How Do We Know Isotopes Exist?

Why are we doing this?

When John Dalton proposed the formal atomic theory, he stated "atoms of the same element are identical." Today we know that is not true—mane elements contain several different isotopes, or atoms that differ in mass. Mass spectroscopy is the principle technique used to study isotopes. It is used to both "count" and "weigh" atoms in a sample, just not in the traditional sense.

Your Learning Outcomes

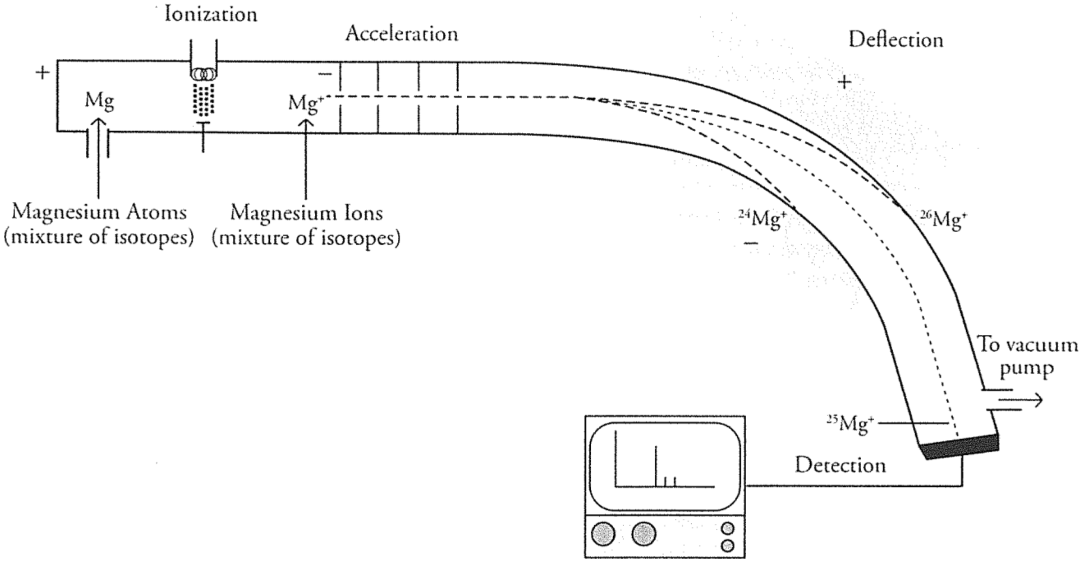
You will be able to:
1. Explain how a mass spectrometer generates data about the atomic or molecular mass.
2. Predict the mass spectrum that corresponds to a particular atom or molecule.
3. Use the mass spectrum to estimate the average atomic mass of an element.

The Plan

1. Assign roles*.
   a. ***Manager*** – This person will keep the team on task and provide direction to the group. This person is responsible for uploading the group's work to Gradescope. Make sure you make a note of everyone in the group. You must add everyone's name when submitting your answers to Gradescope.
   b. ***Spokesperson*** – This person will represent the group be responsible for speaking for the group to the rest of the class.
   c. ***Recorder*** – This person will be responsible for recording the team's answers to the Critical Thinking Questions in an organized and coherent manner.
   d. ***Analyst*** – This person will be responsible for critical analysis of the team's work (i.e., the Devil's Advocate). This person should make sure everyone understands what is happening before the group moves forward.
2. Complete the Critical Thinking Questions as a group.
3. Submit your team's work via Gradescope. Groups may choose to work in a Word document or write out their answers on a separate sheet of paper. All work must be upload to Gradescope as a PDF file.

**Students may choose to complete this activity independently if they are unable to attend discussion due to illness or injury; in which case, the student must perform all roles and complete all aspect of the activity. To receive full credit, documentation as to the need for the absence from discussion must be included with the submission and your TA must be notified of the absence.*

Model 1: Sorting by Mass



1. According to Model 1, what four processes occur inside a mass spectrometer?
   Ionization, acceleration, deflection, and detection
2. Consider where the sample is introduced into the mass spectrometer in Model 1. Which one of the processes from Question 1 is the first process?
   Ionization
3. Match the four processes from Question 1 to the following descriptions:

   Detection 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.
   Deflection Ions are attracted to the negative side of the electromagnetic field causing separation of the mixture based on the mass and charge.
   Ionization Electrons are knocked off the sample particles to form (mostly) +1 ions.
   Acceleration Ions move through a series of charged plates to form a narrow beam of high-speed particles with equal kinetic energy.

4. When a sample is injected into the mass spectrometer, do the atoms or molecules turn into positive or negative ions? Justify your answer with at least two pieces of evidence from Model 1.
   The ions formed are positive because they are attracted to the negative terminals in the ionization chamber and of the electromagnetic field.
5. According to Model 1, what causes the sample mixture to become separated?
   The mass of the ion changes the amount of deflection by the electromagnetic field. Heavier ions are not deflected as much as lighter ones.

Information:

The key to mass spectrometry is that all of the particles go into the deflection chamber with the same kinetic energy. They do not, however, have the same **mass/charge ration (m/z)**. Although most of the ions a formed are +1 ions, their masses are different. Therefore, the amount of deflection they experience by the electromagnet is different. The strength of the electromagnet can be varied so only particles with a particular mass/charge ratio can make it to the detector. Other particles collide with the metallics sides of the instrument, are neutralized, and then removed by the vacuum pump. The machine is calibrated using carbon-12 isotopes which are, by definition 12 amu (12.0000000…amu).

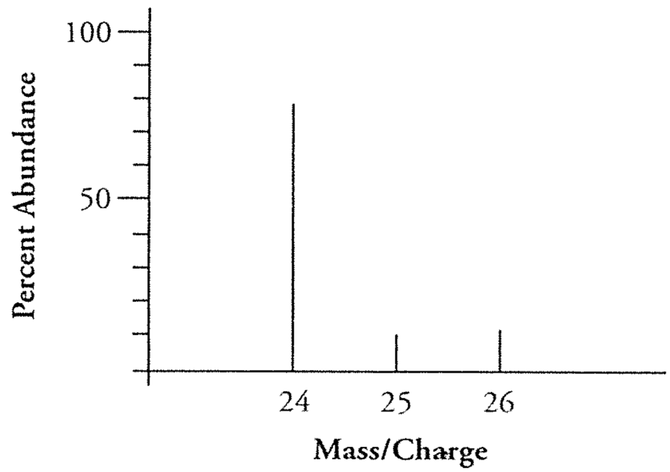
6. Consider the following ions formed in a mass spectrometer. Rank the ions in terms of their degree of

deflection by the electromagnet.

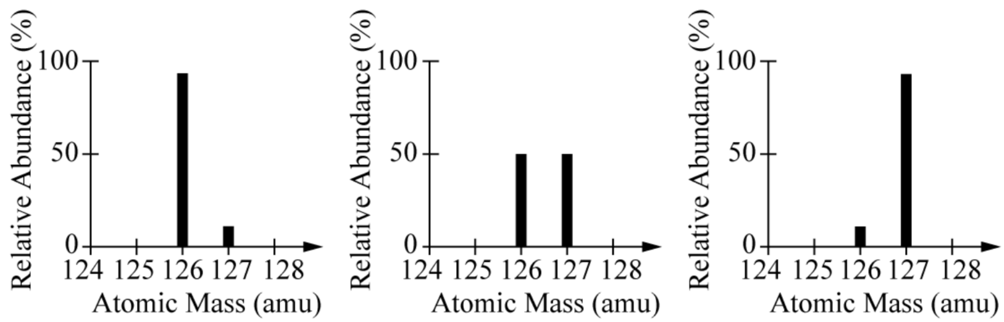
$^{19}F^{1+}$	$^{16}O^{1+}$	$^{17}O^{1+}$
Least	Most	Moderate

7. Why is it necessary to have the mass spectrometer chamber under vacuum (very low pressure) for it to work properly?
The ions must travel in continuous paths towards the detector. If there were gaseous atoms in the mass spectrometer chamber, they might impede the travel of the ions in the sample.

Model 2: A Mass Spectrum



8. Model 2 to the right is the mass spectrum that resulted from the experiment in Model 1.
   a. What is the mass number of the most common isotope of magnesium?
   24
   b. What is the percent abundance of the most common isotope of magnesium?
   80%
9. The average atomic mass of an element can be estimated from the data on a mass spectrum.
   a. Calculate the average atomic mass of magnesium using the data from Model 2.
   Average atomic mass = 24(.80) + 25(.10) + 26(.10) = 24.3 am
   b. Given two reasons why your calculated value in part a is only an estimate of the average atomic mass of the element magnesium.
   The mass number is not the same as the atomic mass of the isotopes. The average atomic mass would most likely not be an integer value. Also, it is difficult to read the exact percent abundance on the mass spectrum, so they are considered estimates.
10. Students were asked to sketch the mass spectrum for iodine. Consider the three mass spectra below. Which would best represent a sample of iodine atoms? Explain your choice.

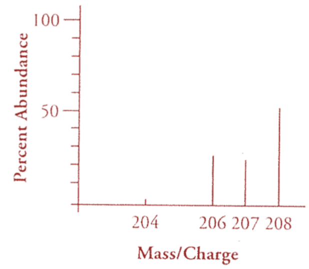


Spectrum A Spectrum B Spectrum C

Spectrum C would best depict a sample of iodine atoms. The atomic mass of iodine is 126.90 amu. This indicates that the average atomic mass is weighed most closely to iodine-127.

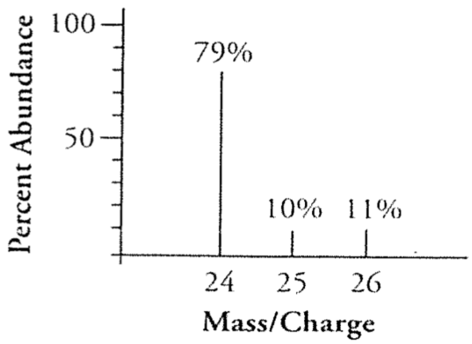
11. The table below provides the mass number and percent abundance information for the element lead. Draw a mass spectrum for lead. (You can assume only +1 ions of lead are formed.

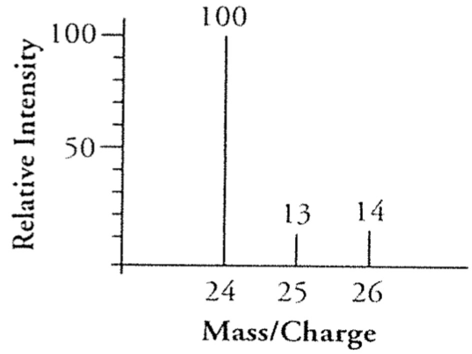
^{204}Pb	1.4%
^{206}Pb	24.1%
^{207}Pb	22.1%
^{208}Pb	52.4%



Information

The mass spectra you have been looking at in this activity used the percent abundance on the y-axis. Typically, however, the spectra use relative intensity. The ions from the same are sorted by mass/charge ration by the mass spectrometer. The ion that hist s the detector most often is assigned a relative intensity of 100. The other ions are given proportional relative intensities based on their abundance in the sample. An example of magnesium's mass spectrum shown both ways is given below.



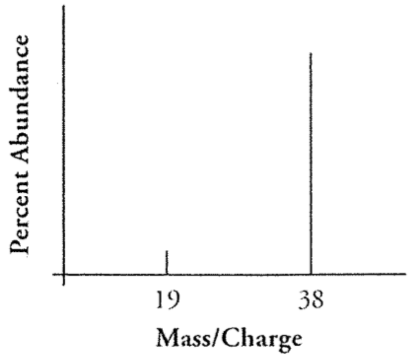


12. Consider the two mass spectra above.
    a. The sum of all percent abundances for magnesium is equal to 100. Explain why this is reasonable.
    If all isotopes are accounted for, you must have 100% of the atoms.
    b. The sum of all relative intensities for magnesium does not equal 100. Explain why this is reasonable.
    Since the tallest peak is assigned 100, the total of all peaks will be greater than 100 unless there is only one isotope (one peak).
13. Imagine that the relative intensities on the mass spectra represent the number of particles in a sample.
    a. Theoretically, how many magnesium ions were detected by the mass spectrometer?
    100+13+14=127
    b. What percentage of ions were ^{24}Mg ions? Show mathematical work to support your answer.
    (100/127)*100 = 78.7% ≈ 79%
    c. Show mathematically how to convert the 13 peak in the relative intensity spectrum to the 10% shown in the percent abundance spectrum.
    (13/127)*100 = 10.2% ≈ 10%

Information

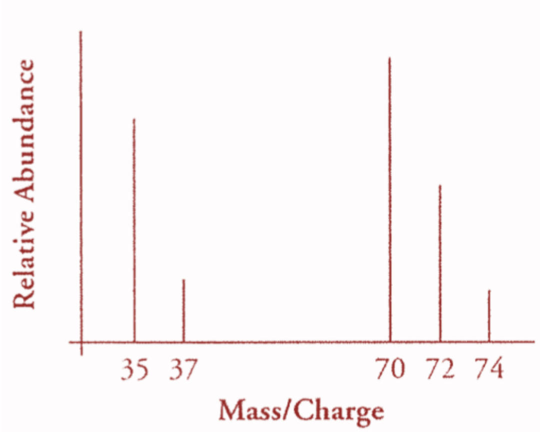
The process of ionization inside the mass spectrometer is quite violent. There are several methods of ionization used in industry, but many of them remove electrons from atoms or molecules by high energy particle bombardment. In other words, the electrons are knocked off the atoms or molecules by high 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 molecule.

14. The information shown on the right was gathered by the mass spectroscopy for the element fluorine. Fluorine has one natural isotope and tends to form diatomic molecules. Propose an explanation for the two lines on fluorine's mass spectrum.
    The mass number for atomic fluorine is 19. A diatomic molecule of fluorine would have an approximate mass of 38. Since most of the fluorine would be diatomic, that peak is larger. Some of the molecules would be fragmented to give the atomic peak at 19. This happens only occasionally, so the 19 peak is much smaller.



15. The element chlorine has two natural isotopes: ^{35}Cl (76% abundance) and ^{37}Cl (24% abundance). The mass spectrum of chlorine 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.
    $^{35}Cl_2^+$= 70 $^{37}Cl_2^+$= 74 $^{35}Cl—^{37}Cl^+$= 72

    b. Explain the remaining two lines in the spectrum.
    The other lines would be from fragments (single atoms) of chlorine: ^{35}Cl and ^{37}Cl.
    c. Draw a mass spectrum that would result from diatomic chlorine. Include the mass/charge number and estimate the relative abundances 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 isotope of isotope.



Answers will vary. Students should be able to show understanding by including both the single atom peaks and the molecular peaks. The heights of the peaks are more difficult to predict, but there should be some indication that the 35Clis more common, and therefore, those peaks will be higher.