CHEMISTRY 235: INORGANIC CHEMISTRY
AN INVESTIGATION OF THE MAGETIC PROPERTIES OF TRANSITION METAL COMPLEXES

Introduction

This experiment is based on one published in "Selected Experiments in A-Level Chemistry" by Gunnell & Jenkins, pp. 2-3.

Compounds and elements may show any one of three (main) types of magnetic behaviour. These are:

1) Diamagnetism

Diamagnetic substances have no unpaired electrons. They tend to be excluded from a magnetic field. In proximity to a magnet a repulsive force is experienced. This effect is very weak and difficult to measure. It is not observable in ordinary situations.

2) Paramagnetism

Paramagnetic substances have at least one unpaired electron. The presence of just one of these completely overwhelms the diamagnetic effect of any paired electrons. The strength of this effect depends on the number of unpaired electrons. For transition metals this in turn depends on the immediate environment of the metal atom or ion, according to **crystal field theory**. According to this theory the d-orbitals with the same principle quantum number do not all have the same energy in complexes and compounds. Instead they are split into two (or more) groups, the orbitals in each group having the same energy, i.e. being degenerate. There are two main situations to consider:

Octahedral coordination

Here the d-orbitals are split into three t_{2g} orbitals of lower energy, and two e_g orbitals of higher energy. The energy gap between these sets of orbitals is termed Δ_0. It varies in size with the charge on the metal ion and the place in the spectrochemical series of the ligands. Ligands which produce a large Δ_0 are termed *high field* and ones which give a small Δ_0 are termed *low field*. The complex ion is an example of an octahedral complex with high field ligands. If Δ_0 is large, as many d-electrons as possible crowd into the lower energy t_{2g} orbitals and the complex is described as *low-spin*. If Δ_0 is small, the d-electrons spread themselves between the available d-orbitals irrespective of whether they are lower energy t_{2g} orbitals, or higher energy e_g in a way which maximises the number of unpaired electrons. Such complexes are termed *high-spin*. The hexa-aquaferrate(II) ion is low spin.

Tetrahedral coordination.

The situation is reversed in tetrahedral complexes. The d-orbitals are still split into two groups as before, but the order of energies is reversed. Now there are three t_{2g} orbitals of *higher* energy, and two e_g orbitals of *lower* energy. The energy difference, Δ_0, is generally lower than with octahedral coordination and as a result, most tetrahedral complexes are high spin.

Consideration of the environment of a metal atom or ion in a complex can explain the magnetic behaviour of compounds.

3) Ferromagnetism

Ferromagnetism is an extreme case of paramagnetism. The electron spins tend to align spontaneously below some critical temperature. Such materials may be elements, alloys or compounds. "Magnetic oxide of iron" (Fe_3O_4) is one such.

Procedure

a) Fill a small test tube (the smallest you can find) with the substance under consideration and seal it with *Parafilm©*.
b) Suspend the tube by a long thread (light fishing line is ideal) in a draft-free environment.
c) Bring a magnet up to the end of the test tube and see if you can detect (a very small) effect on the behaviour of the tube. If not, the sample is diamagnetic. If you can, the sample is paramagnetic, unless the force is very strong. In this case it is ferromagnetic.

Results Table

Sample	*Formula*	*Number of d- electrons*	*Magnetic type (by experiment)*	*Probable arrangement of d-electrons: e.g. $t_{2g}^3e_g^2$*
Potassium permanganate				
Potassium dichromate				
Potassium hexcyanoferrate(III)				
Potassium hexcyanoferrate(II)				
iron(II) sulfate 7-water				
cobalt(II) nitrate 6-water				
anhydrous iron(II) chloride				
A powdered metal				

d) Now write up your experiment, giving an account describing what you *did*, a diagram of the experimental set-up and a discussion of your results. Include this results table. Mention, and attempt to explain, any conflict between your observations and theory.