Physics in Modern Medicine Winter 2023

Chapter 8 – Magnetic Resonance Imaging

Q8.1

Isotope	**Decay product**	**PET**	**MRI**	**Cancer therapy**	**Radioisotope imaging**
Carbon-11 (6 protons/ 5 neutrons)	Positrons	X	X	maybe	
Carbon-12 (6 protons/ 6 neutrons)	Stable (doesn't decay)				
Carbon-13 (6 protons/ 7 neutrons)	Stable (doesn't decay)		X		
Gold-196 (79 protons/ 117 neutrons)	Gamma rays and electrons		X	X	X
Fluorine-19 (9 protons/ 10 neutrons)	Stable (doesn't decay)		X		
Fluorine-18 (9 protons/ 9 neutrons)	Positrons	X	X	maybe	
Cobalt-60 (27 protons/33 neutrons)	Electrons, gamma		X	X	X

Q8.2 Spatial resolution:

MRI	0.5mm (Kane p. 347)
PET	4mm (Kane p. 288)
US	depends on the frequency: ranges from about 0.3mm (5MHz) to 2mm (1MHz)
Radiography	0.1mm (Kane p. 206)
CT	1.0mm (Kane p. 206

Q8.5 MRI is non-ionizing compared to a CT scan. In addition MRI has a long wavelength compared to x-rays. The x-rays are attenuated as they penetrate into tissue/bone and their energy decreases with increasing distance. MRI does not suffer this effect.

P8.1

a. For a $4T$ research MRI scanner, the resonant frequency varies in proportion to the static magnetic field.

$$f = \frac{\gamma}{2\pi} B$$

For hydrogen, the frequency is $42.5MHz$ in a $B = 1T$ magnetic field. Here the field is four times larger, so the frequency is four times larger, or $4 \times 42.5MHz = 170MHz$.

The resonant frequency for phosphorous-31 at $4T$ can be found from the information given in the text. The text states that phosphorous has a resonant frequency of $26.5MHz$ at $1.5T$. At $4T$, $f = \frac{4T}{1.5T} \times 26.5MHz = 70.7MHz$.

b. The photon energies (in eV) corresponding to these frequencies are calculated from:

$\Delta E = hf$

For the proton in a $4T$ field, $f = 170MHz$,

$$\Delta E = 6.63 \times 10^{-34}Js \times 170 \times 10^{6}s^{-1} \times \frac{1eV}{1.6 \times 10^{-19}J} = 7.04 \times 10^{-7}eV$$

For the phosphorous-31 nucleus, we have,

$$\Delta E = 6.63 \times 10^{-34}Js \times 70.7 \times 10^{6}s^{-1} \times \frac{1eV}{1.6 \times 10^{-19}J} = 2.93 \times 10^{-7}eV$$

These energies are many orders of magnitude below the chemical bond energies quoted in Chapter 3 and the x-ray energies given in Chapters 6 and 7, so the RF photons present in MRI will not affect body chemistry.

P8.2

a. The main magnetic field in a $1T$ MRI scanner varies by 0.01% per cm along the slice-selection gradient direction. The slice thickness dx can be calculated from:

$$f = \frac{\gamma}{2\pi}B \rightarrow \frac{df}{dx} = \frac{\gamma}{2\pi}\frac{dB}{dx} \rightarrow \frac{1}{f}\frac{df}{dx} = \frac{1}{B}\frac{dB}{dx} = \frac{0.0001\frac{T}{cm}}{1T} = 0.0001cm^{-1}$$

$$\Delta x = \frac{\Delta f}{0.0001 cm^{-1} f} = \frac{42.5711 MHz - 45.5689 MHz}{0.0001 cm^{-1} \times 42.57 MHz} = 0.52 cm = 5.2 mm$$

The slice thickness will be about $5 mm$.

b. If the static magnetic field of a MRI scanner varies by 15 to 40 parts per million over the standard MRI field of view, the proton Larmor frequency varies according to:

$\Delta f = \frac{15}{1 \times 10^6} \times 42.57 MHz = 0.00064 MHz$ to $\frac{40}{1 \times 10^6} \times 42.57 MHz = 0.0017 MHz$.

P8.6 Following on the reasoning given in the MRI Contrast Example, we can see how to predict the contrast in T1 and T2-weighted images.

a. In T1-weighted images, the signal intensities will be low for long T1 values. Thus, the ranking from low to high relative signal intensity would go: Cerebrospinal fluid, gray matter, muscle, white matter, liver, fat. This assumes that the scans are designed to minimize the effects of variation in T2 values by using very short TE values, for example.

b. For T2-weighted images, long T2 values give high signal intensities, so the high to low relative signal intensities would correspond to: cerebrospinal fluid, gray matter, white matter, fat, muscle, liver. This assumes that the TR values used exceed the longest value of T1 in the problem, in this case that of cerebrospinal fluid.