SUPERCHARGED SCIENCE

Unit 3: Matter

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Appropriate for Grades:
Lesson 1 (K-12), Lesson 2 (K-12)
Duration: 5-10 hours, depending on how many activities you do!

Atoms are the building blocks of all matter. These odd little fellows make up tables, buildings, chihuahuas and even you. They are impossibly small and yet absolutely vital for all matter and all interaction between matter. They are extremely mysterious and constantly offer new puzzles for science to tackle. And that’s exactly what we’re going to do.

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Materials for Experiments

How many of these items do you already have? We've tried to keep it simple for you by making the majority of the items things most people have within reach (both physically and budget-wise), and even have broken down the materials by experiment category so you can decide if those are ones you want to do.

NOTE: This material list is for the entire Experiment section online.

Shaping Matter
Piece of bread
Scale
Pennies
Marbles
Cereal (about 20 pieces of anything)

States of Matter
Microwave
Grape (green, red, and/or black)
Ivory soap bar
Water bottle
Cooking oil (about ½ cup)
Two water or empty 2L soda bottles
Food coloring/dye (two colors: red, blue, etc.)

Crystals
10 cups of granulated sugar (any cheap brand)
Wooden skewer
Black construction paper
1 cup vinegar (distilled white)
Paper towel or coffee filter
Cleaned pickle, jam, or mayo glass jar
20-50 pennies
2 cups cornstarch
2 cups sand (yes, from the playground is fine)
Clean egg shell
1 full box of Borax
4-6 cups Epsom salts
10' string or yarn
3-6 pipe cleaners
Optional: Nylon fishing line
Optional: Alum (check spice section or gardening aisle)

Additional Items for Grades 9-12:

Electrolysis
2 test tubes or something clear and closed at one end
2 two wires, one needs to be copper (12 inches long)
1 cup
9 volt battery
Long match or a long thin piece of wood
Rubber bands
Masking tape
Salt (table salt is fine)

NOTE: KEEP CHEMICALS OUT OF REACH OF CHILDREN. **STORE THE AMMONIA SEPARATE FROM EVERYTHING ELSE.**

BBQ Crystals
Uniodized salt (sodium chloride)
Ammonia (clear, no additives)
Laundry bluing
Charcoal briquette, sponge, brick, cork, or porous rock
Non-metal pie plate (an old glass pan works great)
Food (dye) coloring

This next experiment is completely optional!

Optional Additional for Grades 9-12: Advanced Crystals
Sodium silicate

Select one (or more) of the following for the Advanced Crystals Experiment (the colors indicated are the colors your experiment will grow…)
Calcium Chloride (white crystals)
Iron Chloride (yellow crystals)
Cobalt Chloride (red crystals)
Copper Sulfate (blue crystals)

NOTE: Store these chemicals out of reach of children and in a dry, cool location. We'll be using these for the rest of the year in different experiments. DO NOT mix these chemicals with anything other than what we indicate, as you can generate lethal gases such as HCN.

Key Vocabulary

An **atom** is the smallest part of stable matter. Atoms are made up of protons and neutrons that are in the center of an atom (the nucleus) and electrons that are moving around outside the nucleus. Atoms differ from one another by how many protons, neutrons, and electrons they have in them. An atom can have as many as seven shells.

Bose-Einstein condensate is atoms at such a low state of energy that the atoms actually blend together. Bose-Einstein condensate occurs only in laboratories under outrageously cold conditions.

Atoms in a solid have a tendency to form **crystals**, since the molecules are pulled close together and tight they form specific patterns.

Density is a measurement of mass and volume. The denser something is the tighter its atoms are packed together. Mathematically, density is mass/volume.

Elasticity is the ability of a solid to be stretched, twisted or squashed and come back to its original shape.

Electrons don't orbit nuclei. They pop in and pop out of existence. Electrons do tend to stay at a certain distance from a nucleus. This area that the electron tends to stay in is called a **shell**. The electrons move so fast around the shell that the shell forms a balloon like ball around the nucleus.

Elements are specific kinds of atoms. Every atom is a type of element. There are over 112 elements. Ninety of which are found naturally. Twelve different elements are the major ingredients of over 90% of all matter. Five different elements are the major ingredients of all living things.

Mass is a measure of how much matter (how many atoms) make up an object.

All **matter** is made of atoms. An atom is the smallest part of stable matter. All matter is made of atoms. The difference between different forms of matter is basically the energy level (motion) of the atoms. Carbon, Hydrogen, Oxygen, Nitrogen, and Calcium are the five main elements that make up all living matter.

A periodic chart has a bunch of boxes, each representing one element. In each box, is a ton of information about each element. In the upper left hand corner of each box is what's called the atomic number. The atomic number is the same as the number of protons in the atom.

Plasma is basically a very high energy gas. It is not very common on Earth but is the most common state of matter in the universe.

A **shell** can only hold so many electrons. The number of electrons a shell can hold can be determined by the formula $2n^2$ where n is the number of the shell. The number of electrons an atom has determines how many shells it has. Atoms are "satisfied" if they have a full outer shell or if they have a multiple of eight electrons in their outer shell. If an atom is not "satisfied" it will gladly share electrons with other atoms forming molecules.

Solids are the lowest energy form of matter on Earth. Solids are generally tightly packed molecules that are held together in such a way that they can not change their position. The atoms in a solid can wiggle and jiggle (vibrate) but they can not move from one place to another. The typical characteristics that solids tend to have are that they keep their shape unless they are broken and they do not flow.

There are five known **states of matter**. Bose-Einstein condensate, solids, liquids, gases and plasma.

Tension and **compression** happen when solids are bent. **Tension** is when things get pulled apart. **Compression** is when things get squashed together.

Unit Description

Atoms are the building blocks of all matter. These odd little fellows make up tables, buildings, Chihuahuas and even you. They are impossibly small and yet absolutely vital for all matter and all interaction between matter. They are extremely mysterious and constantly offer new puzzles for science to tackle. And that's exactly what we're going to do.

If you've been following the energy curriculum up to this point and are looking forward to more great energy stuff, stay tuned. Electromagnetic energy is coming soon. However, before we get there, we need to take a bit of a side road. Remember how energy is things moving over a distance against a force? Well, when it comes to electromagnetic energy those moving things are electrons. What's an electron you ask? Well, that's what this unit is all about. We need to wander into the world of quantum physics for a bit and take a look at the teeny and the mysterious world of atoms.

Objectives

Lesson 1: Atoms and Density

If you've been following the energy curriculum up to this point and are looking forward to more great energy stuff, stay tuned. Electromagnetic energy is coming soon. However, before we get there, we need to take a bit of a side road. We need to wander into the world of quantum physics for a bit and take a look at the teeny and the mysterious world of atoms.

We're going to study atoms, their parts, as well as how they work together. Are you ready?

Highlights for Atoms:

1. All matter is made of atoms.
2. An atom is the smallest part of stable matter.
3. Atoms rarely hang out alone. They join together in groups from two to millions of atoms.
4. Atoms are made of three basic particles. Neutrons, protons, and electrons.
5. Neutrons and protons are together in the middle of the atom and make up the nucleus of the atom. Electrons move around the nucleus. They don't "orbit" the nucleus. Next lesson we will talk more about how they move. It's one of the wacky things about electrons.
6. Atoms differ from one another by how many protons, neutrons, and electrons they have in them.
7. Elements are specific kinds of atoms. Every atom is a type of element.
8. There are over 112 elements. Ninety of which are found naturally. Twelve different elements are the major ingredients of over 90% of all matter. Five different elements are the major ingredients of all living things.
9. Carbon, Hydrogen, Oxygen, Nitrogen, and Calcium are the five main elements that make up all living matter.
10. Most atoms come from stars and have been around since the beginning of time.
11. Atoms get used, and reused again and again as things change over time.

Highlights for Electrons:

1. Electrons don't orbit nuclei. They pop in and pop out of existence.
2. Electrons do tend to stay at a certain distance from a nucleus. This area that the electron tends to stay in is called a shell.
3. The electrons move so fast around the shell that the shell forms a balloon like ball around the nucleus.
4. An atom can have as many as seven shells.
5. The number of electrons an atom has determines how many shells it has.
6. A shell can only hold so many electrons. The number of electrons a shell can hold can be determined by the formula 2n2 where n is the number of the shell.
7. Atoms are "satisfied" if they have a full outer shell or if they have a multiple of eight electrons in their outer shell.
8. If an atom is not "satisfied" it will gladly share electrons with other atoms forming molecules.

Highlights for Density:

1. Density is a measurement of mass and volume.
2. The denser something is the tighter its atoms are packed together.
3. Mathematically, density is mass/volume.

Objectives

Lesson 2: Solids

We're going to study the five different states of matter: plasma, gas, liquid, solids, and BEC (Bose-Einstein Condensate). A gas becomes a plasma when it gets so hot that the collisions start to knock electrons out of atoms.

The most energized state of matter is plasma, the least is BEC. We're going to focus on solids, crystal structure and how to build your own crystal matrix. Are you ready?

Highlights for Solids:

1. There are five known states of matter. Bose-Einstein condensate, solids, liquids, gases and plasma.
2. All matter is made of atoms. The difference between different forms of matter is basically the energy level (motion) of the atoms.
3. Plasma is basically a very high energy gas. It is not very common on Earth but is the most common state of matter in the universe.
4. Bose-Einstein condensate is atoms at such a low state of energy that the atoms actually blend together.
5. Bose-Einstein condensate occurs only in laboratories under outrageously cold conditions.
6. Solids are the lowest energy form of matter on Earth.
7. Solids are generally tightly packed molecules that are held together in such a way that they can not change their position.
8. The atoms in a solid can wiggle and jiggle (vibrate) but they can not move from one place to another.
9. The typical characteristics that solids tend to have are that they keep their shape unless they are broken and they do not flow.
10. Tension and compression happen when solids are bent.
11. Tension is when things get pulled apart.
12. Compression is when things get squashed together.

13. Elasticity is the ability of a solid to be stretched, twisted or squashed and come back to its original shape.

14. Atoms in a solid have a tendency to form crystals, since the molecules are pulled close together and tight they form specific patterns.

Textbook Reading

If you've been following the curriculum up to this point (Units 1 & 2) and are looking forward to more great energy stuff, stay tuned. Electromagnetic energy is coming soon. However, before we get there, we need to take a bit of a side road.

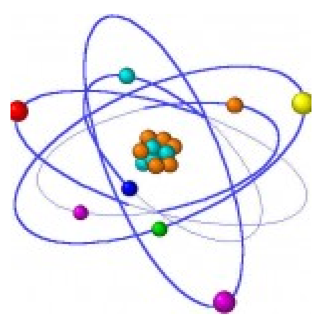
Energy is things moving over a distance against a force. When it comes to electromagnetic energy those moving things are electrons. *"What's an electron?"* you ask? Well, that's what this lesson is all about. We need to wander into the world of quantum physics for a bit and take a look at the teeny and the mysterious world of atoms.

What is an Atom?

My definition of an atom is; the smallest part of stable matter. There are things smaller than an atom, but they are unstable. (Not like my Aunt Edna is unstable but rather like they can't be around for long on their own.) Atoms are very stable and can be around for long, long, long periods of time. Atoms rarely hang out on their own though. They are outgoing little fellows, on the whole, and love to get together in groups. These groups of atoms are called molecules. A molecule can be made of anywhere from two atoms to millions of atoms. Together these atoms make absolutely everything.

All matter is made of atoms. Shoes, air, watermelons, milk, wombats, you, everything is made of atoms. Hundreds, and billions, and zillions of atoms make up everything. When you fly your kite, it's atoms moving against the kite that keep it in the air. When you float in a boat, it's atoms under your boat holding it up.

What's Inside an Atom?

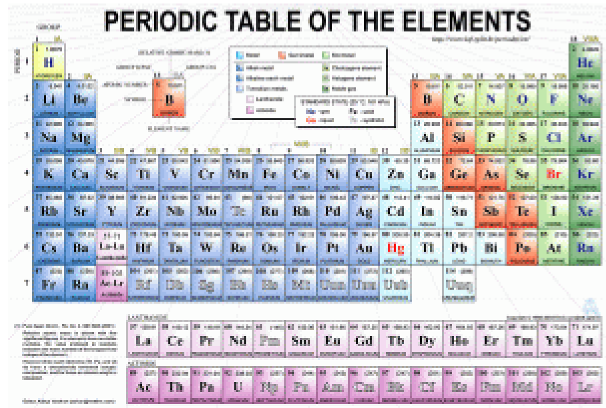


Atoms are made up of bunches of particles, but we will concern ourselves with only three of those particles for now. Atoms are made of protons, neutrons, and electrons. The protons and the neutrons make up the nucleus (the center) of the atom.

The electron wanders around outside the nucleus and, as we'll see next lesson, is a wacky little fellow. Protons and neutrons are made up of smaller little particles, which are made of smaller little particles and so on. Atoms can have anywhere from only one proton and one electron (a hydrogen atom) to over 300 protons, neutrons and electrons in one atom. It is the number of protons that determines the kind of atom an atom is, or in other words, the kind of element that atom is. We'll talk more about elements in a bit.

Here science does us a bit of a favor since it's relatively easy to tell how many electrons, protons, and neutrons are in an atom. The number of protons, basically tells you how many neutrons and electrons are in the atom. If an atom has 4 protons, it probably has 4 neutrons and 4 electrons. I say probably because in the world of atoms you can never be completely sure. These guys do some wacky stuff. Protons and electrons are usually equal in an atom. The number of protons and neutrons are not necessarily equal in some of the larger atoms.

So how do you know how many protons are in an atom? Look at the periodic chart.



A periodic chart has a bunch of boxes. Each box represents one element. In each box, is a ton of information about each element. In the upper left hand corner of each box is what's called the atomic number. The atomic number is the same as the number of protons in the atom.

Once you know that, you know the probable number of electrons and neutrons in that atom! To the right you see how oxygen would look in a periodic table. The atomic number is eight so you know there are eight protons, neutrons and electrons. Isn't it nice when nature makes things simple?

We will talk more about this in future lessons but just to let you know, protons have a positive charge, neutrons have no charge, and electrons have a negative charge. Atoms like to be electrically neutral so that's why the number of protons and electrons tend to be equal. Ten positive protons plus ten negative electrons equals zero net electrical charge. A neutral atom. An atom that is not neutral is called an ion.

So What's an Element?

The question, "what's the difference between an atom and an element?", has caused a lot of confusion among my students. I'm going to try to see if I can clear up that confusion. Atoms are elements in the same way dogs are poodles. There, did that do it for you? No?! Hmm let me try again.

Elements are specific kinds of atoms. If I say, "there's a bunch of atoms in that cup". That doesn't tell you much. But if I say, "there's a bunch of Mercury (a type of element) in that cup." you know (if you have your handy pocket periodic table with you) exactly what kind of atom it is, what the weight of each atom is, what it's atomic number is and due to that, you know how many protons, neutrons, and electrons it probably has. By the way, Mercury is very poisonous so if I said "there's a bunch of Mercury in that cup", RUN!!!

So now do you see what I was talking about with the poodle thing? If I say, there's a bunch of dogs in that room. You don't know if I'm talking about chihuahua's or rottweilers. Dogs, like atoms, are a broad term. Neither word describes things specifically. Now if I said, there's a bunch of rottweilers in that room, you would know that entering that room would be a very bad idea!

Each element (each specific atom) has a different behavior. Hydrogen does different things than Plutonium, which acts differently than Lead, which acts differently than Argon etc, etc. Each atom of Plutonium will act and look like every other atom of Plutonium, but an atom of Plutonium will look and act differently than an atom of Hydrogen.

Do you remember what's different between an atom of Lead and an atom of Hydrogen? Remember the atomic number? That's right, the number of protons, neutrons and electrons are different in a Lead atom than in a Hydrogen atom. A Hydrogen atom will have one proton, no neutrons and one electron. A Lead atom has 82 protons, 82 neutrons and 82 electrons!

The element *gold* has 79 protons, and the symbol for Gold is *Au.* If you're wondering where the "Au" came from, it's from the Latin word: *Aurum*, but the Old English word *geolo* (meaning yellow) was adapted for our modern-day "Gold" word. Similarly, silver which is element number 47 and symbol *Ag* was named after the Latin word *Argentum* (Old English word *seolfor)*.

All atoms are made from the same stuff, it's just the amount of stuff that makes the atoms behave the way they do. Next lesson we'll talk a bit more about how the different atoms behave.

If you look at a periodic table you will notice that (depending how recently the table was made) there will be about 112 to 118 different elements. About 90 of those occur naturally in the universe. The other ones have been man-made and are very unstable. So imagine, everything in existence, in the entire universe, is made of one or several of only about 90 different types of atoms. Everything, from piano's to pistachio's are made from the same set of 90 different Lego's!

Now, if you find that amazing, listen to this: **almost everything in the universe is mostly made of only twelve different kinds of atoms**! But wait there's more…

All living things are mostly made of only five different kinds of atoms! Five! You and a hamster are made of the same stuff! All living and once living things are made mostly of Carbon, Hydrogen, Oxygen, Nitrogen, and Calcium. *Ta daa!* Those are the ingredients for life. Put 'em in a bowl, stir and voila, you can make your own penguin.

OK, obviously it's not that easy. It takes a lot more than that to make life, but at least now you know the ingredients. An easy way to remember the main ingredients for living things is to remember the word CHONC. Each letter in CHONC is the first letter in the 5 elements Carbon, Hydrogen, Oxygen, Nitrogen and Calcium.

One last interesting thing to think about here; of all the atoms in the entire universe, 90% of them are hydrogen. Only 10% of the entire universe is made up of anything other than hydrogen.

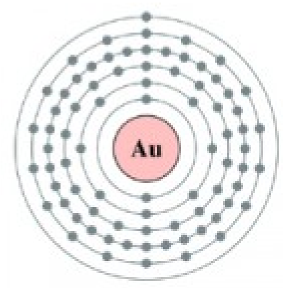
Atoms Recycle

Here's a fun fact. When you exhale a breath, it takes 6 years for the atoms in that breath to become evenly distributed over the whole world. Then, once the atoms are evenly distributed, every person who inhales, gets on average 1 atom that you exhaled. At any moment you have atoms in your lungs that were once in the lungs of every person who ever lived! EVERY PERSON WHO EVER LIVED! Wow! So in your lungs right now are atoms that were once in Newton, Einstein, Tesla, Watt, Jane Goodall, John Armstrong, my Uncle Harry and many more!

Electron “Orbits”

Remember, that atoms are made up of protons and neutrons that are in the center of an atom (the nucleus) and electrons that are moving around outside the nucleus. Now hold on to your hats, here’s where things start to get a bit goofy. Electrons don’t really move around the nucleus...they pop in and out of existence around the nucleus. They exist in one spot, then “pow”, they disappear and reappear in another spot. Then “boink” off they go again and “zip” they are back again. Here’s a fun question...where do they go? That’s an answer that, at this point, nobody knows. You may run into some older books or websites that still refer to electrons orbiting around the nucleus like the planets orbit around the sun. That’s the way folks used to think it worked, but lo and behold, the teeny tiny electron is like nothing else in the universe.

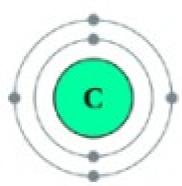
Electron Shells



So why did they ever think electrons orbited the nucleus? Well, just like the Earth stays a certain distance from the Sun, the electron stays a certain distance from the nucleus as it pops in and out of existence. The reason they stay a certain distance is due to one of the strangest things in science and that’s the wave/particle duality nature of electrons. Electrons act like waves, and like particles at the same time!

That concept is one of the keys to quantum physics and gets a little deeper (like seventeen miles deeper) than we are going to go in this lesson, so we’ll leave it at that for now. Suffice it to say that they do stay a certain distance from the nucleus. Since scientists are trying to get away from the “orbit” concept, they are now calling these areas the electrons move in “shells”.

A nice way to visualize this is to think about a balloon with a teeny tiny ball bearing in the middle of it. The ball bearing would represent the nucleus and the balloon would represent the shell. The electrons could be anywhere on the skin of the balloon at any given time. It is this "shell" that gives the atom its body. The electron moves so fast that it actually provides a balloon like shell around the atom and so the atom can be squooshed but not smashed. These balloons, made of several fast moving particles, are what give tables, chairs, walruses, and cheese burgers their structure.



Let's try another way to look at this. You're playing miniature golf and you come to the old wind mill hole. Your friend takes a shot and since the blades of the windmill are going nice and slow he gets the ball right through. Now it's your turn. Suddenly you hear a zap and a pow and sparks go flying. Something has gone wrong with the wind mill and it starts spinning at amazing speeds. You decide to give it a try and hit the ball towards the wind mill.

Well since it is spinning out of control, those blades now form almost a solid disk so that there is no way your ball can get through the wind mill. Electrons do the same thing. They move so fast that even though there may not be many of them, they form a shell that can't be penetrated. (To be clear, particles that are smaller than an atom can go through the shells and pop out the other side.)

Let's go a little further with this shell thing. An atom can have as few as one and as many as seven shells. Imagine our balloon again. Now there can be a balloon inside of a balloon inside a balloon and so on. Up to seven balloons! Each balloon, whoops, I mean shell, can have only so many electrons in it. This simple equation $2n^2$ tells you how many electrons can be in each shell. The n stands for the number of the shell.

The first shell can have up to 2 x 1(first shell)^2 or 2 electrons. The second shell can have up to 2 x 2(second shell)^2 or 8 electrons. The third shell can have up to $2x3^2$ or 18 electrons. The fourth shell can have up to $2x4^2$ or 32 electrons. All the way up to the seventh shell which can have $2x7^2$ or 98 electrons!

One last thing about shells, the shells have to be full before the electrons will go to the next shell. A helium atom will have two electrons. Both of them will be in the first shell. A Lithium atom will have three electrons. Two will be in the first shell and one (since the first shell is filled) will be in the second shell.

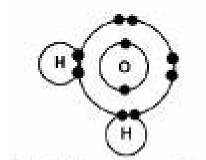
Electron Sharing

Electrons provide the size and stability of the atom and, as such, the mass and the structure of all matter. Electrons are also the key to all electromagnetic energy. But wait, that's not all! It is the number of electrons in an atom that determines if and how atoms come together to form molecules. Electrons determine how and what matter will be.

Atoms like to feel satisfied and they feel satisfied if they are "full". An atom is full if it eats four hot dogs and a large fry. (Just kidding.) An atom is "full" if its outer electron shell has as many electrons as it can hold or if there are eight or a multiple of eight (16, 24 etc.) electrons in the outer shell. This is called the octet rule and works most of the time, but is not perfect.

If an atom is not full, it is not satisfied. An unsatisfied atom needs to do something with its electrons to be happy. Luckily atoms are very friendly and love to share. Most atoms are not satisfied as individuals. The oxygen atom has six electrons in its outer shell. It needs eight electrons to be satisfied.

Luckily, two Hydrogen atoms happen by. Each one of them has only one electron in its outer shell and needs one more to be satisfied. If both Hydrogens share their one electron with the Oxygen, the oxygen has eight electrons and is satisfied. Also, if the Oxygen shares an electron with each Hydrogen, then both Hydrogens are satisfied as well. Just like your mother told you, it's nice to share. It is this sharing of electrons that makes atoms come together to form molecules.



In the upcoming lessons, we are going to begin taking a close look at the different forms of matter that these strange and mysterious atoms can take. Before we do, however, it's worth taking a bit of time to get a handle on the concept of density.

What is Density?

Density is basically how tightly packed atoms are. Mathematically, density is mass divided by volume. In other words, it is how heavy something is, divided by how much space it takes up. If you think about atoms as marbles (which we know they're not from the last lessons but it's a useful model), then something is more dense if its marbles are jammed close together.

For example, take a golf ball and a ping pong ball. Both are about the same size or, in other words, take up the same volume. However, one is much heavier, has more mass, than the other. The golf ball has its atoms much more closely packed together than the ping pong ball and as such the golf ball is denser.

Here's a riddle: *Which is heavier, a pound of bricks or a pound of feathers?* Well, they both weigh a pound so neither one is heavier! Now, take a look at it this way, which is denser, a pound of bricks or a pound of feathers? Aha! The pound of bricks is much denser since it takes up much less space. The bricks and the feathers weigh the same but the bricks take up a much smaller volume. The atoms in a brick are much more squooshed together then the atoms in the feathers.

What is 'stuff' made of?

Now, that you've spent some quality time with atoms and that wacky electron fellow you have a bit of an understanding of what is inside everything. The next thing you need to know is...*what's everything?*

Everything is matter. Well, except for energy, but that's everything else (and we'll get to that later). Everything you can touch and feel is matter. It is made up of solid (kind of) atoms that combine and form in different ways to create light poles, swimming pools, poodles, jello and even the smell coming from your pizza.

Traditionally, there have been three states of matter. State of matter means the way the atoms tend to hang out together. Not to be confused with a state like Utah, Wyoming, or confusion. The three states are solids, liquids and gases. However, leave it up to a science teacher to tell you that that's not the whole story.

There are two more states of matter. They are *plasma* and (are you ready for this next one?) the *Bose-Einstein condensate*. I'm just going to spend a little bit of time talking about these last two states of matter since they are both pretty uncommon on Earth.

Plasma

Believe it or not, plasma makes up a very large percentage of the matter in the universe. Are you wondering how come you've never heard of it before? (By the way, blood plasma is different from this stuff, and a good thing too!)

Well, there is very little of it on Earth and the plasma that is here is very short lived or stuck in a tube. Plasma is basically ionized gas or in other words it is gas that is electrically charged. The stuff in florescent light bulbs is plasma. Plasma TV's have plasma (go figure) inside of them. Lightning and sparks are actually plasma!

Bose-Einstein Condensate

Now let's talk a bit about the Bose-Einstein condensate or the BEC if you want to be hip. Each form of matter corresponds with a level of energy. Plasma is the highest energy state of matter. So energetic, in fact, that it can give off light. BEC is the lowest energy state of matter.

In fact, BEC only happens at energy levels that are almost as low as possible. Basically temperature is a measurement of energy. The higher the temperature, the higher the energy of something and vice-versa. Theoretically the coldest anything can ever get is 0 degrees Kelvin, (the same as -273 degrees Celsius, or -459 degrees Fahrenheit). This temperature is called absolute zero. At absolute zero, there is no energy and no atomic movement. Space is 3 degrees Kelvin. (We'll get deeper into this concept when we get to the thermal energy lessons.)

Scientists have discovered that if you get certain types of atoms cold enough (less than one millionth of a degree above absolute zero) you get this bizarre thing called a Bose-Einstein condensate. When the atoms get that cold they move so slowly that they kind of blend together into one big atomic mush. Satyendra Nath Bose and Albert Einstein predicted that this state of matter existed in 1924. Seventy one years later in 1995, two scientists at the University of Colorado using magnets and lasers made it happen.

Solids

So now that we've gotten those bizarre states of matter out of the way, let's talk about some stuff that really matters (haha…couldn't resist at least one pun). Something to keep in mind is that everything is made of the same stuff, atoms.

What makes the solids, liquids, gases etc. different is basically the energy (motion) of the atoms. From BEC, where they are so low energy that they are literally blending into one another, to plasma, where they are so high energy they can emit light. Solids are the lowest energy form of matter that exist in nature (BEC only happens under laboratory conditions).

In solids, the atoms and molecules are bonded (stuck) together in such a way that they can't move easily. They hold their shape. That's why you can sit in a chair. The solid molecules hold their shape and so they hold you up. The typical characteristics that solids tend to have are they keep their shape unless they are broken and that they do not flow. Let's take a look at a couple of terms that folks use when talking about solids.

Elasticity

Elasticity is what allows you to bounce a basketball and shoot a rubber band across the room. **All solids have some elasticity.** A rubber band has a lot of elasticity, a diamond on the other hand has very little elasticity. Elasticity is basically the ability of solids to be stretched, twisted or squashed and come back to its original shape. You can stretch a rubber band quite a bit and when you stop stretching it comes back to the way it was. A basketball actually squashes a bit when it hits the sidewalk and when it unsquashes it bounces back up. If you stretch, twist or squash something beyond its elastic limit it will break or deform.

Imagine taking a rubber band, for example, and stretching it so much that it breaks. You've stretched it beyond its elastic limit and it broke. Another example, would be taking a wire pipe cleaner. If you bend it just a bit, it will bend back to its original shape. If you go to far, it stays in the new shape. You have bent it beyond its elastic limit.

Tension and Compression

That brings us to tension and compression. Here's a question for you - does a rope support both tension and compression? That is, if I handed you one end of a rope while I held onto the other end, could I push you across the room using just the rope?

No, that's silly! You can't *push* someone with a rope! Pulling, however, is an entirely different matter. So ropes support tension and not compression. That's interesting. So why not build a bridge entirely out of rope? Let's take another look at a different material… like wood.

What about a length of wood, like a broomstick? If we each held onto an end of a broomstick (without the broom part attached), could I push and pull you around the room? Sure I could - that's easy. So a broomstick supports both tension and compression. This is why bridges are made up of both wood sticks (or metal beams) and rope (or cable). Cable is cheaper than metal, so engineers place cables in places where the bridge will only feel a tensile force (tension). It's much easier on the pocketbook, and the bridge never knows the difference.

But in truth, the metal beams actually experience both tension *and* compression. Let me explain - can you imagine a diving board? Great - then imagine yourself hanging out on the very tip of the diving board, just before you jump into the pool.

Notice how the diving board dips down a bit under your weight. If we look carefully at this diving board, you'll find that the top surface is being slightly stretched (to cover a slightly longer distance as it dips down), so the top surface is actually experiencing tension.

And on the underside, the bottom surface of the diving board is being smooshed together slightly, so the bottom surface is feeling slightly compressed. If ten of your friends joined you on the end of the board, what would eventually happen?

Activities, Experiments, Projects

Lesson 1: Atoms & Density

Note: This section is an abbreviated overview of the experiments online.

Experiment: Plasma Grape

CAUTION!! Be careful with this!! This experiment uses a knife AND a microwave, so you're playing with things that slice and gets things hot. If you're not careful you could cut yourself or burn yourself. Please use care!

We're going to create the fourth state of matter in your microwave using food. Note – this is NOT the kind of plasma doctors talk about that's associated with blood. These are two entirely different things that just happen to have the same name. It's like the word 'trunk', which could be either the storage compartment of a car or an elephant's nose. Make sense?

Plasma is what happens when you add enough energy (often in the form of raising the temperature) to a gas so that the electrons break free and start zinging around on their own. Since electrons have a negative charge, having a bunch of free-riding electrons causes the gas to become electrically charged. This gives some cool properties to the gas. Anytime you have charged particles (like naked electrons) off on their own, they are referred to by scientists as *ions*. Hopefully this makes the dry textbook definition make more sense now ("Plasma is an ionized gas.")

So here's what you need to do:

You need: a microwave, a grape, and a knife.

1. Carefully cut the grape almost in half. You want to leave a bit of skin connecting the two halves.

2. Open the grape like a book. In other words, so that the two halves are next to one another still attached by the skin.

3. Put the grape into the microwave with the outside part of the grape facing down and the inside part facing up.

4. Close the door and set the microwave for ten seconds. You may want to dim the lights in the room.

You should see a bluish or yellowish light coming from the middle section of the grape. This is plasma! Be careful not to overcook the grape. It will smoke and stink if you let it overcook. Also, make sure the grape has time to cool before taking it out of the microwave.

Other places you can find plasma include neon signs, fluorescent lights, plasma globes, and small traces of it are found in a flame.

Experiment: Freeze Swap

Fill a plastic container (such as a water bottle) about one-third full of water. *Do not use glass!* Add one-third oil (so the bottle is now two-thirds full) and cap the bottle. Shake it up and see if you can get the two to mix. (If you add blue dye to the water beforehand, it makes this experiment easier to view.)

Which is on top, the water or the oil? Stick the bottle in the freezer overnight (stand it upright and remove the cap first). Now which is floating on top?

Experiment: Hot & Cold Swirl

To clearly illustrate how hot and cold air don't mix, find two identical glasses. Fill one glass to the brim with hot water. Add a drop or two of red food coloring and watch the patterns. Now fill the other glass to the top with very cold water and add drops of blue dye. Do you notice a difference in how the food coloring flows?

Get a thick sheet of heavy paper (index cards work well) and use it to cap the blue glass. Working quickly, invert the glass and stack it mouth-to-mouth with the red glass. This is the tricky part: When the glasses are carefully lined up, remove the card. Is it different if you invert the red glass over the blue?

Activities, Experiments, Projects

Lesson 2: Solids

Note: This section is an abbreviated overview of the experiments online.

Experiment: Microwaving Soap

When you warm up leftovers, have you ever wondered why the microwave heats the food and not the plate? (Well, some plates, anyway.) It has to do with the way microwaves work.

Microwaves use dielectric heating (or high frequency heating) to heat your food. Basically, the microwave oven shoots light beams that are tuned to excite the water molecule. Foods that contain water will step up a notch in energy levels as heat. (The microwave radiation can also excite other polarized molecules in addition to the water molecule, which is why some plates also get hot.)

The following experiment is a quick example of this principle using a naked bar of Ivory soap. The trick is to use Ivory, which contains an unusually high amount of air. Since air contains water moisture, Ivory also has water hidden inside the bar of soap. The microwave will excite the water molecules and your kids will never look at the soap the same way again.

Toss a naked bar of Ivory soap onto a glass or ceramic plate and stick it into the microwave on HIGH for 2-3 minutes. Watch intently and remove when it reaches a “maximum”. Be careful when you touch it after taking it out of the microwave oven – it may still hold steam inside. You can still use the soap after this experiment!

Experiment: Landry Soap Crystals

Can we really make crystals out of soap? You bet! These crystals grow really fast, provided your solution is properly saturated. In only 12 hours, you should have sizable crystals sprouting up.

You can do this experiment with skewers, string, or pipe cleaners. The advantage of using pipe cleaners is that you can twist the pipe cleaners together into interesting shapes, such as a snowflake or other design. (Make sure the shape fits inside your jar!)

Here's what you need: pipe cleaners (or string or skewer), cleaned out pickle, jam, or mayo jar, water, borax (*AKA sodium tetraborate),* adult help, stove, pan, and stirring spoon.

1. Cut a length of string and tie it to your pipe cleaner shape; tie the other end around a pencil or wooden skewer. You want the shape suspended in the jar, not touching the bottom or sides.

2. Bring enough water to fill the jar (at least 2 cups) to a boil on the stove (food coloring is fun, but entirely optional).

3. Add 1 cup of borax (aka sodium tetraborate or sodium borate) to the solution, stirring to dissolve. If there are no bits settling to the bottom, add another spoonful and stir until you cannot dissolve any more borax into the solution. When you see bits of borax at the bottom, you're ready. (You'll be adding in a lot of borax, which is why we asked you to get a full box). You have made a supersaturated solution. Make sure your solution is saturated, or your crystals will not grow.

4. Wait until your solution has cooled to about 130^{o}F (hot to the touch, but not so hot that you yank your hand away). Pour this solution (just the liquid, not the solid bits) into the jar with the shape. Put the jar in a place where the crystals can grow undisturbed overnight, or even for a few days. Warmer locations (such as upstairs or on top shelves) is best.

Exercises for Unit 3: Matter

Lesson 1: Atoms and Density Exercises

1. What is the smallest stable building block of matter?

2. When you go swimming, what are you moving through?

3. What are three particles inside an atom?

4. What makes one atom different from another?

5. What is an element?

6. Where have almost all atoms come from?

7. What five elements are in all living things?

8. True or false: Matter is made of hard, tightly packed, little particles.

9. What do you call a bunch of atoms stuck together?

About Electrons:

1. How do electrons move?

2. Do electrons just go all over the place in an atom?

3. What is a shell?

4. How many shells can an atom have?

5. What determines how many shells an atom has?

6. How many electrons can be in the third shell of an atom?

7. How many shells does a Sodium atom have? Sodium has 11 electrons.

8. Why do atoms come together to form molecules?

About Density:

1. What is density?

2. Which is more dense: a one pound can of beans or a one pound loaf of bread?

3. Which is more dense a gallon of water that weighs 8 lbs or a gallon of gasoline that weighs 6 lbs?

4. Which is more dense: a school bus filled with children or an empty school bus?

Lesson 2: Solids Exercises

1. What is the lowest energy form of matter found naturally?

2. What is the highest energy form of matter?

3. Why do many solids form crystals?

4. If I bend a pencil so far that it breaks, what have I done to it?

5. I love to play with paper clips. However, by the time I'm done with them they are all bent out of shape. (Paper clips run when they see me coming!) How can you explain that using a term from this lesson?

6. Why do crystals tend to break along specific lines?

Answers to Atoms and Density Exercises

About Atoms

1. The atom.

2. Billions and billions of atoms.

3. Neutron, proton (in the nucleus) and electron.

4. The number of particles inside the atom. Atoms are made of identical stuff. It's the number of particles (neutrons, protons, and electrons) that make atoms have different characteristics.

5. Elements are specific kinds of atoms. Each element (each specific atom) has a different behavior from every other element.

6. Exploded stars.

7. Carbon, Hydrogen, Oxygen, Nitrogen, Calcium: CHONC

8. False. Matter is made of atoms that have incredible distances between their incredibly tiny bits of matter.

9. A molecule.

About Electrons:

1. They pop in and out of existence.

2. No. They tend to stay a certain distance away from the nucleus.

3. A shell is the distance that electrons tend to stay in as they pop around the nucleus.

4. Up to seven.

5. The number of electrons an atom has.

6. 18. Remember 2n2. So 2 x 32 = 18.

7. 2 atoms fill the first shell, 8 fill the second, and 1 is left in the third. So Sodium has 3 shells.

8. Because they are “unsatisfied’. They have too many or not enough electrons in their outer shell.

About Density:

1. Density is a measurement of how heavy something is and how much space it takes up. In other words, a measurement of its mass and its volume.

2. The beans are more dense since they have less volume (the can of beans is smaller then the loaf of bread).

3. Believe it or not, gasoline is less dense than water.

4. A full school bus. Both have the same volume but the full one will have more mass.

Answers to Solids Exercises

1. Solids. Remember BEC is only found in science labs.

2. Plasma.

3. The molecules are pulled so tightly together that they tend to fall into specific patterns.

4. I have bent it beyond its tension and/or compression point.

5. I have bent the paper clip beyond its point of elasticity so it no longer snaps back to its original shape.

6. Crystals break along cleavage lines which are there due to the way the molecules lined up when the crystal formed.

