Magnets and superconductors

The phenomenon of magnetism
Which one of us has not played at attracting small pieces of iron with a magnet? A magnet is a material that can attract iron and other metals, like cobalt and nickel. The magnetic properties of some minerals were known since ancient times. In fact the term magnet probably derives from Greek μαγνήτης λίθος (magnètes lithos), i.e. "Magnesian stone" from the name of an area in Asia Minor where there are large deposits of magnetite.

For the first modern study on magnetism, we must wait till the 17th century, when the British physicist William Gilbert published a book with the explanatory title, De Magnete, in 1600. Furthermore, Gilbert was the first to provide a scientific explanation to why the magnetic needles in compasses pointed in the same direction, and indicated that the Earth was the large magnet that could orient the needles. In fact, the Earth has an intense magnetic field which is also responsible for the suggestive phenomenon of the Polar lights or Auroras.

Aurora borealis or Northern lights, above the Bear Lake in Alaska. Credits: Wikimedia Commons

Like a magnet, the Earth has two magnetic poles, near to the geographic North Pole and near the South Pole. When a magnetic needle can move freely, it will always point in the North-South direction. Furthermore it can be shown directly that it is impossible to separate the magnetic poles of a needle or of a magnet. If you try to cut a magnet into two parts, you will simply obtain two smaller magnets, each one having a south magnetic pole and a north magnetic pole.

Illustration of magnetic dipoles. Isolated magnetic poles do not exist. Credits: www.openfisica.com
In fact, magnets are defined magnetic dipoles. As in the case of electric charges, opposite magnetic poles attract, similar poles repel.

Unlike the force of gravity that is an exclusively attractive force, magnetic forces repel or attract, and their intensity decreases proportionally to the square of the distance from the poles (inverse proportionality).

**The magnetic field**

They say that magnets produce a magnetic field. But what is it? The scientific definition of magnetic field involves a number of concepts of Physics, however we can view a magnetic field by simply positioning a magnet on iron filings. A few moments later, we will observe that the iron filings are arranged so as to create a precise configuration that simply illustrates the lines in a magnetic field. The trend of the lines of the field depends on the shape of the magnet.

![Magnetic field produced by a bar magnet. Credits: Wikimedia Commons](image)

**Applications of magnets: Magnetic levitation train**

Magnets are utilized in various instruments, among which credit cards and cash cards, VHS cassettes, floppy disks, hard disks and, among the most interesting uses, we surely include the magnetic levitation train.

Is it possible to propel a train at high speeds using only magnetic attraction and repulsion? The answer is yes! This is the case of magnetic levitation trains, also called Maglev, which travel suspended on railway tracks without ever touching them. And since the train is suspended in the air and never touches the railway tracks, it does not disperse energy because it is not subjected to the effect of friction on the tracks. Obviously there is an air resistance, which however, is also present in the conventional trains. The lesser amount of friction enables the trains to reach very high speeds, up to 581 km/h, with minor energy consumption and noise pollution.

In Shanghai, the Maglev Transrapid train connects the city and the airport, which is 30 km away, in only 7 minutes and 20 seconds, and travels at a speed of 200 km/h, and can reach a peak speed of 501.5 km/h.
These speeds can compete with air transportation. And in Japan, recently, the Japan Railway Comp. completed the speed tests on the new SCMaglev trains, based on superconducting magnetic levitation technology.

The train was driven up to the speed of 505 km/h on a short distance (approximately 42 km) of the Tokyo-Nagoya train line. The aim is to travel from Tokyo to Osaka, on a distance of 500 km, in only 60 minutes. So far, everything seems fantastic: there is however a negative and very significant aspect, the extremely expensive construction costs. The Tokyo-Nagoya section will cost a total of 50.9 billion dollars, and to reach Osaka it will cost 91.7 billion dollars, for a total of approximately 150 billion dollars. This explains why to date use of these trains has been limited to few cases in China, Japan and Germany.

A curious aspect - NASA, the American National Aeronautics and Space Administration, is examining the possibility of using maglev propulsion systems also for space launches, to successfully beat the Earth's
escape velocity (the required speed for an object to escape the Earth’s gravitational field), without excessive fuel consumption.

UAQ4 - excellence that is entirely Italian

Even a small country like Italy is worthy of mention in the magnetic levitation high speed trains sector. This is the case of UAQ4, (Università dell’Aquila university model 4), a train on a guide way or magnetic levitation train, or system in which there is no physical contact between the fixed parts, i.e. the railway line and the train. Created by a team of researchers of Università dell’Aquila university, the system uses super magnets that are distributed along the guide way and superconductors that are cooled with liquid nitrogen on board the vehicle.

And this brings us to the second point, What is a superconductor? And how is it used in the UAQ4 train? Superconductors are particular materials which, when brought to temperatures that are lower than a particular threshold, known as critical temperature, (near absolute zero, 0 K (degrees Kelvin) = -273°C), show an electric resistivity, or electric resistance that is practically inexistent. This phenomenon was discovered in 1911 by the German physicist Heike Kamerlingh Onnes, who observed that electric resistivity of mercury vanished at a temperature around 4 K. Almost immediately, this vanishing characteristic was received with enthusiasm because it enables charges (electric) to move in the conductors, even in the presence of great distances, without any heat dissipation due to the Joule effect (i.e. this is the same phenomenon as in incandescent light bulbs operation). However, there is still the problem with regard to constantly cooling of the conductor.

In the UAQ4 train, interaction between magnetic fields produced by the supermagnets and superconductors suspend and at the same time guide the vehicle in every phase of the movement – in other words the train is constantly suspended and confined to the tracks. And there is no danger of the train being derailed. With this system, in fact, the possibility of derailing decreases to almost zero, as it produces a sort of attracting effect, exactly like a magnet, whenever the train moves away from the set position. All this prevents the train from derailing.

Another interesting application of superconductivity and supermagnets is undoubtedly in the particle accelerators, the most famous of which is the accelerator at CERN in Geneva. Superconductors are used in the particle accelerators to curve their trajectory into a circular orbit.
How can a particle be curved and forced to follow a defined course? When a charged particle moves in a magnetic field a force acts on it, called the Lorentz force, which curves the path of the particle, forcing it to move in a circular orbit.

A charged particle moves in a magnetic field that is perpendicular to the figure.

If the particle has no charge, it is not deflected by the magnetic field

Credits: Wikimedia Commons

Particle speeds are extremely high, and consequently the applied Lorentz forces must be equally high. This condition is obtained by producing very intense magnetic fields, that can be conveniently obtained, from the point of view of energy, only with superconductor magnets that can enormously reduce the power required by the supply units.

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