Magnetic Susceptibility Effects

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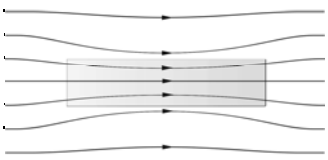
Outlines

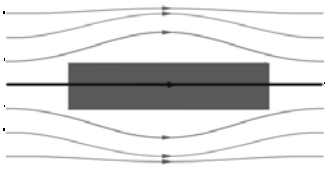
- **Magnetization and magnetic susceptibility**
- **Measurement of magnetic susceptibility**
- **Reducing susceptibility artefacts in fMRI**

Materials in a magnetic field



- **"paramagnetic" materials tend to concentrate flux lines**
- **e.g., iron, cobalt, and O_2**

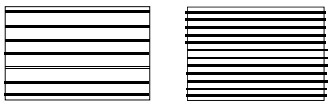
Materials in a magnetic field



- **Diamagnetic materials tend to repel flux lines weakly**
- **e.g., water, protein, and lipid**

Flux density *B* within material depends on

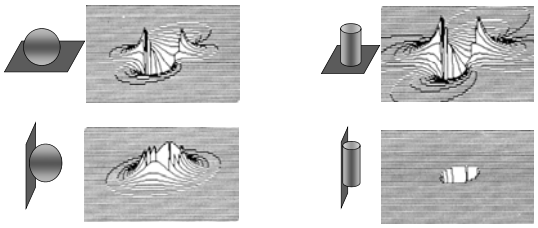
- **the applied magnetic field strength *H***



- **Magnetic properties of the material**

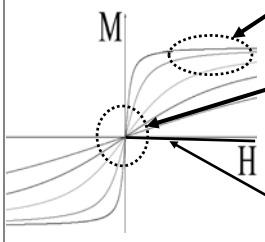
Flux density *B* within material depends on

- **Geometry**



Orientation **Orientation**

Non-linear responses

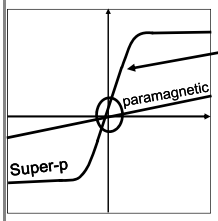


- ***M* tends to saturate at high *H* and low temperatures**
- **Approximate linear at low *H* or high temperatures**

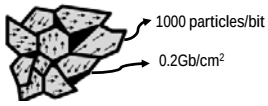
$$\chi = dM/dH \approx M/H$$

- **A small negative χ is diamagnetic**

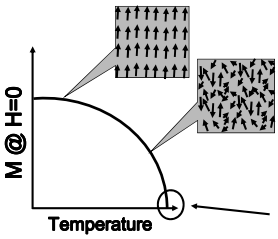
Superparamagnetism



- Magnetic remanence is zero
- High magnetic susceptibility ($1x10^{-2}$ cgs)
- Used for Hard disk, MRI contrast agents, e.g. Nano-Fe_2O_3 , Mn^{2+}

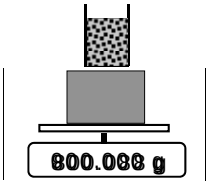


Ferromagnetism



- Having a magnetization in zero field
- Thermal energy can be used to overcome exchange interactions
- Curie temp is a measure of exchange interaction strength

Measurement of magnetic susceptibility
(the principle of MSB)



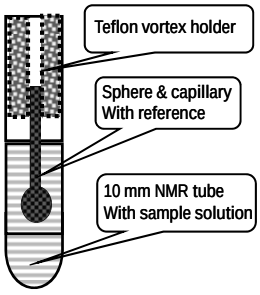
diamagnetic

$\Delta m > 0$

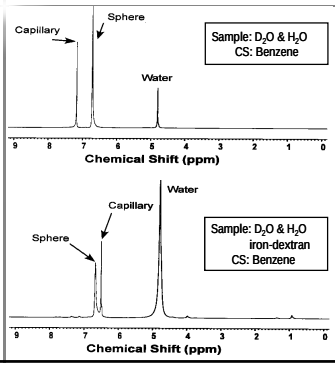
Measurement of magnetic susceptibility with NMR *(Concept in MR. 18A:56, 2003)*

Frei-Benstein exp
Capillary:
I.D. = 1mm
O.D. = 1.5mm
Length=40mm

Sphere:
O.D.=4.1mm



Measurement of magnetic susceptibility with NMR



$-8.82x10^{-6}$SI $\quad -7.68x10^{-6}$SI

$$\delta_c - \delta_s = G_{cs}(\chi_{sample} - \chi_{ref})$$

$G_{cs} = 0.36$

Chemical shift difference of the reference is 0.41ppm

$\delta_c - \delta_s = -0.17$ppm
$= 0.34(\chi_{sample} + 7.68x10^{-6}SI)$

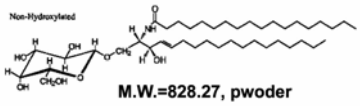
$\chi_{sample} = -8.18x10^{-6}SI$

Lipid composition of adult brain (*J. Lipid Res 6:537, 1965*)

	Gray Matter	White Matter	Myelin
Water	82.3	75.2	—
Total lipid	39.6	64.6	78.0
Nonlipid residue	60.4	35.4	22.0
Cholesterol	7.2	15.1	19.7
Ethanolamine glycerophosphatides	9.2	9.1	11.2
Serine glycerophosphatides	2.9	4.2	5.3
Choline glycerophosphatides	9.0	8.2	8.3
Sphingomyelin	1.9	5.2	4.4
Cerebroside	2.3	12.5	16.0
Cerebroside sulfate	0.8	3.0	3.4
Ceramide	0.5	0.8	0.7

Susceptibility of cerebrocide with NMR?

Cerebrosides Purity >99%



M.W.=828.27, pwoder

~$1000/g

Reference inside CS: D_2O:H_2O=3:1

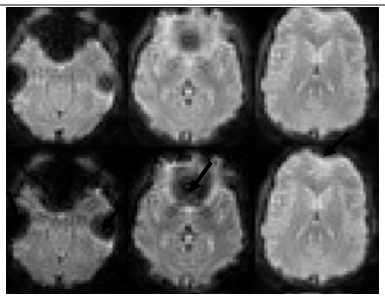
cerebrocide solution: 1g in 6 ml pyridine

Calibration: benzene, acetone, and methanol

Magnetic Susceptibility Artifacts in fMRI

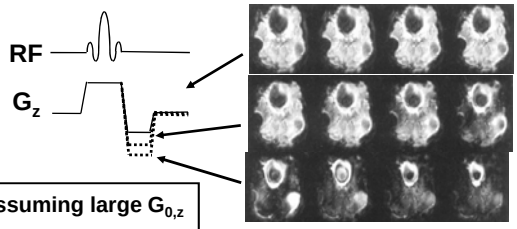
Spiral

EPI



Method for reducing Susceptibility Artifacts

Z-shim method (Glover GH, *MRM* 42:290, 1999)



Assuming large $G_{0,z}$
Low time efficiency

Methods for reducing Susceptibility Artifacts

1) Shorten TE, TE_{eff} (parallel acq)

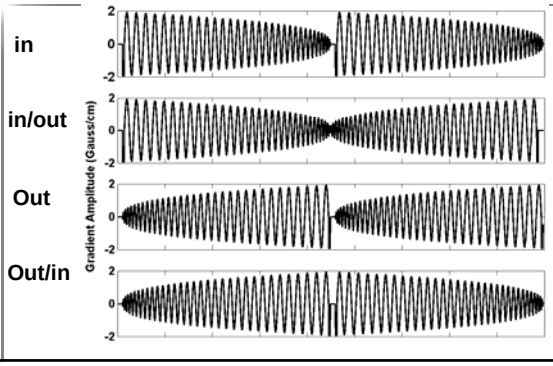
2) Alter orientation of imaging plane

3) Tailored 2D, 3D R.F. pulses
Noll D, et al. *MRM*, 48:15, 2002

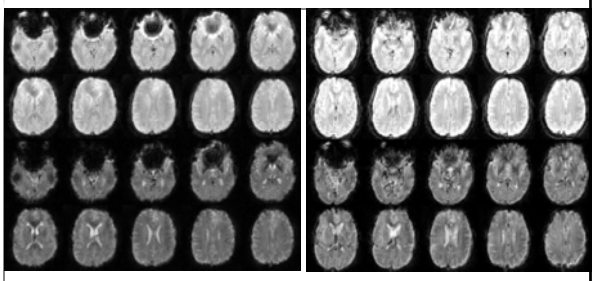
4) Local shim coils

Dual-echo SPiral-In (DSPIN) method

(Li TQ et al. *MRM* 55:325, 2006)

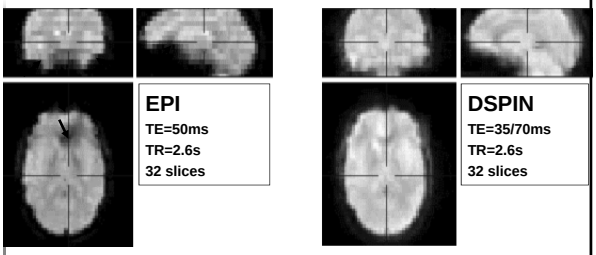


Spiral out | Spiral in



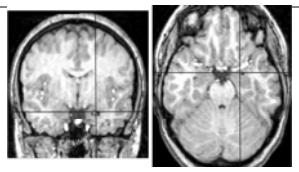
TE1/TE2=20/50ms | TE1/TE2=35/70ms

3D EPI versus 3D DSPIN

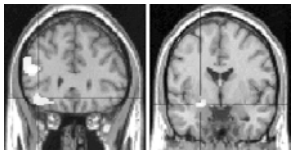


fMRI studies of the amygdala and frontal

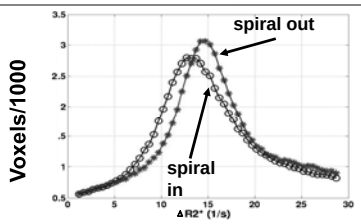
Emotional Stroop task



Olfactory activation
Neuroimage, 25:969, 2005

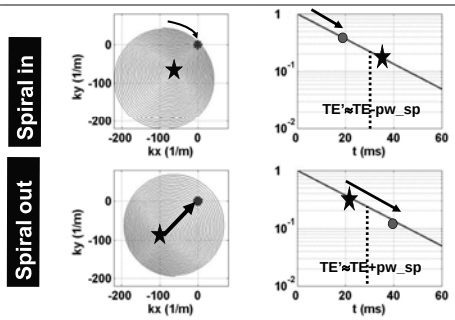


Quantification in bolus tracking of GdTP



	$<T_2^*>$	$<\Delta R_2^*>$
Out-out	69ms	16 s^{-1}
DSPIN	77ms	14 s^{-1}

Simulation: $k(t) = g_0 \cdot t + k(\tau)$



Summery

- **Susceptibility effects depend on tissue types, orientation, geometry**
- **Two methods to measure susceptibility: MSB (powder) and NMR (liquid)**
- **Different methods to reduce susceptibility artefacts in fMRI**