# Magnetism

**Skills to Develop**

- Describe 2 types of dipoles
- Distinguish paramagnetism from diamagnetism

In 1923, Lewis wrote that the study of spectra and magnetism are the 2 best ways to learn about chemical bonding. Some types of spectra are discussed here. In this section, we will describe the magnetic evidence Lewis used. You are familiar with normal magnets, like the ones used to stick restaurant menus to fridges. In this section, however, we are more interested in the magnetic properties of molecular materials, rather than metallic or semi-ionic solids. Most materials are non-magnetic. The molecular materials that are magnetic still wouldn't stick to your fridge, because they only really act magnetic in a magnetic field. Normally, each molecular magnetic has a random direction because the interactions between the molecules are weak. (Just like how molecular materials melt at lower temperature than metals or rocks). If you put them in a magnetic field, if they are cold enough, they will start to line up with the field. If they are too hot, they will continue to move randomly. This is called **paramagnetism**.

## Dipoles

Let's start by reviewing electric dipoles. An **electric dipole** is something that had separated electrical charges. For instance, an HF molecule or a water molecule have an electric **dipole moment** defined as

$$\mu = q \times d \tag{1}$$

where q is the partial charge on each end of the molecule and d is the distance between the charges.

The electric dipole moment of water with δ representing the partial charges.

Generally, solvents with large dipoles have high **dielectric constants**. In Coulomb's law, the dielectric constant D reduces the force between charges.

$$F = \frac{kQq}{Dr^2} \tag{2}$$

Bigger D means less force. This explains how ionic substances dissolve in solvents with large dipole moments and large D. When the ions separate and have water between them, they no longer attract each other strongly.

Although you can have a point charge, magnets are always dipoles (have a North and South pole). Just like solvents and other materials have dielectric constants, they also have magnetic permeabilities.

## Magnetic Measurements

How do you measure **magnetic moments** or magnetic dipoles in molecules? The old way is to put the molecular material between the poles of a big magnet and see what forces are present. For instance, if you put a paramagnetic material (that is cold enough) between the N and S magnetic poles, it will line up with the field and be attracted by the field. Thus if you weigh a paramagnetic material in a magnetic field, it will be heavier than without the field. Most materials are **diamagnetic**, and get lighter in magnetic fields, because they are repelled by the field. So the easiest way to see if a material is magnetic is to weigh it with and without a magnetic field. (Now there is a fancier method also, called SQUID, which is too complicated to explain here.)

An illustration of a magnetic moment generated from a charged, spinning nucleus.

## How is Magnetism Related to Chemical Bonding?

Lewis correctly realized that molecules with an odd number of electrons (such as NO, with 7+8 =15, but not CO, with 6+8 =14) have some unusual properties. They are paramagnetic, usually strongly colored, and quite reactive. The huge majority of molecules have even numbers of electrons, and are diamagnetic. Thus, paramagnetism seems to be a result of unpaired electrons, while diamagnetism is a result of paired electrons. Transition metal compounds are often colored and magnetic; most compounds of C,H,O,N etc (such as in your body) have little color, are diamagnetic, and not so reactive. Basically, almost all molecules have all their electrons in pairs.

An illustration of the difference between paramagnetism and diamagnetism.

## Contributors and Attributions

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