# FINAL REPORT
## Arrays of magnetic nanoparticles in a superconducting material

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### PURPOSE OF THE VISIT

The research topic of the visit has been the study of the effect of an artificial array of magnetic nanoparticles in a superconducting material by means of computer simulations. The magnetic dots interact with the superconductor by means of the magnetic flux generated by magnetic textures and supercurrents; this flux pins vortices or creates them, changing the transport properties of the superconductor. The magnetic field from supercurrents (vortices) strongly interacts with the magnetic subsystem, leading to formation of coupled magnetic–superconducting topological defects [1]. Experimentally there is a strong dependence of the transport critical current on the density and strength of the nanoparticle arrays.

The purpose of the visit was to introduce the researcher in the topic of magnetic nanoparticles arrays in a superconducting matrix in a centre of expertise. Besides, the researcher would be able to interact with experimentalists, familiarizing with the sample preparation techniques and proposing experiments. Furthermore, the Device Materials Group in Cambridge University had done a significant amount of experimental work on ferromagnetic-superconducting heterostructures and has a lot of data to be modellized.

The stay would allow to form the basis of longer-term collaboration between the Device Materials Group in the Department of Materials Science and Metallurgy of Cambridge University and the Electromagnetism Group in the Department of Physics in Universitat Autònoma de Barcelona.

### WORK CARRIED OUT DURING THE VISIT

The research work has been centred in the modelling of a magnetic nanoparticle embedded in a superconducting material. The researcher has been working in a numerical procedure, based on the Ginsburg-Landau theory, for solving such system. This model would simulate the spontaneous creation of vortices and antivortices due to the presence of the magnetic dot, the vortex configuration due to en external applied field and the vortex pinning created by the magnetic dot. Thanks to the general Ginzburg-Landau approach, the model is valid for any Ginsburg-Landau parameter, $\kappa$, and an arbitrary superconducting sample shape, including thin films.

In the Device Materials Group in University of Cambridge, the researcher has benefited from frequent discussions with experimentalists, familiarizing with the standard measuring techniques, their limitations and analysis. Moreover he had access to measurements of superconducting samples with magnetic particles and, thus, he is familiar with the qualitative behaviour and magnitudes of the usual physical quantities involved.

## MAIN RESULTS OBTAINED

A significant part of the stay has been used to enter into the research topic of arrays of magnetic dots in superconducting materials, involving the understanding of the state of the art. With the supervision of Prof. Blamire, the specific problem to be studied has been determined.

Once this had been done, a numerical procedure for solving the nonlinear differential Ginzburg-Landau equations have been developed and set up using the C++ programming language. The computer program, which consists of around 1500 lines, is of significant complexity, since it has to discretize a three dimensional region and accurately compute spatial derivatives. The Ginzburg-Landau equations are to be solved by minimizing the nonlinear Ginzburg-Landau free energy. Such minimization is performed using a novel minimizing technique. However, in the present stage the computer program is only partially implemented due to the limited time of the visit and, hence, needs debugging and further developing.

## FUTURE COLLABORATION WITH HOST INSTITUTION

The Device Materials Group in the Department of Materials Science and Metallurgy of the University of Cambridge has obtained extensive experimental data about superconducting materials with magnetic particles in their volume. The numerical procedure described above, to be completed in the Grup d'Electromagnetisme in the Department of Physics of Universitat Autònoma de Barcelona, should provide a theoretical description of the measured data, setting the basis of a collaboration.

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[1] I. F. Lyuksyutov and V. L. Pokrovsky, Adv. Phys. **54**, 67 (2005).