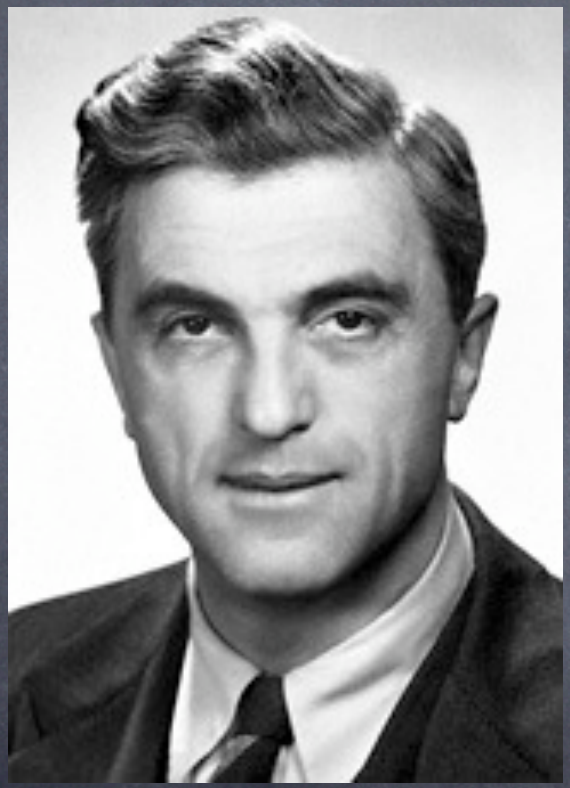
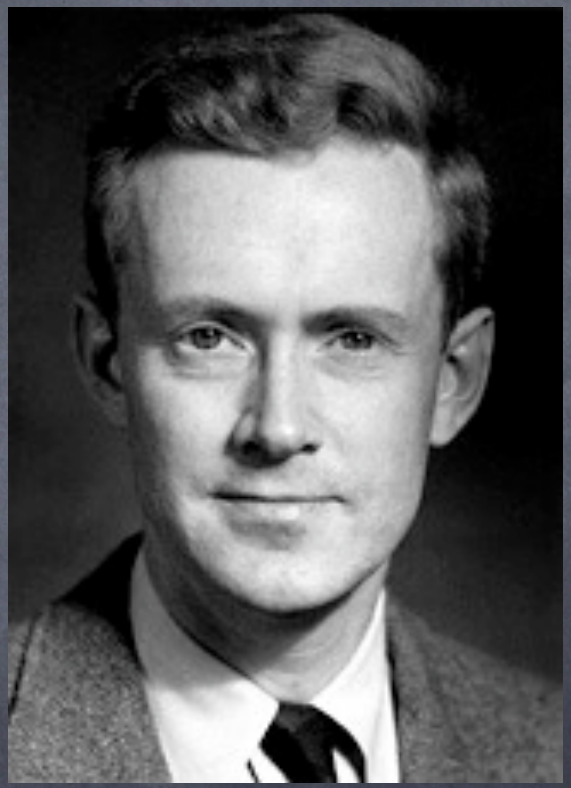
# NMR Nobel Prize 1952





Bloch & Purcell

# NMR Frequencies

| Nuclei | Unpaired Protons | Unpaired Neutrons | Net Spin | $\gamma$ (MHz/T) |
|---|---|---|---|---|
| $^{1}H$ | 1 | 0 | 1/2 | 42.58 |
| $^{2}H$ | 1 | 1 | 1 | 6.54 |
| $^{31}P$ | 1 | 0 | 1/2 | 17.25 |
| $^{23}Na$ | 1 | 2 | 3/2 | 11.27 |
| $^{14}N$ | 1 | 1 | 1 | 3.08 |
| $^{13}C$ | 0 | 1 | 1/2 | 10.71 |
| $^{19}F$ | 1 | 0 | 1/2 | 40.08 |

# Abundance in Humans

| Element | Biological Abundance* |
|---|---|
| Hydrogen (H) | 0.63 |
| Sodium (Na) | 0.00041 |
| Phosphorus (P) | 0.0024 |
| Carbon (C) | 0.094 |
| Oxygen (O) | 0.26 |
| Calcium (Ca) | 0.0022 |
| Nitrogen (N) | 0.015 |

# NMR aka MRI

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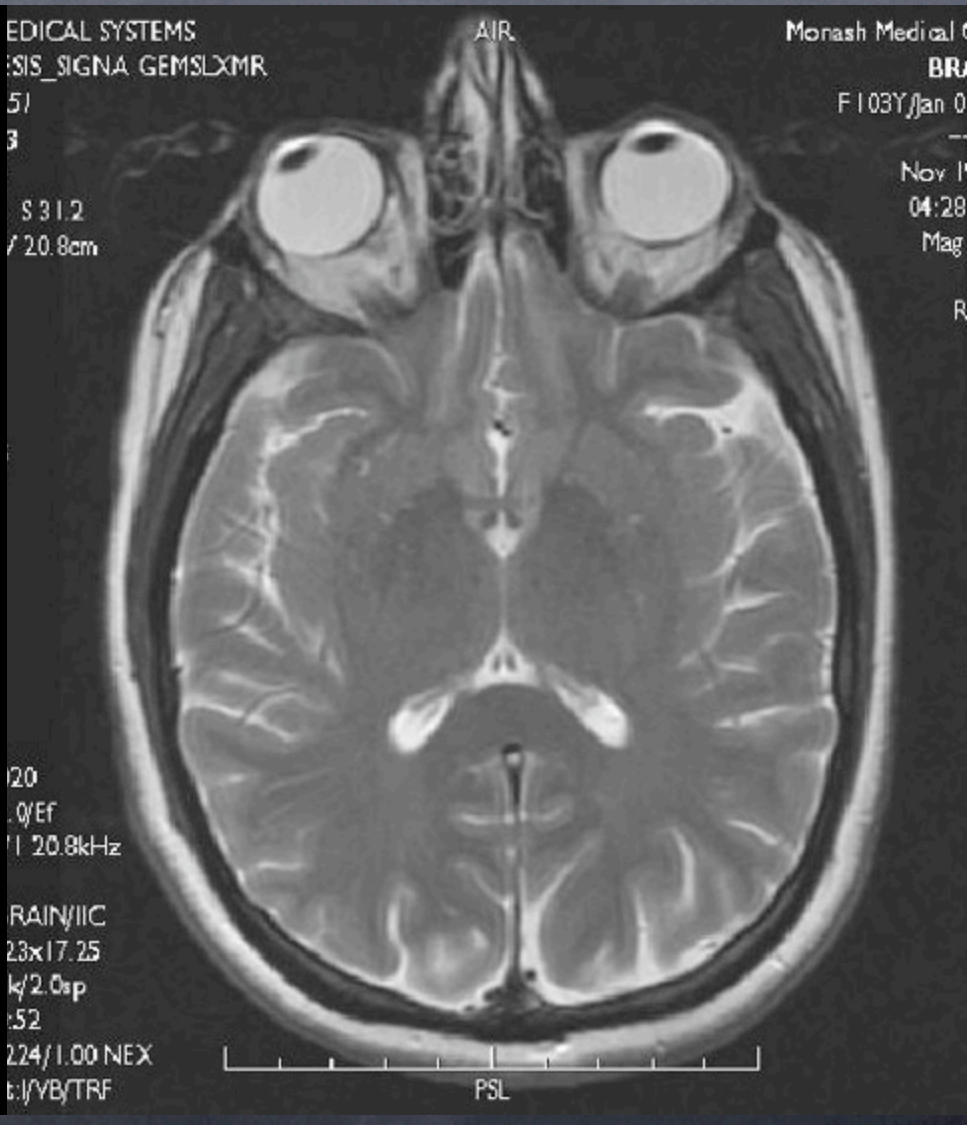

EDICAL SYSTEMS
SIS_SIGNA GEMSLXMR
AIR
Monash Medical
F103Y/Jan 0
S 31.2
20.8cm
Nov
04:28
Mag
20
.0/Ef
20.8kHz
RAIN/IIC
23x17.25
k/2.0sp
:52
224/1.00 NEX
:I/YB/TRF
PSL

# Larmor Precession

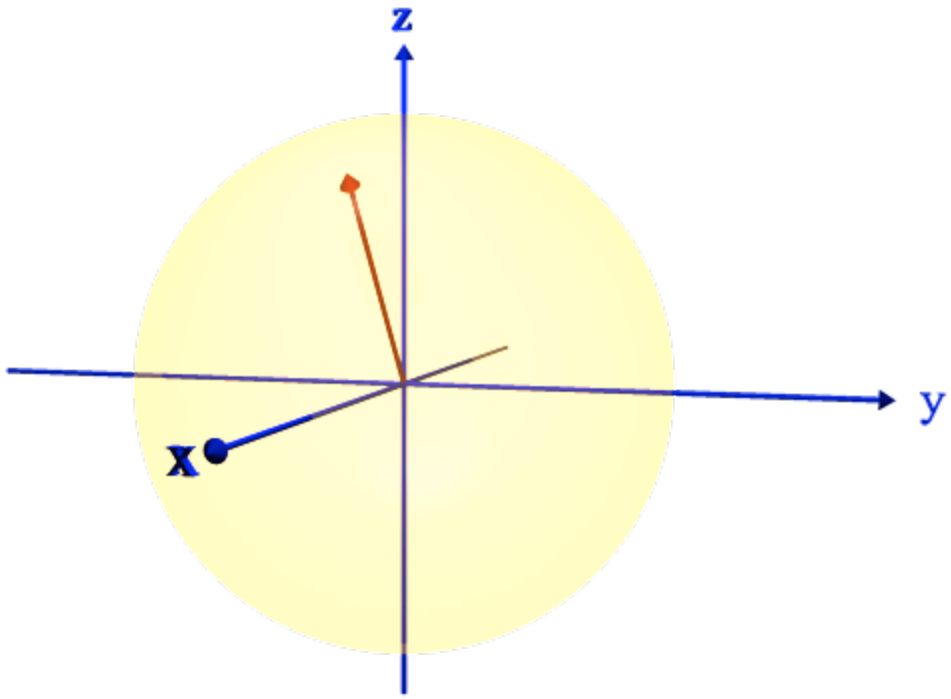
$$|\psi\rangle = \cos(\theta/2)e^{i\omega t/2}|\uparrow\rangle + \sin(\theta/2)e^{-i\omega t/2}|\downarrow\rangle$$

$$\begin{aligned}
\langle\psi|S_x|\psi\rangle &= \frac{\hbar}{2}\sin(\theta)\cos(\omega t) \\
\langle\psi|S_y|\psi\rangle &= \frac{\hbar}{2}\sin(\theta)\sin(\omega t) \\
\langle\psi|S_z|\psi\rangle &= \frac{\hbar}{2}\cos(\theta)
\end{aligned}$$

# Precessing Spin

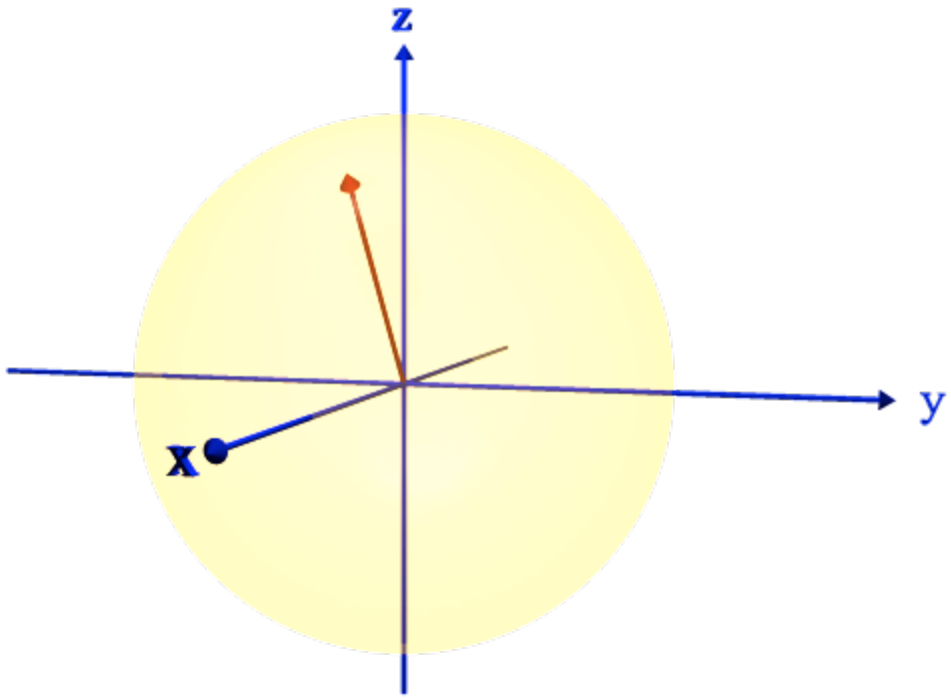
$$|\psi\rangle = \cos(\theta/2)e^{i\omega t/2}|\uparrow\rangle + \sin(\theta/2)e^{-i\omega t/2}|\downarrow\rangle$$

# Precessing Spin




$$|\psi\rangle = \cos(\theta/2)e^{i\omega t/2}|\uparrow\rangle + \sin(\theta/2)e^{-i\omega t/2}|\downarrow\rangle$$

# Precessing Spin




$$|\psi\rangle = \cos(\theta/2)e^{i\omega t/2}|\uparrow\rangle + \sin(\theta/2)e^{-i\omega t/2}|\downarrow\rangle$$

represent any two level system

# Dephasing

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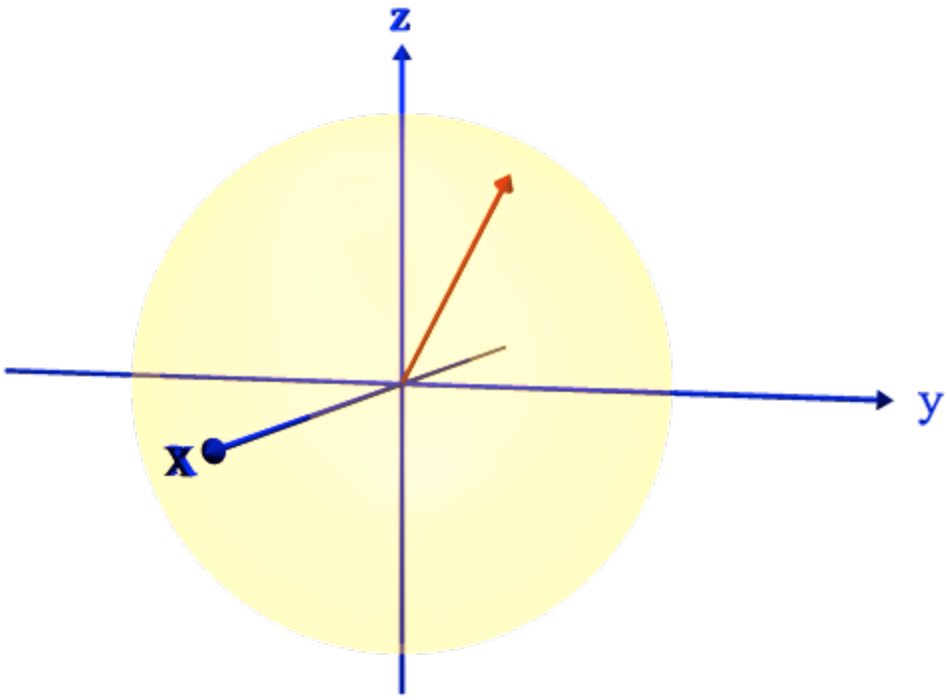
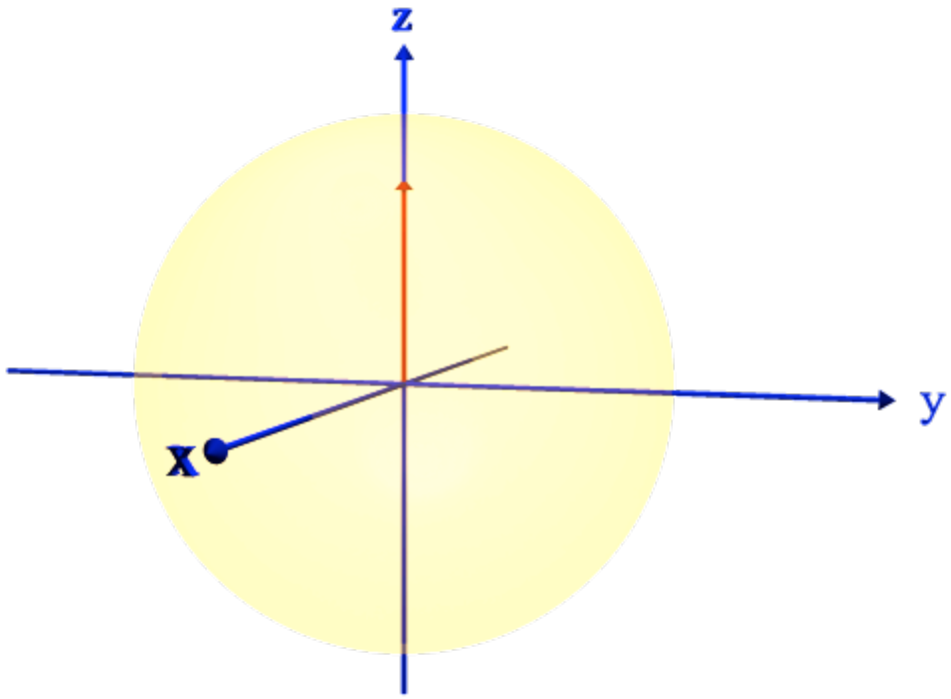


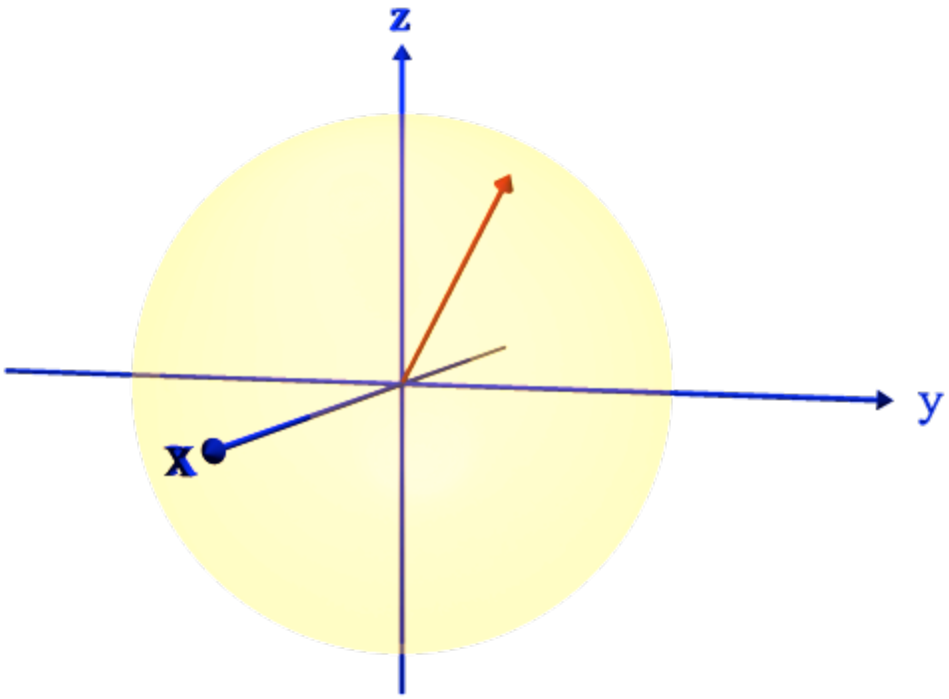
# Dephasing



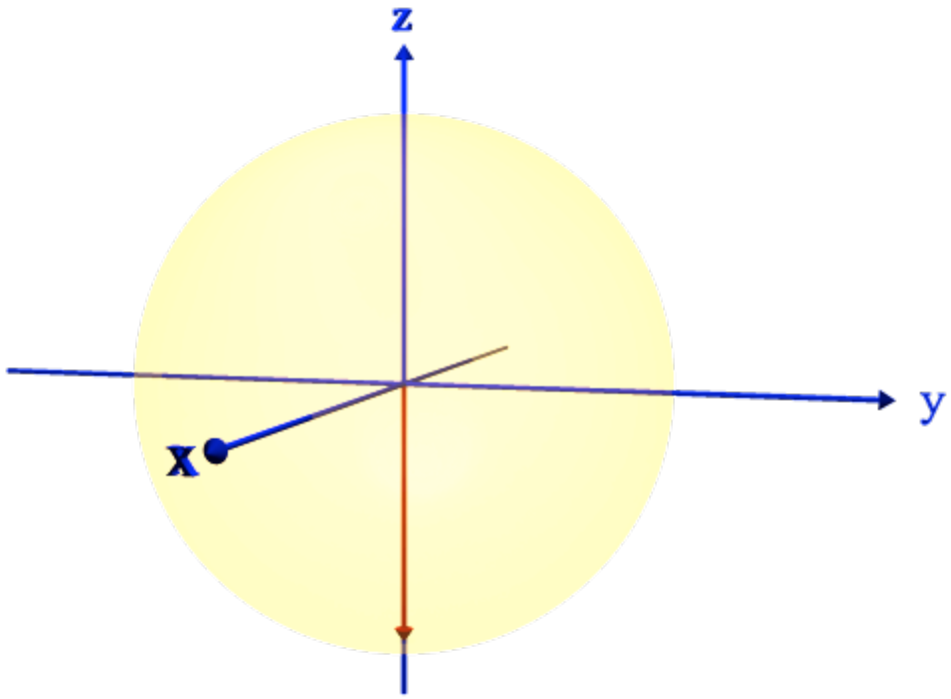

$T_2$

decoherence time

# Population Decay



# Population Decay




$T_1$

# Quantum Computing

$$|\psi_1\rangle = c_0|0\rangle + c_1|1\rangle$$

$$|c_0|^2 + |c_1|^2 = 1$$

$$|\psi_2\rangle = c_{00}|00\rangle + c_{01}|01\rangle + c_{10}|10\rangle + c_{11}|11\rangle$$

$$\begin{aligned}|\psi_3\rangle = c_{000}|000\rangle + c_{001}|001\rangle + c_{010}|010\rangle + c_{100}|100\rangle \\ + c_{011}|011\rangle + c_{101}|101\rangle + c_{110}|110\rangle + c_{111}|111\rangle\end{aligned}$$

$N$ particles $\rightarrow 2^N$ states

# Quantum Computing

examples:

- NMR - specific nuclei in a molecule
  each has different resonant frequency
- Ion traps - hyperfine levels
  each ion has a different location
- Superconductor - Cooper pair controlled by
  voltage across a tunneling junction

# Quantum Computing

Number of operations: $N = \frac{T_2}{T_{\rm op}}$

| | $T_2$ | $T_{\rm op}$ | $N$ |
|---|---|---|---|
| NMR | $10^4$ s | $10^{-3}$ s | $10^7$ |
| Ion Trap | 10 s | $10^{-6}$ s | $10^7$ |
| Cooper Pair | $10^{-8}$ s | $10^{-10}$ s | $10^2$ |