Synthesis of Magnetic Iron Oxide Nanoparticles

Magnetic Iron Oxide Nanoparticles (MION) present many potential possibilities in biomedicine. Since they range from a few nanometers up to 200 nanometers, they rival the size of most cells, viruses, proteins, and genes. This means that they can interact with these biological units "up close". Applications of MION include uses as drug delivery devices, in bioseperations and hyperthermia treatment, and as a contrast agent for magnetic resonance imaging. The potential uses for MION is steadily increasing, and, with it, the need for a simple, fast and efficient, and, most importantly, reproducible method for preparing and functionalizing MION with variable size and narrow dispersity

MION exist in two forms: magnetite (Fe_3O_4) and maghemite (γFe_2O_3). The former consists of FeO and Fe_2O_3 and is sensitive to oxidation. In the presence of oxygen, magnetite is readily oxidized to maghemite. They are commonly referred to as being superparamagnetic because, while on a microscopic level they are ordered, they are magnetized as a whole in the presence of an externally applied magnetic field (paramagnetism).

Microwave irradiation is becoming widely used as a rapid heating method for the synthesis of MION. Beyond rapid heating, microwave irradiation also reduces the reaction time and increases product yield when compared to conventional heating methods. It is important that the MION are monodispersed; typically accomplished by separating the nucleation stage and the crystal growth stage. In theory, the uniform and rapid heating from microwave irradiation promotes these two separate stages to eliminate multiple nucleations that lead to the loss of the nanoparticles monodispersity. The microwave hydrothermal (M-H) method increases the kinetics of crystallization from uniform microwave heating and reaction rate due to super heating of the solution. Superheating allows high temperatures (>200^{o}C) to be reached more readily using microwave irradiation than conventional methods, such as an oil bath.

Scientists at three different research institutes in China synthesized MION of magnetite and maghemite using the CEM Discover®(Figure 1a).[1] The results are shown in Scheme 1. Ellipsoidal αFe_2O_3 nanoparticles were made with the addition of hydrogen peroxide and microwave irradiation, while irregular nanoparticles and rods were made via oil bath heating, as shown in Figure 2. X-ray powder diffraction patterns were used to determine structure and phase purity of the iron samples.

Figure 1. (a) Single mode Discover S-Class® dedicated microwave synthesizer (b) MARS® multimode system

Scheme 1. Microwave assisted synthesis of MION

$$FeCl_3 \cdot 6H_2O \quad + \quad \text{20 kDa PEG} \xrightarrow[\text{MW, 100}^{o}\text{C, 10 min}]{N_2H_2} Fe_3O_4 \quad \text{20 nm nanoparticles}$$

$$FeCl_3 \cdot 6H_2O \quad + \quad \text{20 kDa PEG} \xrightarrow[\text{MW, 100}^{o}\text{C, 10 min}]{N_2H_2,\ H_2O_2} \alpha Fe_2O_3 \quad \text{50 x 100 nm ellipsoid nanocrystal}$$

$$FeCl_3 \cdot 6H_2O \quad + \quad \text{20 kDa PEG} \xrightarrow[\text{Oil bath, 100 }^{o}\text{C, 10 min}]{N_2H_2,\ H_2O_2,} \alpha Fe_2O_3 \quad \text{nanoparticles and rods}$$

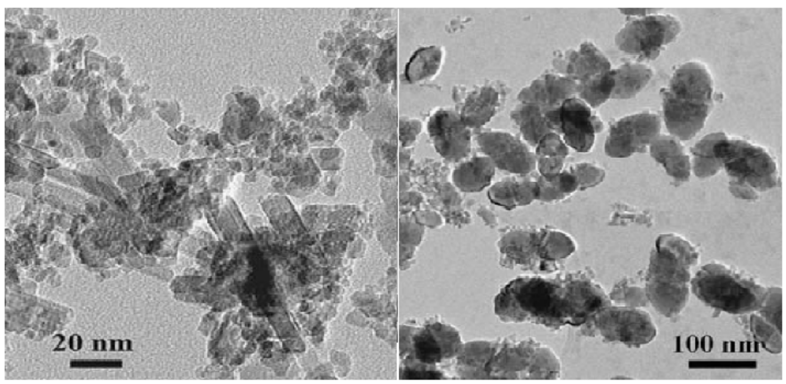

Figure 2. MION prepared via oil bath (left) and MW irradiation (right).[2]

Joy and Sreeja synthesized γFe_2O_3 via the M-H method using the CEM MARS® (Figure 1b).[3] Iron (III) chloride-hexahydrate and iron (ii) sulfate-heptahydrate were mixed in a 2:1 stoichiometric molar ratio in sodium hydroxide solution. The mixture was heated at 150^{o}C and 150 psi for 25 minutes. The resulting crystals ranged from 8-13 nm in size, with an average particle size of 10 nm and a blocking temperature of 200 K.

Similarly Katsuki and Somarneni at Penn State University investigated the effects of temperature and time on the yield and size of αFe_2O_3 nanoparticles (Figure 3).[4] The reactions were heated to 100^{o}C, 120^{o}C, 140^{o}C, and 160^{o}C for 2, 4, and 8 hours each, (total of 12 runs). They found that time and heating method (microwave vs oil bath) played a major factor in yield, while increased temperatures contributed to larger crystal size: from 45nm (100^{o}C) to 65 nm (160^{o}C). They also noted that βFeOOH was formed under conventional hydrothermal heating methods. Only after 72 hours of treatment were pure αFe_2O_3 formed. By using the M-H method, the authors synthesized αFe_2O_3 nanoparticles without βFeOOH crystals in two hours. The size of the nanoparticles obtained from conventional heating ranged from 100 – 180 nm, while those from microwave heating ranged from 30 – 66 nm.

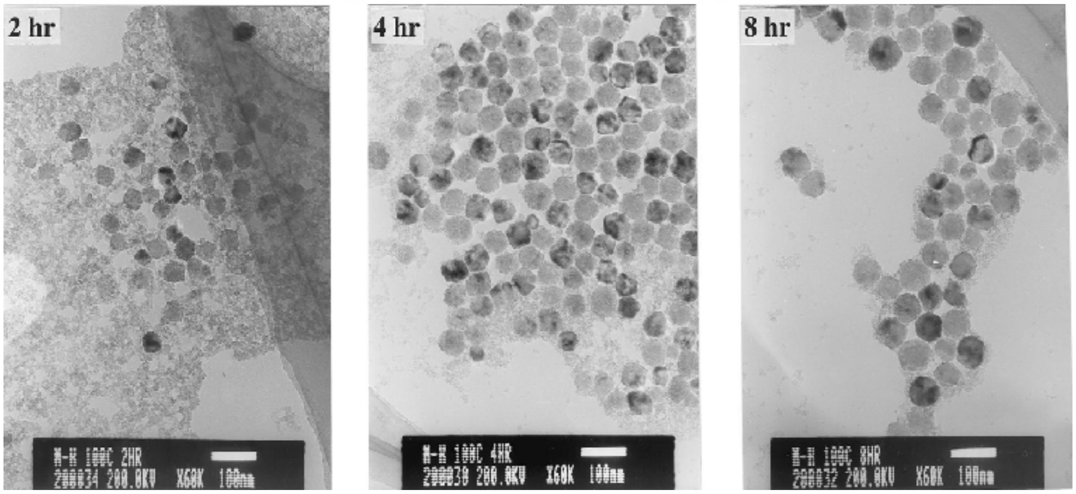

Figure 3. Morphology of γFe_2O_3 via MW irradiation for 2 h (left), 4 h (middle), and 8 h (right).[5]

In conclusion, the synthesis of MION using M-H method has become ideal due to the strong absorbing characteristics of iron which lead to faster reaction, increased yields, a higher degree of size control, and a lower particle size dispersity. For more information on MION and their potential applications see: Muller R. N. et al. *Chem. Rev*. **2008**, *108*, 2064 – 2110, along with other reviews in *J. Phys. D: Appl. Phys*. **2003**, *36*, R167 –R206.

References

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4) Katsuki, H.; Komarneni S. *J. Am. Ceram. Soc*. **2001**, *84*, 2313 – 2317. **DOI**: 10.1111/j.1151-2916.2001.tb01007.x
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