NANOMATERIALS IN CANCER THERAPY - A MODEL EXPERIMENT FOR CHEMISTRY EDUCATION

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INTRODUCTION

Nanomaterials are not only used in products for end consumers and industry, they hold great potential for medicine too [1]. Magnetite nanoparticles are superparamagnetic and mostly used in ferrofluids or toner. When placed into an alternating magnetic field, the magnetite heats up so much that a tumor can be consequently damaged or even destroyed. This therapy is referred as "local hyperthermal treatment". If the tumor is damaged, other agents can better act on the tumor, so the nanoscale magnetite also supports other active ingredients [2]. Since the phenomenon of induction heat already is an exciting topic, this offers the option of a promising expansion of the subject area, which will be presented in the following.

THEORETIC BACKGROUND

For local hyperthermal treatment, a ferrofluid is initiated into the affected tissue. The ferrofluid consists of dispersed magnetite nanoparticles with the aid of a stabilizer to prevent particle growth. The tissue is now placed in an appropriate alternating magnetic field. Depending on the strength of the magnetic field, the frequency and the nature of the nanoparticles, the particles starts to heat up. In some kitchens, a similar phenomenon is utilized during induction cooking. Here, a magnetic pot or pan is exposed to an alternating magnetic field, causing it to heat up. Although there are many parallels in both processes, there are nevertheless serious differences in the material. The pot is ideally ferromagnetic, while the nanoparticles in the ferrofluid are superparamagnetic. In simplified terms, a ferromagnet consists of various elementary magnets that have the same orientation in magnetic domains. By applying a magnetic field, all elementary magnets of all domains now align themselves with it. In case of the nanoparticles, each particle represents its own magnetic domain. In an alternating magnetic field both materials change their magnetic orientation regularly and heat up due to magnetization losses. But for the nanoparticles, there is an additional effect: not only can the magnetic orientation within the particle change, but the entire particle can rotate according to the constantly changing field direction, thus generating additional heat [2]. These nanoparticles can easily be synthesized so this phenomenon can be dealt with as shown below.

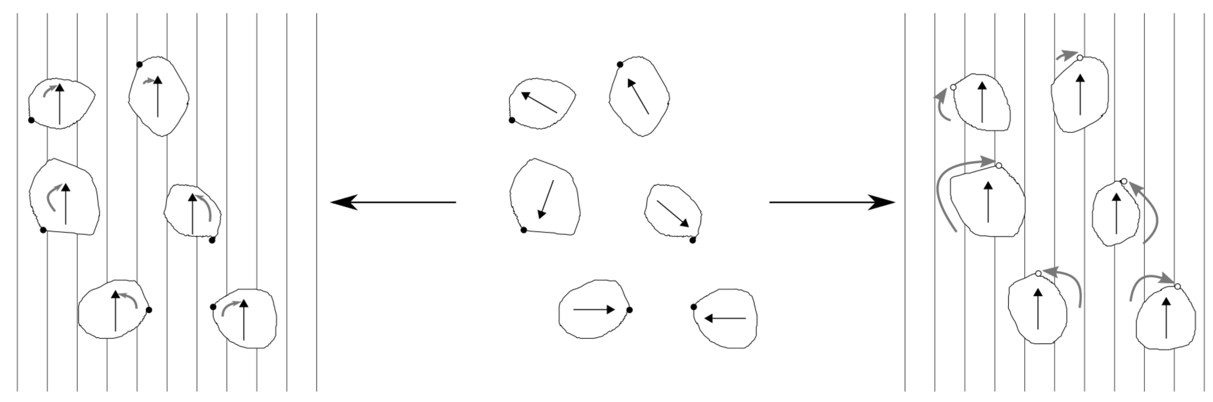

Figure 1
For superparamagnetic nanoparticles the orientation of the magnetization (arrow to the left) or the whole particle can align to the field (arrow to the right).

SYNTHESIS

Best results were obtained with an adapted variant of Berger et al. [3].
First, the magnetite nanoparticles are prepared. For this, iron(II) sulfate and iron(III) chloride are dissolved in water. To this, an ammonium hydroxide solution is added over the course of about five minutes with vigorous stirring (1). During the addition, the initially yellow liquid quickly turns deep black. After complete addition of the base, the black solid can be fixed to the bottom with a strong neodymium magnet and the liquid can be poured off. By adding water again and then decanting analogously, unreacted educts and interfering products are removed (2). After washing several times, tetrabutylammonium hydroxide solution is added and the mixture stirred well. With the help of the magnet the characteristic Rosensweig lines occur and indicate the presence of superparamagnetic nanoparticles (3/4).

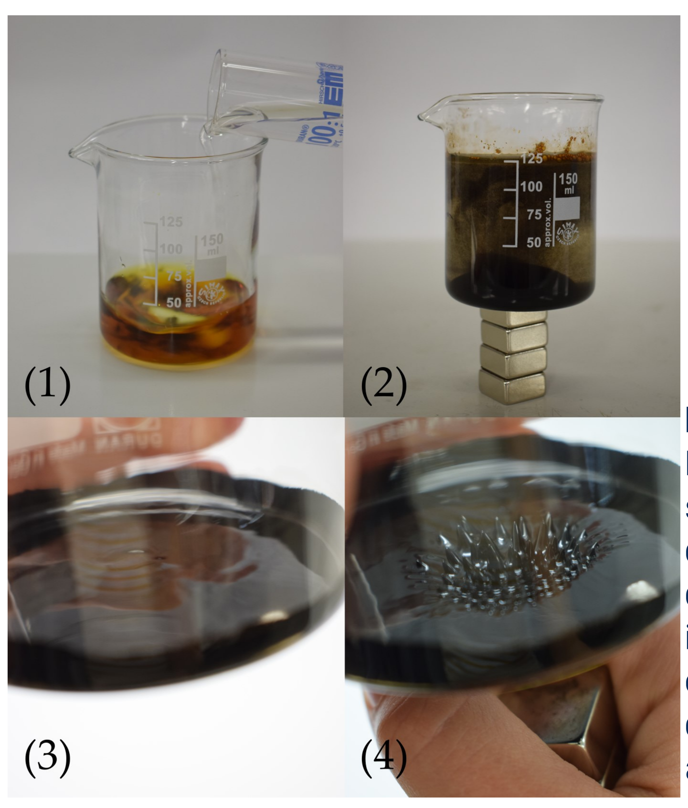

Figure 2
Main steps of the ferrofluid synthesis: (1) Solving and addition of ammonia solution; (2) decanting and washing; the finished ferrofluid after addition of tetrabutylammonium hydroxide solution without (3) and with magnetic field (4).

MODEL EXPERIMENT

For the measurement, two vials are placed on an induction plate. One vial is filled with the ferrofluid and water, the other with the same amount of water. A temperature probe is now held in each of them. Now the plate can be switched on and the temperature is measured in both vials. At the latest after 20 minutes at a power of 3500 W, a clear trend can be seen: the ferrofluid heats up more than the reference. The measurement with the LabPi [6] measuring station has proven itself well in the student laboratory, since not only the initial and final temperature, but also the curve progression can be compared. Although the metal of the sensor also heats up during operation, the effect is the same for both and therefore negligible.

Figure 3
Induction plate with two prepared vials while measuring the temperature over time with LabPi.

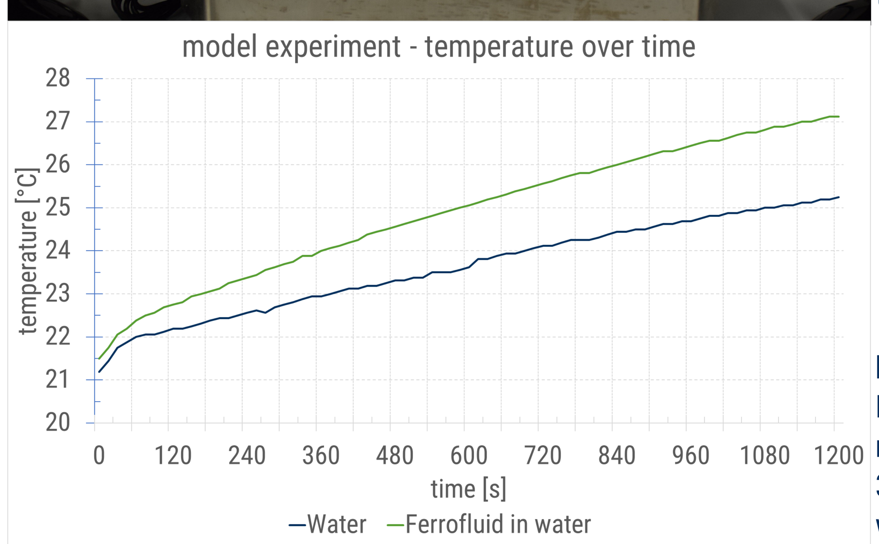

Figure 4
Results after 20 minutes with 3500 W; measured with LabPi.

RESULTS & OUTLOOK

While the synthesis is mainly chemical in nature, the model experiment is suitable to incorporate in physics lessons. However, the knowledge of induction and eddy currents is important for this, so it is typically addressed in secondary level K-12 grades.
Both experiments have been piloted with students during a summer school; the synthesis has also been included in a laboratory practical course of the teacher training program at the Friedrich Schiller University Jena. In both cases, the experiments were carried out successful by students and described as exciting and motivating. When the pandemic situation allows further evaluation, this experiment series will be carried out in regular chemistry and physics lessons and implemented into teacher formation.
The didactic potential of nanomedicine will be enhanced by linking it with other research areas and contexts, e.g. polymer chemistry, resulting in topics like targeted drug delivery [2,4] or smart material design [5].

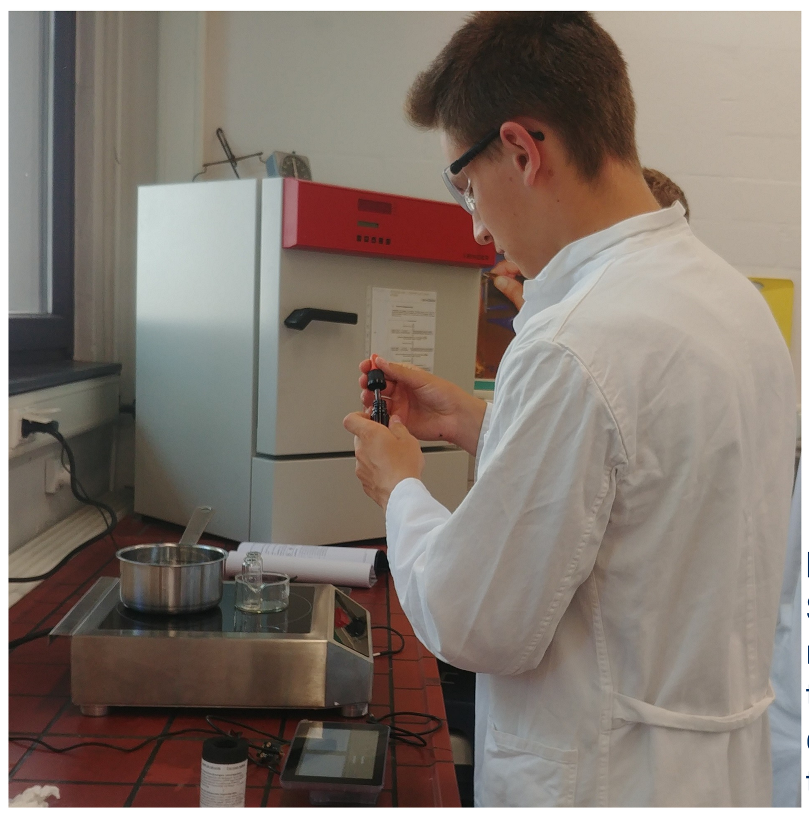

Figure 5
Students at the summer school, preparing the vials for the model experiment (picture taken 2019).

REFERENCES

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