Magnetism

Select LEARNING OBJECTIVES:

- Explain how magnetic fields can be created without current.
- Use superposition to find the magnetic field at a location when multiple magnets are present.

TEXTBOOK CHAPTERS:

Boxsand :: Magnetic fields

WARM UP: In the classical model of the hydrogen atom, an electron moves in a circular orbit about a proton under the action of an electrical force. Assume that the electron is traveling in a counter-clockwise direction when observed from above. The direction of the magnetic moment of the electron due to this orbital motion is

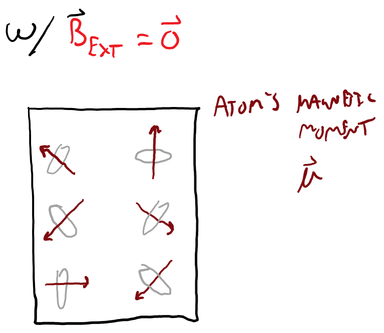
1. Up.
2. Down.
3. Points in the plane of the orbit.
4. Not specified by the information given.

The classical model of atoms suggest that electrons move in orbits around the nucleus. This orbital motion would then result in "microscopic current" that would create magnetic fields. However, we now know that electrons don't actually orbit the nucleus, thus there is no microscopic current in bulk matter. Take a piece of iron for example, there is no microscopic current, or macroscopic current for that matter. But you might have experience with iron and be familiar with its magnetic properties. So if there is no current within iron, but the iron creates a magnetic field, then what gives? Our model for creating magnetic fields currently consists of the need for current or moving charged particles, yet both are non-existent in iron. It turns out there is another way to create magnetic fields, quantum mechanics. Although the electrons don't actually orbit the nucleus, they do have a quantum orbital angular momentum that creates a magnetic moment. On top of this orbital angular moment, electrons have an intrinsic spin orbital momentum (often referred to as just "spin") that creates another magnetic moment. The sum of these magnetic moments lead to a net magnetic moment. On top of just the electrons angular momentums, the nucleus even has angular momentum which creates a magnetic moment, however it's usually much smaller in magnitude than the electron's contribution and thus ignored. Since we already invoked quantum mechanics, you can imagine the mechanisms that contribute to the overall magnetic field of bulk matter is complicated. We are skipping over a lot of those discussions, including magnetic domains among other things. The main goal here is to recognize that magnetic fields can also be created by bulk matter even in the absence of current. Below are three classifications of matter that create magnetic fields due to these weird quantum mechanical effects.

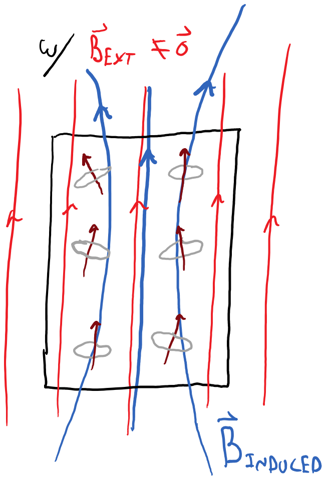
Paramagnetism

Examples: Tungsten, aluminum, lithium, magnesium, sodium

Paramagnetic materials are those whose internal magnetic moments weakly align in the same direction with an external magnetic field. Without an external magnetic field, paramagnetic materials do not produce any significant magnetic field. Once placed into an external magnetic field, the internal magnetic moments align in the same direction as the external magnetic field. The now aligned magnetic moments add vectorially to create an induced magnetic field. Below is a physical representation of this behavior.



*VECTOR CANCELATION OF ATOM'S $\vec{\mu}$ PRODUCES NO $\vec{B}_{INDUCED}$

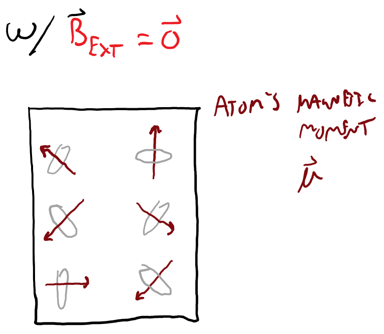


*VECTOR ADDITION OF EACH ATOM'S $\vec{\mu}$ PRODUCES A $\vec{B}_{INDUCED}$

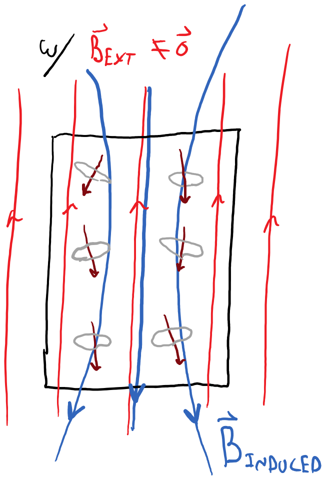
Diamagnetism

Examples: Silver, lead, copper, water, frogs?

Diamagnetic materials are those whose internal magnetic moments weakly align in the opposite direction with an external magnetic field. Without an external magnetic field, diamagnetic materials do not produce any significant magnetic field. Once placed into an external magnetic field, the internal magnetic moments align in the opposite direction as the external magnetic field. The now aligned magnetic moments add vectorially to create an induced magnetic field. Below is a physical representation of this behavior.



*VECTOR CANCELATION OF ATOM'S $\vec{\mu}$ PRODUCES NO $\vec{B}_{INDUCED}$

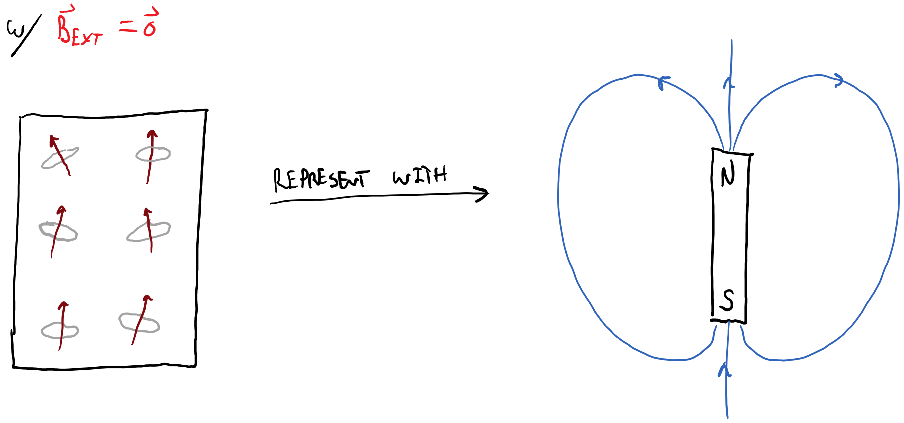


*VECTOR ADDITION OF EACH ATOM'S $\vec{\mu}$ PRODUCES A $\vec{B}_{INDUCED}$

Ferromagnetism

Examples: Iron, nickel, cobalt,

Ferromagnetic materials are those whose inherent magnetic moment are aligned even when not in an external magnetic field. Below is a physical representation of this behavior. We typically use the bar magnet representation shown on the right.



* USE SUPERPOSITION TO FIND $\vec{B}$ AT A POINT DUE TO MULTIPLE PARAMAGNETS OR FERROMAGNETS

PRACTICE: Imagine that two identical bar magnets are placed at right angles to one another with their north poles oriented as shown in the figure. The magnets are equidistant from point P, the point that lies along the centerlines of both magnets. What is the direction of the magnetic field at point p?

1. towards 1
2. towards 2
3. towards 3
4. towards 4
5. towards 5
6. towards 6
7. towards 7
8. towards 8