Atomic Pudding
Models of the Atom

Think About It

The drawing depicts a very tiny sample of gold taken from a gold ring.

The spheres in the cube of gold are so small that they cannot be seen. What are the spheres, and what does this drawing tell you about the element gold?

How are the smallest bits of matter described?

To answer this question, you will explore

1. Atoms: Small Bits of Matter
2. Models of the Atom
3. Simple Atomic Model

Exploring the Topic

1. Atoms: Small Bits of Matter

Imagine you break a piece of matter in half, and then break it in half again and again. How many times can you do this? Can you keep going, getting ever smaller? Around 460 B.C.E., the Greek philosopher Democritus wondered the same thing. He thought that if he could just keep breaking matter in half he would eventually end up with the smallest bit of matter possible.
Democritus proposed that all matter was composed of tiny particles that could not be divided further. Today we use the word **atom** to describe these bits of matter. Of course, atoms are too small to actually be seen. Democritus’ idea was disregarded for the next two thousand years, in part, because Democritus did not have evidence to support it.

In 1803, the British scientist John Dalton suggested that the idea of atoms could help explain why elements come together in specific ratios when they form compounds. He imagined atoms of different elements combining to form compounds in the ratios specified by the chemical formulas of the compounds. For example, to form the compound titanium sulfide, TiS$_2$, titanium and sulfur atoms combine in a 1:2 ratio.

Dalton had more than an idea about atoms. He conducted experiments and made observations to back up his idea. His observations provided strong evidence to support his explanation of how matter behaves.

In science, the word “theory” indicates that an explanation is supported by overwhelming evidence. The word “theory” allows room for doubt and revision, but indicates a greater degree of certainty than the word does in everyday use. The **atomic theory** states that all matter is made up of atoms. The atomic theory helps us make accurate predictions about the behavior of matter.
Models of the Atom

Since Dalton’s time, scientists have created many models to describe atoms and their parts. Models are simplified representations of something you want to explain. For example, a model airplane is a small representation of a larger aircraft. Models take many forms. They can be a plan, a physical structure, a drawing, a mathematical equation or even a mental image. A model that represents the structure of an atom is called an atomic model.

EXPERIMENT 1  1803
In 1803, John Dalton studied how elements combine chemically to form compounds. He observed that elements combine in whole-number ratios to form compounds and that matter is not created or destroyed in chemical reactions. Dalton reasoned that elements are made of tiny, indivisible spherical particles called atoms.

EXPERIMENT 2  1897
In 1897, J.J. Thomson, a British scientist, zapped atoms with electricity. He observed that negatively charged particles were removed. Thomson reasoned that atoms contain negatively charged particles, which he called electrons.

PLUM PUDDING MODEL

The atom can be divided into a fluid (the “pudding”) and electrons. Most of the atom is made of fluid. The fluid spreads out in the atom and is positively charged. The electrons are very tiny and negatively charged.
**EXPERIMENT 3 1911**
In 1911, Ernest Rutherford, a New Zealand–born scientist, shot tiny positively charged particles, called alpha particles, at thin gold foil. He observed that most of the alpha particles went through the foil, but a few bounced back. Rutherford reasoned that there must be something small, massive, and positively charged in an atom, which he called the nucleus.

**EXPERIMENT 4 1913**
In 1913, Neils Bohr, a Danish scientist, developed a model of the atom that explained the light given off when elements are exposed to flame or electric fields. He observed that only certain colors of light are given off. For example, hydrogen atoms give off red, blue-green, and blue light. Bohr reasoned that the electrons orbit around the nucleus at different distances like planets orbiting the Sun. The electrons in these orbits have different energies. When an electron falls from an outer to an inner orbit, the color of the light given off depends on the energies of the two orbits.

**NUCLEAR MODEL**
- Negative electron
- Positive nucleus

The atom can be divided into a nucleus and electrons. The nucleus occupies a small amount of space in the center of the atom. The nucleus is dense and positively charged. The electrons circle around the nucleus. The electrons are tiny and negatively charged. Most of the atom is empty space.

**SOLAR SYSTEM MODEL**
- Negative electron
- Positive nucleus

The atom can be divided into a nucleus and electrons. The nucleus is in the center of the atom. The nucleus is massive and positively charged. The electrons circle around the nucleus in specified orbits. The electrons are tiny and negatively charged. Different electrons are in orbits at different distances from the nucleus.
**EXPERIMENT 5 1918**
In 1918, Rutherford made a further contribution. He found he could use alpha particles as bullets to knock off small positively charged particles, which he called protons. He reasoned that the nucleus must be a collection of protons.

**PROTON MODEL**

The nucleus contains protons. The protons are tiny and positively charged. The electrons circle around the nucleus. The electrons are tiny and negatively charged. Most of the atom is empty space.

**EXPERIMENT 6 1927**
In 1927, Werner Heisenberg, a German scientist, proposed a cloud model of the atom. Heisenberg suggested that the location of an electron could not be specified precisely. Instead, it is only possible to talk about the probability of where an electron might be. This led to a cloud model of the atom; the electron cloud indicates where you will most likely find a single electron.

**EXPERIMENT 7 1932**
In 1932, a British physicist, James Chadwick, found that the nucleus also included uncharged, or neutral, particles, which he called neutrons. He reasoned that the neutrons were important in holding the positively charged protons together.

**ELECTRON CLOUD MODEL**

An electron cloud surrounds the nucleus. The cloud is made up of fast-moving electrons: The nucleus is made up of protons: and neutrons:
Dalton pictured the atom as a hard, solid sphere. Over the next two hundred years, scientists gathered evidence to support and expand on Dalton’s model of the atom. It became clear that the atom was more than just a solid sphere.

But how did scientists gather evidence about something too small to be seen? Scientists found they could learn more about atoms and their structure by shooting small pieces of matter at them or by heating them in a flame. Observations from these experiments provided evidence that helped scientists make changes and refine the model of the atom.

The model of the atom was refined and changed as new evidence was gathered. This is what science is all about—a continual process of gathering new knowledge to improve our understanding of the world.

![Simple Atomic Model](image)

### Simple Atomic Model

All of the models have something valuable to offer in terms of visualizing matter at an atomic level. At right is a simple atomic model of an atom. In the very center of the atom is the **nucleus**. The nucleus consists of positively charged **protons**, and **neutrons**, which have no charge. The **electrons** are even tinier than the protons and neutrons, and they orbit the nucleus. In this particular atom the electrons are located at two different distances from the nucleus.

Each electron has a charge of $-1$. The neutrons are neutral and thus have no charge. Each proton has a charge of $+1$. A neutral atom has no overall charge. It has equal numbers of positive protons and negative electrons.
BIG IDEA
An atom has a nucleus made of protons and neutrons, and electrons orbiting the nucleus.

The nucleus occupies a very tiny volume. If an atom were the size of a baseball stadium, the nucleus would be smaller than a baseball.

Lesson Summary
How are the smallest bits of matter described?

Long ago, some philosophers imagined that matter was made up of tiny particles called atoms. Over time, scientists gathered evidence from experimental observations to create models of the atom. Today we know the atom is made up of protons, neutrons, and electrons. The protons and neutrons are in the center of the atom, in the nucleus. Electrons are outside the nucleus. They are much smaller than the protons and neutrons. In a neutral atom, the positive charges on the protons are equal to the negative charges on the electrons.
**FIVE MODELS OF THE ATOM**

**NUCLEAR MODEL:** The atom can be divided into a nucleus and electrons. The **nucleus** occupies a small amount of space at the center of the atom. The nucleus is dense and positively charged. The **electrons** circle around the nucleus. The electrons are tiny and negatively charged. Most of the atom is empty space.

**SOLID SPHERE MODEL:** The atom is a **solid sphere** that cannot be divided up into smaller particles or pieces.

**PROTON MODEL:** The atom can be divided into a **nucleus** and **electrons**. The nucleus occupies a small amount of space at the center of the atom. The nucleus consists of **protons** that are positively charged. The electrons circle the nucleus. The electrons are tiny and negatively charged. Most of the atom is empty space.

**PLUM PUDDING MODEL:** The atom can be divided into a fluid (the “pudding”) and electrons (the “plums”). The **fluid** spreads out in the atom and is positively charged. The **electrons** are very tiny and negatively charged. Most of the atom is made of fluid.

**SOLAR SYSTEM MODEL:** The atom can be divided into a nucleus and electrons. The **nucleus** is at the center of the atom and is positively charged. The **electrons** circle around the nucleus in specified orbits. The electrons are tiny and negatively charged. Different electrons are in orbits at different distances from the nucleus. Most of the atom is empty space.
Models of the Atom Exercises

Reading Questions

1. What evidence caused Thomson to change Dalton’s solid sphere model into the plum pudding model?

2. What evidence caused Rutherford to change Thomson’s plum pudding model into the nuclear model?

3. What evidence caused Bohr to change Rutherford’s nuclear model into the solar system model?

Reason and Apply

4. Positive and negative charges are attracted to one another. Which of the following are attracted to a negative charge: an electron, a proton, a neutron, a nucleus, an atom? Explain your thinking.
5. Hydrogen and helium are different elements. How can you use the plum pudding model to show how atoms of the two elements might be different from one another?

6. Suppose you discovered protons shortly after Thomson discovered electrons. How would you revise the plum pudding model to include protons? Draw a picture of your revised model of the atom.

7. Draw a solar system model showing one electron, one proton, and one neutron.

8. Use the Internet or other resource to find out how the size of an atom compares with the size of its nucleus. Is the diameter of an atom 10 times, 1,000 times, or 100,000 times the diameter of the nucleus?
9. The nuclear model and the solar system model both show atoms with electrons circling around the nucleus.
   a. How do these two models differ?

   b. How are these two models similar?

   c. How can you refine the solar system model so that the atoms do not look flat?

10. The ancient Greeks discarded the atomic theory because there was no evidence to support it. Try to provide evidence that atoms do indeed exist. Use the Internet to help you.

11. The ancient Greeks claimed that atoms were the smallest pieces of matter. Were they correct? Explain your thinking.

12. Give an example that shows how science is a process of gathering evidence and refining models.
Evaluating Historical Models of the Atom

Goal: Use evidence from historical and current experiments described in the article provided to justify the development of various models of the atom.

In 1803 John Dalton proposed that atoms were simply solid spheres. This is a model that we used as our particulate model of solids, liquids and gases. In the years since this solid sphere model was proposed, scientist have collected a lot of evidence that suggests that there is internal structure to the atom.

1. Look over the five models of the atom handout. In the space below, list the parts of each model that make it different from the other 4 models.

<table>
<thead>
<tr>
<th>MODEL</th>
<th>Unique Features</th>
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<tbody>
<tr>
<td>Solid Sphere Model</td>
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<tr>
<td>Plum Pudding Model</td>
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<tr>
<td>Nuclear Model</td>
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<tr>
<td>Solar System Model</td>
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<td>Proton Model</td>
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The following are three pieces of evidence that have been used to suggest one of the five models.

Evidence 1: It is possible to remove a negatively charged particle from an atom using electrical forces. (Thomson 1897)

Evidence 2: If a tiny particle is shot into the middle of an atom it hits something dense in the center and bounces back in the direction from which it came. If a tiny particle is shot into the edges of the atom it goes through. Most tiny particles shot at an atom will go through. (Rutherford, 1911)
Evidence 3: The farther from the center of an atom the negatively charged particles are, the easier they are to remove. (Bohr, 1913)

2. For each model, explain whether or not each piece of evidence is consistent with the model AND explain your reasoning. (I.e., why is the evidence consistent or why is it not consistent?)

<table>
<thead>
<tr>
<th>MODEL</th>
<th>Evidence 1</th>
<th>Evidence 2</th>
<th>Evidence 3</th>
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3. In 1932, British scientist James Chadwick discovered that the nucleus was made up of uncharged, or neutral, particles called neutrons, in addition to the protons discovered by Rutherford. Describe all the ways in which the three small particles found in the atom (electron, proton, neutron) differ from one another.
Wrap Up:

Answer the following questions individually in preparation for a short class discussion:

1. List at least three classroom activities that involve one of five models explored today.

<table>
<thead>
<tr>
<th>Model</th>
<th>Classroom Activity</th>
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2. Which atomic model is most similar to our particulate nature of matter model and why?

3. If you were to choose a model that explains electrolysis of water, which model would you choose and why?

4. Models are not wrong, they have limitations. Why do we sometimes want to use models that are incomplete or don’t explain all observations?