Introduction

Magnetic resonance imaging (MRI) uses magnetic fields and radio waves to produce an image that is dependent on the distribution of hydrogen in the body. Hydrogen atoms are magnetic due to the intrinsic spin of their nuclei, a property that can be utilised by placing the patient at the centre of a superconducting electromagnet. Under the influence of the strong magnetic field slightly more of the hydrogen nuclei become aligned with the field than against it and the body acquires a net magnetisation. The alignment of the nuclei is then disturbed using radio pulses and as they re-align they produce a radio signal of their own. The signal is very sensitive to the local chemical environment and can be used for high contrast anatomical or functional mapping of organs such as the brain. Another distinguishing feature of MRI, especially when compared to techniques that use ionising radiation such as X-ray or gamma imaging is that extended scans can be carried out without exposing the patient to any additional risk.

Additional guidance:
MRI contains some challenging concepts and is a topic that will stretch high ability students. The slides and notes below concentrate on the principles of signal generation and do not cover, for example, the use of magnetic field gradients for locating the source of the signal. It is strongly recommended that students are also shown chapter 6 of the schools and college lecture on MRI to enhance understanding.

Lesson notes

MRI scans

MRI relies on magnetising the patient by placing them at centre of electromagnet. Human body is weakly magnetic; degree of magnetisation much smaller than that of iron/steel (susceptibility approximately a billion times less).

Detection system: Radio transmitter and coil.

Advantage of MRI: radio waves do not cause ionisation (unlike gamma and X-rays methods).
Magnetic fields

Magnetic fields are created by moving charges.

Current loops:
- field lines point away from a north pole and towards a south pole.
- clockwise current corresponds to a south pole, counter clockwise corresponds to a north pole.

Electromagnets:
- strength is proportional to number of turns and magnitude of current.
- MRI electromagnet cooled (to near absolute zero using liquid helium) in order to remove its electrical resistance and sustain a strong magnetic field.

Hydrogen nucleus:
- MRI relies on the fact that the body contains hydrogen atoms in the form of water (and other organic molecules).
- Hydrogen nuclei behave like miniature electromagnets due to their charge and (intrinsic) spin

For simplicity, direction of magnetic field can be represented by an arrow pointing away from north pole.

Radio waves

A current carrying wire creates a magnetic field.

- CLICK: production of a radio wave by an alternating current

Radio waves are generated using a high frequency alternating current. The magnetic field around a wire carrying alternating current changes direction every half cycle and the resulting electromagnetic disturbance (i.e. radio-wave) is transmitted outwards at speed of light (for simplicity, associated electric field is not shown)

Wavelength is distance between two peaks in the magnetic (or electric) field.

Wave speed = frequency x wavelength.

[Note: MRI systems use transmission coils to produce radio waves rather than the simple dipole shown here]
Magnetising the body

In absence of external magnetic field hydrogen nuclei have random orientation; body’s net magnetisation is negligible.

In the strong external field $B$ (a slight excess of) hydrogen nuclei align with the field and the body acquires a net magnetisation $M$.

In order to construct an image a radio wave is used to disturb $M$. The varying magnetic field of the radio wave transfers energy to the nuclei and makes $M$ “wobble” (precess).

- **CLICK**: analogy: (large number of) hydrogen nuclei in an external magnetic field behave (collectively) like a spinning top/gyroscope in a gravitational field.

Radio wave is switched off once $M$ is precessing at $90^\circ$ to $B$.

Making an image

As $M$ rotates and passes through coil it induces a voltage because “field lines are cut.”

- **CLICK**: signal created by the precession of $M$ similar to that created by a rotating bar magnet

Signal gradually decays as $M$ re-aligns to $B$ and energy imparted by radio waves “leaks” away to surroundings. Signals die away at a rate that is dependent of composition of the tissue so computer can use signal to distinguish between (for example) water and fat.

MRI often used to map brain structure and function.

- **Chapter 6**: launch chapter 7 of schools lecture 2011 on magnetic resonance imaging.

- **Chapter 8**: launch chapter 8 of schools lecture 2011 on functional magnetic resonance imaging.

- **Inside story**: launch interactive; investigate functional MRI of brain.
Worksheet mark-scheme

1. 
   (a) increase number of turns OR change core

   (b) south Pole

   (c) reduce/eliminate resistance

   (d) magnetise the body OR align (hydrogen) atoms/nuclei

2. 
   (a) 60,000,000 Hz/ 60 MHz

   (b) (radio waves do) not cause ionisation/ not cause cancer

   (c) alternating current (in wires/coils)

   (d) rotate magnetisation/knock over M/make M wobble/precess

3. *Explanation to include:*

   rotating magnetic field (of body/due to nuclei)

   changes field through coil/ field lines cut/ induces voltage

TOTAL: 10 Marks