

PHY 127 FS2026

Prof. Ben Kilminster

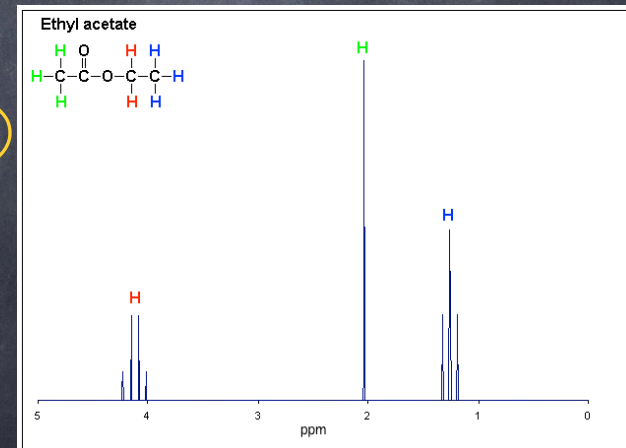
Lecture 12

May 22nd, 2026

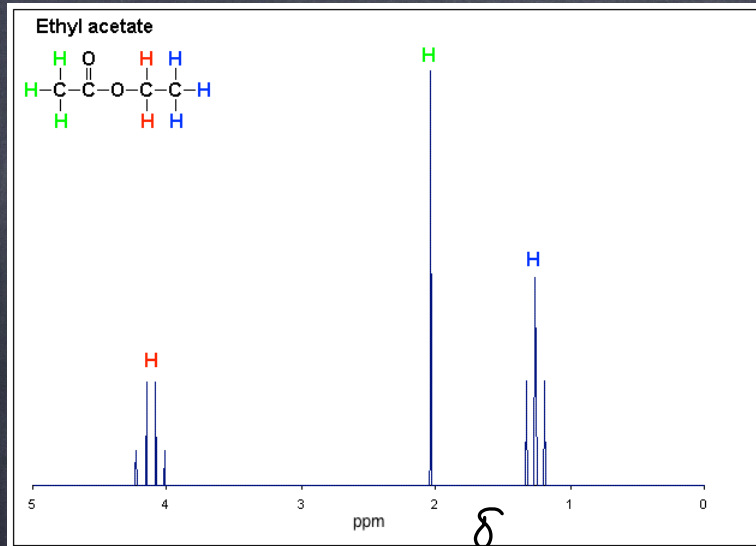
Today:

- 1) NMR: Nuclear Magnetic Resonance
→ useful for determining molecular structure, functional groups, dynamic processes (exchange + rotation)
- 2) MRI: Magnetic Resonance Imaging
→ useful for medicine: creating detailed, non-destructive, images of soft tissue (brain, heart, organs)
- 3) intro to nuclear physics

NMR



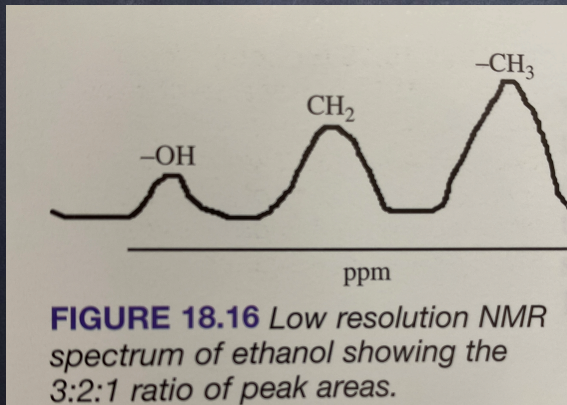
NMR: we seek to determine molecular structure,
typically by measuring the hydrogen^(proton) nuclear
magnetic moments.



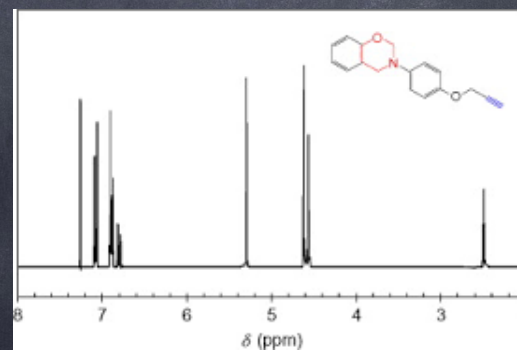
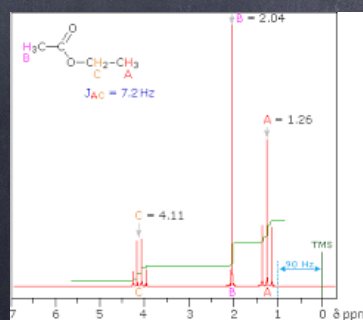
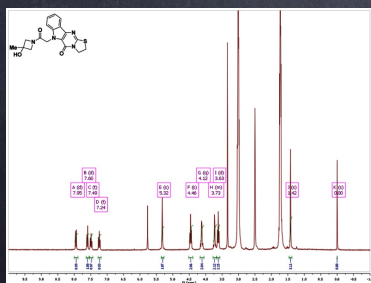
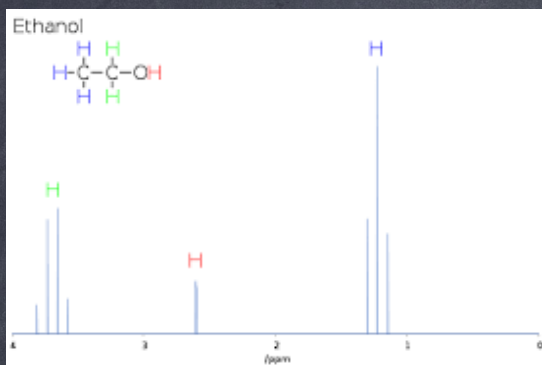
Resonances occur when RF frequency matches local Larmor frequency
(Electron shielding changes local Larmor frequency)

δ is measured through induced currents in detecting solenoid.

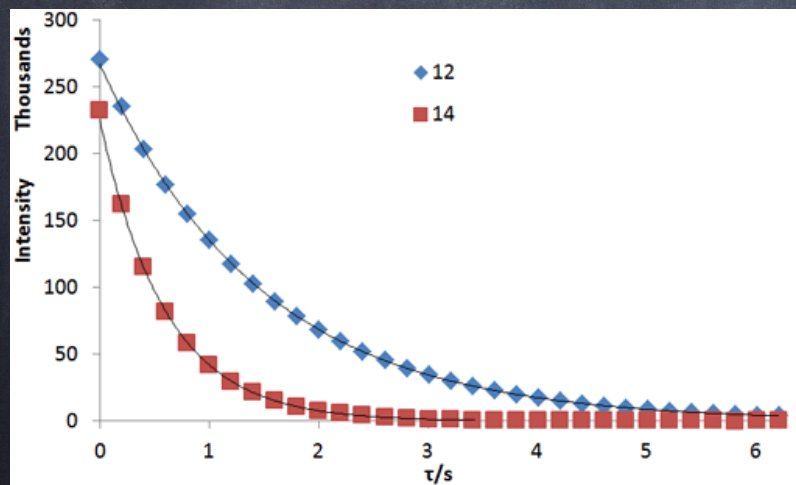
NMR spectra encode molecular structure through local magnetic environments & spin interactions

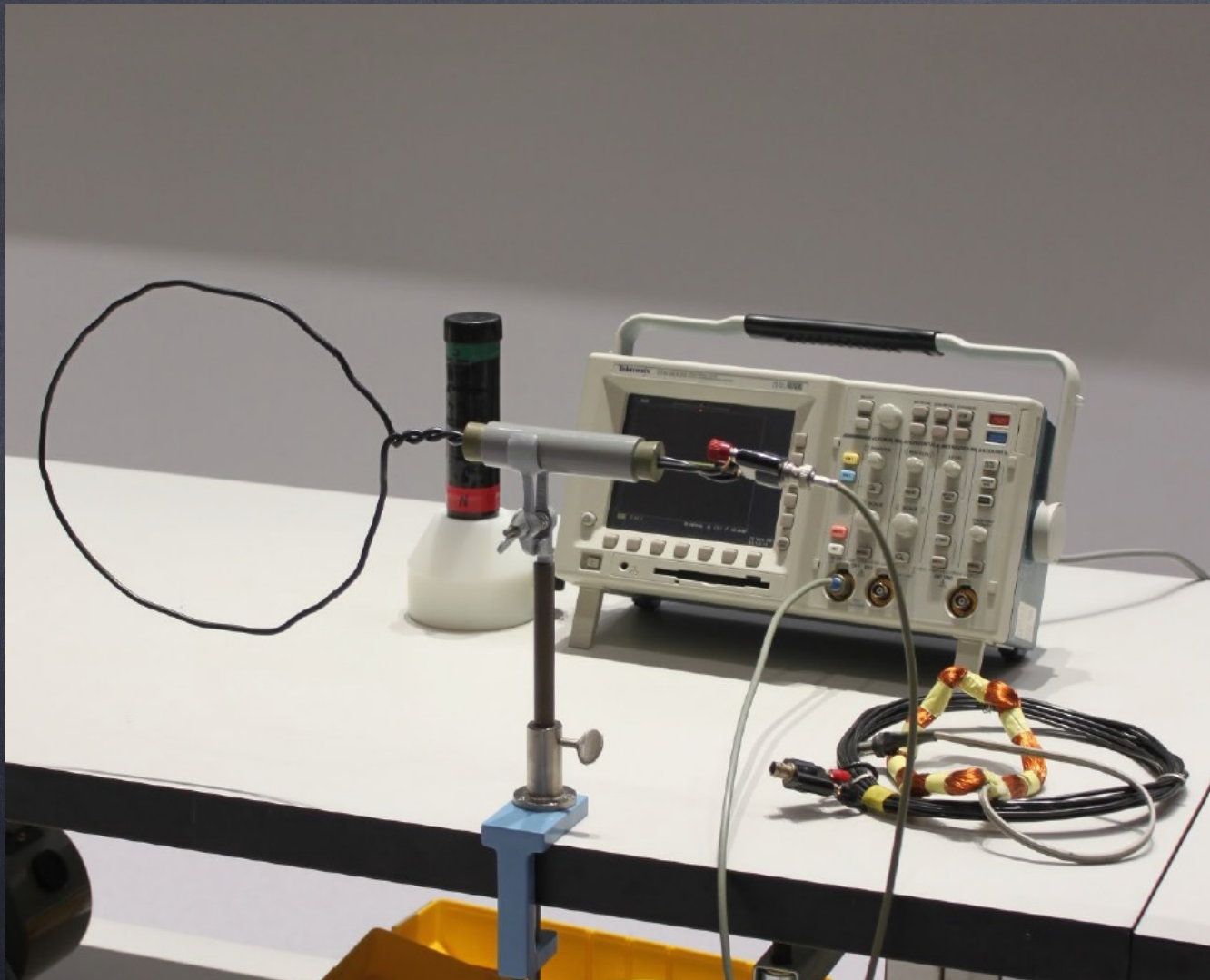


Examples of NMR spectra



Another measurable effect in NMR:





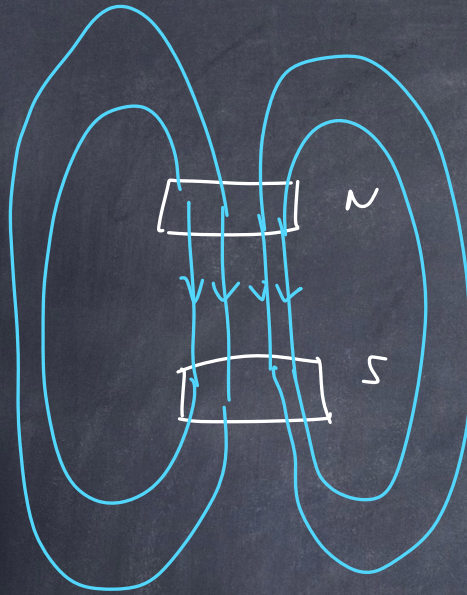
In our class experiment, we change magnetic field, + measure the induced current in a solenoid.

Now, we talk about MRI (magnetic resonance imaging)
Our goal is to do a 3-D scan of a human body, non-destructively



In MRI, we apply a magnetic field gradient to our body in 3 dimensions. The magnetic field will vary in 3-D as a function of x, y, z

Magnetic field gradient



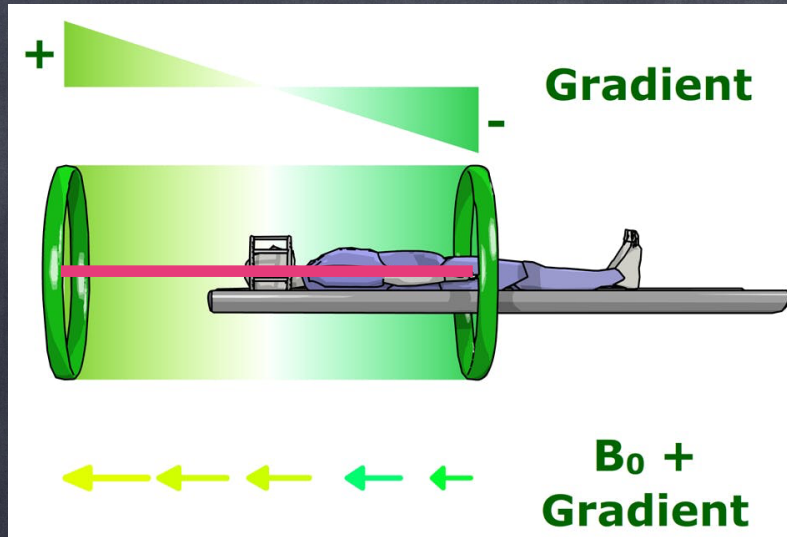
In figures,
 \vec{B} is stronger
when
lines are
closer
together



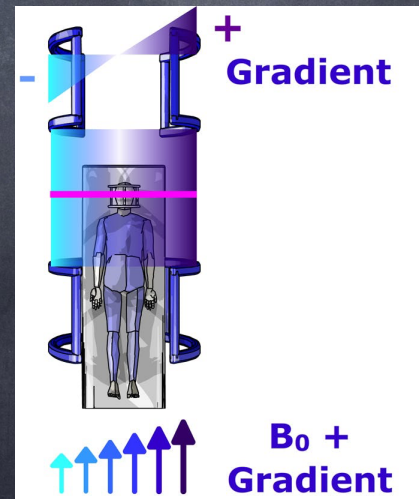
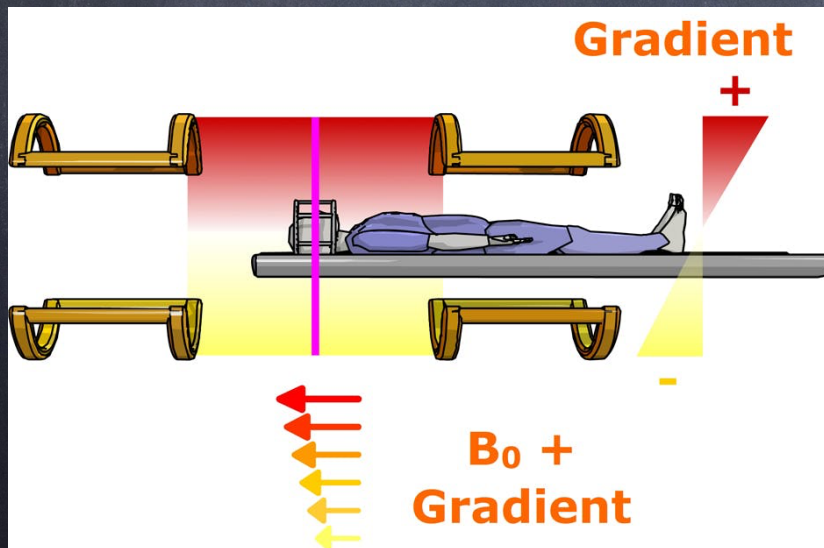
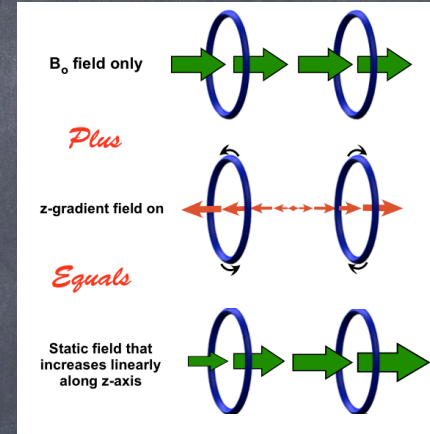
we would have gradients in t, y, z

$$B(y) = B_{0y} + B_{3r}(y)$$

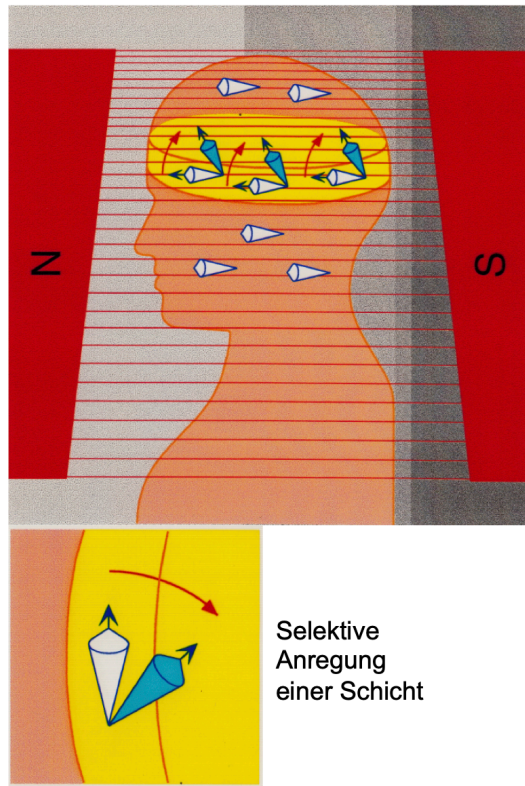
$$B(z) = B_{0z} + B_{3r}(z)$$



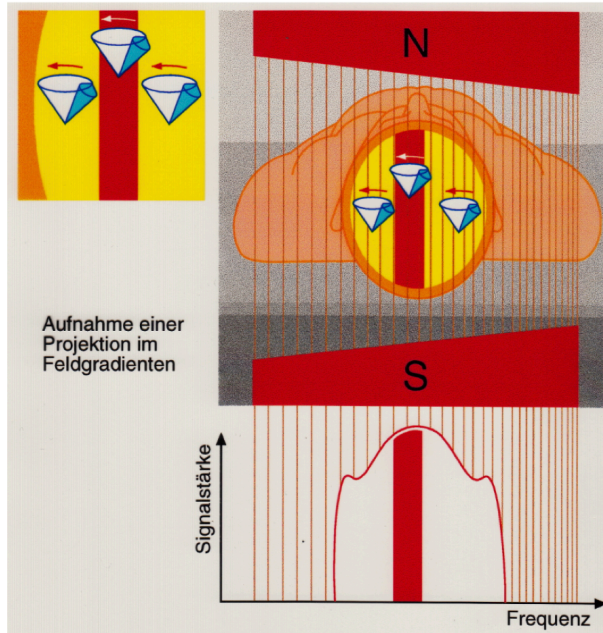
How to make a B-field gradient :



Magnetische Resonanz-Tomographie



Selektive
Anregung
einer Schicht

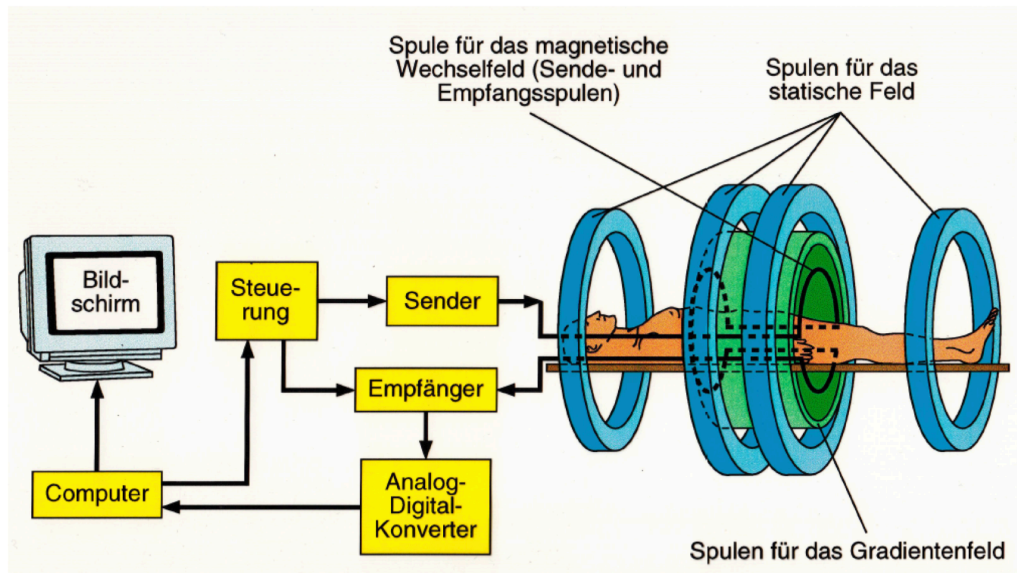


Aufnahme einer
Projektion im
Feldgradienten

Die verschiedenen Schnitte und Projektionen werden im Computer zu einem drei-dimensionalen Bild zusammengefügt, woraus man dann Schnitte in beliebigen Richtungen generieren kann. (altgriechisch 'tome' bedeutet Schnitt)

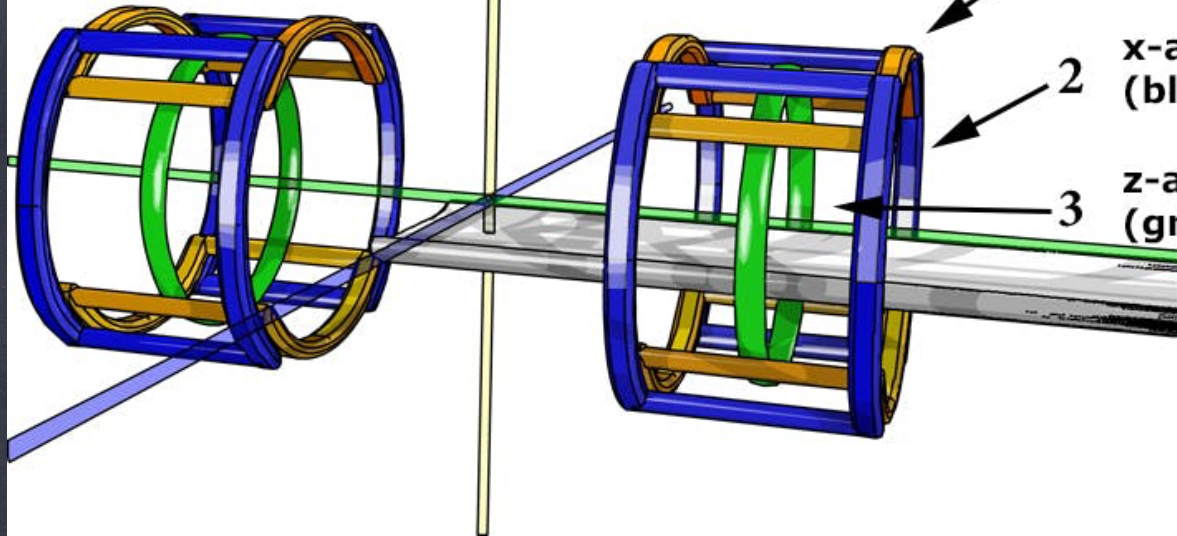
von Hugo Keller

Aufbau einer MRT-Anlage



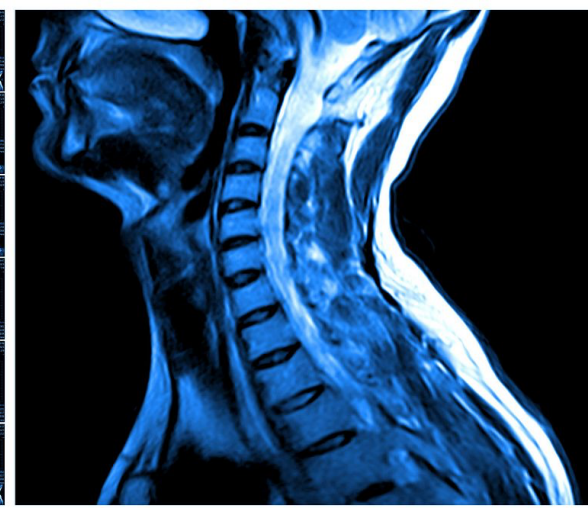
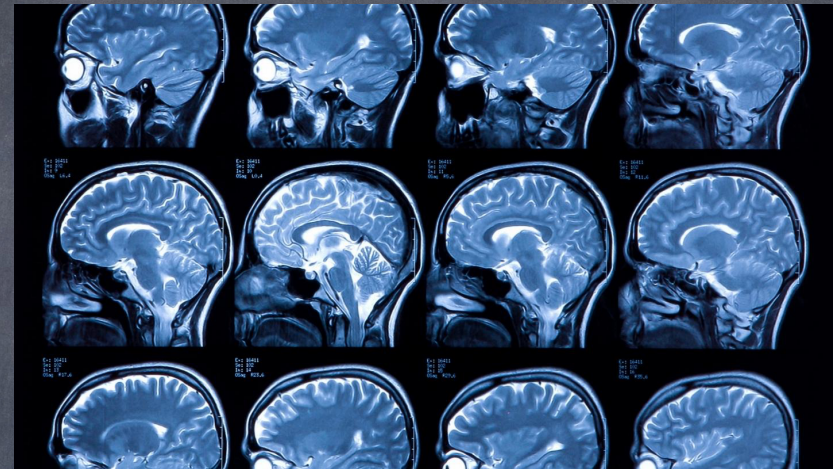
von Hugo Keller

Gradients X, Y, Z



- 1 y-axis gradient (yellow coils)
- 2 x-axis gradient (blue coils)
- 3 z-axis gradient (green coils)

Examples of MRI



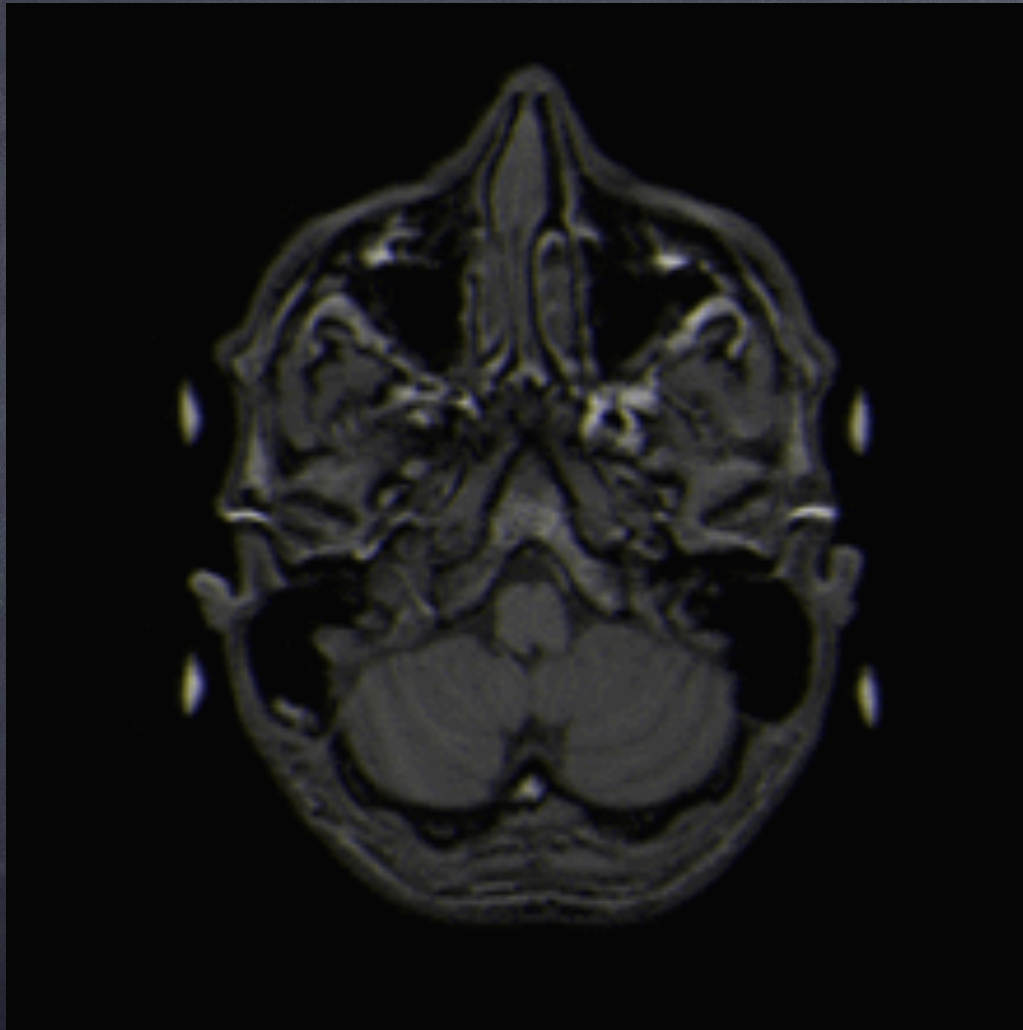


TABLE 23.5

Relaxation time of hydrogen nuclear spins in an external magnetic field as a function of tissue with and without tumours

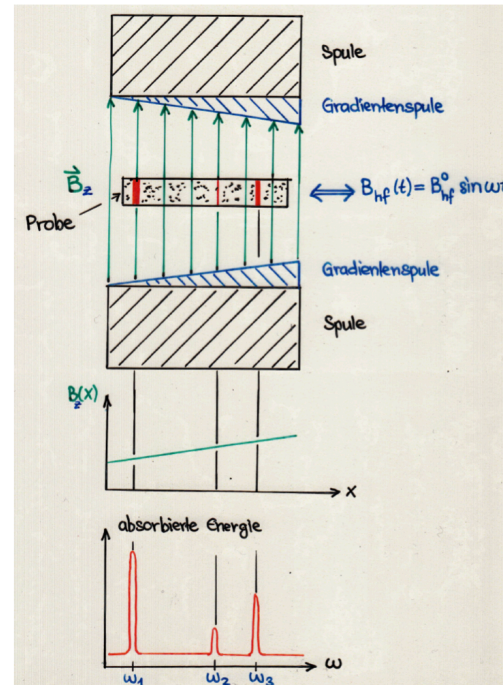
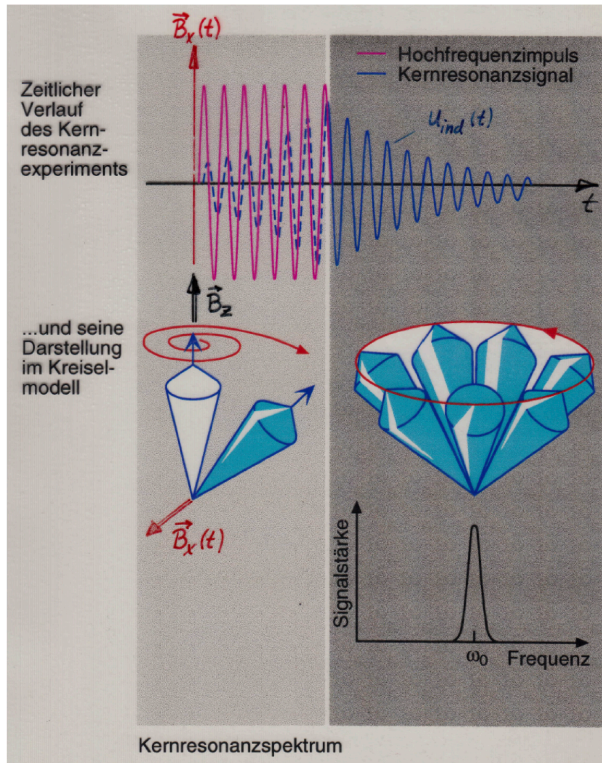
Tissue	Relaxation time T_{relax} (s)	
	Healthy	With tumour
Breast	0.37	1.08
Skin	0.62	1.05
Muscle	1.02	1.41
Liver	0.57	0.83
Stomach	0.77	1.24
Lung	0.79	1.10
Bone	0.55	1.03
Water	3.6	—

Table 18.2 Water Content of Normal Human Tissue

Tissue	% water
Brain (white matter)	84
Kidney	81
Myocardium	80
Skeletal muscle	79
Brain (gray matter)	72
Liver	71
Nerve	56
Bone (cortex)	12
Teeth	10

MRS uses the same scanner as MRI

Magnetische Resonanz-Spektroskopie



Die Ortsinformation, von woher ein Signal stammt, wird über die bekannte Ortsabhängigkeit des B-Feldes kodiert, welche in die Resonanzfrequenz eingeht.

von Hugo Keller

MRS
can be used
to do
chemical/
metabolic
analysis

Summary :

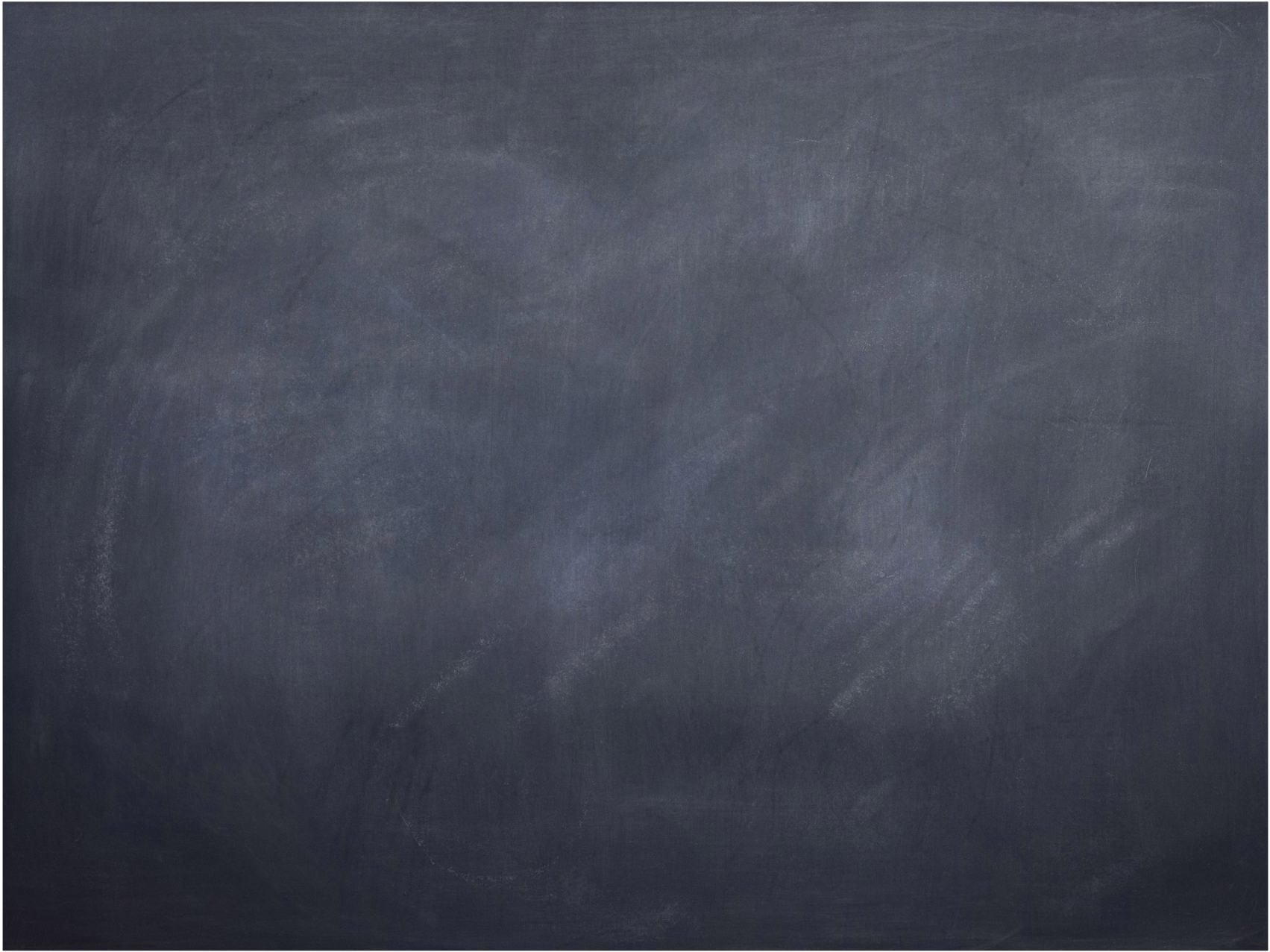
Comparison Table: NMR vs MRI vs MRS

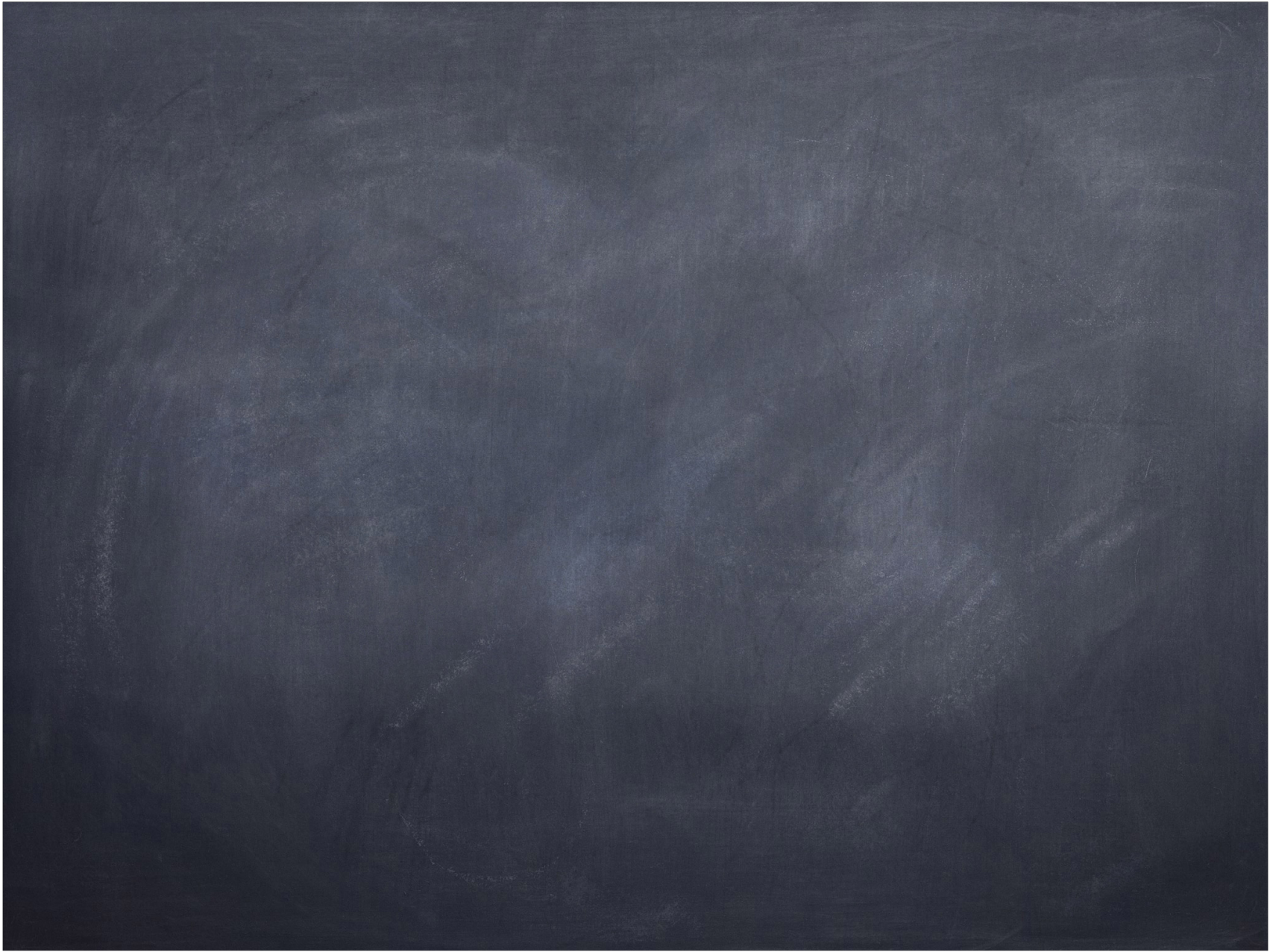
Feature	NMR	MRI	MRS
Full Name	Nuclear Magnetic Resonance	Magnetic Resonance Imaging	Magnetic Resonance Spectroscopy
Primary Purpose	Determine molecular structure	Visualize anatomical structures	Measure in vivo metabolite concentrations
Used In	Chemistry, Physics, Materials Science	Medicine, Neuroscience, Radiology	Medicine, Clinical Research
Sample Type	Purified chemical samples (liquids/solids)	Living organisms (e.g., humans)	Living tissues (brain, muscle, etc.)
Output	Spectrum (chemical shifts)	Image (anatomical map)	Spectrum (metabolite peaks)
Spatial Resolution	Not applicable	High (millimeter scale)	Low (single voxel ~12 cm)
Spectral Resolution	High (ppm scale)	Low	Moderate
Key Nucleus	H, C, F, P, etc.	H (mostly)	H, P, sometimes C
In Vivo Capability	No	Yes	Yes
Chemical Information	Yes detailed	Limited (based on contrast)	Yes for select metabolites
Imaging Capability	No	Yes	No (usually overlay on MRI)
Mention of 'Nuclear'	Yes	No (removed for public comfort)	No (removed for clinical use)
Clinical Use	No	Yes	Yes (as part of MRI systems)

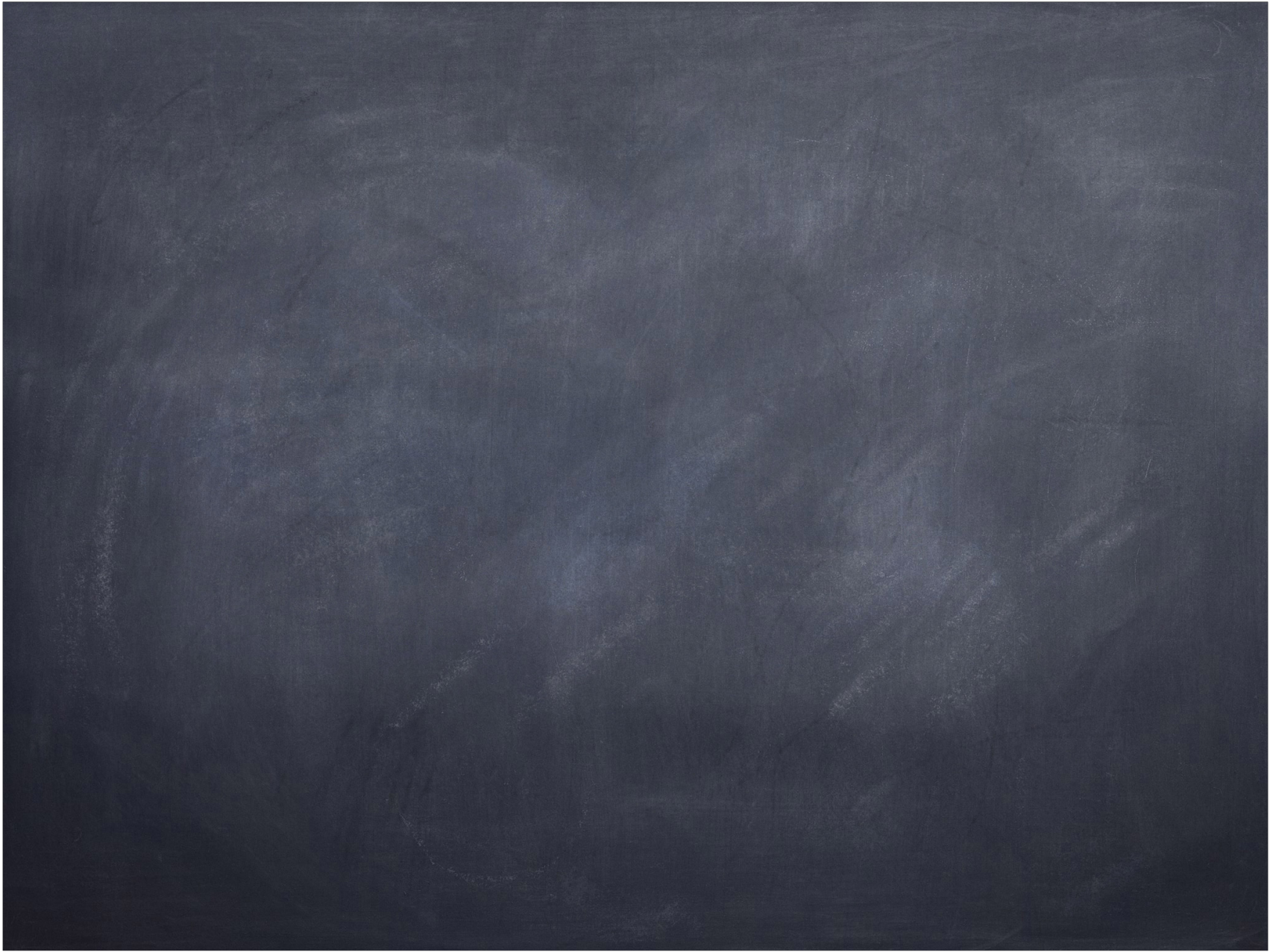
Comparison: Imaging vs. Spectra in MRI, MRS, and NMR

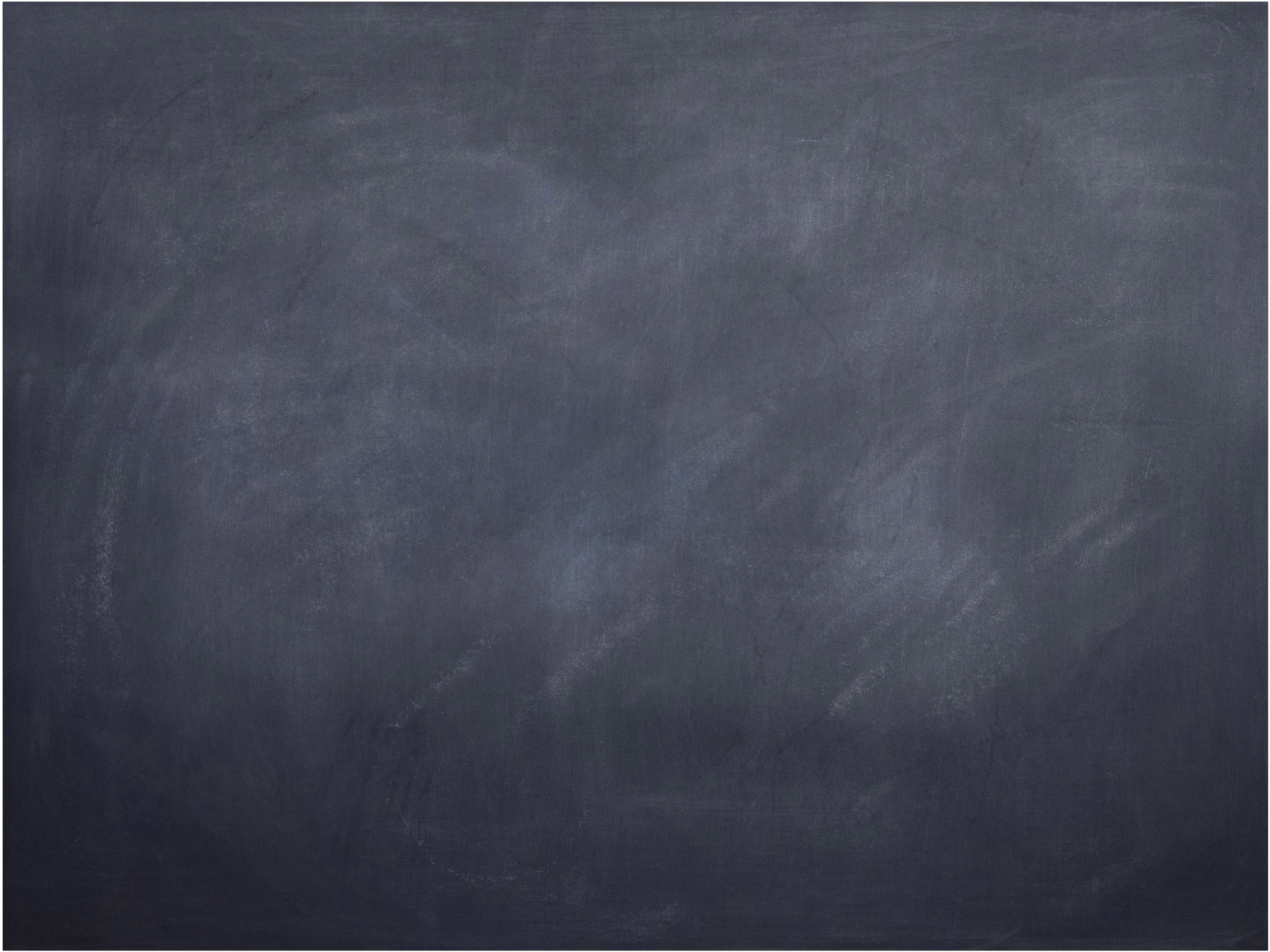
Modality	Produces Images?	Produces Spectra (delta)?
MRI	Yes	No
MRS	Optional (overlay on MRI)	Yes (spectra per voxel)
NMR	No	Yes

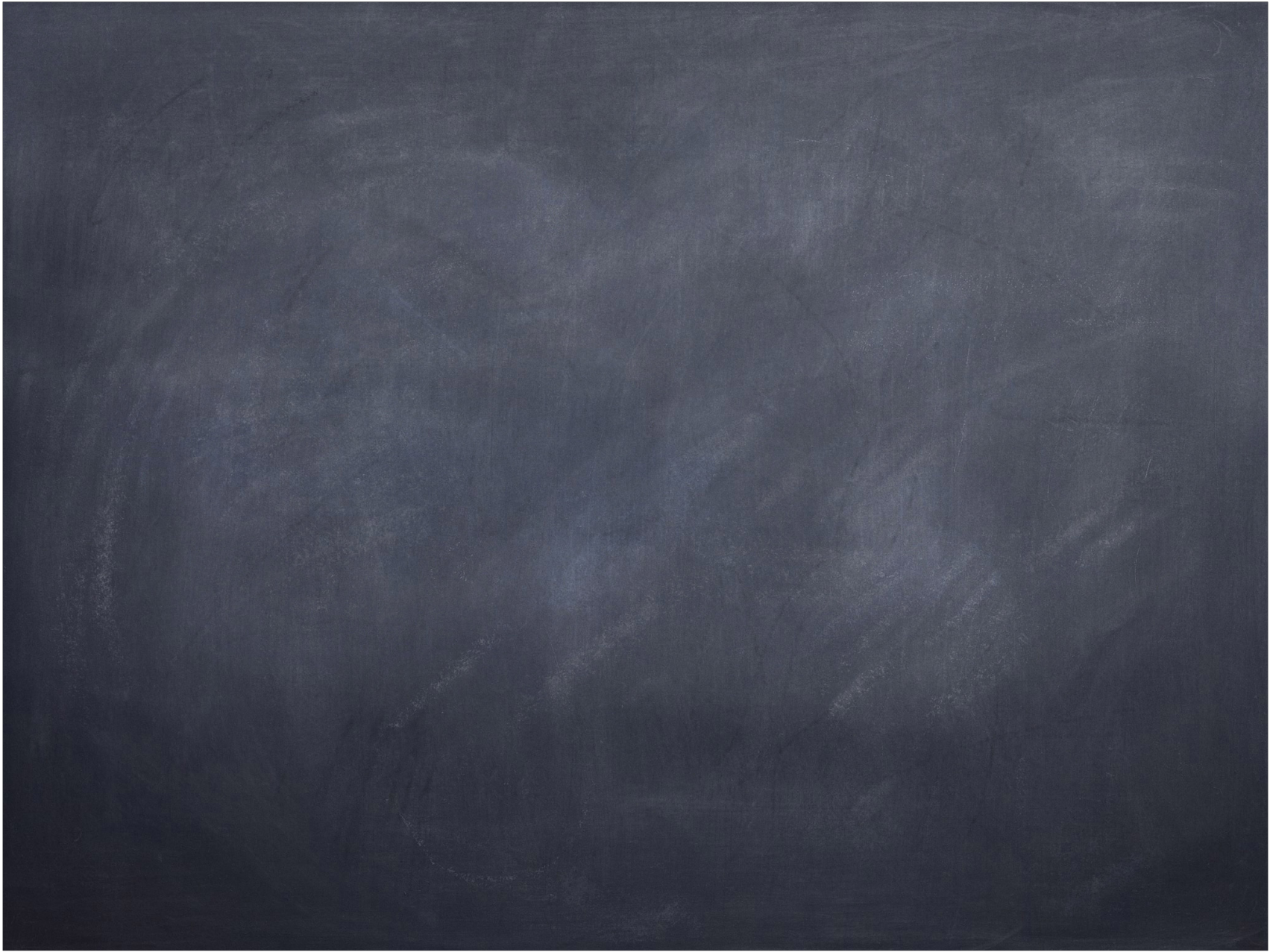
Nuclear physics





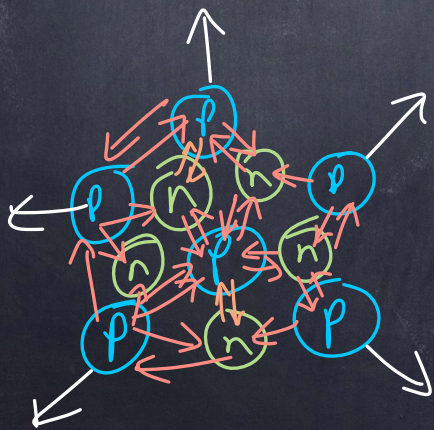
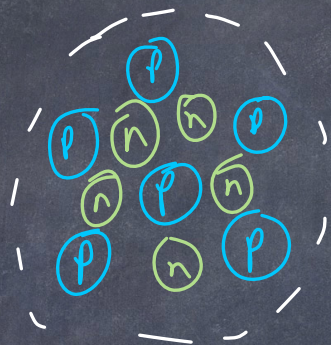




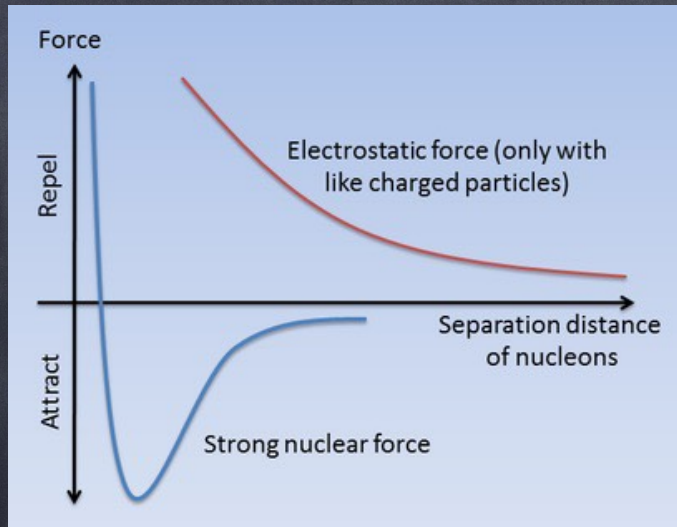


nucleon = proton or a neutron

Nucleus

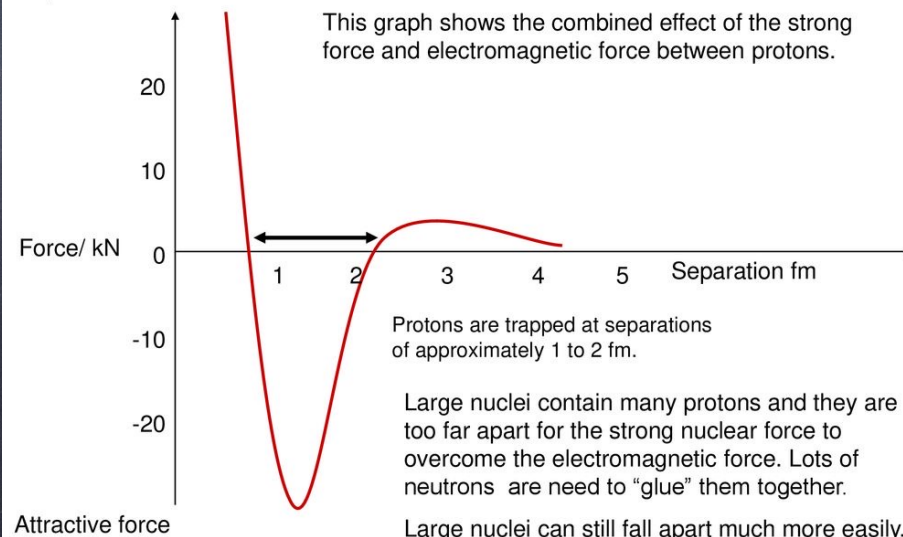


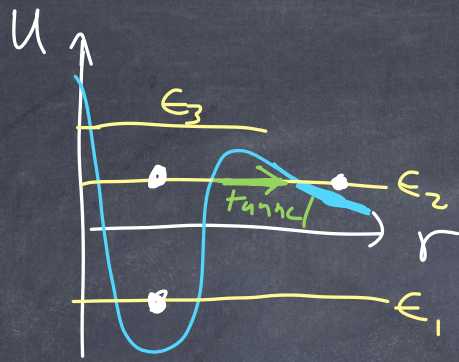
Force between protons : two separate forces



The force between protons

Repulsive force





U : potential energy of a proton at a given radius

Imagine a proton of different energies in a nuclear potential well.

For a neutron
it is very different!



"Liquid drop model" of a nucleus

The total energy of a nucleus is the sum of the kinetic & potential energy of the constituents (nucleons). The potential energy is negative and larger than the kinetic energy, so the total energy is negative.

The total energy of the individual nucleons is larger than the energy of the assembled nucleus. The difference is due to the binding energy of the nucleus.