

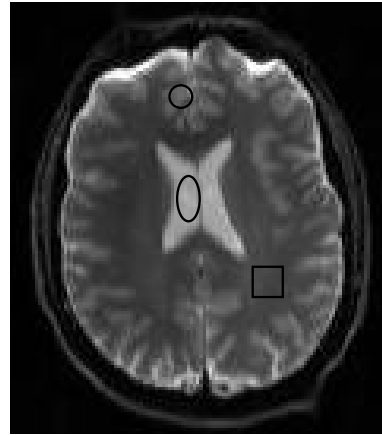
## Exercise: Measurement of the ADC



1. Calculate the apparent diffusion coefficient (ADC) from the DWI images in White Matter (WM), Grey Matter (GM), and Cerebrospinal Fluid (CF)

Experiment #1: 2 images were measured (DWI\_b0.IMA, DWI\_b1000.IMA, data at: <http://www.ma.uni-heidelberg.de/inst/cbtm/ckm/lehre/> „Medical Physics: Lab Rotation MR-Radiology“) with  $b = 0$  and  $1000 \text{ s/mm}^2$ . Plot signal intensity (= pixel mean value of ROI) semi-logarithm as a function of b-value and calculate ADC

- group 1: CF (○)
- group 2: WM (□)
- group 3: GM (○)



$$S = S_0 \exp(-bD)$$

## Exercise: Measurement of the FA

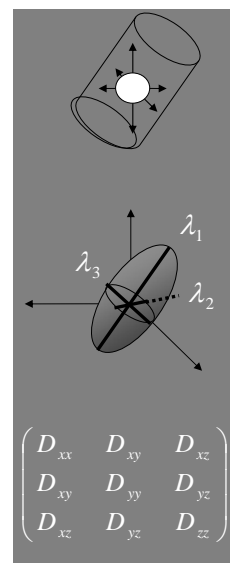


2. Calculate the fractional anisotropy (FA) from the DTI images in White Matter (WM), Grey Matter (GM), and Cerebrospinal Fluid (CF)

Experiment #2: 6 images were measured (DTI\_b1000\_1.IMA ... DTI\_b1000\_6.IMA, data at: <http://www.ma.uni-heidelberg.de/inst/cbtm/ckm/lehre/> „Medical Physics: Lab Rotation MR-Radiology“) with  $b = 1000 \text{ s/mm}^2$  and 6 different directions. Evaluate signal intensity (= pixel mean value of ROI) for the different directions and calculate FA

- group 2: CF (○)
- group 3: WM (□)
- group 1: GM (○)

$$FA = \sqrt{\frac{3}{2}} \frac{\sqrt{(\lambda_1 - \bar{\lambda})^2 + (\lambda_2 - \bar{\lambda})^2 + (\lambda_3 - \bar{\lambda})^2}}{\sqrt{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}$$



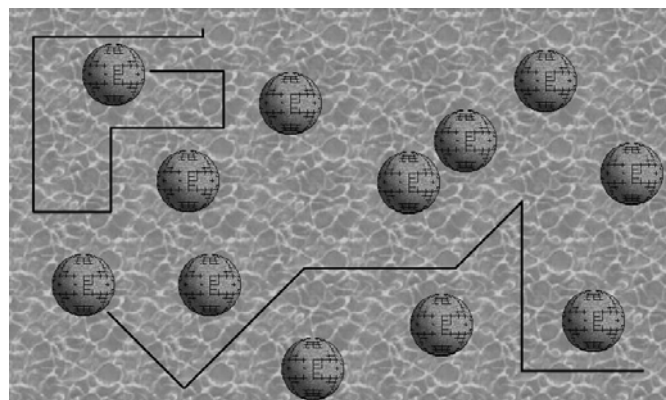


## Diffusion

# Diffusion

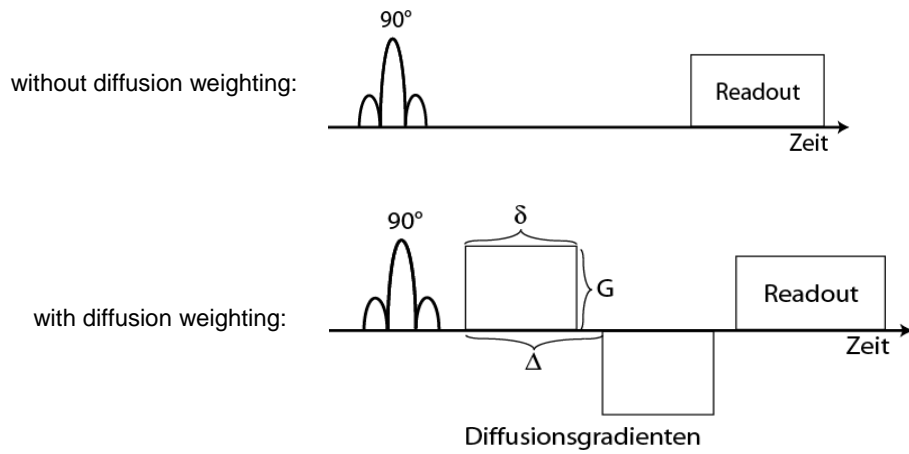


## Free Diffusion

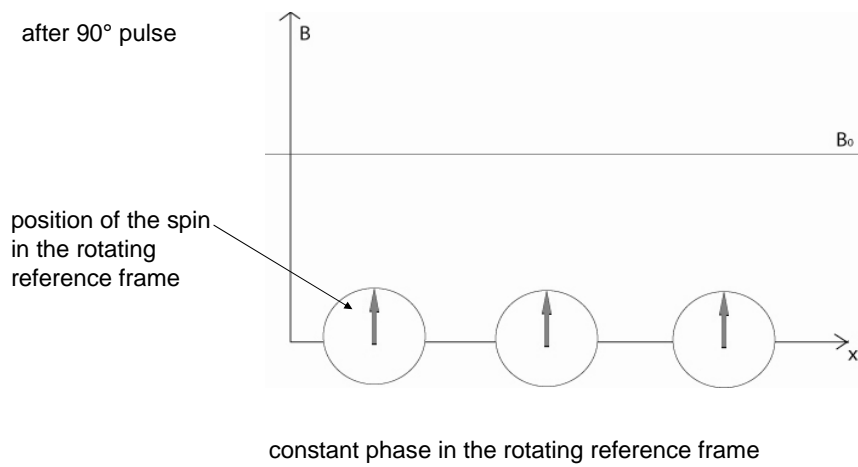


- mean diffusion length  $\langle x^2 \rangle = 6 Dt$   
(D = diffusion coefficient, t = time)

## Principle of DWI I



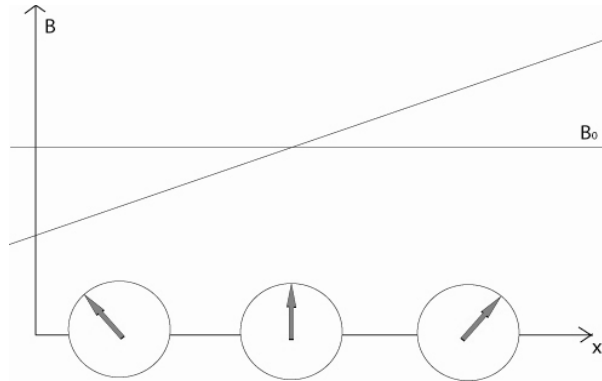
## Principle of DWI II



## Principle of DWI III



without diffusion:

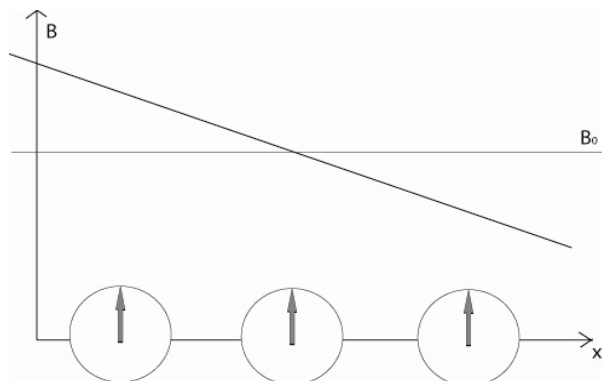


1. gradient  $\rightarrow$  relative phase shift in the rotating frame

## Principle of DWI IV



without diffusion:

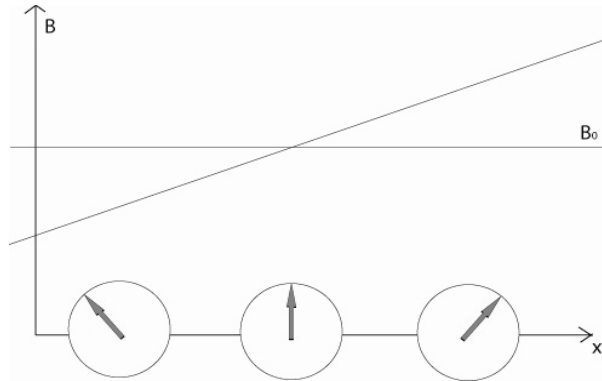


2. gradient  $\rightarrow$  rephasing of the phase  $\rightarrow$  gradient echo

## Principle of DWI V



with diffusion:

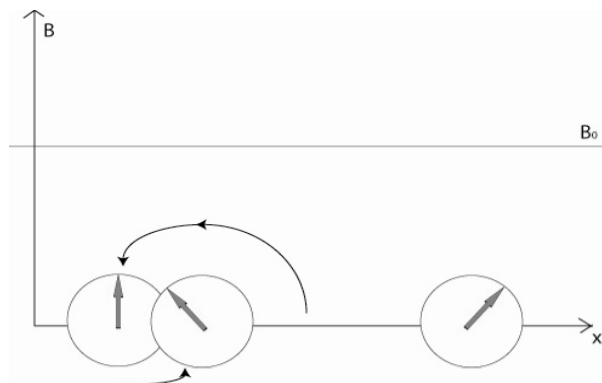


1. gradient  $\rightarrow$  relative phase shift in the rotating frame

## Principle of DWI VI



with diffusion:

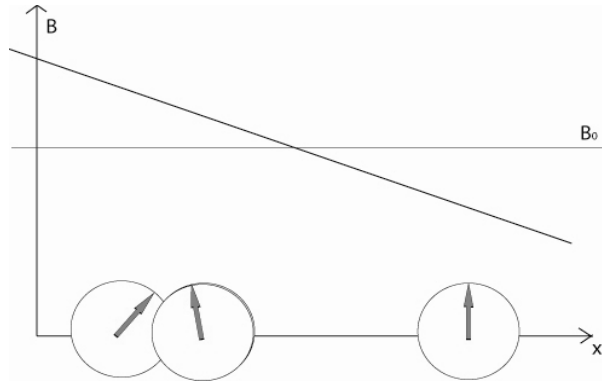


diffusion during the gradients  $\rightarrow$  spins on a different position

## Principle of DWI VII

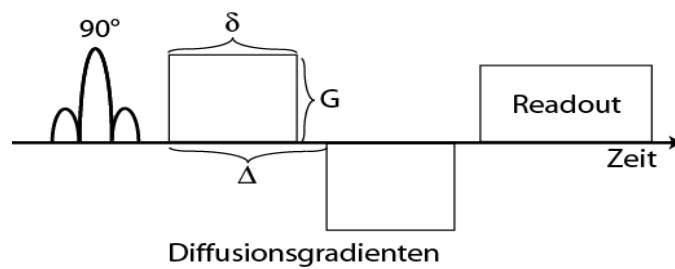


with diffusion:



2. gradient → spins not completely rephased → signal reduction

## Dependence of the Signal Decay



strength of the diffusion weighting:

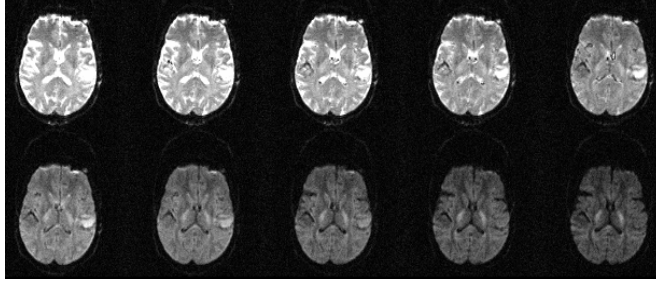
$$b = \gamma^2 G^2 \delta^2 (\Delta - \delta / 3)$$

signal decay:

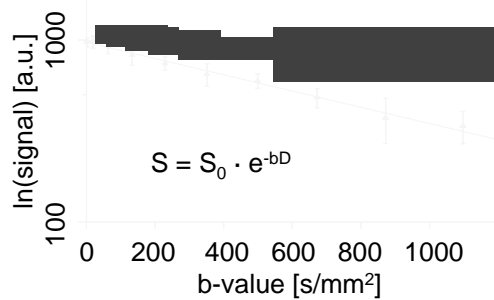
$$S = S_0 \exp(-bD)$$

- b-value can be calculated from the sequence
- two DWIs are necessary to calculate D

## Diffusion Measurement: Calculation of D



b-values = 0.5 – 1100 s/mm<sup>2</sup>

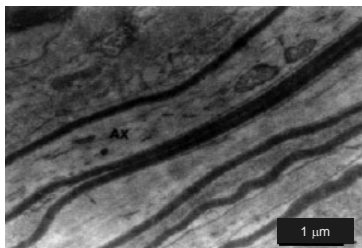
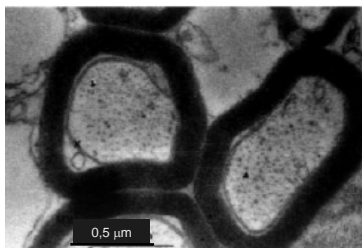


white matter  
 $D \sim 0.6 \cdot 10^{-3} \text{ mm}^2/\text{s}$

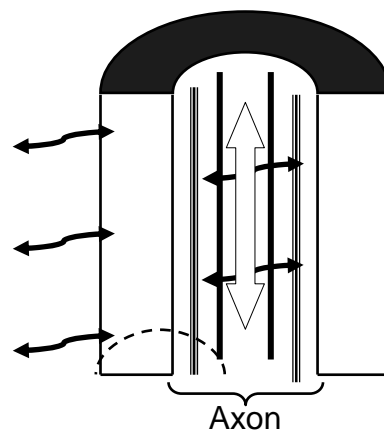
water  
 $D \sim 2.4 \cdot 10^{-3} \text{ mm}^2/\text{s}$

Measurement of D in biological tissue is called ADC

## Anisotropic Diffusion



Bealieu, NMR Biomed., 2002

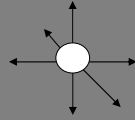


⇒ free diffusion along the fiber  
restricted orthogonal to the fiber

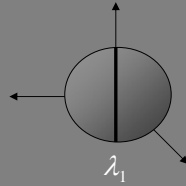


## Diffusion Tensor Imaging (DTI)

water molecule

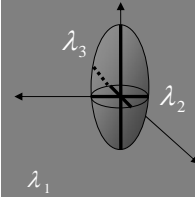
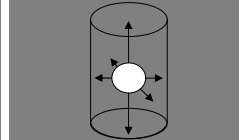


diffusion ellipsoid

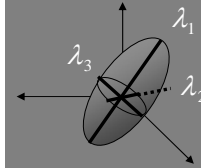
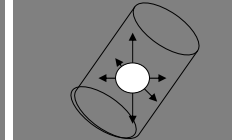


diffusion tensor

$$\begin{pmatrix} D & 0 & 0 \\ 0 & D & 0 \\ 0 & 0 & D \end{pmatrix}$$



$$\begin{pmatrix} D_x & 0 & 0 \\ 0 & D_y & 0 \\ 0 & 0 & D_z \end{pmatrix}$$



$$\begin{pmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{xy} & D_{yy} & D_{yz} \\ D_{xz} & D_{yz} & D_{zz} \end{pmatrix}$$



## DTI: Quantification

derived quantities

apparent diffusion coefficient

$$ADC = \frac{(\lambda_1 + \lambda_2 + \lambda_3)}{3}$$

fractional anisotropy (FA)

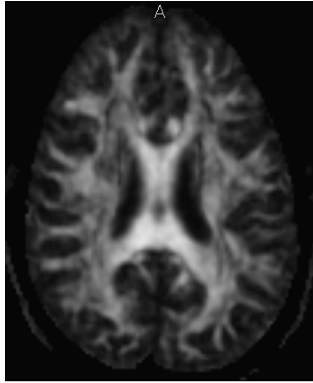
$$FA = \frac{\sqrt{3}}{\sqrt{2}} \frac{\sqrt{(\lambda_1 - \bar{\lambda})^2 + (\lambda_2 - \bar{\lambda})^2 + (\lambda_3 - \bar{\lambda})^2}}{\sqrt{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}$$



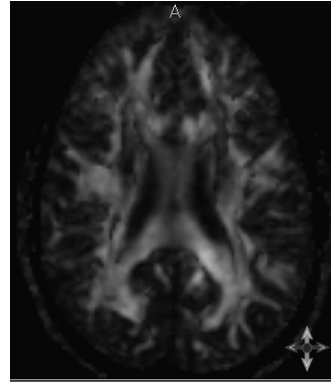
$0 < FA < 1$



## Fractional Anisotropy



FA-map



FA-colormap

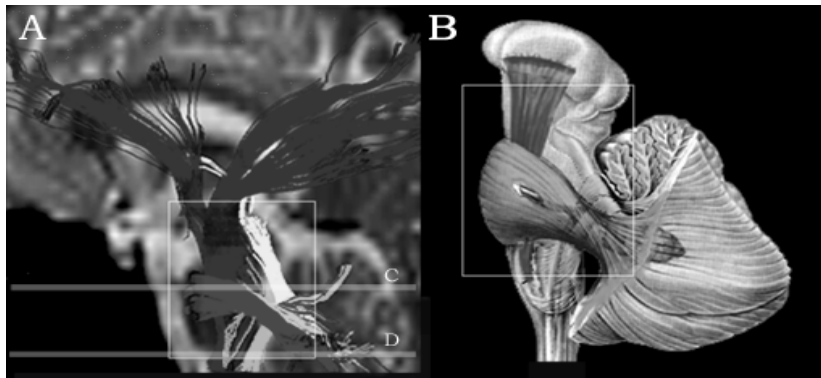
white matter:  
 $FA = 0.4 - 0.8$

grey matter:  
 $FA = 0.05 - 0.2$

## 3D Fibertracking



- fibertracking method:  
using main eigenvector of diffusion tensor the main direction  
of fibers can be tracked pixel by pixel



in vivo DTI

post mortem atlas