Hypothesis-Experiment Classbook

If You Could See an Atom

Kiyonobu Itakura

First edition in Japanese 1976,　English Edition Ver. 3.0 2025
Association for Studies in Hypothesis-Experiment Class (ASHEC)

The Educational Significance of 'If You Could See an Atom'

Kiyonobu Itakura

'If You Could See an Atom' is the most well-established Hypothesis–Experiment Classbook (HEC book). Originally, this HEC book was meant to be a science picture book – one of Dr. Itazura's science books*– intended to introduce the basic concepts of atomic theory to 10–12-year-old children.

*Itazura, which resembles Itakura, means mischievous or funny in Japanese.

However, the contents of this book were welcomed not only by children but also by teachers who used it as a teaching plan for classes in middle and senior high schools. Finally, this plan was successfully used even in 6–8-year-old children's classes. These results have exceeded the author's expectations.

When traditional educators hear that we use atom models in our classes, they regularly claim that elementary school students cannot possibly understand or accept such a difficult concept. But actually, the students have entirely welcomed the contents of this HEC Classbook without any concern for these educators' misgivings. Why do children like lessons that use atomic models?

This HEC Classbook first introduces 'All the things in this universe are made of atoms.' Then, children ask questions such as, 'Is my body also made of atoms?' 'How about this desk?' 'How about this book and cup?' 'How about the Sun or the stars?' When the teacher tells them, 'Yes, everything around you is made of atoms, exactly,' the students say, 'Really!?' It is not because they do not trust the teacher but because they are amazed by the discovery.

Children tend to trust the results of scientists' work. Modern science education should remember this and be careful not to betray children's trust when teaching them what they want to know. With this in mind, we promote the use of 'If You Could See an Atom,' which has been welcomed by children and their parents.

In a typical HEC Classbook, we provide interesting and challenging problems with experiments and let every student guess and discuss the results before performing the experiment. The children are deeply motivated by the fact that they can discover the problem by themselves. This is also one of the major goals of HEC. Children will lose the sense of pleasure and challenge in investigating the problem alone if they already know the result. Therefore, we have decided that the Problems in the HEC Classbook should not be released as a matter of course.

'If You Could See an Atom' is exceptional among HEC Classbooks because it does not contain questions; it only has statements, drawings, or models of atoms and molecules based on scientists' research. This particular Classbook is more useful if taught in a class. Children can use the atom models in various ways: looking at atom or molecule models the teacher shows them, making them themselves, or discussing atoms and molecules. They acquire knowledge of atoms and molecules through group studies in their class. The learning environment is very relaxed and enjoyable.

The 'If You Could See an Atom' Classbook has also succeeded in letting students imagine the concept of molecular motion in their minds. Of course, in real life, gas molecules such as oxygen, nitrogen, and water [vapor] are moving around very actively all together. Moreover, nowadays, students can see computer simulations of molecular motion. Many people know that gas molecules are flying around in a vacuum, but they often think that the motion of the molecules might be decreased by air resistance. The so-called air resistance does not affect the motion of gas molecules in a vacuum. The only factor affecting motion is the collision of molecules in the air.

Most children who learned using this Classbook became familiar with atoms and molecules. But many others, usually high school or university students, often express distaste for the topic of atoms and molecules and say, 'We will never understand those sorts of things.' We need to be familiar with an easy and understandable model of atoms from our childhood. We hope this plan will be a good way of sharing the magnificent experience of scientific thinking with atom models.

The sizes of the atom and molecule models in this book are magnified one hundred million times. The original size of atoms and molecules is based on the van der Waals radius. It was named after a Dutch scientist, Johannes Diderik van der Waals (1837–1923), who researched the size of gas molecules. The models in this book are called Stuart-type models after the German scientist Herbert Arthur Stuart (1899–1974). He proposed making molecule models based on the van der Waals radius in 1934, and after that, they came into practical use. The Stuart-type model is also called the solid volume model because the actual size of atoms is used as a reference. There are various types of models that scientists use for different purposes. Recently, the solid volume model has become one of the most popular. The Stuart-type model has enabled us to imagine real atoms and molecules.

May 2008

Although this HEC book is primarily the reading material, teachers can implement it in various teaching styles based on HEC's concept of practices that consider the conditions for establishing scientific cognition.

Three basic methods are commonly used: reading the text interactively with the students, making it equally interactive with the app that includes a simulation, or combining both.

As the story progresses, it is practical to incorporate hands-on activities such as showing models, coloring, building models, and observing water evaporation.

Try to keep the class in a relaxed atmosphere where students comment and interact with each other and the teacher about their predictions and ideas.

Please take a look at the bibliography at the end of this document.

ASHEC Translation Project Group 2025

Hypothesis–Experiment Classbook

If You Could See an Atom

Atoms and molecules in the air

Have you ever seen the air?
Have you heard the word atom before?
Have you ever seen an atom or a molecule?

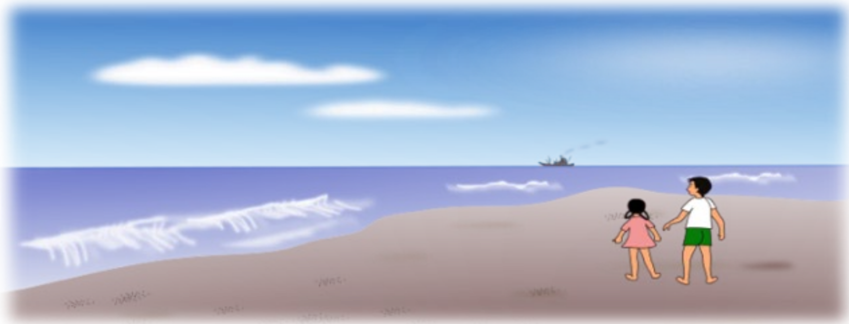
The word "atom" comes from the ancient Greek for "indivisible".

Have you ever seen an atom?
There are atoms all around us.

The stones and soil are made of atoms. Paper and trees consist of many atoms.
Iron, glass, air, and clouds are also made of atoms.
Of course, our body is made up of a huge number of atoms.

Everything around us is made of atoms, even though we cannot see them.
The naked eye cannot see an atom like you cannot see the air.

Have you ever seen planet Earth?
Everyone has seen the ground, but none of you have seen the Earth as a globe. You can see it in a photograph, though.
At the seashore, the horizon appears to be a straight line; it does not look curved.



But we can draw a picture of the Earth and make a model of it. We can imagine it even though we cannot look at the entire Earth directly.

The Earth is too large to be seen all at once, while the atom is too small to be seen with the eye.

However, scientists know about atoms very well. They have researched it in detail by:

- exercising imagination,
- carrying out complex calculations,
- and doing various experiments.

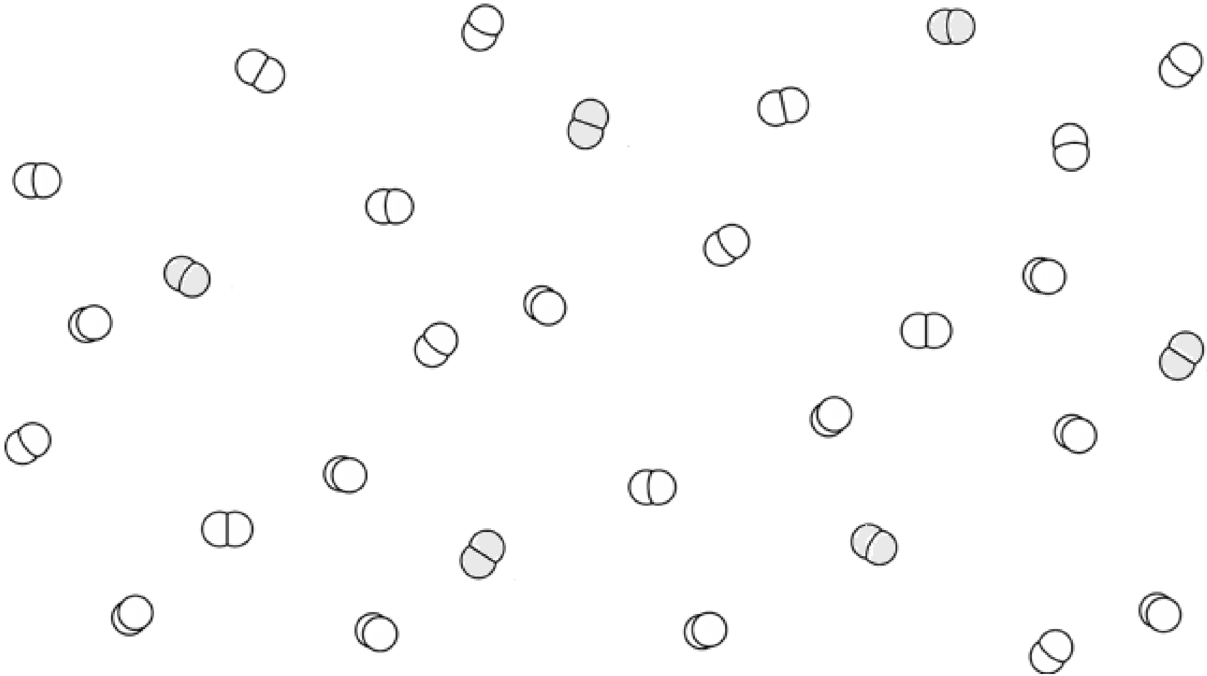
Scientists can draw pictures of the atom and make models as if they had seen atoms with their own eyes. They can also take an electron microscopic picture of atoms today.

Why don't you draw a picture of an atom and make a model with your friends?

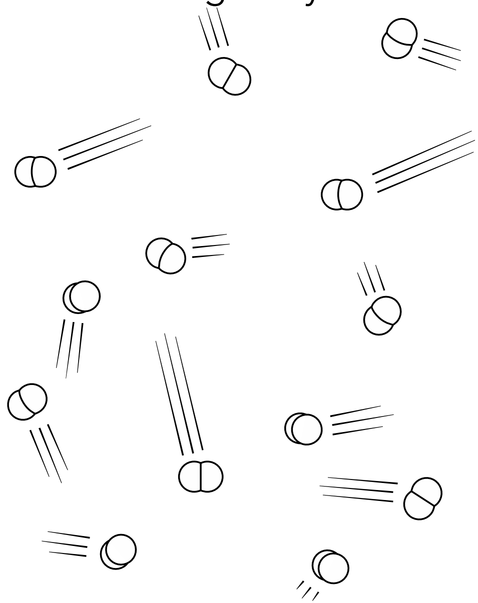
Question 1

If you could see the world of atoms, what would the air around you look like? Imagine what it would look like and draw a picture.

This is a picture of the air drawn by scientists as they imagine it.



In this picture, you can see some small particles. These particles are flying about actively. They sometimes collide and are sent bounding away.



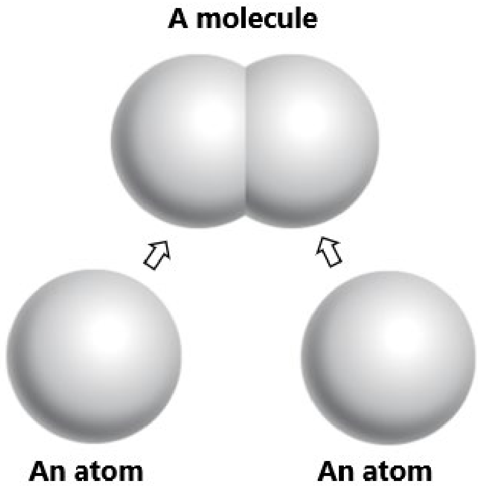
The place between particles is empty. There is nothing whatsoever there. It is completely empty.
Scientists call this true emptiness a "vacuum".

The particles of air run through the vacuum at a very high speed. They move in a straight line until they hit each other because this space is empty.

The particles flying around are like two balls stuck together.

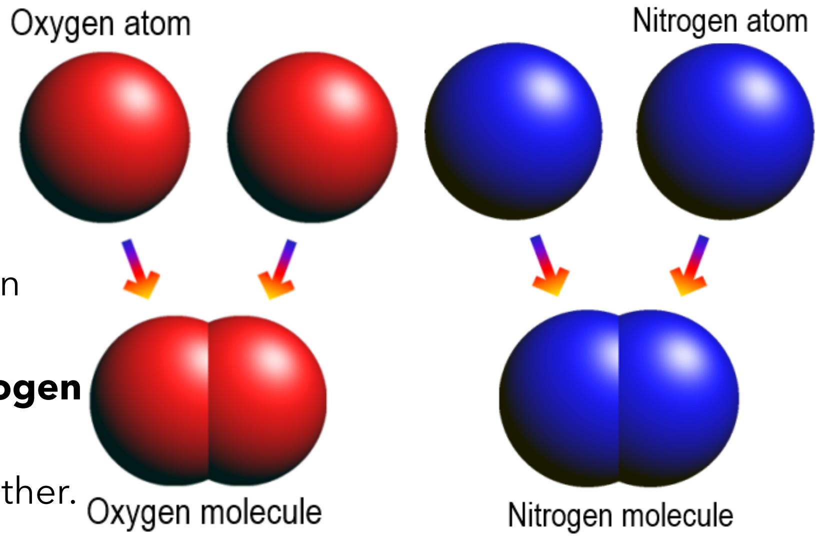
The two round balls are firmly intertwined and bonded. Each of these individual round balls is an **atom**.

Two (or more) atoms stuck together is called a **molecule**.



There are two kinds of air particles. Imagine that you picked them up and enlarged them. The models of the atoms are colored, but in reality, the atoms do not have any colors. We color them to know which is which easily.

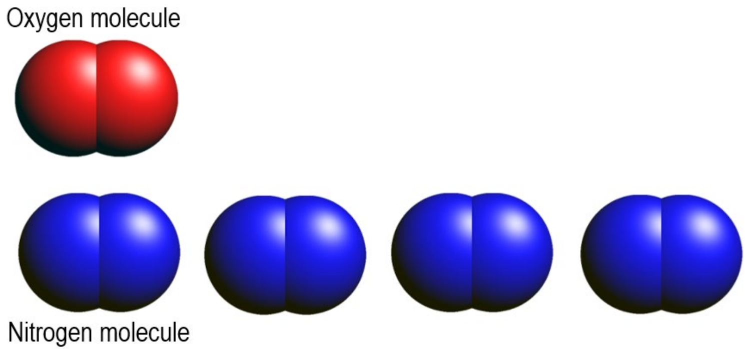
Two Oxygen atoms can combine firmly. Two Nitrogen atoms also can combine firmly. The two atoms are bonded firmly in combination and do not separate easily.



Scientists call the two oxygen atoms bonded together an **oxygen molecule**. The **nitrogen molecule** has two nitrogen atoms that are bonded together.

Your teacher will show you a model of the oxygen and nitrogen atoms and the molecule model made of two atoms.
If atom models are available, try to make a molecule with them yourself.

There are more nitrogen molecules than oxygen molecules in the air. The number of nitrogen molecules is four times higher than the number of oxygen molecules.



By the way, how many nitrogen and oxygen molecules do you think are in the air?

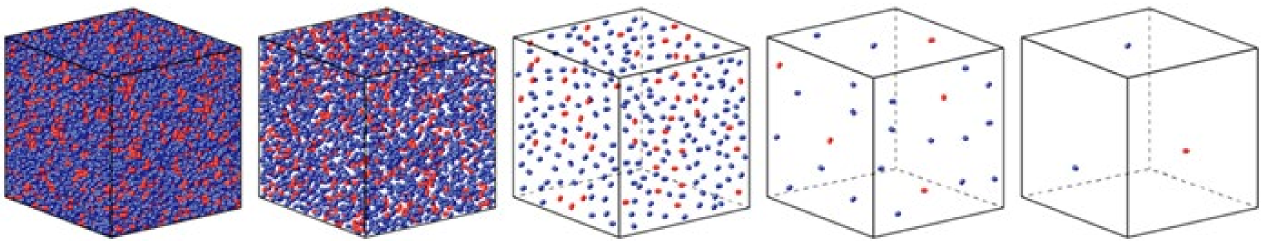
Problem

Imagine building a model of air using these 100 million times larger models of molecules. We take a cubic section of the air that measures 0.000001 cm on each side and magnify it 100 million times.

It will become a cube, with each side measuring 100 cm (1 m).

How many nitrogen and oxygen molecule models should be put inside a '1 m × 1 m × 1 m' cube to make a model of the air?

What do you think?

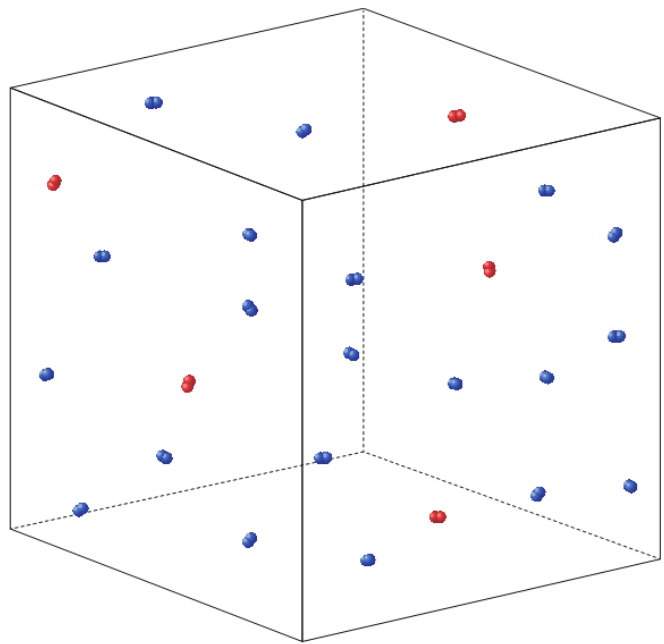


a. About 30000   b. About 3000   c. About 300   d. About 30   e. About 3

If the air were magnified one hundred million times…

When scientists examine a cube measuring 0.000001 cm on each side, it seems to contain 25 air molecules. Therefore, in our magnified cubic model, which measures 1 meter on each side, there will also be 25 model air molecules. Those molecules have been magnified one hundred million times.

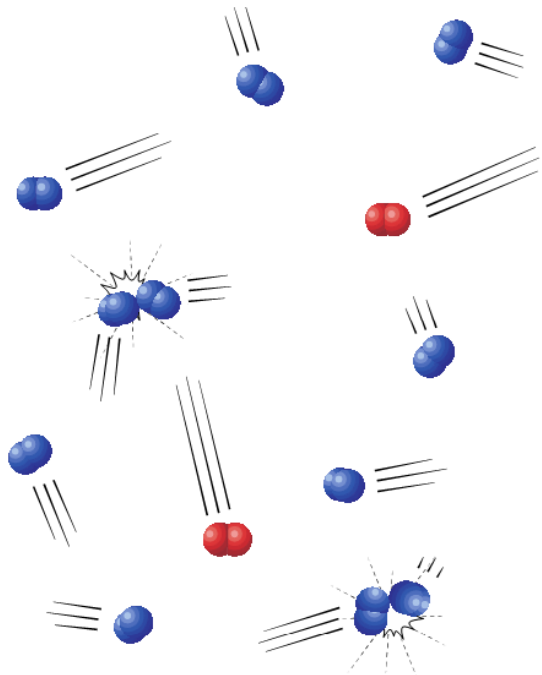
The number of nitrogen molecules in the air is nearly four times the number of oxygen molecules. We would, therefore, expect to find about five oxygen molecules among these 25 molecules.



Some of these molecules move at high speed, but some move slowly. On average, they move at about 400–500 m/s (1,400–1,800 km/h); sound moves through the air at 340 m/s. That means the speed of the molecules is 1.5 times faster than the speed of sound (Mach 1.5).

But there are a lot of molecules. Each molecule in the air collides with other molecules when advancing, on average, about 0.000007 cm in a straight line; on impact, it changes direction and collides with another molecule. It will collide with another molecule after advancing another 700 cm (7 m) in our model, magnified one hundred million times.

Of course, this is on average. Some likely molecules collide at a shorter distance, and others advance for longer without colliding.



How big would an object be if it were magnified one hundred million times?

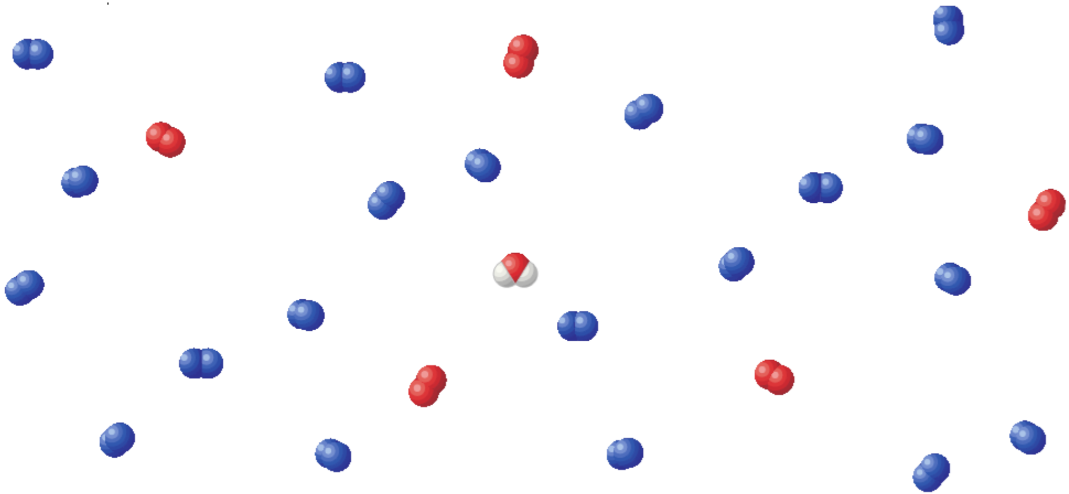
To imagine this, how about thinking of the size of your head magnified one hundred million times?

The diameter of a human head is a little larger than about 15 cm. Therefore, if we were to enlarge it one hundred million times, it would be about 1,500,000,000 cm, equal to over 15,000 km, which is enormous!

The diameter of the Earth is about 13,000 km. Therefore, if a person's head were to be enlarged one hundred million times, it would grow bigger than the size of the Earth.

If we were to magnify your head and the molecules we are studying, each one hundred million times, your head would grow to a size more significant than Earth's, and an individual molecule would be about the size of a ping pong ball.

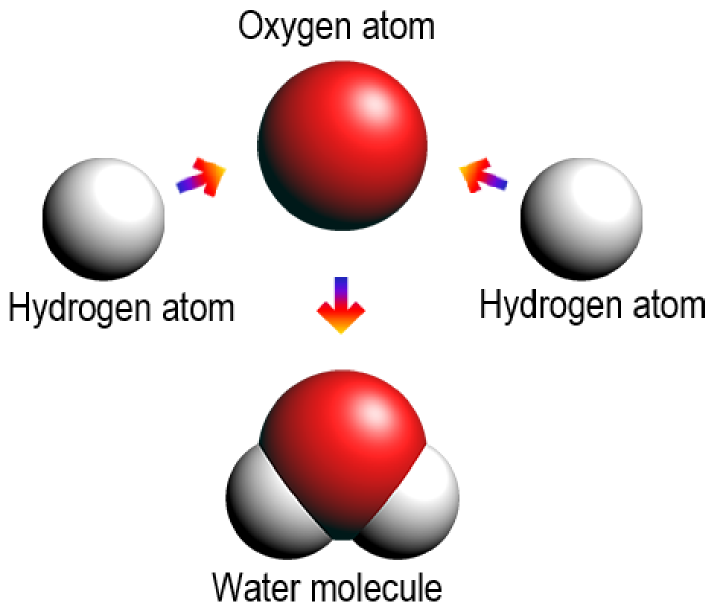
Does the air contain any other molecules aside from nitrogen and oxygen molecules?



Look at the drawing of the air and search for other particles.
Oh. Can you see another molecule? It is neither a nitrogen molecule nor an oxygen molecule. It has a different shape.

The large atom in the center is an oxygen atom. The two small atoms that bond to either side of the red oxygen atom are called hydrogen atoms.

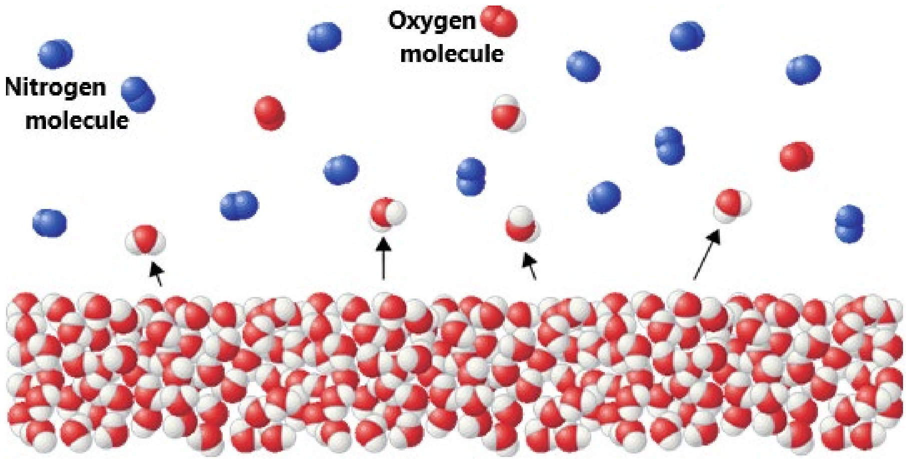
When two hydrogen atoms combine with one oxygen atom, this is called a **water molecule**.



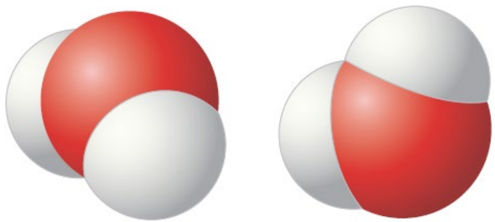
The water we see and use daily is made of many particles, much like the models you just made.

Why do you think that the water molecule is in the air?

If we leave some water in a dish for some time, it might decrease without us noticing. This is because some of the water molecules from the dish escape into the air.

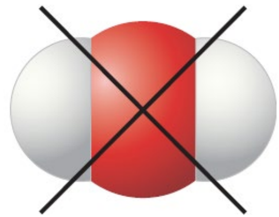


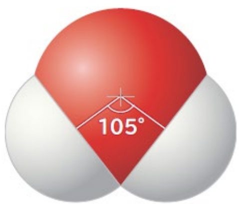
Water molecules also roam freely in the air, just as oxygen molecules and nitrogen molecules do.



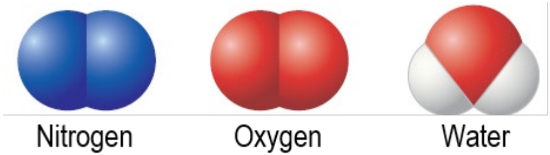
The shape of the water molecule is strange.

The one oxygen atom and two hydrogen atoms do not bond in a straight line.

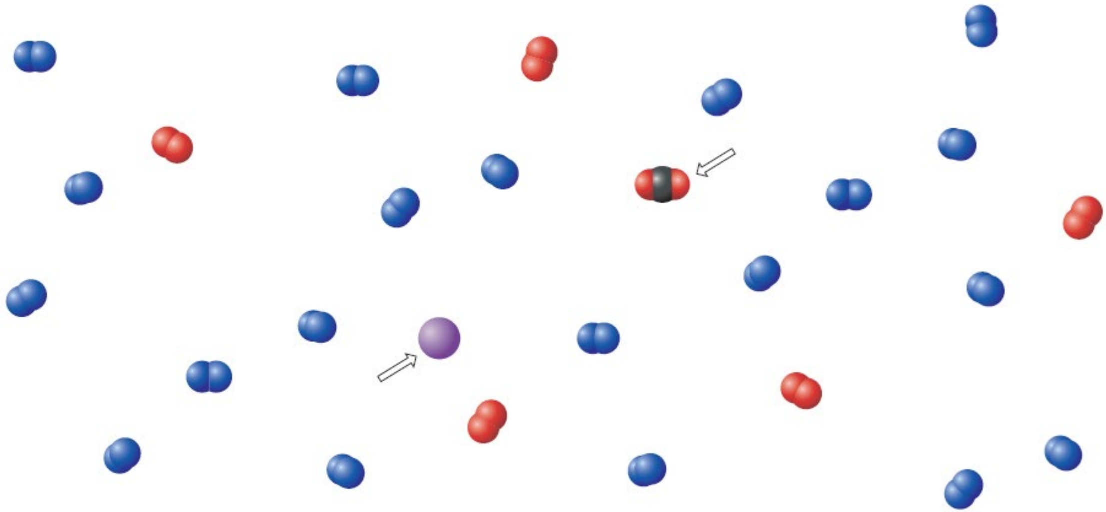




However, how the two hydrogen atoms are combined with the oxygen atom is not random. Two hydrogen atoms always maintain this same angle when they stick to the oxygen atom.

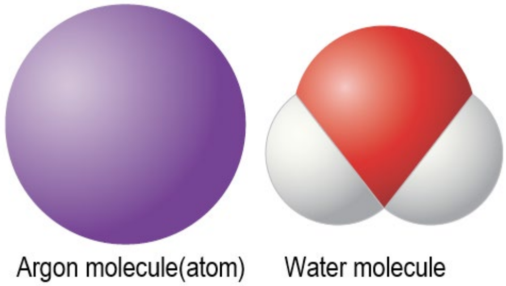


Is there anything else besides the nitrogen, oxygen, and water molecules in the air?



Look again at a drawing of the contents of the air. It contains a few other kinds of molecules.

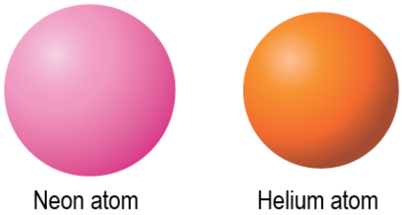
A purple-colored particle in the drawing is **Argon**. There is about one argon molecule per every 100 air molecules.
Draw a picture of an argon molecule next to the water molecule.



The argon molecule is round no matter where you look at it. Argon molecules also fly around in the air, but we find them in single atoms, unlike other molecules such as Oxygen or Nitrogen. Because of this, you may use the terms "molecule" or "atom" interchangeably when describing Argon.

Two oxygen atoms or nitrogen atoms tend to bond together, but the argon atom does not do this. The argon atom also cannot combine with any other kind of atom.

In the air, there are still other atoms, like Argon, that do not bond with others. These are the **neon** atom and the **helium** atom.



However, the air contains few neon and helium atoms. Only one or two are found in one hundred thousand air particles.

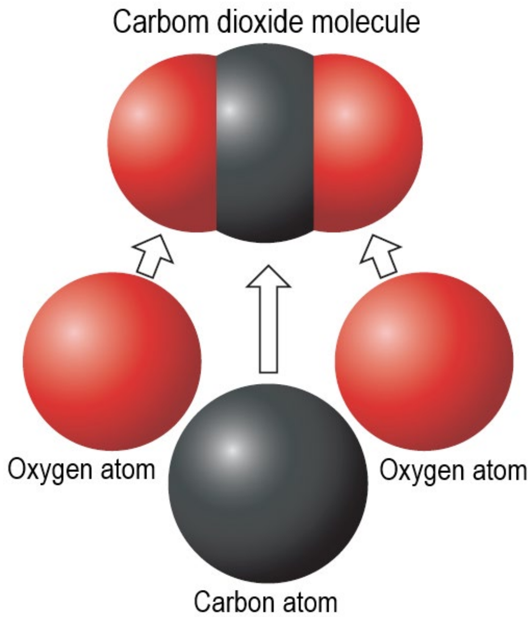
The red and black colored molecule is a **carbon dioxide** molecule.

Two oxygen atoms combine with a carbon atom, which is why it is called carbon dioxide ['di' means two].

On the right is a magnified carbon dioxide molecule.

The three atoms that make carbon dioxide align up straight in a row and do not bend like the water molecule.

Only four molecules of carbon dioxide can be seen in 100,000 air molecules.

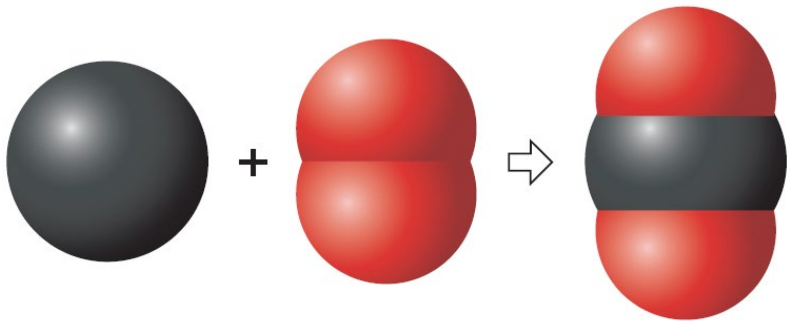


A lot of carbon atoms are in plants and animals. Charcoal is almost wholly made of the carbon atoms.

When we burn wood and paper, the carbon atoms in the wood or paper combine with oxygen molecules in the air to form carbon dioxide molecules. At this point, the carbon dioxide molecule is moving very fast and producing heat.

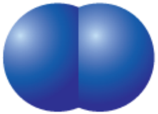
We breathe to take oxygen from the air into our bodies.

As the carbon atoms in our bodies bond with the oxygen atoms from the air, the energy that allows us to move and warms our bodies is produced.

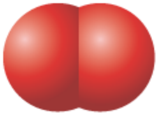


When we breathe out, we release the carbon dioxide molecules produced through this process.

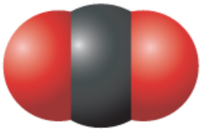
These are what we find in every 100,000 air molecules.



Nitrogen molecule ... about 80,000



Oxygen molecule ... about 20,000



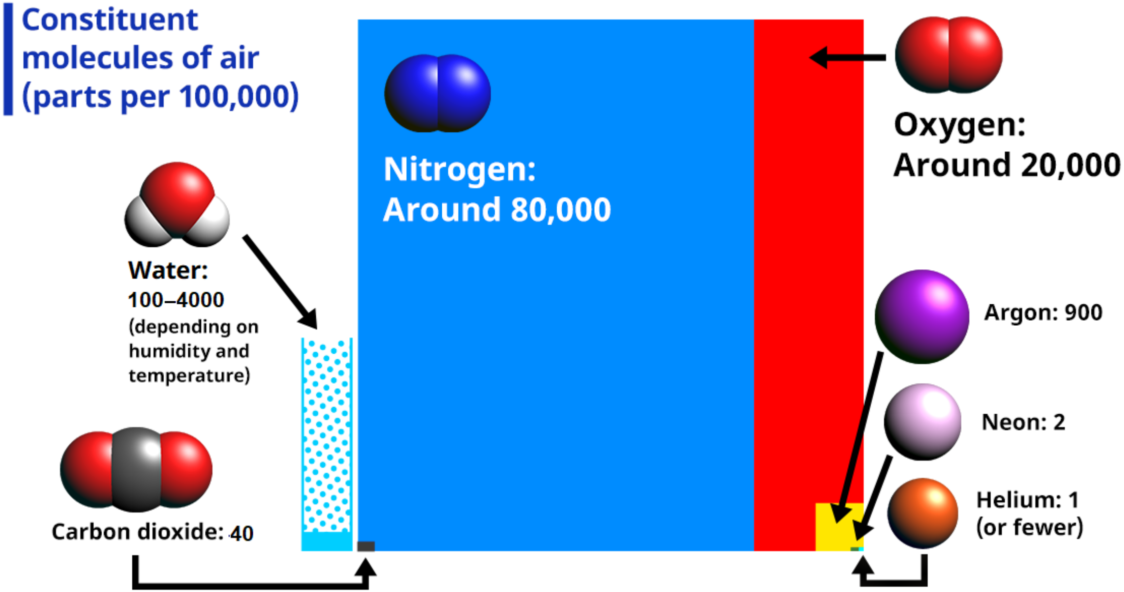
Carbon dioxide molecule ... about40

Water molecule ... 100–4,000
(Depending on the temperature and humidity)

Argon atom ... about 1,000

Neon atom ... 2

Helium atom ... 1 or fewer


Constituent molecules of air (parts per 100,000)
Nitrogen: Around 80,000
Oxygen: Around 20,000
Water: 100–4000 (depending on humidity and temperature)
Argon: 900
Neon: 2
Helium: 1 (or fewer)
Carbon dioxide: 40

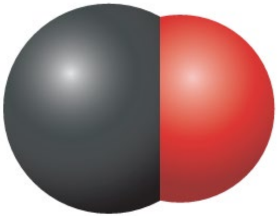
The types of molecules described on the previous pages appear in clean air.

However, because humans have burned many different things, other molecules are in the air besides these.

We will now look at the air in our cities, which is dirty because of exhaust emissions from many cars and smoke from factories. What kind of molecules do you think you could find in the city air?

Have you ever heard the name of a gas harmful to plants, men, and other animals? If you have heard of this gas, please tell everyone.

Guess what molecule is this?



Do you recognize the black-colored atom? It is the carbon atom.
What about the red-colored atom? It is an oxygen atom.

This molecule is very much like carbon dioxide but has fewer oxygen atoms. This molecule is called "**carbon monoxide**." [Just like 'di' means two, 'mono' means one]. It may be easy to remember.

Carbon monoxide is released when fuels like gasoline and kerosene are not burned completely. Carbon atoms are contained in gasoline and kerosene. When burned, two oxygen atoms will connect to each carbon atom and produce carbon dioxide.
However, when oxygen is insufficient, only one oxygen atom may bond with a carbon atom, producing carbon monoxide.

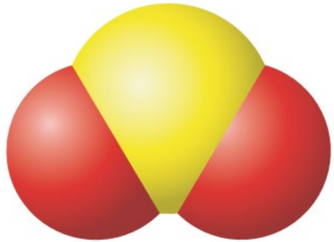
Burning kerosene or gas in an enclosed room can produce considerable amounts of carbon monoxide due to a lack of oxygen.

Carbon dioxide is not as toxic to the human body; however, carbon monoxide may kill humans quickly if they inhale a lot. You should ensure good ventilation when you burn kerosene or gas in your house.

Carbon monoxide is a flammable gas. If one more oxygen atom is bonded with it when it burns, it will become carbon dioxide. We can, therefore, remove carbon monoxide, which is harmful to the body, by burning it.

Recently, technology has been developed that burns carbon monoxide from exhaust gases or gases released from factories and changes it into carbon dioxide. Doing this has decreased the amount of carbon monoxide released into the air.

Next, what is this molecule?



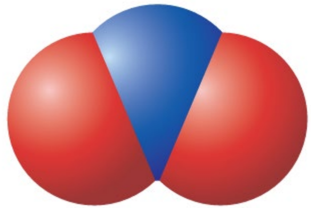
The yellow one is a sulfur atom. Two oxygen atoms bond with the sulfur atom, producing a shape similar to the water molecule.

Oil, such as gasoline and kerosene, which are extracted underground, usually contains sulfur atoms. When we burn oil, sulfur atoms react with oxygen and produce **sulfur dioxide**.

Volcanic gases also contain sulfur dioxide.

Sulfur dioxide molecules are harmful to human health. Therefore, sulfur is now removed from petroleum in advance, and sulfur dioxide is removed from exhaust gases produced by burning.

There is another harmful molecule which is emitted from factories and cars. It is the **nitrogen dioxide** molecule.



One nitrogen atom is connected to two oxygen atoms, becoming nitrogen dioxide.

There are a lot of nitrogen molecules and oxygen molecules in the air. However, the two never bond naturally. Nitrogen dioxide can be produced in high temperatures, such as in factories or car engines.

Nitrogen dioxide can also cause respiratory illness. However, the abundance of oxygen and nitrogen atoms in the air makes it very difficult to prevent the formation of nitrogen dioxide. Methods have been devised to prevent high temperatures when burning things and to avoid the release of nitrogen dioxide into the air.

When nitrogen atoms combine with oxygen atoms, "nitric oxide molecules" are formed. Molecules in which oxygen and nitrogen are combined are collectively called "nitrogen oxides" or "NOx (hazardous substances).

Question 2

Now, please draw a picture of the air again. Imagine what it would look like 'if you could see the atoms and molecules in the air.'

Please do not pay too much attention to the size of the molecules and the space between them. Use the space below or a piece of drawing paper.

The end

Dear Teachers,

I appreciate your interest in the Hypothesis–Experiment Class(HEC). If you conduct a class, we would appreciate it if you could provide the Association for Studies in HEC with a record of the class (the HEC Classbook title, target age group, country/region, students impressions, number of students on each 5-point scale*, your impressions as a conductor, etc.). Your record is valuable and needed to improve the HEC Classbooks.

For queries, please email contact2ashec@kasetsu.org

Thank you,

Association for Studies in Hypothis–Experiment Class

* Example: Out of 56 students, 43 rated 5, 10 rated 4, 2 rated 3, 0 rated 2, and 1 rated 1.

For more information on this 5-step evaluation, please refer to the HEC Management Guide, available for download from the same site as this document..

Association for Studies in Hypothesis–Experiment Class

https://www.kasetsu.org/index.html

ASHEC Translation Project Group 2024 email contact2ashec@kasetsu.org

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