nonmetal (66)
metalloid (66)
semiconductor (66)
main-group elements (66)
transition elements (transition metals) (66)
family (group) (66)
noble gases (66)
alkali metals (66)
alkaline earth metals (66)
halogens (68)

**Section 2.8**
atomic mass (69)
mass spectrometry (70)

**Section 2.9**
mole (mol) (73)
Avogadro's number (73)
molar mass (75)

# CONCEPTS

## Brownian Motion (2.1)

- Brownian motion is the erratic, jittery motion of small particles that was first observed by Robert Brown in 1827. The description of Brownian motion by Einstein in 1905 and confirmation by Perrin in 1908 removed any lingering doubt about the particulate nature of matter.

## The Atomic Theory (2.2, 2.3)

- Each element is composed of indestructible particles called atoms.
- All atoms of a given element have the same mass and other properties.
- Atoms combine in simple, whole-number ratios to form compounds.
- Atoms of one element cannot change into atoms of another element. In a chemical reaction, atoms change the way that they are bound together with other atoms to form a new substance.

## The Electron (2.4)

- J. J. Thomson discovered the electron in the late 1800s through experiments with cathode rays. He deduced that electrons are negatively charged, and he measured their charge-to-mass ratio.
- Robert Millikan measured the charge of the electron, which—in conjunction with Thomson's results—led to the calculation of the mass of an electron.

## The Nuclear Atom (2.5)

- In 1909, Ernest Rutherford probed the inner structure of the atom by working with a form of radioactivity called alpha radiation and developed the nuclear theory of the atom.
- Nuclear theory states that the atom is mainly empty space, with most of its mass concentrated in a tiny region called the nucleus and most of its volume occupied by relatively light electrons.

## Subatomic Particles (2.6)

- Atoms are composed of three fundamental particles: the proton (1 amu, +1 charge), the neutron (1 amu, 0 charge), and the electron (~0 amu, −1 charge).
- The number of protons in the nucleus of the atom is its atomic number ($Z$) and defines the element.
- The sum of the number of protons and neutrons is the mass number ($A$).
- Atoms of an element that have different numbers of neutrons (and therefore different mass numbers) are isotopes.
- Atoms that lose or gain electrons become charged and are ions. Cations are positively charged and anions are negatively charged.

## The Periodic Table (2.7)

- The periodic table tabulates all known elements in order of increasing atomic number.
- The periodic table is arranged so that similar elements are grouped together in columns.
- Elements on the left side and in the center of the periodic table are metals and tend to lose electrons in chemical changes.
- Elements on the upper right side of the periodic table are nonmetals and tend to gain electrons in chemical changes.
- Elements located on the boundary between metals and nonmetals are metalloids.

## Atomic Mass and the Mole (2.8, 2.9)

- The atomic mass of an element, listed directly below its symbol in the periodic table, is a weighted average of the masses of the naturally occurring isotopes of the element.
- One mole of an element is the amount of that element that contains Avogadro's number ($6.022 \times 10^{23}$) of atoms.
- Any sample of an element with a mass (in grams) that equals its atomic mass contains one mole of the element. For example, the atomic mass of carbon is 12.011 amu; therefore, 12.011 g of carbon contains 1 mol of carbon atoms.

# EQUATIONS AND RELATIONSHIPS

Relationship between Mass Number ($A$), Number of Protons (p), and Number of Neutrons (n) (2.6)

$$A = \text{number of protons (p)} + \text{number of neutrons (n)}$$

Atomic Mass (2.8)

$$\text{Atomic mass} = \sum_n (\text{fraction of isotope } n) \times (\text{mass of isotope } n)$$

Avogadro's Number (2.9)

$$1 \text{ mol} = 6.0221421 \times 10^{23} \text{ particles}$$

## LEARNING OUTCOMES

| Chapter Objectives | Assessment |
|---|---|
| Apply the mass laws that are the basis of modern atomic theory (2.3) | Examples 2.1, 2.2 **For Practice** 2.1, 2.2 **Exercises** 29–38 |
| Describe the experiments that led to the discovery of the electron and its charge (2.4) | Exercises 43–46 |
| Explain the structure of an atom (2.5) | Exercises 39–42 |
| Describe the properties of subatomic particles and interpret isotope symbols (2.6) | Example 2.3 **For Practice** 2.3 **Exercises** 47–58 |
| Relate the periodic law to the organization of the periodic table (2.7) | **Exercises** 63–70 |
| Predict the charge of ions (2.7) | Example 2.4 **For Practice** 2.4 **Exercises** 59–62 |
| Determine the atomic mass of atoms (2.8) | Example 2.5 **For Practice** 2.5 **For More Practice** 2.5 **Exercises** 71–80 |
| Apply the mole concept (2.9) | Examples 2.6, 2.7, 2.8, 2.9 **For Practice** 2.6, 2.7, 2.8, 2.9 **For More Practice** 2.7, 2.8, 2.9 **Exercises** 81–94 |

# EXERCISES

**Mastering Chemistry** provides end-of-chapter exercises, feedback-enriched tutorial problems, animations, and interactive activities to encourage problem-solving practice and deeper understanding of key concepts and topics.

## REVIEW QUESTIONS

1. What is Brownian motion? How is it related to the development of the idea that matter is particulate?
2. Summarize the history of the atomic idea. How was Dalton able to convince others to accept an idea that had been controversial for 2000 years?
3. State and explain the law of conservation of mass.
4. State and explain the law of definite proportions.
5. State and explain the law of multiple proportions. How is the law of multiple proportions different from the law of definite proportions?
6. What are the main ideas in Dalton's atomic theory? How do they help explain the laws of conservation of mass, of constant composition, and of definite proportions?
7. How and by whom was the electron discovered? What basic properties of the electron were reported with its discovery?
8. Explain Millikan's oil drop experiment and how it led to the measurement of the electron's charge. Why is the magnitude of the charge of the electron so important?
9. Describe the plum-pudding model of the atom.
10. Describe Rutherford's gold foil experiment. How did the experiment prove that the plum-pudding model of the atom was wrong?
11. Describe Rutherford's nuclear model of the atom. What was revolutionary about his model?
12. If matter is mostly empty space, as suggested by Rutherford, then why does it appear so solid?
13. List the three subatomic particles that compose atoms and give the basic properties (mass and charge) of each.
14. What defines an element?
15. Explain the difference between $Z$ (the atomic number) and $A$ (the mass number).
16. Where do elements get their names?
17. What are isotopes? What is percent natural abundance of isotopes?
18. Describe the two different notations used to specify isotopes and give an example of each.
19. What is an ion? A cation? An anion?
20. State the periodic law. How did the periodic law lead to the periodic table?
21. Describe the characteristic properties of metals, nonmetals, and metalloids.
22. List the characteristic properties of each group.
    a. noble gases
    b. alkali metals
    c. alkaline earth metals
    d. halogens
23. How do you predict the charges of ions formed by main-group elements?
24. What is atomic mass? How is it calculated?
25. Explain how a mass spectrometer works.
26. What kind of information can be determined from a mass spectrum?
27. What is a mole? How is the mole concept useful in chemical calculations?
28. Why is the mass corresponding to a mole of one element different from the mass corresponding to a mole of another element?

# PROBLEMS BY TOPIC

*Note: Answers to all odd-numbered Problems, numbered in blue, can be found in Appendix III. Exercises in the Problems by Topic section are paired, with each odd-numbered problem followed by a similar even-numbered problem. Exercises in the Cumulative Problems section are also paired, but somewhat more loosely. (Challenge Problems and Conceptual Problems, because of their nature, are unpaired.)*

## The Laws of Conservation of Mass, Definite Proportions, and Multiple Proportions

**29.** A hydrogen-filled balloon is ignited, and 1.50 g of hydrogen reacts with 12.0 g of oxygen. How many grams of water vapor form? (Assume that water vapor is the only product.)
**MISSED THIS?** *Read Section 2.3; Watch KCV 2.3*

**30.** An automobile gasoline tank holds 21 kg of gasoline. When the gasoline burns, 84 kg of oxygen is consumed, and carbon dioxide and water are produced. What is the total combined mass of carbon dioxide and water that is produced?

**31.** Two samples of carbon tetrachloride are decomposed into their constituent elements. One sample produces 38.9 g of carbon and 448 g of chlorine, and the other sample produces 14.8 g of carbon and 134 g of chlorine. Are these results consistent with the law of definite proportions? Explain your answer.
**MISSED THIS?** *Read Section 2.3; Watch KCV 2.3*

**32.** Two samples of sodium chloride are decomposed into their constituent elements. One sample produces 6.98 g of sodium and 10.7 g of chlorine, and the other sample produces 11.2 g of sodium and 17.3 g of chlorine. Are these results consistent with the law of definite proportions? Explain your answer.

**33.** The mass ratio of sodium to fluorine in sodium fluoride is 1.21:1. A sample of sodium fluoride produces 28.8 g of sodium upon decomposition. How much fluorine (in grams) forms?
**MISSED THIS?** *Read Section 2.3; Watch KCV 2.3*

**34.** Upon decomposition, one sample of magnesium fluoride produces 1.65 kg of magnesium and 2.57 kg of fluorine. A second sample produces 1.32 kg of magnesium. How much fluorine (in grams) does the second sample produce?

**35.** Two different compounds containing osmium and oxygen have the following masses of oxygen per gram of osmium: 0.168 and 0.3369 g. Show that these amounts are consistent with the law of multiple proportions.
**MISSED THIS?** *Read Section 2.3; Watch KCV 2.3*

**36.** Palladium forms three different compounds with sulfur. The mass of sulfur per gram of palladium in each compound is listed here. Show that these masses are consistent with the law of multiple proportions.

| Compound | Grams S per Gram Pd |
|---|---|
| A | 0.603 |
| B | 0.301 |
| C | 0.151 |

**37.** Sulfur and oxygen form both sulfur dioxide and sulfur trioxide. When samples of these are decomposed, the sulfur dioxide produces 3.49 g oxygen and 3.50 g sulfur, while the sulfur trioxide produces 6.75 g oxygen and 4.50 g sulfur. Calculate the mass of oxygen per gram of sulfur for each sample and show that these results are consistent with the law of multiple proportions.
**MISSED THIS?** *Read Section 2.3; Watch KCV 2.3*

**38.** Sulfur and fluorine form several different compounds including sulfur hexafluoride and sulfur tetrafluoride. Decomposition of a sample of sulfur hexafluoride produces 4.45 g of fluorine and 1.25 g of sulfur, while decomposition of a sample of sulfur tetrafluoride produces 4.43 g of fluorine and 1.87 g of sulfur. Calculate the mass of fluorine per gram of sulfur for each sample and show that these results are consistent with the law of multiple proportions.

## Atomic Theory, Nuclear Theory, and Subatomic Particles

**39.** Which statements are *consistent* with Dalton's atomic theory as it was originally stated? Why?
**MISSED THIS?** *Read Section 2.3; Watch KCV 2.3*
**a.** Sulfur and oxygen atoms have the same mass.
**b.** All cobalt atoms are identical.
**c.** Potassium and chlorine atoms combine in a 1:1 ratio to form potassium chloride.
**d.** Lead atoms can be converted into gold.

**40.** Which statements are *inconsistent* with Dalton's atomic theory as it was originally stated? Why?
**a.** All carbon atoms are identical.
**b.** An oxygen atom combines with 1.5 hydrogen atoms to form a water molecule.
**c.** Two oxygen atoms combine with a carbon atom to form a carbon dioxide molecule.
**d.** The formation of a compound often involves the destruction of one or more atoms.

**41.** Which statements are *consistent* with Rutherford's nuclear theory as it was originally stated? Why?
**MISSED THIS?** *Read Section 2.5*
**a.** The volume of an atom is mostly empty space.
**b.** The nucleus of an atom is small compared to the size of the atom.
**c.** Neutral lithium atoms contain more neutrons than protons.
**d.** Neutral lithium atoms contain more protons than electrons.

**42.** Which statements are *inconsistent* with Rutherford's nuclear theory as it was originally stated? Why?
**a.** Since electrons are smaller than protons and since a hydrogen atom contains only one proton and one electron, it must follow that the volume of a hydrogen atom is mostly due to the proton.
**b.** A nitrogen atom has seven protons in its nucleus and seven electrons outside of its nucleus.
**c.** A phosphorus atom has 15 protons in its nucleus and 150 electrons outside of its nucleus.
**d.** The majority of the mass of a fluorine atom is due to its nine electrons.

**43.** A chemist in an imaginary universe, where electrons have a different charge than they do in our universe, performs the Millikan oil drop experiment to measure the electron's charge. The charges of several drops are recorded here. What is the charge of the electron in this imaginary universe?
**MISSED THIS?** *Read Section 2.4*

| Drop # | Charge |
|---|---|
| A | $-6.9 \times 10^{-19}$ C |
| B | $-9.2 \times 10^{-19}$ C |
| C | $-11.5 \times 10^{-19}$ C |
| D | $-4.6 \times 10^{-19}$ C |

**44.** Imagine a unit of charge called the *zorg*. A chemist performs the oil drop experiment and measures the charge of each drop in zorgs. Based on the results shown here, what is the charge of the electron in zorgs (z)? How many electrons are in each drop?

| Drop # | Charge |
|---|---|
| A | $-4.8 \times 10^{-9}$ z |
| B | $-9.6 \times 10^{-9}$ z |
| C | $-6.4 \times 10^{-9}$ z |
| D | $-12.8 \times 10^{-9}$ z |

**45.** On a dry day, your body can accumulate static charge from walking across a carpet or from brushing your hair. If your body develops a charge of −15 μC (microcoulombs), how many excess electrons has it acquired? What is their collective mass?
**MISSED THIS?** *Read Section 2.4*

**46.** How many electrons are necessary to produce a charge of −1.0 C? What is the mass of this many electrons?

**47.** Which statements about subatomic particles are true?
**MISSED THIS?** *Read Section 2.4, 2.5*
**a.** If an atom has an equal number of protons and electrons, it will be charge-neutral.
**b.** Electrons are attracted to protons.
**c.** Electrons are much lighter than neutrons.
**d.** Protons have twice the mass of neutrons.

**48.** Which statements about subatomic particles are false?
**a.** Protons and electrons have charges of the same magnitude but opposite signs.
**b.** Protons have about the same mass as neutrons.
**c.** Some atoms don't have any protons.
**d.** Protons and neutrons have charges of the same magnitude but opposite signs.

**49.** How many electrons does it take to equal the mass of a proton?
**MISSED THIS?** *Read Section 2.4*

**50.** A helium nucleus has two protons and two neutrons. How many electrons does it take to equal the mass of a helium nucleus?

## Isotopes and Ions

**51.** Write isotopic symbols in the form X-*A* (e.g., C-13) for each isotope. **MISSED THIS?** *Read Section 2.6; Watch KCV 2.6*
**a.** the silver isotope with 60 neutrons
**b.** the silver isotope with 62 neutrons
**c.** the uranium isotope with 146 neutrons
**d.** the hydrogen isotope with one neutron

**52.** Write isotopic symbols in the form ${}^{A}_{Z}\mathrm{X}$ for each isotope.
**a.** the copper isotope with 34 neutrons
**b.** the copper isotope with 36 neutrons
**c.** the potassium isotope with 21 neutrons
**d.** the argon isotope with 22 neutrons

**53.** Determine the number of protons and the number of neutrons in each isotope.
**MISSED THIS?** *Read Section 2.6; Watch KCV 2.6, IWE 2.3*
**a.** ${}^{14}_{7}\mathrm{N}$ **b.** ${}^{23}_{11}\mathrm{Na}$ **c.** ${}^{222}_{86}\mathrm{Rn}$ **d.** ${}^{208}_{82}\mathrm{Pb}$

**54.** Determine the number of protons and the number of neutrons in each isotope.
**a.** ${}^{40}_{19}\mathrm{K}$ **b.** ${}^{226}_{88}\mathrm{Ra}$ **c.** ${}^{99}_{43}\mathrm{Tc}$ **d.** ${}^{33}_{15}\mathrm{P}$

**55.** The amount of carbon-14 in ancient artifacts and fossils is often used to establish their age. Determine the number of protons and the number of neutrons in carbon-14 and write its symbol in the form ${}^{A}_{Z}\mathrm{X}$.
**MISSED THIS?** *Read Section 2.6; Watch KCV 2.6, IWE 2.3*

**56.** Uranium-235 is used in nuclear fission. Determine the number of protons and the number of neutrons in uranium-235 and write its symbol in the form ${}^{A}_{Z}\mathrm{X}$.

**57.** Determine the number of protons and the number of electrons in each ion.
**MISSED THIS?** *Read Section 2.6; Watch KCV 2.6, IWE 2.3*
**a.** $Ni^{2+}$ **b.** $S^{2-}$ **c.** $Br^{-}$ **d.** $Cr^{3+}$

**58.** Determine the number of protons and the number of electrons in each ion.
**a.** $Al^{3+}$ **b.** $Se^{2-}$ **c.** $Ga^{3+}$ **d.** $Sr^{2+}$

**59.** Predict the charge of the ion formed by each element.
**MISSED THIS?** *Read Section 2.7*
**a.** O **b.** K **c.** Al **d.** Rb

**60.** Predict the charge of the ion formed by each element.
**a.** Mg **b.** N **c.** F **d.** Na

**61.** Fill in the blanks to complete the table.
**MISSED THIS?** *Read Section 2.6; Watch KCV 2.6, IWE 2.3*

| Symbol | Ion Formed | Number of Electrons in Ion | Number of Protons in Ion |
|---|---|---|---|
| Ca | $Ca^{2+}$ | _____ | _____ |
| _____ | $Be^{2+}$ | 2 | _____ |
| Se | _____ | _____ | 34 |
| In | _____ | _____ | 49 |

**62.** Fill in the blanks to complete the table.

| Symbol | Ion Formed | Number of Electrons in Ion | Number of Protons in Ion |
|---|---|---|---|
| Cl | _____ | _____ | 17 |
| Te | _____ | 54 | _____ |
| Br | $Br^{-}$ | _____ | _____ |
| _____ | $Sr^{2+}$ | _____ | 38 |

## The Periodic Table and Atomic Mass

**63.** Write the name of each element and classify it as a metal, nonmetal, or metalloid.
**MISSED THIS?** *Read Section 2.7; Watch KCV 2.7*
**a.** K **b.** Ba **c.** I **d.** O **e.** Sb

**64.** Write the symbol for each element and classify it as a metal, nonmetal, or metalloid.
**a.** gold **b.** fluorine **c.** sodium **d.** tin **e.** argon

**65.** Determine whether or not each element is a main-group element. **MISSED THIS?** *Read Section 2.7; Watch KCV 2.7*
**a.** tellurium
**b.** potassium
**c.** vanadium
**d.** manganese

**66.** Determine whether or not each element is a transition element.
**a.** Cr **b.** Br **c.** Mo **d.** Cs

**67.** Classify each element as an alkali metal, alkaline earth metal, halogen, or noble gas.
**MISSED THIS?** *Read Section 2.7; Watch KCV 2.7*
**a.** sodium **b.** iodine
**c.** calcium **d.** barium
**e.** krypton

**68.** Classify each element as an alkali metal, alkaline earth metal, halogen, or noble gas.
**a.** F **b.** Sr **c.** K **d.** Ne **e.** At

**69.** Which pair of elements do you expect to be most similar? Why?
**MISSED THIS?** *Read Section 2.7; Watch KCV 2.7*
**a.** N and Ni **b.** Mo and Sn
**c.** Na and Mg **d.** Cl and F
**e.** Si and P

**70.** Which pair of elements do you expect to be most similar? Why?
**a.** nitrogen and oxygen
**b.** titanium and gallium
**c.** lithium and sodium
**d.** germanium and arsenic
**e.** argon and bromine

**71.** Gallium has two naturally occurring isotopes with the following masses and natural abundances:
**MISSED THIS?** *Read Section 2.8*

| Isotope | Mass (amu) | Abundance (%) |
|---|---|---|
| Ga-69 | 68.92558 | 60.108 |
| Ga-71 | 70.92470 | 39.892 |

Sketch the mass spectrum of gallium.

**72.** Magnesium has three naturally occurring isotopes with the following masses and natural abundances:

| Isotope | Mass (amu) | Abundance (%) |
|---|---|---|
| Mg-24 | 23.9850 | 78.99 |
| Mg-25 | 24.9858 | 10.00 |
| Mg-26 | 25.9826 | 11.01 |

Sketch the mass spectrum of magnesium.

**73.** The atomic mass of fluorine is 18.998 amu, and its mass spectrum shows a large peak at this mass. The atomic mass of chlorine is 35.45 amu, yet the mass spectrum of chlorine does not show a peak at this mass. Explain the difference.
**MISSED THIS?** *Read Section 2.8*

**74.** The atomic mass of copper is 63.546 amu. Do any copper isotopes have a mass of 63.546 amu? Explain.

**75.** An element has two naturally occurring isotopes. Isotope 1 has a mass of 120.9038 amu and a relative abundance of 57.4%, and isotope 2 has a mass of 122.9042 amu. Find the atomic mass of this element and identify it.
**MISSED THIS?** *Read Section 2.8; Watch IWE 2.5*

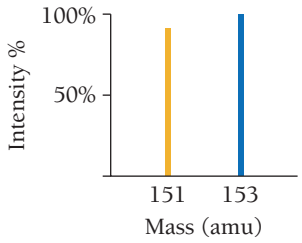
**76.** An element has four naturally occurring isotopes with the masses and natural abundances given here. Find the atomic mass of the element and identify it.

| Isotope | Mass (amu) | Abundance (%) |
|---|---|---|
| 1 | 135.90714 | 0.19 |
| 2 | 137.90599 | 0.25 |
| 3 | 139.90543 | 88.43 |
| 4 | 141.90924 | 11.13 |

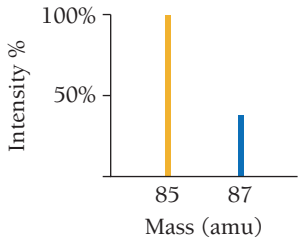
**77.** Bromine has two naturally occurring isotopes (Br-79 and Br-81) and has an atomic mass of 79.904 amu. The mass of Br-81 is 80.9163 amu, and its natural abundance is 49.31%. Calculate the mass and natural abundance of Br-79.
**MISSED THIS?** *Read Section 2.8; Watch IWE 2.5*

**78.** Silicon has three naturally occurring isotopes (Si-28, Si-29, and Si-30). The mass and natural abundance of Si-28 are 27.9769 amu and 92.2%, respectively. The mass and natural abundance of Si-29 are 28.9765 amu and 4.67%, respectively. Find the mass and natural abundance of Si-30.

**79.** Use the mass spectrum of europium to determine the atomic mass of europium.
**MISSED THIS?** *Read Section 2.8; Watch IWE 2.5*




**80.** Use the mass spectrum of rubidium to determine the atomic mass of rubidium.




## The Mole Concept

**81.** How many sulfur atoms are there in 5.52 mol of sulfur?
**MISSED THIS?** *Read Section 2.9; Watch KCV 2.9*

**82.** How many moles of aluminum do $3.7 \times 10^{24}$ aluminum atoms represent?

**83.** What is the amount, in moles, of each elemental sample?
**MISSED THIS?** *Read Section 2.9; Watch KCV 2.9*
**a.** 11.8 g Ar **b.** 3.55 g Zn
**c.** 26.1 g Ta **d.** 0.211 g Li

**84.** What is the mass, in grams, of each elemental sample?
**a.** $2.3 \times 10^{-3}$ mol Sb
**b.** 0.0355 mol Ba
**c.** 43.9 mol Xe
**d.** 1.3 mol W

**85.** How many silver atoms are there in 3.78 g of silver?
**MISSED THIS?** *Read Section 2.9; Watch KCV 2.9, IWE 2.8*

**86.** What is the mass of $4.91 \times 10^{21}$ platinum atoms?

**87.** Calculate the number of atoms in each sample.
**MISSED THIS?** *Read Section 2.9; Watch KCV 2.9, IWE 2.8*
**a.** 5.18 g P **b.** 2.26 g Hg
**c.** 1.87 g Bi **d.** 0.082 g Sr

**88.** Calculate the number of atoms in each sample.
**a.** 14.955 g Cr **b.** 39.733 g S
**c.** 12.899 g Pt **d.** 97.552 g Sn

**89.** Calculate the mass, in grams, of each sample.
**MISSED THIS?** *Read Section 2.9; Watch KCV 2.9, IWE 2.8*
**a.** $1.1 \times 10^{23}$ gold atoms
**b.** $2.82 \times 10^{22}$ helium atoms
**c.** $1.8 \times 10^{23}$ lead atoms
**d.** $7.9 \times 10^{21}$ uranium atoms

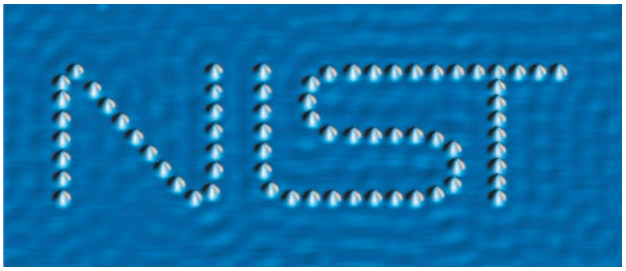
**90.** Calculate the mass, in kg, of each sample.
**a.** $7.55 \times 10^{26}$ cadmium atoms
**b.** $8.15 \times 10^{27}$ nickel atoms
**c.** $1.22 \times 10^{27}$ manganese atoms
**d.** $5.48 \times 10^{29}$ lithium atoms

**91.** How many carbon atoms are there in a diamond (pure carbon) with a mass of 52 mg?
**MISSED THIS?** *Read Section 2.9; Watch KCV 2.9, IWE 2.8*

**92.** How many helium atoms are there in a helium blimp containing 536 kg of helium?

**93.** Calculate the average mass, in grams, of one platinum atom.
**MISSED THIS?** *Read Section 2.9; Watch KCV 2.9, IWE 2.8*

**94.** Scientists at the National Institute for Standards and Technology (NIST) wrote the initials of their agency with 70 individual cobalt atoms (as shown below). Calculate the total mass of these letters in grams.



## CUMULATIVE PROBLEMS

**95.** A 7.83 g sample of HCN contains 0.290 g of H and 4.06 g of N. Find the mass of carbon in a sample of HCN with a mass of 3.37 g.

**96.** The ratio of sulfur to oxygen by mass in $SO_2$ is 1.0:1.0.
**a.** Find the ratio of sulfur to oxygen by mass in $SO_3$.
**b.** Find the ratio of sulfur to oxygen by mass in $S_2O$.

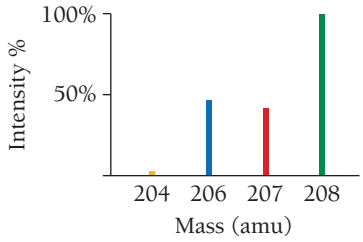
**97.** The ratio of oxygen to carbon by mass in carbon monoxide is 1.33:1.00. Find the formula of an oxide of carbon in which the ratio by mass of oxygen to carbon is 2.00:1.00.

**98.** The ratio of the mass of a nitrogen atom to the mass of an atom of $^{12}C$ is 7:6, and the ratio of the mass of nitrogen to oxygen in $N_2O$ is 7:4. Find the mass of 1 mol of oxygen atoms.

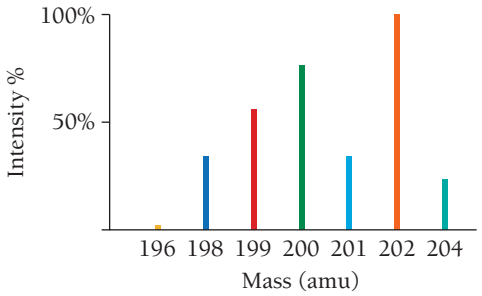
**99.** An $\alpha$ particle, $^4He^{2+}$, has a mass of 4.00151 amu. Find the value of its charge-to-mass ratio in C/kg.

**100.** Naturally occurring iodine has an atomic mass of 126.9045 amu. A 12.3849 g sample of iodine is accidentally contaminated with an additional 1.00070 g of $^{129}I$, a synthetic radioisotope of iodine used in the treatment of certain diseases of the thyroid gland. The mass of $^{129}I$ is 128.9050 amu. Find the apparent "atomic mass" of the contaminated iodine.

**101.** Use the mass spectrum of lead to estimate the atomic mass of lead. Estimate the mass and percent intensity values from the graph to three significant figures.




**102.** Use the mass spectrum of mercury to estimate the atomic mass of mercury. Estimate the masses and percent intensity values from the graph to three significant figures.



**103.** Nuclei with the same number of *neutrons* but different mass numbers are called *isotones*. Write the symbols of four isotones of $^{236}$Th.

**104.** Fill in the blanks to complete the table.

| Symbol | Z | A | Number of p | Number of $e^-$ | Number of n | Charge |
|---|---|---|---|---|---|---|
| Si | 14 | ____ | ____ | 14 | 14 | ____ |
| $S^{2-}$ | ____ | 32 | ____ | ____ | ____ | 2− |
| $Cu^{2+}$ | ____ | ____ | ____ | ____ | 34 | 2+ |
| ____ | 15 | ____ | ____ | 15 | 16 | ____ |

**105.** Fill in the blanks to complete the table.

| Symbol | Z | A | Number of p | Number of $e^-$ | Number of n | Charge |
|---|---|---|---|---|---|---|
| ____ | 8 | ____ | ____ | ____ | 8 | 2− |
| $Ca^{2+}$ | 20 | ____ | ____ | ____ | 20 | ____ |
| $Mg^{2+}$ | ____ | 25 | ____ | ____ | 13 | 2+ |
| $N^{3-}$ | ____ | 14 | ____ | 10 | ____ | ____ |

**106.** Neutron stars are composed of solid nuclear matter, primarily neutrons. Assume the radius of a neutron is approximately $1.0 \times 10^{-13}$ cm. Calculate the density of a neutron. [*Hint*: For a sphere $V = (4/3)\pi r^3$.] Assuming that a neutron star has the same density as a neutron, calculate the mass (in kg) of a small piece of a neutron star the size of a spherical pebble with a radius of 0.10 mm.

**107.** Carbon-12 contains six protons and six neutrons. The radius of the nucleus is approximately 2.7 fm (femtometers), and the radius of the atom is approximately 70 pm (picometers). Calculate the volume of the nucleus and the volume of the atom. What percentage of the carbon atom's volume is occupied by the nucleus? (Assume two significant figures.)

**108.** A penny has a thickness of approximately 1.0 mm. If you stacked Avogadro's number of pennies one on top of the other on Earth's surface, how far would the stack extend (in km)? [For comparison, the sun is about 150 million km from Earth, and the nearest star (Proxima Centauri) is about 40 trillion km from Earth.]

**109.** Consider the stack of pennies in the previous problem. How much money (in dollars) would this represent? If this money were equally distributed among the world's population of 7.0 billion, how much would each person receive? Would each person be a millionaire? A billionaire? A trillionaire?

**110.** The mass of an average blueberry is 0.75 g, and the mass of an automobile is $2.0 \times 10^3$ kg. Find the number of automobiles whose total mass is the same as 1.0 mol of blueberries.

**111.** Suppose that atomic masses were based on the assignment of a mass of 12.000 g to 1 mol of carbon, rather than 1 mol of $^{12}$C. What would the atomic mass of oxygen be? (The atomic masses of carbon and oxygen based on the assignment of 12.000 g to 1 mol of $^{12}$C are 12.011 amu and 15.9994 amu, respectively.)

**112.** A pure titanium cube has an edge length of 2.78 in. How many titanium atoms does it contain? Titanium has a density of 4.50 g/cm$^3$.

**113.** A pure copper sphere has a radius of 0.935 in. How many copper atoms does it contain? [The volume of a sphere is $(4/3)\pi r^3$, and the density of copper is 8.96 g/cm$^3$.]

**114.** What is the radius (in cm) of a pure copper sphere that contains $1.14 \times 10^{24}$ copper atoms? [The volume of a sphere is $(4/3)\pi r^3$, and the density of copper is 8.96 g/cm$^3$.]

**115.** What is the edge length (in cm) of a titanium cube that contains $2.55 \times 10^{24}$ titanium atoms? The density of titanium is 4.50 g/cm$^3$.

**116.** Boron has only two naturally occurring isotopes. The mass of boron-10 is 10.01294 amu, and the mass of boron-11 is 11.00931 amu. Calculate the relative abundances of the two isotopes.

**117.** Lithium has only two naturally occurring isotopes. The mass of lithium-6 is 6.01512 amu, and the mass of lithium-7 is 7.01601 amu. Calculate the relative abundances of the two isotopes.

**118.** Common brass is a copper and zinc alloy containing 37.0% zinc by mass and having a density of 8.48 g/cm$^3$. A fitting composed of common brass has a total volume of 112.5 cm$^3$. How many atoms (copper and zinc) does the fitting contain?

**119.** A 67.2 g sample of a gold and palladium alloy contains $2.49 \times 10^{23}$ atoms. What is the composition (by mass) of the alloy?

**120.** Naturally occurring chlorine is composed of two isotopes: 75.76% Cl-35 (mass 34.9688 amu) and 24.24% Cl-37 (mass 36.9659 amu). Naturally occurring oxygen is composed of three isotopes: 99.757% O-16 (mass 15.9949 amu), 0.038% O-17 (mass 16.9991 amu), and 0.205% O-18 (mass 17.9991 amu). The compound dichlorine monoxide is composed of two chlorine atoms and one oxygen atom bonded together to form the $Cl_2O$ molecule. How many $Cl_2O$ molecules of different masses naturally exist? Give the masses of the three most abundant $Cl_2O$ molecules.

**121.** Silver is composed of two naturally occurring isotopes: Ag-107 (51.839%) and Ag-109. The ratio of the masses of the two isotopes is 1.0187. What is the mass of Ag-107?

**122.** The U.S. Environmental Protection Agency (EPA) sets limits on healthful levels of air pollutants. The maximum level that the EPA considers safe for lead air pollution is 1.5 $\mu$g/m$^3$. If your lungs were filled with air containing this level of lead, how many lead atoms would be in your lungs? (Assume a total lung volume of 5.50 L.)

**123.** Pure gold is usually too soft for jewelry, so it is often alloyed with other metals. How many gold atoms are in an 0.255-ounce, 18 K gold bracelet? (18 K gold is 75% gold by mass.)

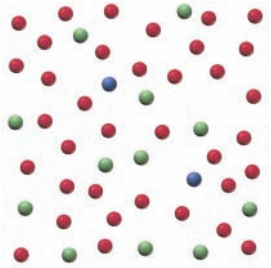
## CHALLENGE PROBLEMS

**124.** In Section 2.9, it was stated that 1 mol of sand grains would cover the state of Texas to several feet. Estimate how many feet by assuming that the sand grains are roughly cube-shaped, each one with an edge length of 0.10 mm. Texas has a land area of 268,601 square miles.

**125.** Use the concepts in this chapter to obtain an estimate for the number of atoms in the universe. Make the following assumptions: **(a)** All of the atoms in the universe are hydrogen atoms in stars. (This is not a ridiculous assumption because over three-fourths of the atoms in the universe are in fact hydrogen.

Gas and dust between the stars represent only about 15% of the visible matter of our galaxy, and planets compose a far tinier fraction.) **(b)** The sun is a typical star composed of pure hydrogen with a density of 1.4 g/cm$^3$ and a radius of $7 \times 10^8$ m. **(c)** Each of the roughly 100 billion stars in the Milky Way galaxy contains the same number of atoms as our sun. **(d)** Each of the 10 billion galaxies in the visible universe contains the same number of atoms as our Milky Way galaxy.

**126.** Below is a representation of 50 atoms of a fictitious element called pearsonium (Ps). The red spheres represent Ps-296, the blue spheres Ps-297, and the green spheres Ps-298.



**a.** Assuming that the sample is statistically representative of a naturally occurring sample, calculate the percent natural abundance of each Ps isotope.
**b.** Draw the mass spectrum for a naturally occurring sample of Ps.
**c.** The mass of each Ps isotope is measured relative to C-12 and tabulated. Use the mass of C-12 to convert each of the masses to amu and calculate the atomic mass of Ps.

| Isotope | Mass |
|---|---|
| Ps-296 | 24.6630 × Mass($^{12}$C) |
| Ps-297 | 24.7490 × Mass($^{12}$C) |
| Ps-298 | 24.8312 × Mass($^{12}$C) |

**127.** The ratio of oxygen to nitrogen by mass in $NO_2$ is 2.29. The ratio of fluorine to nitrogen by mass in $NF_3$ is 4.07. Find the ratio of oxygen to fluorine by mass in $OF_2$.

**128.** Naturally occurring cobalt consists of only one isotope, $^{59}$Co, whose relative atomic mass is 58.9332. A synthetic radioactive isotope of cobalt, $^{60}$Co, has a relative atomic mass of 59.9338 and is used in radiation therapy for cancer. A 1.5886 g sample of cobalt has an apparent "atomic mass" of 58.9901. Find the mass of $^{60}$Co in this sample.

**129.** A 7.36 g sample of copper is contaminated with an additional 0.51 g of zinc. Suppose an atomic mass measurement was performed on this sample. What would be the measured atomic mass?

**130.** The ratio of the mass of O to the mass of N in $N_2O_3$ is 12:7. Another binary compound of nitrogen has a ratio of O to N of 16:7. What is its formula? What is the ratio of O to N in the next member of this series of compounds?

**131.** Naturally occurring magnesium has an atomic mass of 24.312 and consists of three isotopes. The major isotope is $^{24}$Mg, natural abundance 78.99%, relative atomic mass 23.98504. The next most abundant isotope is $^{26}$Mg, relative atomic mass 25.98259. The third most abundant isotope is $^{25}$Mg, whose natural abundance is in the ratio of 0.9083 to that of $^{26}$Mg. Find the relative atomic mass of $^{25}$Mg.

## CONCEPTUAL PROBLEMS

**132.** Which answer is an example of the law of multiple proportions? Explain.
**a.** Two different samples of water are found to have the same ratio of hydrogen to oxygen.
**b.** When hydrogen and oxygen react, the mass of water formed is exactly equal to the mass of hydrogen and oxygen that reacted.
**c.** The mass ratio of oxygen to hydrogen in water is 8:1. The mass ratio of oxygen to hydrogen in hydrogen peroxide (a compound that only contains hydrogen and oxygen) is 16:1.

**133.** Lithium has two naturally occurring isotopes: Li-6 (natural abundance 7.5%) and Li-7 (natural abundance 92.5%). Using circles to represent protons and squares to represent neutrons, draw the nucleus of each isotope. How many Li-6 atoms are present, on average, in a 1000-atom sample of lithium?

**134.** As we saw in the previous problem, lithium has two naturally occurring isotopes: Li-6 (natural abundance 7.5%; mass 6.0151 amu) and Li-7 (natural abundance 92.5%; mass 7.0160 amu). Without doing any calculations, determine which mass is closest to the atomic mass of Li.
**a.** 6.00 amu **b.** 6.50 amu **c.** 7.00 amu

**135.** The mole is defined as the amount of a substance containing the same number of particles as exactly 12 g of C-12. The amu is defined as 1/12 of the mass of an atom of C-12. Why is it important that both of these definitions reference the same isotope? What would be the result, for example, of defining the mole with respect to C-12, but the amu with respect to Ne-20?

**136.** Without doing any calculations, determine which of the samples contains the greatest amount of the element in moles. Which contains the greatest mass of the element?
**a.** 55.0 g Cr **b.** 45.0 g Ti **c.** 60.0 g Zn

**137.** The atomic radii of the isotopes of an element are identical to one another. However, the atomic radii of the ions of an element are significantly different from the atomic radii of the neutral atom of the element. Explain.

## QUESTIONS FOR GROUP WORK

*Active Classroom Learning*

Discuss these questions with the group and record your consensus answer.

**138.** The table shown here includes data similar to those used by Mendeleev when he created the periodic table. On a small card, write the symbol, atomic mass, and a stable compound formed by each element. Without consulting a periodic table, arrange the cards so that atomic mass increases from left to right and elements with similar properties are above and below each other. Copy the periodic table you have invented onto a piece of paper. There is one element missing. Predict its mass and a stable compound it might form.

| Element | Atomic Mass | Stable Compound |
|---|---|---|
| Be | 9 | $BeCl_2$ |
| S | 32 | $H_2S$ |
| F | 19 | $F_2$ |
| Ca | 40 | $CaCl_2$ |
| Li | 7 | LiCl |
| Si | 28 | $SiH_4$ |
| Cl | 35.4 | $Cl_2$ |
| B | 10.8 | $BH_3$ |
| Ge | 72.6 | $GeH_4$ |
| N | 14 | $NF_3$ |
| O | 16 | $H_2O$ |
| Ga | 69.7 | $GaH_3$ |
| As | 75 | $AsF_3$ |
| C | 12 | $CH_4$ |
| K | 39 | KCl |
| Mg | 24.3 | $MgCl_2$ |
| Se | 79 | $H_2Se$ |
| Al | 27 | $AlH_3$ |
| Br | 80 | $Br_2$ |
| Na | 23 | NaCl |

**139.** In a naturally occurring sample, 19.8% of boron atoms have five neutrons and 80.2% have six neutrons. What is the mass number of each boron isotope? Sketch a sample of 10 atoms that is nearly representative of a natural sample. What is the average mass of the atoms in your drawing? What is the atomic mass of boron? (Boron-10 has a mass of 10.01294 amu, and boron-11 has a mass of 11.00931 amu.)

**140.** In complete sentences, describe the similarities and differences between:

**a.** different isotopes of an element

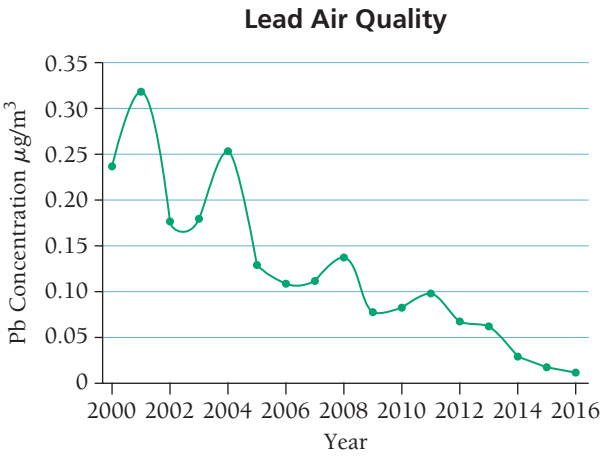
**b.** a neutral atom and an ion of the same element

**141.** Calculate the mass in grams of one mole of each of the following (the mass of a single item is given in parentheses): electrons ($9.10938 \times 10^{-28}$ g), protons ($1.67262 \times 10^{-24}$ g), neutrons ($1.67493 \times 10^{-24}$ g), atoms of carbon-12 ($1.992646 \times 10^{-23}$ g), and doughnuts (74 g). Compare the mass of one mole of carbon-12 atoms to the sum of the masses of the particles that it contains. If the doughnut mentioned in this question were made entirely of carbon, how many atoms would it contain?

## DATA INTERPRETATION AND ANALYSIS

### Lead Air Quality

**142.** The U.S. Environmental Protection Agency (U.S. EPA) monitors air quality in the United States. Lead is among the pollutants regularly monitored and regulated. Lead is released into the atmosphere primarily by the processing of metal ores containing lead and by lead-based battery manufacturing. The effects of too much exposure to lead include neurological damage and cardiovascular disease. Because of the Clear Air Act and its amendments, the amounts of lead in air have been decreasing for many years. The chart below shows the lead concentration in air in the United States from 2000 to 2016. Examine the data and answer the questions that follow.




◀ Source: U.S. EPA Air Trends (http://www3.epa.gov/airtrends/lead.html)

**a.** Determine the lead concentrations in 2000 and in 2016.

**b.** Calculate the percent change in lead concentration that occurred from 2000 to 2016. *Hint:* Calculate the percent change with the following equation:

$$\text{percent change} = \frac{(\text{final concentration} - \text{initial concentration})}{\text{initial concentration}} \times 100\%$$

**c.** How many lead atoms were in one cubic centimeter of air in 2011?

**d.** Examine the mass spectrum for lead shown below. How many Pb-206 atoms were in one cubic centimeter of air in 2011?