NO PREP

Radiocarbon Dating

How Old Is This Really?

Includes: Student reading, case study, differentiated questions, teacher key

Name: Period: Date:

Radiocarbon Dating: How Old Is This Really?

The Carbon Clock Inside Every Living Thing

In 1949, an American chemist named Willard Libby announced a discovery that would earn him the Nobel Prize and fundamentally transform archaeology. He had figured out how to use a radioactive form of carbon to determine the age of ancient organic materials. The method, known as radiocarbon dating or carbon-14 dating, relies on a simple but elegant principle: all living things absorb carbon from the atmosphere, including a tiny proportion of radioactive carbon-14. When an organism dies, it stops absorbing new carbon, and the carbon-14 it contains begins to decay at a predictable rate. By measuring how much carbon-14 remains in a sample, scientists can calculate how long ago the organism died. Carbon-14 is created high in the atmosphere when cosmic rays from space collide with nitrogen atoms. The resulting carbon-14 atoms are chemically identical to regular carbon-12 and carbon-13, so they mix freely into the atmosphere's carbon dioxide. Plants absorb this carbon dioxide during photosynthesis, animals eat the plants, and predators eat those animals.

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Half-Life: The Countdown That Never Stops

The key concept behind radiocarbon dating is the half-life. Carbon-14 has a half-life of approximately 5,730 years, which means that every 5,730 years, half of the carbon-14 in a sample decays into nitrogen-14. After one half-life, 50 percent of the original carbon-14 remains. After two half-lives (about 11,460 years), 25 percent remains. After three half-lives (about 17,190 years), only 12.5 percent remains. This decay continues in a predictable pattern until the amount of carbon-14 left is too small to measure accurately. This is why radiocarbon dating has an upper limit of approximately 50,000 years. After about nine half-lives, the remaining carbon-14 is so minuscule that it falls below the detection threshold of even the most sensitive instruments. For anything older than 50,000 years, archaeologists must use different methods entirely, such as potassium-argon dating or luminescence dating. The predictability of the half-life is what makes the method work. If you know the starting ratio of carbon-14 to carbon-12 (which is roughly constant in the atmosphere) and you measure the current ratio in your sample, simple math gives you the elapsed time since the organism died. The fewer carbon-14 atoms remaining, the older the sample.

When Carbon-14 Gets It Wrong

Radiocarbon dating is powerful, but it is not foolproof. Several factors can produce inaccurate dates, and understanding these limitations is essential for any archaeologist working with the method. Contamination is the most common source of error. If newer carbon gets introduced to an old sample, through contact with plant roots, groundwater, or even careless handling in the lab, the sample will appear younger than it actually is. Conversely, if old carbon contaminates the sample (for example, from ancient limestone dissolved in groundwater), the date will appear too old. Careful sample preparation, including cleaning and chemical pretreatment, helps minimize contamination, but it cannot always be eliminated entirely. Another challenge is that the ratio of carbon-14 in the atmosphere has not remained perfectly constant over time. Variations in solar activity, volcanic eruptions, and changes in the earth's magnetic field have caused the atmospheric carbon-14 level to fluctuate. This means that the simple calculation based on a constant starting ratio does not always produce accurate calendar dates. To correct for these fluctuations, scientists have developed calibration curves that compare radiocarbon

dates to independently dated records like tree rings and lake sediment layers. A raw radiocarbon date must be calibrated before it can be converted to a reliable calendar date. The method also has some inherent limitations in what it can date. Radiocarbon dating only works on organic materials, things that were once alive. It cannot date stone tools, pottery, metal objects, or geological formations directly. And because it relies on the death of the organism, it dates when the material stopped living, not when it was used by humans. A wooden beam in a building tells you when the tree was cut down, not when the building was constructed, which could have been years or even centuries later if recycled timber was used.

AMS: Making Radiocarbon Better

In the early decades of radiocarbon dating, the method required relatively large samples because it measured the decay of carbon-14 atoms directly by counting the radiation they emitted. This meant that dating a sample might require destroying several grams of material, which was a serious problem when working with rare or precious artifacts. Museum curators were understandably reluctant to hand over chunks of ancient textiles or bone for destructive testing. The development of Accelerator Mass Spectrometry, or AMS, in the late 1970s solved this problem dramatically. Instead of waiting for carbon-14 atoms to decay and emit radiation, AMS counts the carbon-14 atoms themselves by accelerating them to enormous speeds and sorting them by mass. This approach is far more sensitive, requiring only tiny samples, sometimes as small as a single grain of wheat or a fragment of thread. AMS also produces faster results and can detect smaller amounts of carbon-14, extending the effective range of the method. AMS technology has opened up entirely new categories of research. Scientists can now date individual seeds found at ancient sites, revealing exactly when specific crops were first cultivated. They can date the adhesive on a stone tool to determine when it was hafted. They can even date the proteins preserved in ancient pottery residue, telling archaeologists what was cooked in a vessel thousands of years ago. The ability to work with tiny samples has also made it possible to date precious artifacts, like the Shroud of Turin, which was famously radiocarbon dated in 1988 using postage-stamp-sized samples cut from the edge of the cloth. The results dated the linen to between 1260 and 1390 CE, suggesting it was a medieval creation rather than a relic from the time of Jesus.

Key Information: Radiocarbon Dating Facts

Detail	Information
Discovered by	Willard Libby in 1949; awarded Nobel Prize in Chemistry in 1960
How it works	Measures the decay of carbon-14 in organic materials after the organism dies
Half-life of carbon-14	Approximately 5,730 years
Effective range	Up to about 50,000 years (approximately 9 half-lives)
Materials it can date	Organic materials: wood, bone, charcoal, shell, seeds, textiles, leather
Materials it cannot date	Stone, metal, pottery, and other inorganic materials
AMS (Accelerator Mass Spectrometry)	Counts carbon-14 atoms directly; requires only tiny samples
Calibration	Raw radiocarbon dates must be adjusted using calibration curves based on tree rings and other records
Famous application	The Shroud of Turin was dated to 1260-1390 CE using AMS in 1988

Case Study: The Suspicious Manuscript

Lab technician Sofia Andersen carefully placed the tiny fiber sample under the AMS preparation hood and began the chemical pretreatment process. The sample had arrived that morning from a private collector in Switzerland who claimed to own a previously unknown medieval manuscript, supposedly written by monks in the twelfth century. If authentic, the manuscript would be worth millions and rewrite part of European literary history. The collector wanted a radiocarbon date to prove its age before approaching auction houses. Sofia had seen cases like this before. She followed her standard protocol meticulously, removing potential contaminants and converting the sample to graphite for the AMS machine. Three weeks later, the results came back: the parchment dated to between 1920 and 1955 CE. "It's modern," Sofia told her supervisor, Dr. Hoffman. "The parchment is less than a hundred years old." Dr. Hoffman frowned. "The collector will not be happy. Are you confident in the result?" Sofia nodded. "I ran the sample twice. The ink could theoretically be applied to old parchment, but the parchment itself is twentieth century. This manuscript was not made by medieval monks." She paused. "Should we notify anyone beyond the client? If someone is selling this as an authentic medieval document, that is fraud."

1. Based on the reading, explain why radiocarbon dating is an effective method for detecting forged manuscripts. What specific properties of organic materials like parchment make this possible?

2. Sofia mentions that ink could theoretically be applied to old parchment. How does this connect to the reading's discussion of what radiocarbon dating actually measures? What additional tests might be needed to fully authenticate or debunk the manuscript?

Multiple Choice

1. What happens to carbon-14 in an organism after it dies?

    a) It remains constant indefinitely

    b) It begins to decay into nitrogen-14 at a predictable rate

    c) It converts into carbon-12

    d) It increases as the organism decays and absorbs carbon from the soil

2. Why must raw radiocarbon dates be calibrated before they can be used as calendar dates?

    a) Because the ratio of carbon-14 in the atmosphere has not remained constant over time

    b) Because carbon-14 decays at different rates in different materials

    c) Because radiocarbon dating cannot distinguish between carbon-12 and carbon-14 isotopes

    d) Because calibration makes the dates less accurate but more consistent

3. What major advantage does AMS technology offer over traditional radiocarbon dating?

    a) It extends the effective range to 500,000 years

    b) It can date inorganic materials like stone and metal more accurately

    c) It requires only tiny samples, preserving precious artifacts

    d) It does not require calibration

Matching

Write the letter of the correct definition on the line next to each term.

Term	Definition
1. ___ Carbon-14	A) The process of adjusting raw radiocarbon dates using independent records like tree rings
2. ___ Half-life	B) Accelerator Mass Spectrometry, a method that counts carbon-14 atoms directly using very small samples
3. ___ Contamination	C) The time it takes for half of a radioactive substance to decay, about 5,730 years for carbon-14
4. ___ AMS	D) A radioactive isotope of carbon that decays at a known rate after an organism dies
5. ___ Calibration	E) The introduction of foreign carbon to a sample that produces inaccurate dates

Fill-in-the-Blank

1. Willard Libby discovered radiocarbon dating in 1949 and was awarded the _____ Prize in Chemistry in 1960.

2. Carbon-14 has a half-life of approximately _____ years, meaning half of it decays in that time.

3. The Shroud of Turin was radiocarbon dated in 1988 and found to be from between 1260 and _____ CE.

Short Answer

Answer each question in 2-4 complete sentences.

1. Explain the concept of half-life in your own words. Why does radiocarbon dating become unreliable for materials older than about 50,000 years?

2. A farmer finds an old wooden beam in the foundation of a medieval church. Radiocarbon dating shows the wood is 200 years older than the church's known construction date. Does this mean the date is wrong? Explain your reasoning using information from the reading.

3. How did AMS technology change what archaeologists could study? Give at least two specific examples from the reading of research that was only possible because of AMS.