

Abstract

Magnetic Nanoparticles and Magnetic Sensors for Ultrasensitive and Fast Diagnostics [†]

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Abstract: A novel methodology for the sizing of magnetic nanoparticles (MNPs) based on diffusion is described herein. The sensing core is an electrical coil wrapped around a capillary filled by an MNP solution. We show that it is possible to determine MNPs' hydrodynamic radius by employing off-the-shelf electronic equipment by measuring the decrease in coil inductance when MNPs diffuse out of the coil by Brownian motion.

Keywords: biosensors; point-of-care sensors; superparamagnetic nanoparticles



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1. Introduction

The early detection of molecular biomarkers (BMs) allows for targeted therapies of various diseases, substantially reducing the doses required for pharmacological therapy and surgical invasiveness. Protein BMs are widely recognized as key indicators for important orthopedic disorders [1], cancer [2], neurodegenerative diseases [3], and others. Even though their discovery has been an impressive advancement for science, the development of clinical diagnostic tools based on BMs remains, as of yet, an actively pursued goal by both academia and industry. Herein, we describe a novel concept for an ultrasensitive bio-diagnostic based on the different diffusivity of magnetic nanoparticles (MNPs) with and without the examined BM. The diffusivity of MNPs can be suitably and accurately measured with various magnetic sensors due to the presence of the magnetic moment of the nanoparticles. Magnetic detection can be operated across a vast range of BM concentrations, starting from ultra-low femtogram quantities to nano-, micro-, and milligrams, by employing different types of sensors. Herein, we address the concentrations in the range of a few mg/ml and demonstrate that the simple inductive coil-based detection of magnetic species allows one to define the diameters of the MNPs with accuracies close to a few nanometers.

2. Materials and Methods

The sensing core is an electrical coil wrapped around a capillary where a batch of MNPs are initially magnetically confined. Upon releasing the confining magnet, the MNPs are free to diffuse out of the coil as sketched in Figure 1. By measuring the associated decrease in the coil's inductance, we can determine the diffusivity coefficient of the MNPs and hence their hydrodynamic radius by employing off-the-shelf electronic equipment.

Herein, we experimentally show that our device can reliably measure the diameter of Fe_3O_4 MNPs with three different sizes: 70, 30, and 20 nm (as measured via TEM).

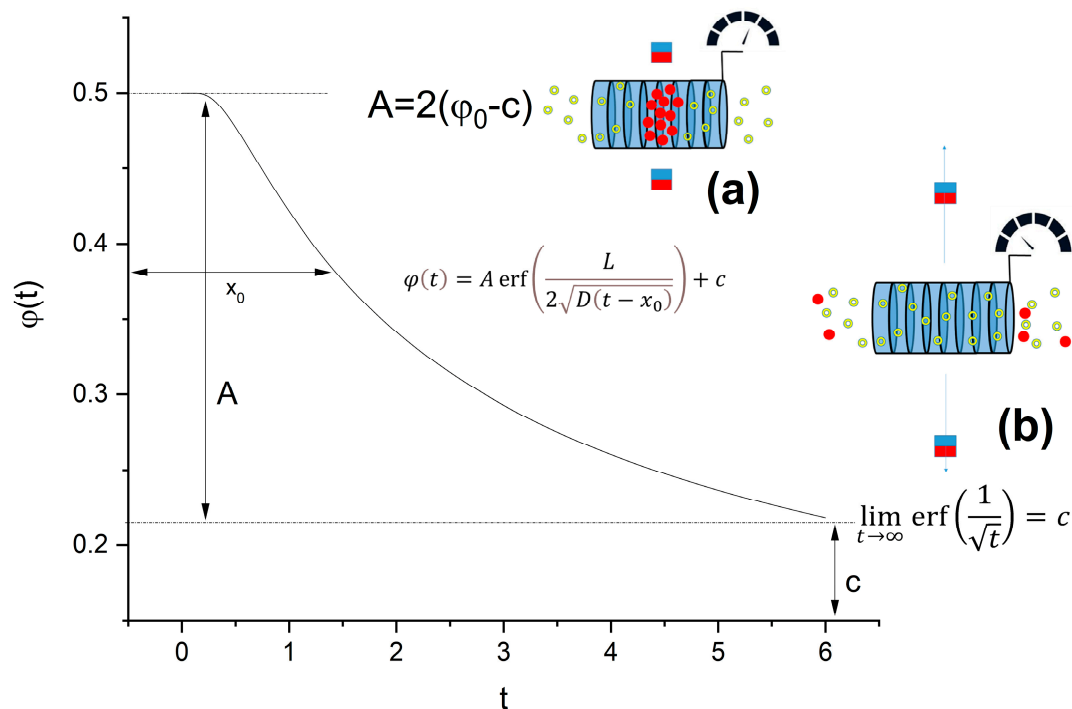


Figure 1. Concept of the sensor. At the beginning of the experiment (a), MNPs are magnetically confined in the coil and it has a high inductance. When the MNPs are free to diffuse, they leave the coil and its inductance decreases (b). The decrease in inductance follows the equation shown in the picture. In the plot, inductance (y-axis) and time (x-axis) are given in arbitrary units.

Moreover, the direct detection of a protein is demonstrated on the BSA-coated 20 nm large Fe_3O_4 MNPs as to mimic the presence of a clinically important BM. Our results indicate that this simple detection scheme, compatible with portable point-of-care devices, provides a detection accuracy by far exceeding the wide-spread dynamic light scattering technique.

We will also report on the very attractive option of magnetically enhancing by orders of magnitude the concentration of BMs in patient samples, thus providing the possibility to employ standard diagnostic techniques, such as ELISA, for concentrations well below their factual limits [4,5].

Author Contributions: A.S. performed the experiments and analyzed the experimental results, L.G. performed the experiments, T.S. conceptualized the experiments, M.A.G.-G., Y.P. and J.R. fabricated and characterized the MNPs. G.G. and V.A.D. were in charge of project administration and funding acquisition. A.S., L.G., T.S. and V.A.D. conceptualized the experiments and wrote the manuscript. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

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