Let us start with a general overview of MRI . . .

The single steps of an MRI examination can be described quite simply:

1. the patient is placed in a magnet,
2. a radio wave is sent in,
3. the radio wave is turned off,
4. the patient emits a signal, which is received and used for
5. reconstruction of the picture.

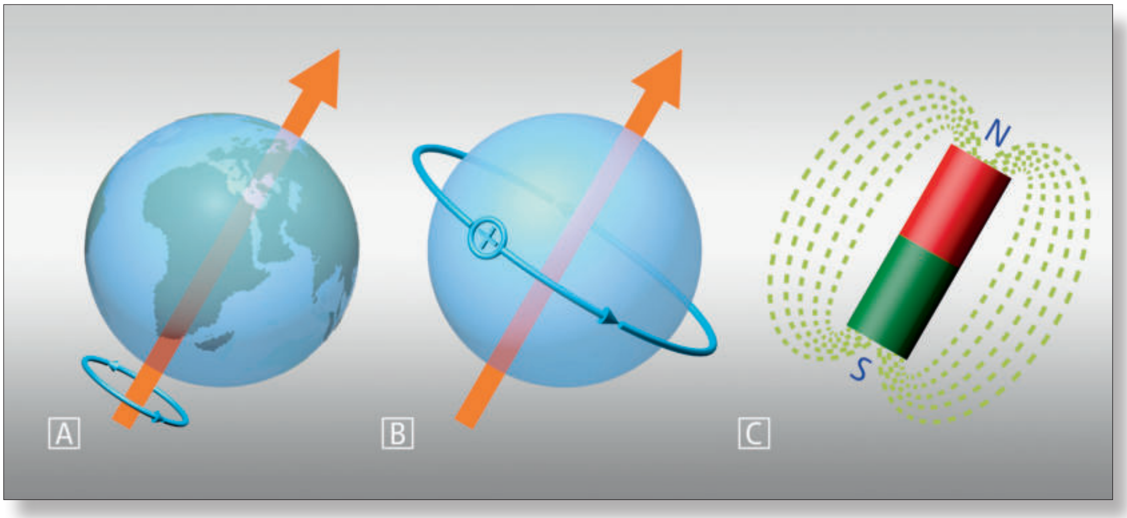

Fig. 1: Protons possess a positive charge. Like the earth, they are constantly turning around an axis and have their own magnetic field.

Let's take a look at these steps in detail

What happens, when we put a patient into the magnet of an MR machine?

To understand this, it is necessary to at least know some very basic physics – even though this may seem to be boring.

As we all know, **atoms** consist of a **nucleus** and a **shell**, which is made up of electrons. In the nucleus – besides other things – there are **protons**, little particles, that have a positive electrical charge (whatever that may actually be). These protons are analogous to little planets. Like the earth, they are constantly turning, or spinning around an axis (figure 1); or – as one says, protons possess a **spin**. The positive electrical charge, being attached to the proton, naturally spins around with it. And what is a moving electrical charge? It is an **electrical current**.

Now, may be you remember from your physics at school that an electrical current induces, causes a **magnetic force**, or **magnetic field**. So, where there is an electrical current, there is also a magnetic field.

This can be demonstrated very easily. Take a rusty nail and approach an electrical outlet – closer, closer. Do you feel it being repelled by the magnetic force, so you do not put the nail into the outlet?

Let's review what we have read

A proton has a spin, and thus the electrical charge of the proton also moves. A moving electrical charge is an electrical current, and this is accompanied by a magnetic field. Thus, the proton has its own magnetic field and can be seen as a little **bar magnet** (figure 1C).

What happens to the protons, when we put them into an external magnetic field?

The protons – being little magnets – align themselves in the external magnetic field like a compass needle in the magnetic field of the earth. However, there is an important difference. For the compass needle there is only one way to align itself with the magnetic field, for the protons, however, there are two (figure 2):

The protons may align with their South and North Poles in the direction of the external field, parallel to it. Or they may point in the completely opposite direction, anti-parallel. These types of alignment are on different energy levels. To explain this: a man can align himself parallel to the magnetic field of the earth, i.e. walk on his feet, or he can align himself anti-parallel, in the opposite direction. Both states are on different energy levels, i.e. they need different amounts of energy.

Walking on one's feet is undoubtedly less exhausting, takes less energy than walking on one's hands. (In the figures, this will be illustrated as pointing up or down, see figure 2).

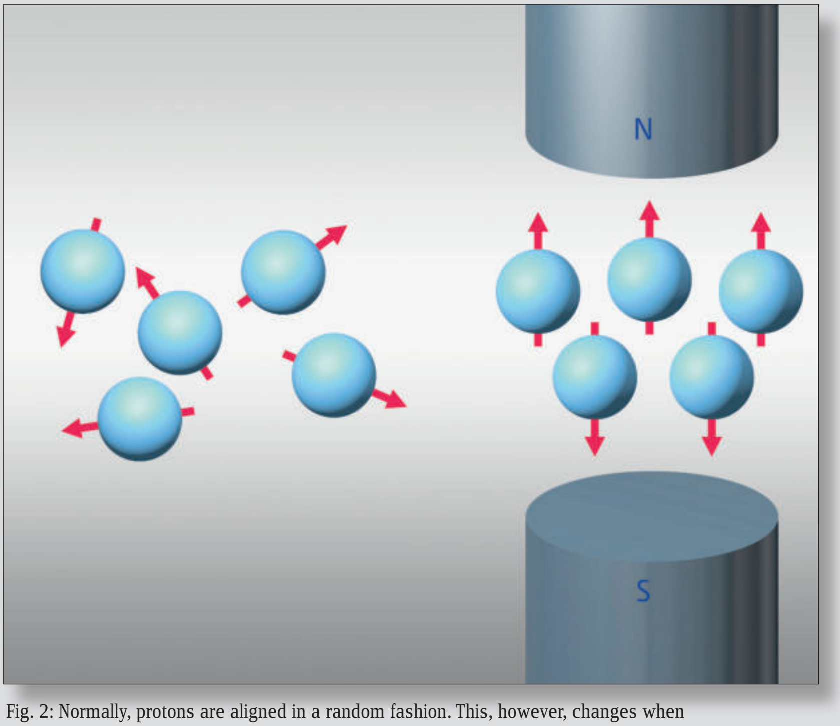

Fig. 2: Normally, protons are aligned in a random fashion. This, however, changes when they are exposed to a strong external magnetic field. Then they are aligned in only two ways, either **parallel** or **anti-parallel** to the external magnetic field.

Fig. 3: When there are two possible states of alignment, the one that takes less energy, is on a lower energy level, is preferred.

Naturally, the preferred state of alignment is the one that needs less energy. So more protons are on the lower energy level, parallel to the external magnetic field, walking on their feet, so to speak. A smaller number is on the higher energy level, anti-parallel, “walking on their hands”.

The difference in number is, however, very small and depends on the strength of the applied magnetic field. To get a rough idea: for about 10 million protons “walking on their hands”, there are about 10,000,007 “walking on their feet”. The difference “007” is probably easy to remember, isn’t it?

It may be obvious at this point already that for MRI the **mobile protons** are important (which are a subset of all protons that are in the body).

The movement of protons – precess

Let us take a closer look at these protons

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What type of movement is “precession”?

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Fig. 4: A spinning top which is hit, performs a wobbling type of motion. Protons in a strong magnetic field also show this type of motion, which is called precession.

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Introducing the coordinate system

Time to take a break

Fig. 5: Using a coordinate system makes the description of proton motion in the magnetic field easier, and we can also stop drawing the external magnet.

Fig. 6: The five protons, which “point” down, cancel out the magnetic effects of the same number of protons, which “point” up (A). So in effect it is sufficient to look only at the four unopposed protons (B).

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Fig. 7: The magnetic force of proton A, illustrated as an arrow, a vector, can be seen as resulting from two components: one pointing up along the z-axis, and one in direction of the y-axis. The component along the y-axis is cancelled out by proton A', the magnetic force of which also has a component along the y-axis, but in the opposite direction. The same holds true for other protons, e.g. B and B', which cancel their respective magnetic vectors along the x-axis. In contrast to the magnetic vectors in the x-y-plane, which cancel each other out, the vectors along the z-axis point in the same direction, and thus add up to a new magnetic sum vector pointing up.

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Fig. 8: In a strong external magnetic field, a new magnetic vector is induced in the patient, who becomes a magnet himself. This new magnetic vector is aligned with the external magnetic field.

Fig. 9: Magnetization along an external magnetic field cannot be measured. To achieve this, a magnetization transverse to the external magnetic field is necessary.