.2×10^9 (*A.m.*) seem consistent among the social insects.

Different magnetic material contents were found for different species of each social insects [1,3,10] and even more, different values were observed in individuals from the same colony [2] possibly related to the different local geomagnetic field, diet and function in the colony and also the experimental approaches. The magnetoreception mechanism complexity in animals, particularly in social insects, has appeared from behavior studies [1,6,7,9,13]. A few models have been proposed to explain this geomagnetic influence based on biomineralized magnetite particles [14] (see also references in Ref. [13]). This study supports the hypothesis of these models, where two kind of magnetic structures, SD/aggregates and SPM, are required.

Acknowledgements

The authors thank Dr. Dean Rao for remanence measurements of *A.m.* and *S.* sp. E. Wajnberg and D.M.S. Esquivel thank CNPq and D. A-Avalos thanks FAPERJ for financial supports.

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