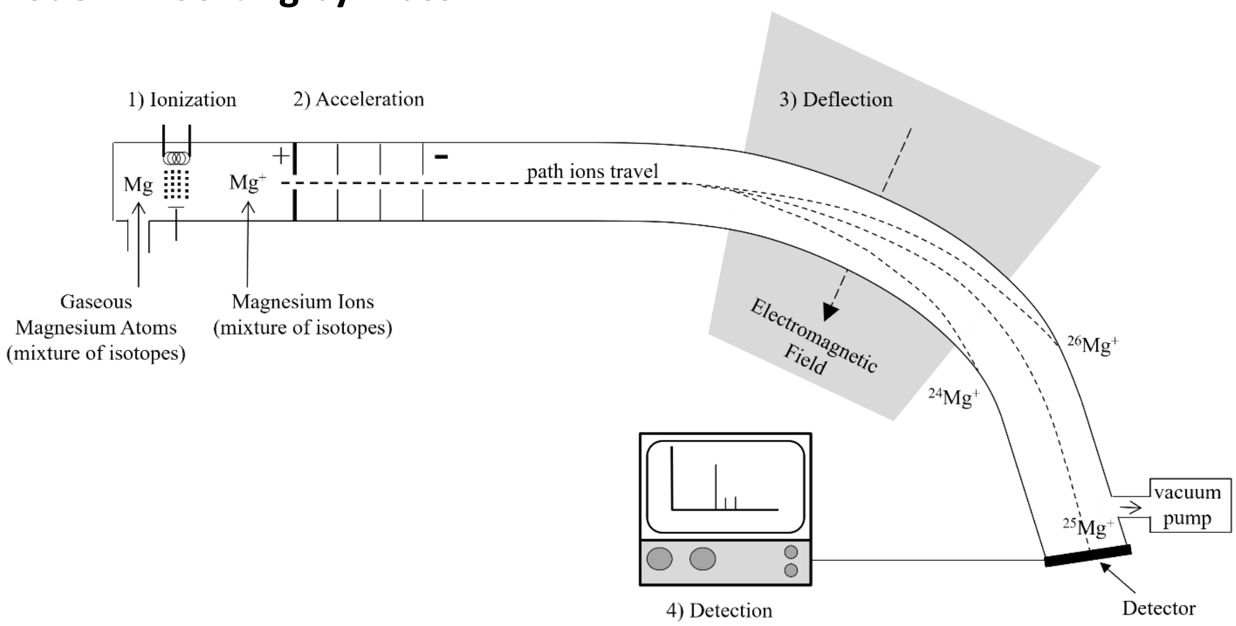
Mass Spectroscopy

How do we know isotopes exist?

Why?

When John Dalton proposed the first formal atomic theory, he stated “Atoms of the same element are identical.” Today we know that is not true – many elements contain several different isotopes, or atoms, that differ in mass. Mass spectroscopy is the principal technique used to study isotopes. It is used to “count” and “weigh” atoms or molecules in a sample, just not in the traditional sense.

Model 1 – Sorting by Mass



1. As a team, consider Model 1. What four processes occur inside a mass spectrometer?

2. Work as a team to match the four processes from Question 1 to the following descriptions.

_____________ Ions collide with a metal plate. Electrons are transferred from the metal to the ion, producing a current and thus a signal to a computer.

_____________ Ions move through an electromagnetic field causing separation of the mixture based on mass and charge.

_____________ Electrons are knocked off sample particles to form (mostly) +1 ions.

_____________ Ions move through a series of charged plates to form a narrow beam of high-speed particles with equal kinetic energy.

3. When a sample is injected into the mass spectrometer, do the atoms or molecules turn into positive or negative ions? Justify your answer with evidence from Model 1.

4. According to Model 1, what causes the sample mixture to separate into different streams of ions?

Read This!

Within the mass spectrometer, the electromagnetic fields of sample ions interact with the electromagnetic field applied to the chamber. This causes the path of the sample ions to bend. The extent of the bend, also called the amount of deflection, depends on the **mass to charge ratio (m/z)** of the sample ions, as well as the strength of the applied electromagnetic field. Smaller masses, higher positive charge, and a stronger applied field would all increase the path curvature, or deflection, of the sample particles. While the applied electromagnetic field is usually "tuned" to focus only one stream of ions at the detector at a time, it is adjusted during the sample analysis to eventually detect all the ion streams. Particles not focused on the detector collide with the metallic sides of the chamber, are neutralized, and then removed by the vacuum pump.

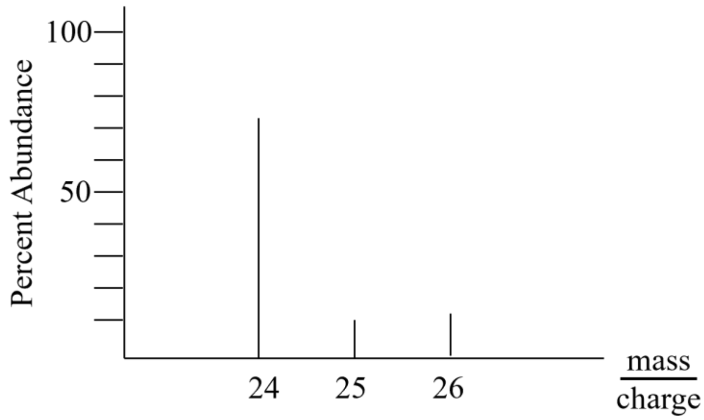
5. As a team, consider Model 1.
   a. Which isotope was deflected most by the electromagnetic field?
   b. Which isotope hit the detector?

6. Consider the following ions. Note they all have a +1 charge. Rank the ions in terms of their degree of deflection by the electromagnetic field from least to greatest. Make sure all team members are able to explain the ranking.

   $^{19}F^{1+}$ $^{16}O^{1+}$ $^{17}O^{1+}$

7. Inside the mass spectrometer, charged particles travel in predictable paths through a vacuum (very few gas particles present). Why is it necessary to have the mass spectrometer chamber under vacuum for it to work properly?

Model 2 – A Mass Spectrum



8. Model 2 is the mass spectrum of magnesium produced from the experiment in Model 1.
   a. According to Model 2, what is the mass number of the most common isotope of magnesium?

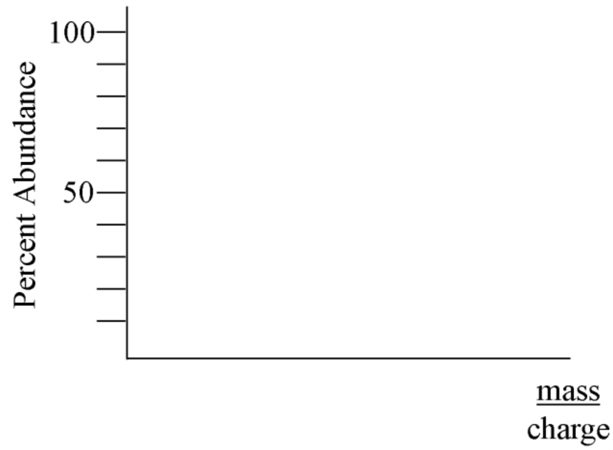
   b. According to Model 2, what is the percent abundance of the most common isotope of magnesium?

9. The average atomic mass of an element can be estimated from data on a mass spectrum.
   a. Estimate the average atomic mass of magnesium using data from Model 2. *Hint: You will not get the correct answer if you add 24, 25 and 26 and divide by 3.*

   b. Give two reasons why your calculated value in part *a* is only an estimate of the average atomic mass of the element magnesium.

10. The table below provides mass number and percent abundance information for the element lead. Draw a mass spectrum for lead. (You can assume only +1 ions of lead are formed.)

^{204}Pb	1.4%
^{206}Pb	24.1%
^{207}Pb	22.1%
^{208}Pb	52.4%

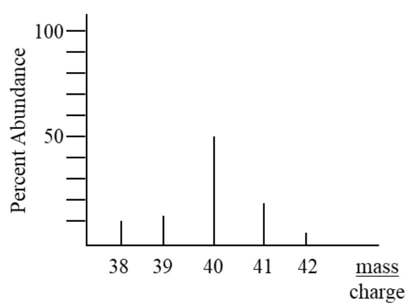


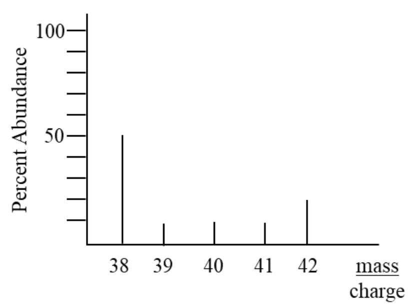
Read This!

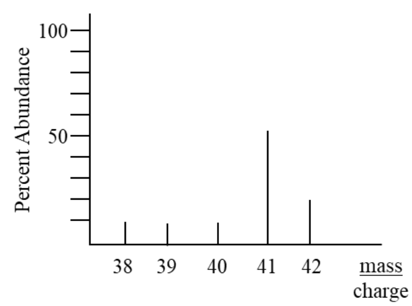
Notice that the average atomic mass calculated from a mass spectrum cannot be determined by simply looking at the highest peak. One must consider the smaller peaks and how they might skew the average mass to be higher or lower than the tallest, most common mass peak.

11. Consider the three hypothetical mass spectra below. Label each spectrum with one of the average atomic masses listed below. Do not use a calculator. Just look at the placement and height of the lines.

39.40 u 39.95 u 40.60 u





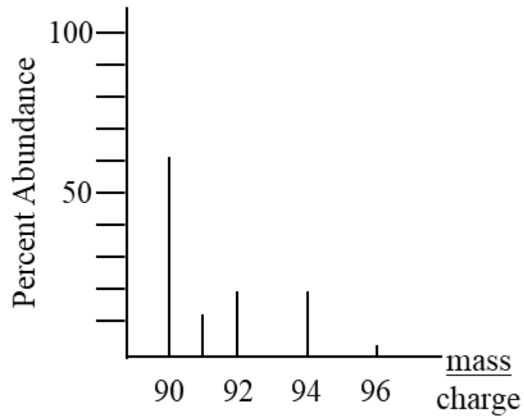


12. As a team, check your answers for Question 11 with a calculator. Divide the work equally. If you matched one of the spectrums incorrectly, discuss your mistake. Summarize your corrected thinking process here for estimating the average atomic mass without a calculator.

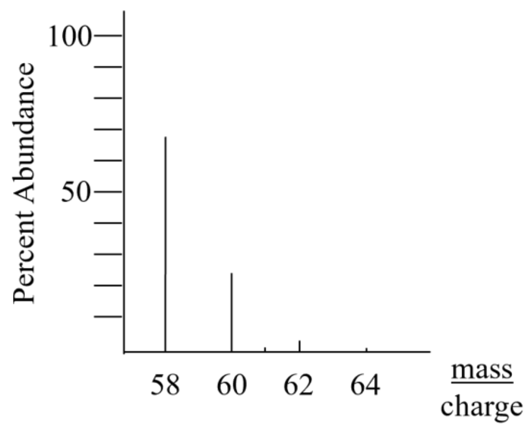
13. Consider the spectrum to the right.
    a. How many isotopes of the element are represented by the spectrum?

    b. Circle the element below that is represented by this mass spectrum. Justify your reasoning.

    Th Nb Zr Mo



14. Cobalt and nickel have very similar average atomic masses. Cobalt has only one natural isotope, while nickel has five. A researcher feared that her nickel sample had become tainted with cobalt impurities from another experiment. To determine if the nickel was pure or contaminated, she ran a sample in the mass spectrometer. The spectrum to the right was the result. Was her sample of nickel tainted? Justify your reasoning.



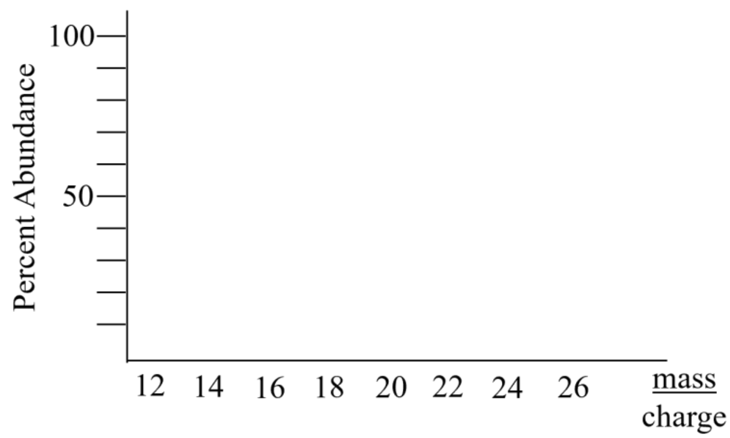
STOP

Extension Questions

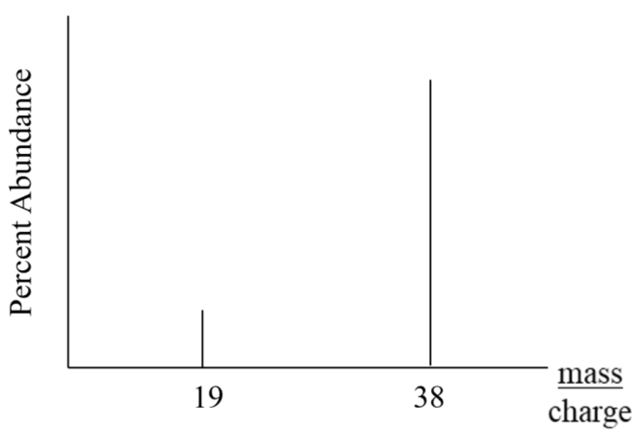
Read This!

The process of ionization inside of a mass spectrometer is quite violent. There are several methods of ionization used in industry, but many of them remove electrons from the atoms or molecules by high energy particle bombardment. In other words, the electrons are knocked off the atoms or molecules by high-speed particles colliding with them. Occasionally this process will break apart a molecule. This is called **fragmentation**. The pieces are analyzed by the mass spectrometer along with the whole molecules. Also possible is the formation of higher positive charges, which change the mass/charge ratio.

15. What would the mass spectrum of magnesium look like if a small portion of atoms were ionized to 2+ ions?



16. The following information was gathered by mass spectroscopy for the element fluorine. Fluorine has only one natural isotope, but it does form diatomic molecules naturally. Propose an explanation for the two lines on fluorine's mass spectrum.



17. The element chlorine has two natural isotopes: ^{35}Cl (76% abundance) and ^{37}Cl (24% abundance). The mass spectrum of molecular chlorine (Cl_2) has five lines.

   a. Three of the lines in the mass spectrum are from diatomic molecules of chlorine. List the three possible combinations of the two isotopes and their total mass number.

   b. Explain the remaining two lines in the spectrum.

   c. Draw a mass spectrum that would result from diatomic chlorine. Include the mass/charge number and estimate the relative abundance of each ion. (Assume only +1 ions are formed.) Although the heights of the peaks are difficult to predict, you should be able to determine which will be taller or shorter based on the abundance of each chlorine isotope.