Paramagnetic Transition Metal Ions

Electron Configuration

Introduction

Several transition metal salts are affected by a strong magnet. Students are generally familiar with the fact that metallic iron is magnetic, but the science behind this observation is not necessarily understood. Paramagnetic salts generally contain transition metal ions that have at least one unpaired electron in their electron configuration. In this demonstration, a neodymium magnet is used to deflect small v-shaped chambers containing paramagnetic transition metal salts.

Concepts

- Paramagnetism
- Diamagnetism
- Electron configuration
- Orbitals

Materials

Calcium sulfate, $CaSO_4z2H_2O$, 4 g
Copper(II) sulfate, $CuSO_4z5H_2O$, 4 g
Manganese(II) sulfate, $MnSO_4zH_2O$, 4 g
Zinc sulfate, $ZnSO_4z7H_2O$, 4 g
Dowel rod with hooks, 2
Ion Identification Card Sheet
Mega magnet
Pipet elbows, 4
Pipets, plastic, 8
Ring stand
Scissors
Thread, 6-in, 4
Utility clamps, 2
Velcro® dots, 4 sets

Safety Precautions

Copper(II) sulfate is a skin and respiratory irritant and is moderately toxic by ingestion and inhalation. Manganese(II) sulfate is a body tissue irritant. Zinc sulfate is an irritant and is slightly toxic. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information. Wash hands thoroughly with soap and water before leaving the laboratory.

Preparation

1. Use scissors to cut the stems of two pipets 1″ from the tip of the pipet. The pipets should fit snugly around the pipet elbow (see Figure 1).
2. Fill each bulb of the two pipets with 2 g of copper(II) sulfate, $CuSO_4$.
3. Slip the filled pipet stems over the plastic elbow (see Figure 2).
4. Repeat steps 1–3 using manganese(II) sulfate, $MnSO_4zH_2O$, zinc sulfate, $ZnSO_4$, and calcium sulfate, $CaSO_4$.
5. Cut four six-inch pieces of thread. Tie a piece of thread around the elbow of each pipet assembly.
6. Clamp the dowel rods to the utility clamps (see Figure 3).
7. Attach the utility clamps (with dowel rods) to the ring stand (see Figure 4).

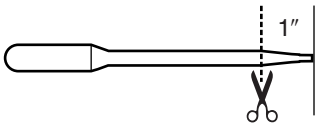

Figure 1.

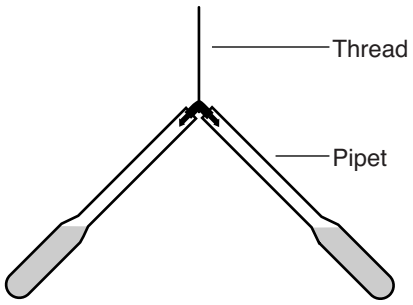

Figure 2.

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8. Suspend the filled pipets by attaching the thread to the hooks on the dowel rods (see Figure 5). The pipets should hang evenly.
9. Cut out the ions from the Ion Identificaion Card Sheet. Attach each ion card to the dowel rod in the appropriate position using the provided Velcro dots (see Figure 5).

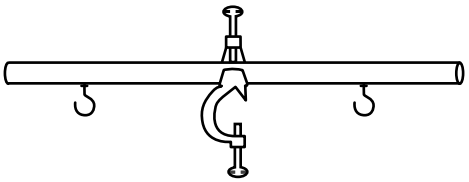


Figure 3.

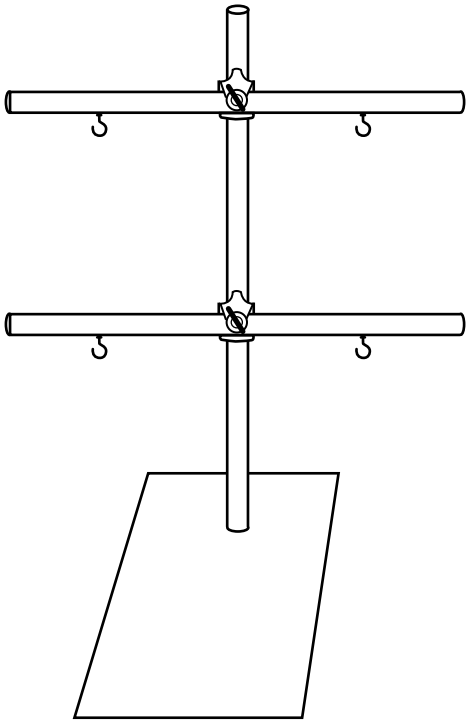


Figure 4.

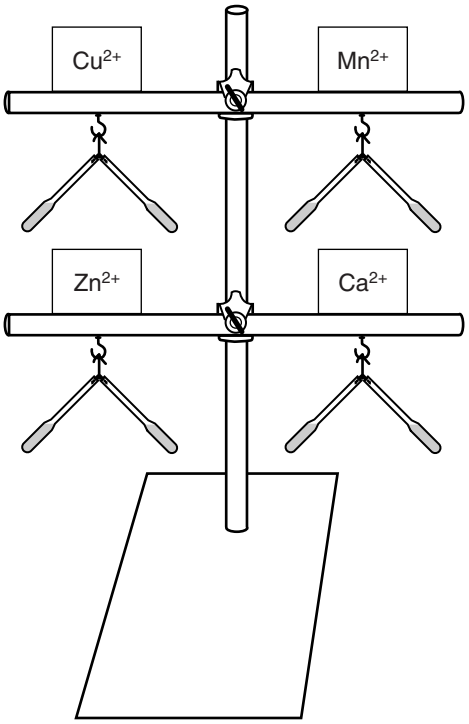


Figure 5.

Procedure

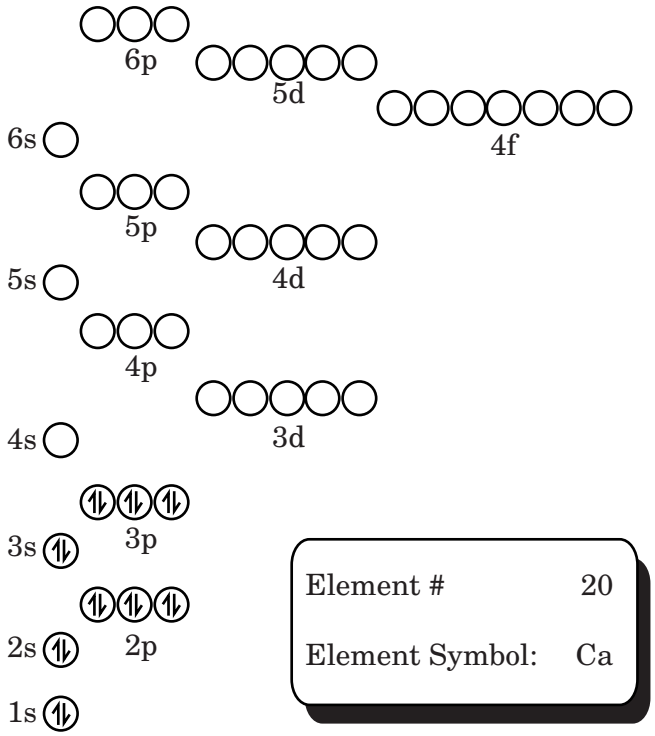
Bring a neodymium magnet near each one of the suspended pipets. Observe how the different salts respond to the magnet.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. Calcium sulfate, copper(II) sulfate, and zinc sulfate may be reused or placed in the trash according to Flinn Suggested Disposal Method #26a. Manganese(II) sulfate may be reused or disposed of properly by a licensed removal company according to Flinn Suggested Disposal Method #27f.

Tips and Extensions

- The chemicals in this demonstration may be stored in the pipet assemblies and reused as many times as desired.
- As an extension, have students fill out the given Electron Configuration Worksheet for each ion. Make one copy of the worksheet for each student. You may wish to make an overhead transparency of the given Teacher Electron Configuration Chart and follow along or help guide the students on the overhead projector transparency. On the next page you will find a sample completed electron configuration for Ca^{2+}.



Electron Configuration: $1s^2 2s^2 2p^6 3s^2 3p^6$

- Have students discuss why some materials are paramagnetic and others are not.
- The magnetism of other salts may be experimented with as well.

Discussion

The pipets containing the manganese and copper salts will be influenced by the strong magnet, while the other two pipets will be unaffected by the magnet. The explanation for these observations lies in the electron configuration of the transition metal cations in each salt. The manganese ion has five unpaired electrons while the copper ion has one unpaired electron. Not surprisingly, the magnetic attraction of the manganese ion is much stronger since it has more unpaired electrons. The other metal cations possess no unpaired electrons and are not affected by a magnetic field.

Atoms or ions that have only paired electrons (i.e., no unpaired electrons) are essentially unaffected by a magnetic field. These atoms or ions are classified as *diamagnetic*. The magnetic moments of the paired electrons are effectively cancelled out.

A *paramagnetic* substance is defined as possessing at least one unpaired electron. In a paramagnetic solid, the unpaired electrons of the atoms or ions are not influenced by the electrons on adjacent atoms or ions. The magnetic moments on the individual ions are randomly oriented. However, when subjected to a magnetic field, the magnetic moments become aligned roughly parallel to each other, producing a net attractive interaction with the magnet.

A *ferromagnetic* substance is much more strongly affected by a magnetic field. Ferromagnetism occurs when the unpaired electrons of the atoms or ions in a solid sense the orientations of electrons of the neighboring atoms or ions. The most stable or lowest energy arrangement occurs when the spins of the electrons on adjacent atoms or ions are aligned in the same direction. The attraction of a ferromagnetic compound for a magnet may be as much as one million times greater than that of most paramagnetic substances.

Electron configurations of selected ions

Ca^{2+} $1s^2 2s^2 2p^6 3s^2 3p^6$ (diamagnetic)

Cu^{2+} $1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^9$ (paramagnetic, 1 unpaired e^-)

Mn^{2+} $1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^5$ (more paramagnetic, 5 unpaired e^-)

Zn^{2+} $1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^{10}$ (diamagnetic)

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation

Content Standards: Grades 5–8
Content Standard B: Physical Science, transfer of energy

Content Standards: Grades 9–12
Content Standard B: Physical Science, conservation of energy and increase in disorder, interactions of energy and matter

Acknowledgment

Flinn Scientific would like to thank Jeff Bracken, chemistry teacher at Westerville North High School in Westerville, Ohio for sharing this original idea. Jeff Bracken would like to thank his student lab assistant, Matt Cocuzzi, for his assistance with the development of this chemical demonstration.

References

Brown, T. L.; LeMay, H. E.; Bursten, B. E. *Chemistry: The Central Science*, 5th Ed., Prentice Hall, 1991, p 891–892.

Burke, J. A. *J. Chem. Educ.* **1972,** *49*, 568.

Cortel, A. *J. Chem. Educ.* **1998,** *75*, 61–63.

Gross, G. R.; Bilash, B.; Koob, J. K. *A Demo A Day.* Flinn Scientific, Inc. 1995, p 124.

Marzzacco, C. J. *Chem 13 News*, January, 1999, p 16.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

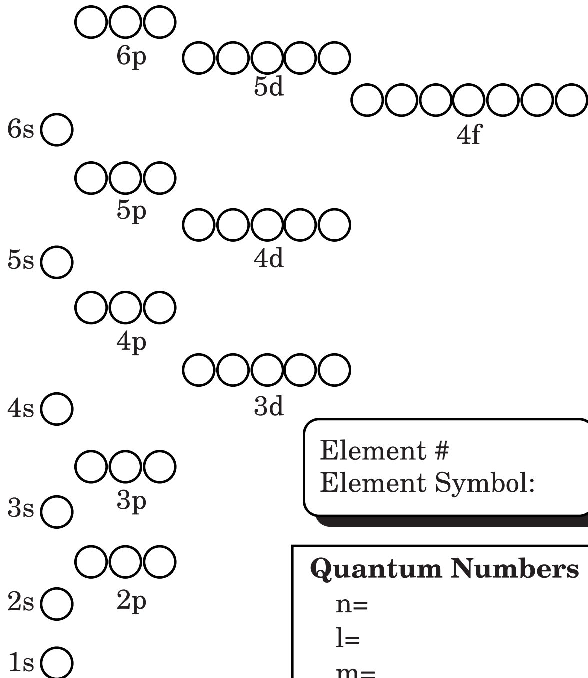
A video of the *Paramagnetic Transition Metal Ions* activity, presented by Jeff Bracken, is available in *Electron Configuration*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Paramagnetic Transition Metal Ions* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Paramagnetic Metal Ions—Chemical Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP6309	Paramagnetic Metal Ions—Chemical Demonstration Kit
AP2253	Pipets, Beral-Type, Wide-Stem, Pkg/20
M0030	Manganese(II) Sulfate, 100 g
C0215	Copper(II) Sulfate, 25 g
C0353	Calcium Sulfate, 50 g
Z0023	Zinc Sulfate, 100 g
AP1738	Mega-Magnet

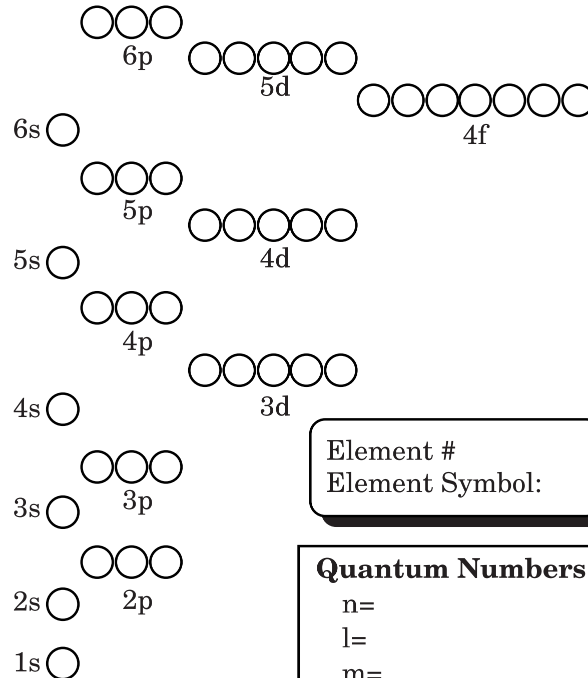
Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.



Element #
Element Symbol:

Quantum Numbers
n=
l=
m=
s=

Electron Configuration:



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l=
m=
s=

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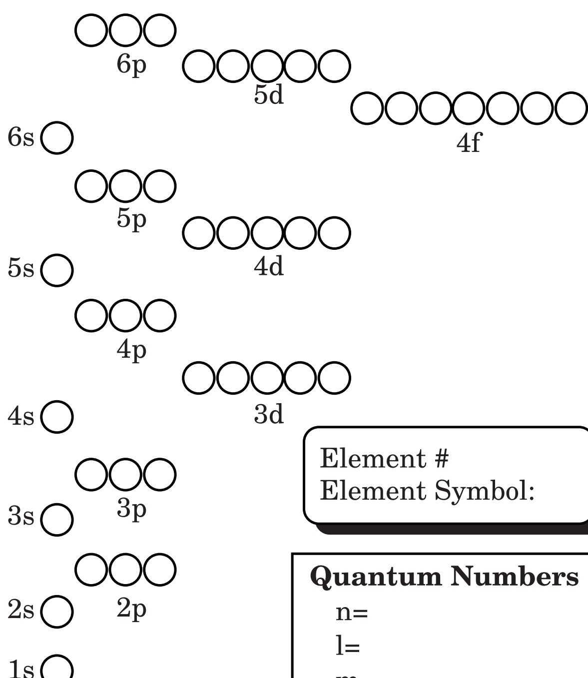

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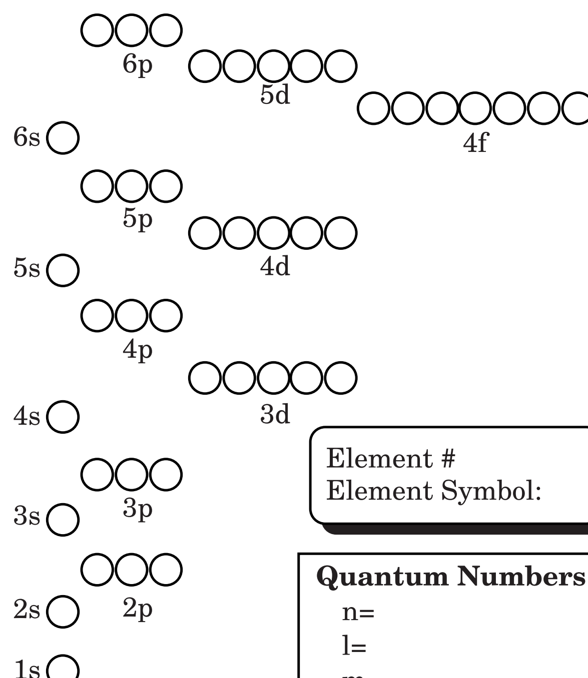
l=
m=
s=

Electron Configuration:



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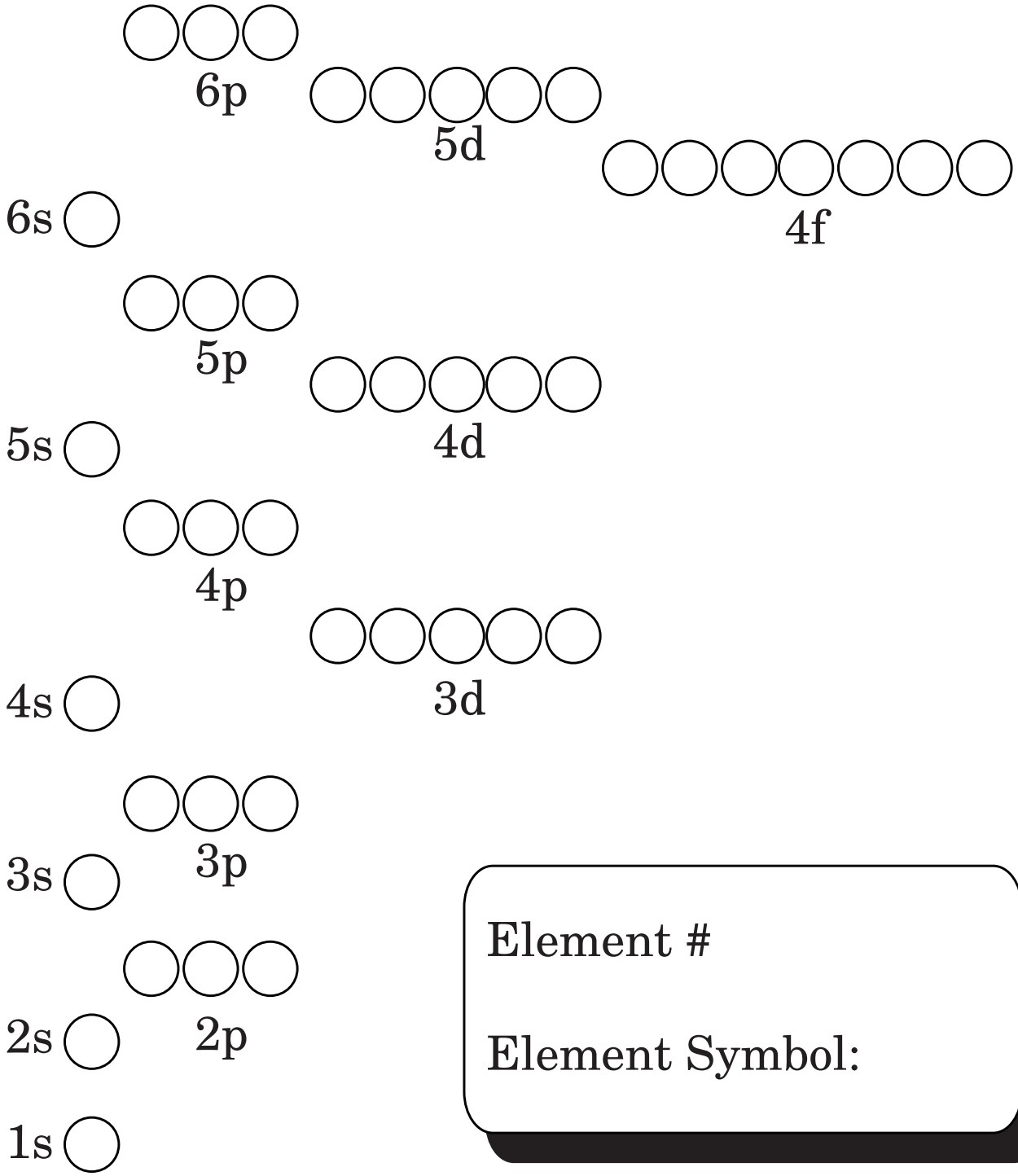

Element #

Element Symbol:

Electron Configuration:

Ion Identification Card Sheet

Ca^{2+}

Velcro

Cu^{2+}

Velcro

Mn^{2+}

Velcro

Zn^{2+}

Velcro