4

HOW DID THE EARTH FORM?

New stars and space debris spinning like pizza dough are a couple of the things that explain the formation of solar systems like ours. In this three-part lecture, David Christian explains how chemical elements link to form simple molecules and about the Goldilocks Conditions that produced rocky planets. You will learn how molecules produced by exploding stars, floating in space near new stars, smashed together and through chemistry, gravity, and electricity formed dust, meteorites, asteroids, and planets. After reading the text below and watching this video, you should be able to explain the process by which solar systems form and planets emerge.

Key questions

1 What were the Goldilocks Conditions that led atoms to connect?

2 How did the planets in our Solar System form?

Transcript: Part 1

0:11-1:06

DOZENS OF ELEMENTS, MILLIONS OF POSSIBILITIES

Hi. I'm back at Lakeside School and I'm in the chemistry lab as you can see.

Now, look around you and try to count how many different sorts of materials you can see. Ten easily, a hundred not too hard, and if you counted really carefully — well, look at all these materials here — you could probably come up quite easily to 1,000, 10,000, or maybe even 100,000. That's because in a universe with 100 elements you haven't just got 100 different materials. Those elements can combine with each other in a huge number of different ways to form millions and millions of new materials; all the materials we see in the world around us. All these new materials eventually combine to create entirely new astronomical bodies. The most important by far for us, of course, is our home planet, the Earth.

1:06-2:25

A CHEMICALLY BORING UNIVERSE

A CHEMICALLY INTERESTING EARTH

But before we describe how the Earth and the other planets of the Solar System were created, there's a little problem that we have to take up. You'll remember from the last unit we saw that all those new elements that were created made up only 2 percent of all the atoms in the Universe. Yet, if we look at our Earth we'll find that 90 percent of the Earth is made up of elements like iron, oxygen, silicon, magnesium, and other elements created in supernovae and dying stars. So how did they get concentrated like this to form planets and bodies like that? Now, before I give my answer, I'd like to ask if you have any ideas about how that might have happened. To answer these questions we must think about chemistry.

Now, chemistry is all about how different elements link up; how their atoms link up to form what we call molecules. How atoms link up depends very much on the arrangement of their electrons. Some elements, such as **helium**, are very, very stable; they hardly ever link up with other atoms. In fact, they're known as the **noble gases**. It's as if they're too snooty to join up with other atoms. You'll find them on the right side of the periodic table by the way. But most atoms really like to link up with other atoms. We say they're reactive.

2:25-3:06

Hydrogen and oxygen, for example, are always looking for chances to link up with other atoms. If you see burning, or you see a flame, what you're really seeing is oxygen linking up really violently with other atoms. It's very reactive indeed.

COMBINATIONS OF ATOMS ARE CALLED MOLECULES

Now, when atoms join together we call them **molecules**. Each molecule has its own distinctive qualities which may be very different for the elements in which their formed. For example, hydrogen and oxygen are both gases, but when they combine they form a very, very familiar liquid — water, H_2O — and water has qualities completely different from both hydrogen and oxygen.

3:06-4:13

DIFFERENT TYPES OF BONDS CONNECT ATOMS

Different types of molecules also have different types of **bonds**. Some bonds are extremely rigid, but others are very flexible. Some are very strong, very hard to break; others are very easy to break. So there is this huge variety of different types of links between molecules. **Carbon**, for example, can link up with itself to form diamonds. In a diamond the bonds are extremely strong and extremely rigid, so a diamond is very tough indeed, but carbon atoms can also link up with themselves to form a very different material, graphite. Now, graphite is the lead in a pencil. It's very soft stuff indeed. So different bonds make a lot of difference.

Now, these different types of links, different types of bonds, mean we have a huge variety of different types of materials. That's what explains a huge variety of these materials, but note that it's mostly elements other than hydrogen or helium that make up these chemicals and that's one reason why when we talk about rich chemistry we're talking mostly about that tiny 2 percent of elements from the periodic table.

Transcript: Part 2

4:16-5:32

SPECTROSCOPES HELP US SEE THE CHEMICAL MAKE-UP OF THINGS

Atoms begin to form molecules even in deep space in the clouds of matter rejected by supernovae and dying stars. How do we know this? Well, using spectroscopes we can tell what elements and what chemicals are out there, and we know there's water, plenty of ice, carbon dioxide, ammonia, acetic acid, a whole range of simple molecules that are very familiar in daily life. There are also lots of **silicates**. Silicates are molecules made from silicon and oxygen and they make up most of the rocks in the Earth's crust.

SILICATE MOLECULES GET INTERESTING AROUND NEW STARS

Now, in space these molecules — which were pretty simple by the way — they included 10 to 20 atoms, at most 60. In space these molecules couldn't do a huge amount of interesting stuff, but around newly born stars it turns out you could do a huge amount of interesting stuff with these molecules; in fact, you can make planets.

To see how this works, what we're going to do is we're going to travel back in time 4.5 billion years and we're going to zoom in. We've been looking at the Universe so far in this course. We're going to zoom in on one average galaxy, the **Milky Way**, we're going to zoom in on one tiny part of it and we're going to look at the birth of our Solar System.

5:32-6:56

Now, our **Sun** formed like any other star — from the collapse of a cloud of matter under the pressure of gravity. That collapse, like many others, was probably triggered by a huge supernova explosion somewhere in our region of the Milky Way. That **supernova** explosion also seeded this cloud with lots of new materials from other supernovae and from dying stars. As the cloud collapsed, it began to spin like spinning pizza dough. As it spun it slowly flattened out to form a disc.

SPINNING PIZZA DOUGH IN THE UNIVERSE MAKES SOLAR SYSTEMS

Now, this is something that happens throughout the Universe, which is why the Universe is full of flat discs from the Milky Way itself to our Solar System, even to the rings around Saturn. Astronomers call this sort of disc a **protoplanetary disc** or a **proplyd**. Now, as the proplyd that eventually formed our Solar System began to collapse, at its center it got hotter, and hotter, and hotter until eventually **fusion** began and our Sun was born. About 99 percent of all the material in the proplyd went into the Sun: 99.9 percent in fact. That leaves 0.1 percent for the rest of the Solar System. All that stuff was orbiting around the Sun. Amazingly, that tiny residue is what formed all the rest of the Solar System.

MOST OF THE PIZZA DOUGH FUELS THE SUN; THE REST MAKES PLANETS AND ASTEROIDS

6:56-8:12

THE SUN PUSHES GAS TO THE EDGE OF THE SOLAR SYSTEM

Now, let's begin by looking at the outer gassy planets and how they were formed. The intense heat of the young Sun drove away gassy materials from the inner parts of the Solar System, and above all it drove away a lot of hydrogen and helium, leaving that as a region deprived of hydrogen and helium. All that gassy material gathered further out in the Solar System and eventually condensed to form the **gassy giants**. They are Jupiter, Saturn, Uranus, and Neptune. Now, they contained about 99 percent of the **leftovers**. So what we're left with is a tiny residue of a tiny residue to form the inner rocky planets, including our Earth.

SOLID MATERIAL GATHERS CLOSER TO THE SUN

Closer to the Sun from that tiny residue of a residue you find material orbiting in the inner orbits. That material is less gassy; there's more sort of solid stuff. You have little dust motes that will eventually gather together through electrostatic forces or collisions to form little rocks. You have particles of ice that will eventually form snowball-like objects, and eventually they form things like meteorites or asteroids and they're getting bigger, and bigger, and bigger and they're colliding with each other.

8:12-9:25

FORCES COMBINE SOLIDS TO FORM ROCKY PLANETS LIKE EARTH

In each orbit you'll eventually get large objects that finally sweep up through their gravitational pull everything else that's in the orbit. So eventually over a 100 million years, in each orbit, you have a **rocky planet**.

ACCRETION IS THE NAME FOR THE VIOLENT WAY PLANETS FORM

Now, this process is called **accretion**. It's extremely violent. It's a huge amount of space stuff smashing into other space stuff. If you want to be persuaded how violent it was, get out a pair of binoculars, look at the Moon one night, and look at those craters. Those are evidence of how violent the process of accretion was. Our Moon was probably created when an object perhaps the size of Mars collided with our young Earth and it gouged out a huge chuck of the Earth. That stuff orbited around the Earth and slowly accreted to form the object that we call the Moon.

So in this way, through these processes over about 10 to 20 million years, our Solar System formed and we end up with a solar system that has inner rocky planets in the inner orbits, the large gassy planets in the outer orbits, and woven through them lots of space debris. It includes meteorites, asteroids, and comets.

9:25-10:16

SATELLITE TELESCOPES SUGGEST THAT MANY OTHER SOLAR SYSTEMS EXIST

No one knew if there were any other solar systems anywhere else in the Universe. It was quite possible this was the only solar system in the Universe. But in the last 15 years there's been some quite magical astronomical research — a lot of it based on satellite telescopes such as the Kepler satellite, and what we're now able to do is actually see other solar systems. They vary hugely, but we now know that solar systems are actually very, very common indeed.

IF OTHER SOLAR SYSTEMS ARE OUT THERE, LIFE IS PROBABLY OUT THERE ON EXOPLANETS

Strangely, what that does, is it rather increases the chances that out there somewhere there is life of some form. So exciting is the science, by the way, that I even have an app on my phone that tells me all about the most recent discoveries of so-called **exoplanets**, which is what planets around other stars are called.

Transcript: Part 2

10:20-11:06

HOW SOLAR SYSTEMS FORMED

Let's return to the problem we began with in this unit. How is it possible from all these rare, new chemical elements to create entirely new things? I hope by now we have the beginnings of an answer.

First, we saw that chemistry links chemicals to form simple molecules. A whole range of new materials are floating through space. Secondly, we saw that in the environments — we can call them the "Goldilocks Environments" — around newly formed stars, those molecules get smashed together; they get brought together by chemistry and by gravity and by electricity to form objects like dust motes, meteorites, asteroids and eventually planets and solar systems.

11:06-11:54

SOLAR SYSTEMS: THE FOURTH THRESHOLD OF INCREASING COMPLEXITY

Now, we regard the creation of solar systems as the fourth great **threshold** in this course and that's because planets, and in particular rocky planets like our Earth, are significantly more complex than stars. They're more complex because they have more internal structure, but they are also much more complex chemically. They contain a much greater diversity of materials.

HISTORIANS LOOK GOOD IN LAB COATS

Okay. Now, I've worn this lab coat throughout this whole lecture even though I'm a historian. I think it's time to take it off, but I hope you're beginning to see that what's happening is that our Universe is getting more complex, more diverse, and more interesting.