APPLICATION NOTE 033

Interpreting and Understanding the Results of Measurements Using the Micromeritics MA-1040 Magnetic Analyzer Insert

The purpose of this Application Note is to assist users in obtaining the best possible measurements using the MA-1040 Buck Magnetic Analyzer and then to guide them in correctly interpreting the results.

The Buck Magnetic Analyzer is capable of detecting the presence of as little as one part in 10,000,000 of magnetic material in other materials. With such extraordinary sensitivity comes special requirements to avoid artifacts that may produce inaccurate or misleading readings.

While the Buck Magnetic Analyzer's stated purpose is to measure the weight fraction of magnetic iron or magnetic iron compounds (sometimes nickel and cobalt also) in a sample of material, and it does so very well in most situations, there are still some circumstances in which the results have to be considered in greater depth to arrive at the proper conclusions concerning sample composition. This is most often true when the amount of magnetic material is quite low and other types of magnetic field interactions are present at the same time as the desired one.

Our everyday experience tends to convince most of us that materials are either magnetic or they are totally non-magnetic. We expect that a permanent magnet will either stick to a material or it will not and thereby tell us which is which. That is true until one wishes to measure content of magnetic materials down to the tens of parts per million. Then we see confusing results such as materials which give negative readings or pure materials which are not supposed to be magnetic but which give readings in the 100 ppm range by weight of magnetic content in spite of the fact they contain no iron, nickel, or cobalt whatsoever. One might, when this happens, think the MA-1040 is malfunctioning since such results seem nonsensical. However, there exist several ways other than the expected manner that matter interacts with the magnetic fields such as are used in the MA 1040. In fact, there exists no material of any kind which at some level does not either strengthen or weaken the magnetic field within it and produce a measurable change in the MA-1040 readings.

There are 5 different properties of matter to which the MA-1040 responds and only two of them are the ones we are expecting: The two are ferromagnetism and ferrimagnetism which are quite strong and obvious effects. Along with a third one, paramagnetism, which is relatively weak and of which most people are unaware, these 3 produce positive readings in the MA-1040 because the magnetic field is strengthened by the presence of materials with these properties.

Two other effects, electrical conductivity and diamagnetism both produce negative readings in the MA-1040. Depending upon the degree of electrical conductivity and the size of the conducting path, electrical conductivity can either make any reading whatsoever impossible, or it can be just a minor nuisance. Diamagnetism is usually the weakest effect but it causes negative readings in the few to tens of ppm range. The most difficult situations occur when samples are composed of mixtures of different materials having different magnitudes and polarities of magnetic effect.

A review of these properties and some background follows:

(1.) Ferromagnetism is the most common interaction we all think of. It is the strongest interaction and usually only occurs in iron, nickel, and cobalt metals but under some special conditions gadolinium and dysprosium can also be ferromagnetic. Also, some alloys of these metals with some non-ferromagnetic elements can become strongly ferromagnetic.

Ferromagnetism results from unpaired electrons in the outer shells of the atom but is not usually observed unless other factors make large numbers of atoms align in what are called domains such that these unpaired electrons all spin in the same direction instead of being randomly oriented. The result is that these domains of aligned spins interact with the applied magnetic field to greatly increase the external strength of the field. This gives very high positive readings on the MA 1040 and is one of the two cases for which it was primarily designed.

(2.) Electrical conductivity of a material tends to partially or completely (depending upon physical form and properties) prevent the field from entering the material due to induced electrical currents whose magnetic fields oppose and at least partially cancel that of the applied field. This reduces the field strength produced in the material by the MA1040 sensing coils and causes a negative reading on the MA 1040. To demonstrate, place a rod of aluminum or copper in the sample holder. To avoid having their conductivity alter the results on iron, nickel, or cobalt it is necessary to avoid large solid areas of metal in the sample holder, usually by powdering or laminating the material so that induced currents cannot easily flow at right angles to the magnetic field.

The effect of electrical conductivity effect can be quite large. Placing electrically conductive materials in the MA 1040 is not an intended use of the instrument but some samples of interest will exhibit a mix of conductivity along with the properties we wish to measure. To a degree, with slightly conducting samples, the detector of the MA 1040 can discriminate against conductivity effects but it cannot completely do so for high conductivity samples because no meaningful results can be obtained if signal overload from the large negative signals occurs.

(3.) Ferrimagnetism is similar to ferromagnetism in its origin and its external effects but it involves a somewhat different physical interaction. Ferromagnetic materials are usually non-metallic compounds and may behave as insulators or as semiconductors. It is what is seen in magnetite, the most common magnetic particle found in minerals and soils. Advanced ferrimagnetic materials using rare earths are essential to modern radio communications and electronics. This effect is as strong and obvious as ferromagnetism in most cases. It also gives large positive readings in the MA1040.

(4.) Paramagnetism is very common but usually not noticed because it is most often weak but in some cases can be moderately strong. It also arises from unpaired electrons in atoms' outer shells but in most elements of the periodic table it is not subject to the domain formation effect which would make it much stronger and highly apparent. The lighter paramagnetic elements usually have only faint evidence of it and it must be looked for carefully but in heavier elements it is easier to show its presence. The extent of manifestation of paramagnetism depends upon the chemical compounds in which the paramagnetic element is involved. Copper Sulfate is a common lab substance which will show paragmetism at a moderately high level. To see a table of the relative strengths of paramagnetic effects, look on page 9-57 of the CRC Handbook of Physics and Chemistry.

(5.) Diamagnetism is also very common but it is even weaker and may be hard to observe unless one is aware to look for it. It arises from fully paired electrons randomly oriented to the magnetic field which resist the intrusion of the MA-1040 magnetic field into their orbits. This resistance slightly reduces the magnetic field strength generated by the MA-1040 coils and causes a negative reading on the MA-1040 display. A common substance which exhibits relatively high levels of diamagnetism is common table sugar (sucrose). Most organic compounds and most oxides of light elements will show diamagnetic effects, including the sample holder (plastic) of the MA 1040. As with paramagnetism, the chemical compound in which the element is found greatly affects the strength of the diamagnetic signal.

When samples need to be measured to the ppm level and contain mixtures of compounds, each possibly exhibiting differing magnetic interactions, one needs to develop procedures for separating and backing out the masking effects of paramagnetism, diamagnetism, and electrical conductivity. At a minimum, nulling out the effects of the sample holder and the bulk of the "non-magnetic" material in the sample to allow only the ferromagnetic and/or the ferrimagnetic components to be detected are needed.

The "Zero" control on the MA-1040 is provided so that, if one inserts a sample holder filled with only the pure matrix "non-magnetic" material of the sample which is completely free of the magnetic component and the "Zero" control is adjusted to read 0.0 ppm on that arrangement, then when a real sample is inserted what will be displayed is the true magnetic content.

Obviously, the variety of sample types customers may wish to test is large and may vary in matrix composition from one sample to the next so it may be difficult to always create a true "Zero" magnetic content sample that works for all cases, but the user should always be aware that he must keep the possibility in mind when working at very low levels of magnetic content that he may be seeing positive readings that are not due to the presence of ferromagnetic materials such as iron, cobalt, or nickel or, conversely, that those elements may be present but not detected properly because other materials present cause negative effects that reduce the readings well below what would otherwise have been observed.