If a core of soft iron is placed inside a coil, the core increases the magnetic field to thousands of times the strength of the field of the coil alone, due to the magnetic permeability $\mu$ of the ferromagnetic material.

**Deficiencies:**

The explanation suggests that the magnetization, and thus the magnetic flux density of the iron increases with the permeability $\mu$. The magnet, so it may seem, has a field that is the stronger, the greater $\mu$ is, which is not correct. In order to get an electromagnet from coil, it is sufficient that $\mu$ is great compared to 1. It makes almost no difference whether $\mu$ is equal to 1000, 10 000 or 100 000.

**Origin:**

The electromagnet can easily and directly be explained by using Maxwell’s equation

$$\oint \mathbf{H} \cdot d\mathbf{r} = \int (\mathbf{j} + \mathbf{D}) \cdot d\mathbf{A}$$

which makes a statement about the magnetic field intensity $\mathbf{H}$.

Unfortunately, it has become customary to describe magnetic fields mainly by the vector quantity $\mathbf{B}$. Sometimes, this restriction is justified by an argument, that should have no place in physics. It is said that $\mathbf{B}$ is the magnetic field. Sometimes it is said that $\mathbf{B}$ is the fundamental field quantity, whereas $\mathbf{H}$ is a derived quantity. Here a mistake is made, that we normally do not forgive to our students: A physical quantity is confused with a physical system. Neither $\mathbf{H}$ nor $\mathbf{B}$ is the field. They cannot be the field, since they are physical quantities, i.e. mathematical objects, invented by man, whereas the field is a physical system, that exists even if no intelligent being is there to observe or to describe it.

The description of the role of the iron core in an electromagnet gets much easier when using $\mathbf{H}$ instead of $\mathbf{B}$.

First, it is easier to define what we understand by a soft-magnetic material: Inside such a material $\mathbf{H} = 0$ A/m, whatever the field strength outside of the material is. (This property gets lost when the material gets into saturation. Then the material is not soft-magnetic anymore.) Second, using $\mathbf{H}$ we can define a quantity that does not change its value when the iron core is inserted into the coil, i.e. an invariant: The line integral along a curve that loops once around the wires of the coil. If on a fraction of the curve, i.e. inside the iron core, the magnetic field strength is made equal to zero, the contribution to the integral on the remaining part of the curve must increase correspondingly.

The explanation by means of $\mathbf{B}$ is more complicated and less convincing: It is more difficult to characterize a soft-magnetic material, and there is no invariant when introducing the magnetic core into the solenoid.
Disposal:

When dealing with the magnetism of matter, use $H$, not $B$. When considering $H$ as a measure for what we understand by "much field" or "few field", the fact that $H$ is zero inside the magnetic core can be formulated as follows: Soft-magnetic materials do not allow the magnetic field to penetrate, just like an electric conductor doesn’t allow the electric field to penetrate into it. So it is not difficult to understand the role of the iron core of an electromagnet: Introducing the iron core, while letting the electric current constant, the field is squeezed out of the coil.

Friedrich Herrmann, Karlsruhe Institute of Technology