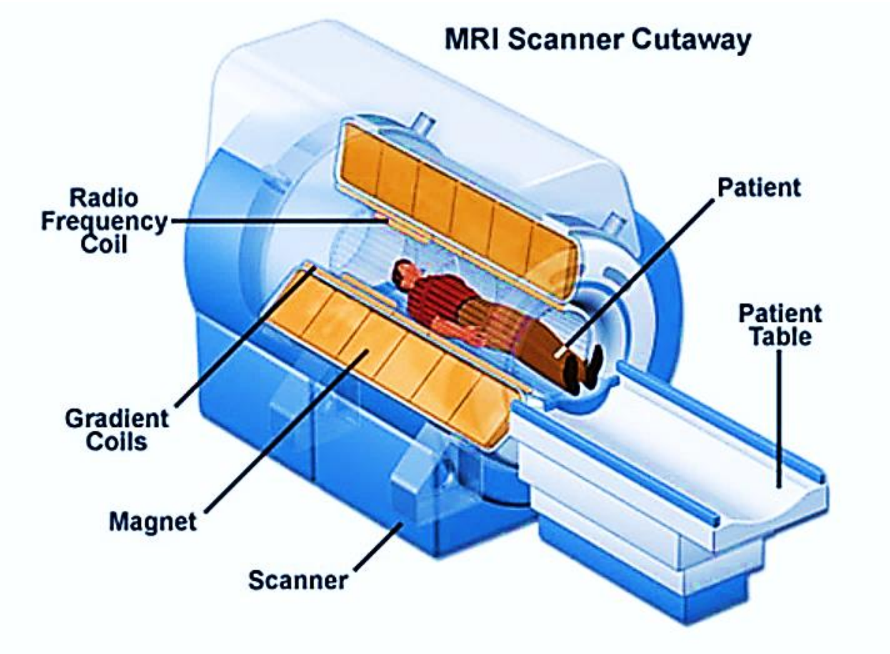
For Examiner's Use

7 Read the passage below and answer the questions that follow.

Magnetic resonance imaging (MRI) is a medical imaging technique used in radiology to form pictures of the anatomy and the physiological processes of the body. MRI is widely used in hospitals and clinics for medical diagnosis, staging and follow-up of disease and provides excellent contrast in images of soft tissues, e.g., in the brain or abdomen. However, it may be perceived as less comfortable by patients, due to the usually longer and louder measurements with the subject in a long, confining tube. Additionally, implants and other non-removable metal in the body can pose a risk and may exclude some patients from undergoing an MRI examination safely.

Fig. 7.1 illustrates the basic design of an MRI scanner. The scanner consists of a main magnet of magnetic flux density 0.50 to 2.0 T, a Radio Frequency (RF) coil, gradient coils, patient table, and a computer system.



Source: https://snc2dmri.weebly.com/components--functions.html

Fig. 7.1

MRI is based on the magnetisation properties of atomic nuclei. A powerful, uniform, external magnetic field is used to align the protons that are normally randomly oriented within the water nuclei of the tissue being examined. This alignment (or magnetisation) is next disrupted by introduction of an external RF energy. The nuclei absorb the RF energy and return to their resting alignment through various relaxation processes and emit RF energy while doing so. After a certain period following the initial RF, the emitted signals are measured. The computer system then converts the signals to create different types of images.

Spin is a fundamental property of nature like electrical charge or mass. It comes in multiples of $\frac{1}{2}$. Protons and neutrons possess spin. Individual unpaired protons and neutrons each possesses a spin of $\frac{1}{2}$ while paired protons and neutrons have no spin. For example, in the deuterium nuclei ${}^{2}_{1}H$, with one unpaired proton and one unpaired neutron, the net spin is 1.

When placed in a magnetic field of magnetic flux density *B*, a particle with a net nuclear spin can absorb a photon of a particular resonance frequency ν. This is related to *B* by the equation

$$\nu = \gamma B$$

where γ is a constant called the gyromagnetic ratio, which is specific to the particle.

This process of absorption of photons by particles is called nuclear magnetic resonance. Fig. 7.2 shows the γ values of some nuclei with a net nuclear spin that are of interest in MRI.

nuclei	γ / MHz T^{-1}
${}^{1}_{1}H$	42.58
${}^{2}_{1}H$	6.54
${}^{31}_{15}P$	17.25
${}^{23}_{11}Na$	11.27

Fig. 7.2

Two factors that influence the strength of the MRI signal are the natural abundance of the isotope and biological abundance. The natural abundance of an isotope is the fraction of the element's nuclei having a given mass number while the biological abundance is the fraction of one element in the human body. Fig. 7.3 lists the natural and biological abundances of some nuclei studied in MRI.

element	nuclei	natural abundance	biological abundance
Hydrogen	${}^{1}_{1}H$	0.99985	0.63
	${}^{2}_{1}H$	0.00015	
Phosphorus	${}^{31}_{15}P$	1.00	0.0024
Sodium	${}^{23}_{11}Na$	1.00	0.00041

Fig. 7.3

Since its development in the 1970s and 1980s, in addition to detailed spatial images, MRI can also be used to form images of non-living objects, such as mummies and capture neuronal tracts and blood flow in the human nervous system.

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(a) To generate the magnetic field, the MRI scanner uses a solenoid-shaped coil made of alloys cooled in liquid helium to a temperature of 10 K to create a superconducting magnet. Fig. 7.4 shows the side view of this coil.

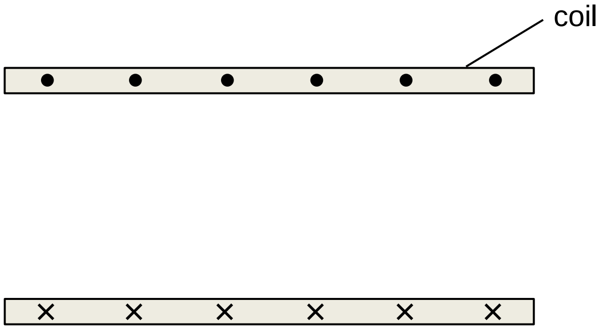

Fig. 7.4

(i) On Fig. 7.4, sketch the magnetic field generated by the coil when current flows in the coil as shown. [2]

(ii) Suggest why the coil is cooled to a temperature of 10 K.

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(b) Suggest why patients with implants and other non-removable metal in the body may not be allowed to undergo an MRI examination.

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(c) **(i)** State and explain the net spin for a Hydrogen ${}^{1}_{1}H$ nuclei.

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.... [2]

[Turn over

For Examiner's Use

(ii) Suggest why a Carbon $^{12}_{6}C$ nuclei cannot undergo nuclear magnetic resonance.

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(d) Determine the energy of the photon that will be absorbed by a Hydrogen $^{1}_{1}H$ nuclei in a magnetic field of magnetic flux density 1.5 T.

energy = ………………….. eV [3]

(e) MRI is considered a safe imaging technique as it uses radiation that is non-ionising. The ionisation energy for a typical organic molecule is 6.0×10^{-19} J.

(i) State one effect of ionising radiation on living tissues and cells.

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(ii) Using appropriate calculations, show that X-rays are ionising.

[2]

For Examiner's Use

(f) **(i)** Explain the significance of the Phosphorous $^{31}_{15}P$ nuclei having a natural abundance value of 1.00.

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(ii) Using the information in Fig. 7.3, explain why the hydrogen $^{1}_{1}H$ nuclei gives the strongest MRI signal among the nuclei listed.

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(iii) Hence, describe how MRI can produce excellent contrast in the images of soft tissues.

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