Intelligent Analysis of Biomedical Images

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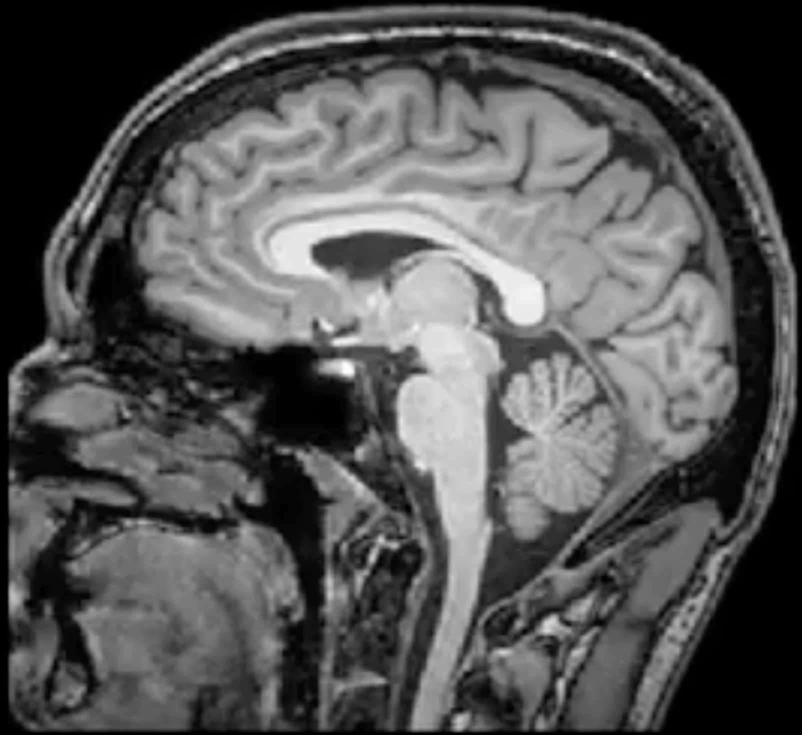
Courtesy: Slides are adopted from
https://www.youtube.com/watch?v=TQegSF4ZiIQ

Magnetic Resonance Imaging

How does an MRI work?

"Magnetic Resonance Imaging"

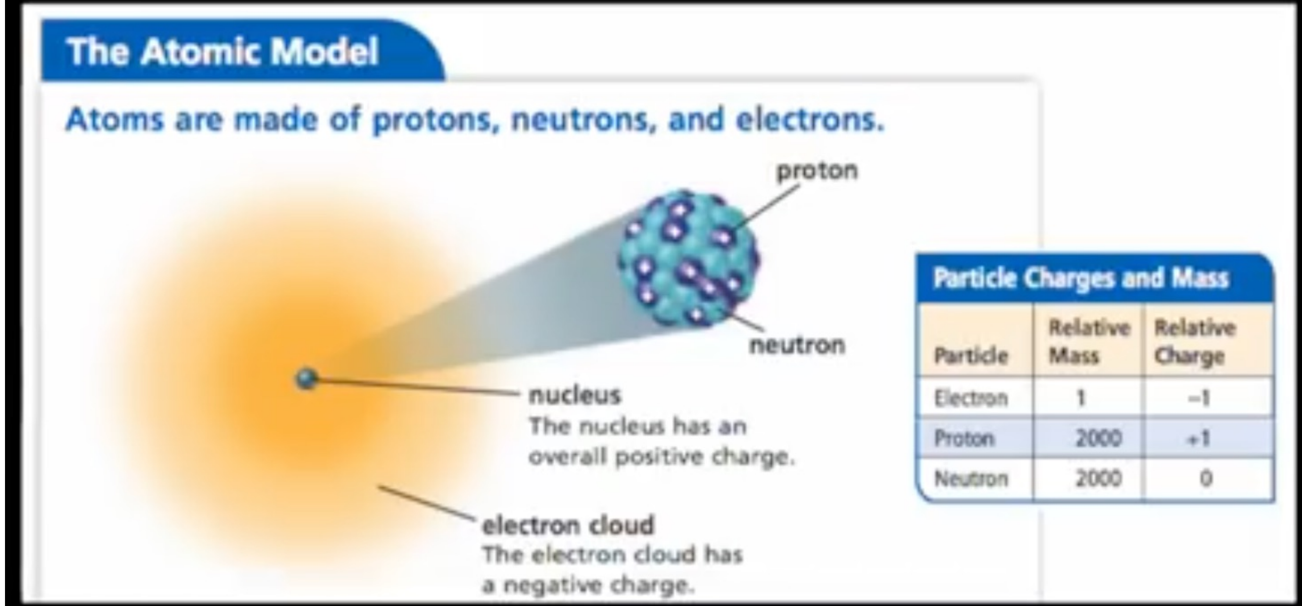


How does an MRI work?

"Magnetic Resonance Imaging"

Nuclear Magnetic Resonance:

Certain atomic nuclei demonstrate the ability to absorb and re-emit radiofrequency energy when placed in a magnetic field.

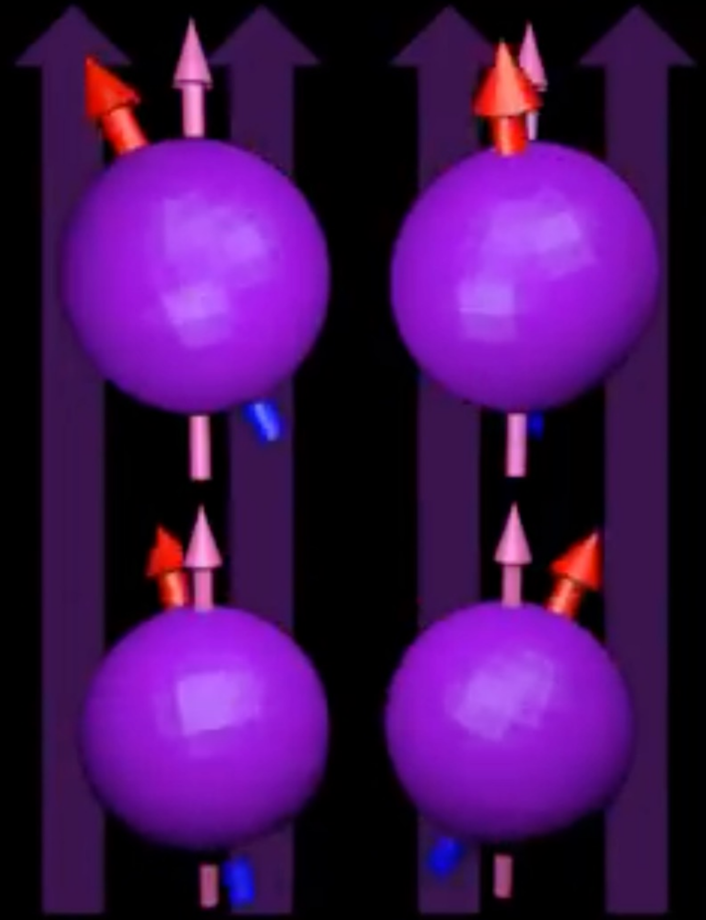


Particle	Relative Mass	Relative Charge
Electron	1	–1
Proton	2000	+1
Neutron	2000	0

^{1}H ^{4}He ^{6}Li ^{12}C ^{19}F ^{129}Xe ^{67}Zn ^{18}F ^{16}O

How does an MRI work?

"Magnetic Resonance Imaging"



1. Magnetic field aligns nuclei
2. RF pulse tips nuclei
3. Nuclei *precess* giving off rf signal (NMR)

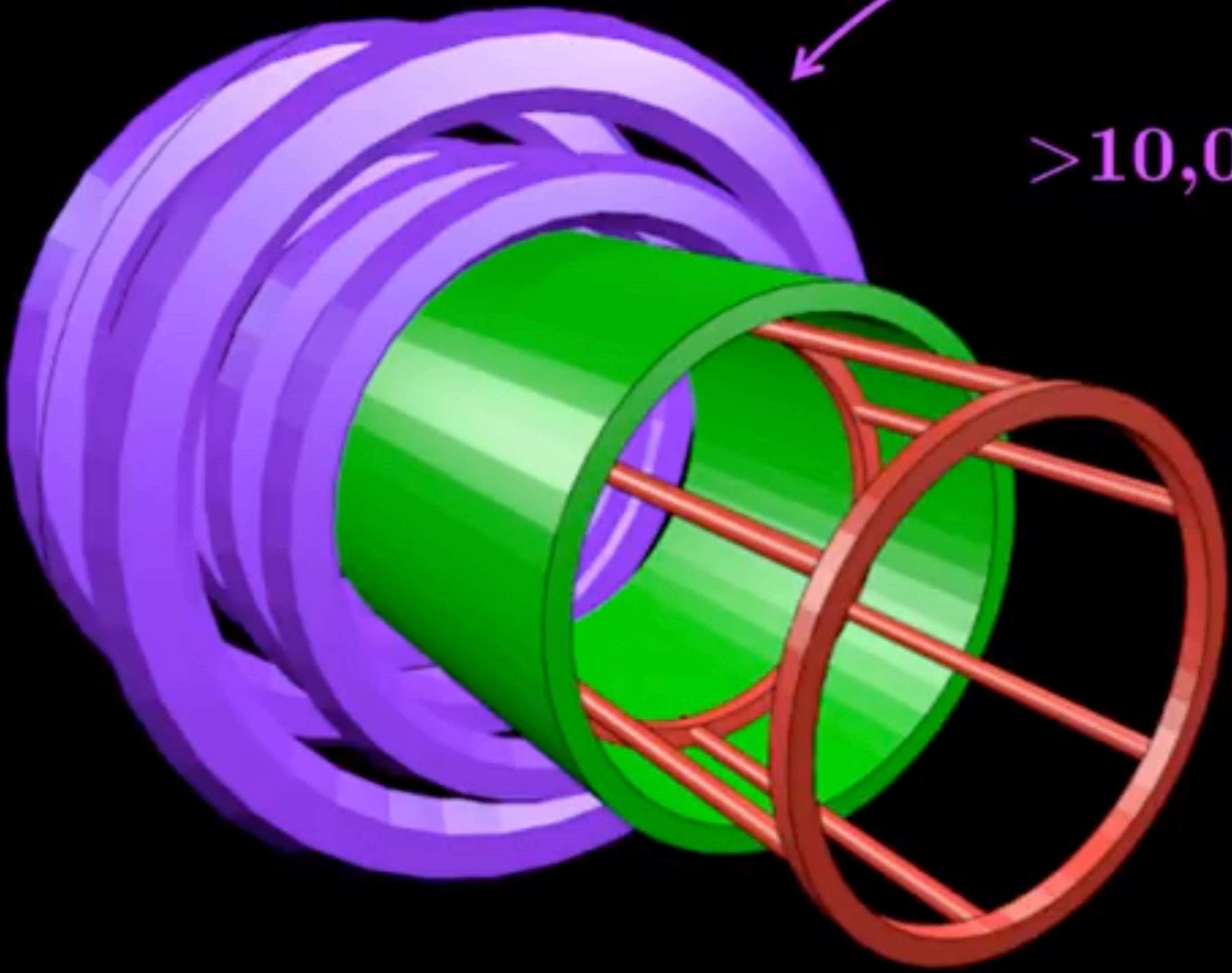
   $\rightarrow$ T_2 relaxation
4. Nuclei realign with the field

   $\rightarrow$ T_1 relaxation

$$\omega = \gamma B$$

The frequency of precession, ω, is proportional to the magnetic field strength, B!

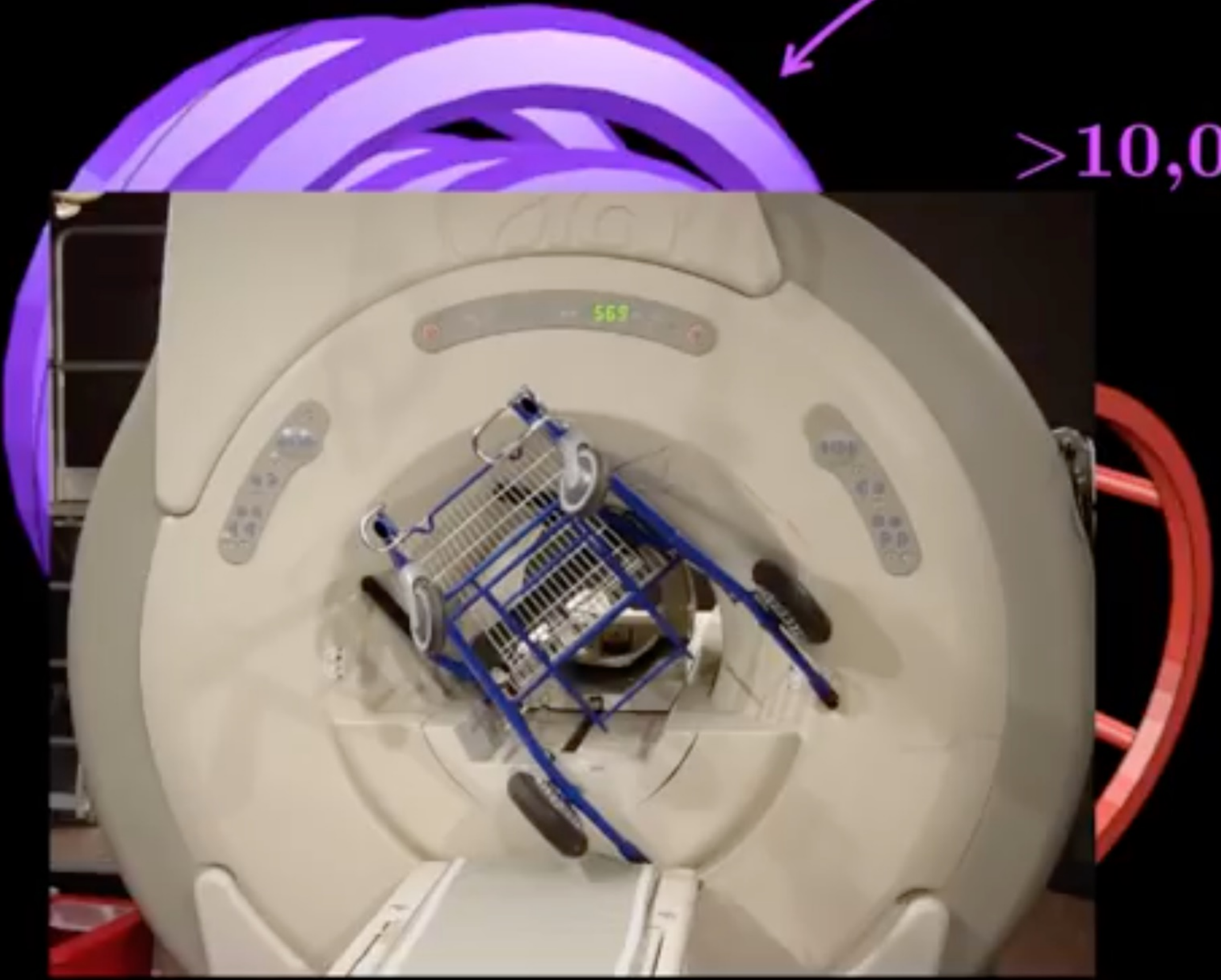
Magnet: B_0 field



$>$**10,000**$\times$ earth's magnetic field

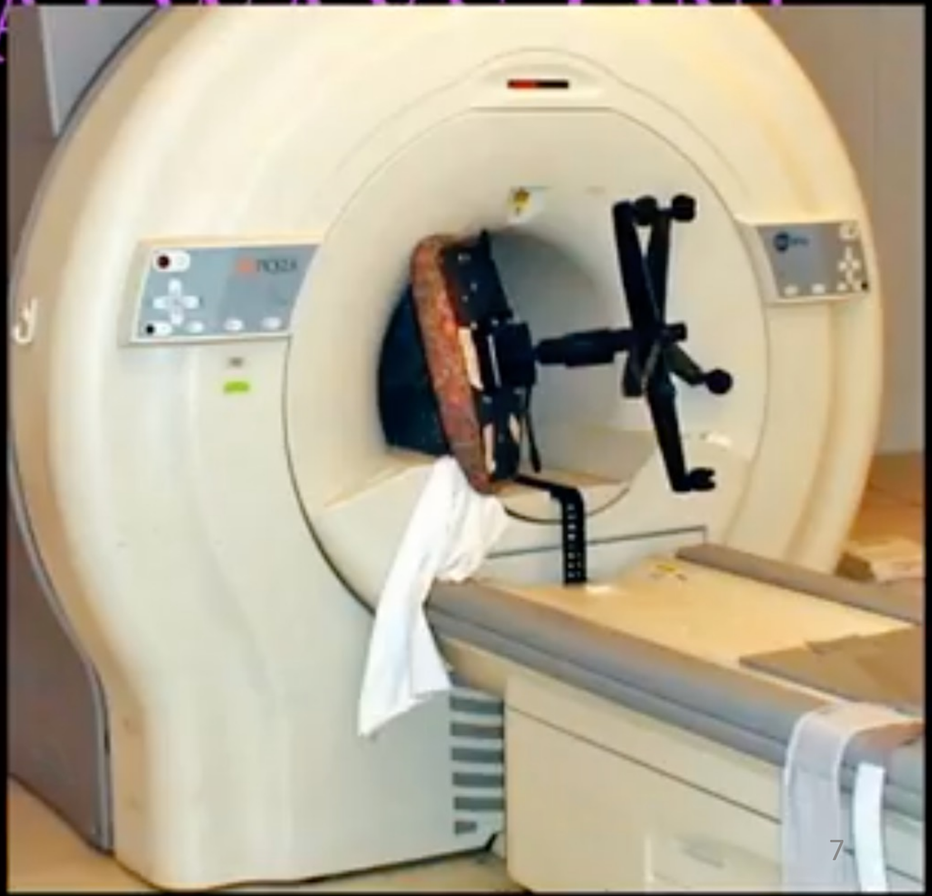
ALWAYS ON!

Magnet: B_0 field

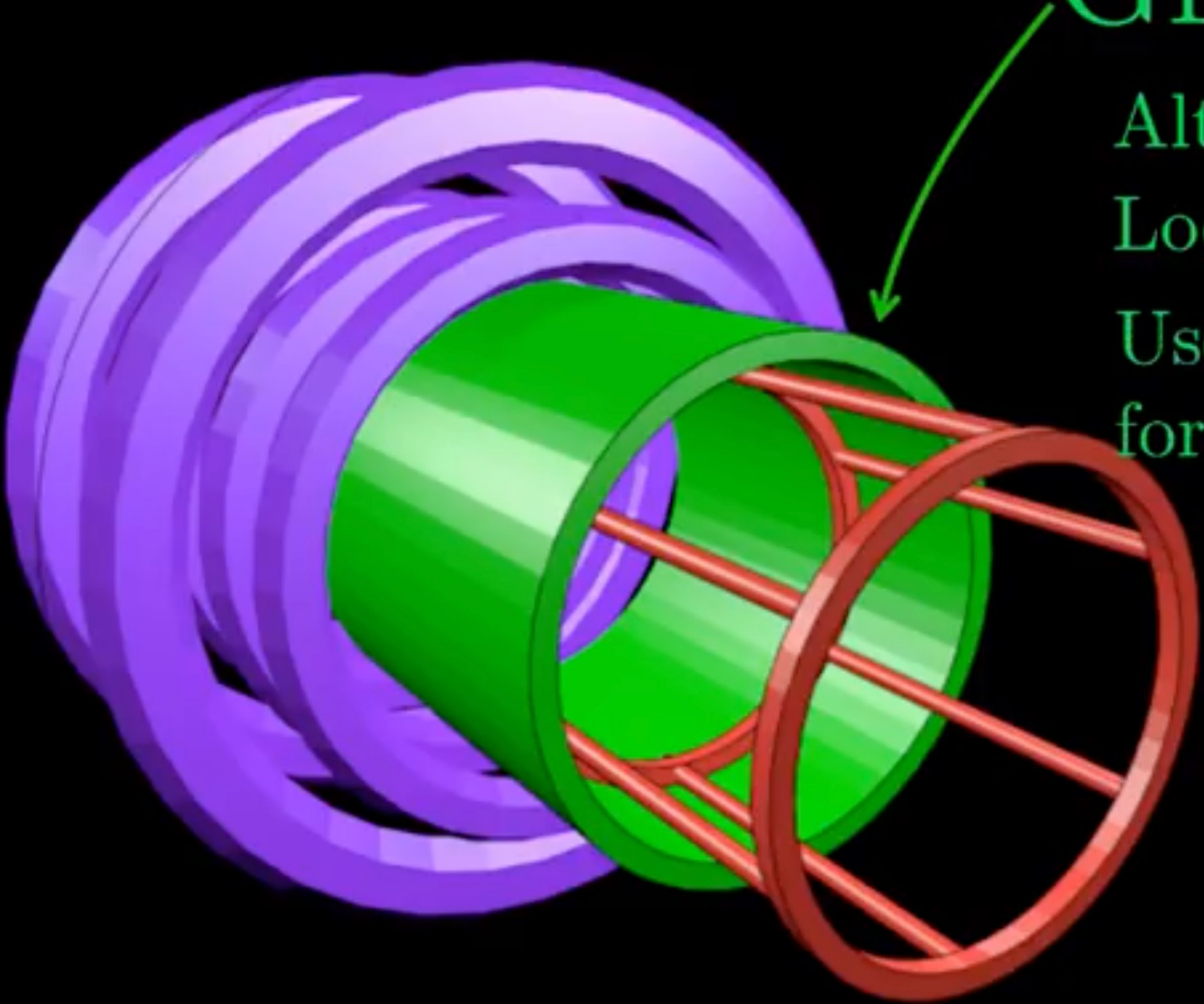


>10,000× earth's magnetic field

ALWAYS ON!



Gradient Coils



Alter $\vec{B}$ field in $\hat{x}$, $\hat{y}$, and $\hat{z}$

Localizes the rf signal in space

Used to provide contrast for diffusion/flow imaging

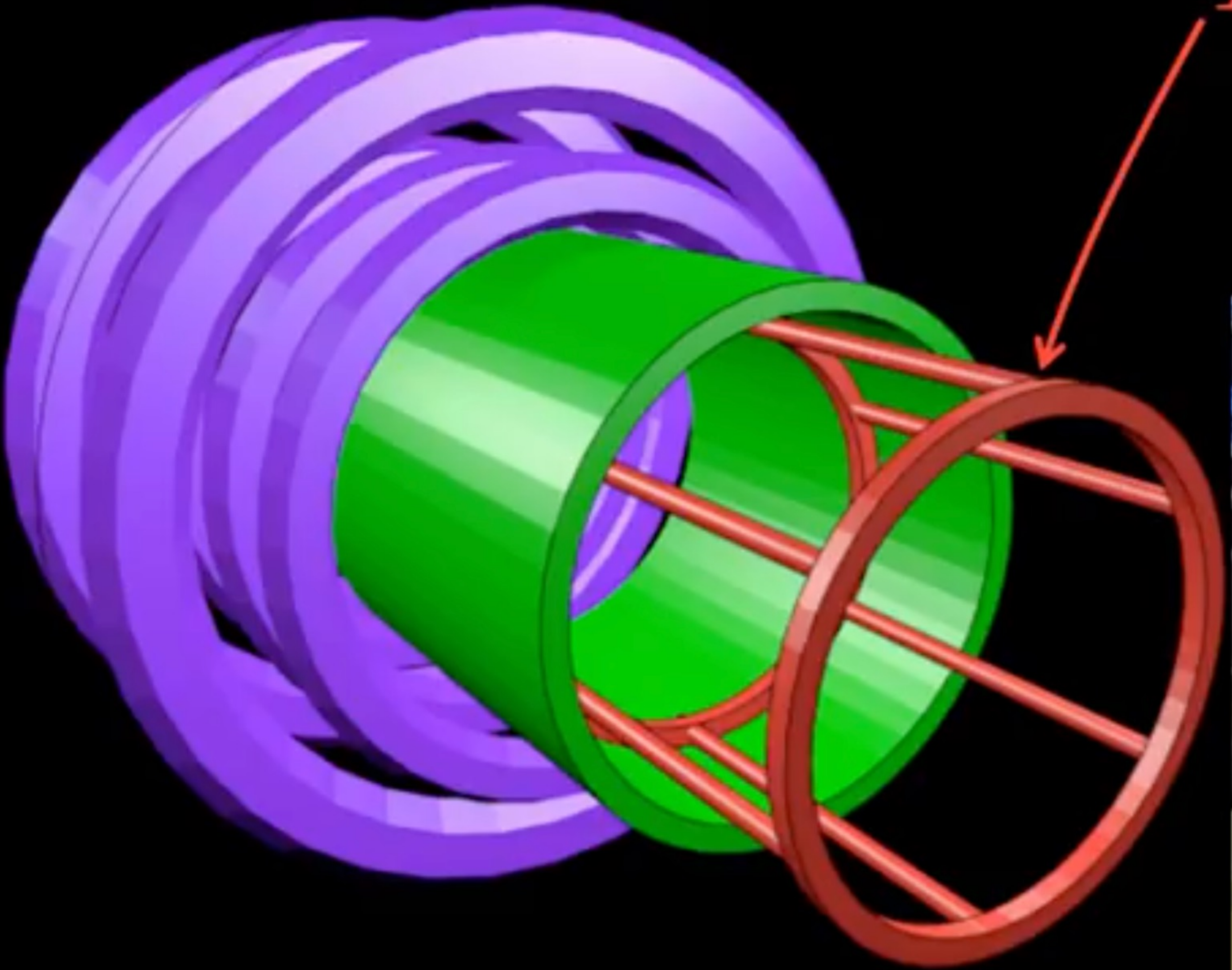
Gradient Coils

Alter $\vec{B}$ field in $\hat{x}$, $\hat{y}$, and $\hat{z}$

alizes the rf signal in space

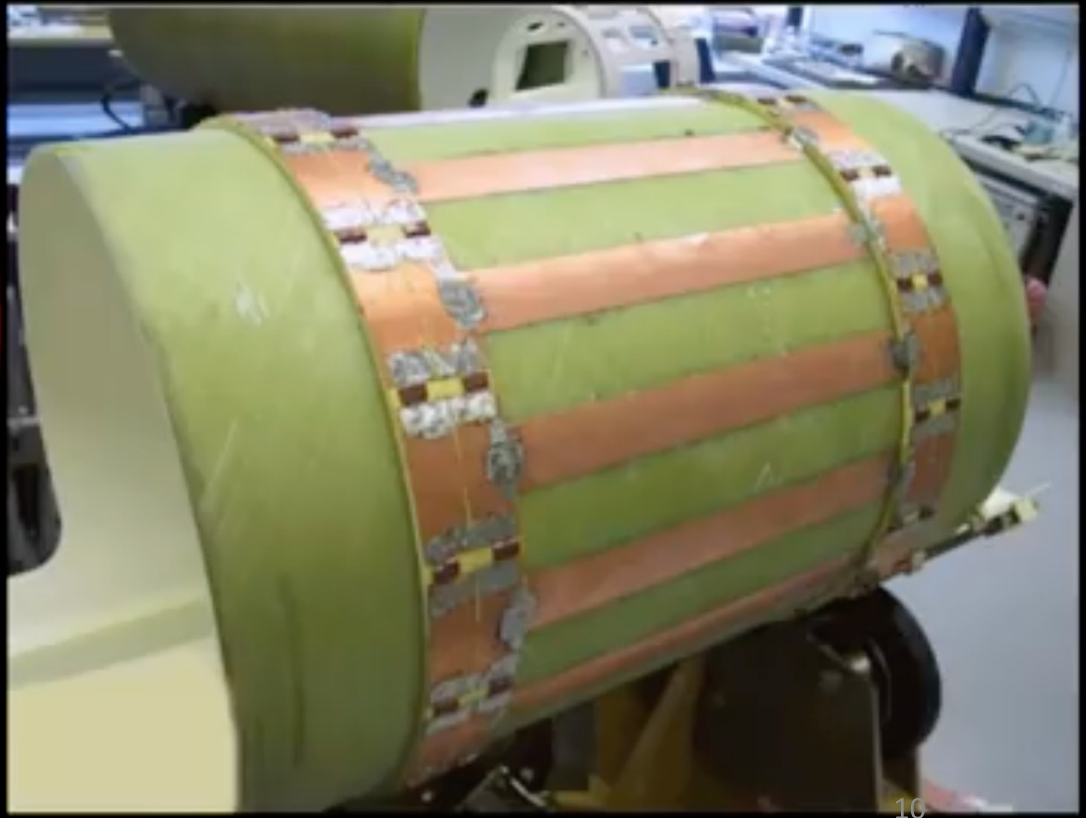
d to provide contrast

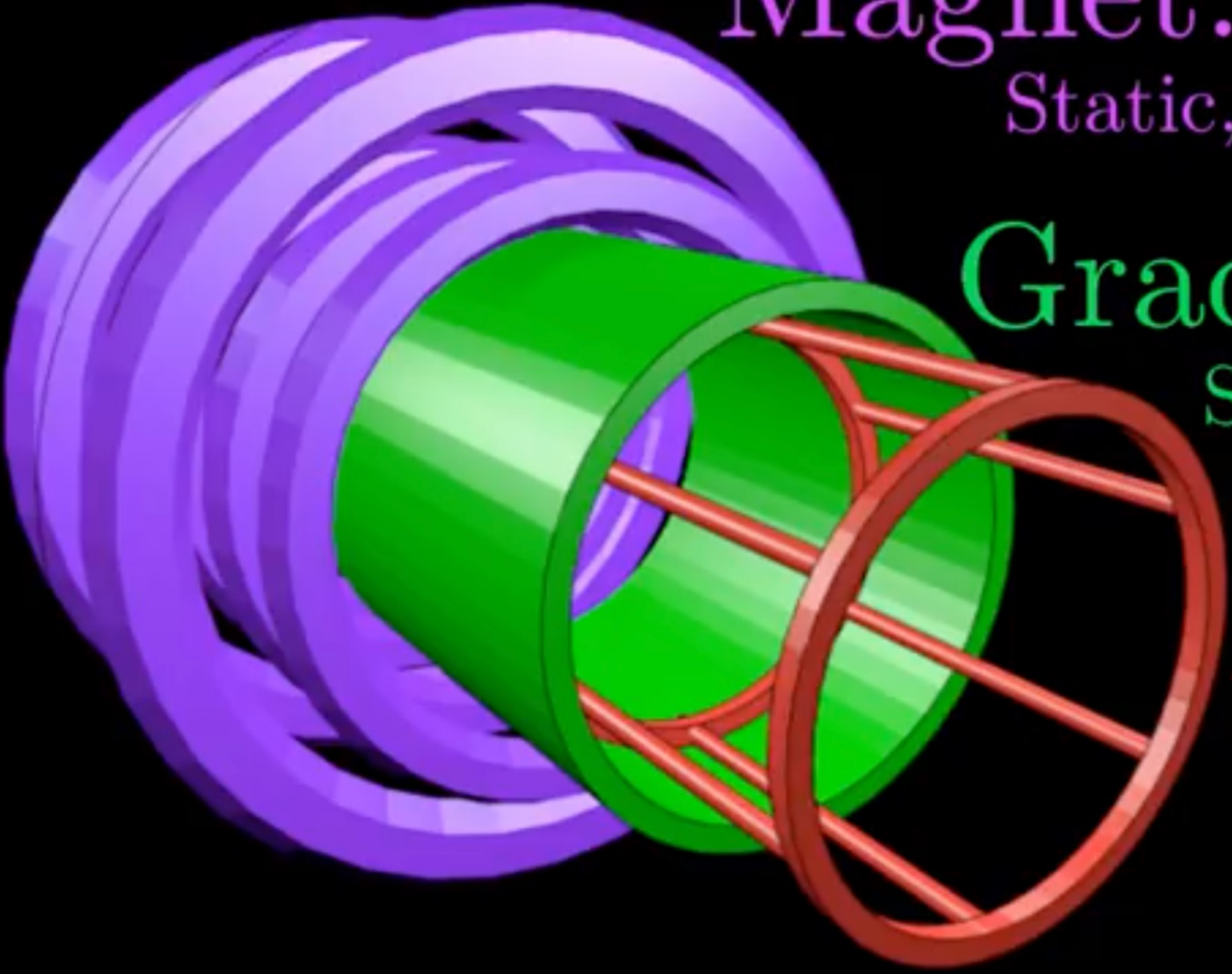
diffusion/flow imaging



RF coil(s)

Sends/recieves rf signals to/from tissue





Magnet: B_0 field

Static, homogeneous, [$\sim$ T]

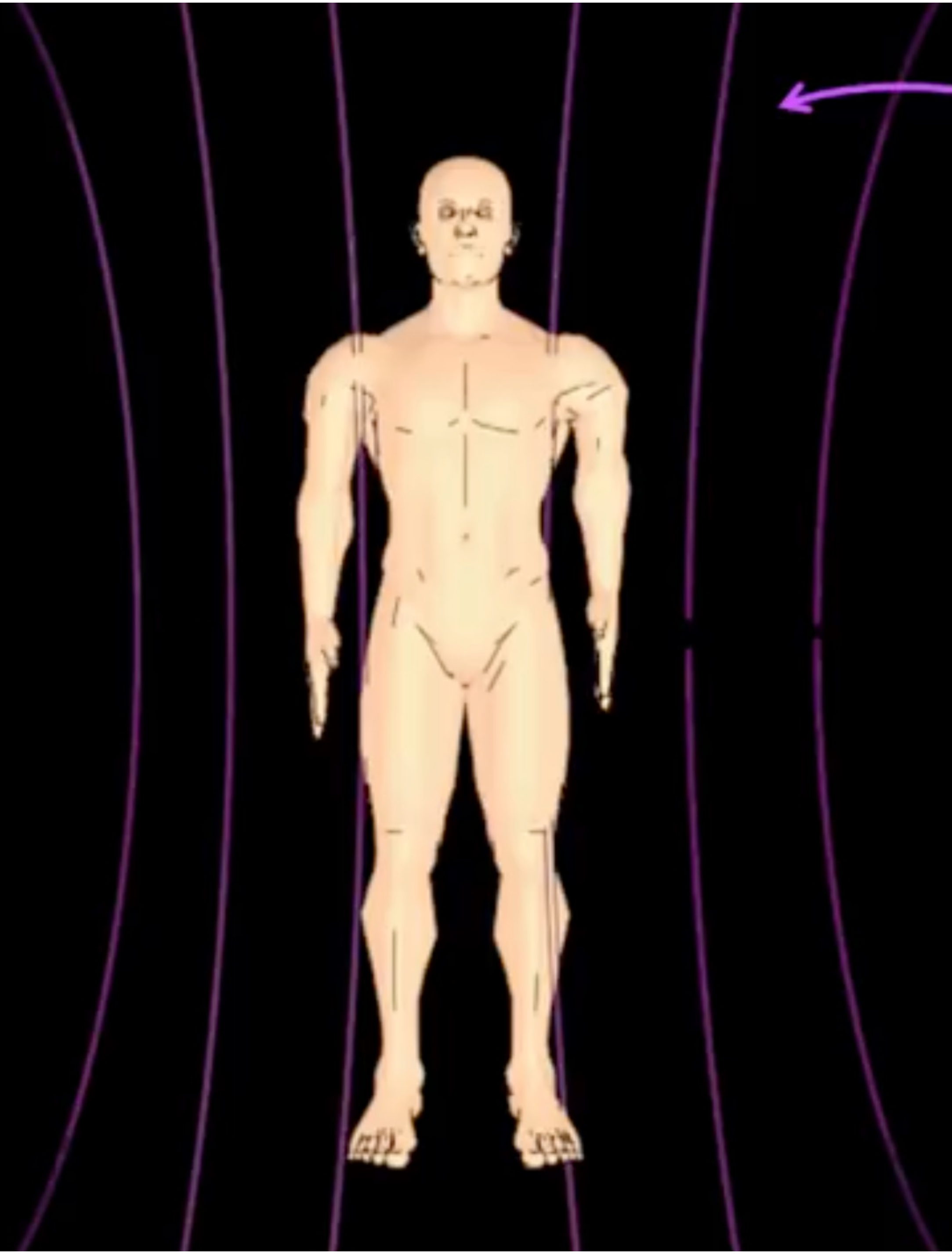
Gradient Coils

Spatially varying, [$\sim$ mT]

RF Coil(s)

Temporally varying, [$\sim \mu$T]

Magnetic Field: $\vec{B}$



Proton (^{1}H nucleus)

Mass - $m_p = 1.67 \times 10^{-27}$ kg

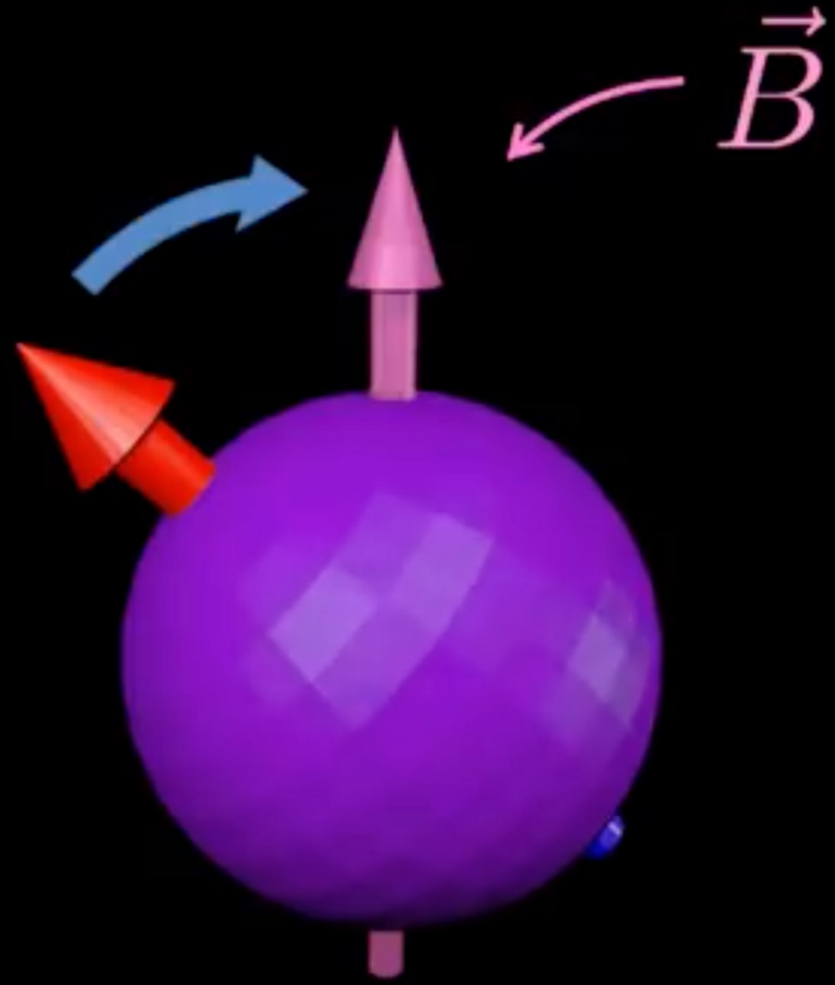
Charge - $q_p = 1.6 \times 10^{-19}$ C

Spin - $\vec{S} = \pm\frac{1}{2}$

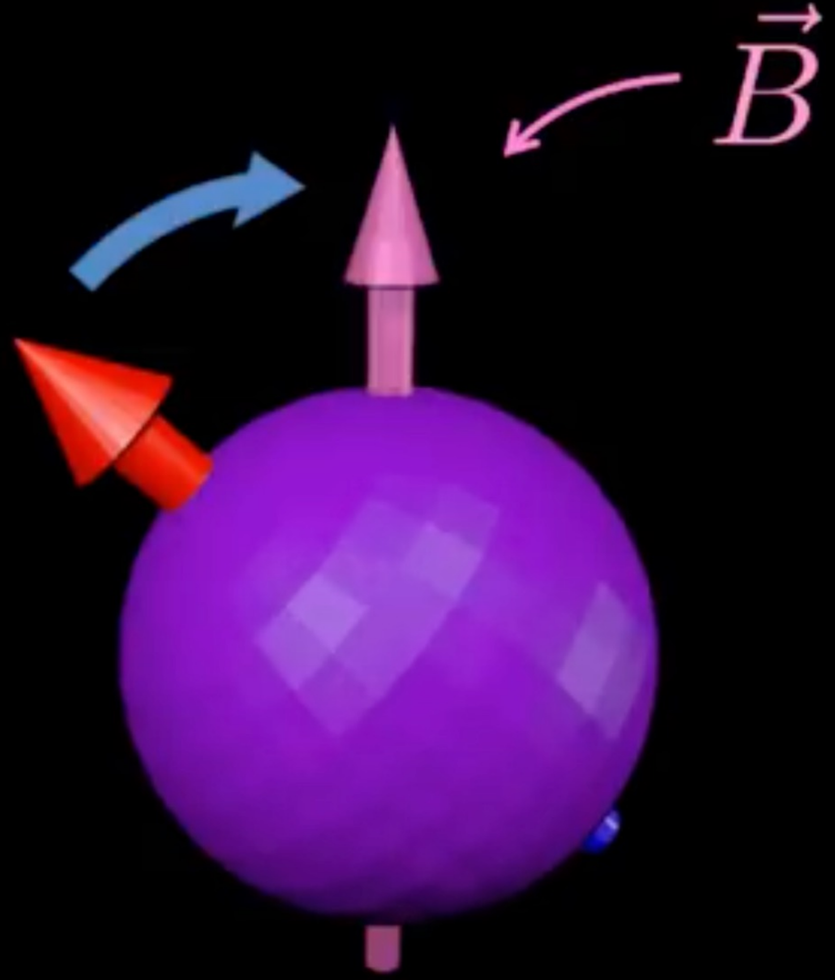
Spin $\begin{cases} \text{1. Angular Momentum} \\ \text{2. Magnetic Moment} \end{cases}$

$$\vec{\mu} = \hbar \vec{S} \gamma$$

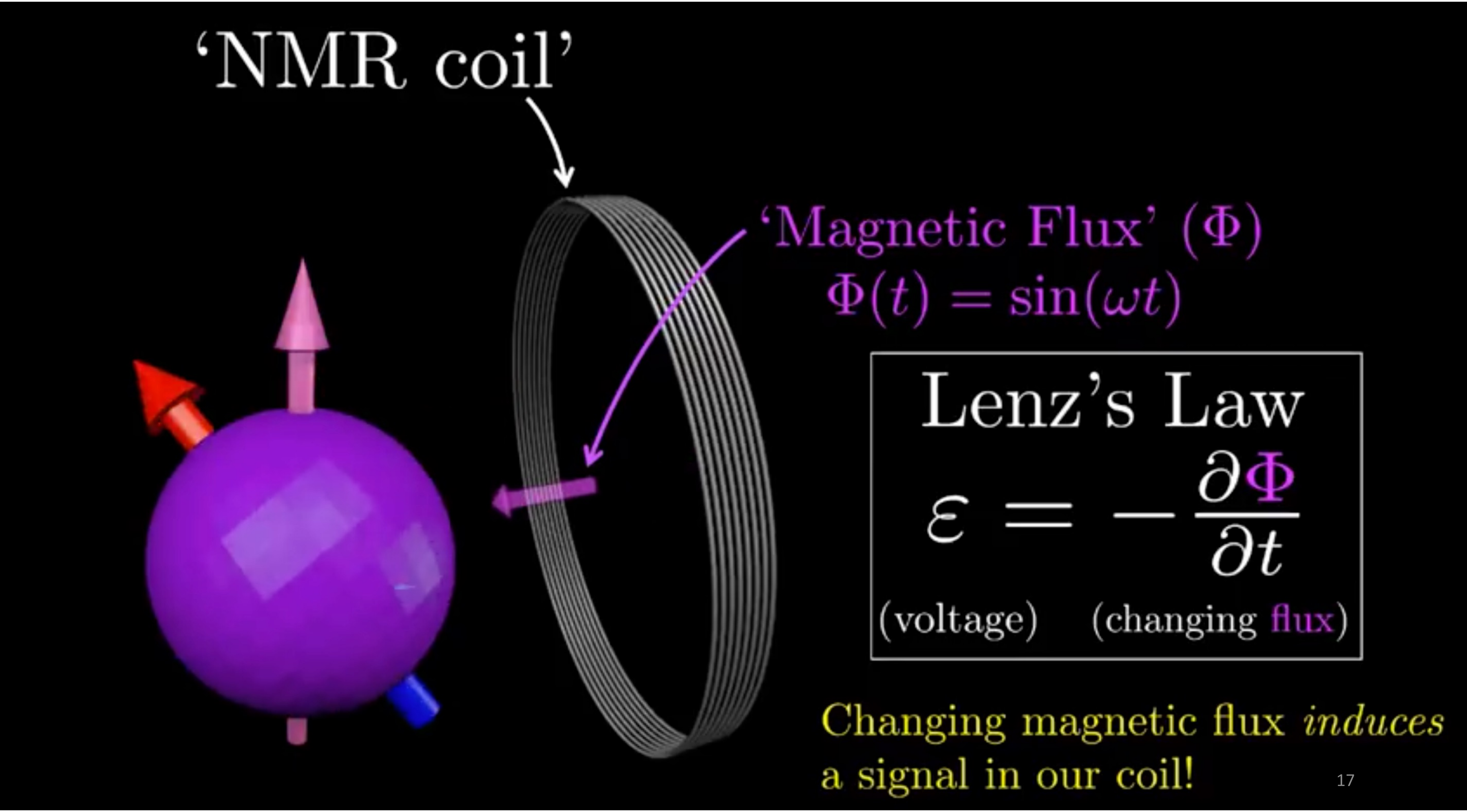
$$\text{Spin} \begin{cases} 1.\ \text{Angular Momentum} \\ 2.\ \text{Magnetic Moment} \end{cases}$$

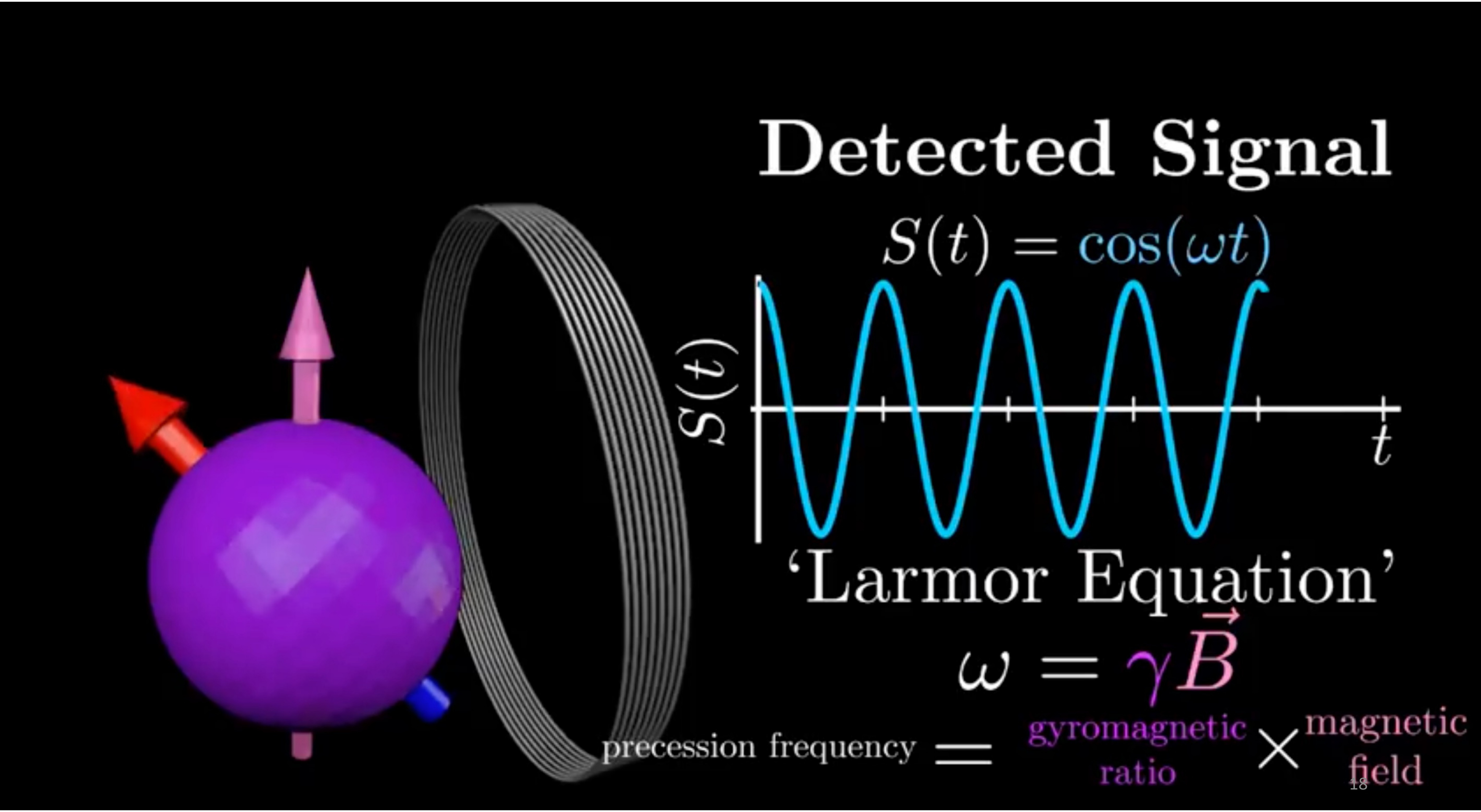


Spin $\begin{cases} \text{1. Angular Momentum} \\ \text{2. Magnetic Moment} \end{cases}$



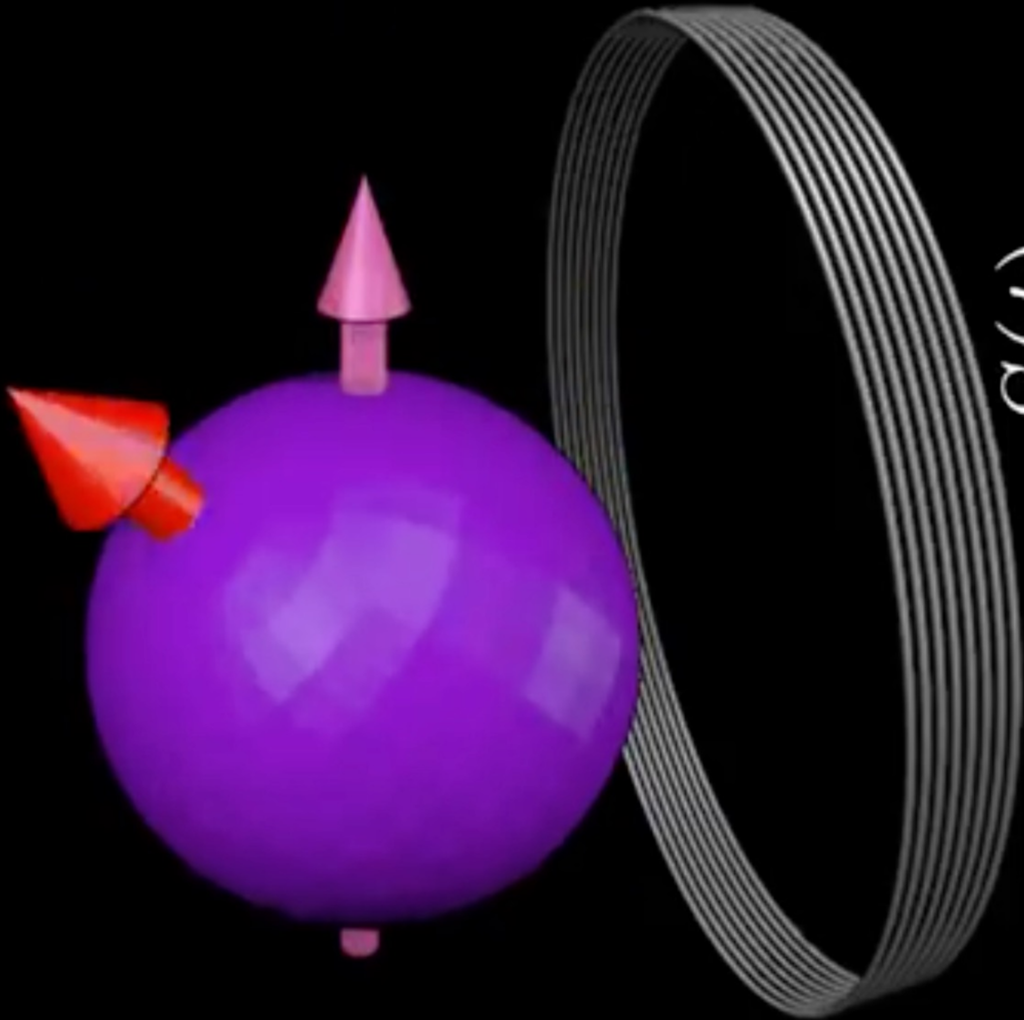
“Precession”

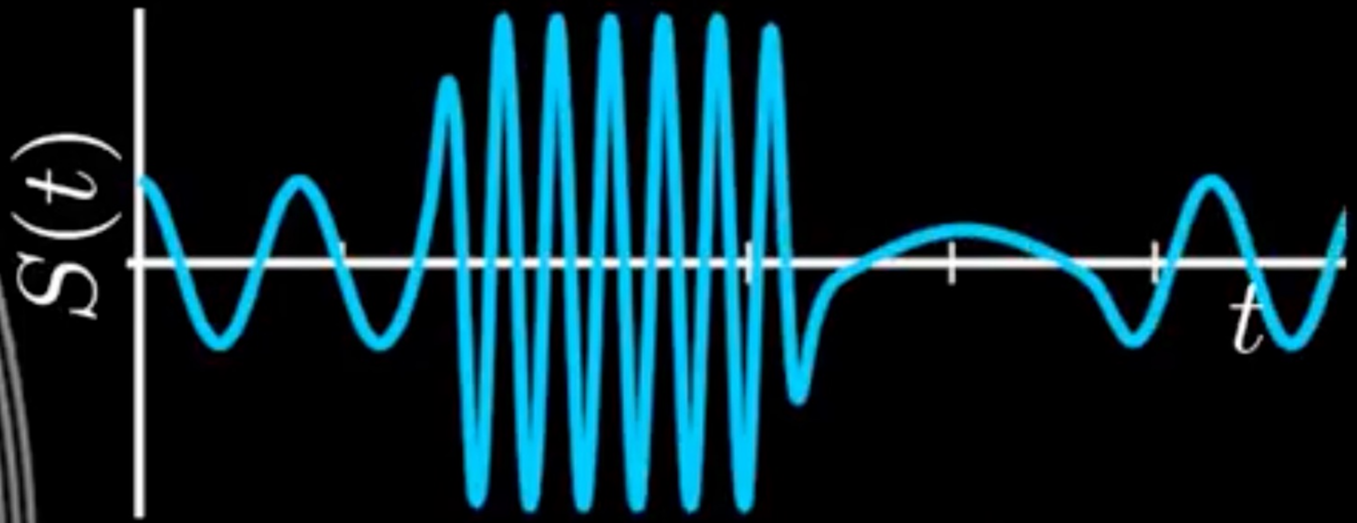

'NMR coil'
'Magnetic Flux' (Φ)
$\Phi(t) = \sin(\omega t)$
Lenz's Law
$\varepsilon = -\frac{\partial \Phi}{\partial t}$
(voltage) (changing flux)
Changing magnetic flux *induces* a signal in our coil!


Detected Signal
$S(t) = \cos(\omega t)$
$S(t)$
t
'Larmor Equation'
$\omega = \gamma \vec{B}$
precession frequency = gyromagnetic ratio × magnetic field

Detected Signal

$$S(t) = \cos(\omega t)$$



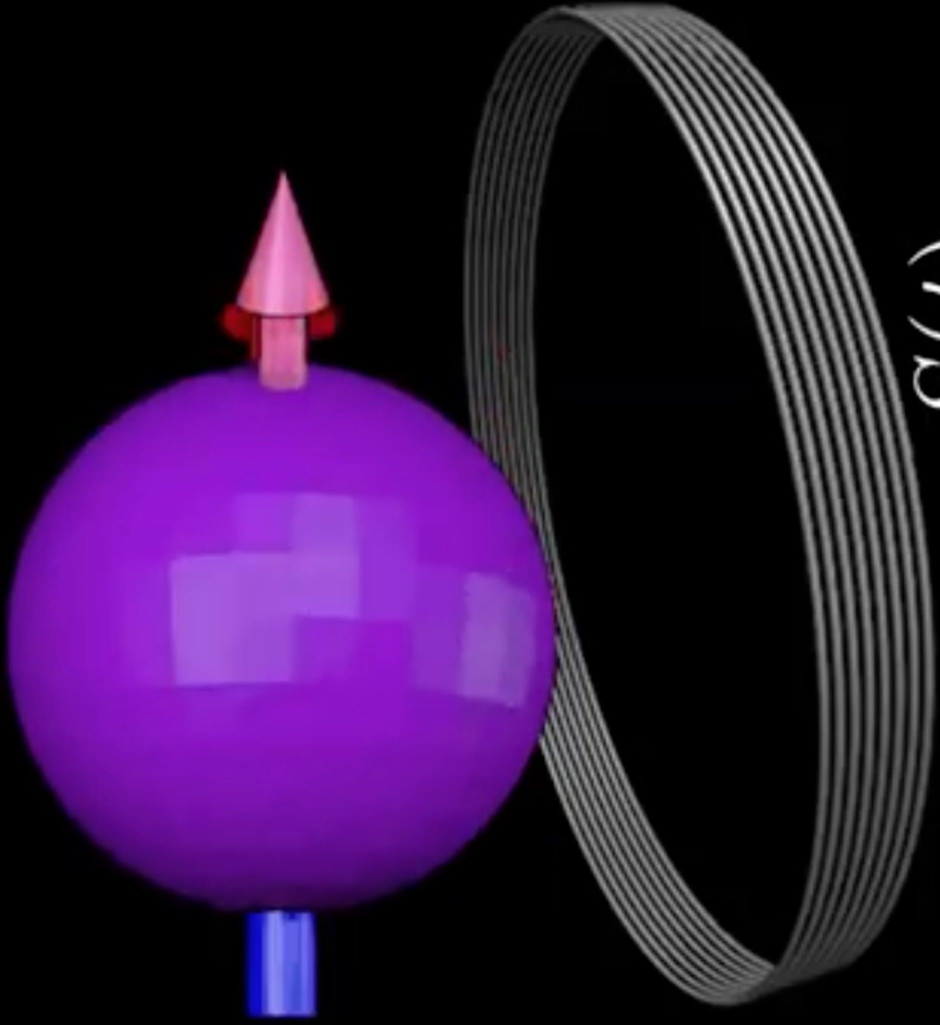


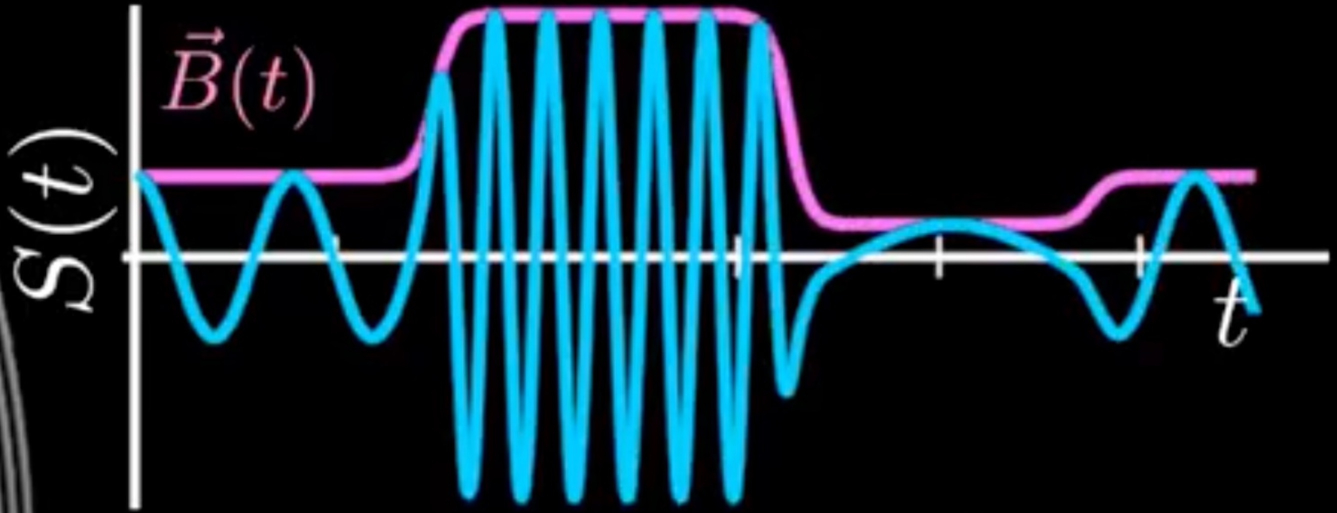
$$\omega = \gamma \vec{B}$$

$$\varepsilon = -\frac{\partial \Phi}{\partial t}$$

Detected Signal

$$S(t) = \gamma B \cos(\omega t)$$

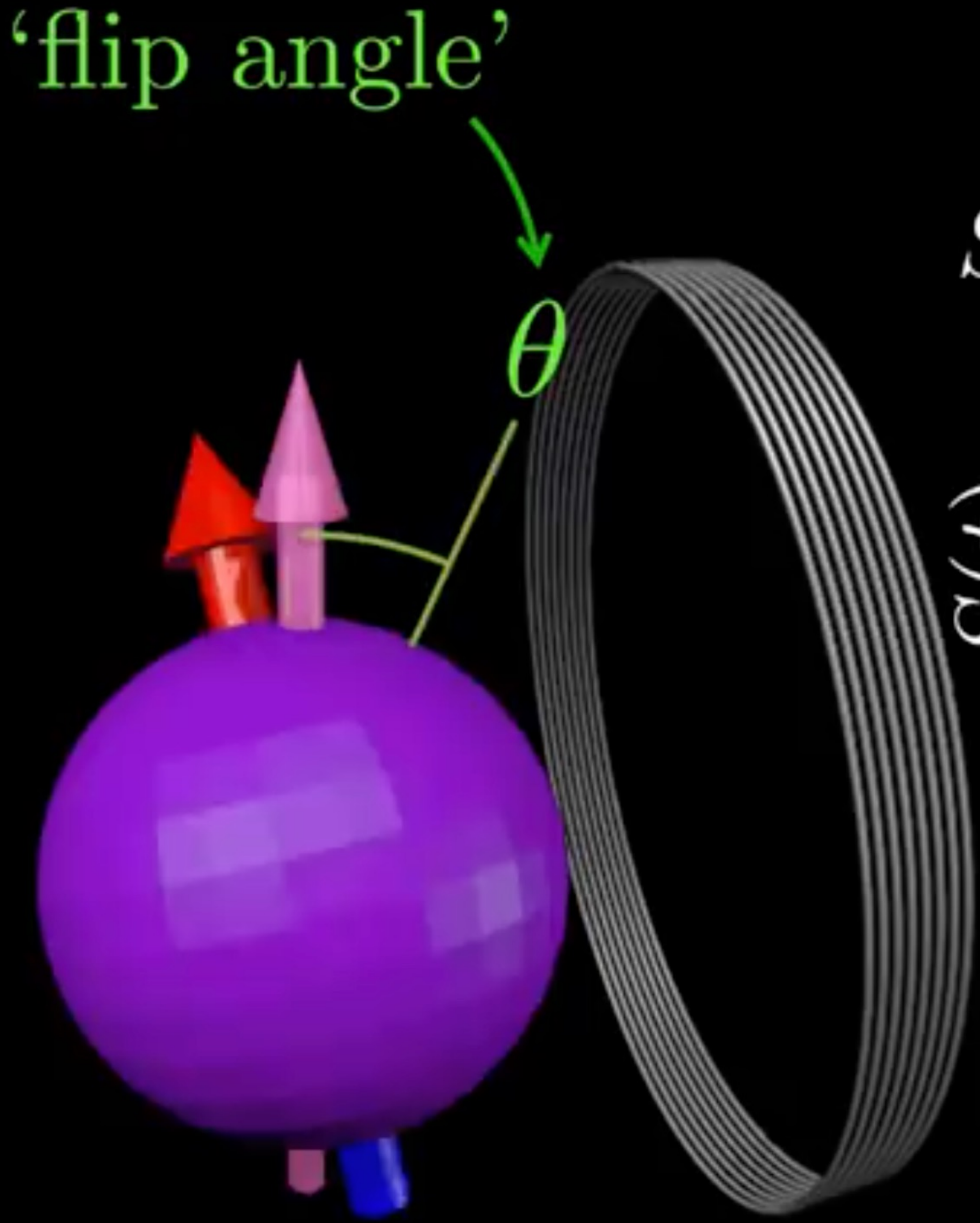


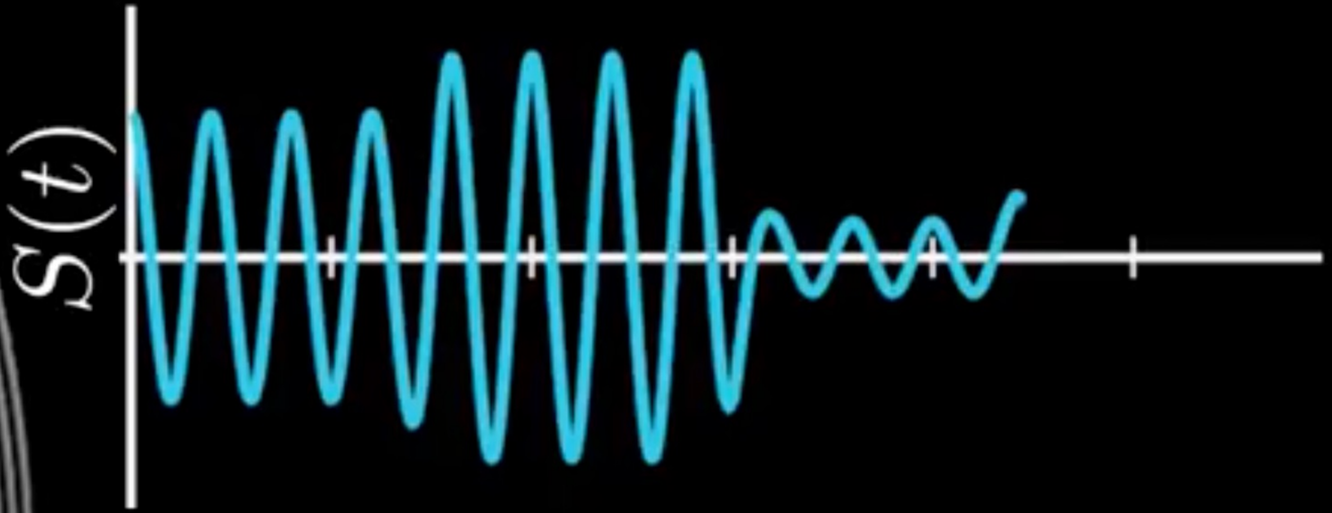


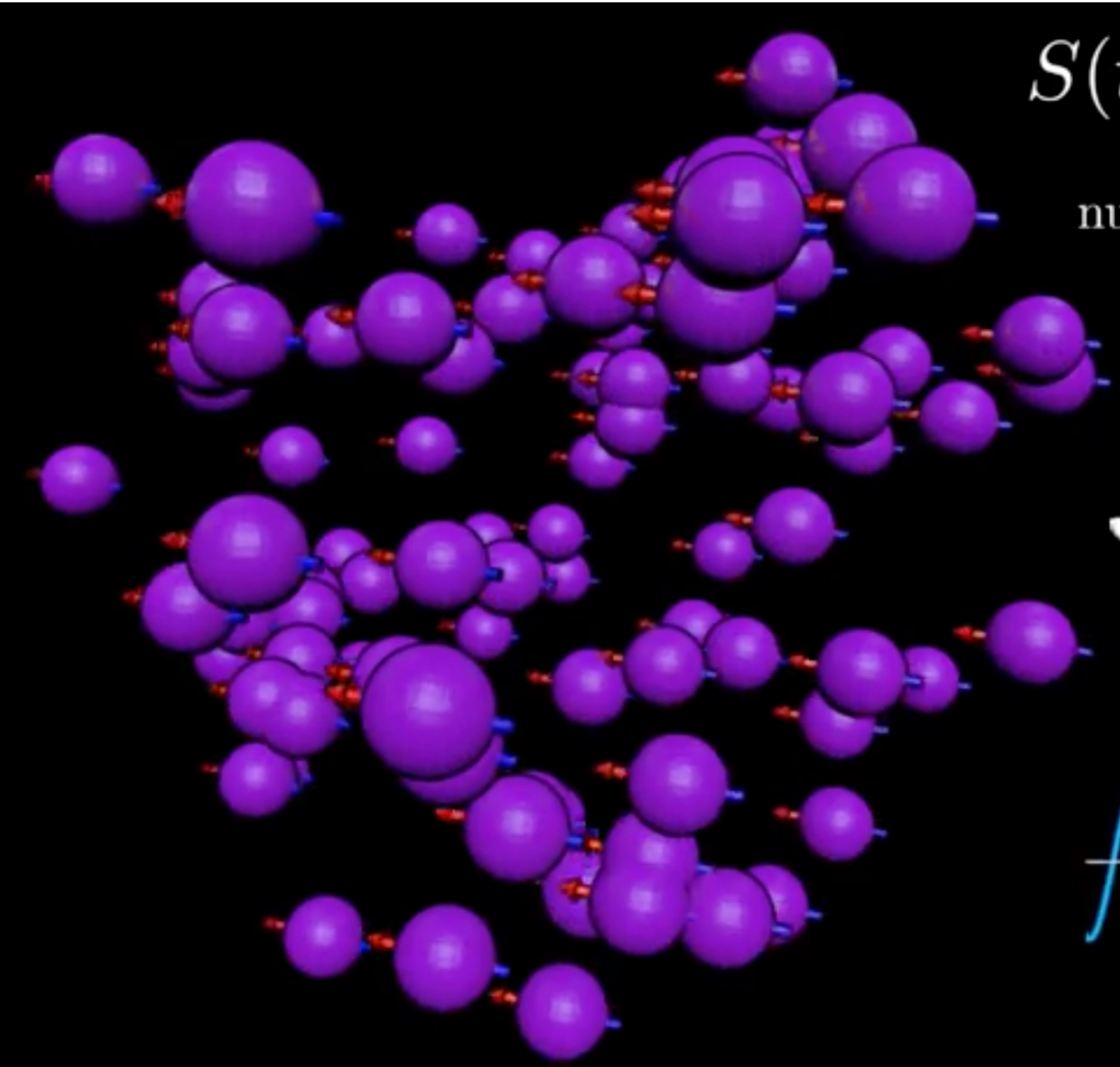
$$\omega = \gamma \vec{B}$$

Detected Signal

$$S(t) = \sin(\theta)\gamma B \cos(\omega t)$$







$$S(t) = N \sin(\theta) \gamma B \cos(\omega t)$$

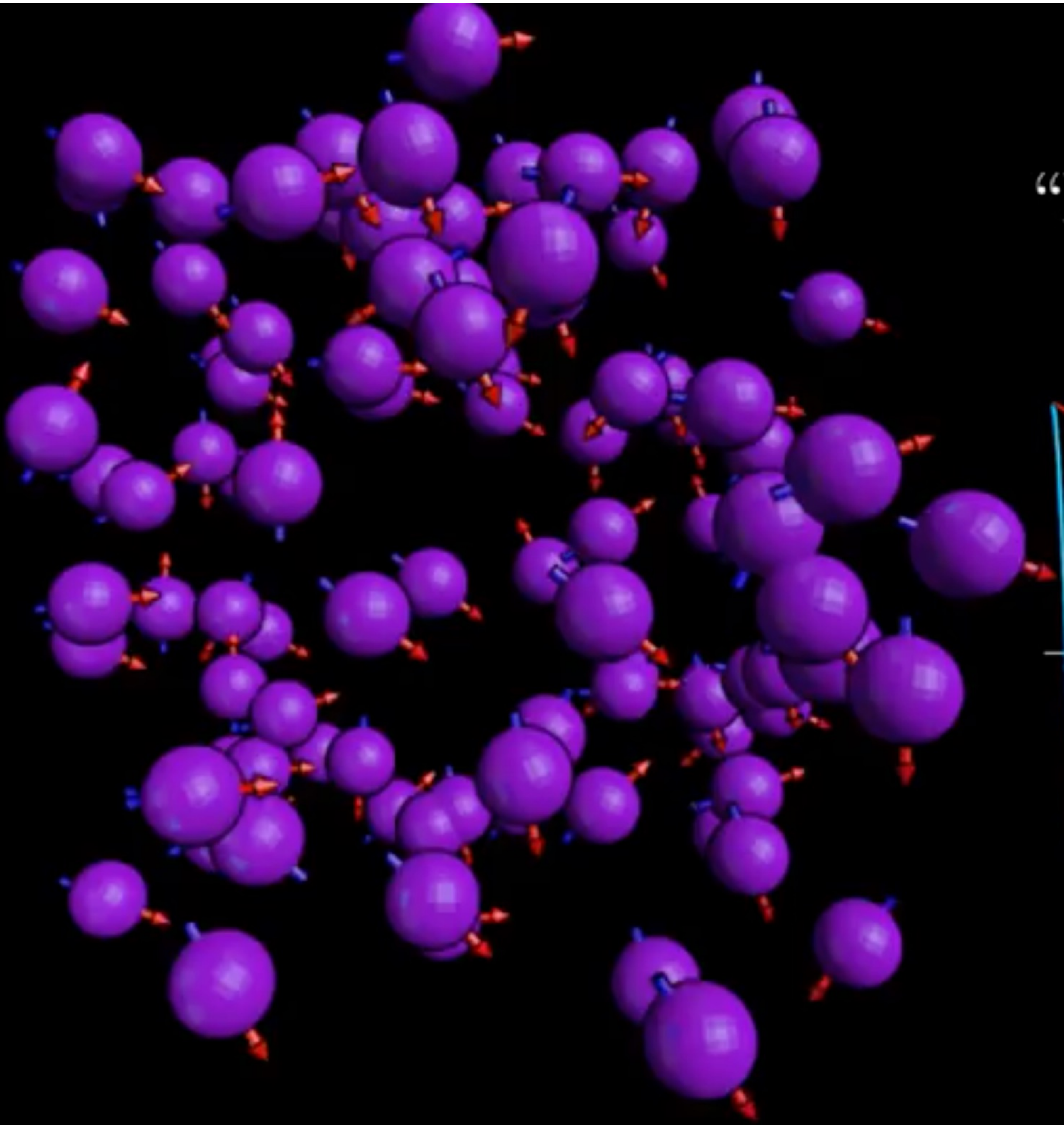
number of spins

flip angle

gyromagnetic ratio

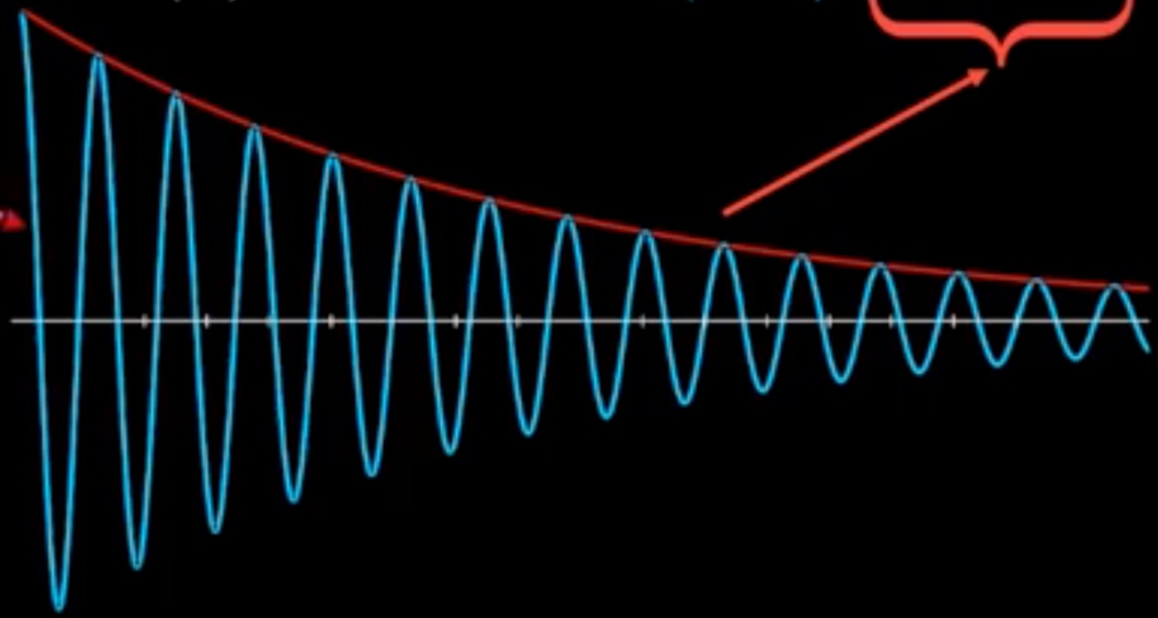
magnetic field

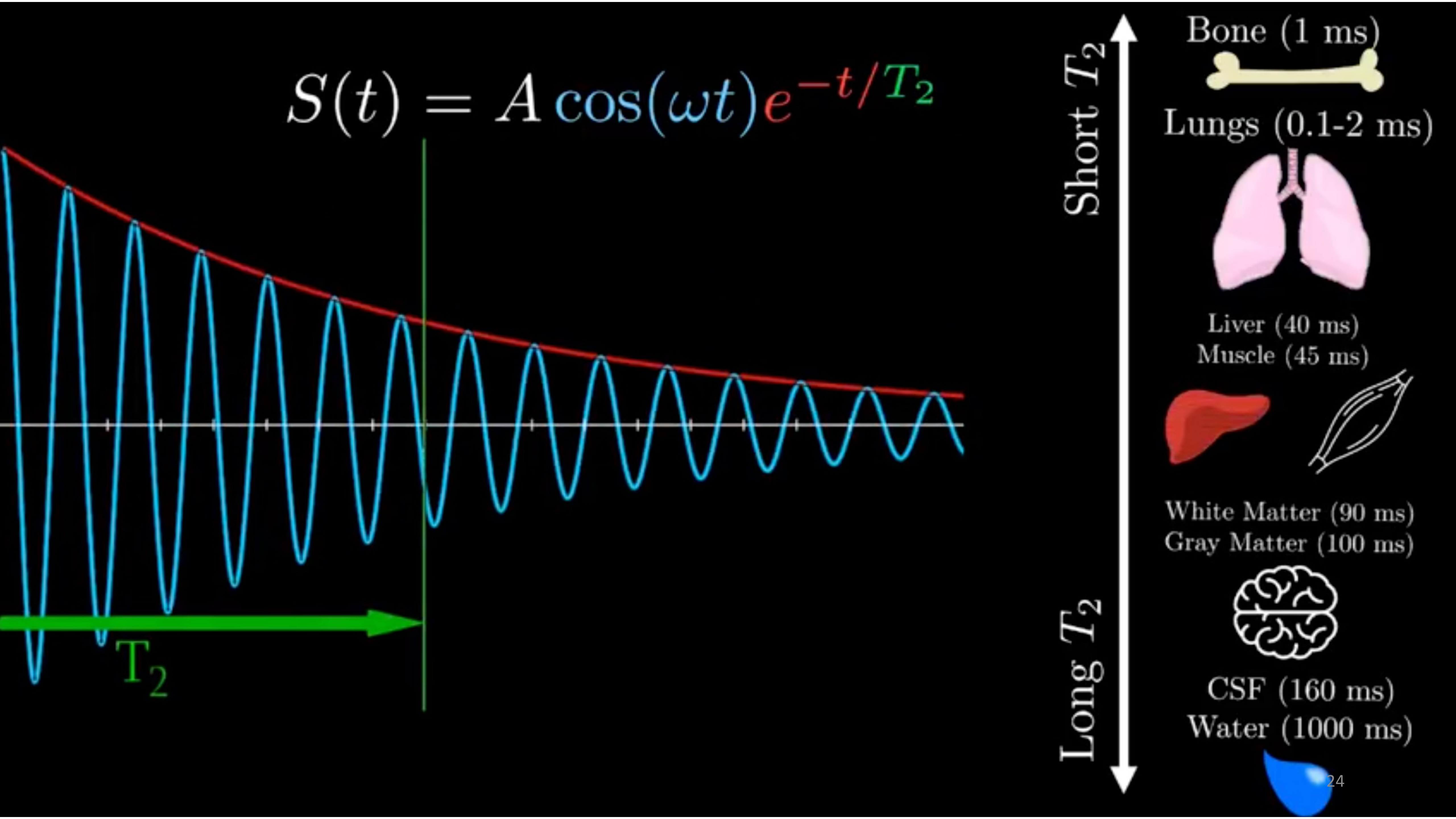
$$S(t) = A \cos(\omega t)$$



"Free Induction Decay" (FID)

$$S(t) = A\cos(\omega t)e^{-t/T_2}$$

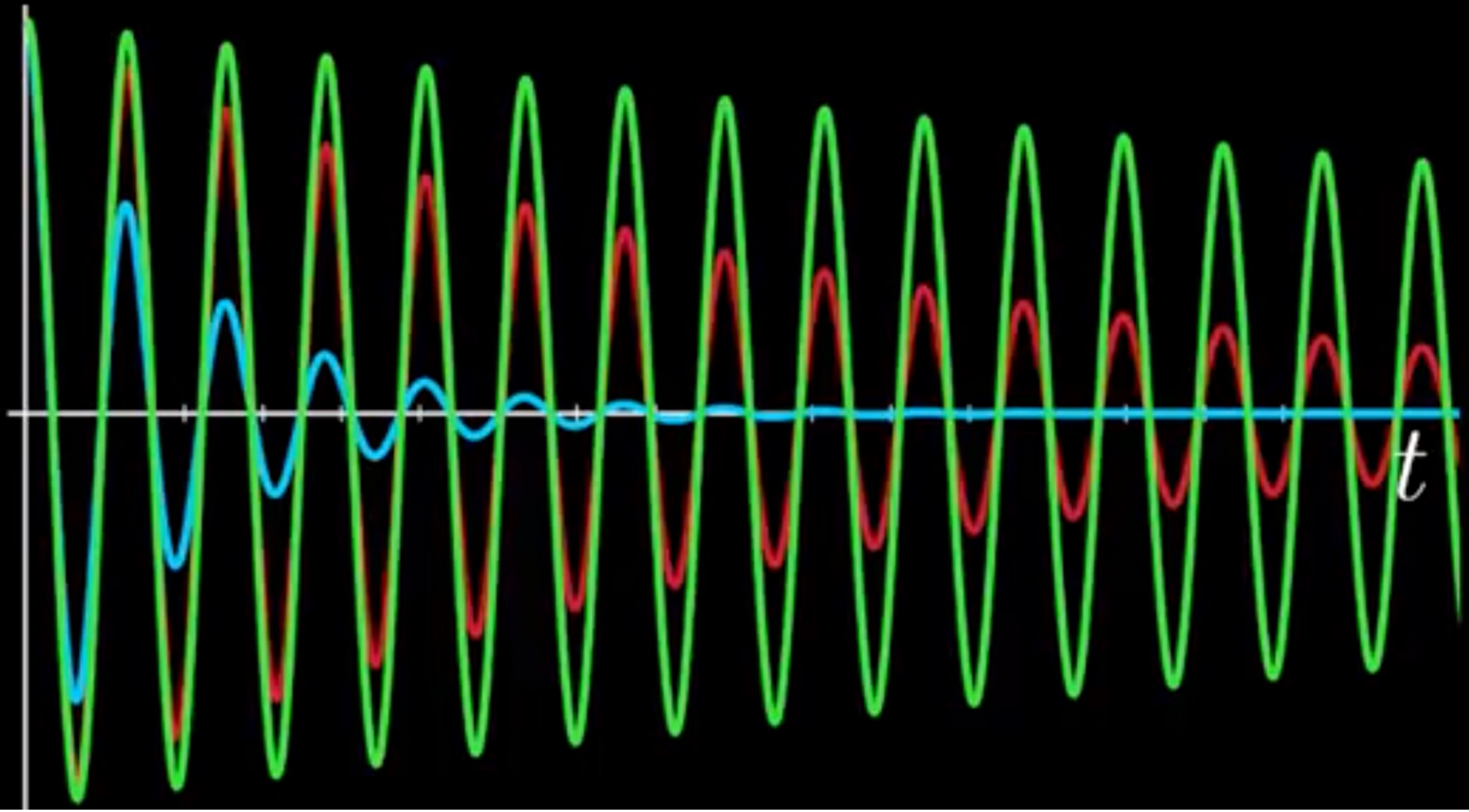



$S(t) = A\cos(\omega t)e^{-t/T_2}$
T_2
Short T_2
Long T_2
Bone (1 ms)
Lungs (0.1-2 ms)
Liver (40 ms)
Muscle (45 ms)
White Matter (90 ms)
Gray Matter (100 ms)
CSF (160 ms)
Water (1000 ms)

$$S(t) = e^{-t/T_{2s}} \cos(\omega t)$$

$$S(t) = e^{-t/T_{2m}} \cos(\omega t)$$

$$S(t) = e^{-t/T_{2l}} \cos(\omega t)$$



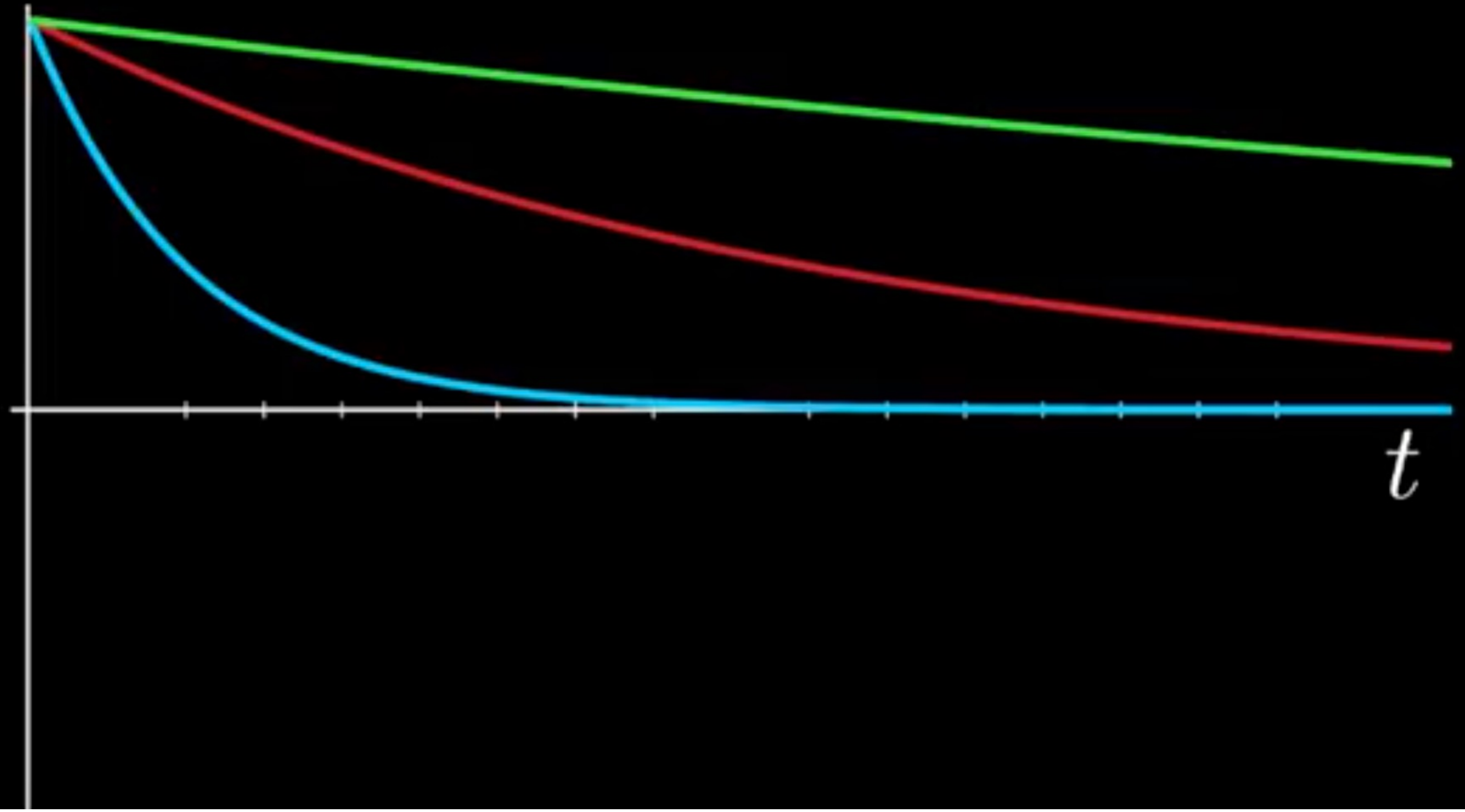
$$S(t) = e^{-t/T_{2s}}$$

$$S(t) = e^{-t/T_{2m}}$$

$$S(t) = e^{-t/T_{2l}}$$

Transition to the 'Rotating Frame'

Let $\omega \to 0$

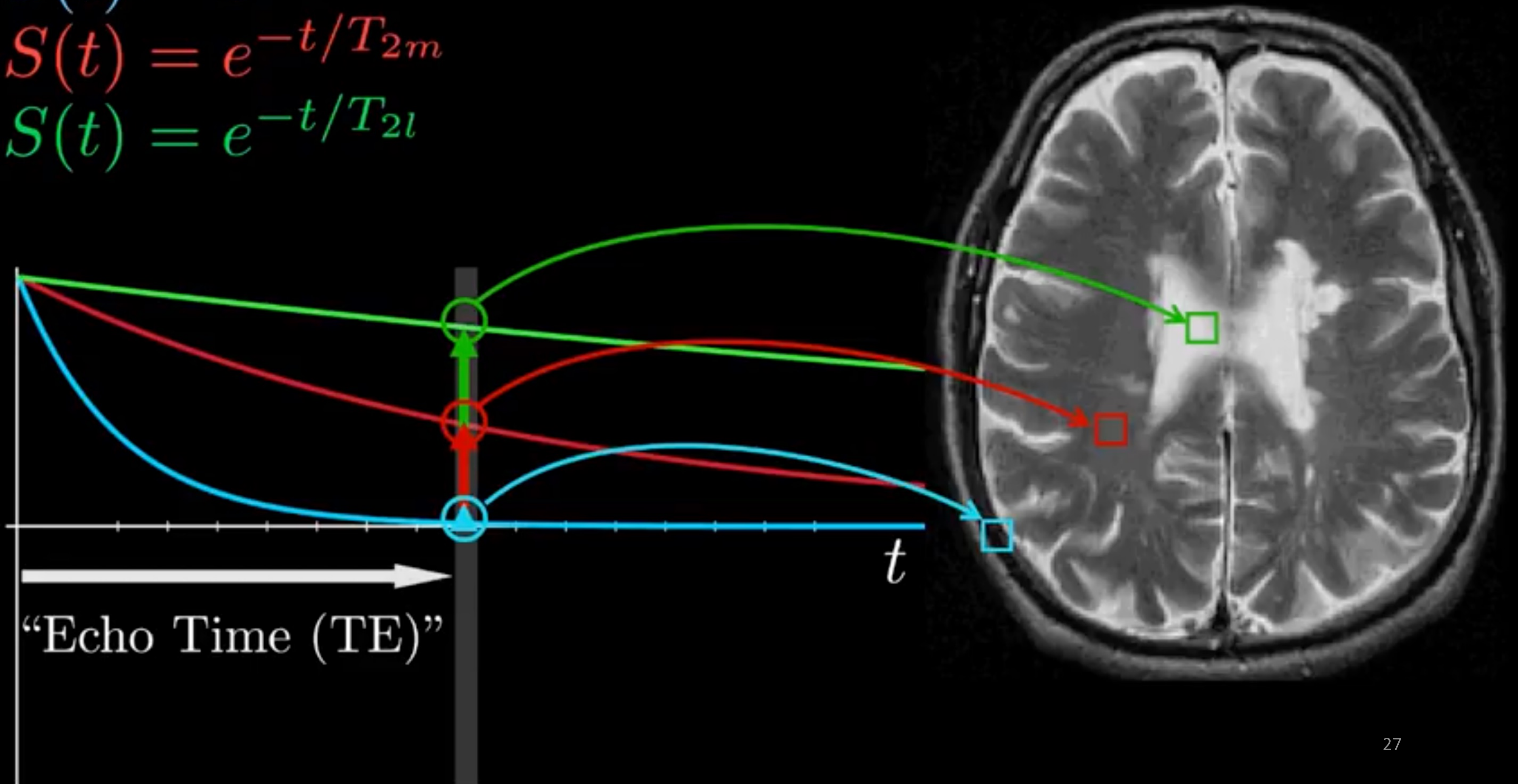


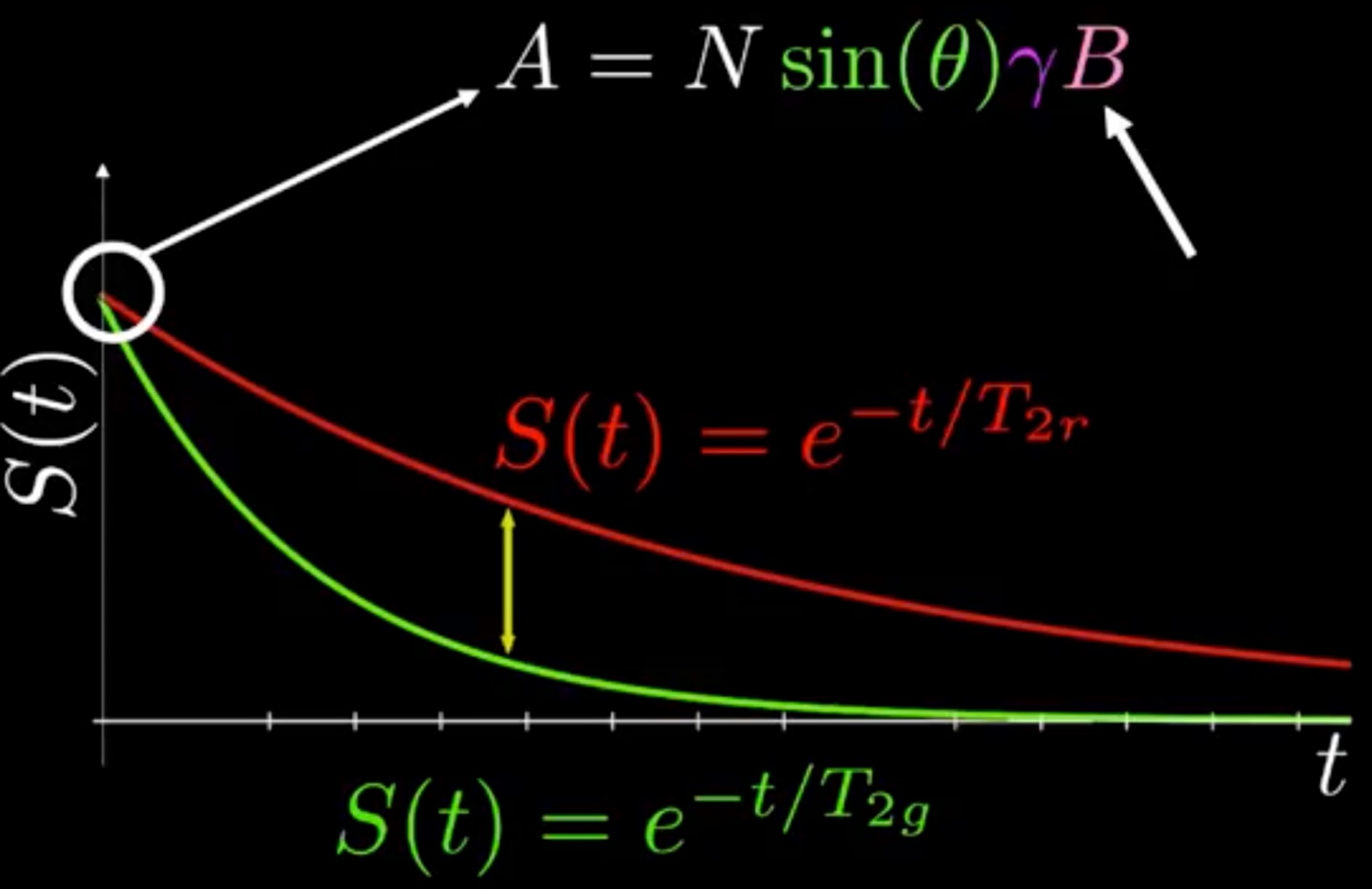
"T_2 Weighted Image"

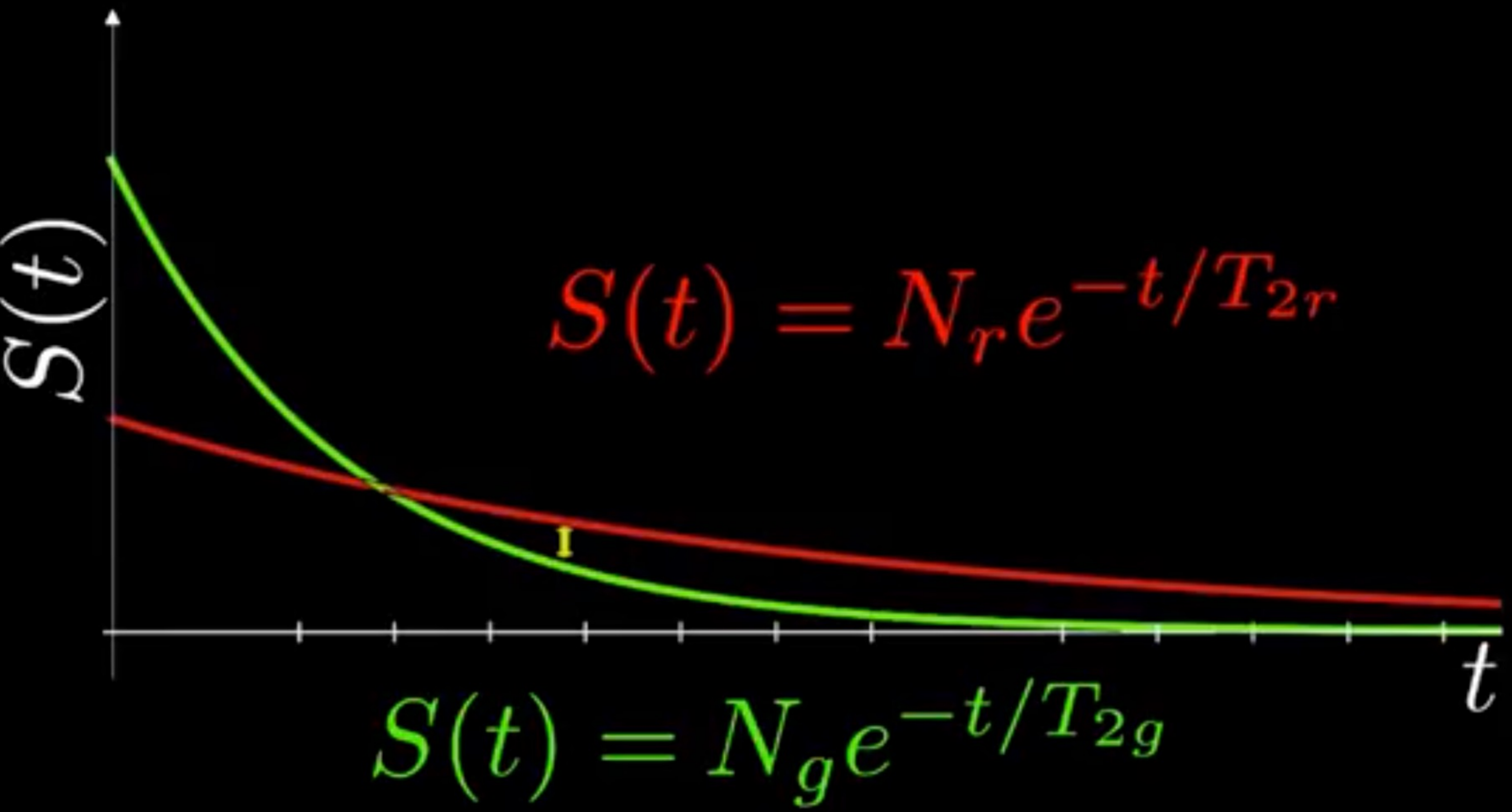
$$S(t) = e^{-t/T_{2s}}$$

$$S(t) = e^{-t/T_{2m}}$$

$$S(t) = e^{-t/T_{2l}}$$

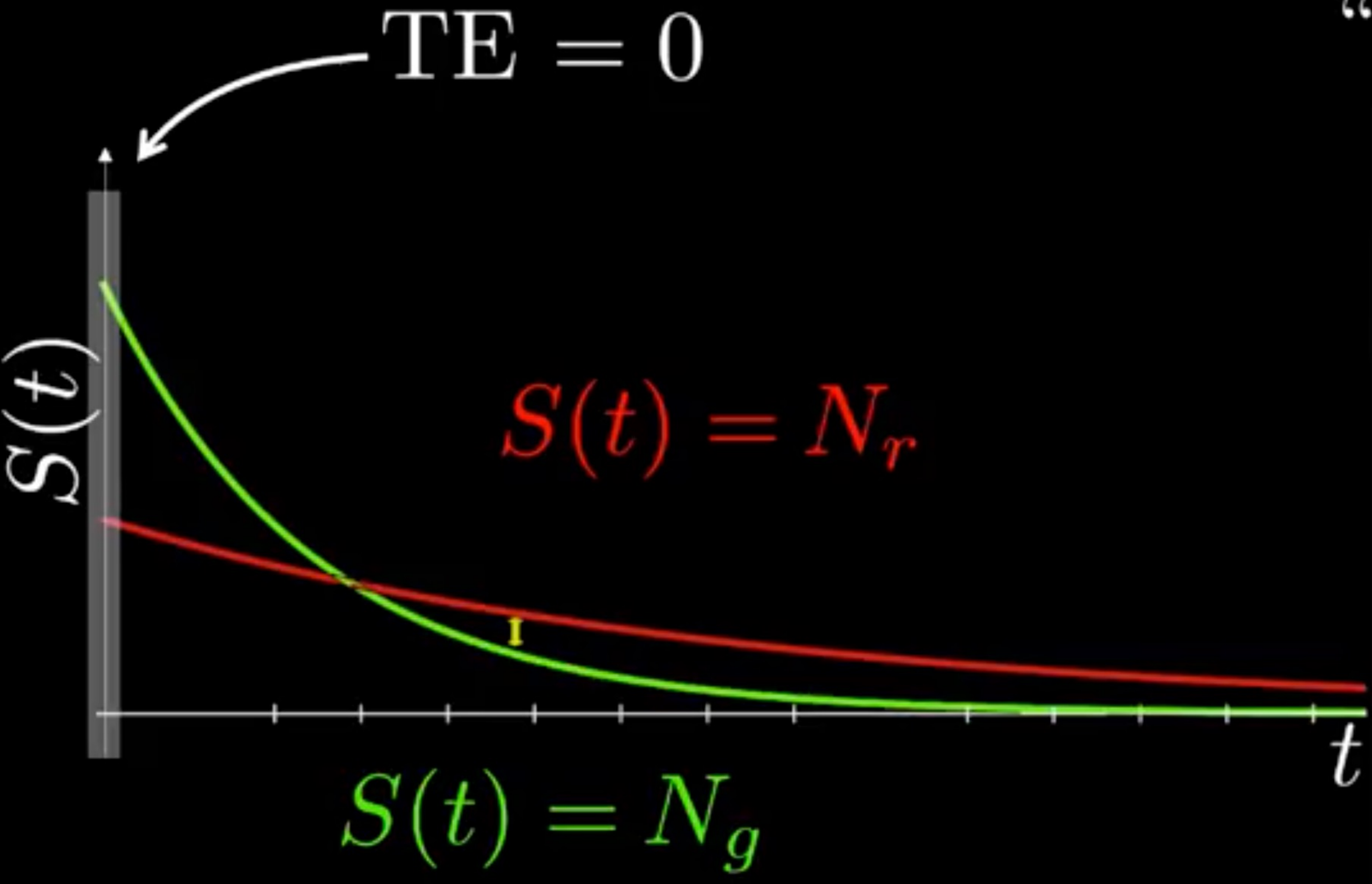


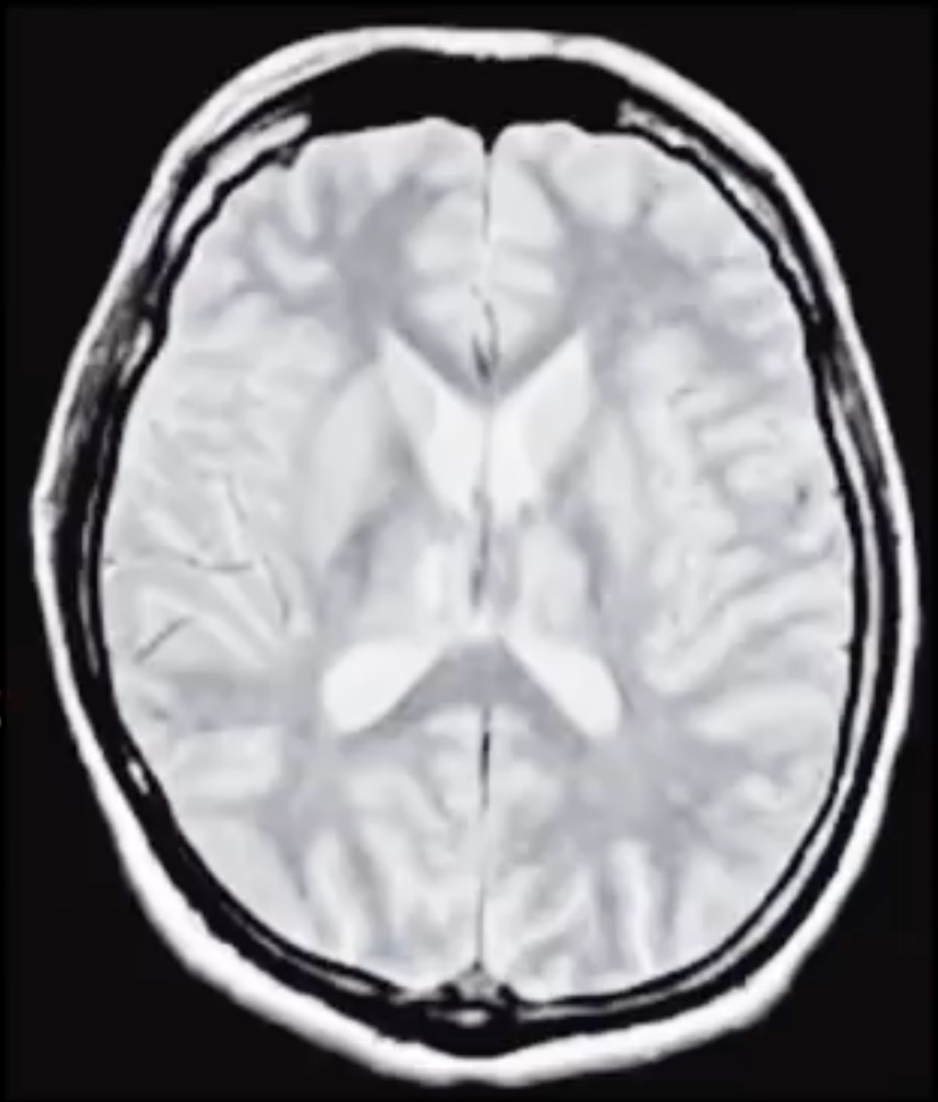

$A = N \sin(\theta)\gamma B$
$S(t)$
$S(t) = e^{-t/T_{2r}}$
t
$S(t) = e^{-t/T_{2g}}$



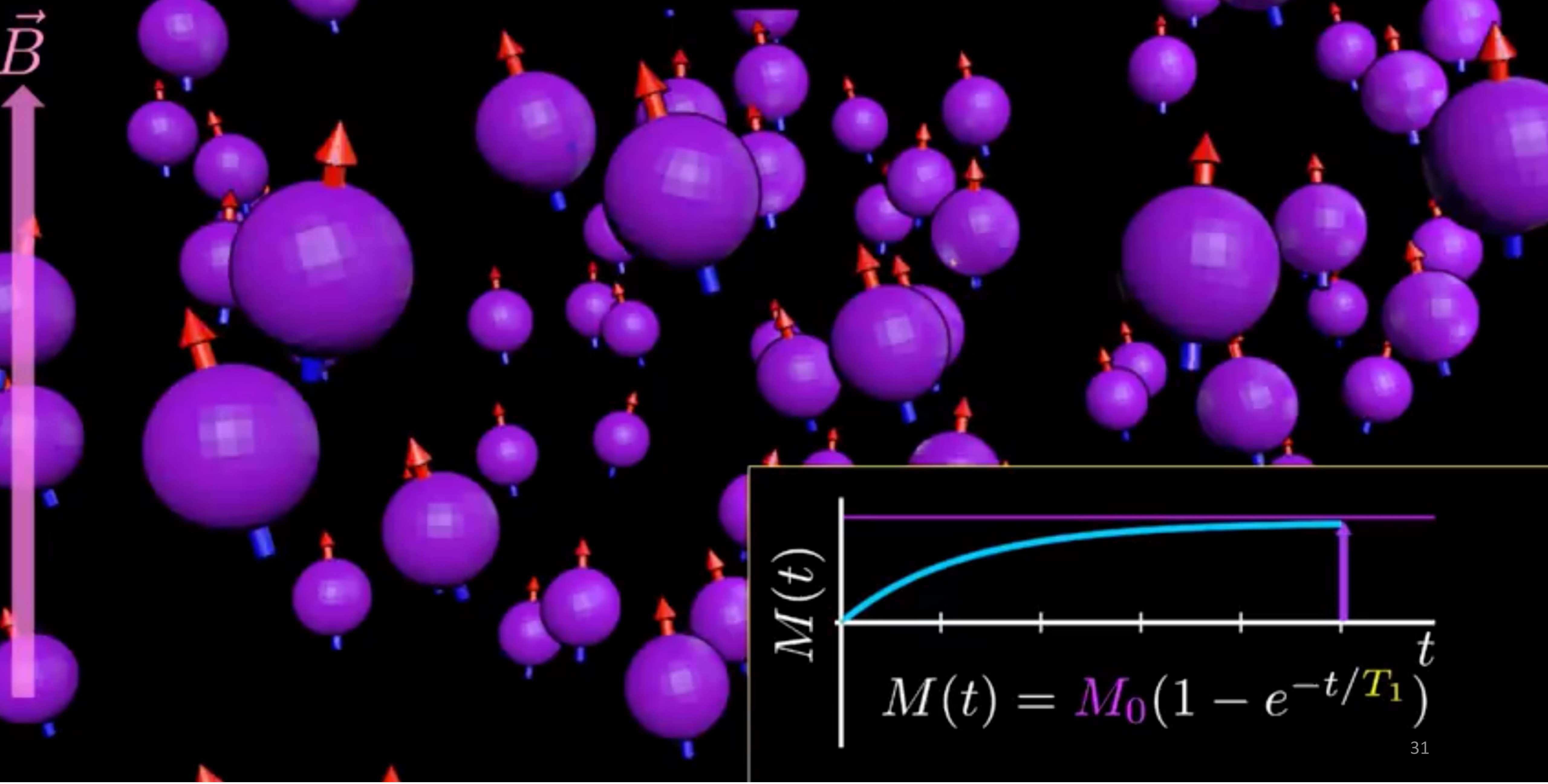
$S(t) = N_r e^{-t/T_{2r}}$
$S(t)$
t
$S(t) = N_g e^{-t/T_{2g}}$

“Spin Density Image”

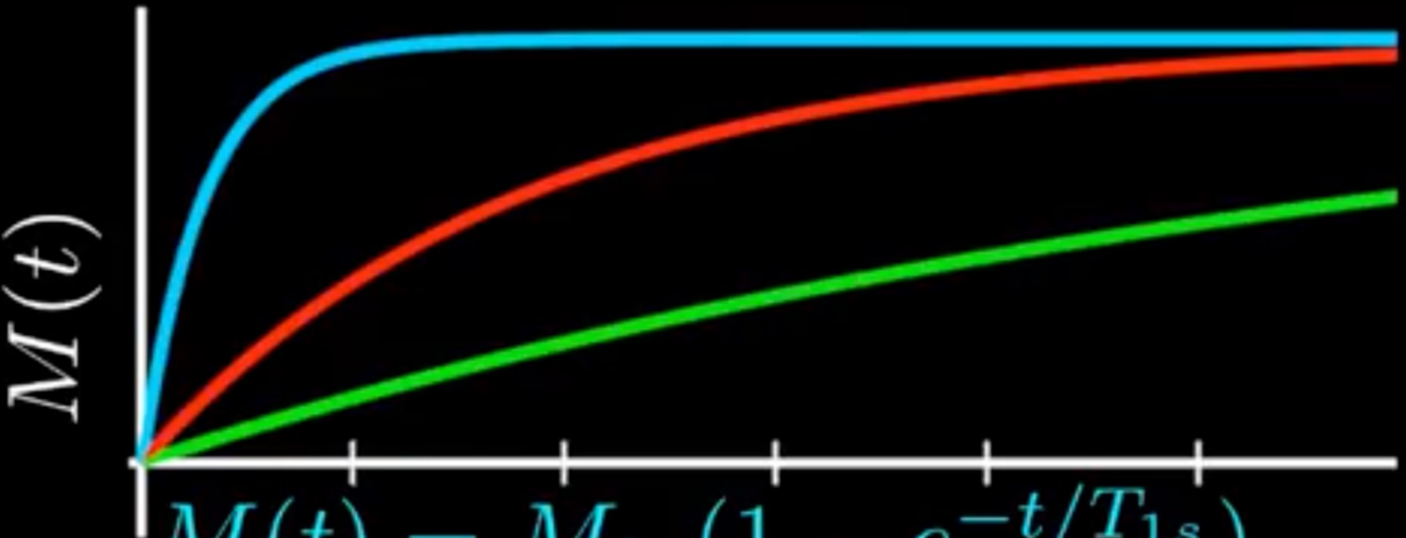




"T_1 Relaxation"



"T_1 Relaxation"



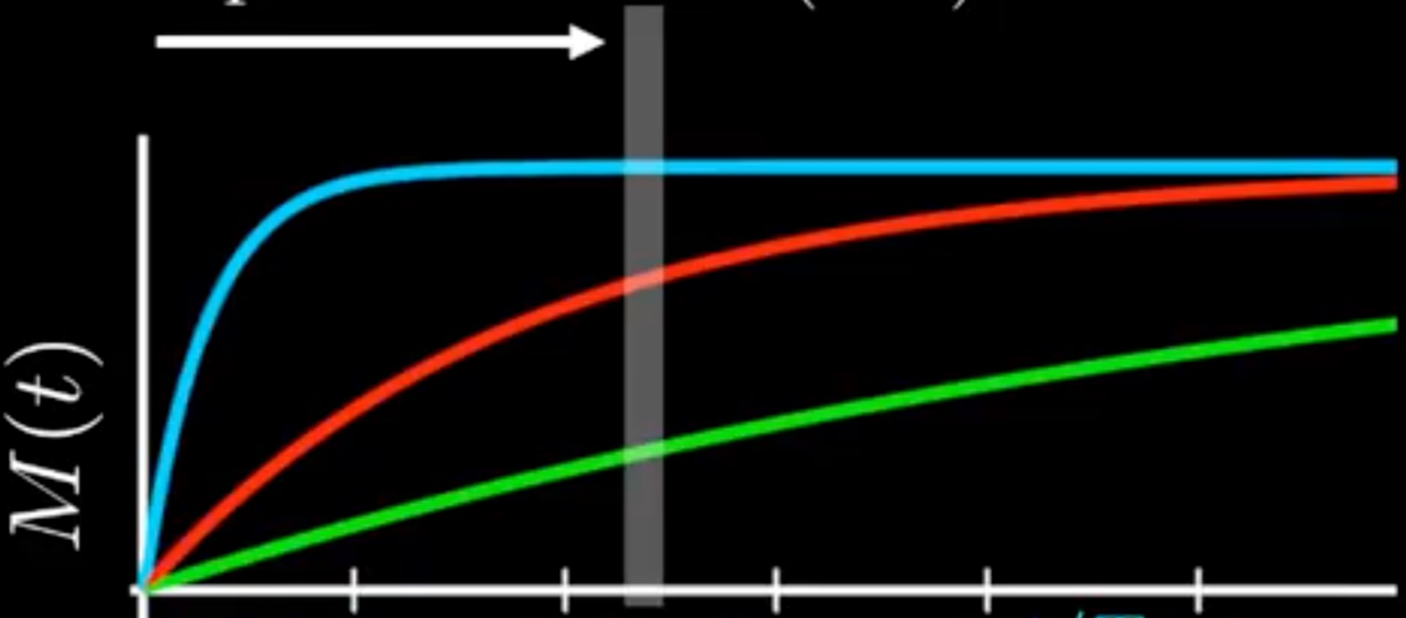
$$M(t) = M_{0s}(1 - e^{-t/T_{1s}})$$

$$M(t) = M_{0m}(1 - e^{-t/T_{1m}})$$

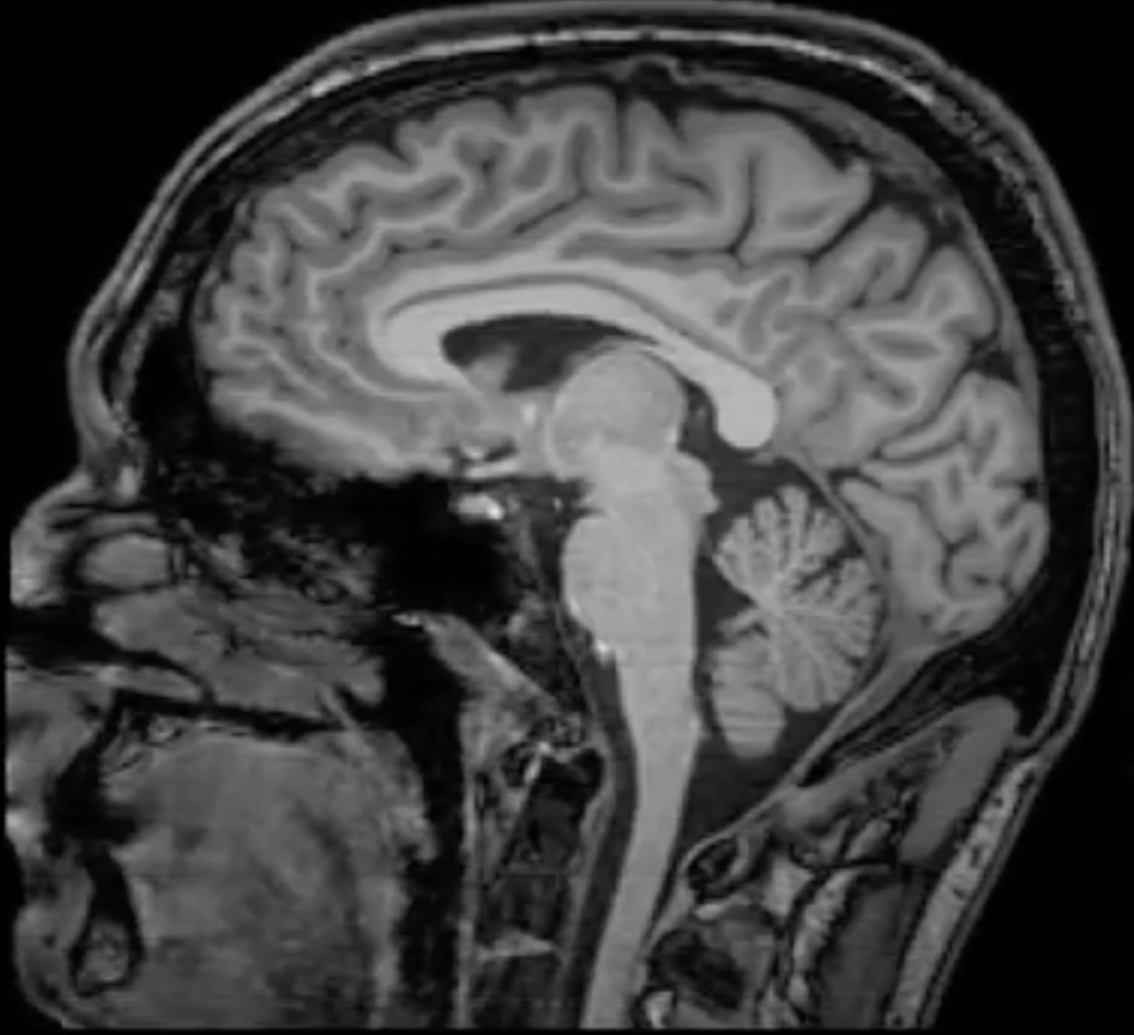
$$M(t) = M_{0l}(1 - e^{-t/T_{1l}})$$

"T_1 Relaxation"

"Repetition Time (TR)"



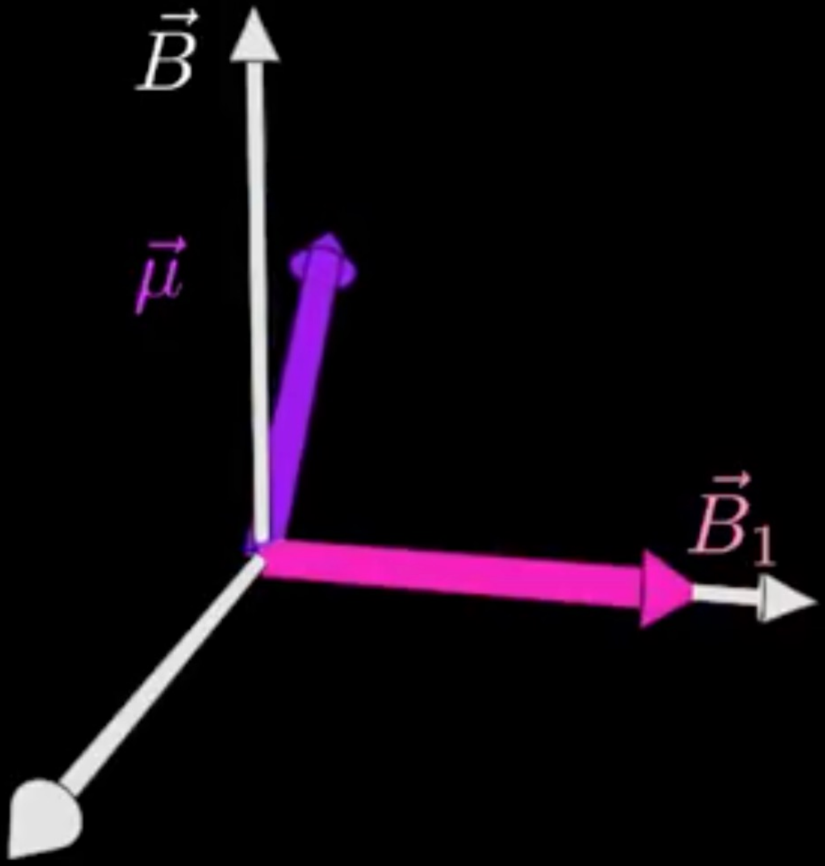
$$M(t) = M_{0s}(1 - e^{-t/T_{1s}})$$
$$M(t) = M_{0m}(1 - e^{-t/T_{1m}})$$
$$M(t) = M_{0l}(1 - e^{-t/T_{1l}})$$



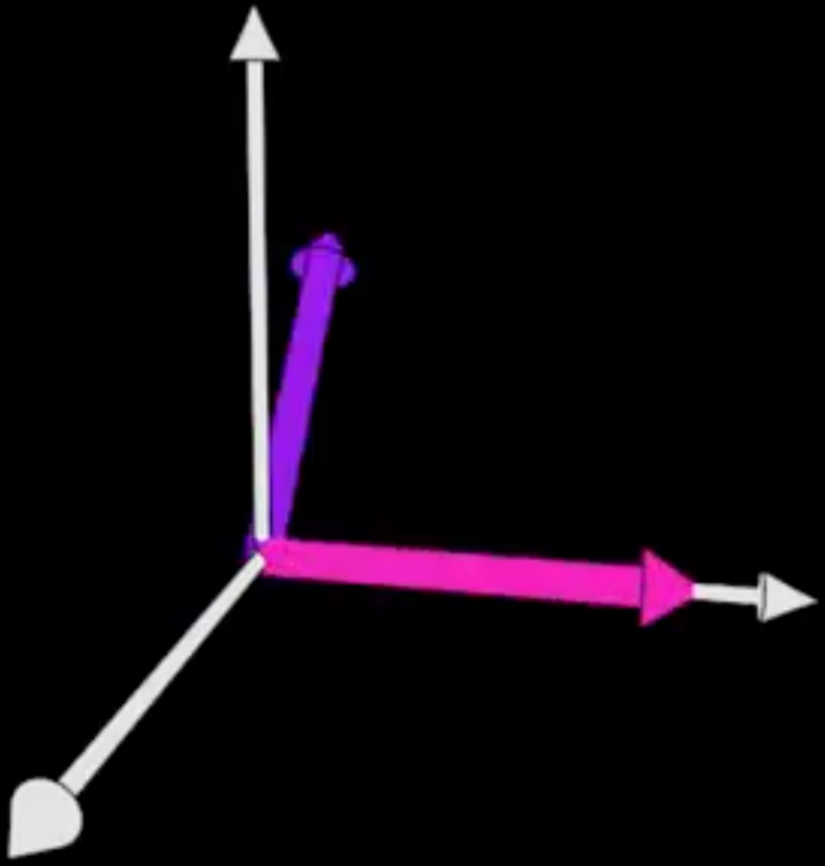
"T_1-Weighted Image"

How excatly do we excite (flip) spins?

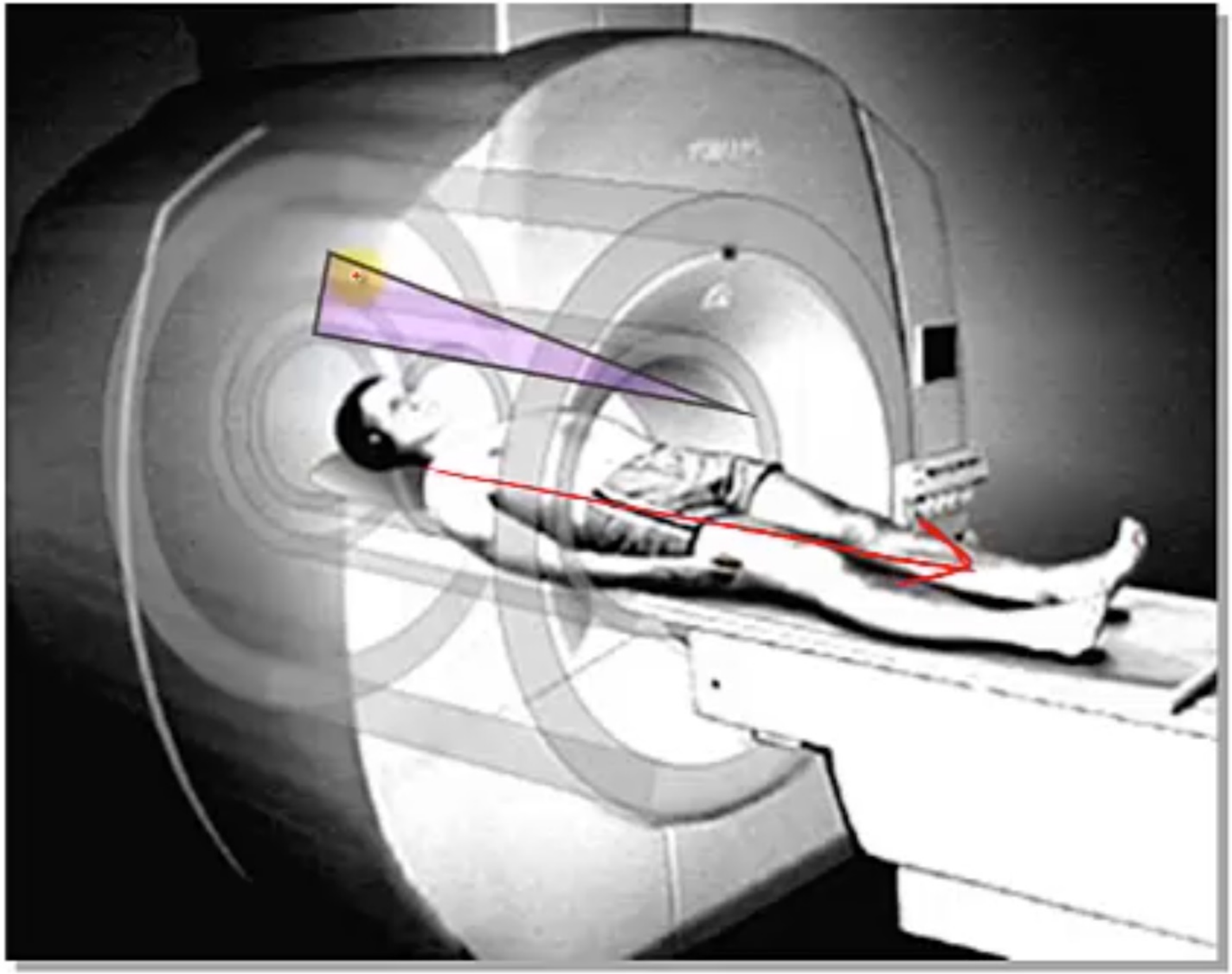
$\rightarrow$ send in radiofrequency pulse, B_1, perpendicular to $\vec{B}_0$ of the same Larmor frequency, ω, as our precessing spin.



Rotating Frame



Lab Frame

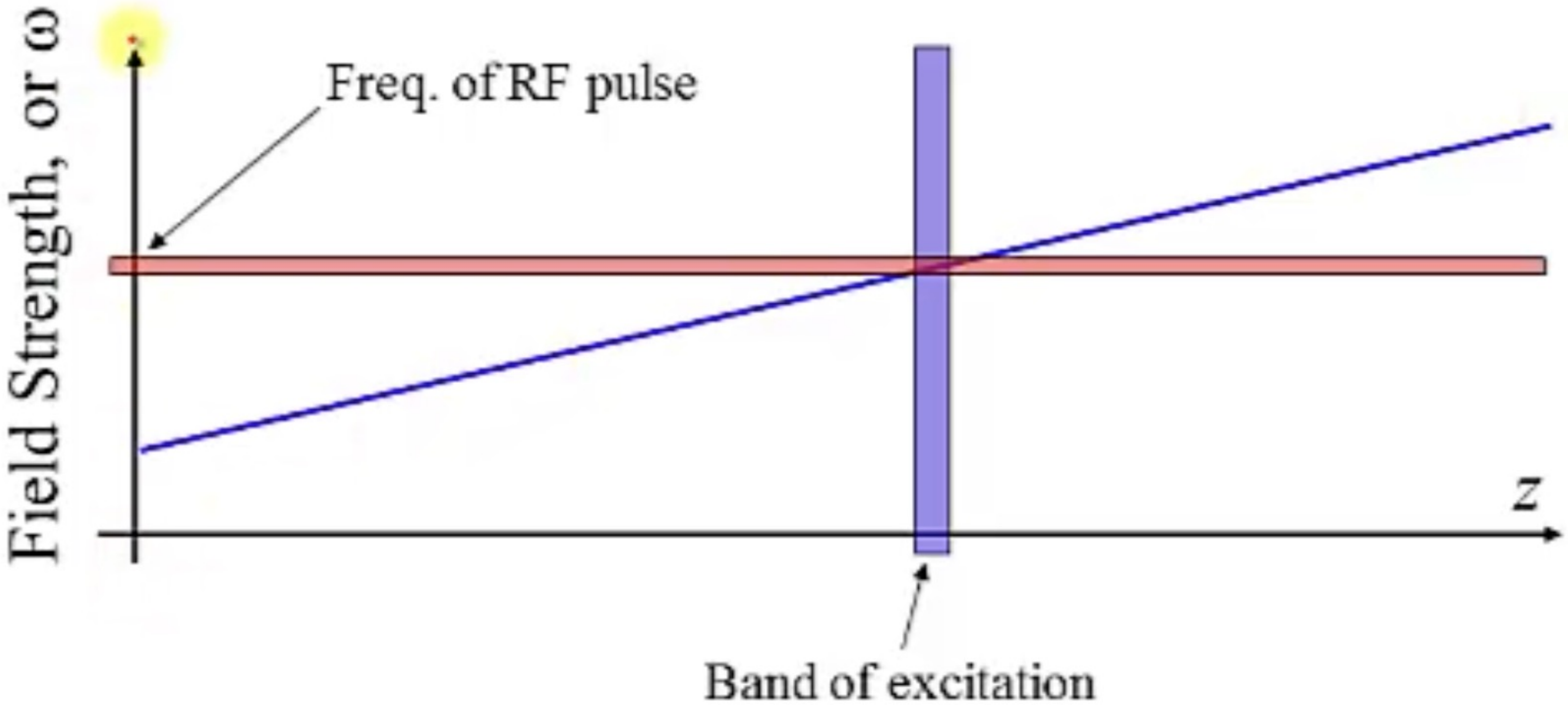


http://nobelprize.org/nobel_prizes/medicine/laureates/2003/press.html

Paul C Lauterbur and Peter Mansfield, Nobel Prize 2003 in Physiology or Medicine

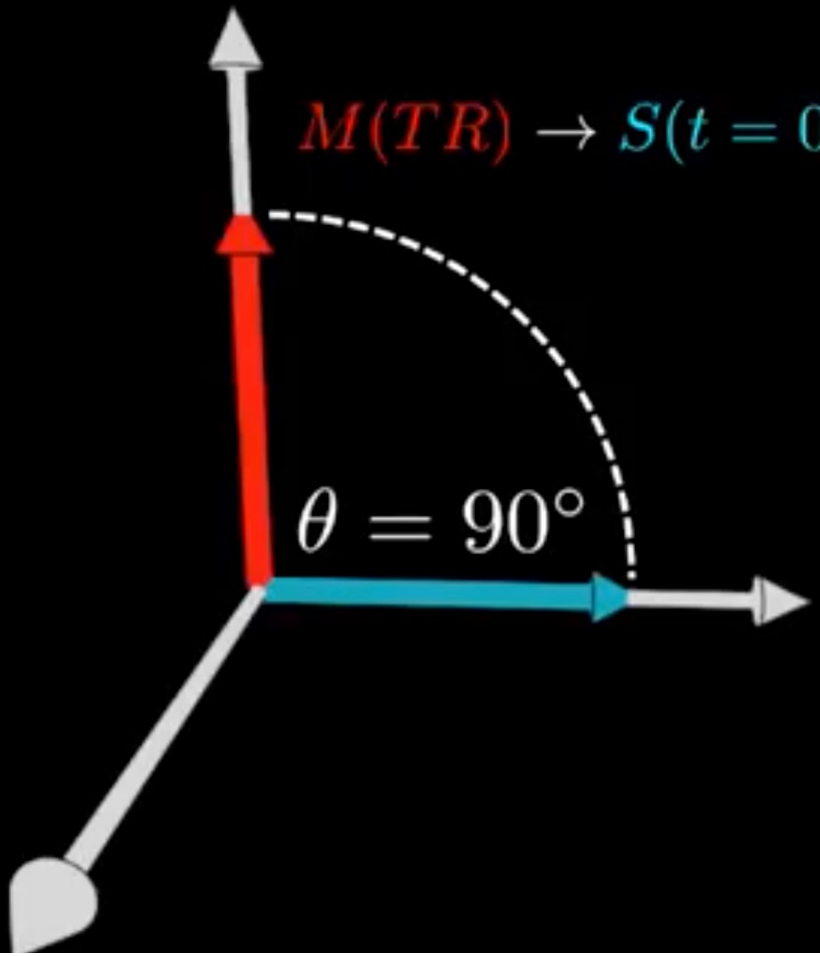
Slice Selection

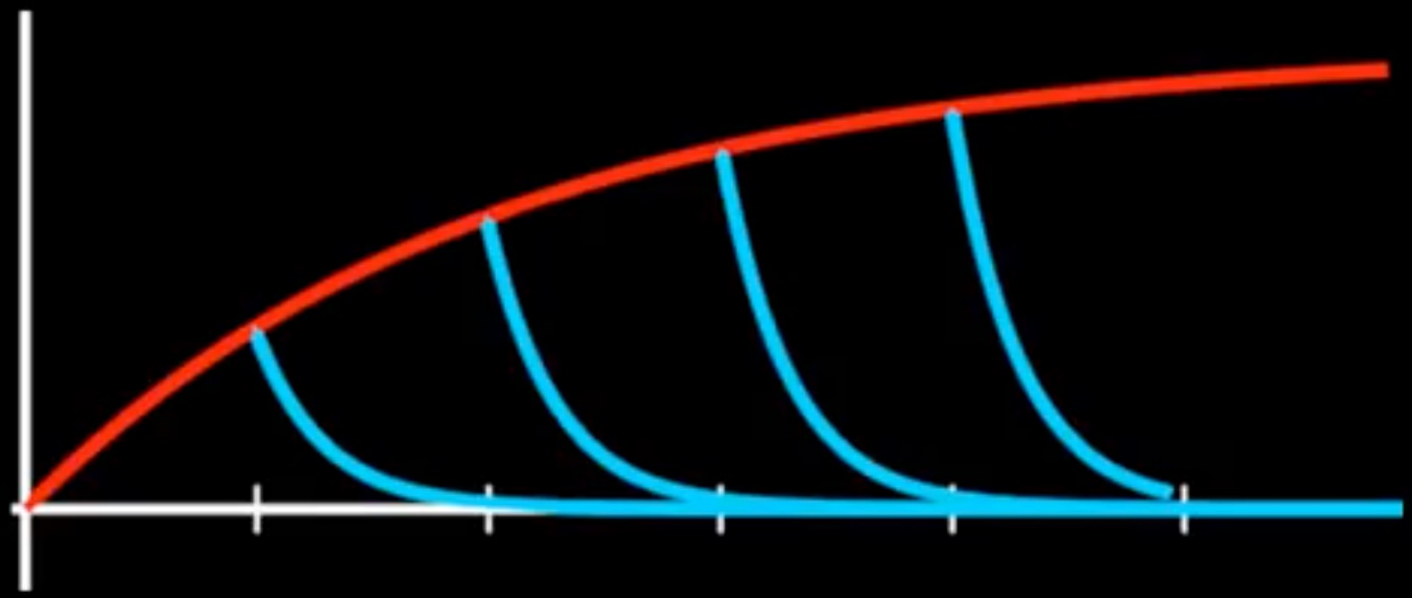
Adding a gradient to the magnetic field causes a gradient in Larmour frequency. The frequency of the RF pulse will only excite a thin band of matter.



$$M(t) = M_0(1 - e^{-\mathrm{TR}/T_1})$$

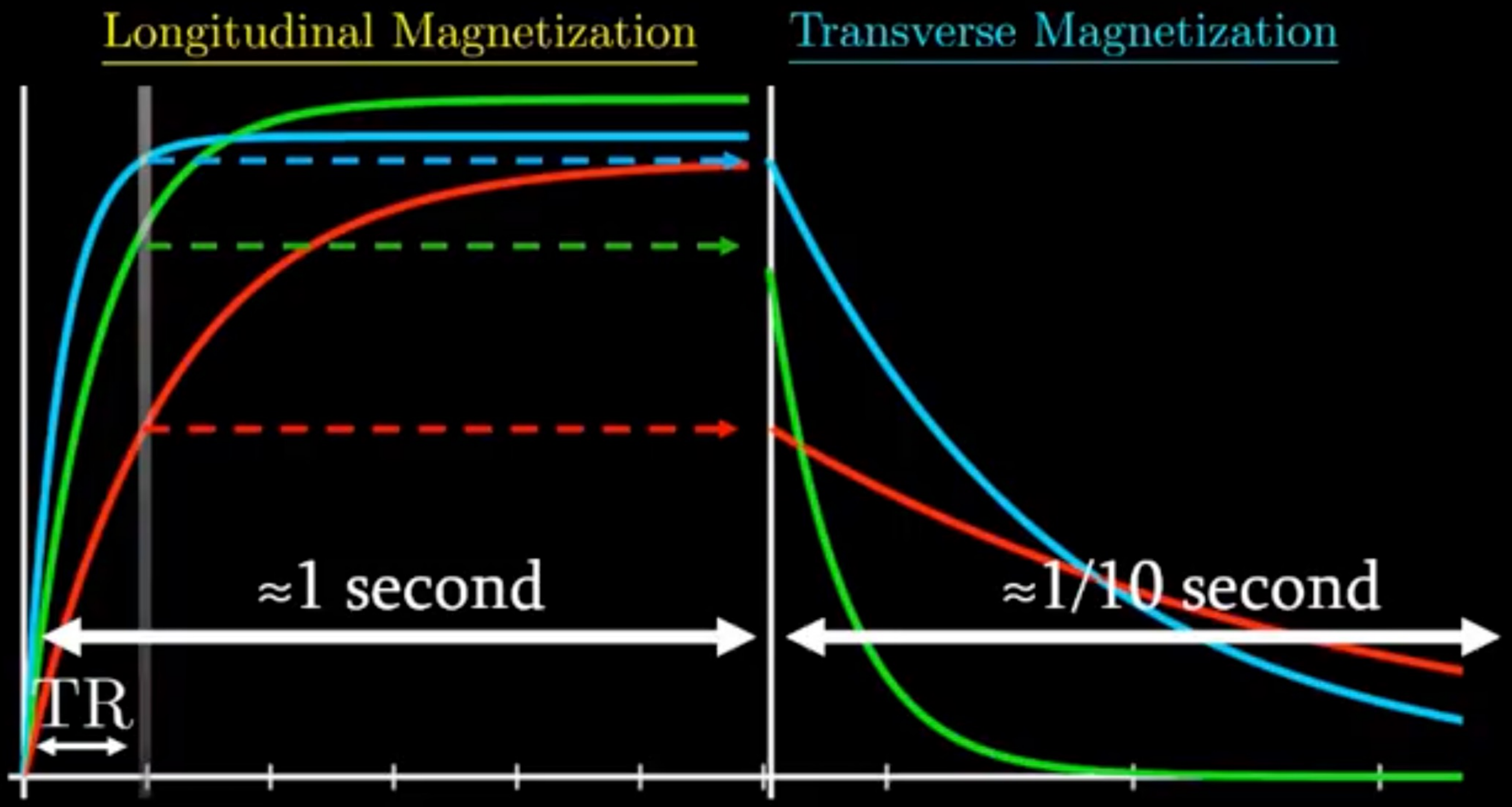
$$\to S(t) = M_0(1 - e^{-\mathrm{TR}/T_1})e^{-t/T_2}$$





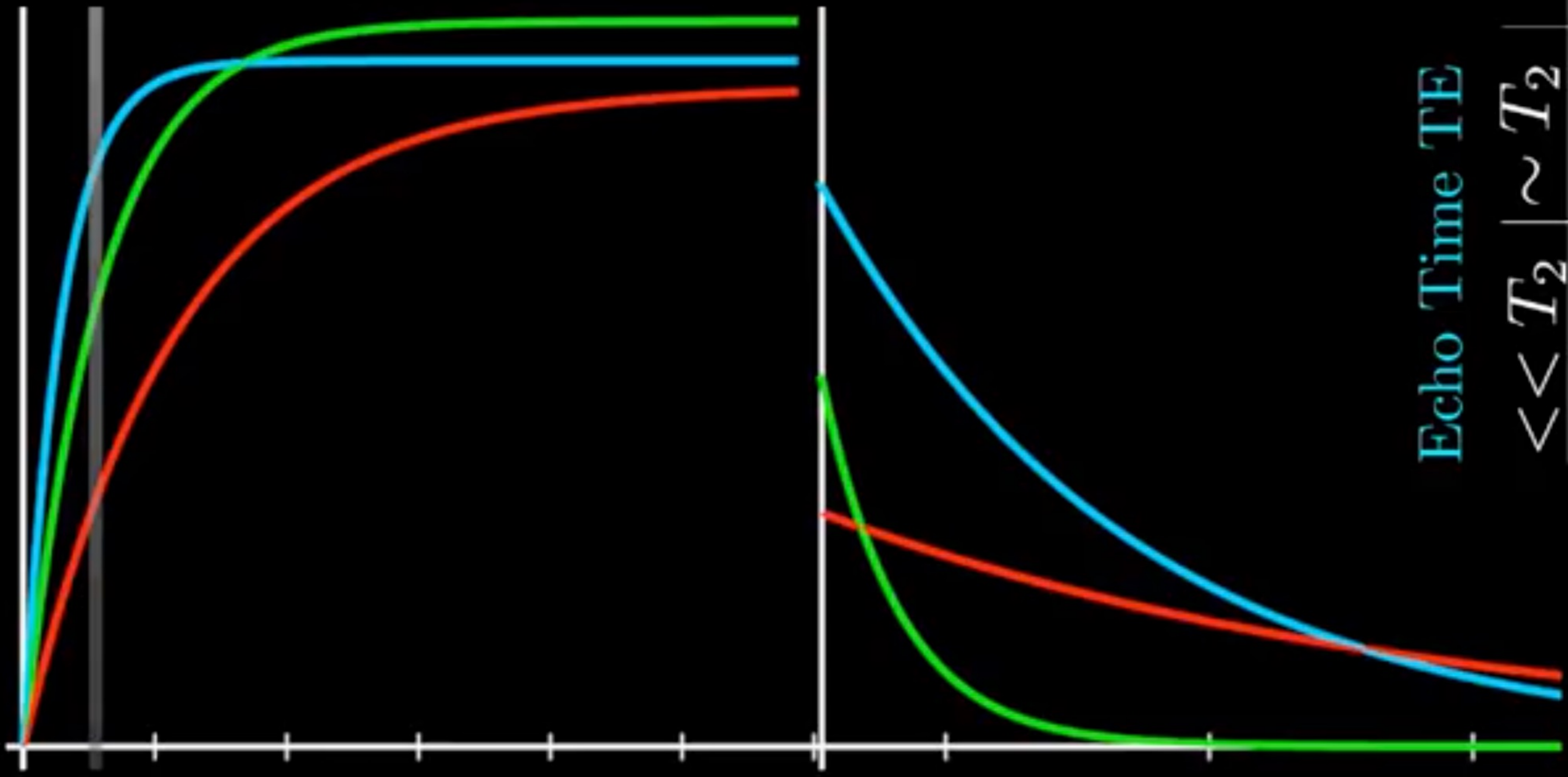
Tissue Signal = amount of T_1 weighting Boltzmann Magnetization (spin density) amount of T_2 weighting

$$S(\mathrm{TR},\mathrm{TE}) = \left(1 - e^{-\mathrm{TR}/T_1}\right) M_0 e^{-\mathrm{TE}/T_2}$$



Tissue Signal = amount of T_1 weighting Boltzmann Magnetization (spin density) amount of T_2 weighting

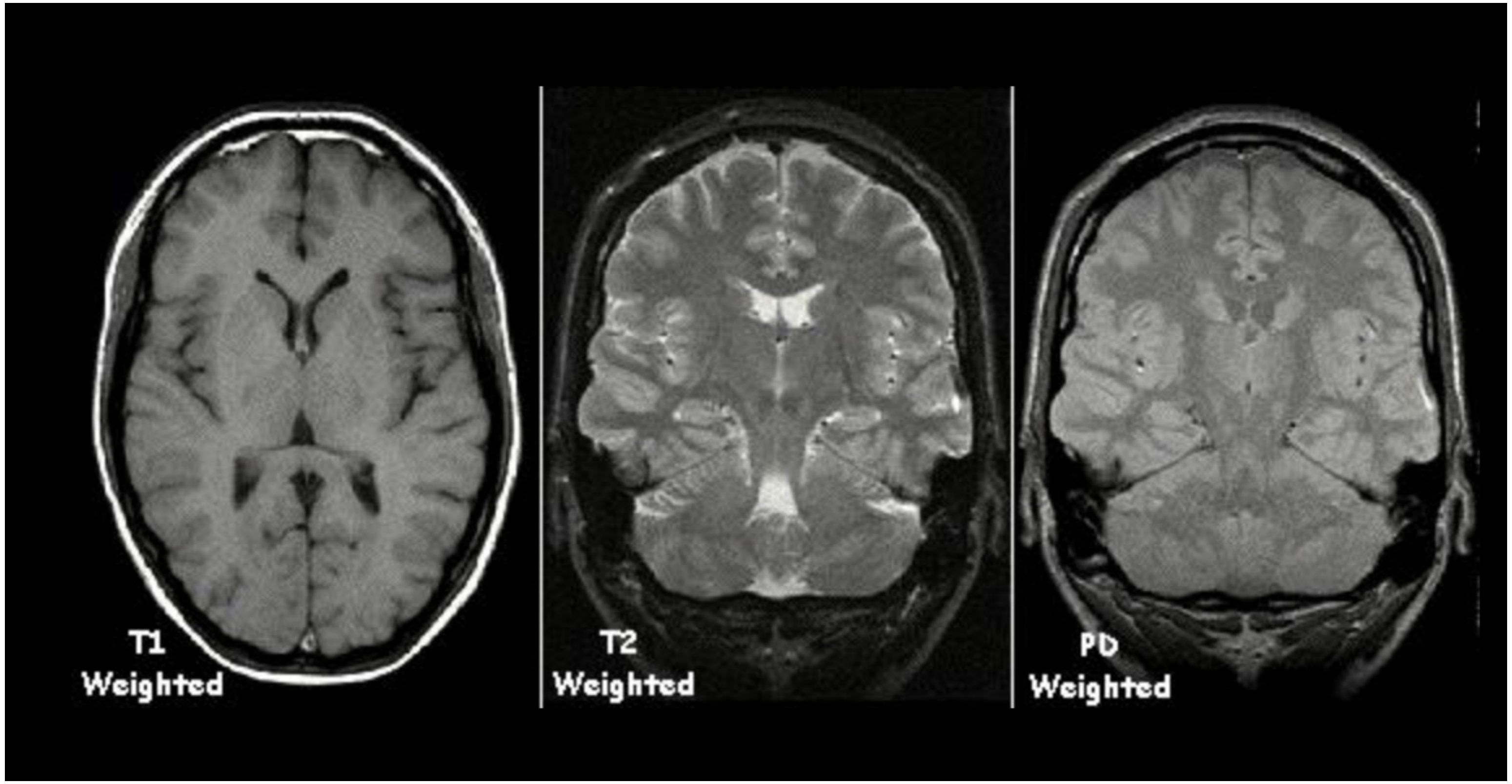
$$S(\mathrm{TR},\mathrm{TE}) = (1 - e^{-\mathrm{TR}/T_1}) M_0 e^{-\mathrm{TE}/T_2}$$



Repetition Time TR

Echo Time TE	$\sim T_1$	$>> T_1$
$\sim T_2$	?	T_2
$<< T_2$	T_1	M_0

Signal	T1-weighted	T2-weighted
High	• Fat[11][12] • Subacute hemorrhage[12] • Melanin[12] • Protein-rich fluid[12] • Slowly flowing blood[12] • Paramagnetic or diamagnetic substances, such as gadolinium, manganese, copper[12] • Cortical pseudolaminar necrosis[12] • Anatomy	• More water content,[11] as in edema, tumor, infarction, inflammation and infection[12] • Extracellularly located methemoglobin in subacute hemorrhage[12] • Fat • Pathology
Inter-mediate	Gray matter darker than white matter[13]	White matter darker than grey matter[13]
Low	• Bone[11] • Urine • CSF • Air[11] • More water content,[11] as in edema, tumor, infarction, inflammation, infection, hyperacute or chronic hemorrhage[12] • Low proton density as in calcification[12]	• Bone[11] • Air[11] • [11] • Low proton density, as in calcification and fibrosis[12] • Paramagnetic material, such as deoxyhemoglobin, intracelullar methemoglobin, iron, ferritin, hemosiderin, melanin[12] • Protein-rich fluid[12]


T1
Weighted
T2
Weighted
PD
Weighted