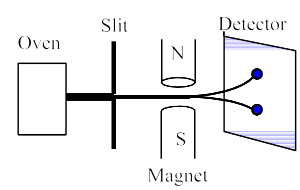
ELECTRON CONFIGURATIONS AND THE MAGNETIC PROPERTIES OF MATTER

Moving electrons create a magnetic field. In your earlier studies you may have prepared an electromagnet by wrapping a coil of wire around a nail and connecting the wire leads to an battery. You where then able to lift a number of paper clips or tacks with the electromagnet produced. How does this work since an iron nail is not a magnet? One nail or paper clip does not noticeably attract another nail or paper clip. However, if you gently stroke a nail with a permanent magnet always moving in the same direction, you can make a magnet from an iron nail. This new magnet can then be used to pick up another small nail, tack, or paper clip. When the magnet is formed, it is believed that the spins of the unpaired electrons in the iron atoms align themselves with the spins opposite to those of the electrons in the atoms of the permanent magnet. forming another magnet. This ability of certain elements or alloys to exhibit strongly magnetic properties is called *ferromagnetism*. These properties are due to both the electron configuration of these elements and the nature of the bonding between atoms.

While we normally associate magnetism with metallic iron or a pure nickel coin, other materials demonstrate magnetic properties as well. Earlier studies such as the Stern-Gerlach experiment described below have demonstrated that the spin of an electron causes it to behave like a small magnetic. If an atom has at least one unpaired electron, it will be attracted to a magnet. The more unpaired electrons an atom has with like spins, the greater is its attraction. This phenomenon is called *paramagnetism.* If all the electrons in an atom are paired, their spins cancel, and the substance is actually repelled slightly from the magnet. This property is known as *diamagnetism*. The magnetic properties of matter are important in science as one piece of the experimental evidence which lead to the development of modern atomic theory.

The Stern-Gerlach Experiment



One such experiment which studied the magnetic properties of matter was the Stern-Gerlach experiment. In 1920, Otto Stern and Walter Gerlach vaporized silver atoms in an oven. The silver vapor was first passed through a slit and then through a magnetic field. Stern and Gerlach observed that the beam of silver atoms was split in two parts which made separate deposits on a detector plate. As a result of this experiment, scientists concluded that electrons act like tiny magnets. It did not take long for the concept of the spinning electron to be developed. In 1925, Wolfgang Pauli showed that the *doublet* in alkali emission spectra (two spectral lines very close together) consisted of two separate states. George Uhlenbeck and Samuel Goudsmit then showed that multiple spectral lines could be explained by introducing a new quantum number, s, which could have two values, +½ and -½. But the most convincing evidence of spinning electrons was still the Stern-Gerlach experiment.

The principles behind the Stern-Gerlach experiment are as follows:

1. Spinning electrons generate a magnetic field.

2. A pair of electrons with opposite spins has no net magnetic effect. The magnet field of one electron is “canceled out” by the magnetic field of the second electron.

3. In a silver atom, 23 electrons spin one way and 24 electrons spin the other way. The magnetic property of silver atoms is dependent only on the spin of the one unpaired 5s electron. The electron configuration for silver is given in the adjacent drawing. Note that like copper, silver is an exception to the Aufbau order with an electron configuration of $4d^{10}$, $5s^1$, instead of the expected, $4d^9$, $5s^2$.

The Electron Configuration of Silver

$_{47}Ag$	[Kr]	↑↓	↑↓	↑↓	↑↓	↑↓	↑
		4d	4d	4d	4d	4d	5s

4. In a large sample of silver atoms, the probability is that both types of atoms will be present, some with an unpaired electron with a clockwise spin and some with an unpaired electron with a counterclockwise spin. Due to attractions and repulsions, the magnetic field will separate the beam of silver atoms into two beams.

In addition to the spin quantum number, s, the other two important scientific principles conceived from magnetic properties were Hund’s rule and the Pauli Exclusion Principle. The concept promoted by Hund’s Rule is that “*the most stable arrangement of electrons is that with the maximum number of unpaired electrons, all with the same spin direction*.” That is, the electron configuration of nitrogen has the 2p sublevel filled with three single electrons as opposed to one pair and one single electron as demonstrated below.

$_7N$	↑↓	↑↓	↑	↑	↑	not	$_7N$	↑↓	↑↓	↑↓	↑	
	1s	2s	2p	2p	2p			1s	2s	2p	2p	2p

The second of the two theorems developed from magnetic properties is the Pauli Exclusion Principle, “*no two electrons can have the same set of four quantum numbers.*” Applying the Pauli principle to the electron configuration of nitrogen, the two electrons in each orbital must have opposite spins.

$_7N$	↑↓	↑↓	↑	↑	↑	not	$_7N$	↑↓	↑↓	↑	↑	↑
	1s	2s	2p	2p	2p			1s	2s	2p	2p	2p

The purpose of this experiment is to measure the attraction of some common transition chlorides to a magnet and compare this attraction with the electron configuration of the transition metal ion present in the substance.

Materials:

Vials containing cobalt (II) chloride, $CoCl_2$, copper (II) chloride, $CuCl_2$, iron (II) chloride, $FeCl_2$, manganese (II) chloride, $MnCl_2$, nickel (II) chloride, $NiCl_2$, and zinc chloride, $ZnCl_2$, a large neodymium-boron-iron magnet, centigram or better balance, spacer, and a support assembly to hold the vial above the magnet.

Pre-laboratory Activity:

Part 1. For each transition element contained in the compounds studied, give its electron configuration in the order of increasing energy in the space provided. For example, the electron configuration for calcium, atomic number 20, would be $1s^2$, $2s^2$, $2p^6$, $3s^2$, $3p^6$, $4s^2$. **NOTE:** The order in which the electrons fill the sublevels in copper is an exception to the order of increasing energy studied. That is, in copper, the <u>3d sublevel</u> is completely filled before any electrons are added to the <u>4s sublevel.</u>

$_{25}Mn$ ______________________________

$_{26}Fe$ ______________________________

$_{27}Co$ ______________________________

$_{28}Ni$ ______________________________

$_{29}Cu$ ______________________________

$_{30}Zn$ ______________________________

Part 2. Using the electron configurations for each transition element written in part 1, write its orbital notation in the space provided below:

	1s	2s	2p	2p	2p	3s	3p	3p	3p	3d	3d	3d	3d	3d	4s
$_{25}Mn^0$															
$_{26}Fe^0$															
$_{27}Co^0$															
$_{28}Ni^0$															
$_{29}Cu^0$															
$_{30}Zn^0$															

Part 3. For each transition metal ion contained in the chemical compounds studied, give its orbital notation from its oxidation number in the space provided below:

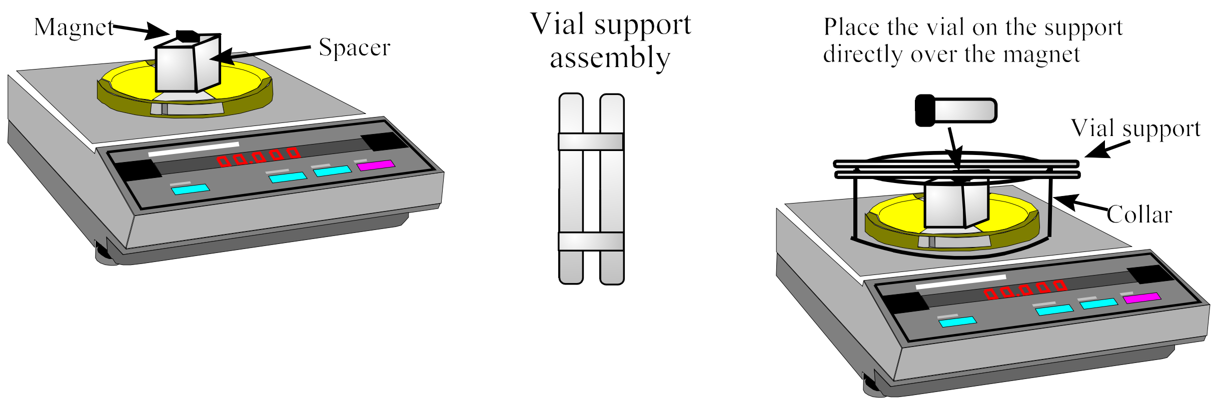
How does the orbital notation of the ion below differ from the orbital notation of its element? Answer, it contains a different number of electrons. That is, a positive one ion contains one less electron that the element and a negative one ion contains one more electron than the element. Which electrons are removed when an atom forms a positive ion? Answer, the electrons in the highest energy level are removed first.

Ion	1s	2s	2p	2p	2p	3s	3p	3p	3p	3d	3d	3d	3d	3d	4s
$_{25}Mn^{2+}$															
$_{26}Fe^{2+}$															
$_{27}Co^{2+}$															
$_{28}Ni^{2+}$															
$_{29}Cu^{2+}$															
$_{30}Zn^{2+}$															

PROCEDURE:

CAUTION: The neodymium-boron-iron magnet used in this experiment is very powerful but extremely brittle. **DO NOT** test the magnet on the exposed metal at your laboratory station or bring another similar magnet near your magnet. **Always** return the magnet to its storage container when not in use.

1. Place a large neodymium-boron-magnet on a spacer on the pan of a balance. Next, place a paper collar on the balance body followed by the vial support assembly. The object of the collar and vial support is to hold a vial containing the transition metal compound as close as possible to the magnet without touching the magnet.



2. Tare or “zero” the balance. Place one of the vials being studied on the vial support and adjust the positioning in order that the vial is centered over the magnet giving the maximum contact between the magnet and the vial.

3. Record the compound’s color and balance reading to the precision of your balance on the your data table. Ignore the negative sign on the balance reading. It simply indicates that the balance pan is being lifted as the magnet is drawn toward the vial.

4. Continue the experiment by testing the substances in the remaining vials in the same manner.

5. Remove all to materials from the balance and tare or “zero” the balance. Place the magnet in its protective container and return all materials to their storage area.

DATA:

Compound	# of unpaired electrons	Color	Balance Reading
Cobalt (II) chloride			gram
Copper(II) chloride			gram
Iron (II) chloride			gram
Manganese (II) chloride			gram
Nickel (II) chloride			gram
Zinc chloride			gram

QUESTIONS:

1. Preparing a graph plotting the balance reading in grams vs the number of unpaired electrons in its orbital notation.

2. (a) Compare the orbital notations of the substances investigated in this experiment with their attraction to the magnet. What unique feature in the orbital notation could be used to predict an attraction to a magnet? Explain your answer.

   (b) Compare the orbital notations of the substances studied in this experiment. What is the relationship between the strength of their magnetic attraction and their orbital notation?

3. The element chromium has three common oxidation states, Cr^0, Cr^{3+}, and Cr^{6+}.

   (a) Write the orbital notation for the three common oxidation states of chromium. (The electron configuration of Cr^0 is an exception to the Aufbau order. Its electron configuration ends $3d^5$, $4s^1$ instead of the expected order, $4s^2$, $3d^4$.)

   (b) Substances which are attracted to a magnet are said to be *paramagnetic*. Which of the different oxidation states chromium would you expect to be paramagnetic and why?

   (c) List the different oxidation states of chromium in order of increasing attraction to a magnet.

   (d) What balance readings would you expect if you were to experiment with vials containing the three different oxidation states of chromium?

4. One of the scientific principles applied when writing orbital notations is Hund's rule.

Hund's rule states that "the most stable arrangement of electrons is that with the maximum number of unpaired electrons, all with the same spin direction."

(a) Explain briefly how your experiment supports Hund's rule.

(b) How would your experimental results be different if electrons did not fill sublevels according to Hund's rule? That is, if each orbital was filled with a pair of electrons in order rather than first filling the sublevel with single electrons as now required.

5. Another important rule applied when writing electron configurations is the Pauli Exclusion Principle, "no two electrons can have the same set of four quantum numbers." How would your results be different if all electrons have the same spin quantum number?