Cosmic Chemistry from the Big Bang to You

Course Description

In his Cosmos TV series Carl Sagan said: “If you want to make an apple pie from scratch, you must first invent the universe.” He was pointing out that the chemical ingredients of an apple pie have a fascinating history that starts with the big bang, continues through the cores of stars and violent supernova events, and ends with complex molecules doing service in the kitchen. The road to an apple pie involves enormous amounts of time and space.

This course will survey cosmic chemistry through the lens of eight iconic elements. Selected from among 92 elements in the periodic table, these eight have particularly fascinating stories to tell. For each element, we will cover the astrophysics of their origin, their unique chemical properties, their role in the history of human culture and technology, and their use in the modern world. We will also learn the stories of their discovery. The eight highlighted are: hydrogen, helium, carbon, oxygen, silicon, iron, gold, and uranium.

Course material includes astrophysics and chemistry, where the science content is layered with history and culture. Elements will be covered in pairs over four weeks of two-hour classes. Each lecture will be in two parts, split by 20 minutes for discussion and questions and answers. Students will be encouraged to share their sense of the role of these elements in their lives, and to bring to class examples of each one. The class readings will be taken from a new book by the instructor, which will be published early in 2026 by MIT Press. The class notes and readings will be available as pdf files.

Course Outline

Week 1

Introduction
Making an apple pie from scratch, its chemical ingredients, the elements for biology.

Hydrogen – The Primordial Element
Something rather than nothing, why the universe has matter and where it came from. From the big bang to atoms, the quantum universe creates radiation and 10^{80} atoms. Architecture of the cosmos, gravity makes structure, the case of the missing hydrogen. Discovering hydrogen, Henry Cavendish, hydrogen as a powerful but explosive fuel. The quest for antihydrogen, the scarcity of antimatter, the most expensive substance. A clean energy future, hydrogen as a clean, renewable fuel, vast reserves available.

Helium – Unbearable Lightness of the Big Bang
The first alien element, helium discovered in the Sun, spectroscopy an essential tool. Composition of the stars, the female computers at Harvard, what stars are made of. An elusive but useful element, liberated in the Earth, it’s many uses beyond balloons.

Creating the Sun on Earth, the extreme difficulty of controlled fusion within a reactor.
Helium from the big bang, it took three minutes to turn ¼ of the universe into helium.

Week 2

Carbon – First Stars and Cosmic Chemistry
Carbon is a fluke, Feed Hoyle and a nuclear coincidence that makes carbon possible.
Infinite complexity, the shape-shifting element making molecules of infinite complexity.
Carbon is everywhere, no one discovered it, charcoal for smelting metal ore, diamonds.
Carbon in the modern world, Lavoisier, respiration and combustion, the carbon cycles.
Interstellar chemistry, interstellar molecules with carbon, in a universe built for biology.
The web of life, how life on Earth started, the role of carbon, Earth a microbial planet.

Oxygen – The Essence of Water and Life
Discovering oxygen, Joseph Priestley, experiments on air, photosynthesis discovered.
Oxygen across the universe, creation in stars, in the Earth's crust, in distant galaxies.
Water is special, peculiar properties of the molecule, 17 forms of ice, hydrological cycle.
History of a volatile gas, creation by cyanobacteria, the oxidation event, Snowball Earth.
Searching for life beyond Earth, surging exoplanet discoveries, oxygen as a biomarker.

Week 3

Silicon – Technology Through the Ages
Hidden in plain sight, sand, clay, crystals, human uses, history of ceramics and glass.
Making pure silicon, Jacob Berzelius and new elements, modern chemical notation.
A protean element, quartz and its uses, silanes, silicone, carborundum, and zircons.
The chip that changed the world, silicon semiconductors and the growth of computing.
The perfect detector, AT&T and CCDs lead to a Nobel Prize, their use in astronomy.
From stardust to planets, silicon from massive stars, we are stardust, silicon biology.

Iron – From Dying Stars to Planet Cores
An explosive origin, from iron as a fusion dead end to stellar death as a supernova.
The heart of planets, iron in interstellar grains, meteorites, and in the core of planets.
A magnetic metal, magnetic metals, Earth as a giant magnet, compass navigation.
Age of iron, the Iron Age, making iron and steel, its effect on trade, politics, society.
Iron in the modern world, a proxy for human progress, the two industrial revolutions.

Week 4

Gold – Hunting Stellar Cataclysms
Precious throughout history, gold's scarcity, first gold smelted, Egyptian craftmanship.
The false promise of alchemy, Philosopher's Stone, J.K. Rowling, Newton alchemist.
Money and gold, gold coins in antiquity, debasing coins, the first instance of inflation.
Treasure and fabulous objects, Incan gold, war gold, gold objects from ancient Troy.
Gold in the modern world, history of currency, the Spanish dollar, the Gold Standard.
Born in a stellar collision, Jocelyn Bell and pulsars, LIGO and neutron star collisions.

Uranium – Things Fall Apart
Dangerous discoveries, Pierre & Marie Curie, Nobel Prize, radioactivity, Radium Girls. Stable and unstable elements, radioactivity as a random process, radiation and half-life. Radioactivity and the Earth, the clock in the rock, radioactive dating, age of the Earth. Transuranic elements, going beyond uranium, modern day alchemy, island of stability. Reactors and bombs, natural reactor, first controlled fission, bombs and nuclear waste.

Coda
Dimitri Mendeleev and the periodic table, the power of dreams, odyssey of the atoms.

Professor Bio

Chris Impey is a University Distinguished Professor of Astronomy at the University of Arizona. He has over 450 publications on education, observational cosmology, quasars, and galaxies, and his research has been supported by $20 million in NASA and NSF grants. He has won eleven teaching awards and has taught four online classes with over 420,000 enrolled and 8 million minutes of video lectures watched. Chris Impey is past Vice President of the American Astronomical Society, and he has won its career Education Prize. He has also been NSF Distinguished Teaching Scholar, Carnegie Council's Arizona Professor of the Year, and a Howard Hughes Medical Institute Professor. He has written over 120 popular articles on cosmology, astrobiology and education, two textbooks, a novel called Shadow World, and ten popular science trade books: The Living Cosmos, How It Ends, Talking About Life, How It Began, Dreams of Other Worlds, Humble Before the Void, Beyond: The Future of Space Travel, Einstein's Monsters: The Life and Times of Black Holes, and Worlds Without End: Exoplanets, Habitability and the Future of Humanity. His upcoming book is Recipe for a Universe: Cosmic Chemistry from the Big Bang to You. He's taught three Humanities Seminars and in 2022 he won the Ted and Shirley Taubeneck Superior Teaching Award.