

## Objectives:

- Standard CHEM.1.1: Obtain, evaluate, and communicate information regarding the structure of the atom on the basis of experimental evidence. Emphasize the relationship between proton number and element identity, isotopes, and electrons in atoms. Examples of experimental evidence could include the gold foil experiment, cathode ray tube, or atomic spectrum data. (PS1.A)
- Standard CHEM.1.2: Analyze and interpret data to identify patterns in the stability of isotopes and predict likely modes of radioactive decay. Emphasize that different isotopes of the same element decay by different modes and at different rates depending on their nuclear stability. Examples of data could include band of stability charts, mass or nuclear binding energy per nucleon, or the inverse relationship between half-life and nuclear stability. (PS1.C)

**Total time predicted: 120 minutes**

## Introductory activity (15 minutes):

Break students into groups of 4. Each group will need:

- Some textbooks (about 3) to put a track on
- Some Hot Wheels™ track
- A large metal ball bearing
- A small metal ball bearing
- A rubber ball
- A magnet (relatively strong)

Before beginning the activity, ask students to make predictions about where each of the balls will end up. Be sure that they give reasoning supporting their prediction (you can ask, “why do you think this is?”) As an additional support, you could print of a diagram of the experiment setup and ask them to trace where they think each ball will go (I recommend three different colors of crayons). Alternatively, consider printing and laminating 1 copy of the activity per group and have students draw with a whiteboard marker.

Have students complete the activity as directed. They should record results on the same page.

Discuss results as a class. Possible prompts for discussion include:

- Which ball was most effected by the magnet? Why do you think this is?
- Which ball was least effected by the magnet? Why do you think this is?
- If you had 500 balls of varying masses, could you use this method to separate them? Explain.
- If we used electrical forces instead of magnetic forces, how could this influence our results?
- What types of objects could we study using electric forces in a similar setup?

Be sure students developed the following understandings:

- 1) To interact with the magnet, the object must be metallic. The rubber ball was not impacted by the magnet.
- 2) Lighter objects will turn at sharper angles. This means that we can use similar methods to sort objects by mass.

## **Background information (have students read this section, potentially with their groups)**

### Model 1 (O<sub>2</sub>):

Students will need a copy of this per person or per group. It has been fit to a single page so you can print and have students looking at just this model before moving on. Consider having students write directly on it like a worksheet, or (again) laminate it and have them use a whiteboard marker.

After they complete part of this page, hold a class discussion about it. Possible prompts include:

- What structure(s) could explain the peak at the m/z ratio of 16?
  - Single oxygen with -1 charge
  - Double oxygen with -2 charge
- How do we know which of these is correct?
  - You're not looking for anything specific here. This question is just to get students thinking.
- What structure(s) could explain the peak at the m/z ratio of 32?
  - Double oxygen with -1 charge
- Where would you see a peak if a single oxygen atom developed a -2 charge? Is there a peak there? What does this tell us about that configuration?
  - You would expect a peak at 8. The graph doesn't show a peak there, indicating this is not a likely structure or that the graph was cut off.
- In the mass spectrum above, the peak at 16 is much shorter than the peak at 32. The height of the peak represents relative amounts detected. Since the peak at 32 is higher than the peak at 16, more of it was detected. What does this say about the stability of the different configurations discussed above?
  - The peak at 32 is MUCH higher than the peak at 16. This indicates that the two oxygens sticking together with a -1 charge is the most likely outcome for this setup.

### Model 2:

Overall, this is a much more complicated model. It introduces multiple new factors:

- More atoms to rearrange, and thus more possible structures
- One of the peaks can ONLY be explained with a -2 charge

If you would like to reinforce these skills for students, do the activity. If you are concerned that your students are not ready for these two skills, you may skip it, and do model 3 as a guided practice.

With your guidance, students will need to make a chart of possible structures and predict their m/z ratios. They should identify possible structures independently, should compare their list to the table below (they don't have the table), and will need you to walk through the predicted m/z ratios. Complete 2-3 of these with them, then have them finish the rest.

Arrangement	m/z ratio expected if -1 charge	m/z ratio expected if -2 charge
Carbon by itself	$12/1=12$	$12/2=6$
Oxygen by itself	$16/1=16$	$16/2=8$
1 carbon and 1 oxygen	$12+16=28$ ; $28/1=28$	$28/2=14$
1 carbon and 2 oxygen	$12+16*2=44$ ; $44/1=44$	$44/2=22$
2 oxygens together	$16*2=32$ ; $32/1=32$	$32/2=16$

You may choose to add a group discussion here to check for student understanding, or check groups individually. If you choose to check groups individually, have them show you're their completed chart and their answers to the 3 prompts.

For group discussions, you might ask the questions posed in the worksheet:

- Which of your predicted peaks are present?
  - 12 (Carbon by itself)
  - 16 (Oxygen by itself, or double oxygen with -2)
  - 28 (1 carbon with 1 oxygen)
  - 44 (CO<sub>2</sub> stayed together with -1 charge)
  - 22 (CO<sub>2</sub> stayed together with -2 charge)
- What peaks (if any) are shown that you didn't predict?
  - There is a small peak at 22 that sometimes blends in
  - There is also a small peak at 45 that students might miss. This is an isotope peak caused by variations in Carbon.
- Which peak(s) can only be explained by having a molecule with a charge of 2?
  - 22 (CO<sub>2</sub> stayed together with -2 charge)

Model 3 (N<sub>2</sub>):

If you chose to skip model 2, you will need to complete the table of predicted structures and m/z ratios for this molecule with the class. Otherwise, they should be able to complete this section independently.

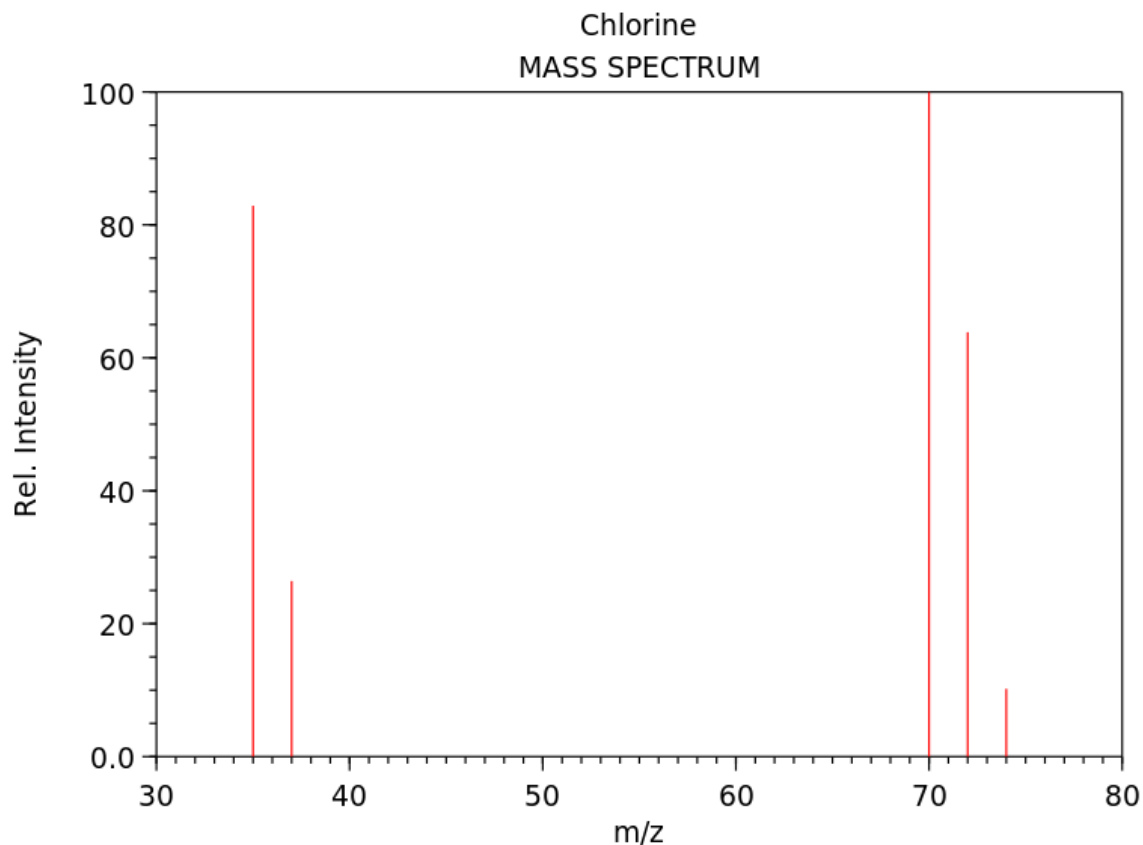
Model 4 (Br<sub>2</sub>):

Students should be able to complete the prediction section independently. During the follow-up questions, they will be confronted with isotope peaks (see questions 9-11). You could guide their thinking by asking separately about protons, neutrons, and electrons. The conclusion is that the only explanation for these peaks is the neutrons.

- Protons would change the elements present
- Neutrons would move the peaks slightly because they affect the mass but not the charge
- Electrons would move the charge significantly because they would change the charge, so you would be dividing by a larger number.

Model 5 (Cl<sub>2</sub>):

Students will need computer access for this portion. They will be looking for a mass spectrum for chlorine. The mass spectrum is included below in case of technical difficulties:



NIST Chemistry WebBook (<https://webbook.nist.gov/chemistry>)

New understandings from this problem are that isotopes exist in different ratios. On #16, they should be able to predict that since chlorine-35 is more common, the average mass should be closer to 35 than it is to 37. For AP students, you could have them calculate relative amounts and do a weighted average, but that is beyond the scope of this course.

Conclusions:

Have a final discussion with the class about how we know that the isotope peaks (different masses, but still same element) can only be adequately described by changes in the numbers of neutrons. There is a table for students to fill out to help guide their thinking.

Make sure they remember the following:

Protons determine the identity of the elements (neutrons and electrons have no influence on this)

Protons and neutrons can both influence mass (but we already ruled out protons as the cause)

Electrons don't noticeably impact mass, they only affect the charge.

Therefore, isotopes can also be defined as atoms of the same element with different numbers of neutrons.

After this activity, they will be reading about isotopes from the state's OER book. You may choose to have them read this in the middle of this activity (after either model 2 or model 3).

<https://emedialib.uen.org/courses/utah-oer-textbooks-chemistry-seed/view>

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## Objectives:

- I can identify common isotopes from a mass spectrum
- I can describe how these isotopes differ from each other

## Introductory activity (15 minutes):

Get in groups based on your teacher's instructions.

### Materials:

Some textbooks (about 3) to put a track on

Some Hot Wheels™ track

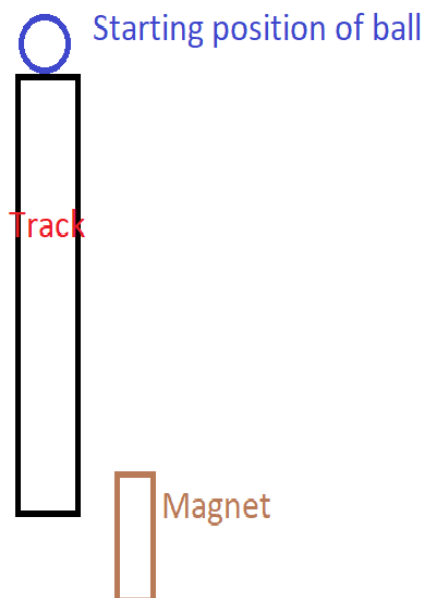
A large metal ball bearing

A small metal ball bearing

A rubber ball

A magnet (relatively strong)

Before beginning the activity, make predictions about where each of the balls will end up. Be sure to give reasoning supporting your prediction. Draw your predicted path for each of the 3 balls in dotted lines of different colors on the drawing below:



Stack the books, then put one end of the track on the books with the other end on the floor. Place the magnet near the bottom of the track.

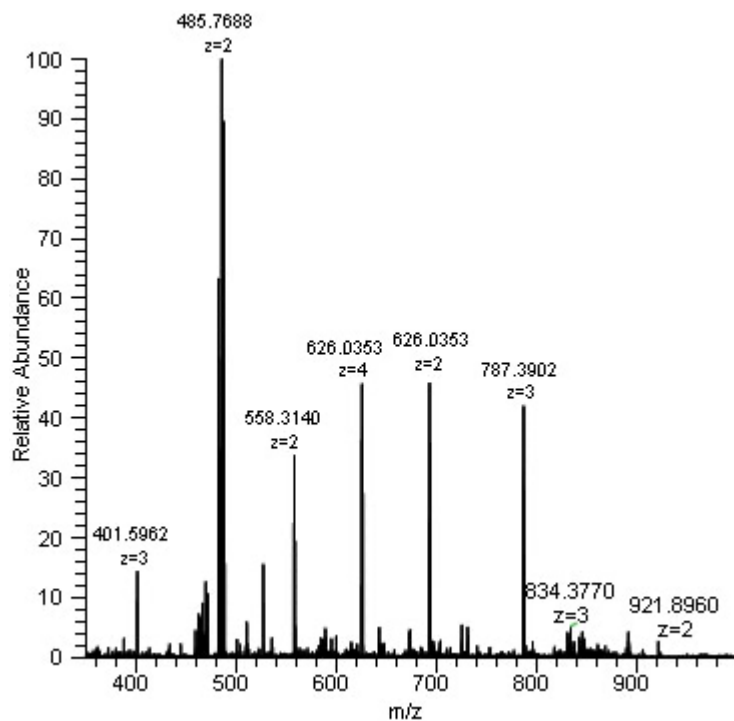
Then, place the large ball bearing on the top of the track. Release it, then mark where it goes after passing the magnet. Draw your results as a solid line. Repeat for both the small ball bearing and the rubber ball. Be prepared to discuss your predictions as well as your results with the class.

## **Background information:**

The periodic table is a compilation of several pieces of information. For example, we can easily look at the periodic table and identify how many protons are in an atom of helium (we look at the atomic number, which for helium is 2). We can also find the average mass of that element (not all individual atoms are the same; more on that later. The averages are consistent though). For example, the average mass of Carbon is 12.011 (again, remember this is an average). We can also tell how many electrons that atom has (so far, we've used the atomic number for that as well, so that the protons and electrons balance each other out.)

Atoms frequently gain and lose electrons. When they do so, they become electrically charged, and are referred to as ions. This can happen in a large variety of ways, including interactions with other atoms, exposure to high-energy light, and others. Knowing the charge of an ion allows us to further study and understand its behavior. We'll learn more about common charges of atoms later in the course.

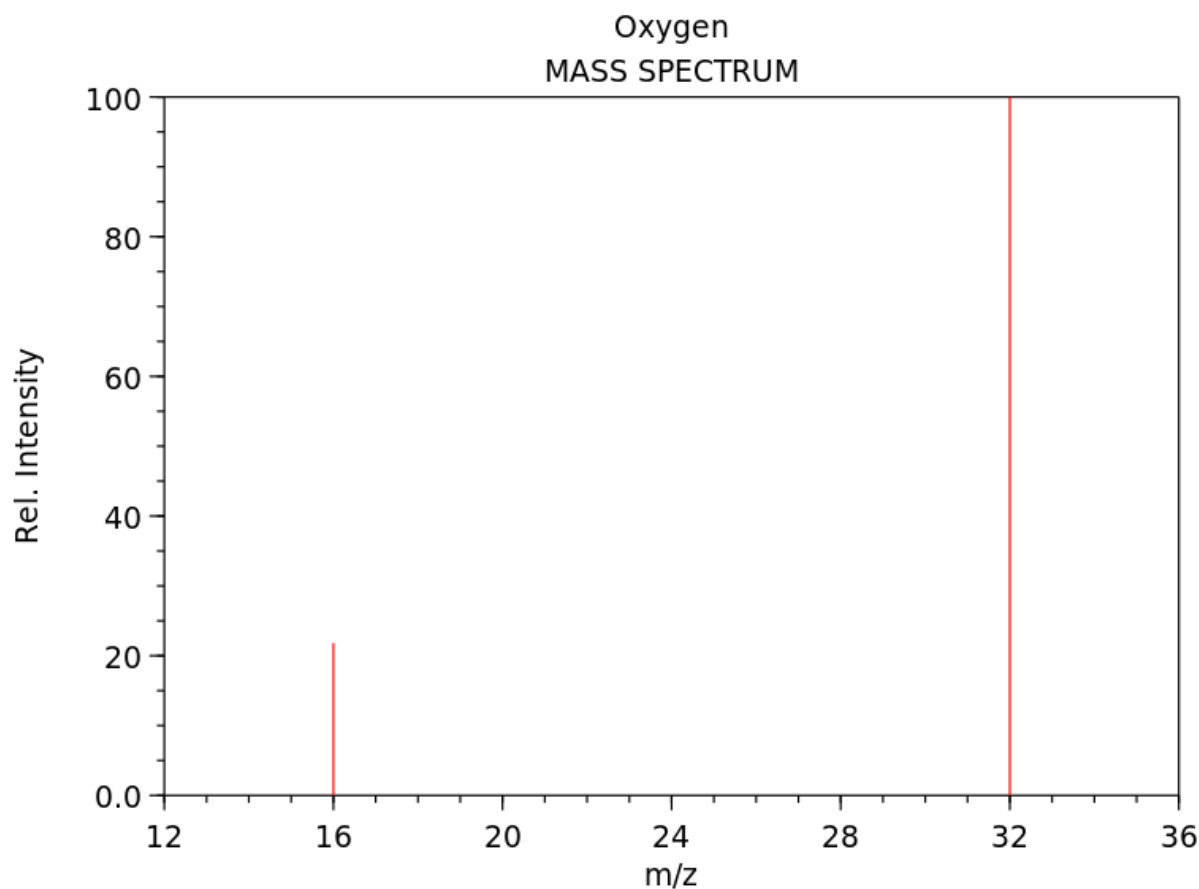
If we know both the mass of an atom and its charge (how many electrons it has gained or lost), we can calculate the mass/charge ratio (abbreviated  $m/z$ ). This quantity is highly useful in a field of chemistry known as mass spectroscopy. Mass spectroscopy identifies substances based on the mass/charge ratio. The mass/charge ratio ( $m/z$ ) is calculated by taking the mass of an ion and dividing by its electrical charge. It is always reported as a positive number, so take the absolute value as needed. Using electrical forces, the substances involved are sorted by this ratio. For example, every ion with a  $m/z$  ratio of 7 will end up behaving differently than ions with a  $m/z$  ratio of 8. We can then measure the quantity of each of these groups. This gives us information about which substances are present, and also how much of each is present. A graph is produced of the data that looks like the following:



Scientists then look at the high points (peaks) of the graph to determine the amounts of the substances present, ignoring the lower portions, referred to as "noise". For simplicity, the graphs you will be analyzing will show just the peaks; the "noise" has been taken off for clearer communication.

Model 1 (O<sub>2</sub>):

Let's look at the mass spectrum for Oxygen (O<sub>2</sub>):



NIST Chemistry WebBook (<https://webbook.nist.gov/chemistry>)

Question: At what m/z values do you see peaks?

Question: According to the periodic table, what is the atomic mass of oxygen?

Question: In O<sub>2</sub>, there are 2 oxygen atoms. List as many ways as you can think of that these can be rearranged (we'll refer to these as the structures).

Question: On the graph above, label the peaks according to which of your predicted structures would correspond to it.

Question: One of the peaks in the above graph is higher than the other. What does this tell you about the two structures?

Question: Which of your predicted structures is more stable? How do you know?

Be prepared to answer these questions during the class discussion.



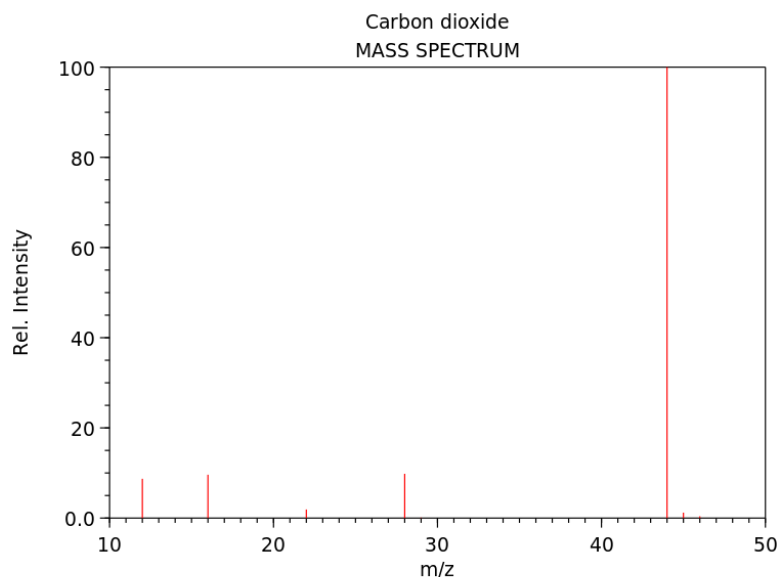
Model 2 (CO<sub>2</sub>):

For our next task, we will be looking at the mass spectrum of CO<sub>2</sub>. Remember: this contains 1 carbon atom and 2 oxygen atoms. Before we look at the graph, identify as many ways as you can to separate this molecule into pieces. You will be comparing to other the rest of the class.

During the class discussion, fill out the table below:

Structure	m/z ratio expected if -1 charge	m/z ratio expected if -2 charge

As we look at the graph, if we see peaks at those points, then the prediction was a valid possibility. Look at the graph and identify the peaks present:



NIST Chemistry WebBook (<https://webbook.nist.gov/chemistry>)

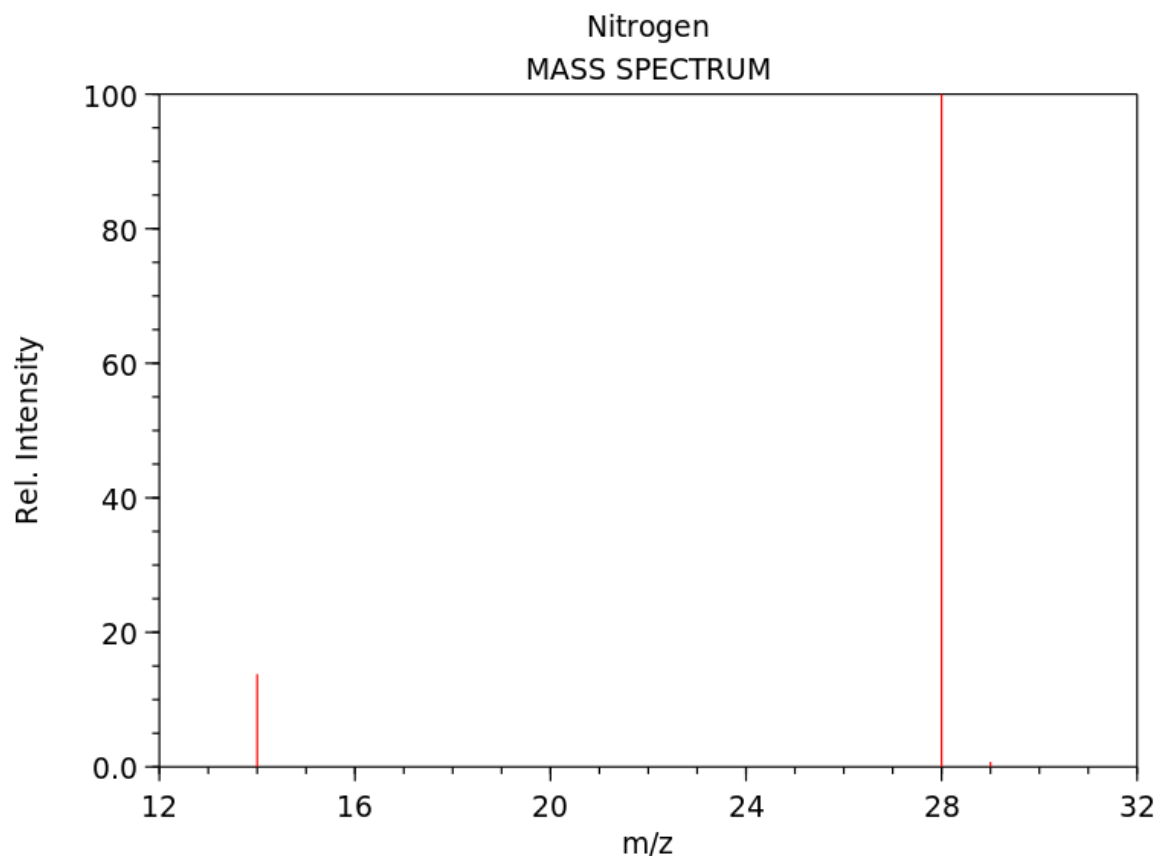
**Answer the following questions:**

1. Above each peak, list the structure it corresponds to.
2. Which of your identified structures is the most stable? How do you know?
3. Which peak(s) can only be explained by having a molecule with a charge of 2?

Model 3 (N<sub>2</sub>):

Predictions:

Structure	m/z if -1 charge	m/z if -2 charge



NIST Chemistry WebBook (<https://webbook.nist.gov/chemistry>)

4. At what m/z ratios are there peaks? (Look at the x-axis)

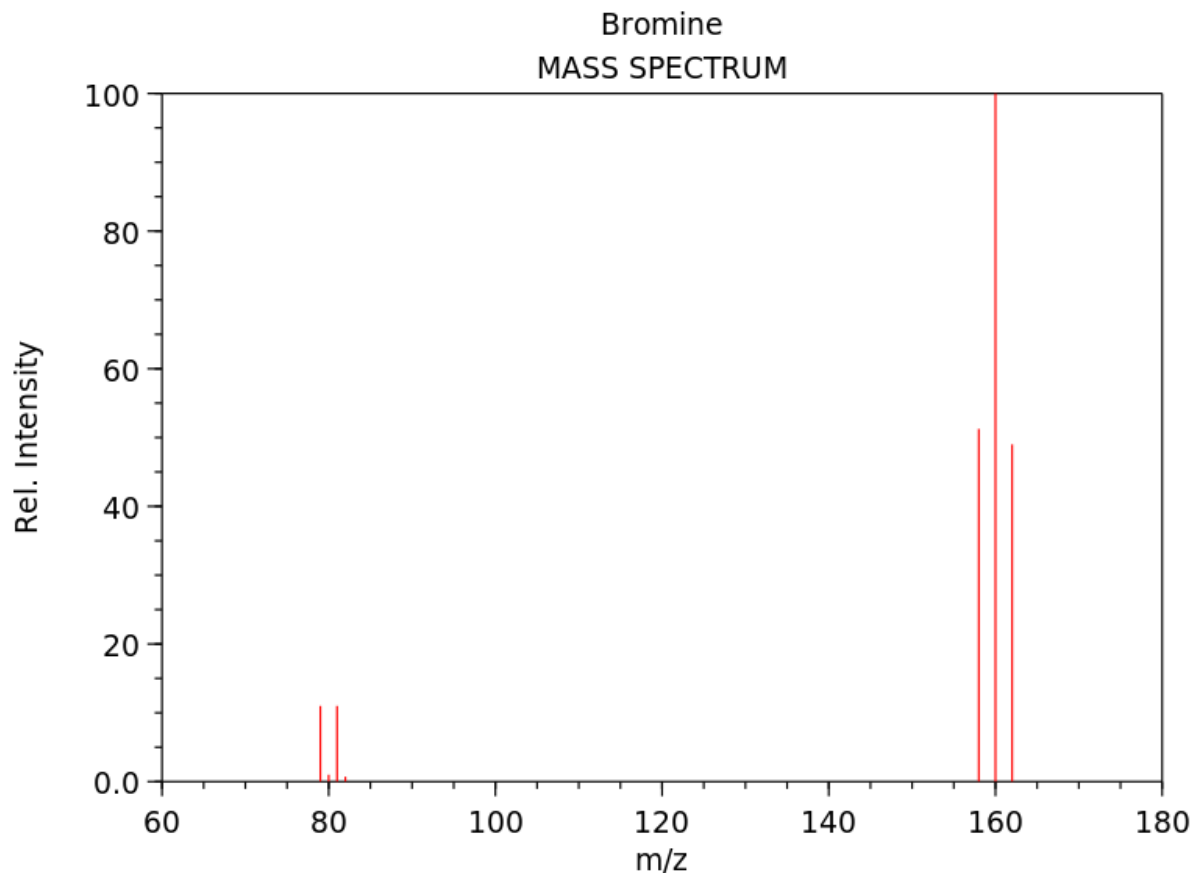
5. Which peak is the highest? What is the most likely structure of the atoms for this peak?

6. There is a small peak of a m/z ratio of 29. What do you think is causing that peak? Why do you think it is so much smaller than the peak at 28?

Model 4 (Br<sub>2</sub>):

**Predictions:**

Structure	m/z if -1 charge	m/z if -2 charge



NIST Chemistry WebBook (<https://webbook.nist.gov/chemistry>)

7. At what m/z ratios are there peaks?

8. Which peak is the highest? What is the most likely structure of atoms for this peak?

9. For the other substances examined so far, there has been a peak at exactly half of the highest peak. Bromine breaks this trend. Where are the peaks at instead?

10. As you can see, there is a peak at 79 and another at 81. This means that there are two different m/z ratios detected. What could differ about the atoms shown in each peak? (Hint: remember that atoms are composed of protons, neutrons, and electrons).

11. Use your answer to #10 to describe why we also see peaks at 158 and 162.

Model 5 (Cl<sub>2</sub>):

**Predictions:**

Structure	m/z if -1 charge	m/z if -2 charge

Use the internet to find a mass spectrum for Chlorine (Cl<sub>2</sub>). Sketch what you see below:

12. What peaks are present in the graph above?

13. Based on the data given and your own predictions, which structure of atoms is the most common for chlorine?

14. On the left side of the graph, there are two distinct peaks (35 and 37). Since chlorine is the only element present, they must both be chlorine. How could differences in atomic structure (protons, neutrons, and electrons) lead to there being multiple peaks?

15. Based on the graph given, what form of chlorine do you expect to be the most common? Justify your answer.

16. The average mass of Chlorine is 35.45. What relation does this average have to the height of the peaks observed?

17. Use the data and your answer to #15 to explain why the peak at 74 is shorter than the peaks at 70 and 72.

18. Copy the URL of your chosen source here. Then, explain why you feel your source is reliable.

## Conclusions:

The mass spectra we have looked at show a lot about the atoms and their structure. The first few looked at how mass spectra can identify different structures of the atoms and how common different groupings are. The last few, however, demonstrated that many elements have multiple versions, called "isotopes". Isotopes are atoms of the same element with different masses.

For each of the 3 subatomic particles, describe how they would impact the identity of the chemical and the mass spectrum.

Subatomic Particle	Effect on Element Identity	Effect on Mass Spectrum
Proton		
Neutron		
Electron		

Which of the particles above is most likely responsible for the formation of isotopes?