Nuclear Magnetic Resonance

independently by Stern, Rabi (1934)

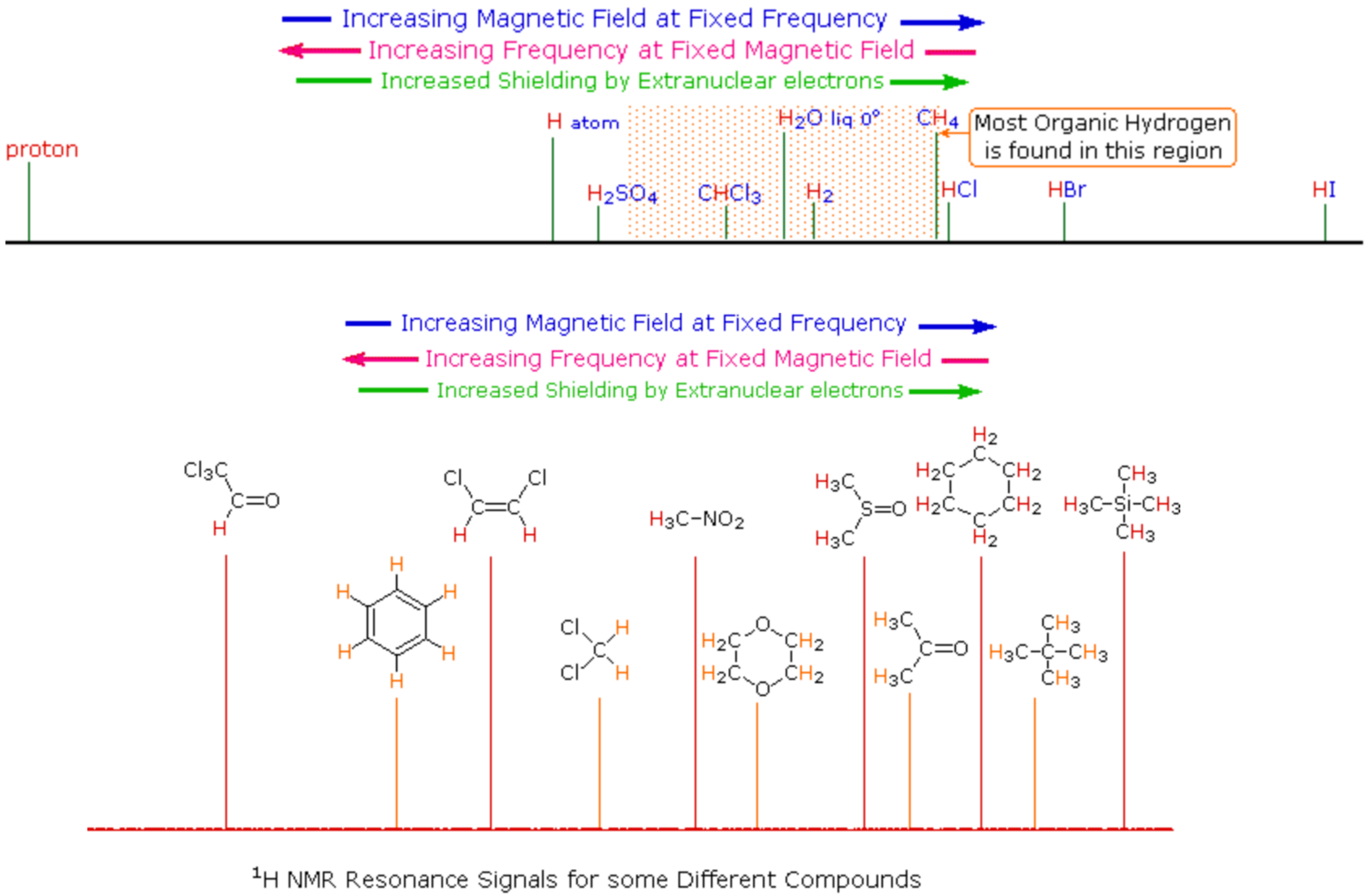
$f = e g_p / (2 m_p) / 2\pi$ = 42.6 Mhz/T

$g_p = 5.58$

basic idea: pulse @ f flips spin, observe relaxation echo

NMR basics

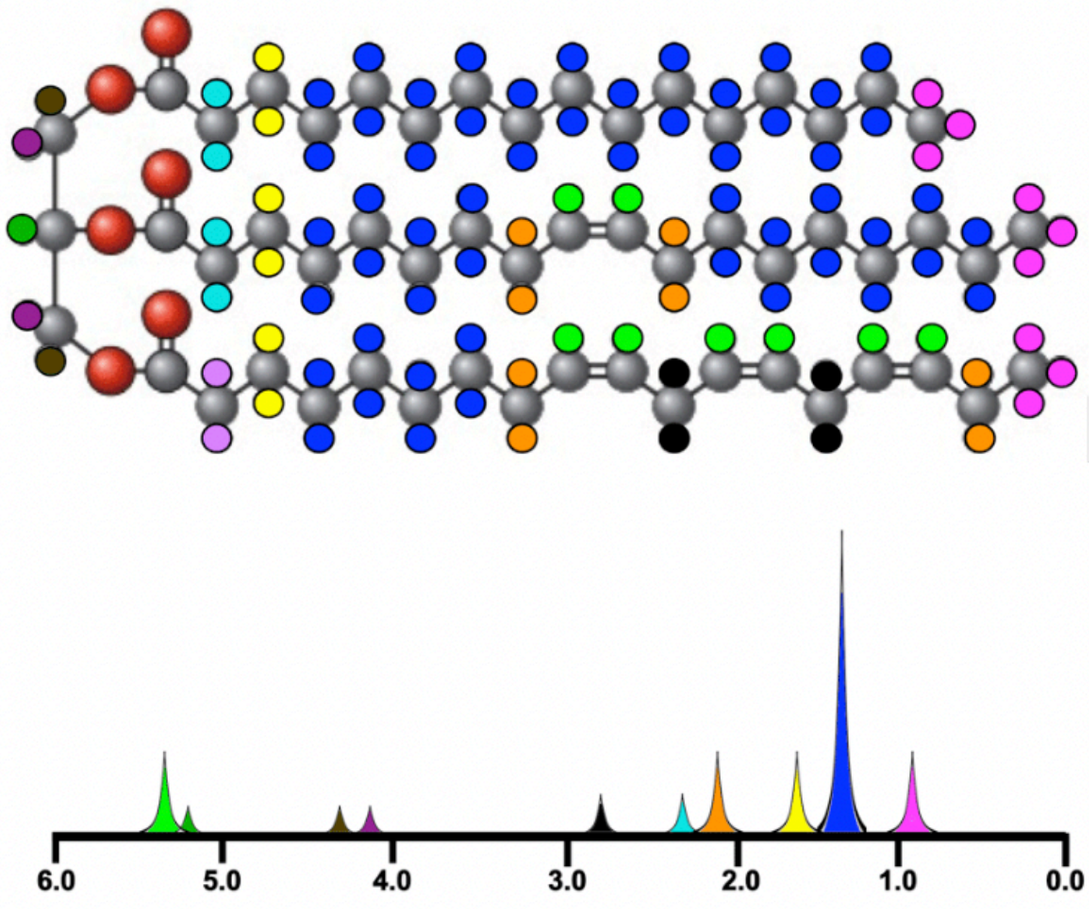
https://www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/Spectrpy/nmr/nmr1.htm



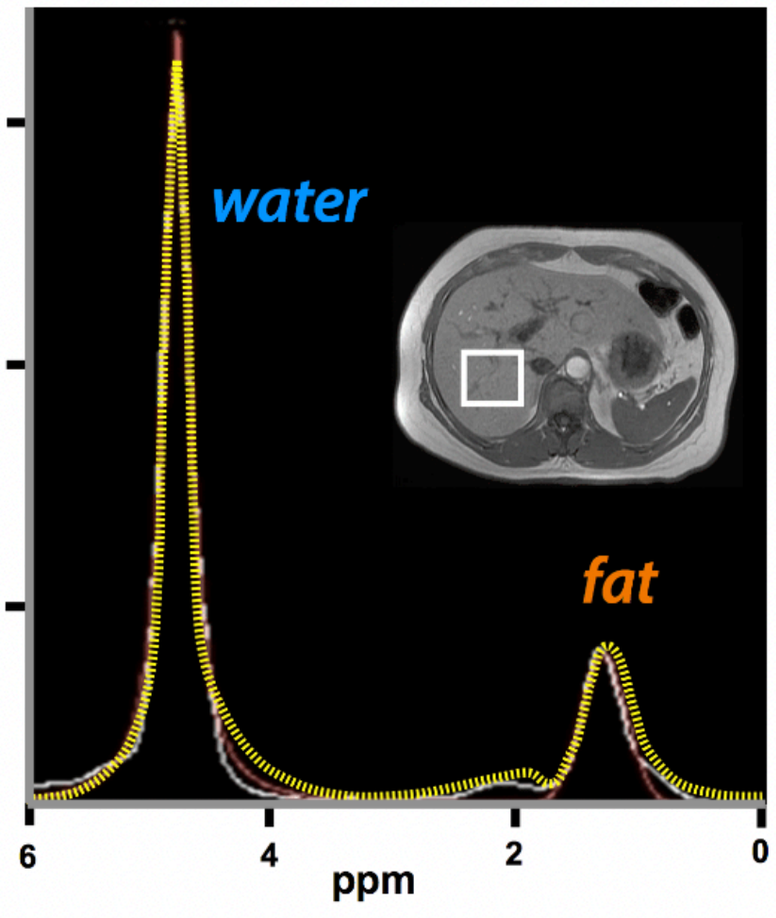
^{1}H NMR Resonance Signals for some Different Compounds

https://mriquestions.com/liver-sup1h-mrs.html

The liver is a large, heterogenous organ that moves with respiration, making MR spectroscopy particularly challenging. ^{31}P MRS has long been used to study liver energy stores, but ^{1}H MRS has gained more recent attention for its potential to understand fat deposition during our modern "epidemic" of obesity and diabetes. A basic goal is to use MRS to quantify hepatic fat fraction non-invasively. Most of this fat is stored as ***intrahepatic triglycerides (IHTG)***, whose representative chemical structure and spectral peaks are illustrated below.



^{1}H-spectrum of a typical triglyceride. Most peaks are in the δ = 0.9–2.4 ppm range, with the largest (at 1.3 ppm) derived from $-CH_2-$ protons.



Single-voxel ^{1}H-MRS study of the liver shows dominant water and fat peaks. After correction for T2 effects and modeling, the relative areas under each peak can be used to calculate hepatic fat fraction.

Physics 521 feature

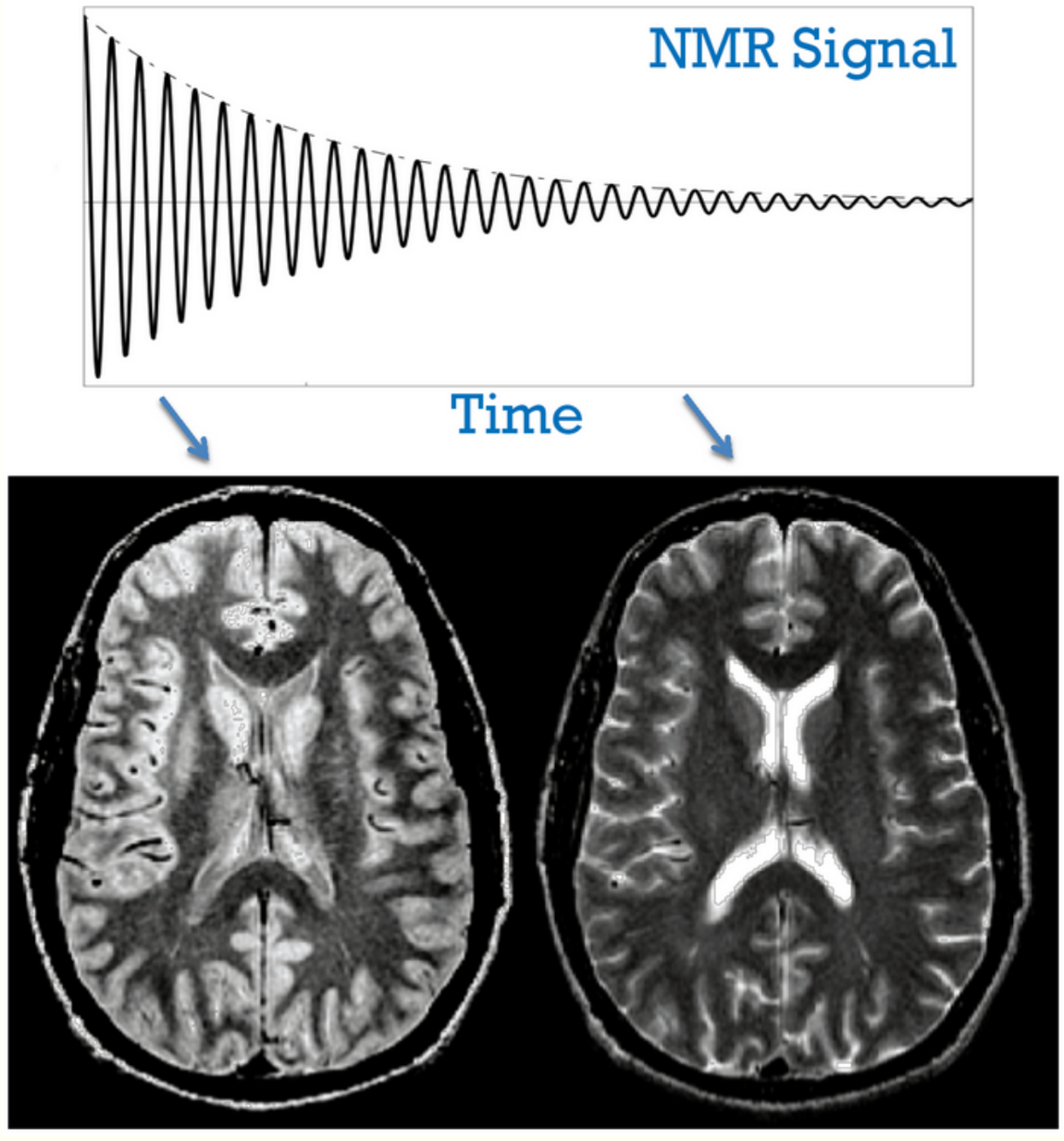
Fall 2023, M. Gold

http://fmri.ucsd.edu/Research/whatisfmri.html

Magnetic Resonance Imaging (MRI)

MRI has become a standard tool for Radiology because it provides high resolution images with good contrast between different tissues. It works by exploiting the fact that the nucleus of a hydrogen atom behaves like a small magnet. Using the phenomenon of *nuclear magnetic resonance* (NMR), the hydrogen nuclei can be manipulated so that they generate a signal that can be mapped and turned into an image. When you lay in the strong magnetic field of an MRI system all of the hydrogen nuclei in your body, most of which are in water molecules, tend to align with that magnetic field. When a radio frequency (RF) magnetic pulse is applied at the right frequency, these hydrogen nuclei absorb energy and then create a brief, faint signal (the MR signal) that is detected by the RF coils in the MRI system.

The MR image is a map of the distribution of the MR signal, and by manipulating the timing of the RF pulses and the delays before detecting the signal MRI is a sensitive tool for detecting subtle changes in brain anatomy. However, mapping brain structure is not the same as mapping brain *function*.



Courtesy of Dr. Richard Buxton, UC San Diego

fMRI

blood oxygenation level dependent effect **(BOLD)**

Ogawa, Lee, Kay and Tank (1990) Bell Labs

http://www.pnas.org/content/87/24/9868.full.pdf

dicular to the cortical surface. This BOLD contrast was completely lost (Fig. 1*b*) when the gas inhaled was switched to 10% CO_2/90% O_2. The addition of CO_2 to the inhalant gas increased blood CO_2 levels from 50 to 80 mmHg (1 mmHg = 133 kPa). In general, increased blood CO_2 produces increased blood flow. This increased blood flow provides a greater supply of oxygen to the brain and, in the absence of a change in the metabolic load, should increase venous blood oxygenation, consistent with our observed loss of BOLD contrast with change in blood CO_2 level. By using a presaturation-

used C02 to >blood flow

>blood flow >venous O_2
⇒no (contrasting) dark lines.

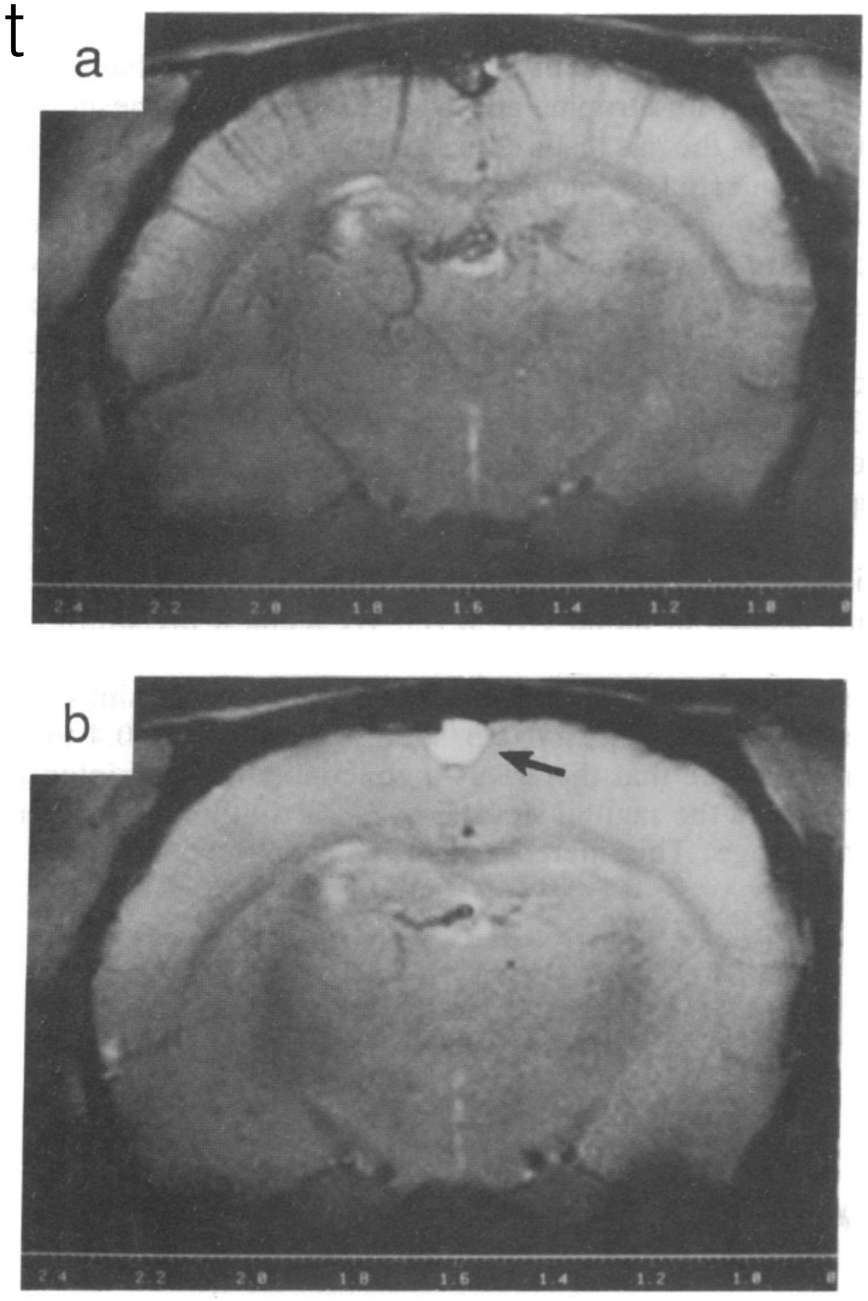


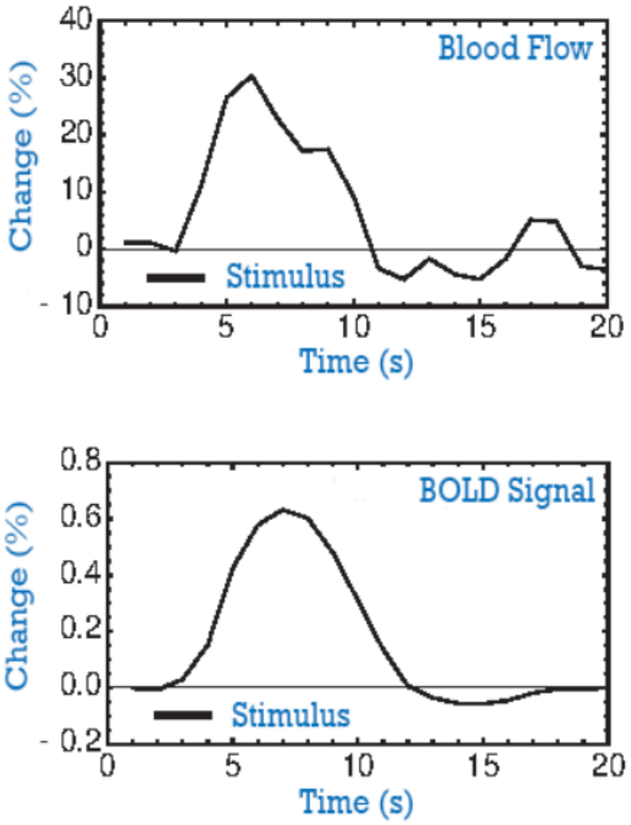
FIG. 1. Effect of blood CO_2 level on BOLD contrast. (*a*) Coronal slice brain image showing BOLD contrast from a rat anesthetized with urethane. The gas inspired was 100% O_2. (*b*) The same brain but with 90% O_2/10% CO_2 as the gas inspired. BOLD contrast is greatly reduced. The arrow points to the sagittal sinus, showing increased signal intensity, indicative of increased blood oxygenation. The magnetic field was perpendicular to the slice plane. The imaging time was 9 min with a repetition time of 0.26 sec and an echo time of 12 msec. The pixel size of the images was 117 μm × 117 μm with a slice thickness of 550 μm. The scale represents linear dimension in cm. Core body temperature was maintained at 35–36.5°C.

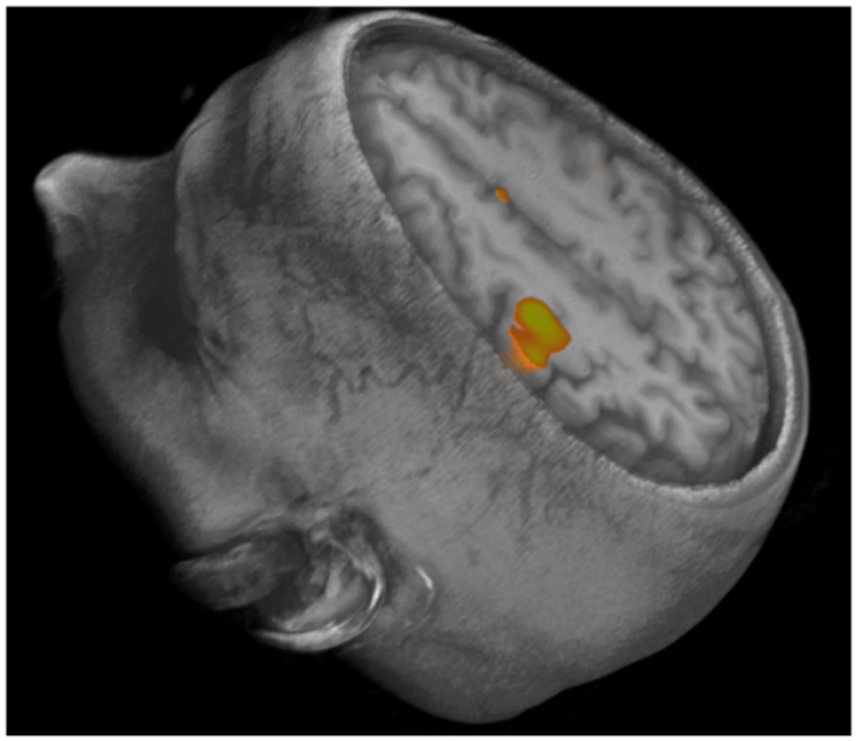
fMRI

Functional NMR

Why is the MR Signal Sensitive to Changes in Brain Activity?

Net Rev Neurosci. 2007 Sep;8(9);700-11.





Courtesy of Dr. Richard Buxton, UC San Diego

It is not because the MR signal is directly sensitive to the neural activity. Instead, the MR signal change is an indirect effect related to the changes in blood flow that follow the changes in neural activity. The picture of what happens is somewhat subtle, and depends on two effects. The first effect is that oxygen-rich blood and oxygen-poor blood have different magnetic properties related to the hemoglobin that binds oxygen in blood. This has a small effect on the MR signal, so that if the blood is more oxygenated the signal is slightly stronger. The second effect relates to an unexpected physiological phenomenon. For reasons that we still do not fully understand, neural activity triggers a much larger change in blood flow than in oxygen metabolism, and this leads to the blood being more oxygenated when neural activity increases. This somewhat paradoxical *blood oxygenation level dependent* (BOLD) effect is the basis for fMRI.

Physics 521 feature

Fall 2023, M. Gold

fMRI

Δ(signal) ~1%

diamagnetism— induced currents oppose magnetic field < reducing local field

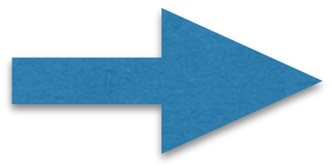
paramagnetism— dipoles align with magnetic field, > local field; proton phase dispersion reduces signal

HEM-0 oxygenated, diamagnetic, > signal

HEM de-oxygenated, paramagnetic >susceptibility <signal

active brain tissue: greater flow, > signal (bright)

oxy oxy de-oxy

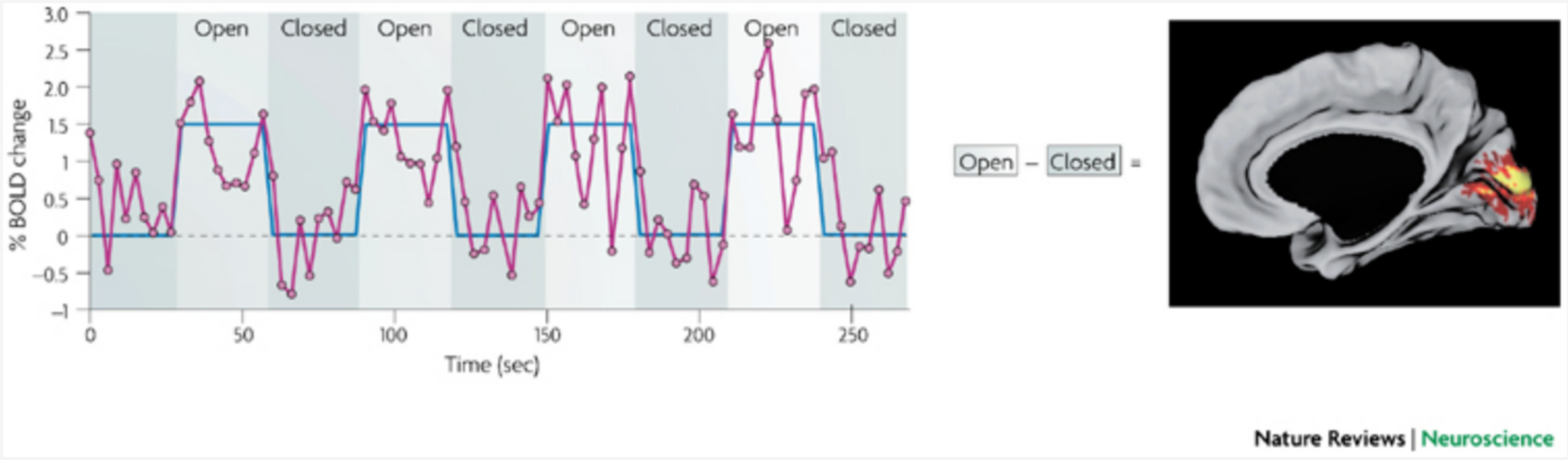


inactive brain tissue: less flow, < signal (dark)

oxy de-oxy de-oxy

What is fMRI ?

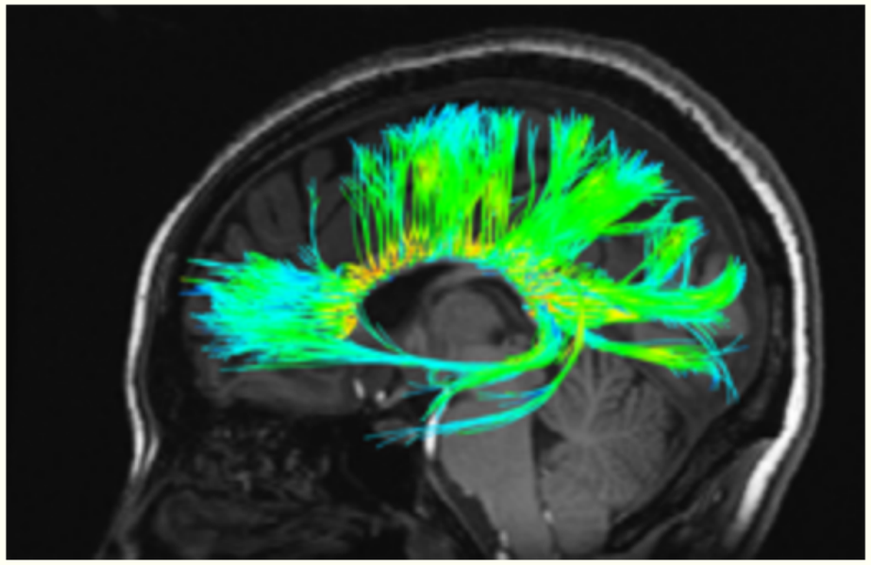
http://fmri.ucsd.edu/Research/whatisfmri.html



Unaveraged blood oxygen level dependent (BOLD) time course (magenta) from a region in the primary visual cortex during a simple task paradigm that requires subjects to open and close their eyes. The paradigm is shown in blue (delayed to account for the haemodynamic response). Traditional functional magnetic resonance imaging (fMRI) analysis involves correlating BOLD data with a stimulation time-course across multiple blocks. This in effect averages across each condition and performs a subtraction, minimizing 'noise' in the BOLD signal and highlighting regions that are modulated by the task paradigm. In this case, subtraction of the eyes-closed condition from the eyes-open condition identifies a BOLD signal intensity difference in the primary visual cortex (shown on the right).

http://fmri.ucsd.edu/Research/whatisfmri.html

Diffusion Tensor Imaging (DTI)



Courtesy of Dr. Lawrence Frank, UC San Diego

Brain function depends on the wiring between brain regions, the complex web of axons carrying signals from one neuron to another. In addition to methods for detecting brain activation with fMRI, MRI also provides a way to measure these anatomical connections. The white matter of the brain consists of bundles of these axonal fibers, so that within a small region the fibers are all aligned, and *diffusion tensor imaging* (DTI) is able to measure the direction of this alignment. Knowing the orientation of the fibers at each point it is possible to trace paths through the brain that map the fiber tracts. The method exploits the sensitivity of the magnetic resonance signal to the small random motions of water molecules. This *diffusion* of water molecules is analogous to a drop of ink slowly expanding in a pool of water as the ink molecules diffuse. In white matter fiber tracts the displacements of water molecules due to diffusion are much greater along the direction of the fibers than in a perpendicular direction, making it possible to map the fiber orientation with DTI. In addition to mapping white matter fiber tracts, these methods are useful for detecting and characterizing disorders of white matter in disease.

A. from counting in soup, 86 billion

https://mitpress.mit.edu/books/brain-soup