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# Nuclear diagnostics and Magnetic Resonance Imaging

## Week 4; Lecture 9; Determination of $T_1$ and $T_2$

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# Contents

Section 1

# Determination of the spin-lattice relaxation time, $T_1$

# What does it take to make an MRI image

NMR can be used to generate signals that depend on the concentration of $^1$H in tissue; the basis of an imaging technique

The spin-lattice and spin-spin relaxation times, $T_1$ and $T_2$ respectively, depend on tissue type—so can be used to distinguish neighbouring tissues

To generate an image need to:

- Extract $T_1$ and $T_2$; and
- Spatially localise the signal

This lecture: extraction of $T_1$ and $T_2$ using RF pulse sequences
Next lecture: spatial localisation

# Relaxation times revisited

| Tissue Type | T1 (ms) | T2 (ms) |
|---|---|---|
| Adipose tissues | 240-250 | 60-80 |
| Whole blood (deoxygenated) | 1350 | 50 |
| Whole blood (oxygenated) | 1350 | 200 |
| Cerebrospinal fluid (similar to pure water) | 4200 - 4500 | 2100-2300 |
| Gray matter of cerebrum | 920 | 100 |
| White matter of cerebrum | 780 | 90 |
| Liver | 490 | 40 |
| Kidneys | 650 | 60-75 |
| Muscles | 860-900 | 50 |

Relaxation times characteristic of tissue type

For materials important for human imaging $T_1 > T_2$

$T_1$ characteristic of recovery of longitudinal magnetisation

$T_2$ must be extracted from the decay of the transverse magnetisation which is characterised by $T_2^*$ which is related to $T_2$ by:

$$\frac{1}{T_2^*} = \frac{1}{T_2} + \frac{1}{T_2'}$$

# The spin-lattice relaxation time constant, $T_1$

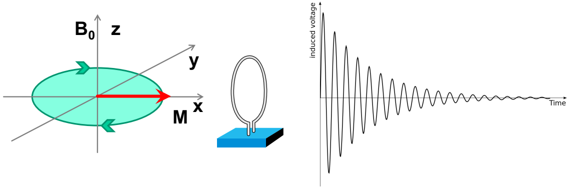
System set up in equilibrium; net magnetisation, $\mathbf{M}_{\rm eqm}$, parallel to $\mathbf{B}_0$ and of magnitude $M_{\rm eqm}$

90° RF magnetic field pulse applied to rotate net magnetisation, $\mathbf{M}_{\rm eqm}$, into $x, y$ plane

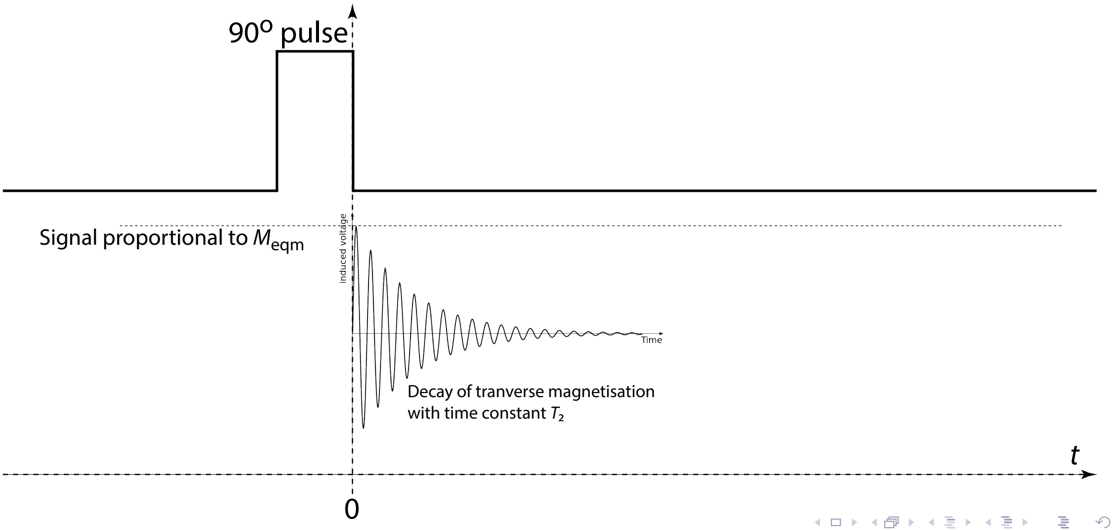
Take $t = 0$ to be time at which 90° degree pulse ends. Magnitude of transverse magnetisation, $M_{xy}$, at $t = 0$:

$$M_{xy}(t = 0) = M_{xy}(0) = M_{\rm eqm}$$

$M_{xy}$ decays exponentially, as described in lecture 8



# The spin-lattice relaxation time constant, $T_1$



# The spin-lattice relaxation time constant, $T_1$

Longitudinal magnetisation recovers according to:

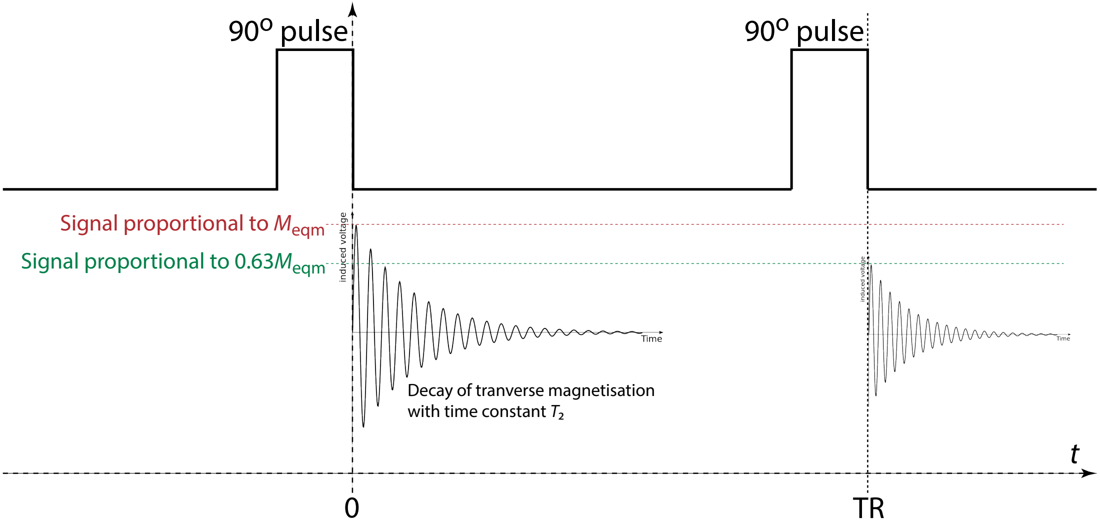
$$M_z(t) = M_{\rm eqm}\left[1 - \exp\left(-\frac{t}{T_1}\right)\right]$$

So, for $t \gtrsim 5T_1$, $M_z - M_{\rm eqm} \lesssim 0.5\%$, i.e. longitudinal magnetisation has recovered

If a second $90^\circ$ pulse is applied for $t < 5T_1$ then the resulting $M_{xy}$ will be less than $M_{\rm eqm}$

For example, if the second $90^\circ$ pulse is applied at $t = T_1$, then $M_{xy}(t = T_1) = 0.63M_{\rm eqm}$

# The spin-lattice relaxation time constant, $T_1$



# The spin-lattice relaxation time constant, $T_1$

Longitudinal magnetisation recovers according to:

$$M_z(t) = M_{\mathrm{eqm}}\left[1 - \exp\left(-\frac{t}{T_1}\right)\right]$$

So, for $t \gtrsim 5T_1$, $M_z - M_{\mathrm{eqm}} \lesssim 0.3\%$, i.e. longitudinal magnetisation has recovered

If a second $90^\circ$ pulse is applied for $t < 5T_1$ then the resulting $M_{xy}$ will be less than $M_{\mathrm{eqm}}$

In general:

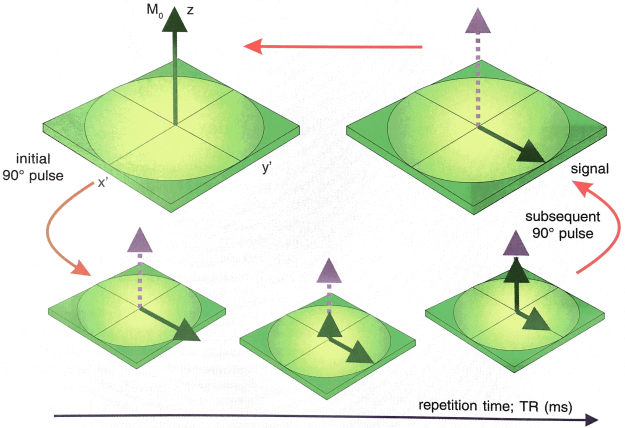
$$M_z(\mathrm{TR}) = M_{\mathrm{eqm}}\left[1 - \exp\left(-\frac{\mathrm{TR}}{T_1}\right)\right]$$

So, repetition of $90^\circ$ pulse at $t = \mathrm{TR}$ gives $M_{xy}(\mathrm{TR}) = M_z(\mathrm{TR})$

Can extract $T_1$ by measuring $M_{xy}(\mathrm{TR})$ as a function of TR

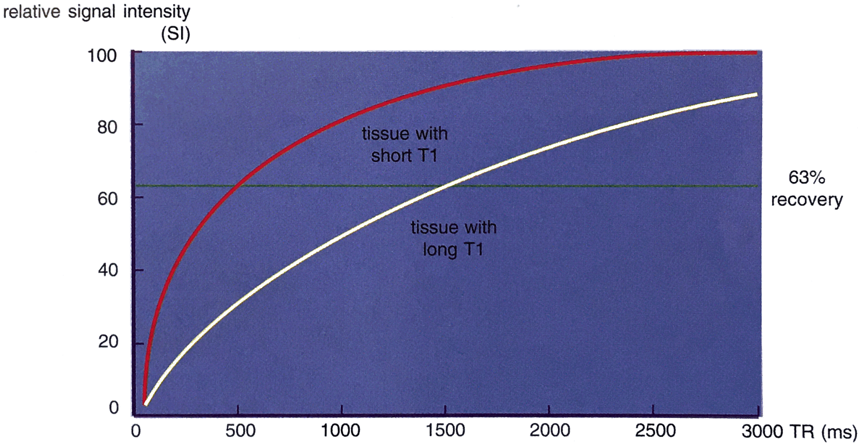
# The spin-lattice relaxation time constant, $T_1$

"**Partial saturation pulse sequence**", graphical representation of evolution of magnetisation

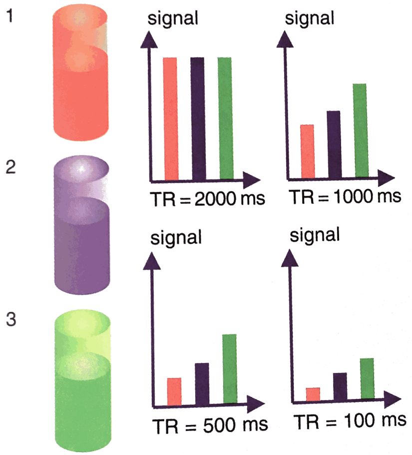


# The spin-lattice relaxation time constant, $T_1$

Comparison of relative signal intensity in partial saturation sequence for two different tissues



# The spin-lattice relaxation time constant, $T_1$



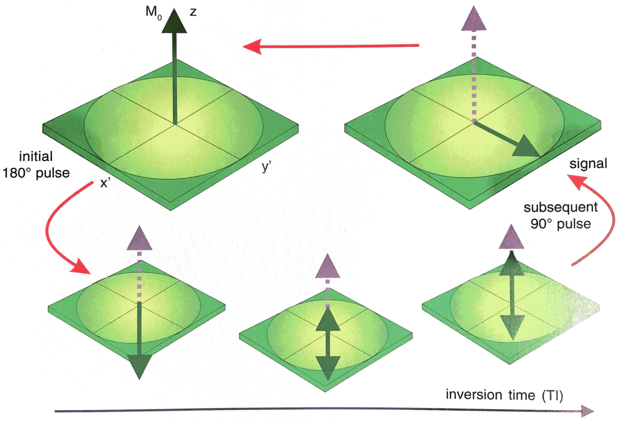

Example three types of tissue:

1. Blood: $T_1 = 1350\,\text{ms}$
2. Muscle: $T_1 = 875\,\text{ms}$
3. Fat: $T_1 = 230\,\text{ms}$

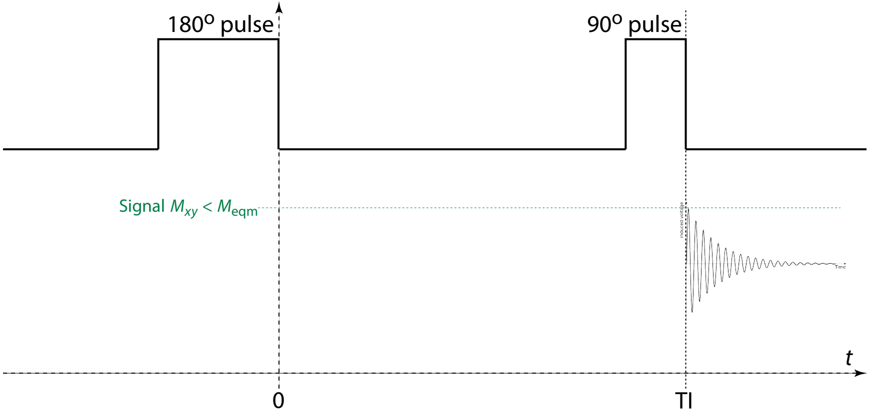
Note how tissues can be distinguished by comparing signal behaviour as a function of TR

# Inversion recovery pulse sequence: $T_1$

"**Inversion recovery pulse sequence**", graphical representation of evolution of magnetisation



# Inversion recovery pulse sequence: $T_1$




$$M_z(\mathrm{TI}) = M_{\mathrm{eqm}}\left[1 - 2\exp\left(-\frac{\mathrm{TI}}{T_1}\right)\right]$$

# Summary of section 1

$T_1$, the longitudinal or spin-lattice, relaxation time constant can be reconstructed using pulse sequences in which the net magnetisation is repeatedly rotated into the $x, y$ plane and the evolution of the maximum of the transverse magnetisation is observed

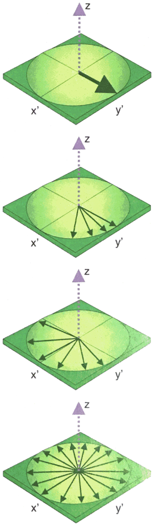
Pulse sequences used to obtain $T_1$:

- $90^\circ$ pulse sequence
- Inversion recovery pulse sequence

Section 2

# Determination of the spin-spin relaxation time, $T_2$

# Spin-spin relaxation time, $T_2$



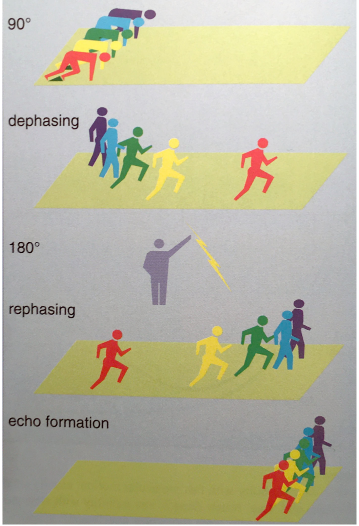

System set up in equilibrium; net magnetisation, $\mathbf{M}_{\mathrm{eqm}}$, parallel to $\mathbf{B}_0$ and of magnitude $M_{\mathrm{eqm}}$

$90^\circ$ RF magnetic field pulse applied to rotate net magnetisation, $\mathbf{M}_{\mathrm{eqm}}$, into $x, y$ plane

Take $t = 0$ to be time at which $90^\circ$ degree pulse ends. At this instant net magnetisation begins to precess around $\mathbf{B}_0$

Rate of precession of individual $^1$H nuclei depends on local magnetic environment: some precess faster, some slower. Results in decoherence, time constant $T_2^*$ (see lecture 8)

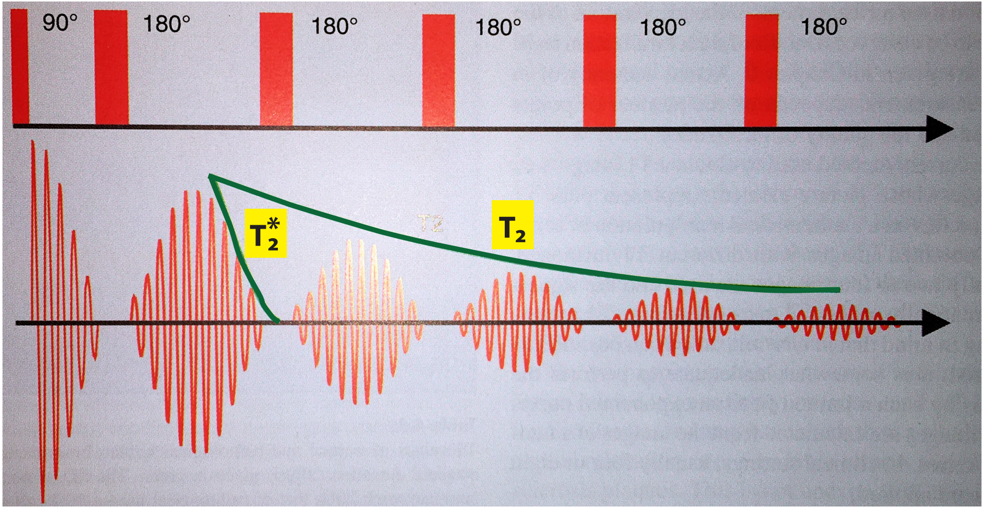
# Spin-spin relaxation time, $T_2$




Before "doing the spins", an analogy:

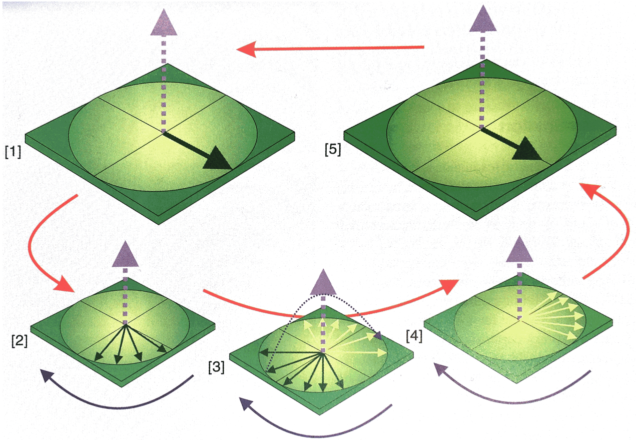
- A set of sprinters have been prepared at the starting line
- The "starting gun" is the end of the 90° pulse
- The sprinters run for a period of time, $t_{\rm run}$
- At $t_{\rm run}$ the sprinters' phase is rotated by 180°:
  The first becomes the last, etc.
- After a further $t_{\rm run}$ all sprinters are back in line
- The line of sprinters at $t = 2t_{\rm run}$ is an "echo" of the situation at $t = 0$

# Spin-spin relaxation time, $T_2$



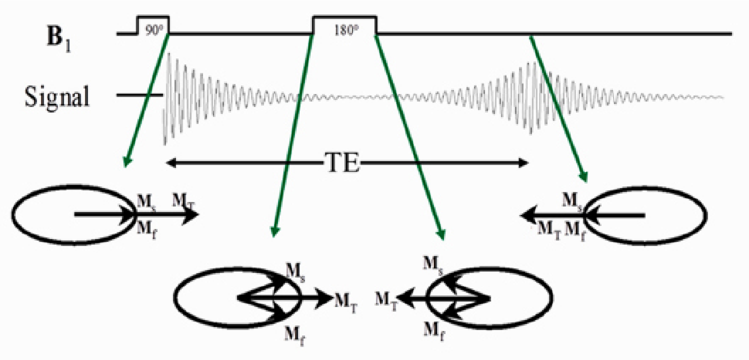
# The spin-spin relaxation time constant, $T_2$

"**Spin echo sequence**", graphical representation of evolution of magnetisation

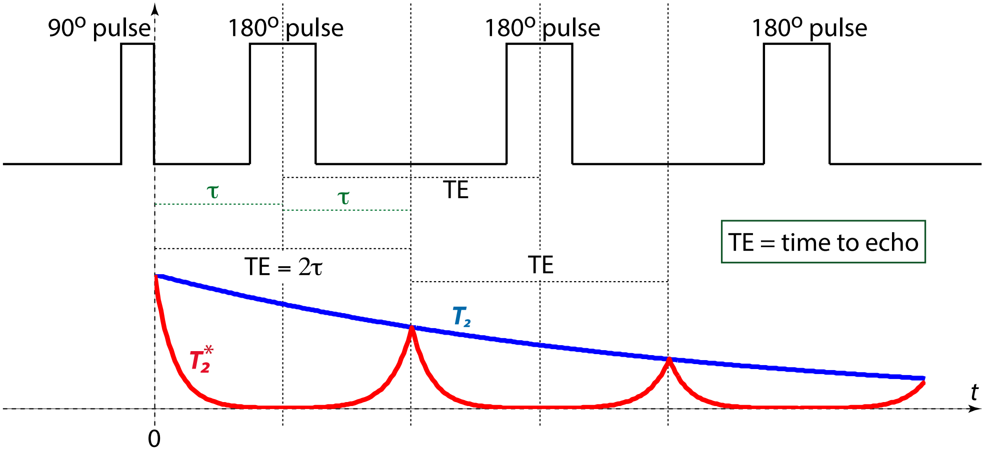


# The spin-spin relaxation time constant, $T_2$

"**Spin echo sequence**", graphical representation of evolution of magnetisation



# Spin-spin relaxation time, $T_2$




$$M_{xy}(\mathrm{TE}) = M_{\mathrm{eqm}} \exp\left(-\frac{\mathrm{TE}}{T_2}\right)$$

# Summary of section 2

$T_2$, the spin-spin, relaxation time constant can be reconstructed using a spin-echo pulse sequence