GRANDPA'S GLOSSARY

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Acceleration Due to Gravity: Gravity is a force of attraction between all physical objects. If an object on Earth is dropped or thrown, the force of gravity between Planet Earth and the object will cause it to accelerate towards Earth. On Earth, the acceleration (rate of change of velocity) due to this gravitational force is 9.8 meters per second per second. That means that the velocity changes by 9.8 meters per second every second. The acceleration due to gravity on the moon is 1/6 the value on Earth. The value depends on the mass and radius of the Earth or moon.

Andromeda Galaxy: Andromeda is the nearest neighboring galaxy to our Milky Way galaxy. It is approximately 2.5 million light-years from Earth. Andromeda is a spiral galaxy (like the Milky Way) consisting of about 1 trillion stars. The Milky Way and Andromeda galaxies are expected to collide in around 4.5 billion years.

Antibodies: An antibody is a large, Y-shaped molecule used by a body's immune system to fight foreign objects like bacteria and viruses. The antibody can attach to the foreign object to prevent it from being dangerous as it does with the Covid-19 coronavirus. Or it can attach to the foreign object to identify it for destruction by other parts of the immune system.

Antigravity Machine: This is science fiction again, like the flying car in the movie Back to the Future. There is no theory in science on which a machine can be built to turn off gravity. However, scientists believe there is something called dark energy that is pushing the stars and galaxies away from each other, working against the force of gravity (an antigravity force).

Asteroid that Killed the Dinosaurs: In 1980, scientists Luis Alvarez and his son Walter Alvarez proposed that the extinction of the land dinosaurs was caused by an asteroid that hit Planet Earth. Their proposal was based on a 65-million-year-old rock layer (the Gubbio layer) that has been found all over the world. The layer is the dividing line between older rocks below, in which dinosaur fossils are found, and newer rocks above, in which there are no dinosaur fossils. The clue to the asteroid impact as the source of the layer was its chemical composition, which was more like a meteor than normal earth rock. The conclusion was that this worldwide layer was caused by a major asteroid impact. A crater discovered in the 1970s on the Yucatán Peninsula of Mexico near the town of Chicxulub has since been identified as the likely impact site for the asteroid that killed the dinosaurs.

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.

Atoms: Every solid, liquid, or gas in our world is made of atoms. Most things, like water, people, trees, houses, or cars, 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, and these are called chemical elements. The atom is the smallest unit that defines a chemical element. Anything made of atoms has mass, meaning that a force is necessary to make it go faster or slower, and it experiences a gravitational attraction to other masses. Atoms are very small. A single strand of human hair is almost 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 in solids or liquids. 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 build atoms in the *Building the Universe* game available on Store.SteamPowered.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. And then there is *dark energy* and *dark matter*, which we think are 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.

Atom's 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 about a trillion times smaller than a sand grain. 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.

Bacteria: Bacteria are single celled organisms that can't be seen with the naked eye but can be seen under a microscope. Bacteria can cause disease such as strep throat and pneumonia. But bacteria also have beneficial uses such as in the production of yogurt, cheese, and vinegar. Bacteria occur in the shape of spheres, rods and spirals. They were among the first life forms to appear on Earth over 3 billion years ago and are present almost everywhere on Earth.

Barringer Meteorite Crater: This crater located in the Arizona desert is a well-preserved 50,000-year-old impact feature. It is 1.2 kilometers in diameter and 170 meters deep. The rim of the crater rises 45 meters above the desert floor. It was formed when a large meteorite hit the Earth.

The Big Bang: More than two thousand years ago, humans looked at all the things in the sky and decided that the universe consisted of the Earth at the center with the sun, moon, and stars all revolving around the Earth. In the fifteenth and sixteenth centuries, Copernicus and then

Kepler and Galileo said that the universe has the sun as the center, and everything revolves around the sun. Then, in the nineteenth century the picture changed to the sun and planets revolving around the center of the Milky Way galaxy. In the early twentieth century, the work of Henrietta Leavitt and Edwin Hubble showed that the Milky Way galaxy was only a small part of the universe, which has billions more galaxies like the Milky Way. What's more, Hubble's measurements, and the predictions of Alexander Friedmann and Georges Lemaître, showed that the universe is expanding, with the most distant stars moving away from us the fastest. Based on the Theory of Relativity, Lemaître made a bold prediction. He reasoned that if you follow the universe back in time, it gets smaller. The further back in time you look, the smaller it has to be. So, if the evolution of the universe were a movie showing its expansion, and you played it backwards, it would be contracting. The contraction of the universe would put it in one tiny super-dense point about 14 billion years ago. Lemaître pictured the expansion of the universe from that point as the hatching of "the *Cosmic Egg* exploding at the moment of the creation." Other scientists call this the *Big Bang* theory.

Lemaître gave lectures explaining his theory, including at Princeton University, where Albert Einstein was in attendance. It was reported that Einstein said, "This is the most beautiful and satisfactory explanation of creation to which I have ever listened." How do we know that the *Big Bang* theory is correct? Well, scientists can calculate what occurred as the universe expanded from that first point. They can make predictions about the concentrations of elements in the universe and about the leftover radiation from the earliest times, which can still be seen as the cosmic microwave background. They can predict the size of stars, galaxies and galaxy clusters, and the rate of the universe's expansion. Compared with the observations, the *Big Bang* theory is very accurate.

When we look at all the things that have to be just right for the universe to evolve as it has, and for us to be here on our Goldilocks planet, it seems that we live in a Goldilocks universe too. But we understand our Goldilocks planet as being the one that is just right in the millions of other planets that aren't just right. Living things may be on the ones that are just right, but not on the others that aren't. So, is our Goldilocks universe just the one that is right out of the millions of other universes that aren't just right? Are there millions of other universes out there that aren't just right? So, just like we found the Earth, and then the sun, and then the Milky Way galaxy were only a small part of the universe, maybe the universe that evolved from our Big Bang is only a small part of the multiverse. Or was there a creator of the Goldilocks universe that chose the conditions to be just right?

Black Holes: Black holes are super dense masses that, thanks to their enormous gravitational pulls, suck everything into them like enormous monster vacuums. Their gravity is so strong that even light can't escape. That's why they're black. Black holes were predicted by Einstein's General Theory of Relativity. There is a supermassive black hole at the center of our Milky Way

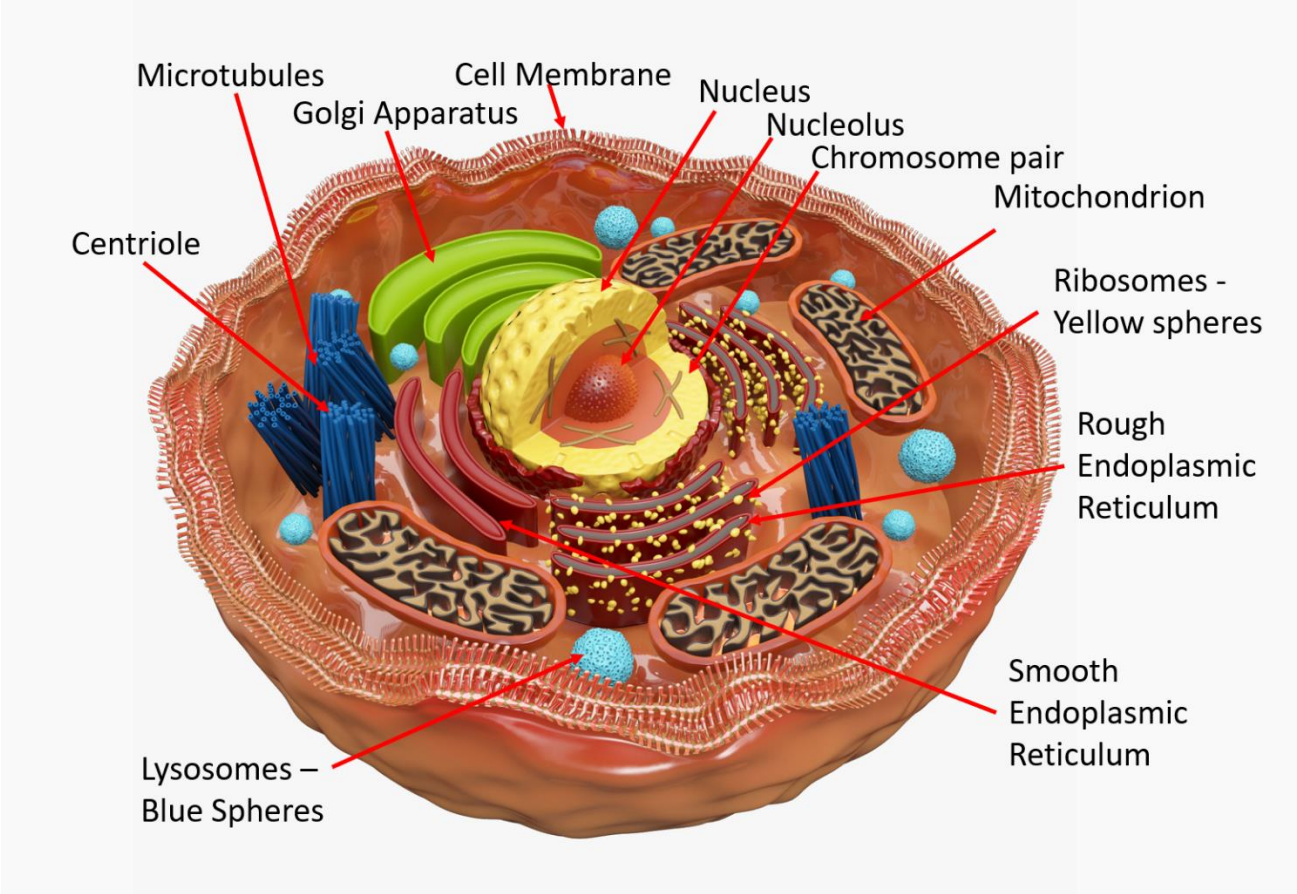
galaxy. The biggest black hole is believed to have a mass of over 6 billion times the mass of our sun.

Brain Machine: Like the time machine and the teleporter, the brain machine (learning by listening while you sleep) has been part of science fiction, and even pop culture. There was an episode of The Simpsons where Homer Simpson tried to reduce his appetite by listening to a tape recording while sleeping, but somehow increased his vocabulary instead. Research indicates that learning a language by playing information during sleep doesn't work. But some improvement in game skills or remembering vocabulary of a new language have been reported.

Carbon Cycle: There is a lot of carbon in the oceans, soil, and fossil fuels. But that carbon is stuck there for long periods of time, like thousands of years. The places that Albert Einstein's carbon is likely to go, and the places where our carbon is likely to come from would be the atmosphere and plants, because that is the carbon that circulates the most. For example, Einstein exhaled carbon dioxide all his life. Lots of that carbon dioxide is still in the atmosphere. It gets absorbed as plants grow, so Einstein carbons are in our fruits and vegetables. There is an estimated 800 billion tons of carbon in the atmosphere and 550 billion tons of carbon in plants. And these get mixed back and forth and circulate all over the world.

Carbon Pools: The diagram above shows where all the carbon atoms on earth are located in carbon pools (atmosphere, plants, ocean, etc.) and the rates at which they move from pool to pool. The amount in each pool are in gigatons. To convert that to the number of atoms, we start with a mole of carbon which is a mass of carbon in grams equal to the atomic mass (12). 12 grams (a mole) of carbon will have, by definition, a number of atoms equal to Avogadro's number (602 billion trillion). So to see how many carbon atoms there are in each carbon pool, we need to convert gigatons (billion tons) to grams. There are 2,000 pounds per ton and 2.2 pounds per 1,000 grams. Using the gigaton values on the chart above gives 25,100 trillion trillion trillion carbon atoms in the plants pool, 36,500 trillion trillion trillion carbon atoms in the atmosphere pool, and 2,630,000 trillion trillion trillion carbon atoms on Earth. That is 2.63 x 1042, or 263 followed by 40 zeros, or 2,630,000,000,000,000,000,000,000,000,000,000,000,000,000.

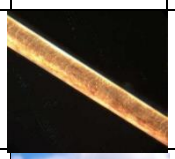
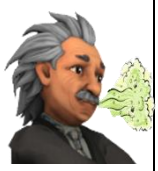
Cells: The cell is the basic building block for all living things. The cell was discovered by Robert Hooke in 1665 from studies of living material in which he observed very small repeating structures using a microscope. He called the structures cells because they resembled cells of a honeycomb. The first living things on Earth were single-celled organisms. Each cell was able to perform all the functions necessary for life. They could feed themselves and reproduce. Multicell creatures like humans have highly specialized cells that perform specific functions, such as nerve cells which are long and can transmit signals, muscle cells which contract to move arms and legs, and killer T-cells which can attack foreign objects to protect the body. Most cells are between 1 micron (1/1,000,000 of a meter) and 100 microns in size. The human body contains about 100 trillion cells whose size is like the thickness of a hair.



Cell Nucleus: The cell nucleus is a highly specialized structure of every cell of living things. The cell serves as the information processing and administrative center of the life form. This structure has two major functions: it stores the cell's hereditary DNA material (the information on the organism's characteristics; the blueprint and instructions for its construction) in the genes, and it coordinates the cell's activities, which include growth, metabolism, protein synthesis, and reproduction (cell division).

Cepheid Variable Stars: Cepheid variable stars are special stars whose appearance cycles from large and bright to smaller and dimmer. Henrietta Leavitt had a hunch that the time period it took to go from bright to dim might depend on the size of the star. To test her idea, she reasoned that stars in the Small Magellanic Cloud (a distant star cluster) would be about the same distance away from Earth, so their brightness would indicate their size. She found twenty-five variable stars in the cluster and determined that the period varied with the size or average brightness. Bigger, brighter stars took longer to change than smaller, dimmer stars. Knowing how the time for the brightness to change varied with a star's size allowed astronomers, for the first time, to determine the size of any Cepheid variable star in the universe. By knowing the size, the astronomers could use the peak brightness to determine the distance from Earth.

Chart of Big Numbers: All the huge numbers for how many atoms there are in the body, how many stars there are in the universe, and the distances to the furthest galaxies is confusing. So, here is a chart that compares the numbers in different ways, using names, zeros, special units like LIZZYs, light-years, and scientific notation. In scientific notation we give the number of zeros. For example, 1 million (1,000,000) would be written 1 x 10^6 or 1E+6 to show it has six zeros. That saves a lot of space when you are writing numbers in the trillion trillion trillions.

The Big Number	**Picture**	**Number**	**LIZZYS or Light Years**	**Scientific Notation**
Number of Atoms in a Piece of Hair		1,000,000,000,000,000,000 1 followed by 18 zeros 1 billion billion atoms	2.5 LIZZY carbons	1 x 10^{18} carbons
Number of Molecules in the Air in Average House		10,000,000,000,000,000,000,000,000,000 1 followed by 28 zeros 10 billion billion billion molecules	25 billion LIZZY molecules	1 x 10^{28} molecules
The Number of Atoms in an Adult Human Body		8,000,000,000,000,000,000,000,000,000 8 followed by 27 zeros 8 billion billion billion atoms	20 billion LIZZY atoms	8 x 10^{27} atoms
The Number of Carbon Atoms Breathed in 60 Years		284,000,000,000,000,000,000, 000,000,000 284 followed by 27 zeros 284 thousand trillion trillion carbons	710 billion LIZZY carbons	284 x 10^{27} carbons
The Number of Carbon Atoms in the Atmosphere and Plants		61,500,000,000,000,000,000,000,000,000, 000,000,000,000 615 followed by 38 zeros 61,500 trillion trillion trillion Carbons.	0.154 trillion trillion LIZZY carbons	615 x 10^{38} carbons
Number of Stars in the Milky Way		250,000,000,000 25 followed by 10 zeros 250 billion stars	6.25 x 10^{-7} LIZZY Stars	25 x 10^{10} stars

Number of Stars in the Universe		100,000,000,000,000,000,000,000 1 followed by 23 zeros 100 trillion billion stars	1 million LIZZY stars	1×10^{23} stars
The Distance across the Milky Way		950,000,000,000,000,000 95 followed by 16 zeros 950 million billion kilometers	100,000 Light-years	95×10^{16} kilometers
The Distance from Earth to the Pinwheel Galaxy		240,000,000,000,000,000,000 24 followed by 19 zeros 240 billion billion kilometers	25,000,000 Light-years	24×10^{19} kilometers
The Distance from Earth to the Most Distant Galaxies		124,000,000,000,000,000,000,000 miles 124 followed by 21 zeros 124 billion trillion kilometers	13 billion Light-years	124×10^{21} kilometers

Chromosomes: These are the threadlike bodies in the cell nucleus that carry the genes (your body's building instructions) in a linear order: the human species has twenty-three pairs, designated one to twenty-two in order of decreasing size and the X and Y female and male sex chromosomes respectively.

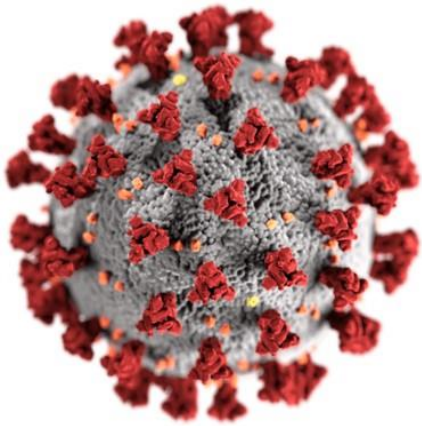
Combining Carbon and Oxygen: For your cells to function, they must have energy. That energy comes from the food you eat. The foods are digested and stored as fats and sugars. When energy is needed, the blood carries sugar and fat molecules to the cells, where they pass through the cell membrane into the cell. The blood also delivers oxygen. The chemistry is complicated, but eventually the oxygen is combined with the fats and sugars to produce energy for the cell, plus carbon dioxide and water, which are removed by the blood to be discarded by the body.

Company is Going to Take People to the Moon: There is a real company called Virgin Galactic that is developing a space craft to take people into Earth orbit. They are now selling tickets for $250,000 per ride.

Continental Drift: Continental drift was a theory proposed in 1912 by Alfred Wegener, a geophysicist and meteorologist, that explained how continents shift positions on Earth's surface. The theory proposed that the present continents were once joined, forming a supercontinent called Pangaea. It explained why lookalike animal fossils, plant fossils, and similar rock formations are found on different continents. While details of how the continents moved were

incorrect, the general ideas were important. Today, the theory of continental drift has been replaced by the science of plate tectonics that provides the explanation for how the continents move.

Cosmological Constant: The solutions to Einstein's General Relativity equations predicted that the universe would be expanding or contracting. Think of a ball that you throw up in the air. It could be going up or it could be going down, but it can't stay still. But at the time Einstein was working on his theory, everyone believed that the universe was static (or still). So, Einstein added a term to his equations called the Cosmological Constant. It was an anti-gravity term to "hold back gravity" and achieve a static universe. But Edwin Hubble's measurements showed that the universe was expanding, so then the Cosmological Constant could be removed. But wait a minute, cosmologists have discovered that there is something called dark energy that is acting like antigravity in accelerating the expansion of the universe. So now the Cosmological Constant is back in the equations of General Relativity.



Covid-19 Coronavirus: COVID-19 is a disease produced by a coronavirus that can cause an infection of the respiratory system (sinuses, nose, throat, windpipe, and lungs). The disease spreads mainly by sharing of the coronavirus particles through person-to-person transmission (most often in airborne droplets containing the virus particles). Coronaviruses are named for the distinct crown-like protein spikes on their surface. They cause many different diseases, including Covid-19 and the common cold. A virus is a particle one-hundredth the size of most bacteria, too small to be seen with an optical microscope. Virus particles consist of their genetic code material in the form of DNA or RNA, a protein coat which surrounds and protects the genetic material and in some cases an outside oily layer. The double strand DNA or single strand RNA molecules contain the genetic code for the virus's structure. The code is written in the order of atoms and molecules that make up the DNA or RNA. Some scientists consider viruses to be living organisms because they carry their genetic code, reproduce, and evolve through natural selection. Others disagree because viruses lack cell structure and cannot independently reproduce. To make copies of themselves, they employ the capability of living cells to reproduce organic components from RNA-coded instructions. They invade the cells of living organisms and induce the cell's own mechanisms to reproduce the virus based on the virus's RNA genetic code. Viruses can pull off this trick with cells of animals, plants, and microorganisms such as bacteria. When infected, the host cells are forced to rapidly produce thousands of identical copies of the original virus. One of the vaccines to combat the Covid-19 Coronavirus (the mRNA vaccine) uses the virus's own trick to defeat it. A small piece of the virus's RNA with the code to produce the protein spikes is presented to the body's cells. The cells reproduce lots of copies

of the protein spikes. These virus pieces get the body's immune system primed to combat the virus without any danger of producing the disease.

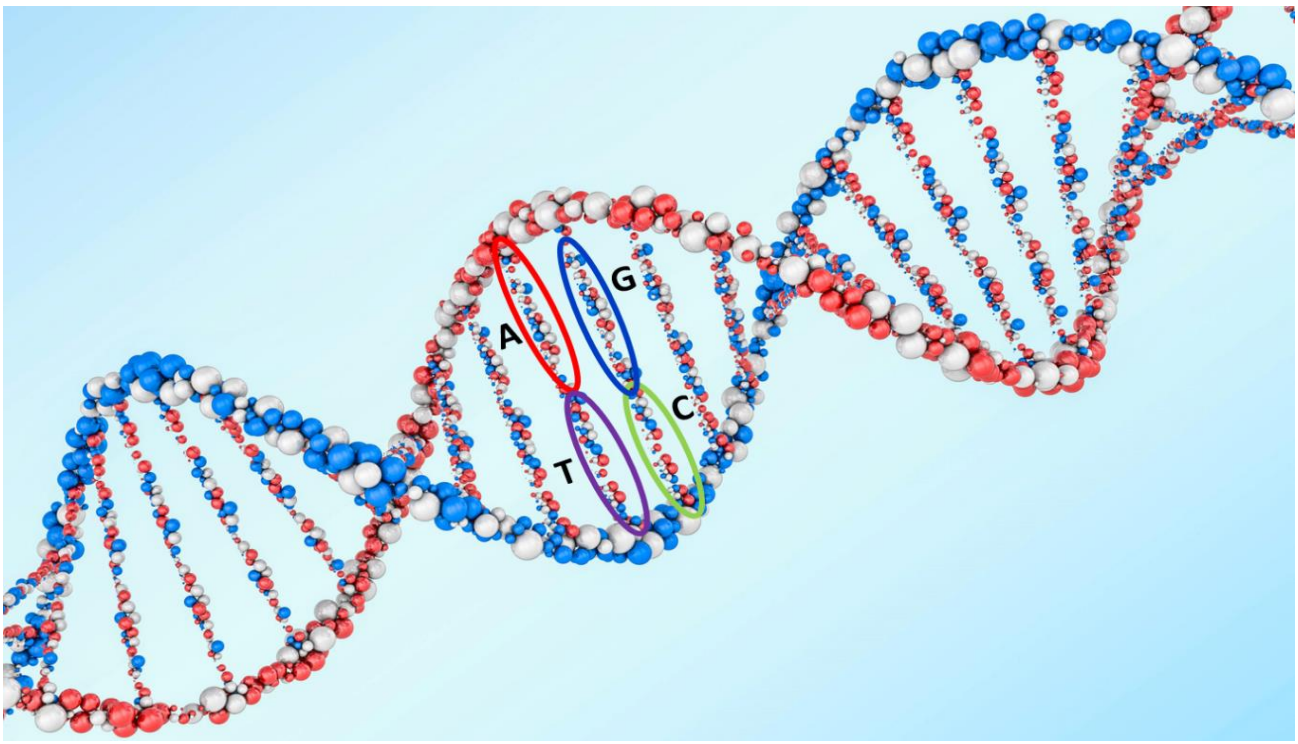
Cyanobacteria: Cyanobacteria are small, single-celled, bacteria organisms that live in water and manufacture their own food and grow by photosynthesis. They often grow in colonies large enough to see. Cyanobacteria are the oldest known fossils, 3.5 billion years old, but are still around today. They were essential in shaping the course of evolution on Earth, being responsible for the planet's oxygen gas concentration required by oxygen breathing life forms. Before the cyanobacteria generated oxygen in the oceans and atmosphere by photosynthesis, the planet was unsuitable for life as we know it today.

Dark Energy: Dark energy, like dark matter, is a fudge factor. It is actually the same fudge factor that Einstein called the Cosmological Constant. So, what is the problem this time. Let's consider throwing a ball in the air again. What happens? The force of gravity pulls on the ball, causing it to accelerate in the direction of the force, which is downward toward the Earth. So, as you know, the ball will slow down, turn around and accelerate back toward you. But what if it didn't behave that way. What if it started accelerating away from the Earth? We would have to assume that there was a stronger force pulling the ball up, or some other force pushing it up. Well, that is the problem with the universe. It is expanding and our normal physics would suggest that the expansion should be slowing down as gravity exerted its force to pull the galaxies back. But the galaxies are accelerating away, not back. OK, new fudge factor. All of space is filled with dark energy and that is what exerts the push against gravity. Calculations show that dark energy constitutes 73 percent of all the matter and energy in the universe. So, if dark energy is 73 percent then matter is 27 percent. And dark matter is 85 percent of that 27 percent or 23 percent. That leaves only 4 percent of the energy and matter in the universe as the stuff, the visible matter, we really know about.

Dark Matter: Dark matter is one of the big puzzles in physics today. Dark matter is what we scientists call a fudge factor. We put it into our theories when the physics we know doesn't work. So, why do we need dark matter? Where does our physics not work? The answer is the structure of the universe. Normal physics says it shouldn't look like it does. Take a galaxy like our Milky Way. It is rotating like a pizza dough when the pizza guy throws it in the air. It gets bigger because of centrifugal force, which wants to push the dough away from the center. You feel that force when you stand at the edge of a merry-go-round. If you don't hold on, you fall off. Well, gravity is holding onto the stars at the edge of the Milky Way disk as it rotates. But gravity from the visible matter isn't enough to do the job. Our Milky Way would fly apart if the only gravity was from visible matter. Hence, the fudge factor. Let's assume there is enough extra matter to do the job of keeping the stars from flying off the galaxy. But we can't see it, hence the name dark matter. Calculations show that dark matter makes up more than 85 percent of the total matter in the universe.

Dark Matter and The Dinosaurs: In her book *Dark Matter and The Dinosaurs*, particle physicist Professor Lisa Randall of Harvard makes a case that dark matter had something to do with killing off the dinosaurs. Her proposal goes like this: When geologists and paleontologists look at the fossil records, there appears to be evidence that a major species extinction occurs every 30 to 33 million years. So, she asks, is there a physical reason to explain that? There is a physical event that has such a period. It is the oscillations of our solar system up and down through the plane of the Milky Way disk as it makes its way around the galaxy during its 225-million-year orbit. Each such orbit makes a galactic year. The idea is that the passage through the plane with its higher gravitational field might knock comets and asteroids out of their normal orbits around the sun, and some of these unhinged bodies might hit our planet. But calculations of this effect suggest gravity from normal matter is not sufficient to dislodge these objects from their orbit. Hence, she proposes that there is some extra gravity exerted by a disk of dark matter that lies within the disk of the visible Milky Way. The combined gravity from the normal matter disk and the dark matter disk might be enough to do the job.

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 are contained in the DNA, which is reproduced in every cell. Each living thing has its own unique DNA code. 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 in Epilogue 2. 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), and phosphorus. The links between the two twisted backbones of the DNA are made up of 4 protein molecules in pairs. They are designated by the letters A paired with T, and G paired with C. The building instructions are determined by the order or sequence in which the four molecules are arranged. This is like thousands of words created with different sequences of the twenty-six letters of the English alphabet, or computer codes created with different sequences of ones and zeros. 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 are coded in your DNA. A single double strand of a human's DNA if stretched out straight would be 2 meters long. If all the DNA in a human body were stretched out and connected end to end it would be 60 billion kilometers long, long enough to extend to Pluto and back to Earth 4 times.

Do Carbon Atoms Last? The half-life of carbon 14 (6 protons and 8 neutrons in the nucleus) is 5,730 years. If you have a block made of carbon 14, that is the time for half of the carbon 14 atoms to decay to nitrogen 14. In that decay one of the carbon's 8 neutrons decays to a proton (and an electron) leaving 7 protons and 7 neutrons in the nucleus. The half-life of the most abundant form, carbon 12, is 20 billion years. It is stable. If you have a block of carbon 12 mixed with carbon 14, the ratio of carbon 14 to carbon 12 will decrease as the block gets older. That ratio in an old fossil can be used to tell how old it is. That is called carbon dating. Here is how it works. The natural ratio of carbon 14 to carbon 12 in the atmosphere is 1 part in 1 trillion and is constant in time. This is because new carbon-14 atoms are continuously being formed in the upper atmosphere (due to cosmic rays) to replace those that decay. When an organism is formed it has the natural ratio of carbon 14 to carbon 12. When the organism dies, it no longer gets carbons from the atmosphere and its carbon 14 decays. The change from the natural ratio when the organism was living to the ratio in the fossil determines how long ago the organism died.

E = Mc2: Einstein's famous equation was published in 1905 as part of his Special Theory of Relativity in a paper called "Does the Inertia of a Body Depend Upon Its Energy Content?" The meaning of the equation is that mass can be changed into energy, and energy can be changed into mass. So, to a stationary observer, an object that is moving very fast appears to have more mass than when it was at rest. This concept is related to Einstein's cosmic speed limit which says that no object can go faster than the speed of light, because as it approaches the speed of light, its mass would become infinite. At the beginning of World War II, physicists proposed that E =

mc2 could be the basis for a new weapon, the atomic bomb. They reasoned that if a heavy atom were split into two lighter ones, there would be energy released if the sum of masses of the lighter atoms were less than that of the heavy one. That situation was the case for very heavy atoms like uranium and plutonium. The huge Manhattan Project, authorized by President Franklin Roosevelt, developed the atomic bomb before the end of the war. Practical use of the same energy-generation method led to the building of nuclear power plants.

The Earth Revolves in Paths, Called Orbits, around the Sun: In the solar system, the Earth travels in a path around the sun, called an orbit. To understand an orbit, take an object attached to a string (such as a yo-yo) and twirl it around. The path it travels is a circle. A force is required to change the direction of the object to keep it in the circle. For the yo-yo, that force is supplied by the string, and since the string has a fixed length, the orbit is a circle. For the Earth, the force of attraction to the sun is gravity, and that force depends on the distance, r, between the Earth and the sun and the mass of each object. The force of attraction (F) is equal to the gravitational constant (G) times the mass, m, of Earth times the mass, M, of sun divided by the distance r, squared). G is a constant. So the force varies as 1 over r2. The general orbit for such a distance-dependent force is an ellipse (an elongated circle) where the circle is just one special case of an ellipse.

The equation is written: F = G * (m x M) x 1/r2

Electromagnetic Force: The electromagnetic force is the force associated with electric and magnetic fields. It is the attractive and repulsive force associated with electrical charge that holds atoms and molecules together and participates in chemical reactions. It is the attractive and repulsive force associated with magnetism and all other electromagnetic phenomena. Like gravity, the electromagnetic force has an infinite range and obeys the inverse-square law. It is one of the four fundamental forces in nature, weaker than the strong nuclear force but stronger than the weak force and gravity.

Electron Microscope: For over 100 years scientists believed that there was a limit to the size of an object (how small it could be) to 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 of an object that was large compared to 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 because the ball is smaller than the object. 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 of 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

Electrons: 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. They were formed in the Big Bang.

Epidemics: An epidemic is the rapid spread of a disease to a community or region within a short period of time. It is the sudden increase in the number of cases of a disease above what is normally expected in that population in that area.

Evolution: Charles Darwin's theory of evolution was first presented in his book *On the Origin of Species* in 1859. Darwin described the process by which organisms change over time as a result of changes in inherited or behavioral traits. Changes that allow an organism to better adapt to its environment will help it acquire its needed resources to survive and have more offspring. This is the principal of *survival of the fittest*. What species is fittest may be dictated by changes in the environment, as is seen in numerous species extinction events where some species are better suited to the new environment. We now know that changes in an organism's DNA (mutations) can lead to alterations passed down to subsequent generations. This can sometimes lead to a new species that will be successful if it is fit for its environment.

Family Bubble: During the Covid-19 pandemic, groups of friends, family members, sports teams, business employees, etc. formed groups (bubbles) that could meet in person. Members of each bubble followed agreed-upon rules of safe behavior to reduce the risk of contracting Covid-19. They typically agreed to eliminate all non-protected contact with individuals outside the bubble.

Faster Than the Speed of Light: According to Einstein's Special Theory of Relativity, the speed of light in a vacuum is an absolute cosmic speed limit. Nothing can go faster. According to the theory, as an object approaches light speed, its observed mass gets larger and larger. So, more and more force is required to accelerate the object to approach light speed, In order to reach the speed of light, you'd need an infinite amount of force, and that's impossible! So objects cannot reach or exceed the speed of light.

Flying Car: Flying cars already exist. They have wings that fold up when they drive on the road like a car and unfold when they fly like an airplane.

Force of Gravity: Gravity is the weakest of the four fundamental forces of nature. It is a force by which all things with mass (including ordinary objects, atoms, planets, stars, and galaxies) are attracted to one another. On Earth, gravity's pull on an object gives it weight. Gravity has an

infinite range, although its effects become increasingly weaker as objects get further away. First Galileo, and then Sir Isaac Newton, predicted the inverse-square law of gravitation (the force is proportional to 1 divided by the distance between them squared). Newton proposed the following equation: F = G*m(1)*m(2)/r2, where F is the force between two masses, m(1) and m(2), r is the distance between the centers of the masses, and G is the gravitational constant. Gravity is more accurately described by the General Theory of Relativity proposed by Albert Einstein. Even light is affected by gravity in Einstein's theory.

Frozen Fusion: This process was called cold fusion when it was announced to the world in 1989. As you have learned, fusion of hydrogen to form helium takes place on the sun at a temperature of 15 million degrees C. Fusion to form heavier atoms like iron or uranium requires temperatures of 100 billion degrees C. The high temperatures required for hydrogen fusion on Earth have been accomplished in a hydrogen bomb, but no practical fusion energy power source has yet been developed. So, the announcement in 1989 that fusion had been achieved in room temperature experiments that could be performed in a laboratory were very exciting. Unfortunately, other laboratories were unable to reproduce the results and cold fusion was eventually called junk science and crackpot science. But the idea of cold fusion didn't go away. If it could actually be developed, it would solve all of the world's energy needs with cheap abundant power. So, many laboratories continued to do experiments. In 2009, Sixty Minutes did a piece on the current status of what is now called a nuclear effect rather than cold fusion. Many laboratories have now seen excess energy produced in an experimental apparatus similar to what was used in 1989. But many scientists still doubt the results. We will have to wait and see.

Fusion Reactor: See Grandpa's Glossary Nuclear Fusion for information on the fusion reaction that takes place in stars and in the hydrogen bomb. When I took my first job in 1965, the company was working on a fusion process for a power plant. The problem is developing a way to contain the enormously high temperature for the reaction. Work on such a device is still in progress today with no practical solution. So, the Cosmic Egg fusion reactor is fictional.

Galileo's Experiment: There is a popular story, which may or may not be true, that in 1589, the Italian scientist Galileo Galilei had dropped two objects of different masses from the Leaning Tower of Pisa to demonstrate that their fall time was the same. This showed that the objects had the same acceleration due to gravity. This observation disproved Aristotle's theory of gravity, which states that objects fall at speeds that depend on their masses. We now know that—whether or not the story of Galileo dropping objects from the Leaning Tower of Pisa is true or not—his theory was correct.

Genes: These are the basic arrangement of DNA molecules in the chromosomes of the cell nucleus that determines the body's characteristics like hair color, eye color, and height. Genes are linear sequences of nucleotide molecules along a segment of DNA that provides the coded instructions for hereditary characteristics (your body's building instructions). A gene is a basic

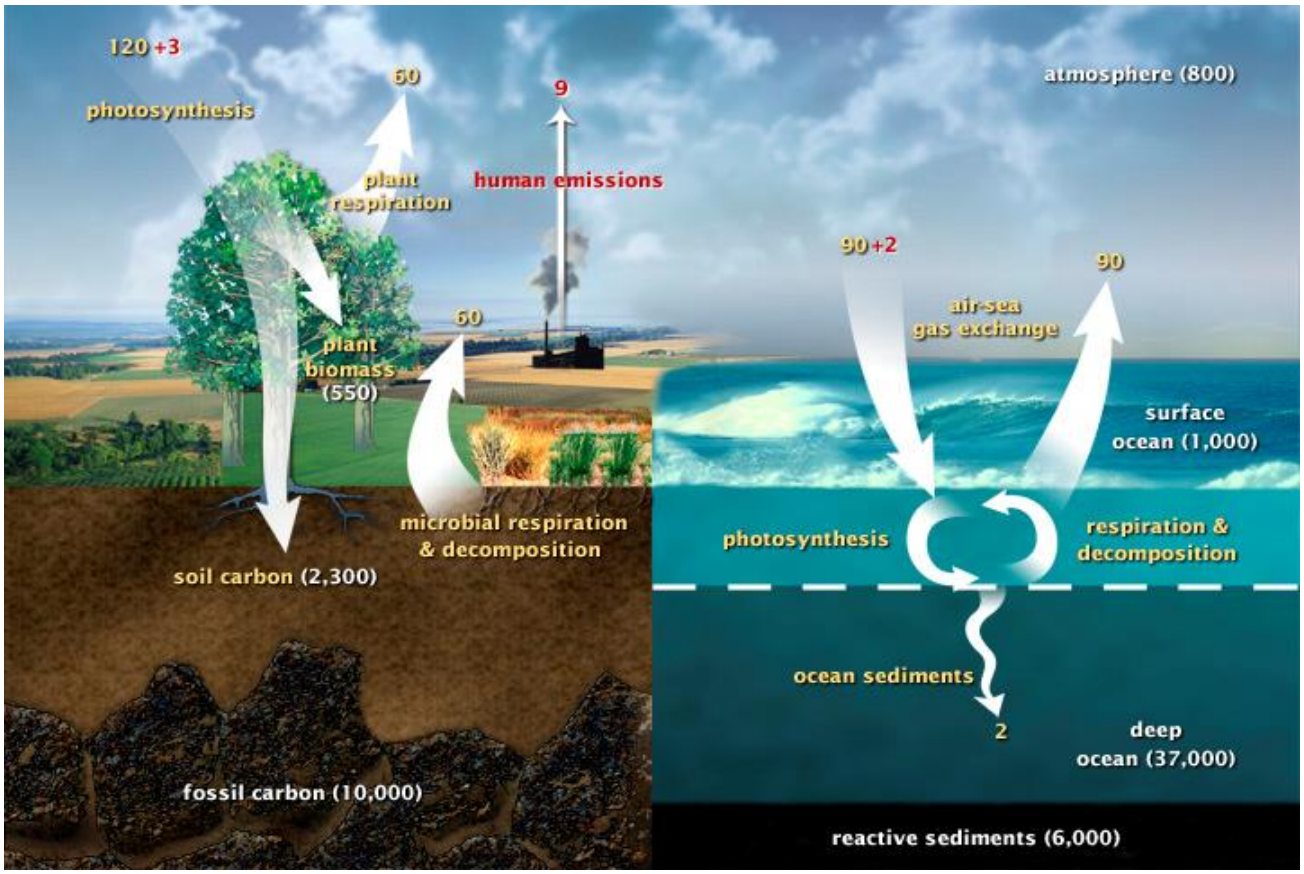
unit of heredity. During gene expression, the DNA is first copied into RNA which transmits the instructions to the cells of the organism.

General Theory of Relativity: General Relativity is the geometrical theory of gravitation published by Albert Einstein in 1915. When Einstein became aware that being weightless in the absence of gravity, or freely accelerating because of it, were equivalent and something extremely fundamental, he called it the "happiest thought of his life." This observation guided him in the development of the theory in which gravity is a geometric property of space. In Einstein's theory, mass tells space how to curve and the curvature of space tells mass how to move. The General Theory of Relativity has important predictions. Georges Lemaître's solution of Einstein's equations for an expanding universe led to his Big Bang theory. The bending of light by gravity can lead to the phenomenon of gravitational lensing, in which multiple images of the same distant astronomical object are visible in the sky. The attraction of light by mass leads to the prediction of black holes, whose mass is so large that no light can escape. The theory predicts that cosmic events can produce gravitational wave distortions of space itself that travel at the speed of light. The first observation of gravitational waves was made by LIGO in 2015. The theory predicts the *Twin Paradox* described in *The Race to the Big Bang* Chapter 18. The predictions of general relativity have been confirmed in all observations and experiments to date.

Genetic Code: The genetic code is the molecular system used by living cells to translate information encoded within genetic material into the products and substances required by the organisms. For living cellular organisms the code is created by the sequence of four molecules designated by the letters A, C, G, and T strung together in the DNA. The code for any molecular substance can be transcribed into messenger RNA in a way that the cellular factories, the ribosomes, can read them and turn them into protein molecules. In some viruses, the genetic code is written in single stranded RNA rather than the double stranded DNA.

Genetic Engineering: Genetic engineering is the process of using DNA and RNA in technology to alter the genetic makeup of an organism. Genetic engineering involves the direct manipulation of one or more genes. Sometimes, a gene from another species is added to an organism's genome to give it a desired feature.

Global Carbon Cycle:



Global Warming: The Earth's temperature is controlled by two things: (1) the energy radiated from the sun (sunlight in the form of photons of visible light, lower frequency infrared light, and higher frequency ultraviolet light) that reaches the Earth's surface; and (2) the energy radiated from the Earth's surface that reaches outer space. Now, very hot things like the sun radiate mostly high-frequency photons (visible and ultraviolet), while cooler things like the Earth radiate lower-frequency photons (infrared). You can see this effect on an electric stove where the heating coils look white when they are on high heat but dark red or no color at all when they are on low heat. You need one more piece of information to understand global warming. Infrared light is absorbed by molecules like carbon dioxide and other "greenhouse gases" like methane. So, those molecules, if they are in the atmosphere, will absorb the energy radiated by the Earth. When the molecules release the energy as radiation, half will go into space and half back to the Earth's surface. This trapping of infrared energy makes the Earth warmer than it would be if there were no absorbing gases. There is no similar effect for the sun's energy coming in because the higher frequency energy of the sun is not absorbed by these molecules. The same infrared energy-trapping effect occurs in a greenhouse. Sunlight passes through the glass without absorption, while infrared light from inside the greenhouse is absorbed by the glass. Half of the absorbed light is returned to the inside and keeps the greenhouse warm. So, here is the problem. Carbon dioxide (a strong infrared absorber) has been increasing steadily for the last 100 years because of the increase in burning fossil fuels like coal and oil to produce electricity

or run cars and trucks. There is no controversy about this observed increase. The increased carbon dioxide absorbs more of the radiation leaving the Earth and returns more back to the Earth. The higher the concentration of carbon dioxide, the more radiation that gets returned to Earth, and the warmer the Earth will get. This is called Global Warming. The existence of this effect is also not controversial. The debate is over how big the effect is. Has the man-made increase in carbon dioxide led to the observed recent climate change of a degree or so increase in the Earth's temperature, or is the increase a normal part of the Earth's temperature swings? It is important to know which is happening, because if it is a man-made increase in temperature it will get worse as more carbon dioxide is added to the atmosphere. Most climate scientists believe that the human contribution is the cause of the increased temperature. To control it, we must reduce our carbon dioxide emissions.

Gluons: Gluons are particles that are part of the Standard Model of elementary particles. Like photons that travel back and forth between two charged particles to create the electromagnetic force, gluons do the analogous thing between quarks to create the strong force that "glues" the quarks together. Different quarks are glued in groups of three to form protons and neutrons.

Goldilocks Planet: We live on a Goldilocks planet. It is not too hot, it is not to cold, it is just right. Well most of the time. It also has water and all the atoms need for life as we know it. So, if life as we know it exists out there on some other star system, it will be on a planet that is also just right. Astronomers call such planets the Goldilocks planets. Astronomers believe that there could be billions of such planets out there.

Gravitational Wave: Like black holes, gravitational waves are predicted by Einstein's General Theory of Relativity. They are disturbances in space itself (stretching and contracting) that travel at the speed of light away from the event that caused them.

Great Oxygen Event: Today's bird, insect, and land animal life on Earth is supported by an atmospheric oxygen concentration of 21 percent. But the early Earth had no atmospheric oxygen at all. Today's atmospheric oxygen concentration is the product of cyanobacteria. These single-celled organisms use carbon dioxide and water to produce carbohydrates and oxygen gas by photosynthesis using sunlight. Early cyanobacteria were largely in the oceans releasing oxygen that promoted the development of sea life. It was not until two billion years ago that the cyanobacteria started to release oxygen to the atmosphere. This time marks the start of the Great Oxygenation Event in which the oxygen concentration steadily grew to reach today's level. This event has supported the evolution of life as we know it today.

Heaviest Atoms: These are the atoms produced in the cores and subsequent supernovas of second and third generation stars occurring billions of years after the Big Bang. They were also produced in neutron star pair mergers. Atoms between zirconium (atomic number 40) and uranium (atomic number 92) were produced.

Hologram: Using a hologram plate (film) and a laser, a three-dimensional object can be made to appear to a viewer. The hologram plate is a photographic record produced by illuminating an object with a laser so that light reflected from the object plus light from the laser fall on a photographic plate. Later, when the plate is illuminated with the same laser light, a viewer seeing the light reflected from the plate will see what appears to be the original object on the other side of the plate. The window through which the kids saw the creature was a hologram illuminated by laser light.

How Big Are My Atoms video: See https://www.youtube.com/watch?v=jw1-wMR7JRM, on the STARDUST MYSTERY YouTube Channel

How the Heavy Atoms Form in a Supernova: Also see Grandpa's Glossary for Nuclear Fusion. There is a picture of two heavy forms of hydrogen atoms, deuterium and tritium, banging into one another to form Helium and a neutron. The requirement for fusion to take place is that the banging has to be done with lots of energy. The two hydrogens have to be going very fast to make the fusion happen. In this case, where helium is formed, a temperature of 15 million degrees C is required. That temperature was available shortly after the Big Bang and is available at the center (the core which is the hottest part) of our sun. The temperature after the Big Bang and on the sun is also hot enough to form some smaller amounts of lithium (three protons) and beryllium (four protons), and in the core of the sun, small amounts of carbon, oxygen, nitrogen, and other elements. The formation of larger atoms requires much higher temperatures. Where can we find higher temperatures? Stars that are bigger than the sun have more gravity crushing the atoms together, and so the temperature in their core is hotter than on our sun. The biggest stars can form big atoms in their cores. Another place for higher temperatures is in a supernova. When second-generation big stars have used up all their hydrogen (about 5 billion years after they formed), they start to cool. Then gravity starts to crush all the atoms into the center. This creates fusion reactions of bigger atoms and much higher temperatures. As second generation stars end their lives, the core gets so hot, 100 billion degrees C, that fusion runs away, producing atoms up to the size of uranium with 92 protons and the star explodes in what is called a supernova. The explosions are so spectacular, that they can be seen with the naked eye from Earth. They can last for up to two years. Supernovas that occur at the end of the shorter-lived first-generation stars produce smaller atoms up molybdenum. Supernovas do three things that are important for us to exist: (1) they created the heavy atoms we needed to form a solid Earth to live on and the atoms required to make living things; (2) the explosion rocketed those atoms out into the universe where eventually they could condense to form the Earth and us—those atoms that formed in the supernovas are the stardust; and (3) supernovas produce gamma rays which may help to drive mutations, important in the evolution of species.

Hydrogen Generator: The water molecule, which has one hydrogen atom and two oxygen atoms, can be split into hydrogen gas and oxygen gas using an electrical current. The process

employs an electrolysis cell. The cell consists of two electrodes separated by an ion exchange membrane and often has a platinum catalyst. When a current is passed through the cell, the water in the cell is split into the two components which migrate to exit the cell at opposite electrodes.

Immune: An organism is immune to an infection if it has resistance to that infection due to the presence of specific antibodies or white blood cells. Such immunity may be naturally occurring or may be acquired from a prior infection or from a vaccine.

Immune System: In a living organism, the immune system is the organisms' mechanisms for fighting disease. In bacteria, the immune system is part of the organism's DNA capable of remembering, identifying and destroying an invading virus. In multi-celled organisms the immune system can be a network of specialized cells, tissues, organs, and substances that help the body fight infections and other diseases. Such systems can produce antibodies and specialized cells which attack an infectious substance as well as cells capable of remembering (sometimes for decades) the infection and producing new antibodies and attack cells should the infection reappear.

Kepler Space Telescope: The Kepler space telescope, named for seventeenth century astronomer Johannes Kepler, was launched by NASA in 2009. Its mission was to discover Earth-size planets orbiting other stars in the Milky Way. Based on the data collected, NASA scientists estimated that there are 300 million stars with at least one habitable planet. The telescope was retired in 2018.

Light Years: The distances to other places in space are huge. For example, the distance from the Earth to the sun is 93 million miles; the distance to the closest star, Proxima Centauri, is 24 trillion miles; and the distance to the nearest galaxy, Andromeda, is 14 million trillion miles (14,000,000,000,000,000,000 miles). Astronomers decided that giving distances in such large numbers of miles or kilometers was not very easy for comparing different distances. So, they decided to invent a new unit of distance called the light-year. The light-year is the distance that light travels in one year. Since the speed of light is 186,282 miles per second, it travels 5.79 trillion miles per year. Proxima Centauri is 4.22 light-years away, and Andromeda is 2.5 million light-years away. When looking at an object in a telescope, the light-year tells us something interesting besides distance. It is the time it took for the light we now are seeing to get here. So, we are really seeing how the object looked at some time in the past. When we see Andromeda in a telescope, we see how it looked 2.5 million years ago. When the Hubble telescope takes pictures of the furthest objects away from us, it is actually seeing what they looked like 13 billion years ago, not that long after the Big Bang. So, looking at objects that are further and further away lets us look at earlier and earlier times in the history of the universe.

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Lightest Atoms: These are the atoms produced by supernovas of the first generation of gas stars occurring within the first few hundred million years after the Big Bang. Atoms between carbon (atomic number 6) and strontium (atomic number 38) were produced.

LIGO: The National Science Foundation funded the development of the Laser Interferometer Gravitational-Wave Observatory (LIGO) to detect gravitational waves. Two of them were built far apart, and a disturbance must be seen simultaneously by both to be identified as a real event. The first event, detected in 2015, was believed to be produced by two black holes merging. In the summer of 2017, LIGO detected a gravitational wave produced by the merging of two neutron stars. Additional measurements from detectors of visible and other radiation wavelengths indicated that that event had produced a weight of gold equal to the weight of planet Earth. Neutron star merging appears to be a very important event that produces our heavy atoms.

Made of the Same Stardust: Stardust pieces are atoms created in the explosive death of stars. We each have carbon atom stardust that once was in the bodies of Albert Einstein and the Last T-Rex. This is how we got them. Einstein and the T-Rex exhaled carbon dioxide made from carbon in their bodies. Some of that carbon dioxide is still in the atmosphere today, and some of the carbon has been used to grow fruits, vegetables, and animals. The food we eat contains large numbers of carbon atoms that were once in Einstein, in each T-Rex, and in all other living things.

Mars Rover: The picture on pg. 52 is of the Mars Rover, Perseverance, that touched down on the surface of Mars on February 18, 2021. The Rover will be collecting samples of the Martian surface which will be sent back to Earth. When returned, the samples will be examined for any evidence of past life on Mars. Perseverance is the latest of 6 probes sent to Mars. The Curiosity Rover that landed in 2011 is still active.

Medical-Cure Scanner: Such a machine was in the science-fiction movie Elysium. It scanned the body to determine what was wrong and then fixed it. Modern Computer Assisted Tomography (CAT) scanners and Magnetic Resonance Imaging (MRI) scanners can often diagnose problems by looking at the body's physical state (broken bone, muscle tears, intestinal problems) but do not fix the problem. A medical-cure scanning invention is in the same category as the teleporter of being theoretically possible, but not practical with today's technology.

Messenger RNA: Messenger RNA, or mRNA, is a single-stranded molecule of RNA that contains the genetic sequence of a gene, a part of the genetic code for a specific functional substance or product. For example, the protein spikes on the coronavirus are such functional products. The mRNA is read by a ribosome in the process of synthesizing the product. The pepsin molecule described in the Epilogue 2 of *The Race to the Big Bang* is another example of a functional product created by a cell's ribosomes using mRNA. The process of copying a gene from DNA into mRNA is called transcription.

Metal Detector: Metal detectors are often seen at the shore, being used by beachcombers searching for lost metal objects like rings and watches. Its operation is relatively simple. The device puts out an electromagnetic wave signal that induces currents in any metal object underneath the device. These currents produce a return signal detected by the device, indicating the presence of a metal object.

MissionKT: MissionKT is a multiplayer video game set in the last days of the dinosaurs. The players have scientific instruments with which to measure properties of the objects in the game (chemical composition, mass, velocity, temperature, density, etc.). The game is available on the video game website, store.steampowered.com.

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 which have only two atoms each. Or different atoms can attach like two hydrogens and one oxygen to form a water molecule. Examples of bigger molecules are found in oil which consist of strings, or rings, of a few to more than twenty carbons with attached hydrogens. Then, there are very large molecules like DNA that have hundreds of millions of atoms of many different kinds.

Moon mass calculation: The circumference of the moon is 10,920 kilometers. The circumference is 2πr where r is the radius of the moon and π=3.14. With the volume equal to 4/3 π r3, we get the volume of the moon as 2.2 x 1025 cubic centimeters. Using the measured density of 3.34 grams/cm3 and the formula Mass=density x volume, we get 7.35 x 1025 grams, or 7.35 x 1022 kilograms for the moon's mass. This is the known mass.

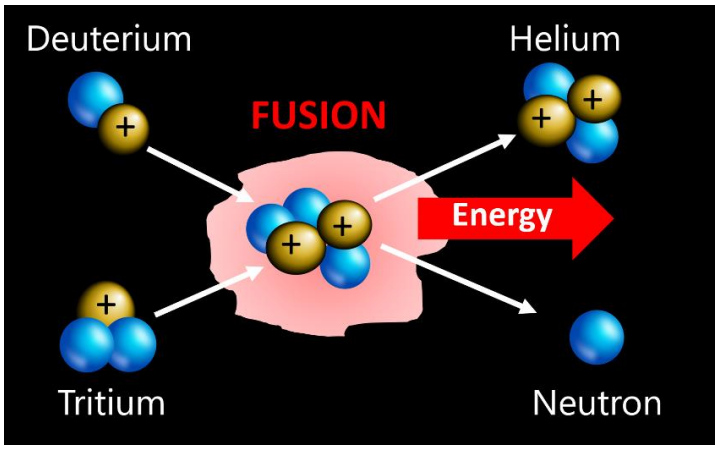
Multi-Messenger Astronomy: The detection of the neutron star pair merger by LIGO and other detectors in 2017 is considered to be an excellent example of Multi-Messenger Astronomy. The messages arriving on Earth are the gravitational waves detected by LIGO and radiation (visible, infrared, ultra-violet, X-ray, and gamma ray) detected by other instruments. The combination of multi-messages provides information not available from a single observation. Such a combination was employed to identify the event as a neutron star pair merger.

Multiverse: The idea that we live in a Goldilocks universe implies that there are many other universes (millions or billions) that have the range of possible constants and physical laws that exist. We live in the one that has the right set of constants and physical laws that support our existence. All of these universes make up everything that exists inclosing all of space, time, matter, and energy. The other universes are called parallel, or alternate universes.

NASA TESS YouTube video: https://youtu.be/85tdoDt1Qh0, TESS Catches its First Star destroying Black Hole.

Neutron Star Pair Merger: A neutron star is the collapsed core of a massive supergiant star, which had a total mass of between 10 and 25 solar masses. Except for black holes, and some hypothetical objects, neutron stars are the smallest and densest currently known class of stellar objects. It Is possible for a pair of such large stars (connected by the gravitational force) to form a pair of neutron stars. These neutron stars will circle each other, getting closer and closer together, until finally they merge in a supernova explosion. Such a merger was observed by LIGO in 2017. Other radiation sensors observed the production of massive amounts of heavy elements. The weight of gold produced was estimated to be equal to the weight of planet Earth. Neutron star pair mergers are now considered to be one of the major sources of heavy elements.

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 really hard, and that requires a temperature of 15 million degrees Celsius. They fuse



into a helium atom with two protons and two neutrons (^{4}He), and the extra neutron comes out with lots of energy. All that energy is what keeps the sun burning bright.

Fusion of bigger atoms on our sun can form atoms like lithium with three protons, and beryllium with four protons, and small amounts of bigger atoms. But really big stars can form big atoms in their cores, where the temperature is really hot. 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. In that supernova, conditions are hot enough (100 billion degrees Celsius) to form atoms like iron that have 26 protons and even uranium (which has 92 protons).

Nucleosynthesis: The term nucleosynthesis is used to describe the formation of new atomic nuclei by nuclear reactions. Nucleosynthesis occurred shortly after the Big Bang to form hydrogen, helium, and some other light atoms. It occurs in the interiors of stars and during supernovas and neutron star collisions to form the heavier atoms in the periodic table.

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 the onion cells that Milo showed in chapter 17 *of The Stardust Mystery*. 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.

Number of Carbon Atoms in a Human: Start with the mass of an average 75 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 the atomic weight of the atom (where 12 is the atomic weight of the carbon atom that 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 x 1023. So, a 75 kilogram human will contain 1,156 x 6.02 x 1023 = 7 x 1026 carbon atoms, 7 followed by 26 zeros: 700,000,000,000,000,000,000,000,000.

One over Distance Squared Part of the Law of Gravity: Sir Isaac Newton's law of gravity proposed in 1687 is the equation written above where F is the force, m and M are the masses of the two objects attracted to one another, r is the distance between the centers of the masses, and G is the gravitational constant. So, the force varies as 1 over r2. This is called the inverse-squared law. Newton also discovered that the acceleration of a body was proportional to the force exerted on it, F = ma, where F is the force, m is the mass of the object and a is the acceleration. So, Kepler's observation that the acceleration of the planets in his orbits was always a constant times 1 over r2 was an important contribution to Newton's law of gravity.

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 electrons and protons in 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, than the magnitude of the force is proportional to 1/r2. The diagrams of the carbon atom and the solar system show the orbits as circles for simplicity, but in general the orbits are elliptical.

Pandemic: A pandemic is a wide area spread of an infectious disease over multiple continents or worldwide, affecting a substantial number of people.

Pangaea: Pangaea was a supercontinent that existed over 300 million years ago. It was made up of all the continents that exist today. Pangaea began to break up about 175 million years ago as plate tectonics started separating the land mass into the separate continents of today.

Parts of the Blood: If you look at the back of the supermarket, you will see loading docks for trucks. Trucks bring the products for the supermarket and carry away the empty boxes and other waste. Your blood, carried in your veins and arteries (circulatory system), is the trucking system for your body. It is pumped around the body by the heart. Blood is composed of a liquid called plasma and blood solids transported by the plasma. The blood solids consist of three types of cells, red blood cells, white blood cells and platelets. Also found in the plasma are dissolved substances such as vitamins, minerals, and digested food molecules from the small intestine. Plasma also carries hormones and brings wastes from the cells to the kidneys or lungs to be removed from the body. Each type of blood cell has a different function. Red cells (that look like donuts in Milo's picture on page 68 and 69) carry oxygen from the lungs to your body's cells and takes carbon dioxide back to your lungs to be exhaled. Platelets are small colorless cell fragments whose function is to promote blood clotting to prevent bleeding. White cells come in many shapes and sizes. Their function is to fight infection. The killer T-cells shown attacking Milo are one kind of white cell.

Photosynthesis: The most common photosynthesis is the process by which green plants. algae, and cyanobacteria use sunlight to synthesize foods (carbohydrates) from atmospheric carbon dioxide. Photosynthesis in plants generally involves the green pigment chlorophyll and releases oxygen gas as a byproduct. Photosynthesis changes sunlight into chemical energy in the form of carbohydrates.

Professor Georges Lemaître: Georges Lemaître was a Belgian Catholic priest, mathematician, astronomer, and professor of physics at the Catholic University of Leuven. He was born in 1894 and died in 1966. In 1927 he published a revolutionary paper in which he proposed the concept of the expanding universe. Based on solutions of Einstein's General Relativity equations, Lemaître presented his "hypothesis of the primeval atom" or "Cosmic Egg," according to which the universe started approximately 14 billion years ago as a tiny point. His prediction of the expanding universe was observationally confirmed soon afterwards in 1929 by Edwin Hubble. Lemaître's hypothesis of the origin of the universe, now called the "Big Bang" theory, has been verified by many observations and is the accepted view of the origin of the universe. Also see Grandpa's Glossary for The Big Bang.

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 natural element uranium has 92 electrons, 92 protons and between 141 and 146 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

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, and neutrinos). 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 actually 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. Protons are made of two up quarks and one down quark. Neutrons are made of two down quarks and one up quark. 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) and some have speculated that this is the reason that Zweig did not received an award.

Quasars: Quasars, or quasi-stellar objects, are extreme radio sources, emitting the energy of an entire galaxy or more. The power for Quasars appears to come from their super-massive black holes.

Radiolab: Radiolab is a radio and podcast program that produced a show called "Dinopocalypse" which presented new information and a theory of the day the dinosaurs died. It had been believed that the dust from the impact of a Mount Everest-size asteroid or comet covered the Earth for long enough to block the sun, so that all vegetation died and consequently, the dinosaurs died of starvation. "Dinopocalypse" presented a new theory. It presented experiments that simulated the asteroid impact with planet Earth, and calculations of what would have happened in the real event. The story they presented is that the impact was so huge, that debris from the impact flew out of the atmosphere and as far as the moon. When the Earth's gravity pulled all the debris back to Earth, it was like billions of meteors hitting the atmosphere at the same time. This rain of burning particles was sufficient to heat the Earth's surface to 1,200 degrees Fahrenheit (649 degrees Celsius), a temperature high enough to kill anything on the surface almost immediately. Only sea-dwelling and burrowing creatures survived. The show has been produced for television as well and can be found on YouTube: https://www.youtube.com/watch?v=ZYoqtBEzuiQ

Recycling: When Grandpa was a kid, his school used to have paper drives. Kids collected old newspapers from the neighbors, tied them in bundles and their moms carted them to school. There was a huge pile of bundles at school that got taken away and used to make new paper and cardboard. They were recycling paper, turning the old paper into new. Today, most towns collect (right at your house) all kinds of recyclable materials including paper, glass, metal, and plastic. So, there are many more things being recycled, but the paper drive is dead. Why should we recycle things? The answer is that by reusing useful materials, we reduce the consumption of new raw materials, reduce processing energy, reduce air and water pollution, and reduce greenhouse gas emissions. So recycling is a win for everyone.

Ribosomes: Ribosomes are complex structures found inside living cells. Their purpose is to produce functional substances or products (proteins) required by the organism according to the instructions contained in messenger RNA created by the organism. Viruses have the ability to hijack a cell's ribosomes to have it make copies of itself from its RNA. The ribosomes are also used by mRNA vaccines to have it make copies of the protein spikes seen on the outside of a coronavirus. The spikes stimulate the body's immune system to prepare it to fight off the virus should it appear.

RNA: Ribonucleic acid (RNA) is a large molecule that is similar to DNA but is only a single chain rather than a double helix. The complete genetic code for the coronavirus is written in its RNA. In humans and other animals, the code for making protein substances and products needed by the body is written in RNA. These special purpose RNA molecules are copied from sections of DNA in a process called transcription. RNA consists of a single backbone chain with protruding pairs of four molecules designated by the letters A paired with U, and G paired with C. So, three of the molecules are the same as those in the connecting chains in DNA. The building instructions are determined by the order or sequence in which the four molecules are arranged. This is like thousands of words created with different sequences of the twenty-six letters of the English alphabet, or computer codes created with different sequences of ones and zeros. Messenger RNA or mRNA is used by cellular organisms to convey the information (genetic code) required for the cells to produce specific products.

Room Communication App: A fictional internet communication software application that permits multiple users to hear and see each other and share their digital device screens. It is like the real app called Zoom.

Solar System Exploration: This NASA website at solarsystem.nasa.gov is an excellent source of data and images for all the objects in the solar system.

Special Theory of Relativity: Albert Einstein's theory of special relativity was published in 1905. It explains how space and time are linked for objects that are moving at a constant speed in a straight line. One prediction of the theory is that as an object approaches the speed of light, its observed mass approaches an infinite value. This is the basis for Einstein's prediction that objects cannot go faster than the speed of light. Another famous prediction is the relationship E=mc2 between mass (m) and energy (E), where c is the speed of light.

The Stardust Mystery: The Stardust Mystery illustrated science storybook is a companion to the MissionKT and Building the Universe video games, TheStardustMystery.com web page, and the STARDUST MYSTERY YouTube channel. It follows the lives of cousins Lizzy, Milo, VC, and Neddy as they unravel the Stardust Mystery. Their adventures take them across time during the evolution of the Universe and the history of Planet Earth in the Cosmic Egg time, space, and size-change travel ship. They must figure out how everyone alive is made of the same Stardust that was once in the bodies of Albert Einstein and the Last T-Rex. They must find out what Stardust is, and how, when, and where it was created. As the Cosmic Kids team, the cousins enter The Science and The Future Contest, held by the mysterious Dr. Q The winners will be taken on a trip around the moon! What could be a better gift for the grandfather they love, a

former NASA astronaut? Along the way, they visit Einstein, dinosaurs, and even the Big Bang. To win, they'll have to use their brains to answer the many science questions, but they'll also have to use their hearts to come together to solve the problems of family.

Stardust Song Video: See https://www.youtube.com/watch?v=rmb3tQRfM9c, the STARDUST MYSTERY YouTube Channel

String Theory: There are two theories that are the foundation of modern physics: General Relativity (that describes gravity), and quantum field theory (that describes the behavior of the basic fundamental particles). String theory is being developed to bring both theories together. If we think of a guitar string, different notes can be played on the string. The string vibrates in ripples or waves like you see on water. In string theory, the elementary particles are thought of as the "musical notes"—or excitation modes—of elementary strings. In string theory, quarks are different excitations of the more fundamental strings.

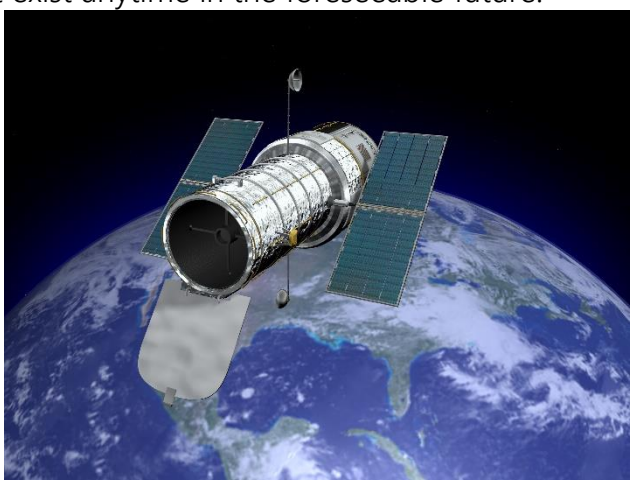
Submillimeter Observatory: These facilities employ telescopes that measure radiation from space in the submillimeter wavelength range (microwave and infrared regions of the spectrum). Their goal is to provide chemical composition data on cosmic gas clouds to investigate the formation of stars.

Supernova Star Explosion: Stars are bright because they are very hot due to nuclear fusion in which hydrogen atoms combine to form helium atoms. After billions of years, all of 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.

Table of Planet Properties

Planet	Radius Earth=1	Mass Earth=1	Surface Gravity (Earth = 1)	Surface Temperature Celsius	Average density (g/cm^3)	Composition (in order of abundance)	Atmosphere Top two Molecules	Atmosphere Pressure surface	Orbit Period in Earth Days	Distance to the Sun {million km)
MERCURY										65
VENUS										108
EARTH	1.00	1	1	15	5.50	Si, Fe, Ni	N_2, O_2	1.00	365	150
MARS										212
JUPITER										767
SATURN										1,493
URANUS										2,959
NEPTUNE										4,477
PLUTO										5,900
MOON	0.19	0.012	0.167	-23	3.30	0, Si, Al	*	0.00	27	150

Teleporter: Teleporters are also part of science fiction. They were used in the movie and television series Star Trek, where the person to be transported from the surface of a planet to the spaceship said, "Scotty, Beam us up." The idea is that the atoms of one's body are disassembled on the planet and reassembled on the spaceship (using atoms available locally). Today's science does not indicate that teleporting a human being is impossible, but the technology for assembling the billion billion billion atoms in a body in exactly the correct places and amounts does not exist and will probably not exist anytime in the foreseeable future.



Telescope: The Hubble space telescope is a satellite developed and launched by the National Aeronautics and Space Agency (NASA) in 1990. Because it is circling the Earth at 347 miles above the surface, it can take pictures free of distortions due to the Earth's atmosphere. The Hubble has been able to collect light that started traveling toward Earth more than 13 billion years ago.

Time Machine: Time machines do not exist except in science fiction books and movies. With today's science a time machine is not believed to be possible.

Time Magazine: *mRNA Technology Gave Us the First COVID-19 Vaccines. It Could Also Upend the Drug Industry* by WALTER ISAACSON, JANUARY 11, 2021. https://time.com/5927342/mrna-covid-vaccine/

Titanic: The Titanic was a British luxury ocean liner launched in 1911. It was carrying more than 2,200 passengers and crew when it sank on its maiden voyage after hitting an iceberg. The ship was 269 meters long with a maximum width of 28.2 meters. The wreck of the Titanic was discovered in 1985 at a depth of 3.78 kilometers.

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 x 1023. So, a 75 kg human will contain 1,156 x 6.02 x 1023 = 7 x 1026 carbon atoms. And that is 7 followed by 26 zeros or 700,000,000, 000,000,000,000,000,000.

The Total Number of Carbon Atoms That the T. Rex Breathed Out in His Lifetime: We want to figure out the number of carbon dioxide molecules a T-Rex will exhale in his lifetime. Let's start with figuring out what a human would exhale in the same thirty-year lifetime typical of a T-Rex. The human takes 12 breaths a minute for 30 years, so he took 12 breaths/minute x 60 minutes/hour x 24 hours/day = 17,280 breaths/day. In his lifetime he took 17,280 breaths/day x 365 days/year x 30 years/lifetime = 189 million breaths/lifetime. Now we have to figure out the number of carbon dioxide molecules in each breath. We start with the knowledge from chemistry that every 22.4 liters of gas at standard pressure and temperature will contain 602 billion trillion molecules (Avogadro's number). But only 4.5 percent of the gas is carbon dioxide, and a 75 Kg human has about 1/2 (0.5) of a liter in each breath. So, 0.5 liter/(22.4 liter) x 4.5 percent/100 percent x 602 billion trillion = 0.605 billion trillion carbon dioxide molecules per breath. So, the total number of carbon dioxides breathed out by a human in a thirty-year lifetime is 189 million breaths x 0.605 billion trillion carbon dioxide molecules per breath = 114,000 trillion trillion carbon dioxide molecules over thirty years. To get the number of carbon dioxide molecules exhaled by the T-Rex, we multiply by the ratio of their weights. Assuming a 75 kilogram (kg) human and a 12,320 kg T-Rex, the total exhaled carbon-dioxide count is (12,320/75) times the human count of 114,000 trillion trillion, or 19 million trillion trillion, or 1.9 followed by 31 zeros.

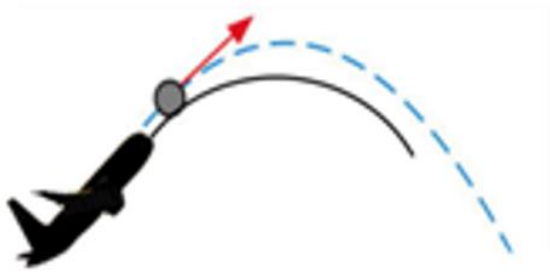
Vaccine: A vaccine is a medicine that can provide immunity to an infectious disease caused by a virus or bacterium. A vaccine uses a weakened, dead, or partial form of the virus or bacterium. When exposed to the vaccine, the body's immune system reacts to destroy the foreign substance. Because the active ingredient resembles the disease-causing agent, the immune system is prepared to defend against the active agent in the future. The treatment using a vaccine is called vaccination.

Virtual World: Virtual worlds, also known as virtual environments, use computer technology to create a simulated world that a user can explore and interact with, while creating a feeling as if he were in that world. The representation of the user in that world is called an avatar. The user can even wear goggles to make it appear that he or she is surrounded by the 3-D virtual world. That is called virtual reality.

Viruses: A virus is an infectious particle that is too small to be seen, even under a microscope. It cannot replicate itself but can hijack living cells of an organism to produce virus copies. Viruses infect all types of life forms: animals, plants, bacteria, and other microorganisms. There are millions of types of viruses in every place on Earth. There are more viruses than any other type of biological entity. The war between viruses and bacteria has been going on for 3 billion years, with each entity developing sophisticated attack and defense strategies. Most biologists say that viruses are not living organisms. They are not made out of cells, they don't grow, they are not stable, and they can't reproduce by themselves.

Watson: Watson is a computer program developed by IBM. Watson can read and understand natural language. When asked a question, Watson generates possible answers (based on a very large database), selects, and scores the best answers. A speech-recognition layer could be added, so that questions could be asked as speech. In 2011, Watson competed on the quiz show Jeopardy against former Jeopardy winners. Watson received the first prize of $1 million. IBM calls Watson a cognitive computer. These kinds of software programs are also called artificial intelligence.

Weak Equivalence Principal: In the zero-g flight, Jackson and the other kids could not tell the difference between being in free fall in a gravitational field or being in a place with no gravity. The equivalence of acceleration and gravity was something that Albert Einstein realized, and it guided him in the development of General Relativity. He called it the weak equivalence principal. This is how it is stated: "Uniform gravitational fields are equivalent to frames that accelerate uniformly relative to inertial frames." General Relativity was one of the two great physics laws of the twentieth century. The other one was quantum mechanics. General Relativity applies to very large masses, like stars, and high velocities near the speed of light. Quantum mechanics applies to very small things like electrons and protons. Einstein's thoughts on the equivalence principal started with the concept of mass. There is gravitational mass (that determines how large the force of gravity will be) and inertial mass (which determines how much force is required to start a body moving or to slow it down. Why should these two masses be the same? Ever since Newton, the importance in the observation that the two are identical was not recognized. When Einstein became aware that this was not just a simple coincidence, that being weightless in the absence of gravity, or freely accelerating because of it, were equivalent and something extremely fundamental, he called it the "happiest thought of his life." This connection between the two types of masses led to the weak equivalence principle. Einstein came to the conclusion that no experiment can tell us whether we are in free space or freely falling in a gravitational field. These equivalences helped Einstein develop General Relativity. For more information, you can go to: http://www.einstein-online.info/spotlights/equivalence_principle Or, you can ask the Albert Einstein Expert Avatar at the Expert Avatar web site.



Zero-G Flight: The idea behind the zero-g ride is simple. If you throw a ball in the air on Earth, it will follow a trajectory. Like the ball in the picture following the dashed blue line. You start out throwing the ball and then gravity starts accelerating the ball toward the Earth. If you are riding in an airplane going up rapidly, and the plane suddenly disappeared, you would follow a similar trajectory. That would be a zero-g ride that would end badly. But the plane doesn't have to disappear to put you on the trajectory. All it has to do is fly slightly below your free-fall trajectory, like on the black line in the image. Then, your body inside the plane is free falling, while the plane itself moves ahead of your fall, making you feel like you are floating.

THE STARDUST MYSTERY PROJECT

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