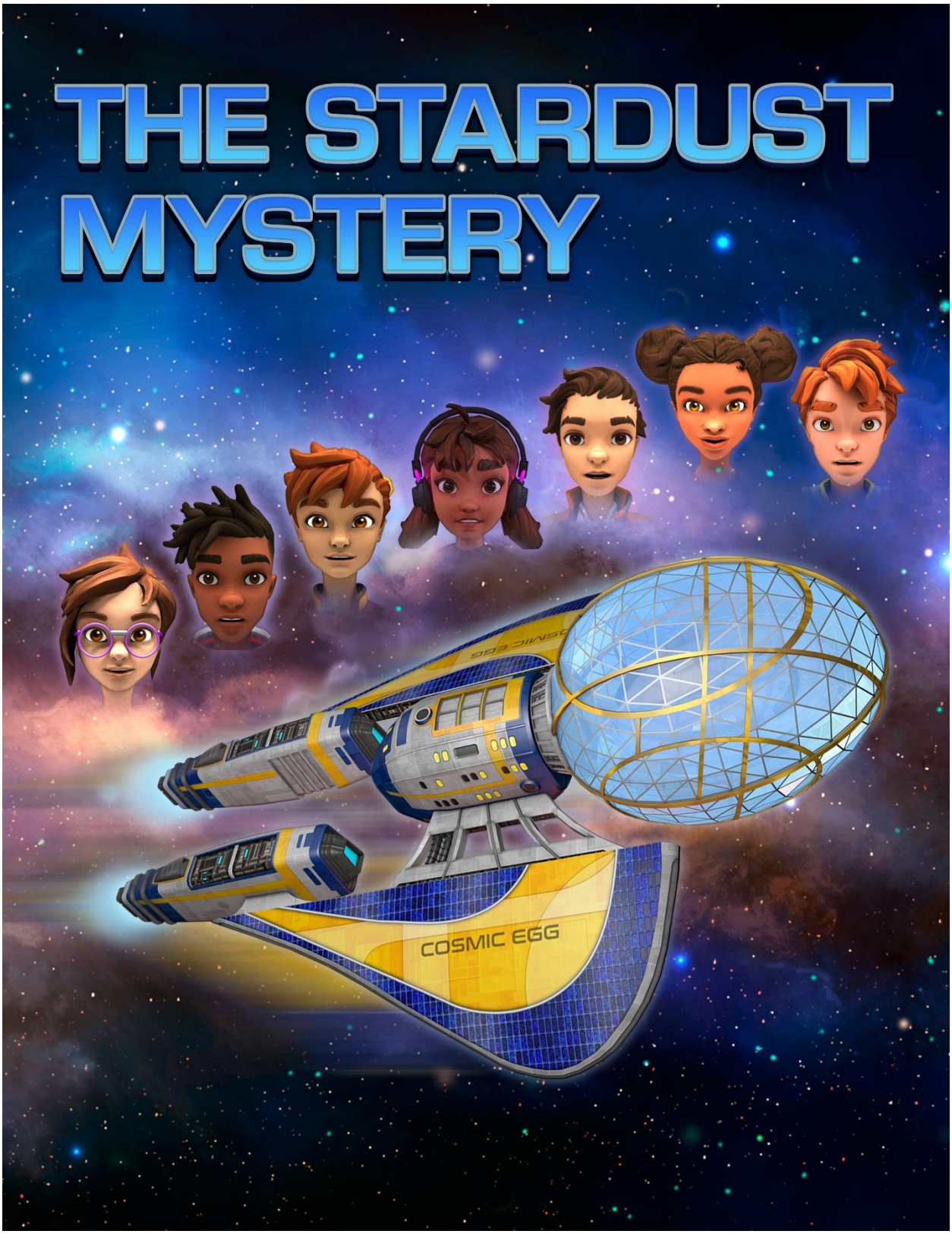
WHAT IN THE WORLD IS STARDUST

To download the PDF, use your browser's *download* or *save as* function.



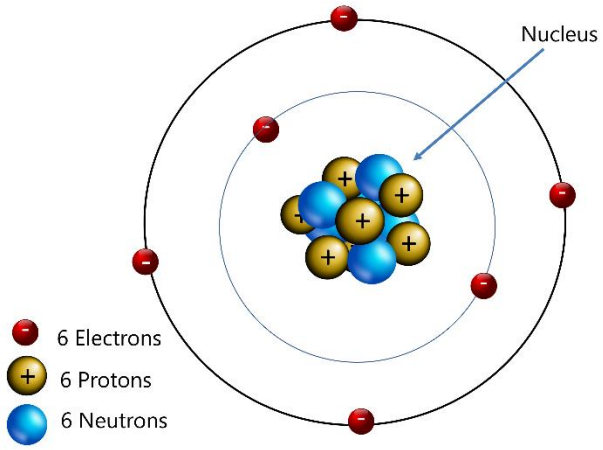
JOHARI'S STORIES

WHAT IN THE WORLD IS STARDUST? (AS TOLD BY JOHARI)

Hi everyone. I am Johari, Jacksons dimwit sister. I am not really dumb but compared to Jackson who is a college student at age 13 and knows all about quantum mechanics and Einstein's Theory of Relativity, it seems that way.

Well, what in the world is stardust? By now, you probably know that stardust is atoms. Every physical thing, like you, and me, and the dog, and our house, and the whole planet Earth is made up of tiny little building blocks called atoms. There are a whole bunch of different kinds of atoms. If you have been on Neddy's page then you know that the atoms were created by nuclear fusion during the life and explosive death of the stars. Your body could have some carbon, nitrogen and oxygen atoms created in first generation star supernovas over 13 billion years ago. If you visited Lizzy's page you learned that the idea of atoms was proposed by the ancient Greek philosopher Democritus. She also told us about the structure of atoms and the number in your body.

The carbon atom has six tiny particles called electrons, racing in paths, called orbits. They are like the paths planets make around the sun and our moon makes around the Earth—those are also called orbits. Orbits can be circles or ellipses. VC and Neddy made a video called *What are Atoms Made of?* that shows what those orbits look like. Electrons orbit around a bunch of bigger particles called protons and neutrons. The protons and neutrons are stuck together in a group at the center called the nucleus.

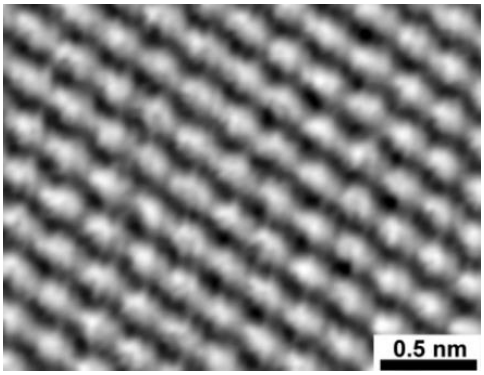


CARBON ATOM

Each atom has its special number of protons or electrons called the atomic number. Atomic numbers go from 1 for hydrogen to 92 for uranium (the highest naturally occurring atom). The atomic number for carbon is 6. When a material is made of just one kind of atom it is called a pure element.

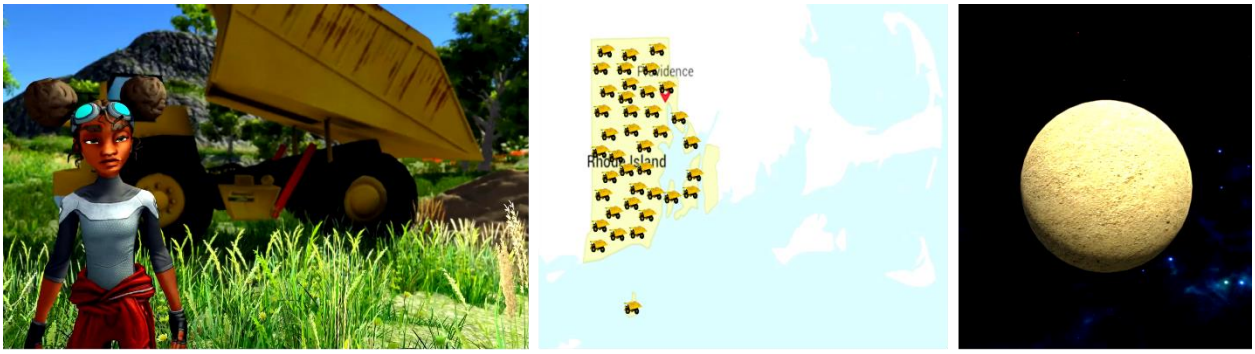
You can also build atoms in the *Building the Universe* game available on Store.SteamPowered.com.

THE SIZE OF ATOMS AND THE NUMBER IN YOUR BODY



Lizzy found an actual picture of carbon atoms. They were taken with a very complex device called an electron microscope. The size of the carbon atoms was so small that they only showed up as fuzzy dots. They were so small, that a billion, times a billion atoms of that size could fit inside a millimeter-long little piece of your hair.

You have about 700 million billion billion carbon atoms in your body. Lizzy tried to make that number more real to us by comparing it to letters in a book. She said, "if you counted *all the letters in every book on earth*, that number would still be less than the number of atoms in that millimeter-long piece of your hair."



Scenes from "How Many Atoms Do I Have? YouTube Stardust Mystery channel

Milo and I had a different idea and we made a video called *How Many Atoms do I Have*? In that video, we figured out how big a beach we would have if the number of sand grains on the beach was the same as the number of atoms in our bodies.

I said, "you would need 100 million dump trucks full of sand to equal the number of atoms in just one eyebrow hair. That would be enough to cover the whole state of Rhode Island in a beach 1 meter deep. And if you had as many sand grains as all the atoms in your body, it would be enough to cover all of planet Earth in a beach 20 kilometers deep."

Milo and I also made a video called *How Big are My Atoms?* In that video, we magically made all the atoms in Milo's body the size of sand grains. That process made Milo almost as big as planet Earth. That is because sand grains are about 6 million times bigger than atoms.

ATOMS ARE THE BUILDING BLOCKS FOR ALL PHYSICAL THINGS

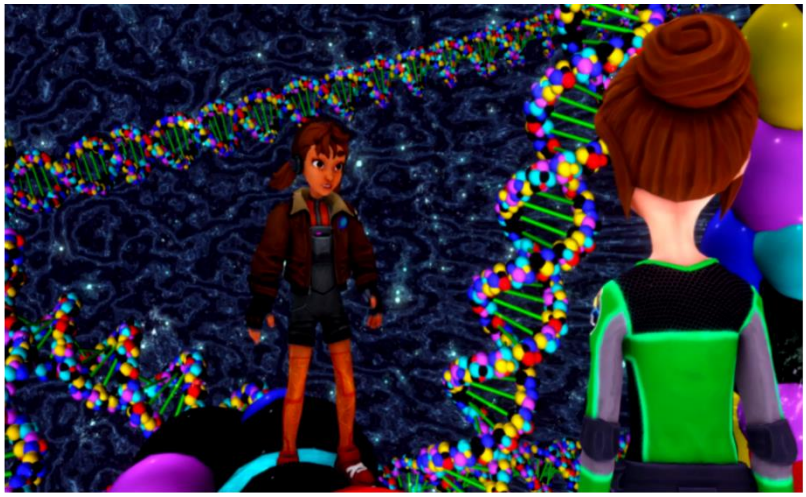
In the video *What are Atoms*? VC and Neddy told us that atoms were the building blocks of all physical things, you, me, our house, the clouds, the atmosphere, the Earth, the sun, asteroids, planets, the Milky Way Galaxy, and all the other galaxies in the universe. Every material thing in the universe is made of atoms. VC and Neddy explored two things made of atoms. First, they went inside a gold nugget to see what it is made of. Gold is a chemical element. It is made of just one kind of atom, gold.

Scenes from "What are atoms? YouTube Stardust Mystery channel

But there are lots of other arrangements and combinations of atom building blocks that make up physical things. Different atoms can be combined to make molecules. Neddy and VC took the *Cosmic Egg* into a human body to see how atoms are arranged there.

They found out that our bodies are mostly made of four different kinds of atoms: carbon, hydrogen, oxygen, and nitrogen, CHON for short. We also have calcium and phosphorus for our bones, and iron for our blood and a bunch of other atoms in small amounts.

VC said. "the coolest arrangements and combinations of atoms that we found were twisted pairs of huge long chain molecules consisting of carbon, hydrogen, oxygen, nitrogen, and phosphorus atoms."



Scene from "What Are Atoms? YouTube Stardust Mystery channel

When they finished exploring, they asked Milo about the twisted pairs of molecules they found. He told them, "what you found was our DNA (Deoxyribonucleic Acid). It is the arrangement of atoms that makes up our chromosomes, which are our collection of genes. The chromosomes are the part of the body where all the information about how to build our body is stored. It's like a recipe book. It says what color our hair should be and our eyes, how tall, how to make our voices sound, everything. The recipe isn't written in words. It's written in a code based on the arrangement of the atoms in the DNA. Just like the arrangement of different letters can create thousands of words, the arrangement of different atoms can create all the instructions to build our bodies. Cool, huh?"

Scenes from "How did Einstein get dinosaur carbon atoms? YouTube Stardust Mystery channel

There are also small molecules like water (H_2O) made of two hydrogen atoms and one oxygen. Water can be in the form of a solid, liquid or gas. Other common molecules in the atmosphere are oxygen (O_2, two oxygen atoms), nitrogen (N_2, two nitrogen atoms), and carbon dioxide (CO_2, one carbon and two oxygen atoms)

Neddy made a video called How did Einstein Get Dinosaur Atoms about CO_2. It shows how CO_2 breathed out by a dinosaur into the atmosphere 66 million years ago is used to grow an apple that gets eaten by Albert Einstein 66 million years later. That is one way the atoms on Earth are shared among its plants and animals.

There are bigger molecules that are liquid, like those that make up oil and gasoline. There are even bigger molecules like the DNA that VC and Neddy found that are solids.

Some things are not made of atoms like electrons, protons, neutrons, quarks, and other elementary particles. Photons that are the components that make light are also not made of atoms.

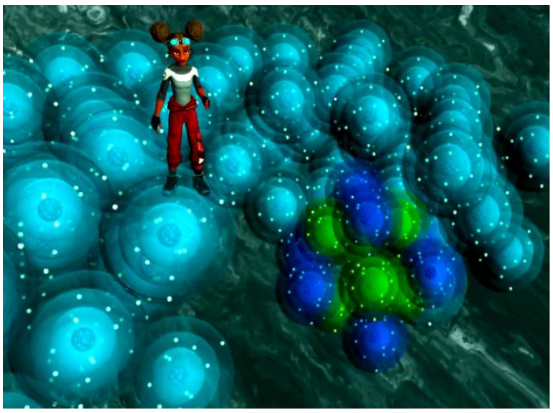
ATOMS DETERMINE THE PROPERTIES OF MATERIALS

The kinds and arrangements of atoms control the material's properties. For example, the elements copper, aluminum, and gold are metals. They are great conductors of electrical current, meaning electricity can flow through them. Power cords for our electrical devices are typically made of two copper wires that carry electrons from the wall outlet to the device and back to the outlet. Copper is a good conductor because some of its electrons can move from atom to atom.

Some materials like plastics made of carbon, hydrogen, oxygen, and other atoms do not conduct electricity. They are insulators because, the electrons are stuck on their atoms. So, these materials are used for the coatings of the copper wires in the power cords. The coatings keep the two wires from touching each other and you.

Scenes from "What Is Aluminum Made Of? YouTube Stardust Mystery channel

I wanted to see how the atoms were arranged in a metal. There was an aluminum shipping box that we used for our missions. So, I hopped up on top and started changing my size. To see the aluminum atoms, I made myself 10 billion times smaller because atoms are 6 million times smaller than sand grains and I am over 1000 times bigger than a sand grain. I made a video about this adventure called *What is Aluminum Made of*? It is also on the STARDUST MYSTERY YouTube Channel.



Scene from "What Is Aluminum Made Of? YouTube Stardust Mystery channel

The arrangement of the aluminum atoms was cool. They were packed in a very regular organized way like eggs in an egg carton. This arrangement is called a crystal lattice.

The atoms in aluminum are arranged in a cubic structure. There is one aluminum atom in each corner of the cube (blue) and one in the center of each face of the cube (green). The arrangement is called a face centered cube. Other metals like copper and gold have the same arrangement.

While I was learning about the aluminum crystal, Milo discovered something interesting. He picked up a small rock that was pure platinum, and it was incredibly heavy. He compared the weight to the weight of the whole aluminum shipping box, and he was amazed that the small platinum nugget was heavier than the box. Neddy said it was because of their densities, their weight per cubic centimeter. She looked it up on her phone and found that the density of platinum (21.5 grams/cm^3) was about 8 times higher than that of aluminum (2.7 grams/cm^3). They decided to do the shrinking thing to see the aluminum and platinum atoms. Why are the densities so different? They made a video about what they found called *What Determines The Density of Materials?*

For their investigation, Neddy asked Milo to put the platinum nugget right next to the aluminum box, so they could see both crystals at the same time when they shrank down to atom size.

Scenes from "What Determines The Density of Materials? YouTube Stardust Mystery channel

When they started to explore at atom size, Milo said, "this is really interesting. Both the aluminum atoms and the platinum atoms are packed into regular face centered cubic crystals that are almost the same size. They have the same number of atoms in similar size spaces. So, what causes the difference in density?"

"That's easy," said Neddy. "The platinum atoms themselves must be way heavier than the aluminum. That's determined by the atomic weight, which is approximately the number of protons plus the number of neutrons in the atom."

Milo looked up the numbers and stated, "aluminum has an atomic weight of 27 and platinum has an atomic weight of 195. 195 divided by 27 is 7.2. So that almost explains the density difference of 8."

The rest of the difference is that the platinum atoms are a little more tightly packed. The size of its lattice cube is smaller. They both thought that it was strange that the platinum atom with 78 electrons circling the nucleus was smaller than aluminum with only 13 electrons.

SUMMARY

So, to summarize the important things about stardust.

- Stardust is our atoms
- Atoms are called stardust because they are created by nuclear fusion during the life and explosive death of stars.
- Those explosive deaths of stars are called supernovas.
- The carbon, oxygen and nitrogen in our bodies were created over 13 billion years ago in supernovas of the first generation of stars.
- Atoms are the building blocks of all physical things: plants, animals, the whole planet Earth with its ground, atmosphere and oceans, asteroids, planets, stars, and galaxies.
- Collections of atoms can form small molecules like H_2O, O_2, N_2, and CO_2.
- Atoms can be arranged in large molecules like oil, plastics, and DNA
- In solids, atoms can be arranged in large regular repeating structures called crystals, like diamond or aluminum
- Solids can have atoms in non-regular arrangements like wax or glass.
- The properties of materials like electrical conductivity and density are determined by the kinds of atoms and their arrangement in the material.

And this is the thing that is the most amazing to me. The color of my eyes and the other things about me are determined by a code which is written in my DNA. And that code is written in the order of the atoms some of which were created in the explosive death of stars over 13 billion years ago. Wow!

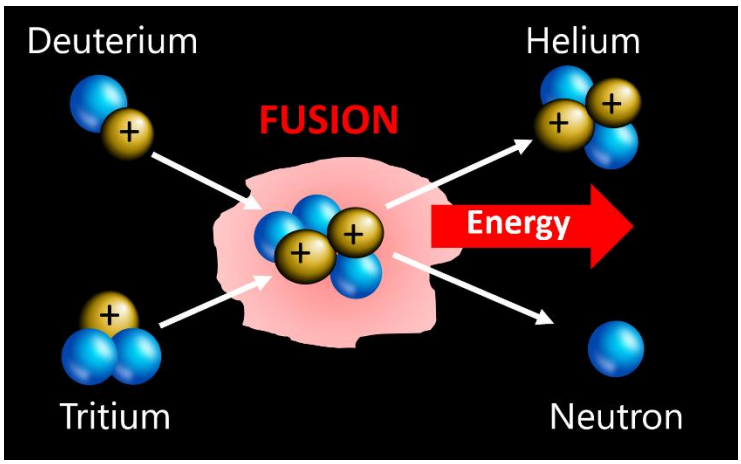
GRANDPA'S GLOSSARY

Atoms: Every solid, liquid, or gas in our world is made of atoms. Most things like water, people, trees, houses, cars, or the air around us, are made of combinations of different kinds of atoms. But some substances like silver or gold or oxygen or carbon are made of only one kind of atom. These are called chemical elements. The atom is the smallest unit that defines the chemical elements. Anything made of atoms has mass, meaning that a force is necessary to make it go faster or slower. Atoms are very small. A single strand of human hair is about 1 million carbon atoms wide. Atoms can be attached to one another in small units called molecules, in large crystals like diamond and salt, in mixtures of crystals, or in random arrangements. You can see some of these arrangements in the animated Science Videos on the STARDUST MYSTERY YouTube channel. Milo, Lizzy, VC, Johari, and Neddy have starring roles in those videos.

You can also build atoms in the *Building the Universe* game available on Store.SteamPowered.com or at https://TheStardustMystery.com

Some things in our world are not made of atoms. The most common is light, which consists of tiny particles called photons. Photons always move fast and have no mass. Some things are parts of atoms like a beam of electrons in an electron microscope or an old television tube. Other parts of atoms are the protons and neutrons made of quarks. And then there is *dark energy* and *dark matter* that we think is out there in the universe but are not made of atoms. We are pretty sure they're there, but we don't yet know what they're made of.

Nuclear Fusion: Nuclear fusion is what happens when two atoms come together and form a new larger atom. We can exist because nuclear fusion on our sun provides light and energy to our planet. On the sun, the main nuclear fusion reaction takes place when one hydrogen atom that has one proton and one neutron (^{2}H, called deuterium or heavy hydrogen) bangs into another hydrogen atom (^{3}H, called tritium) that has one proton and two neutrons. In order to fuse, they must bang into each other very hard, and that requires a high temperature, like 15 million degrees C. They fuse into a helium atom that has two protons and two neutrons (^{4}He) and the extra neutron comes shooting out with lots of energy. The energy is in units of million electron volts (MeVs). All that energy is what keeps the sun burning bright.



Fusion of atoms on our sun can form bigger atoms like lithium with three protons,

and beryllium with four protons, and small amounts of bigger atoms. But big stars can form very big atoms in their core where the temperature is very high. When a star uses all its hydrogen it either becomes a white dwarf the size of Earth (like our sun would do), or if it is a big star, it collapses and forms a supernova. And in that supernova, conditions are hot enough (100 billion degrees C) to form and release atoms like iron that have twenty-six protons, and even uranium (that has ninety-two protons.)

Supernova Star Explosion: Stars are bright because they are very hot due to nuclear fusion in which hydrogen combines to form helium. After billions of years, all the hydrogen is consumed, and the star starts to cool and collapse toward the center. In big stars, the collapse leads to an explosion called a supernova, in which huge amounts of light and material are released. Supernovas are bright enough to be seen on Earth with the naked eye and can last for up to two years.

Orbits: The paths followed by electrons around the nucleus in an atom, planets around the sun, or the moon around the Earth are called orbits. The objects that are trapped in orbits stay there because of the forces of attraction between the object in orbit and the object it travels around. In the case of atoms, the force is the electrical attraction between the electron and the nucleus. In the other examples given, it is the force of gravity. The exact path is controlled by how the force depends on the distance between the objects. Both the electrical force and the gravitational force get smaller as the distance between the objects gets bigger. If r is the distance between the objects, then the magnitude of the force is proportional to $1/r^2$. Diagrams such as those of the solar system often show the orbits as circles for simplicity, but in general the orbits are elliptical.

Protons, Electrons, and Neutrons: All atoms are made of the same three particles: electrons, protons, and neutrons. Electrons are tiny particles that have very little mass and a negative electrical charge. Protons have almost 2,000 times the mass of an electron and are positively charged. Neutrons have almost the same mass as the proton but have no charge. In an atom, the protons and neutrons are tightly bound together in the nucleus, attracted by the nuclear force. The electrons circle around the nucleus and are bound to it because of the electrical force of attraction between the positive and negative charge of the particles. Different kinds of atoms have different numbers of electrons, protons and neutrons. Hydrogen, the lightest element, has only one electron and one proton. The heaviest elements like uranium have almost 100 electrons, 100 protons and a similar number of neutrons.

You can build protons and neutrons from their component quarks in the *Building the Universe* game available on Store.SteamPowered.com or at https://TheStardustMystery.com

Nucleus: At the center of every atom is the nucleus, which has almost all of the atom's mass. The nucleus is made up of positively charged protons and uncharged neutrons. The protons and

neutrons are held together by the strong nuclear force. Electrons orbit the nucleus like the Earth orbits the sun, but not exactly, because the electron orbits are fuzzy clouds described by quantum mechanics. The size of the nucleus for hydrogen with one proton is almost 1 trillion times smaller than onion cells. The nucleus of uranium with 92 protons and between 141 and 146 neutrons is 10 times bigger than the nucleus of hydrogen. The size of the atom is more than 10,000 to 100,000 times bigger than the nucleus.

Atomic Number: Every atom is given an atomic number. It is the number of protons in the nucleus or electrons surrounding the nucleus. Atomic numbers go from 1 for hydrogen to 92 for uranium which is the largest naturally occurring element. Some man-made elements have higher atomic numbers.

Electron Microscope: For over 100 years, scientists believed that there was a limit to the smallest objects that could be seen with an optical microscope. That was because light was in little bundles called photons, whose size was the wavelength of the light. If you bounced light off an object that was larger than the photon, you could see its detail. But if the object was smaller than the photon, you couldn't see detail. Imagine that you are throwing tennis balls at a wall with a door. When you hit the wall or the closed door, the ball bounces back. But if the door is open, the balls fly through and don't come back. You get detail about the door's shape because the ball is smaller than the door. But if you used huge beach balls bigger than the door, the ball would always return, so little information could be learned.

This problem of the size of the light photon prompted the invention of the electron microscope. Instead of using photons, you bounce electrons off the object. Because the electron is much smaller than the photon, you could see much smaller details.

But scientists are continuing to think of new ways of doing things. In 2014, the Nobel Prize in Chemistry was awarded to three scientists that invented new ways of doing optical microscopy. Their methods can get detail 100 times smaller than previously thought possible. For more information see: http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/press.html

The Total Number of Carbon Atoms in an Average Human Body: Start with the mass of an average 75 kg (kilogram) person of which 18.5 percent of the mass is carbon. So, a person contains 13.9 kg or 13,900 grams of carbon. That would be 13,900/12 = 1,156 moles of carbon. A mole of carbon is a weight in grams equal to atomic weight of the atom (where 12 is the atomic weight of the carbon atom which has 6 protons and 6 neutrons). One mole of any atom or molecule has the same number of atoms, and that number is called Avogadro's number (602 billion trillion) = 6.02×10^{23}. So, a 75 kg human will contain $1{,}156 \times 6.02 \times 10^{23} = 7 \times 10^{26}$ carbon atoms. And that is 7 followed by 26 zeros or 700,000,000,000,000,000,000,000,000.

Molecules: Atoms can be attached to other atoms to form a new unit called a molecule. Simple molecules can be made of the same kind of atom, like hydrogen, nitrogen, or oxygen molecules. They have only two atoms each. Or different atoms, like two hydrogens and one oxygen, can attach to form a water molecule. Examples of bigger molecules are found in oil. It consists of strings, or rings, of a few to more than twenty carbons with attached hydrogens. Very large molecules like DNA have hundreds of millions of atoms of many different kinds.

DNA (Deoxyribonucleic Acid): Let's say you wanted to build a robot. You look online and find a set of instructions. It would have to contain lots of things: a list of parts; specifications and drawings for each part (for size, shape, color, function, etc.); and instructions for how the parts are connected. If your friend is going to build one too, you need to copy the instructions. If you are building a complicated robot, the list could be very long, requiring a whole book full of instructions. The instructions for building you and all living things is contained in the DNA which is reproduced in every cell.

The double-helix structure of DNA was identified by James Watson, Francis Crick, Maurice Wilkins, and Rosalind Franklin in separate papers in the journal Nature in 1953. Watson, Crick and Wilson (but not Franklin who died in 1958) received the 1962 Nobel Prize in Physiology or Medicine. You can see a picture of the double helix on page 3. It is two long chains of molecules that are twisted around each other, like a long rope. The molecules are built of mainly five atoms: carbon, hydrogen, oxygen, nitrogen (CHON) as well as phosphorus. The building instructions are determined by the order or sequence in which the atoms are arranged. Just as the twenty-six letters of the English alphabet can be rearranged to spell out thousands of different words, the different kinds of atoms are arranged to spell out the instructions for building a body.

Each cell in your body contains a complete twisted pair of chains in the form of DNA. When you started life as a single cell, one of your DNA chains came from your mother and the other from your father. As your cells multiplied, the DNA was copied so that each cell had an identical copy of your first DNA molecule. The instructions on whether you are a girl or boy, the color of your eyes and hair, how tall you will be, and every other physical thing about you is coded in your DNA.

Quarks: Scientists discovered that besides the well-known building components for atoms (protons, neutrons and electrons), there are over 200 other fundamental particles (photons, W bosons, Z bosons, gluons, Higgs bosons, gravitons, muons, neutrinos, etc.). In 1969 Murray Gell-Mann and George Zweig independently proposed that, just as atoms are composed of smaller particles, all the known elementary particles were composed of a smaller set of particles too. These are called quarks. There are six types, or flavors, of quarks: up, down, strange, charm, bottom, and top. George Zweig, despite his contributions to a theory central to modern physics, was not awarded a Nobel Prize. A Nobel Prize award to Zweig would have required a second Nobel Prize for Gell-Mann (he already

won one in 1969 for his work on the theory of elementary particles). Some have speculated that this is the reason that Zweig did not received an award.

Crystal: A crystal is a solid material whose atoms, molecules, or ions are arranged in a highly ordered repeating structure. Called a "crystal lattice" this structure extends in all directions.

Atomic Weight: The atomic weight or atomic mass is the mass of an atom. Although the atom's mass could be expressed in kilograms, it is more usual to express it in unified atomic mass units (u) also called Daltons. The unit u is approximately equal to ½ the mass of a proton plus a neutron. Since the mass of a neutron is almost the same as that of a proton, an atom's atomic mass or atomic weight is roughly equal to the atom's number of protons plus neutrons. The electrons have so little mass that their contribution to the atom's total mass is negligible.

THE STARDUST MYSTERY PROJECT

THE STARDUST MYSTERY WEBSITE
https://TheStardustMystery.com

STARDUST MYSTERY YouTube channel
https://www.youtube.com/channel/UCa5CQnZA6StFXXvEs418DKg
Science Videos
Game Trailers
How-To Videos

THE STARDUST MYSTERY VIDEO GAMES
https://Store.SteamPowered.com
MissionKT
Building the Universe

ILLUSTRATED SCIENCE ADVENTURE BOOKS
THE STARDUST MYSTERY is on Amazon and Barnes & Noble
THE RACE TO THE BIG BANG: Coming in May 2021

NATIONAL SCIENCE FOUNDATION AWARD 1738291
https://www.nsf.gov/awardsearch/showAward?AWD_ID=1738291&HistoricalAwards=false