a WOW Lab BLUEPRINT

The Maglev Train

Additional Information

The *Maglev Train* achieves levitation through the phenomenon of superconductivity. Superconductivity occurs in special materials when they reach their critical temperature, which in this case is 107 K (-166 ºC). The main feature of superconductivity is the absence of resistance to an electrical current, called a zero-resistance state. In regular materials, the movement of electrons is restricted and an electric potential must be applied in order to create moving charge. Superconductors in the zero resistance-state allow electrons in the material to move free of impedance. Since current is moving charge (electrons), superconductors are able to carry current with almost infinite conductivity.

Figure 1

Another consequence of superconductivity is known as the Meissner effect, which describes how a magnetic field cannot penetrate a superconductor. To understand the Meissner effect and how it leads to levitation, it is important to first look at normal magnets and the magnetic fields they produce. A normal magnet has two magnetic poles. In **figure 1**, magnetic field lines are shown connecting two opposite poles of a magnet, with the field line exiting north and entering south.

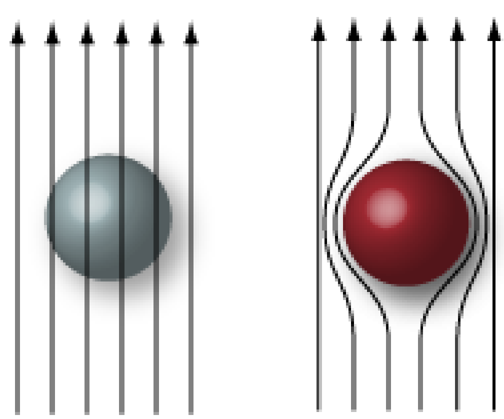
Figure 2

Usually, when another object is placed inside these fields, the field lines will penetrate through the material. However, when a material becomes superconducting, magnetic fields lines can no longer penetrate the surface of the object, as shown in **figure 2**. This effect occurs because the superconducting material becomes perfectly diamagnetic, meaning that it counteracts the applied magnetic field with its own magnetic field pointing in the exact opposite direction. This creates a repulsive force and is responsible for the levitation effect. The physical mechanism for this relies on intricate details of quantum mechanics, but the effects are dramatic and can be easily visualized in this demonstration.

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Inside the body of the train, there are pieces of ceramic that become superconducters when their temperatures are lowered below 107 K. In addition, the train tracks are made out of high strength rare earth magnets, arranged in a specific orientation (which will be discussed below). The superconductors, when placed in the area directly above the tracks, alter the shape of the magnetic fields as shown in the diagrams below.

Looking at the area directly above the magnetic track in **figure 3**, it is evident that the magnetic field lines become compressed when the superconductors are placed on the tracks. At this point, there is a competition between the downward force due to gravity and an upward force created by the repulsion between the superconductor's magnetic field and the applied magnetic field from the tracks. The superconductor floats exactly at the point where the two opposite forces are equal.

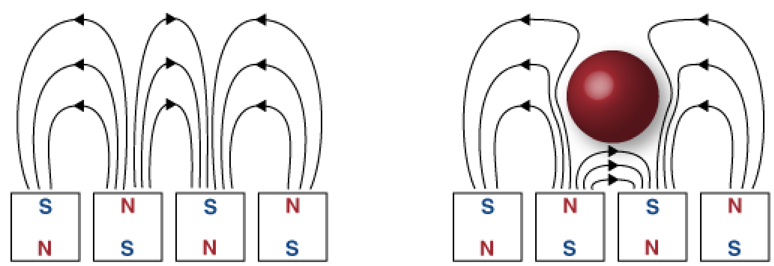

Figure 3

Additionally, the train is not limited to simply statically; it is capable of moving smoothly along the track. In order to understand why this occurs, one should look at the arrangement of magnets in the track. To aid in the explanation, the track is given two direction vectors: x in the length direction and y in the width direction (**Figure 4**).

Looking at the magnetic field arrangement from the track magnets, it becomes evident that the field is uniform in the x direction, but changes considerably in the y direction. Another way of describing the interaction between the superconductor and the magnets would be to say that the superconductor behaves in such a way as to minimize the change in magnetic flux it feels. Since the track's magnetic field has little or no change in the x direction and a large change in the y direction, the superconductor will stay in the middle of the track. The width of the track and the fact that the corners are curved ensures that there will always be more change in the y direction than the x direction. If the y direction had less magnets or the corners were right angles, the train would not be able to go around corners as easily.

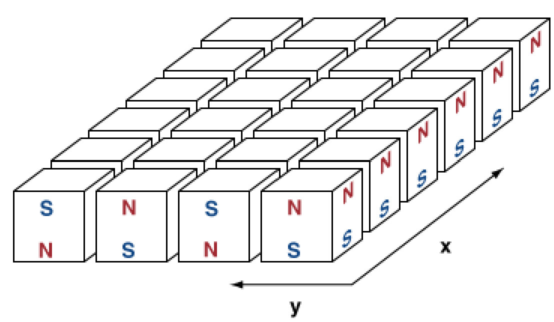

Figure 4