Optimizing the properties of magnetic nanoparticles for biomedical applications

Gavin Lawes
Wayne State University
TEM image of iron oxide nanoparticle

8 nm
Magnetic structure of nanoparticles

~30,000 atomic spins
Magnetic behavior of nanoparticles

\[ M \]

\[ T \]

FC

ZFC

E

EA

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August 22\textsuperscript{nd}, 2008
Potential applications

1. Localizing nanomaterials using external magnetic fields.
2. Provide localized (on the level of individual cells) heating.
3. Magnetic resonance imaging contrast agent.
4. Determining drug concentrations in situ using MRI.
Can magnetic nanoparticles be incorporated with other biomaterials to provide new functionalities?
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1. Magnetic hyperthermia
2. Nanoparticle dynamics
3. Magnetic resonance imaging
4. Combing nanoparticles with other drug delivery platforms
Magnetic hyperthermia
Relaxation in magnetic nanoparticles

Brownian Relaxation
Neel Relaxation
$\text{Fe}_3\text{O}_4$ (TMAH)

$\gamma$-$\text{Fe}_2\text{O}_3$ (alginate)

80 nm
Iron crosslinked sodium alginate

AC magnetic susceptibility

Neel relaxation

Brownian relaxation

Fe₃O₄

γ-Fe₂O₃
Magnetic hyperthermia

250 Oe field
125 kHz
11 mg/mL concentration
Hyperthermia in dextran coated nanoparticles

![Graph showing temperature change over time for cyclohexane and different concentrations of nanoparticles.](image)
Nanoparticle dynamics
Static optical measurements

(volume fraction ~1%)
Intensity parallel to H

$Fe_3O_4$

$\gamma-Fe_2O_3$
Intensity perpendicular to H

$Fe_3O_4$

$\gamma - Fe_2O_3$
Field-induced structures in \( \text{Fe}_3\text{O}_4 \) nanoparticle ferrofluids
Magnetic resonance imaging
Static MR measurements

Quartz tube filled with ferrofluid (Fe$_3$O$_4$)

Bulk magnetization data
$\chi = 103$ ppm at 4.7 T

MRI data
$\chi = 112$ ppm at 4.7 T
MR measurements in flow

500 ml bottled distilled water

point of injection of particles

sink

4.7 T magnet

image section
MR images of flow tube

inlet

4 mm

$\text{t}=0$
(no nanoparticles)

$\text{t} \sim 30 \text{ s}$
after injection
MR intensity in flow tube

Time point

Magnitude

inlet

outlet
Quantifying nanoparticle concentration during flow using MR

![Graph showing concentration vs. $R_2^*$](image_url)
Combining magnetic nanoparticles with drug delivery platforms
Correlation spectroscopy of magnetic nanoparticles and rhodamine 123
Aerosol-OT nanoparticles

• Exhibit controlled and sustained release of doxorubicin
• Delivery improved relative to drug in solution

Mahesh D. Chavanpatil,1 Ayman Khdair,1 and Jayanth Panyam1,2,3

DOI: 10.1007/s11095-006-9203-2
Ca\textsuperscript{2+} crosslinked no nanoparticles

![Image of Ca\textsuperscript{2+} cross-linked material](image)

**Graph (a)**

- **M (10^{-3} emu/g of sol.)**
- **H (kOe)**
- **T(K)**

**Legend**

- **5K**
- **300K**

- **FC**
- **ZFC**

[Caption: Wayne State University]

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Fe$^{2+}$ crosslinked no nanoparticles

(b)

\[ M = 10^{-2} \text{emu/g of sol.} \]

\[ H \text{ (kOe)} \]

\[ T \text{ (K)} \]

- FC
- ZFC

Fe$^{2+}$ cross-linked

500 nm
Ca\textsuperscript{2+} crosslinked with nanoparticles
Fe\textsuperscript{2+} crosslinked with nanoparticles
Model drug loading (R6G)

Dye loading (μg/mg)

- AOT-Alginate
- AOT-Alginate-Fe₃O₄ (5%)

- Ca²⁺-cross-linking
- Fe²⁺-cross-linking
Summary

Hyperthermia is largest for isolated nanoparticles.

Static magnetic fields induce chain formation in ~60 s.

Nanoparticle concentration can be determined using MRI.

Nanoparticles can hamper drug loading capabilities.
Future work

1. Determine magnetic nanoparticle cytotoxicity.
2. Investigate surfactant effects on nanoparticle magnetohydrodynamics.
3. Develop hyperthermia apparatus suitable for animal studies.
Collaborators

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Kettering University
Prem Vaishnav
Corneliu Rablau

Funding

American Chemical Society

National Science Foundation