1.1 EARLY DESCRIPTIONS OF MATTER

Chemistry has been defined as the study of matter and its interconversions. Thus, in a sense, chemistry is a study of the physical world in which we live. But how much do we really know about the fundamental structure of matter and its relationship to the larger macroscopic world? I have in my rock collection, which I have had since I was a boy, a sample of the mineral cinnabar, which is several centimeters across and weighs about 10 g. Cinnabar is a reddish granular solid with a density about eight times that of water and the chemical composition mercuric sulfide. Now suppose that some primal instinct suddenly overcame me and I were inclined to demolish this precious talisman from my childhood. I could take a hammer to it and smash it into a billion little pieces. Choosing the smallest of these chunks, I could further disintegrate the material in a mortar and pestle, grinding it into ever finer and finer grains until I was left with nothing but a red powder (in fact, this powder is known as vermilion and has been used as a red pigment in artwork dating back to the fourteenth century). Having satisfied my destructive tendencies, I would nonetheless still have exactly the same material that I started with—that is, it would have precisely the same chemical and physical properties as the original. I might therefore wonder to myself if there is some inherent limitation as to how finely I can divide the substance or if this is simply limited by the tools at my disposal. With the proper equipment, would I be able to continue dividing the compound into smaller and smaller pieces until ultimately I obtained the unit cell, or smallest basic building block of the crystalline structure of HgS, as shown in Figure 1.1? For that matter (no pun intended), is there a way for me to separate out the two different types of atoms in the substance?

If matter is defined as anything that has mass and is perceptible to the senses, at what point does it become impossible (or at the very least impractical) for me to continue to measure the mass of the individual grains or for them to no longer be perceptible to my senses (even if placed under an optical microscope)? The ancient philosopher Democritus (ca 460–370 BC) was one of the first to propose that matter is constructed of tiny indivisible particles known as atomos (or atoms), the different varieties (sizes, shapes, masses, etc.) of which form the fundamental building blocks of the natural world. In other words, there should be some lower limit as to how
As far back as the Middle Ages, the alchemists learned that one could decompose a sample of HgS by heating it up in a crucible. At temperatures above 580 °C, the heat drives off the sulfur and leaves behind a pool of silvery liquid mercury. Eventually, I could break the molecule itself apart into its individual atoms, but then I could go no further.
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Or could I? In the late 1800s, scientists discovered that if they constructed a hollow glass tube with an anode in one end and a cathode in the other and pumped out as much of the air as they could, an electrical discharge between the two electrodes could produce a faint glow within the tube. Later, *cathode ray tubes*, as they became to be known, were more sophisticated and contained a phosphorescent coating in one end of the tube. William Crookes demonstrated that the rays were emitted from the cathode and that they traveled in straight lines and could not bend around objects in their path. A while later, Julius Plücker was able to show that a magnet applied to the exterior of the cathode ray tube could change the position of the phosphorescence. Physicists knew that the cathode ray carried a negative charge (in physics, the cathode is the negatively charged electrode and because the beam originated from the cathode, it must therefore be negatively charged). However, they did not know whether the charge and the ray could be separated from one another. In 1897, Joseph J. Thomson finally resolved the issue by demonstrating that both the beam and the charged particles could be bent by an electrical field that was applied perpendicular to the path of the beam, as shown in Figure 1.2. By systematically varying the electric field strength and measuring the angle of deflection, Thomson was able to determine the charge-to-mass (\(e/m\)) ratio of the particles, which he called *corpuscles* and which are now known as *electrons*. Thomson measured the \(e/m\) ratio as \(-1.76 \times 10^8 \text{ C/g}\), a value that was at least a thousand times larger than the one expected on the basis of the known atomic weights of even the lightest of atoms, indicating that the negatively charged electrons must be much smaller in size than a typical atom. In other words, the atom was not indivisible, and could itself be broken down into smaller components, with the electron being one of these subatomic particles. As a result of his discovery, Thomson proposed the so-called plum pudding model of the atom, where the atom consisted of one or more of these tiny electrons distributed in a sea of positive charge, like raisins randomly dispersed in a gelatinous pudding. Thomson was later awarded the 1906 Nobel Prize in physics for his discovery of the electron and his work on the electrical conductivity of gases.

In 1909, Robert Millikan and his graduate student Harvey Fletcher determined the charge on the electron using the apparatus shown in Figure 1.3. An atomizer from a perfume bottle was used to spray a special kind of oil droplet having a low vapor pressure into a sealed chamber. At the bottom of the chamber were two parallel circular plates. The upper one of these plates was the anode and it had a hole drilled into the center of it through which the oil droplets could fall under the influence of gravity. The apparatus was equipped with a microscope so that Millikan could observe the rate of fall of the individual droplets. Some of the droplets became charged as a result of friction with the tip of the nozzle, having lost one or more of their electrons to become positively charged cations. When Millikan applied a potential difference between the two plates at the bottom of the apparatus, the positively charged droplets were repelled by the anode and reached an equilibrium.

![Figure 1.2](image)

**Figure 1.2**
Schematic diagram of a cathode ray tube similar to the one used in J. J. Thomson’s discovery of the electron. [Blatt Communications.]
state where the Coulombic repulsion of like charges and the effect of gravity were exactly balanced, so that appropriately charged particles essentially floated there in space inside the container. By systematically varying the potential difference applied between the two metal plates and counting the number of particles that fell through the opening in a given period of time, Millikan was able to determine that each of the charged particles was some integral multiple of the electronic charge, which he determined to be $-1.592 \times 10^{-19} \text{ C}$, a measurement that is fairly close to the modern value for the charge on an electron ($-1.60217733 \times 10^{-19} \text{ C}$). Using this new value of $e$ along with Thomson’s $e/m$ ratio, Millikan was able to determine the mass of a single electron as $9.11 \times 10^{-28} \text{ g}$. The remarkable thing about the mass of the electron was that it was 1837 times smaller than the mass of a single hydrogen atom. Another notable feature of Millikan’s work is that it very clearly demonstrated that the electronic charge was quantized as opposed to a continuous value. The differences in the charges on the oil droplets were always some integral multiple of the value of the electronic charge $e$. Millikan’s work was not without controversy, however, as it was later discovered that some of his initial data (and Fletcher’s name) were excluded from his 1913 publication. Some modern physicists have viewed this as a potential example of pathological science. Nevertheless, Millikan won the 1923 Nobel Prize in physics for this work.

Also in 1909, one of J. J. Thomson’s students, Ernest Rutherford, working with Hans Geiger and a young graduate student by the name of Ernest Marsden, performed his famous “gold foil experiment” in order to test the validity of the plum pudding model of the atom. Rutherford was already quite famous by this time, having won the 1908 Nobel Prize in chemistry for his studies on radioactivity. The fact that certain compounds (particularly those of uranium) underwent spontaneous radioactive decay was discovered by Antoine Henri Becquerel in 1896. Rutherford was the first to show that one of the three known types of radioactive decay involved the transmutation of an unstable radioactive element into a lighter element and a positively charged isotope of helium known as an alpha particle. Alpha particles were many thousands of times more massive than an electron. Thus, if the plum pudding model of the atom were correct, where the electrons were evenly dispersed in a sphere of positive charge, the heavier alpha particles should be able to blow right through the atom. Geiger and Marsden assembled the apparatus shown in Figure 1.4.

A beam of alpha particles was focused through a slit in a circular screen that had a phosphorescent coating of ZnS on its interior surface. When an energetic alpha particle struck the phosphorescent screen, it would be observed as a flash of light. In the center of the apparatus was mounted a very thin piece of metal foil (although it is often referred to as the gold foil experiment, it was in fact a piece of platinum foil, not gold, which was used). While the majority of alpha particles struck the screen
1.1 Early Descriptions of Matter

Immediately behind the piece of metal foil as expected, much to the amazement of the researchers, a number of alpha particles were also deflected and scattered at other angles. In fact, some of the particles even deflected backward from the target. In his own words, Rutherford was said to have exclaimed: "It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you. On consideration, I realized that this scattering backwards must be the result of a single collision, and when I made calculations I saw that it was impossible to get anything of that order of magnitude unless you took a system in which the greater part of the mass of an atom was concentrated in a minute nucleus." Further calculations showed that the diameter of the nucleus was about five orders of magnitude smaller than that of the atom. This led to the rather remarkable conclusion that matter is mostly empty space—with the very lightweight electrons orbiting around an incredibly dense and positively charged nucleus, as shown in Figure 1.5. As a matter of fact, 99.99999999% of the atom is devoid of all matter entirely! On the atomic scale, solidity has no meaning. The reason that a macroscopic object "feels" at all hard to us is because the atom contains a huge amount of repulsive energy, so that whenever we try to "push" on it, there is a whole lot of energy pushing right back.

It wasn’t until 1932 that the final piece of the atomic puzzle was put into place. After 4 years as a POW in Germany during World War I, James Chadwick returned to England to work with his former mentor Ernest Rutherford, who had taken over J. J. Thomson’s position as Cavendish Professor at Cambridge University. It was not long before Rutherford appointed Chadwick as the assistant director of the nuclear physics lab. In the years immediately following Rutherford’s discovery that the nucleus contained protons, which existed in the nucleus and whose charges were
equal in magnitude to the electronic charge but with the opposite sign, it was widely known that the nuclei of most atoms weighed more than could be explained on the basis of their atomic numbers (the \textit{atomic number} is the same as the number of protons in the nucleus). Some scientists even hypothesized that maybe the nucleus contained an additional number of protons and electrons, whose equal but opposite charges cancelled each other out but which together contributed to the increased mass of the nucleus. Others, such as Rutherford himself, postulated the existence of an entirely new particle having roughly the same mass as a proton but no charge at all, a particle that he called the \textit{neutron}. However, there was no direct evidence supporting this hypothesis.

Around 1930, Bothe and Becker observed that a Be atom bombarded with alpha particles produced a ray of neutral radiation, while Curie and Joliot showed that this new form of radiation had enough energy to eject protons from a piece of paraffin wax. By bombarding heavier nuclei (such as N, O, and Ar) with this radiation and calculating the resulting cross-sections, Chadwick was able to prove that the rays could not be attributed to electromagnetic radiation. His results were, however, consistent with a neutral particle having roughly the same mass as the proton. In his next experiment, Chadwick bombarded a boron atom with alpha particles and allowed the resulting neutral particles to interact with nitrogen. He also measured the velocity of the neutrons by allowing them to interact with hydrogen atoms and measuring the speed of the protons after the collision. Coupling the results of each of his experiments, Chadwick was able to prove the existence of the neutron and to determine its mass to be \(1.67 \times 10^{-27}\) kg. The modern-day values for the charges and masses of the electron, proton, and neutron are listed in Table 1.1. Chadwick won the Nobel Prize in physics in 1935 for his discovery of the neutron.

### 1.2 VISUALIZING ATOMS

At the beginning of this chapter, I asked the question at what point can we divide matter into such small pieces that it is no longer perceptible to the senses. In a sense, this is a philosophical question and the answer depends on what we mean as being perceptible to the senses. Does it literally mean that we can see the individual components with our naked eye, and for that matter, what are the molecular characteristics of vision that cause an object to be seen or not seen? How many photons of light does it take to excite the rod and cone cells in our eyes and cause them to fire neurons down the optic nerve to the brain? The concept of perceptibility is somewhat vague. Is it fair to say that we still see the object when it is multiplied under an optical microscope? What if an electron microscope is used instead? Today, we have “pictures” of individual atoms, such as those shown in Figure 1.6, made by a scanning tunneling microscope (STM) and we can manipulate individual atoms on

<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass (kg)</th>
<th>Mass (amu)</th>
<th>Charge (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>(9.10938291 \times 10^{-31})</td>
<td>0.00054857990946</td>
<td>(-1.602176565 \times 10^{-19})</td>
</tr>
<tr>
<td>Proton</td>
<td>(1.672621777 \times 10^{-27})</td>
<td>1.007276466812</td>
<td>(1.602176565 \times 10^{-19})</td>
</tr>
<tr>
<td>Neutron</td>
<td>(1.674927351 \times 10^{-27})</td>
<td>1.00866491600</td>
<td>0</td>
</tr>
</tbody>
</table>

a surface in order to create new chemical bonds at the molecular level using atomic force microscopy (AFM).

But are we really capable of actually seeing an individual atom? Technically speaking, we cannot see anything smaller than the shortest wavelength of light with which we irradiate it. The shortest wavelength that a human eye can observe is about 400 nm, or $4 \times 10^{-7}$ m. As the diameter of an atom is on the scale of $10^{-11}$ m and the diameter of a typical nucleus is even smaller at $10^{-15}$ m, it is therefore impossible for us to actually see an atom. However, we do have ways of visualizing atoms. A scanning tunneling microscope, like the one shown in Figure 1.7, works by moving an exceptionally sharp piezoelectric tip (often only one atom thick at its point) across the surface of a conductive solid, such as a piece of crystalline nickel in an evacuated
chamber. When a small voltage is applied to the tip of the STM, a tunneling current develops whenever the tip is close to the surface of a Ni atom. This tunneling current is proportional to the distance between the tip of the probe and the atoms on the surface of the crystal. By adjusting the STM so that the tunneling current is a constant, the tip will move up and down as it crosses the surface of the crystal and encounters electron density around the nuclei of the nickel atoms. A computer is then used to map out the three-dimensional contour of the nickel surface and to color it different shades of blue in this case, depending on the distance that the tip has moved. The STM can also be used to pick up atoms and to move them around on a surface. In fact, the scientists who invented the STM (Gerd Binnig and Heinrich Rohrer, both of whom shared the 1986 Nobel Prize in physics) used an STM to spell out the name of their sponsoring company IBM by moving around 35 individual Xe atoms affixed to a Ni surface.

The AFM, which has a smaller resolution than the STM, has the advantage of being able to visualize nonconductive surfaces. It functions using a cantilever with a very narrow tip on the end. Instead of interacting directly with the electrons, it vibrates at a specific frequency and when it encounters an atom, the frequency of the vibration changes, allowing one to map out the contour of the surface.

1.3 THE PERIODIC TABLE

While chemistry is the study of matter and its interconversions, inorganic chemistry is that subdiscipline of chemistry which deals with the physical properties and chemistry of all the elements, with the singular exclusion of carbon. An element is defined by the number of protons in its nucleus. There are 90 naturally occurring elements (all of the elements up to and including atomic number 92, with the exception of Tc (atomic number 43) and Pm (atomic number 61)). However, if all of the man-made elements are included, a total of 118 elements are currently known to exist. It has long been known that many of the elements had similar valences and chemical reactivity. In the late 1860s and early 1870s, Dmitri Mendeleev and Julius Lothar Meyer independently discovered that the elements could be arranged into a table in an orderly manner such that their properties would follow a periodic law. In his book *Principles of Chemistry*, Mendeleev wrote: “I began to look about and write down the elements with their atomic weights and typical properties, analogous elements and like atomic weights on separate cards, and this soon convinced me that the properties of elements are in periodic dependence upon their atomic weights.” His resulting periodic table organized the elements into eight broad categories (or Gruppe) according to increasing atomic mass, as shown in Figure 1.8.

At the time of publication in 1871, only about half of the elements known today had yet to be discovered. One of the reasons that Mendeleev’s version of the periodic table became so popular was that he left gaps in his table for as yet undiscovered elements. When the next element on his pile of cards did not fit the periodic trend, he placed the element in the next group that bore resemblance to it, figuring that a new element would someday be discovered with properties appropriate to fill in the gap. Furthermore, by interpolation from the properties of those elements on either side of the gaps, Mendeleev could use his table to make predictions about the reactivity of the unknown elements. In particular, Mendeleev predicted the properties of gallium, scandium, and germanium, which were discovered in 1875, 1879, and 1886, respectively, and he did so with incredible accuracy. For example, Table 1.2 lists the properties of germanium that Mendeleev predicted 15 years before its discovery and compares them with the modern-day values. It is this predictive capacity that makes the periodic table one of the most powerful tools in chemistry. Mendeleev’s periodic table was organized according to increasing mass. With the discovery of
1.4 THE STANDARD MODEL

As an atom is the smallest particle of an element that retains the essential chemical properties of that substance, one might argue that atoms are the fundamental building blocks of matter. However, as we have already seen, the atom itself is not indivisible, as Democritus believed. As early as the 1930s, it was recognized that there were other fundamental particles of matter besides the proton, the neutron, and the electron. The muon was discovered by Carl Anderson and Seth Nedermeyer in 1936. Anderson was studying some of the properties of cosmic radiation when he noticed a new type of negatively charged particle that was deflected by a magnetic
field to a lesser extent than was the electron. The muon has the same charge as the electron, but it has a mass that is about 200 times larger, which explains why it was not deflected as much as an electron. Muons are not very stable particles, however; they have a mean lifetime of only $2.197 \times 10^{-6}$ s. Muons occur when cosmic radiation interacts with matter and are also generated in large quantities in modern-day particle accelerators. As it turns out, however, the muon represents just one strange beast in a whole zoo of subatomic particles that include hadrons, baryons, neutrinos, mesons, pions, quarks, and gluons—to name just a few, begging the question of just how divisible is matter and what (if anything) is fundamental!

The standard model of particle physics was developed in the 1970s following experimental verification of quarks. The standard model incorporates the theory of general relativity and quantum mechanics in its formulation. According to the standard model, there are a total of 61 elementary particles, but ordinary matter is composed of only six types (or flavors) of leptons and six types of quarks. Leptons and quarks are themselves examples of fermions, or particles that have a spin quantum number of $\frac{1}{2}$ and obey the Pauli exclusion principle. It is the various combinations of these fundamental particles that make up all of the larger particles, such as protons and neutrons. Thus, for example, a proton is composed of two up quarks and one down quark (pronounced in such a way that it rhymes with the word “cork”). Electrons, muons, and neutrinos are all examples of leptons. Both leptons and quarks can be further categorized into one of three different generations, as shown in Figure 1.9. First-generation particles, such as the electron and the up and down quarks that make up protons and neutrons, are stable, whereas second- and third-generation particles exist for only brief periods of time following their generation. Furthermore, each of the 12 fundamental particles has a corresponding antiparticle. An antiparticle has the same mass as a fundamental particle, but exactly the opposite electrical charge. The antiparticle of the electron, for instance, is the positron, which has a mass of roughly $9.109 \times 10^{-31}$ kg like the electron, but an electrical charge of +1.602 $\times 10^{-19}$ C or +1e. Whenever a particle and its antiparticle collide, they annihilate each other and create energy. In addition to the 12 fundamental particles and their antiparticles, there are also force-carrying particles, such as

**FIGURE 1.9**  
The 12 fundamental particles (leptons in green and quarks in purple) and the force-carrying particles (in red) that comprise the standard model of particle physics. The newly discovered Higgs boson, which explains why some particles have mass, is shown at the upper right.  
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1.4 THE STANDARD MODEL

the photon, which carries the electromagnetic force. Collectively, the 12 fundamental particles of matter are known as fermions because they all have a spin of $\frac{1}{2}$, while the force-carrying particles are called bosons and have integral spin. The different types of particles in the standard model are illustrated in Figure 1.9.

There are four types of fundamental forces in the universe, arranged here in order of increasing relative strength: (i) gravity, which affects anything with mass; (ii) the weak force, which affects all particles; (iii) electromagnetism, which affects anything with charge; and (iv) the strong force, which only affects quarks. There are six quarks, as shown in Figure 1.10, and they are arranged as pairs of particles into three generations. The first quark in each pair has a spin of $+\frac{2}{3}$, while the second one has a spin of $-\frac{1}{3}$.

Quarks also carry what is known as color charge, which is what causes them to interact with the strong force. Color charges can be represented as red, blue, or green, by analogy with the RGB additive color model, although this is really just a nonmathematical way of representing their quantum states. Like colors tend to repel one another and opposite colors attract. Because of a phenomenon known as color confinement, an individual quark has never been directly observed because quarks are always bound together by gluons to form hadrons, or combinations of quarks. Baryons consist of a triplet of quarks, as shown in Figure 1.11. Protons and neutrons are examples of baryons that form the basic building blocks of the nucleus. Mesons, such as the kaon and pion, are composed of a pair of particles: a quark and an antiquark.

Unlike quarks, which always appear together in composite particles, the leptons are solitary creatures and prefer to exist on their own. Furthermore, the leptons do not carry color charge and they are not influenced by the strong force. The electron, muon, and tau are all negatively charged particles (with a charge of $-1.602 \times 10^{-19} \text{ C}$), differing only in their masses. Neutrinos, on the other hand, have no charge and are particularly difficult to detect. The electron neutrino has an extremely small mass and can pass through ordinary matter. The heavier leptons (the muon and the tau) are not found in ordinary matter because they decay very quickly into lighter leptons, whereas electrons and the three kinds of neutrinos are stable.
Well, now that we know what matter is made of, we might ask ourselves the question of what it is that holds it together. Each of the four fundamental forces (with the exception of gravity, which has not yet fully been explained by the standard model) has one or more force-carrying particles that are passed between particles of matter. The photon is the force-carrying particle of electromagnetic radiation. The photon has zero mass and only interacts with charged particles, such as protons, electrons, and muons. It is the electromagnetic force that holds atoms together in molecules—the electrons orbiting one nucleus can also be attracted to the protons in a neighboring nucleus. The electromagnetic force is also responsible for why particles having the same charge repel one another. Because they are all positively charged, one might wonder how it is that more than one proton can exist within the very small confines of the nucleus. The explanation for this conundrum is that protons are made up of quarks. The quarks are held together in triplets in the proton by the strong force because they have color charge. Likewise, it is the residual strong force, where a quark on one proton is attracted to a quark on another proton or neutron, which holds the protons and neutrons together inside the nucleus. The force-carrying particle for the strong force is the gluon. Quarks absorb and emit gluons very rapidly within a hadron, and so it is impossible to isolate an individual quark. The weak force is responsible for an unstable heavier quark or lepton disintegrating into two or more lighter quarks or leptons. The weak force is carried by three different force-carrying particles: the $W^+$, $W^-$, and $Z$ bosons. The $W^+$ and $W^-$ particles are charged, whereas the $Z$ particle is neutral. The standard model also predicts the presence of the Higgs boson, popularly known as the god particle, which is responsible for explaining why the fundamental particles have mass.

Recently, scientists working at the LHC (Large Hadron Collider) particle accelerator have finally discovered evidence suggesting the existence of the elusive Higgs boson. In fact, Peter Higgs, after which the Higgs boson was named, shared the 2013 Nobel Prize in physics for his contributions in the area of theoretical particle physics. The particles that comprise the standard model of particle physics are to date the most fundamental building blocks of matter. Despite its incredible successes, the standard model has yet to accurately describe the behavior of gravity or why there are more particles in the universe than antiparticles and why the universe contains so much dark matter and dark energy. Physicists continue to search for a grand unified theory of everything, and one is therefore left to wonder whether anything at all is truly fundamental. In the following chapter, we examine some further properties of the nucleus and show how matter and energy themselves can be interconverted.

**EXERCISES**

1.1. In Thomson's cathode ray tube experiment, the electron beam will not be deflected unless an external electric or magnetic field has been applied. What does this result imply about the force of gravity on the electrons (and hence about the mass of an electron)?

1.2. If a beam of protons were somehow substituted in Thomson's cathode ray tube experiment instead of a beam of electrons, would their deflection by an electrical field be larger or smaller than that for an electron? Explain your answer. What would happen if a beam of neutrons were used?

1.3. The following data were obtained for the charges on oil droplets in a replication of the Millikan oil drop experiment: $1.5547 \times 10^{-19}$, $4.6192 \times 10^{-19}$, $3.1417 \times 10^{-19}$, $3.0817 \times 10^{-19}$, $1.5723 \times 10^{-19}$, $1.5646 \times 10^{-19}$, $1.5420 \times 10^{-19}$, and $1.5547 \times 10^{-19}$ C. Use these data to calculate the average charge on a single electron. Explain how you arrived at your result.
1.4. An alpha particle is the same as a helium-4 nucleus: it contains two protons and two neutrons in the nucleus. Given that the radius of an alpha particle is approximately 2.6 fm, calculate the density of an alpha particle in units of grams per cubic centimeter.

1.5. Given that the mass of an average linebacker at Ursinus College is 250 lbs and the radius of a pea is 0.50 cm, calculate the number of linebackers that would be required to be stuffed into the volume of a pea in order to obtain the same density as an alpha particle.

1.6. Given that the radius of the helium-4 nucleus is approximately 2.6 fm, the classical electron radius is 2.8 fm, and the calculated atomic radius of $^4$He is 31 pm, calculate the percentage of the space in a helium-4 atom that is actually occupied by the particles.

1.7. Explain the similarities and differences between scanning tunneling microscopy and atomic force microscopy.

1.8. At the time when Mendeleev formulated the periodic table in 1871, the element gallium had yet to be discovered, and Mendeleev simply left a gap in his periodic table for it. By interpolating data from the elements that surround gallium in the periodic table, predict the following information about gallium and then compare your predictions to the actual values: its atomic mass, its density, its specific heat, its atomic volume, its melting point, the molecular formula for its oxide, the density of its oxide, the molecular formula for its chloride, and the density of its chloride.

1.9. Which of the following particles will interact with an electromagnetic field? (a) An electron, (b) an up quark, (c) an electron neutrino, (d) a proton, (e) a positron, (f) a muon, (g) a pion.

1.10. Explain why it is that electrons traveling in the same region of space will always repel one another, but protons can exist in close proximity with each other in the interior of the nucleus.

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