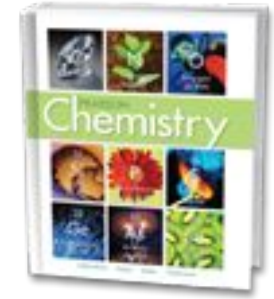
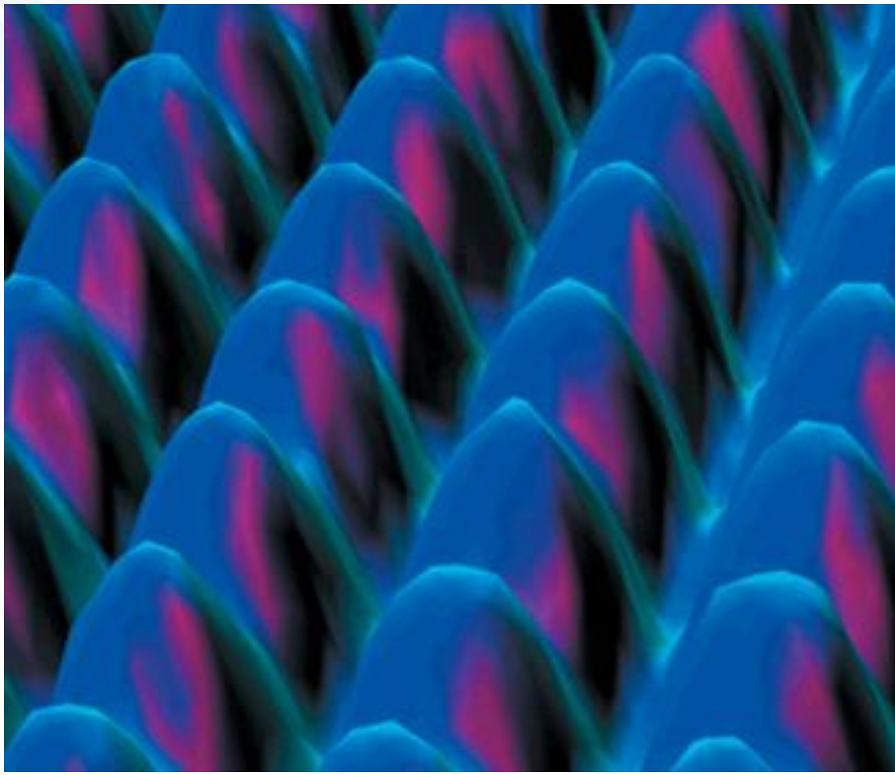




Chapter 4
Atomic Structure

How can there be different varieties of atoms?

Just as there are many types of dogs, atoms come in different varieties too.

Atomic Number and Mass Number

What makes one element different from another?

Atomic Number

Elements are different because they contain different numbers of protons.

- An element's **atomic number** is the number of protons in the nucleus of an atom of that element.
- The atomic number identifies an element.

For each element listed in the table below, the number of protons equals the number of electrons.

Atoms of the First Ten Elements						
Name	**Symbol**	**Atomic number**	**Protons**	**Neutrons**	**Mass number**	**Electrons**
Hydrogen	H	1	1	0	1	1
Helium	He	2	2	2	4	2
Lithium	Li	3	3	4	7	3
Beryllium	Be	4	4	5	9	4
Boron	B	5	5	6	11	5
Carbon	C	6	6	6	12	6
Nitrogen	N	7	7	7	14	7
Oxygen	O	8	8	8	16	8
Fluorine	F	9	9	10	19	9
Neon	Ne	10	10	10	20	10

Atomic Number

Remember that atoms are electrically neutral.

- Thus, the number of electrons (negatively charged particles) must equal the number of protons (positively charged particles).

Understanding Atomic Number

The element nitrogen (N) has an atomic number of 7. How many protons and electrons are in a neutral nitrogen atom?

1 Analyze **Identify the relevant concepts.**

The atomic number gives the number of protons, which in a neutral atom equals the number of electrons.

2 Solve Apply the concepts to this problem.

- Identify the atomic number.
- Then use the atomic number to find the number of protons and electrons.

The atomic number of nitrogen is 7.

So, a neutral nitrogen atom has 7 protons and 7 electrons.

Mass Number

The total number of protons and neutrons in an atom is called the **mass number**.

Mass Number

If you know the atomic number and mass number of an atom of any element, you can determine the atom's composition.

- The number of neutrons in an atom is the difference between the mass number and atomic number.

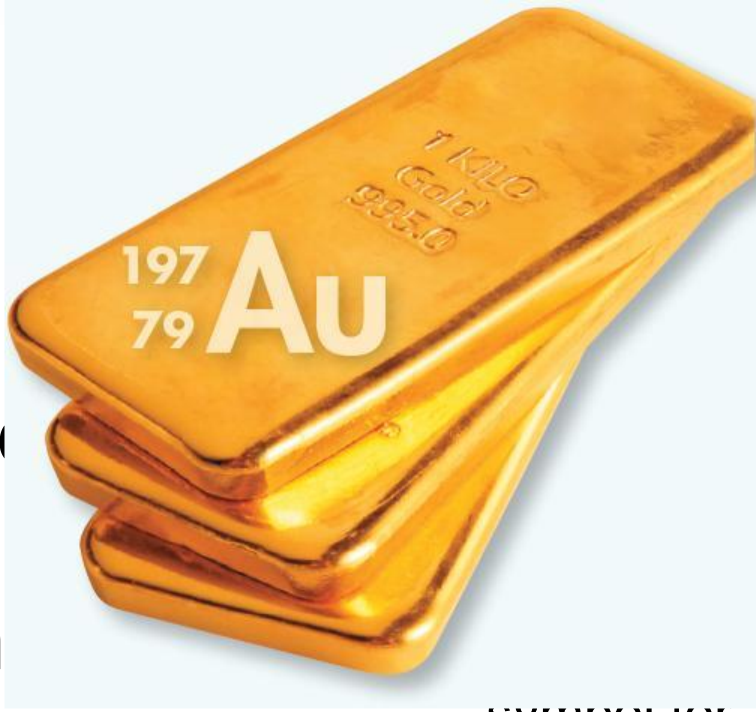
Mass Number

If you know the atomic number and mass number of an atom of any element, you can determine the atom's composition.

Number of neutrons = mass number – atomic number

Mass Number

The composition of any atom can be represented in shorthand notation using atomic number and mass number.

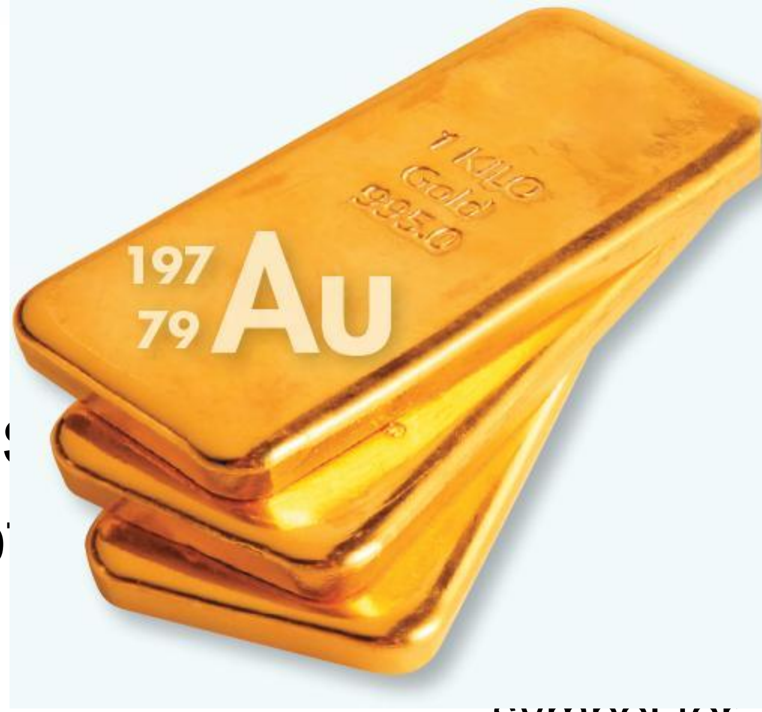


gold.

- The atomic number is the subscript.
- The mass number is the superscript.

Mass Number

You can also refer to atoms by using the mass number and the name of the element.



symbol for gold.

- $^{197}_{79}Au$ may be written as gold-197.

Determining the Composition of an Atom

How many protons, electrons, and neutrons are in each atom?

a. $^{9}_{4}\text{Be}$ **b.** $^{20}_{10}\text{Ne}$ **c.** $^{23}_{11}\text{Na}$

1 Analyze List the knowns and the unknowns.

Use the definitions of atomic number and mass number to calculate the numbers of protons, electrons, and neutrons.

KNOWNS

Beryllium (Be)
atomic number = 4
mass number = 9

Neon (Ne)
atomic number = 10
mass number = 20

Sodium (Na)
atomic number = 11
mass number = 23

UNKNOWNS

protons = ?
electrons = ?
neutrons = ?

2 Calculate **Solve for the unknowns.**

Use the atomic number to find the number of protons.

atomic number = number of protons

a. 4 **b.** 10 **c.** 11

2 Calculate **Solve for the unknowns.**

Use the atomic number to find the number of electrons.

atomic number = number of electrons

a. 4 **b.** 10 **c.** 11

2 Calculate **Solve for the unknowns.**

Use the mass number and atomic number to find the number of neutrons.

number of neutrons = mass number – atomic number

a. number of neutrons = 9 – 4 = 5
b. number of neutrons = 20 – 10 = 10
c. number of neutrons = 23 – 11 = 12

3 Evaluate **Do the results make sense?**

- For each atom, the mass number equals the number of protons plus the number of neutrons.
- The results make sense.

What information is needed to determine the composition of a neutral atom of any element?

What information is needed to determine the composition of a neutral atom of any element?

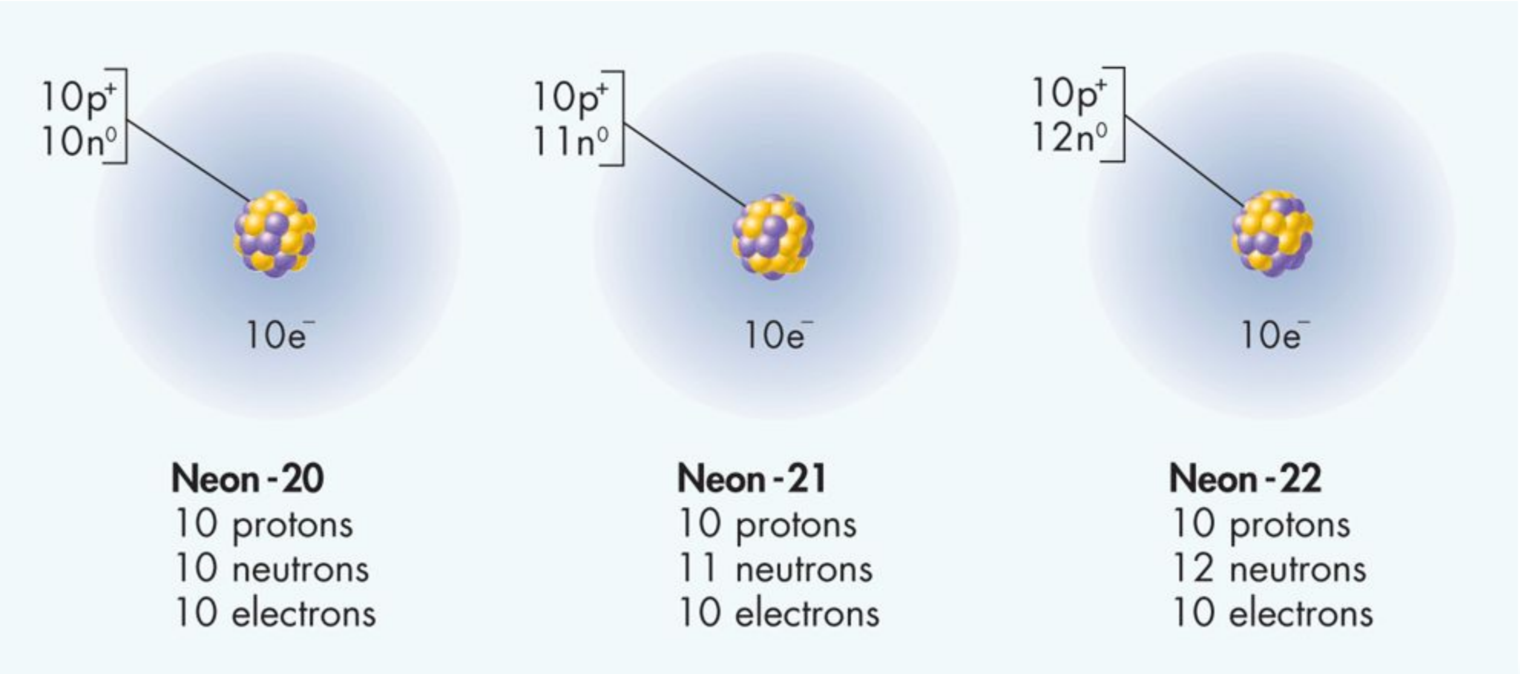
The atomic number and mass number are needed to determine an atom's composition. The atomic number gives the number of protons, which equals the number of electrons. The number of neutrons is the difference between the mass number and the atomic number.

Isotopes

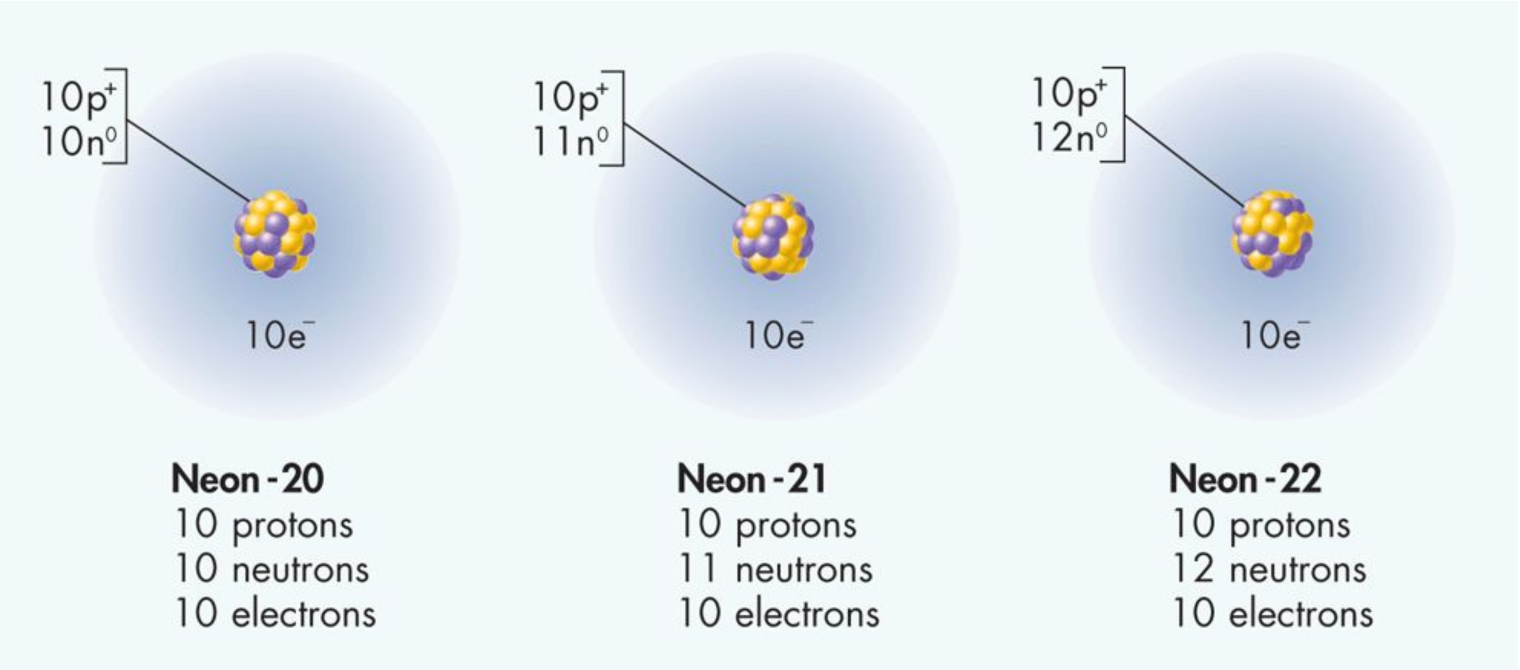
How do isotopes of an element differ?

There are three different kinds of neon atoms.

- How do these atoms differ?

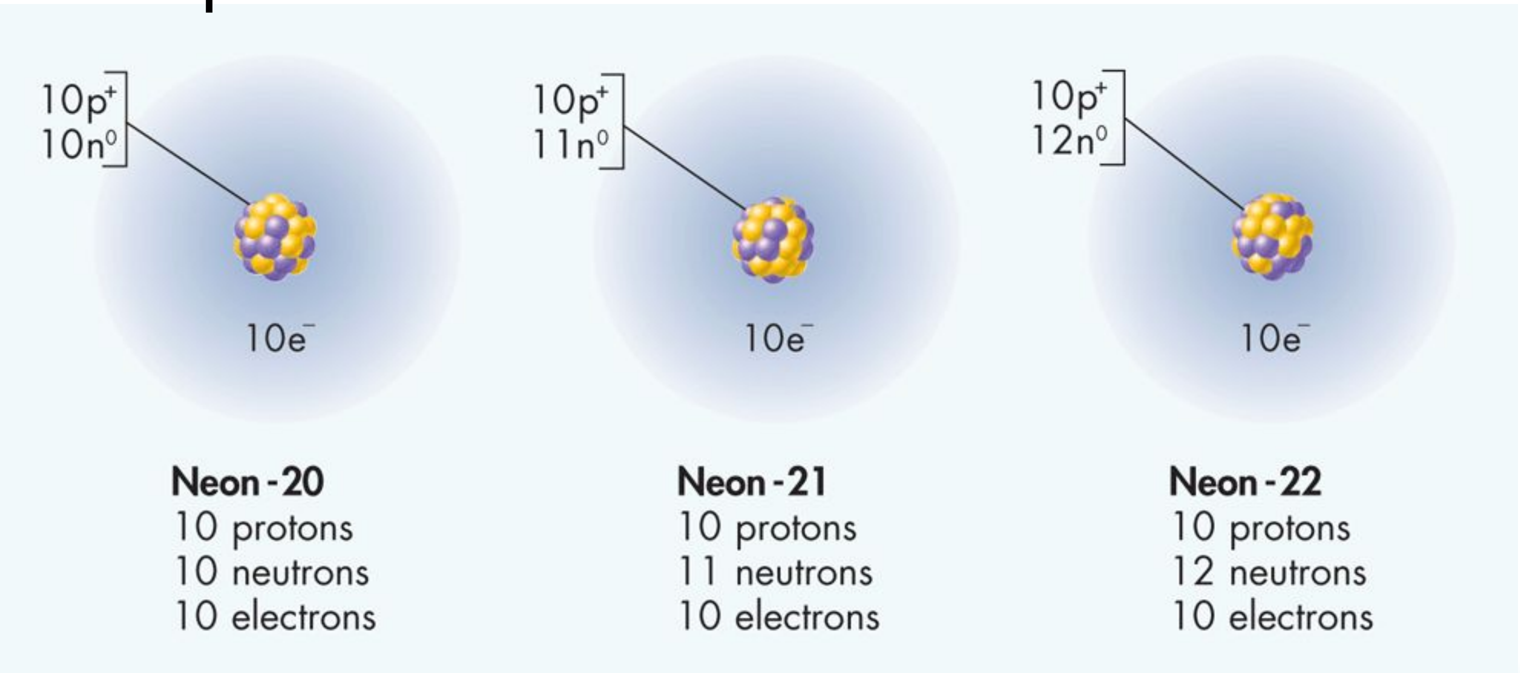


- All have the same number of protons (10).
- All have the same number of electrons (10).
- But they each have different numbers of neutrons.



Isotopes are atoms that have the same number of protons but different numbers of neutrons.

- Neon-20, neon-21, and neon 22 are three isotopes of neon.



Because isotopes of an element have different numbers of neutrons, they also have different mass numbers.

- Despite these differences, isotopes are chemically alike because they have identical numbers of protons and electrons, which are the subatomic particles responsible for chemical behavior.

Remember the dogs at the beginning of the lesson.

- Their color or size doesn't change the fact that they are all dogs.
- Similarly, the number of neutrons in isotopes of an element does not change which element it is because the atomic number does not change.

How are the atoms of one element different from the atoms of another element? How are isotopes of the same element different?

How are the atoms of one element different from the atoms of another element? How are isotopes of the same element different?

Atoms of different elements are different because they contain different numbers of protons. Isotopes of the same element are different because they have different numbers of neutrons, and thus different mass numbers.

Writing Chemical Symbols of Isotopes

Diamonds are a naturally occurring form of elemental carbon. Two stable isotopes of carbon are carbon-12 and carbon-13. Write the symbol for each isotope using superscripts and subscripts to represent the mass number and the atomic number.

1 Analyze **Identify the relevant concepts.**

Isotopes are atoms that have the same number of protons but different numbers of neutrons. The composition of an atom can be expressed by writing the chemical symbol, with the atomic number as a subscript and the mass number as a superscript.

2 Solve **Apply the concepts to this problem.**

Use Table 4.2 to identify the symbol and the atomic number for carbon.

The symbol for carbon is **C**.
The atomic number of carbon is **6**.

2 Solve Apply the concepts to this problem.

Look at the name of the isotope to find the mass number.

For carbon-12, the mass number is **12**.
For carbon-13, the mass number is **13**.

2 Solve **Apply the concepts to this problem.**

Use the symbol, atomic number, and mass number to write the symbol of the isotope.

For carbon-12, the symbol is $^{12}_{6}C$.

For carbon-13, the symbol is $^{13}_{6}C$.

Checkpoint

Why are atoms with different numbers of neutrons still considered to be the same element?

Checkpoint

Why are atoms with different numbers of neutrons still considered to be the same element?

Despite differences in the number of neutrons, isotopes are chemically alike. They have identical numbers of protons and electrons, which determine chemical behavior.

Atomic Mass

How do you calculate the atomic mass of an element?

The mass of even the largest atom is incredibly small.

- Since the 1920s, it has been possible to determine the tiny masses of atoms by using a mass spectrometer.
- The mass of a fluorine atom was found to be 3.155×10^{-23} g.

Such data about the actual masses of individual atoms can provide useful information, but in general these values are inconveniently small and impractical to work with.

- Instead, it is more useful to compare the relative masses of atoms using a reference isotope as a standard.
- The reference isotope chosen is carbon-12.

This isotope of carbon has been assigned a mass of exactly 12 atomic mass units.

- An **atomic mass unit (amu)** is defined as one-twelfth of the mass of a carbon-12 atom.

A carbon-12 atom has six protons and six neutrons in its nucleus, and its mass is set at 12 amu.

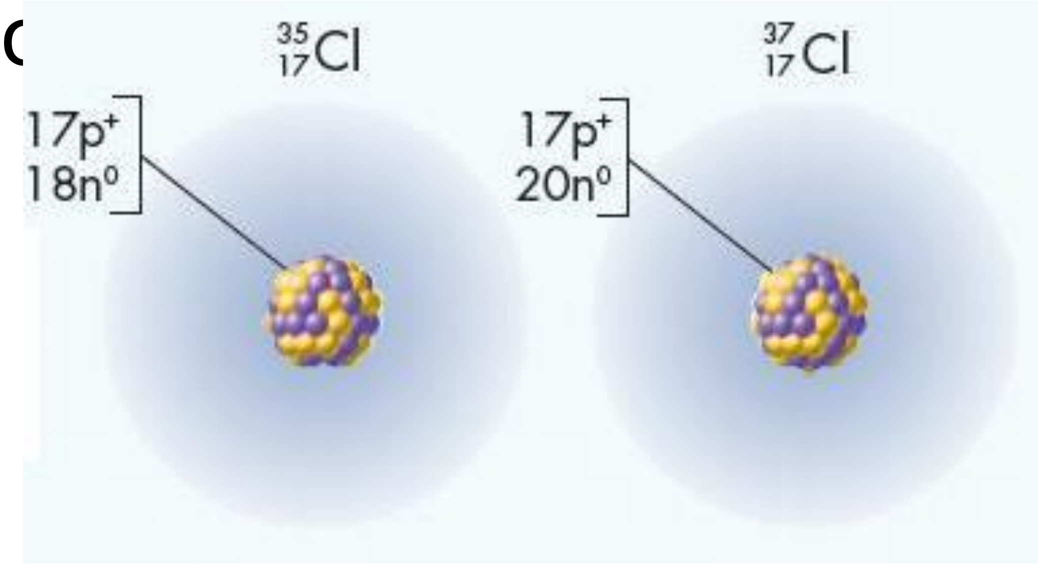
- The six protons and six neutrons account for nearly all of this mass.
- Therefore, the mass of a single proton or a single neutron is about one-twelfth of 12 amu, or about 1 amu.

In nature, most elements occur as a mixture of two or more isotopes.

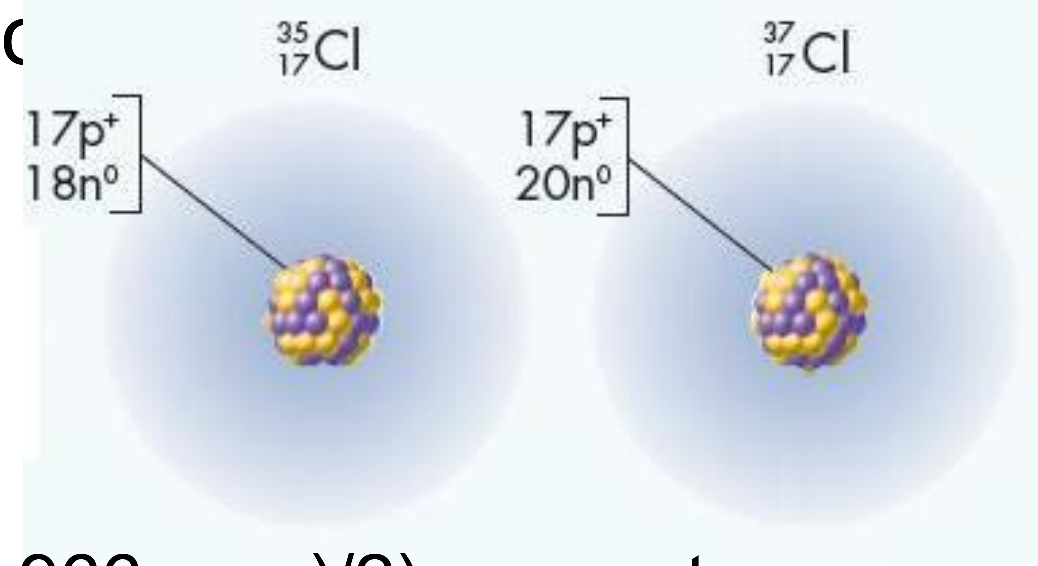
- Each isotope of an element has a fixed mass and a natural percent abundance.

Natural Percent Abundance of Stable Isotopes of Some Elements				
Name	Symbol	Natural percent abundance	Mass (amu)	Atomic mass
Hydrogen	$^{1}_{1}H$	99.985	1.0078	1.0079
	$^{2}_{1}H$	0.015	2.0141	
	$^{3}_{1}H$	negligible	3.0160	
Helium	$^{3}_{2}He$	0.0001	3.0160	4.0026
	$^{4}_{2}He$	99.9999	4.0026	
Carbon	$^{12}_{6}C$	98.89	12.000	12.011
	$^{13}_{6}C$	1.11	13.003	
Oxygen	$^{16}_{8}O$	99.759	15.995	15.999
	$^{17}_{8}O$	0.037	16.995	
	$^{18}_{8}O$	0.204	17.999	
Chlorine	$^{35}_{17}Cl$	75.77	34.969	35.453
	$^{37}_{17}Cl$	24.23	36.966	

Chlorine occurs as two isotopes:
chlorine-35 and chlo

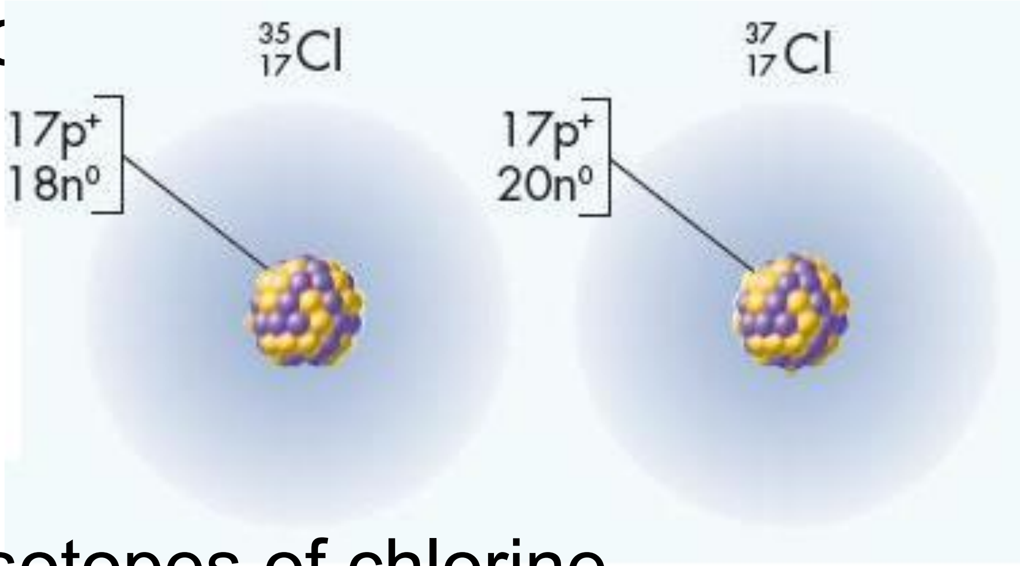


Chlorine occurs as two isotopes: chlorine-35 and chlo



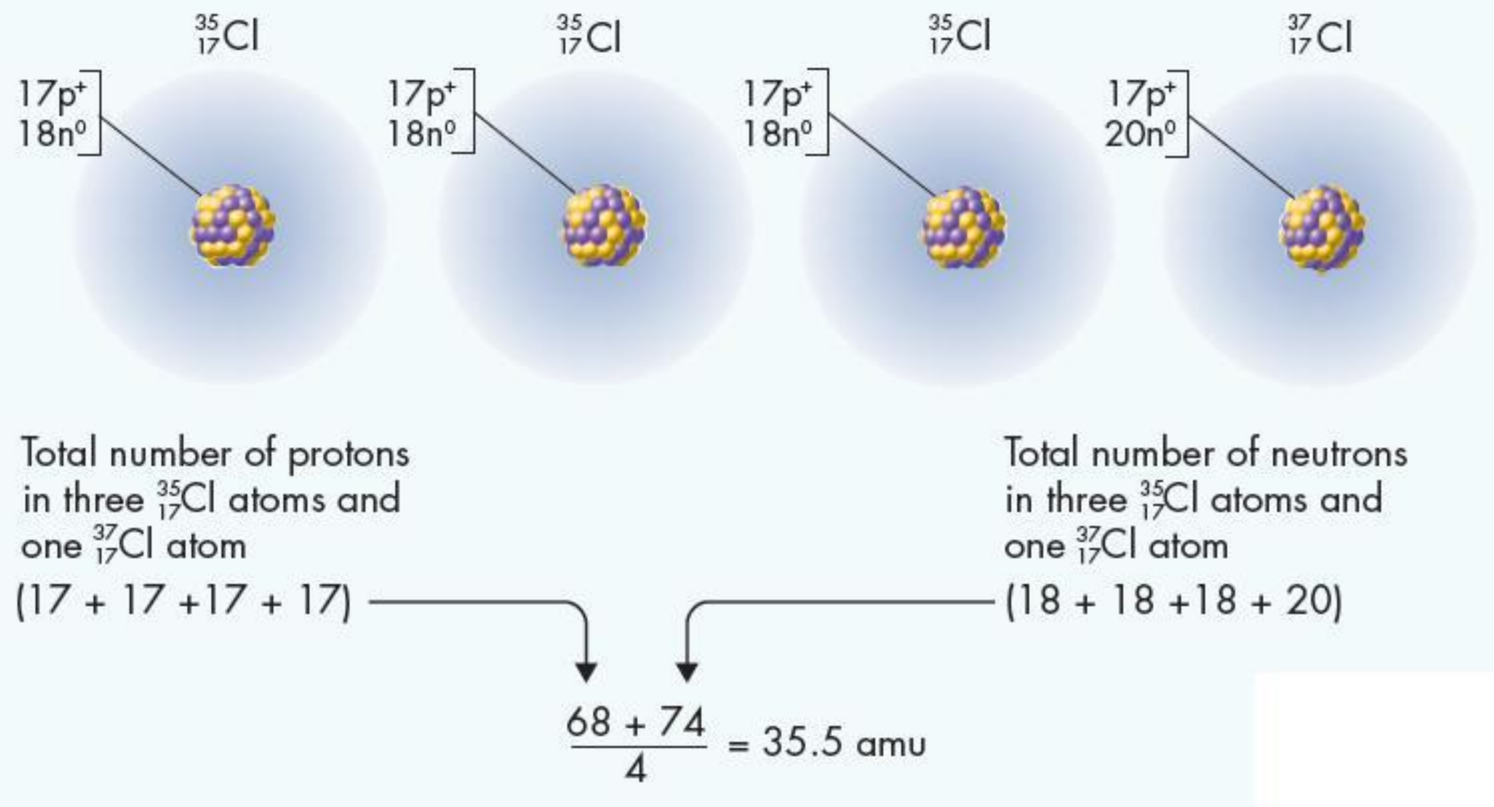
- If you calculate the arithmetic mean of these two masses ((34.968 amu + 36.966 amu)/2), you get an average atomic mass of 35.986.
- However, this value is higher than the actual value of 35.453.

Chlorine occurs as two isotopes: chlorine-35 and chl



- To explain this difference, you need to know the natural percent abundance of the isotopes of chlorine.
- Chlorine-35 accounts for 75 percent of the naturally occurring chlorine atoms; chlorine-37 accounts for only 24 percent.

Because there is more chlorine-35 than chlorine-37 in nature, the atomic mass of chlorine, 35.453 amu, is closer to 35 than to 37.



Weighted Average Mass of a Chlorine Atom

The **atomic mass** of an element is a weighted average mass of the atoms in a naturally occurring sample of the element.

- A weighted average mass reflects both the mass and the relative abundance of the isotopes as they occur in nature.

Understanding Relative Abundance of Isotopes

The atomic mass of copper is 63.546 amu. Which of copper's two isotopes is more abundant: copper-63 or copper-65?

1 Analyze **Identify the relevant concepts.**

The atomic mass of an element is the weighted average mass of the atoms in a naturally occurring sample of the element.

2 Solve Apply the concepts to this problem.

Compare the atomic mass to the mass of each isotope.

The atomic mass of 63.546 amu is closer to 63 than it is to 65.

2 Solve **Apply the concepts to this problem.**

Determine the most abundant isotope based on which isotope's mass is closest to the atomic mass.

Because the atomic mass is a weighted average of the isotopes, copper-63 must be more abundant than copper-65.

You can determine atomic mass based on relative abundance.

- To do this, you must know three things: the number of stable isotopes of the element, the mass of each isotope, and the natural percent abundance of each isotope.

To calculate the atomic mass of an element, multiply the mass of each isotope by its natural abundance, expressed as a decimal, and then add the products.

Carbon has two stable isotopes: carbon-12, which has a natural abundance of 98.89 percent, and carbon-13, which has a natural abundance of 1.11 percent.

- The mass of carbon-12 is 12.000 amu; the mass of carbon-13 is 13.003 amu.
- The atomic mass of carbon is calculated as follows:

Atomic mass of carbon = (12.000 amu x 0.9889) + 13.003 amu x 0.0111)

= (11.867 amu) + (0.144 amu)

= 12.011 amu

Calculating Atomic Mass

Element X has two naturally occurring isotopes. The isotope with a mass of 10.012 amu (^{10}X) has a relative abundance of 19.91 percent. The isotope with a mass of 11.009 amu (^{11}X) has a relative abundance of 80.09 percent. Calculate the atomic mass of element X.

1 Analyze List the knowns and the unknown.

The mass each isotope contributes to the element's atomic mass can be calculated by multiplying the isotope's mass by its relative abundance. The atomic mass of the element is the sum of these products.

KNOWNS

- Isotope ^{10}X:
  mass = 10.012 amu
  relative abundance = 19.91% = 0.1991
- Isotope ^{11}X:
  mass = 11.009 amu
  relative abundance = 80.09% = 0.8009

UNKNOWN

atomic mass of X = ?

2 Calculate **Solve for the unknowns.**

Use the atomic mass and the decimal form of the percent abundance to find the mass contributed by each isotope.

for ^{10}X: 10.012 amu x 0.1991 = 1.993 amu
for ^{11}X: 11.009 amu x 0.8009 = 8.817 amu

2 Calculate **Solve for the unknowns.**

Add the atomic mass contributions for all the isotopes.

For element X, atomic mass = 1.953 amu + 8.817 amu = 10.810 amu

3 Evaluate **Does the result make sense?**

The calculated value is closer to the mass of the more abundant isotope, as would be expected.

Checkpoint

Why is the atomic mass of an element usually not a whole number?

Checkpoint

Why is the atomic mass of an element usually not a whole number?

The atomic mass of an element is usually not a whole number because it is a weighted average of the masses of the naturally occurring isotopes of the element.

- **Elements are different because they contain different numbers of protons.**
- **Because isotopes of an element have different numbers of neutrons, they also have different mass numbers.**
- **To calculate the atomic mass of an element, multiply the mass of each isotope by its natural abundance, expressed as a decimal, and then add the products.**

number of neutrons = mass number – atomic number

- **atomic number**: the number of protons in the nucleus of an atom of an element

- **mass number**: the total number of protons and neutrons in the nucleus of an atom

- **isotopes**: atoms of the same element that have the same atomic number but different atomic masses due to a different number of neutrons

- **atomic mass unit (amu)**: a unit of mass equal to one-twelfth the mass of a carbon-12 atom

- **atomic mass**: the weighted average of the masses of the isotopes of an element

Electrons and the Structure of Atoms

- Atoms of the same element have the same number of protons, which is equal to an atom's atomic number.
- But atoms of the same element can have different numbers of neutrons.
- Atoms of the same element with different numbers of neutrons are isotopes.

END OF 4.3