Taking It Further I

The 3-D structure of atoms in metals usually corresponds to the minimum volume

The simple arrangement of gold atoms that we saw in Figure 1.2 extends for gigantic numbers of atoms not only in the two directions shown, but below the surface layer as well. A schematic representation of the arrangement of the atoms in a layer of gold is presented in Figure 1.22. Run your eye along any one of the parallel horizontal rows of circles in part (a) of the figure, and then focus your attention on one circle near the middle of the row. If you look up (or down) to the adjacent row, you will see that the atoms do not lie *directly* above one another, but rather are displaced by half an atom. Thus each of the second row's atoms is positioned in the *grooves* defined by the first row. The rows alternate in position; you can see in Figure 1.22a that the third row lies directly below the first. A fourth row would be directly below the second. The same positioning applies to layers of atoms above or below the first layer. The atoms of the second layer nestle in the grooves defined by the first layer. Each atom sits in a groove and overlaps the three grooves around it. Each atom touches a total of 12 others—6 in the original layer, plus 3 more in the layer that lies above it and 3 more in the layer below it (Fig. 1.22b), so it has 12 nearest neighbors.

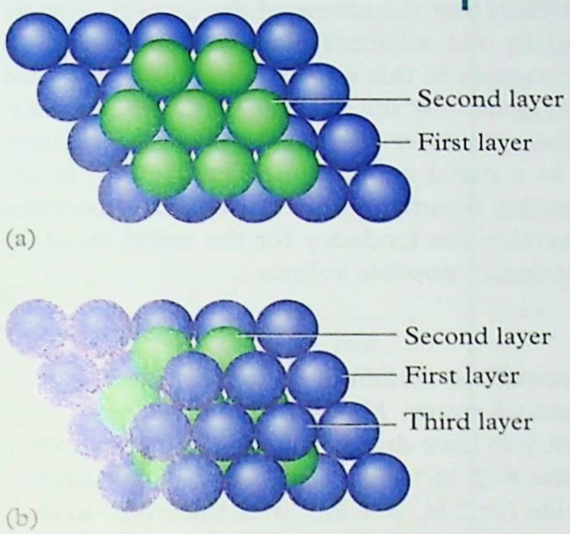


Figure 1.22 The position of atoms in three layers of a close-packed system. The atoms of the second layer occupy the grooves of the first layer. The third layer is positioned directly above or below the first.

The type of 3-D arrangement of atoms described above is called a close-packed structure, since it corresponds geometrically to the most efficient way of packing spherical objects together in order to minimize the total volume of the solid. It is the same type of structure you see in pyramids of oranges and other round fruit in grocery store displays (see Figure 1.23)! Since this is the structure that occurs in most metals, we surmise that it must be important for metal atoms to be, on average, as close together as possible.

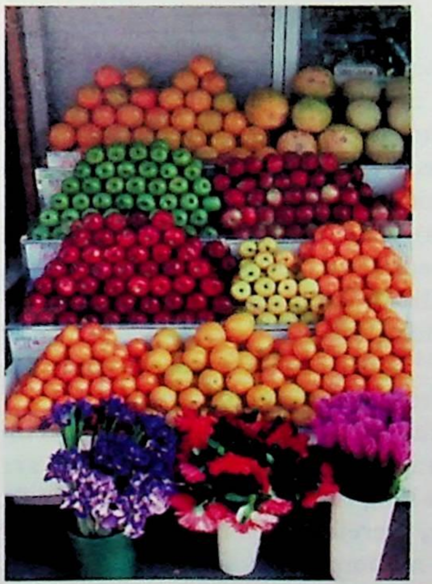


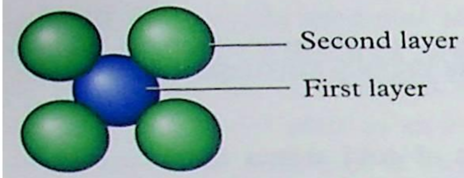
Figure 1.23 Close-packing of fruit. *(Michael Heron/Woodfin Camp & Associates)*

Activity: Using pennies to model close-packing

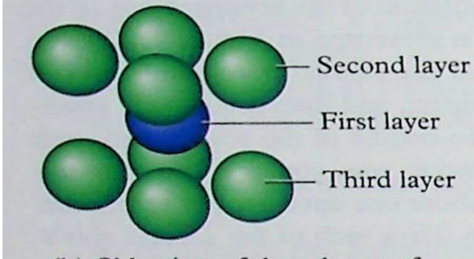
Find out how many pennies, face up, you can pack around a central penny, face down, such that all the outer pennies touch the central one. How is your result relevant to the close-packing of spherical atoms in a metal? Repeat the assignment with nickels or quarters to establish whether the result depends on the size of the coin.

It is the structure of metals at the atomic level that accounts for their malleability and ductility. When the solid is hammered or drawn, rows of atoms roll over and push past others. This occurs without too much effort in the case of metals. This ease of distortion also accounts for the relative softness of many pure metals, such as sodium.

Metals such as iron, chromium, sodium, and potassium have structures that are *not* close-packed but instead are somewhat more open. In particular, the rows of atoms in a plane do not lie in grooves formed by adjacent rows in these metals. Rather, the rows lie directly *beside* each other. Consequently the atoms within a layer do not touch one another (see Figure 1.24). The flat layers lie on top of one another, with adjacent planes offset such that the atoms of the second layer lie within the hollows formed by the adjacent planes. The number of nearest neighbors for a metal atom in this structure is eight, compared to twelve for close-packing, since only the neighboring atoms in adjacent layers—not those in the same layer—actually touch a given atom. When we find the atoms in a metal adopting a structure that is not close-packed, we can reasonably assume that there are forces operating between the atoms that override the tendency for the metal to adopt the structure having the minimum possible volume.



(a) View of iron atoms from above



(b) Side view of three layers of iron atoms

Figure 1.24 The positions of the atoms in iron. In (a) the third layer does not show because it is hidden by the first layer. Notice that this is not a close-packed structure since the atoms in a layer do not touch.

Exercise 1.5

Draw a diagram of a close-packed system of atoms and a diagram of a non-close-packed system of atoms. Make sure that all the circles are the same size and that you have drawn enough circles to cover a 10 cm × 10 cm (or 2 in. × 2 in.) area of paper. Draw a square, 10 cm long and 10 cm wide (or 2 in. × 2 in.), over the atoms in each system. Which system contains more atoms in the square? Explain. If each system formed an interstitial alloy, where would the additional atoms go?

Taking It Further II

Any sample of matter big enough to see contains a huge number of atoms

We have stated that atoms have sizes of about 10^{-10} meters, or 0.1 nanometers, each. From this information, we can obtain an approximate idea of the number of atoms in a sample of matter that is large enough to be seen with the naked eye. Let's estimate that you can see a speck of matter that is about one-tenth of a millimeter in each dimension. Since 1 millimeter (mm) is one-thousandth (10^{-3}) of a meter, it follows that 0.1 mm is equal to 0.1×10^{-3} meters $= 10^{-4}$ meters. Because each atom is about 10^{-10} meter wide, the number of atoms that can be lined up along the 10^{-4}-meter width of the speck is given by the ratio $10^{-4} / 10^{-10} = 10^{6}$. In other words, there are about one million atoms along each row of the speck of matter.

The distance 0.1 mm is about a tenth of the width of a one-sixteenth-inch separation on a ruler.

If we assume that the atoms on the speck are aligned like those on the gold surface illustrated schematically in Figure 1.2e, there are about a million rows a million atoms long on the surface of the speck. The number of atoms on the surface, therefore, is a million million, or $10^{6} \times 10^{6} = 10^{12}$. Since there are a million atoms along each vertical row, our speck is a million rows wide and a million rows deep, with each row containing a million atoms. The total number of atoms in the speck is a million million million, or $10^{6} \times 10^{12} = 10^{18}$. In other words, the number of individual atoms present in a speck of matter just barely big enough to be visible is about 10^{18}, or 1,000,000,000,000,000,000!

The number 10^{18} is a billion billion, since one billion equals 10^9.

Exercise 1.6

Determine the number of atoms in a sugar cube that has dimensions of 1 cm × 1 cm × 1 cm (1 centimeter = 0.01 meter). Assume that each atom has dimensions of 10^{-10} meter each and that the atoms are lined up simply in rows, as we assumed for gold, above.

According to the results of Exercise 1.6, a sugar cube contains about 10^{24} atoms. We know that a cube having a volume of 1 cm^3, and consisting of material such as sugar or water, has a mass of about one gram. It follows then that the mass of each atom is about $1/10^{24} = 10^{-24}$ grams. Thus we see how tiny in size and mass an atom truly is! Because of the different masses of the atoms and the differences in the distances between adjacent atoms, the mass and volume associated with a given number of atoms varies from one element to another, as illustrated by the examples in Figure 1.25.

One cm^3 of water weighs 1 gram.

1. What are the typical dimensions of an atom?
2. How many atoms would be present along the edge of a cubic speck of dust just large enough to be visible?

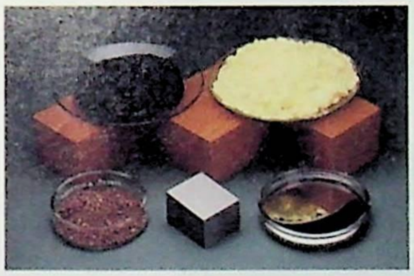


Figure 1.25 Samples of various elements, each containing the same number of atoms. Clockwise, from top left, are carbon, sulfur, mercury, lead, and copper. *(Chip Clark)*

Exercise 1.7

By definition, a liter has dimensions of 0.1 meter × 0.1 meter × 0.1 meter. Determine the number of atoms in one liter of a metal in the shape of a cube. You should assume that each metal atom has a diameter of 10^{-10} meters and that the atoms are lined up simply in rows, as discussed in the chapter. Calculate the volume of matter, with atoms of this same size and arrangement, that contains about 10^{24} atoms.

Exercise 1.8

Your body has a volume of about 0.1 m^3. Assuming that it contains atoms having dimensions of about 1 nanometer that are close-packed together, calculate the number of atoms in your body.