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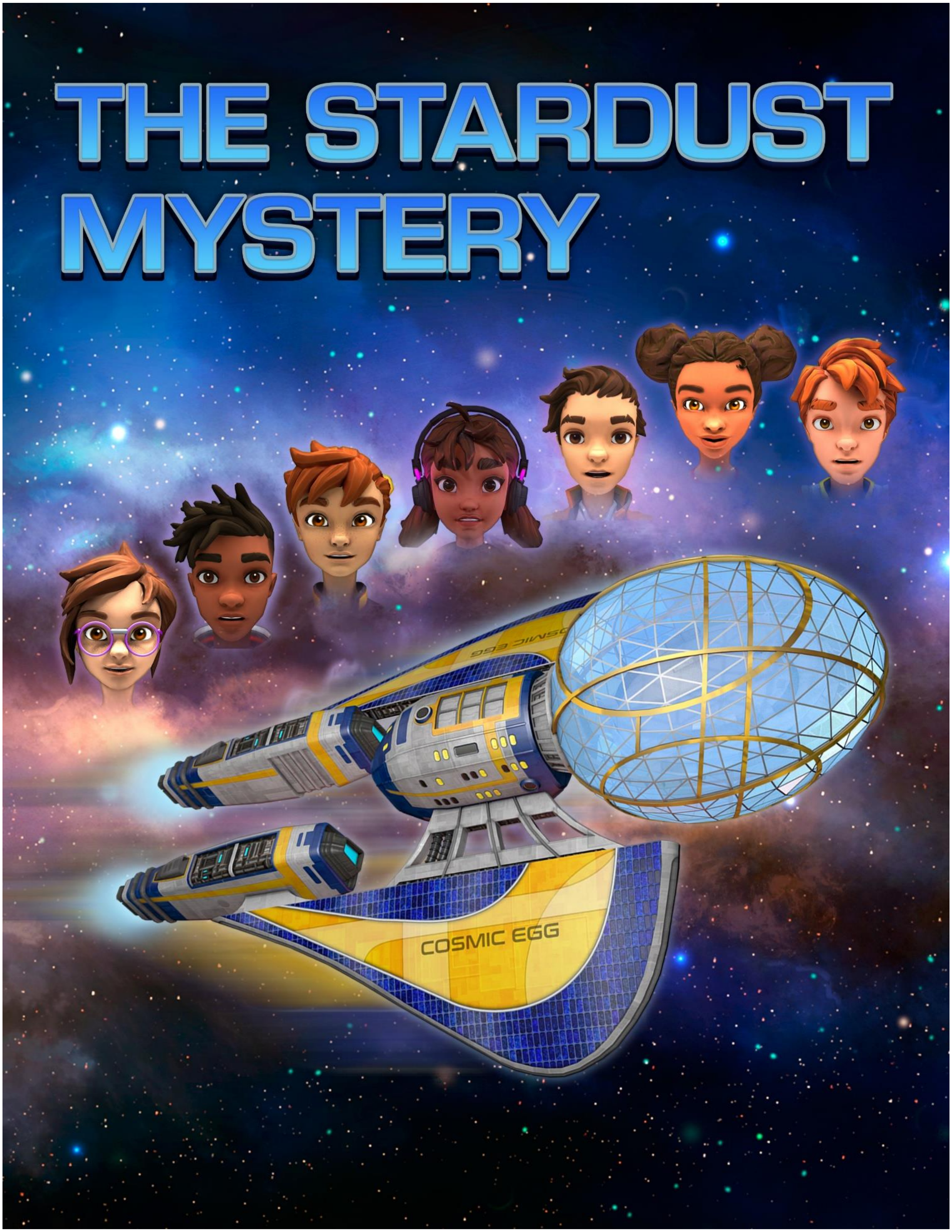
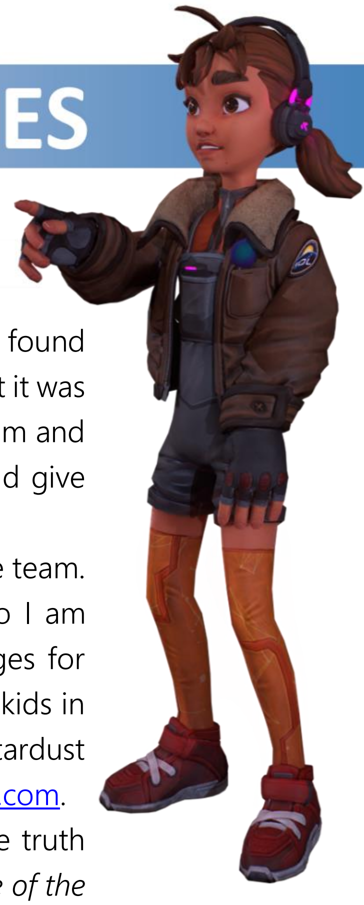


VC’S STORIES

HOW IS STARDUST SHARED

(AS TOLD BY VC)



I had been spending a lot of my free time working on our team blog. I found that I had over 2,000 followers. That’s pretty impressive. Papa thought it was great too. I added the screenshots of Milo swimming in a bloodstream and Lizzy getting attacked by Fleazilla. I didn’t think those images would give away any of our progress.

Besides doing the blog, I started working on a website for the team. I really like computers, but a website is a little above my head, so I am getting help from Papa. We are making the site so that it has pages for people to learn about the Cosmic Kids team and some of the other kids in the contest. It also has links to videos we made that are on our Stardust Mystery YouTube channel. The website is called TheStardustMystery.com.

I knew I was procrastinating by working on the website. The truth was, I had to start working on the problem: *was it possible that some of the atoms in my body were once in the bodies of Albert Einstein and the last T-Rex?*

“Ces’t ridicule,” I said in French to Lizzy who was over at my house. “Professeur Einstein est mort depuis plus de 60 ans, et le T-Rex, plus de 65 million ans.”

“English,” snapped Lizzy, a little annoyed.

“Sorry,” I replied. Sometimes I would totally space out and forget what language I am speaking. I also liked showing off a little bit. “What I said was, ‘That’s ridiculous, Professor Einstein has been dead for over 60 years and the T-Rex for over 65 million years.’”

The plan was that Lizzy and I would work together on this question. And, we had received an important new clue in the mail just that day. It was an empty crushed soda can.

“Who is the guy on your wall?” asked Lizzy.

“Usain Bolt,” I replied, “the fastest 100-meter runner in the world. That’s my best event too.”

“OK,” Lizzy said, “let’s get started. I really want to do a better job than Milo.”

"Let's do it," I replied. "Where do we start?"

"Think about this month's clue," Lizzy answered, holding up the can. "What do we do with crushed aluminum cans?"

"Um, throw them away?" I answered.

"We recycle them!" she said.

I still didn't understand what she was getting at.

"What if this clue is about recycling?" she offered.

"Recycling what?" I asked. "Stardust?"

Lizzy narrowed her eyes. She does that when she's thinking and only half listening.

"You know, when we put old aluminum cans in the recycle bin, and they melt them to make new aluminum cans?"

"So what!" I said exasperated. "I know what recycling is, Lizzy. But what does this have to do with stardust?"

"What if we need to be looking at *atom recycling*!" my brilliant cousin replied. She was completely right.

"That's it!" I said. "We should start by explaining *aluminum* recycling!"

"Yes," she took over, "and then we explain how we relate that to the question about stardust recycling!"

I thought the idea of atom recycling sounded interesting. I ran to my desk and pulled a folded paper out of the bottom drawer. "I think we can explain aluminum recycling with this," I said, unfolding a poster about recycling aluminum that I had made for school last year.

"There are three steps," I continued, "Step one, you put the used soda can into the recycle bin. Step two, they convert the cans to a more usable form by melting them down to make a new block of pure aluminum that is called an ingot. And step three, they use—or *recycle*—the aluminum ingot to make a new soda can." Lizzy nodded. "But what about atoms?" I asked her.

"How do *they* get recycled?

"Well," said Lizzy, "Let's think about Albert Einstein. What happened to the carbon atoms that were once in his body? But the question will have to wait. I need to go home, but I'll come back this afternoon."

• • • • • •

When we met that afternoon, I told Lizzy, "I got a book on the carbon cycle from Mrs. Ortiz at the library. It might help explain atom recycling. Fats and sugars contain carbon and hydrogen, so combining them with oxygen produces carbon dioxide and water. Carbon dioxide and water is what all animals exhale—you know, what we breathe out. Combining the carbon and oxygen is how animals get their energy for activity. Like when you burn things, you combine carbon and oxygen to get carbon dioxide and energy in the form of heat."

"What does that have to do with recycling?" asked Lizzy.

"Well maybe, since part of what we exhale is carbon dioxide, we recycle carbon atoms when we exhale," I answered.

"Oh," Lizzy jumped in, "so like step one—putting the soda can into the recycle bin—would be like Albert Einstein or the T-Rex exhaling carbon dioxide molecules into the *carbon recycle bin*, which is the atmosphere."

"So," I clarified, "you mean the carbon dioxide, including carbon atoms, lands in the atmosphere, just like the soda can lands in the recycle bin. That's step one?"

She nodded saying, "Einstein must have breathed out a lot of carbon dioxide during his lifetime."

"So, what's step two?" I asked. "Do you think that the next person comes along to that recycle bin, and inhales the carbon dioxide right out of it?"

"Yes, we can inhale it," said Lizzy. "but that wouldn't make it part of our bodies. We don't absorb CO_2."

"Is that English?" I asked cutting her off. "What's CO_2?"

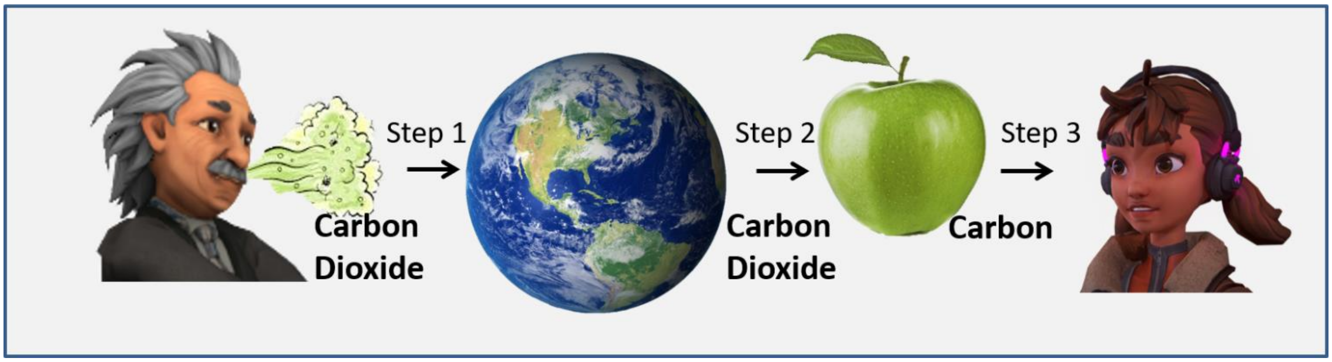
"Sorry, that's the abbreviation for carbon dioxide. One carbon atom, two oxygen atoms. Di- means two. So C. . .O. . . 2 is carbon dioxide." Lizzy continued without pausing. "So, Einstein breathes it out. How do we absorb the carbon? How does the carbon get into our bodies?"

We both looked out my window where I had a giant willow tree standing guard. It felt very protective to me. I really loved that tree.

That's when it hit me. "How about this," I offered. "Step one: carbon dioxide is exhaled by Einstein into the air. Step two: that CO_2 is used by apple trees and plants like broccoli or wheat to grow by photosynthesis."

"Step three," Lizzy took over excitedly, "the apples are eaten by someone like you!"

"Right! Then the process starts over again!" I jumped back in. "Someone exhales, the CO_2



is used to grow food, and then it is eaten. Eventually, we are born, and we are the ones doing the eating!"

"Sounds kind of gross," Lizzy said, crinkling her nose. "Now I have an excuse not to eat my fruits and vegetables. I'll just say that it has carbon atoms that were once in the bodies of gross people, and snakes, and cockroaches."

"Wow!" I said, agreeing. "Like *murderers* share their carbon atoms with us from their gross breath! And it could even be carbon atoms from Milo!"

We both shuddered.

"But," I went on as something else occurred to me, "it won't help to avoid eating fruits and vegetables. Those murderers and Milo still exhale CO_2. Plants like grass use it. Then, those plants are eaten by animals, like cows. So, in that case, step two is putting a murderer's or Milo's, carbon atoms into the grass and then into the cows. And then we eat burgers at Grandma's Fourth of July barbecue for step three. And we *still* get the murderers' carbon atoms anyway."

"Double gross," said Lizzy.

"And so, as you grow," I said, feeling like I was on a roll, "and add more carbon and oxygen atoms to your body, some of those atoms could be from Einstein, the last T-Rex, and lots of others!"

We did it. We had the answer.

"OK, but there is one more question," Lizzy said, halting my internal dance party celebration. "Do carbon atoms last long enough? I mean, will that carbon in the CO_2 . . ." she paused and widened her eyes, "last long enough in the recycle bin to still be there in sixty years? Or millions of years? I mean long enough for us to use it?"

"As Grandma says," I answered shrugging, "diamonds are forever. And she got her diamond ring from *her* grandma, so I guess diamonds can be pretty old. And, diamonds are made of carbon, so carbon must be forever too. Ha, ha, that's a joke. Get it?"

"See if the book says anything about how long carbon atoms last," Lizzy gestured.

I looked and found the answer quickly. "OK, it says carbon atoms mostly live more than 20 billion years!"

"Twenty billion years?" echoed Lizzy. "That's older than the Earth!"

"And older than the stars!" I added.

Lizzy's face brightened as she realized what I was saying. "*Stardust!*" she gasped.

"I think we're on the right track!" I said beaming.

We high-fived.

"Einstein's carbon atoms would definitely still be around," I said. "So would the T-Rex's!"

The two of us worked on a poster of how Einstein's atoms get recycled into other people.

After we finished the poster, I added, "OK, here's another important question. Will Einstein's atoms be only around, say, his house, or work, or wherever he went? Or will they be all over the world?"

"This is what I think," said Lizzy. "A snowstorm in Chicago can reach Hartford in one day. So, I'm willing to bet that carbon dioxide breathed out over sixty years ago would have spread all over the world by now."

"I agree," I said. "It looks like we really could have Einstein's carbon atoms in our bodies. Let's call a meeting of the Cosmic Kids and tell them that we have the answer."

Then I had another great Idea: "We could put on a play to explain recycling."

"OK," agreed Lizzy.

• • • • • •

"Well, geniuses," said Milo when the meeting started in G-Ma's family room. "Did you find out whether we have atoms in our bodies from Albert Einstein and the Last T-Rex?"

"Yes, we did," replied Lizzy.

"We've got a definite answer, and it is *yes*," I added.

Lizzy and I high fived.

"The girl in the hat is an atom," I said pointing at Lizzy in a funny-looking silver hat made of aluminum foil in the shape of a triangle, like a sailor or a space cadet. "Her name is Al and she is a metal. What atom is she?"

"She's plutonium," replied Milo, "because she looks like she came from the dwarf planet Pluto."

"Don't pay attention to him," said Lizzy, rolling her eyes. "He's just trying to ruin our theatrical production."

"I know who she is, I know," shouted Neddy, "she's aluminum. Al—A L—is the abbreviation for aluminum! Like her hat!"

"Correct," I said.

"So is her last name Uminum?" Neddy asked. "Al Uminum."

"I'm millions of years old," continued Miss Uminum, ignoring Neddy's joke. "Recently, me and a bunch of atoms just like me, joined to make this little tank that was filled with a fizzy, brownish, sugary liquid. People drink it, especially when they are hot. What is the little tank?"

"That sounds gross," said Neddy making a disgusted face. "I wouldn't want to drink any of that."

"Yes, you would," Milo argued. "I think it is a soda can, and the drink is cola."

"Correct," I said. "Give that guy a can of soda."

Lizzy tossed Milo a cola. He opened it and took a big theatrical swig. When in Rome . . .

"Well," continued Lizzy/Miss Uminum, "after he drank the contents . . ." she paused and looked at Milo. He figured out what she wanted him to do. He chugged the rest of the cold soda which he said was delicious. Lizzy held up the G-parent's recycle bin.

Milo tossed on cue and it landed in the bin. He mimicked the crowd going wild, which everyone else shushed.

"Nice form, Milo," whispered Neddy. He gave her a thumbs-up.

"Right," said Miss Uminum. "So that is recycling step one: I am tossed into the recycling bin. For step two, I get thrown into a big hot cauldron . . ."

"Can we act out this part too?" Milo asked unhelpfully.

Lizzy rolled her eyes and kept talking. "Step two is where we get made into a more useful form. The temperature is so hot that I melt and combine with all the other melting cans surrounding me. Then we are separated from any other atoms except *aluminum atoms*—all Als, everywhere you turn. We cool into a cube or a brick of pure aluminum called an ingot, which is the more useful form."

"What do you think happens to the aluminum ingot?" I asked.

"I can see from your poster," replied Neddy. "It gets made into new soda cans."

"Right," said Miss Uminum. "I get to start a whole new life as part of a new soda can or foil or some other useful aluminum product."

"And that is recycling step three," I said. "An interesting life, huh?"

"So that's aluminum recycling in three steps," said Lizzy.

"Now let's talk carbon recycling!" I added.

"You see, Mother Nature invented recycling before we did!" said Lizzy

Lizzy held up a poster that had a picture of a Saurolophus dinosaur with little molecules of CO_2 coming out of its mouth. “Step one is the Saurolophus breathing out. In that exhaled breath is carbon dioxide—CO_2. It is produced in a chemical reaction that combines some of its carbon atoms with oxygen atoms that gives the Saurolophus the energy for its physical activity.”

“The carbon dioxide enters and circulates within the *carbon recycle bin*,” I added. “Also known as the Earth’s atmosphere, or the oceans, or the soil.”

“Step two,” continued Lizzy, “is that CO_2 gets absorbed by plants and trees and is incorporated into our fruits and vegetables, or the grasses eaten by animals we eventually eat, like cows and chickens.


Scenes from the science video “How Did Einstein Get Dinosaur Atoms?” Stardust Mystery YouTube channel

“In other words,” I said, “step two is converting the carbon dioxide into a usable form like an apple tree with apples, which was in the middle part of our poster. In step three, someone eats the apple, and gets some of the dinosaur carbon atoms into them.” The last part of the poster showed Einstein chomping on an apple.

“So,” concluded Lizzy as she showed a final poster illustrating Neddy getting T-Rex carbons by eating a carrot, “carbon from *all* people and *all* animals gets recycled into fruits and vegetables and meats and other plants, and then is added to the bodies of people and animals that eat them.”

Neddy tried to give Lizzy a carrot for real, but she recoiled like it was made of poison. So, I took it, and took a big bite with a loud crunch. It was good.

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“Ha!” shouted Milo, “you haven’t finished the job. You showed that it’s possible that Neddy might have some of the T-Rex’s carbon atoms. But you haven’t shown that she absolutely, for sure, has T-Rex’s carbon atoms. You have to show that it is *a sure thing* that Neddy will have T-Rex’s atoms.” And with the chance to get revenge for what the girls had done to him at an earlier team meeting, he started chanting, “Prove it, prove it, prove it . . .” And Neddy joined him in the chant.

Lizzy and I went back to work, but this time we invited Neddy to join us for girl power solidarity.

"OK," Lizzy started, "Milo said that we have to prove that we have atoms from other people or animals, like Albert Einstein, or a T-Rex. But how?"

"Can we test all of our atoms and see which ones are carbon and trace them back in time?" I asked.

"That would take forever," replied Lizzy, "and besides, all the carbon atoms are identical. So, how can we trace one carbon atom? It isn't like they have labels that say *T-Rex*."

"I just had a brainstorm," shouted Neddy. "We can use *probabilities*!"

"What do you mean?" I asked.

"I mean we don't have to show that a particular carbon atom came from Einstein or a T-Rex. We have to figure out the likelihood—or probability—that their carbon atoms recycled from them to us."

"I get it. We have to estimate the probability that we have carbon atoms in us from Einstein or a T-Rex," added Lizzy. "We need to find out more about probabilities."

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So, we rode to the library and while Lizzy and Neddy got out books on probabilities. I went to talk to Mrs. Ortiz, the librarian.

"What's up?" she asked.

"I'm trying to understand probabilities."

"Ok," said Mrs. Ortiz, here is an example. There is a video game arcade in the center of town, where you can play the *Wheel of Fortune*. It has thirty numbers. You pick one number and spin the wheel hoping it will land on your number. The probability that you will win if you pick one number is one in thirty. The *winner fraction* is 1/30 because there is just one winner out of thirty. To get your win probability, you multiply the *winner fraction* by the amount of numbers you get to choose. So, choose ten numbers and your chances of winning are 10 times 1/30, or 10/30. Choose all the numbers, and your chances of winning are 30 times 1/30, or 1, which is 100 percent.

"Mr. Ortiz likes to play the lottery," Mrs. Ortiz continued. "If there is only one winning ticket and a million tickets were sold, what are his chances of having the winning ticket?"

"One in a million?" I ventured.

"Yes! The *winner fraction* is 1/(1 million)," she answered. "999,999 of the tickets are losers, and just one is a winner. But," she continued, "if there's 100,000 winning tickets out of a million, the *winner fraction* is—"

"100,000/1,000,000, or 0.1. That is one in ten!" I called out.

"Exactly: one in ten, or ten percent!"

"Thank you, Mrs. Ortiz," I said, feeling like I was starting to understand.

"Sure, VC," she said. "You'll get it."

I explained to the girls what Mrs. Ortiz had told me about winning the lottery, but we still needed a lot more information. It took us another two days to figure out what the probability is that we had inherited the carbon exhaled by anyone else.

I emailed to the group that we were ready to make another presentation to the team. It was going to be at my house.

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The team met at my house and I showed the kids to the backyard. Grandpa came too. The yard was my brother Griffin's play area. It had big trees with a swing and a tire hanging from the branches and a two-story tree house in one of them. Between the trees was a big playscape and a sandbox. It was a really fun play area.

Lizzy stood by Griffy's sandbox. We had piled all the sand in the center. She announced, "Ladies and germs, this time we have our answer!"

Griffy came over to listen and sat at the top of the slide as I took over. "We all have Albert Einstein and T-Rex carbon atoms in our bodies.

"And almost every other person and animal that ever lived on planet Earth," added Lizzy.

"Whoa," exclaimed Milo as we all settled in for the presentation, "I can't wait to hear this."

"Lizzy and I worked really hard on understanding the probabilities for carbon recycling."

"We showed you last time how a carbon atom *could* get from a T-Rex to one of us," Lizzy said next. "The T-Rex breathed out carbon dioxide molecules—also known as CO_2, also known as one carbon atom, attached to two oxygen atoms. The T-Rex molecules of CO_2 went into the air, the oceans, and the soil, and 66 million years later, the carbon atom from one of those molecules happened to end up in an apple. VC, Neddy, Milo, or I could have eaten that apple."

"So now we *could* have T-Rex carbon atoms," I took over. "What we needed to find out is the *probability* that if I ate any apple, it would have some of Einstein's carbon atoms and the last T-Rex's carbon atoms."

Lizzy pointed to the sand pile and said that this would help us understand the concept of carbon recycling and probabilities. "Pretend that the total supply of carbon atoms on Earth is these grains of sand instead of atoms. The pile of sand represents the carbon recycle bin which is the Earth's atmosphere, oceans, and soil."

Then she held up a bag the size of five pounds of sugar. "The bag contains blue colored sand. Pretend that in step one, instead of exhaling CO_2 molecules, the T-Rex exhales these grains of *blue* sand."

Milo started coughing. "Excuse me," he said. "That sounds uncomfortable."

"Not for real. Just for the sake of understanding what happens to the carbon atoms!" I explained, a little annoyed.

"The T-Rex's carbon atoms are represented by the blue sand," Lizzy said as she poured it from the bag. "It gets added to this big pile. Over time it gets thoroughly mixed in." Lizzy started mixing and asked everyone to help.

In five minutes the two colors of sand were well mixed together. There was still a lot more tan sand than blue sand, but the blue grains were visible throughout. "Over 66 million years," Lizzy continued, "the T-Rex's carbon atoms are mixed into the atmosphere, oceans, and soil, just like the little grains of blue sand are mixed all over the big tan pile.

"Now, pretend," I took over, "an apple grows by getting sand from the pile in step two instead of CO_2. If it takes enough sand, it will probably get at least some of the blue grains."

The next part was a little more confusing. I introduced the idea of the *blue fraction*. I said it was the number of blue grains divided by the total number of grains—tan and blue mixed together. "We can also show it as a *blue percent*, which is the *blue fraction* times 100. The apple or anything else that gets its carbon from the recycle bin will end up with the same *blue fraction* in its smaller sample."

On cue, Griffin jumped down from the slide and filled a bucket with the tan and blue sand. He showed it to everyone and sure enough, it looked like it had the same *blue fraction* as the whole pile.

The number of blue grains in Griffin's bucket will be the total number of sand grains he collected times the *blue fraction*. "And this is really important," Lizzy concluded. "Since we get all our sand from that same recycle bin, we will also have the *blue fraction* of T-Rex grains. And carbon atoms are just like the sand-pile example, so we will have the *T-Rex fraction* of carbon atoms, which is T-Rex's total exhaled carbons divided by all the recyclable carbon atoms on Earth—the carbon in the atmosphere, ocean, soil, and plants."

"And," I continued, "the total number of *T-Rex's* carbons in our body will be the *T-Rex fraction* times the total number of carbon atoms in our bodies."

"OK," Lizzy said, "let's try some examples. If we mix 1,000 blue grains into 100,000 tan grains, then 1 out of every 100 grains will be a blue grain. The *blue fraction* is 0.01, or 1 percent. So, if I take a scoop of 1,000 grains, I will probably get 0.01 times 1,000, or 10 blue grains.

"So, that is the concept," Neddy jumped in. "Now back to carbon atoms."

"Right," I agreed. "So, we have to figure the *T-Rex fraction* of carbon atoms in Earth's recycle bin. And then multiply the *T-Rex fraction* times the total number of carbon atoms in our body to find out how many *T-Rex* carbon atoms we have."

"That is what we did," said Lizzy. "It was a lot of work, and we put all the calculations in our report."

I knew we were losing them. Milo was almost totally zoned out. Probably thinking about his girlfriend. Honestly, I wished I had someone to think about with that annoying moony expression on my face, but someone had to do the heavy lifting. I was still obsessed with winning this contest for Grandpa.

"First," I said, "we need to know the total number of carbons on the Earth recycle bin. NASA created a great diagram created by NASA called the global carbon cycle, which shows the amounts of all the carbons on Earth in carbon pools: the atmosphere, plants, oceans, soil, fossil fuel, and some other forms like rocks. The diagram is in our report. It shows the amounts in billions of tons of carbon. The circulating carbon is mostly in the atmosphere, ocean, plants, and soil. The total for all the carbon on Earth is 57,650 billion tons. We converted that to the number of carbon atoms."

"The total for all of the carbon atoms on Earth is—drum roll please—2.63 million trillion trillion trillion atoms," said Lizzy. "That is 2.63 followed by 42 zeros."

I wrote the number on a giant pad we had set up in front of the room:

263,000,000,000,000,000,000,000,000,000,000,000,000,000,000

"Remember," I said, "when Lizzy was trying to understand such big numbers. She calculated the total of all the letters on every page in all the books on Earth. She called that the LIZZY. Well, this number is equal to almost 5 trillion trillion LIZZYs! So that would be all the letters on every page in all the books on 5 trillion trillion planets like Earth.

"My head is so totally starting to hurt," Neddy complained. "But hey, there is something really important about that NASA diagram. The carbon from the fossil pool has been going into the atmosphere pool because of power plants, cars, and trucks that burn fossil fuel. The atmosphere carbon pool is the highest it's been in a million years. That is causing climate change (global warming). The Earth is heating up."

"Very interesting," Lizzy snapped, "but please let me finish. Next, we need to know the total number of carbon atoms that the T-Rex breathed out in his lifetime. We started first with a human. I had Grandpa breathe out into a plastic bag for a minute to get his volume of breath and figured out his volume per minute. Milo's *Life Science* book says that 4.5 percent of each exhaled breath's volume is carbon dioxide. That is 4.5 molecules out of every 100. So, we just need to figure out the total volume exhaled in a lifetime and multiply by 0.045."

We assumed the T-Rex exhaled volume was 176 times more than Grandpa's because it weighs 12,320 kilograms (kg) compared to Grandpa's 70 kilograms. If you multiply that all out like we did in the report, you get about 19 million trillion trillion carbon dioxide molecules exhaled for the T-Rex's thirty-year lifetime. That is:

"19 million trillion trillion = 19,000,000,000,000,000,000,000,000,000,000,000.

The number of carbon atoms is the same since each carbon dioxide molecule has one carbon atom."

"Now my head hurts," whined Milo. But what else was new?

"Just one more step," I said. "Just divide the number of T-Rex's exhaled carbon atoms by the total number of carbon atoms on Earth, and you get the *T-Rex fraction*. It is 7.7 divided by 1 trillion.

"Only 7.7 winners for every trillion tickets sold?" asked Milo. "It doesn't seem likely I'll win the T-Rex lottery."

"Not true," replied Lizzy. "It depends on how many tickets you buy! And for that, we need to know the total number of carbon atoms you have in your body. We calculated that to be 0.7 billion billion billion carbon atoms."

"So," I said, "multiply the total carbons in a human by the *T-Rex fraction* and you get the number of carbon atoms from each T-Rex in each of us: 7.7/(1 trillion) times 0.7 billion billion billion = 5,390 trillion inherited T-Rex carbon atoms.

"And," Lizzy continued, "multiply the same total carbon atoms in a human by the *Einstein fraction* and you get the number of carbon atoms from Albert Einstein. Einstein was smaller than a T-Rex but lived longer, so the *Einstein fraction* is seventy times smaller than the *T-Rex fraction*. So, the Einstein carbons in each of us is 77 trillion inherited Einstein carbon atoms.

"Wow," exclaimed Milo, "5,390 trillion carbon atoms inherited from one T-Rex and 77 trillion from Einstein. Pretty awesome."

That time his "awesome" didn't make me want to drop-kick him.

Grandpa said that our analysis was great. But he added one small correction. "Remember," he said, "you assumed that Einstein's carbon atoms were evenly distributed in all the carbon pools (atmosphere, soil, plants, and ocean) throughout the world. That's a good assumption for a T-Rex that died 66 million years ago—plenty of time for those atoms to spread out evenly. But for Einstein who only died 65 years ago, there wouldn't be enough time for his carbons to distribute evenly into the deep oceans and soil. So more of his carbons would still be in the atmosphere. Adults would inherit about 300 trillion carbons from Albert Einstein. Even a higher percentage of carbons from people that just died, or who were still living, would still be in the atmosphere."

"What it means," I summarized, "is that there are trillions of atoms in us that were once in Einstein, a T-Rex, and probably every other person and every other animal that ever was."

"So the question about whether our atoms were in other people and other living things is not crazy after all," Milo said. "But," he went on, because he was just eternally a pain, "because this is a probability, it's not *certain* you'd win that lottery."

"Well," Grandpa jumped in, cutting off Milo's totally brain-dead thoughts, "it would be almost impossible not to have some winners."

"And you know what that means?" I added. "Boys really *are* made of snakes and snails and puppy dog tails."

"That's kinda weird," said Milo.

And that ended the meeting.

GRANDPA'S GLOSSARY

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.

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.

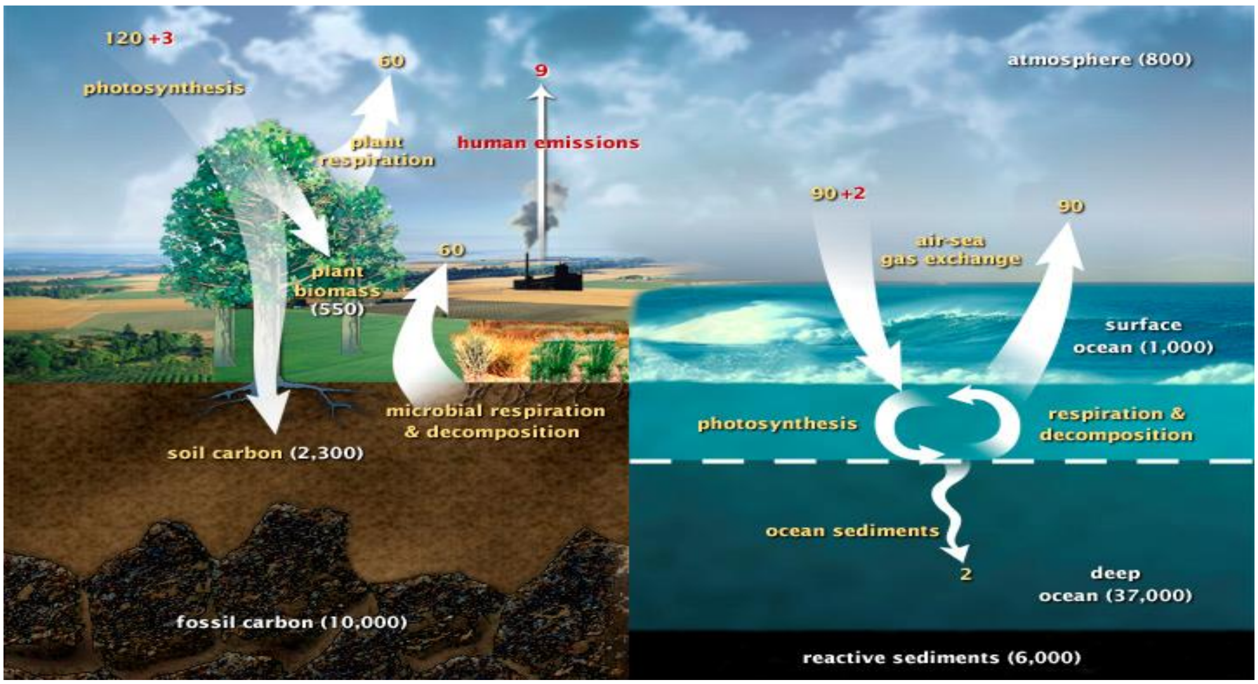
Combining Carbon and Oxygen: For your cells to function, they must have energy. That energy comes from the food you eat. The foods are digested and stored as fats and sugars. When energy is needed, the blood carries sugar and fat molecules to the cells, where they pass through the cell membrane into 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.

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, which flies off the atom) 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. That 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.

Global Carbon Cycle.



Global Carbon Cycle.
Pools (in black) are in gigatons (1 gigaton=1 x 10^8 Tons) of carbon, and fluxes (in purple) are in gigatons of carbon per year.
Diagram curtesy of US Department of Energy/NASA Earth Observatory.

Carbon Pools: 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 10^{42}, or 2,63 followed by 42 zeros, or 2,630,000,000,000,000,000,000,000,000,000,000,000,000,000,000.

Global Warming: The Earth's temperature is controlled by two things: 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 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). 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.

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 must 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 in 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.

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

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