School of ICE

Decoding Ice Cores Isotopic Analysis

How warm was Earth in the past?

(rev. 2025)

By,
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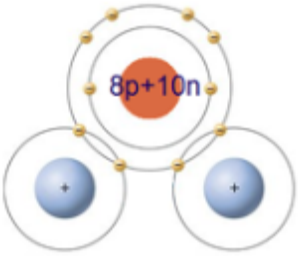
Student Directions-Decoding Ice Cores

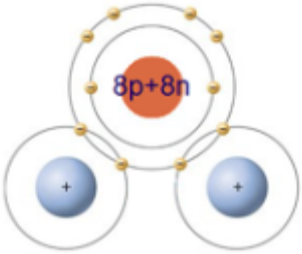
Isotopic Analysis-How warm was the Earth in the past?

Background: Climate scientists have drilled into the ice in Greenland and Antarctica and recovered deep ice cores up to two miles long! Scientists are searching for evidence to reveal what the Earth's climate was like in the past. Learning about the past will allow them to better predict where the climate is likely headed in the future. One thing that can be determined by analyzing the cores is the temperature of the atmosphere when each ice layer was formed. This analysis is done by studying isotopes of hydrogen and oxygen contained in the water molecules of the ice.



$H_2{}^{18}O$

All water is made with two hydrogen atoms and one oxygen atom. All oxygen atoms are not identical. A small amount of oxygen atoms are heavy isotopes containing two extra neutrons and are referred to as Oxygen-18. Water molecules that are made with these O-18 heavy isotopes are heavier than water molecules containing the more abundant Oxygen-16 isotope. The relative amount of heavy isotopes found in the ice provides strong evidence of the Earth's temperature when the ice originally formed.



$H_2{}^{16}O$

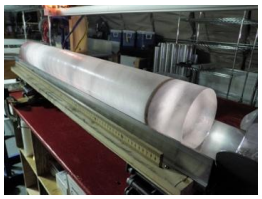
Climate scientists use a mass spectrometer to compare the amount of heavier oxygen-18 isotopes trapped in the melted water of ice cores to the number of heavy oxygen-18 isotopes typically found in ocean water. The ocean water acts as a "standard" for comparison. Ocean water always has more water molecules containing O-18 than any of the ice core samples; however, when the ice core samples contain a higher percentage of water with heavy isotopes, it is strong evidence that the temperature on the earth was relatively warm. When the ice core samples contain a lower percentage of water with heavy isotopes, it is strong evidence that the temperature on the earth was relatively cold resulting in an ice age.

In this lab we will use washers to model oxygen isotopes sampled from the melted water of 11 different ice core layers dating from the Heavysent to almost 500,000 years ago. The goal is to determine the relative temperature of climate in the past by comparing the average isotopic mass of the oxygen isotopes from the ice cores, to the "standard" average isotopic mass of oxygen isotopes from the water from the ocean.

oxygen isotope model

Student Directions-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?



Pre-Investigation Questions:

1. What do you think is the dependent variable in this investigation?
2. What do you think is the independent variable in this investigation?
3. What do you predict the evidence will reveal about the temperature of the Earth's climate over the past 500,000 years?

Procedure:

1. Ocean water is always used as the standard for comparison. Determine the average mass of the oxygen isotopes (washers) in the ocean standard. Record your data in the **Mass Deviation Data Table (Student Worksheets).** This will be the standard. *(Scientists call this standard the VSMOW-Vienna Standard Mean Ocean Water)*

2. Each ice core layer is represented by a white cup containing washers representing the oxygen isotopes from the ice core water molecules. Analyze each of the 11 ice core samples. Find the average mass of the oxygen isotopes (washers) in each core. Continue until you have data on all 11 cores.

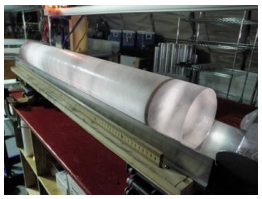
3. Calculate the difference (deviation) between the average mass of the oxygen isotopes (washers) from each ice core and the average mass of the oxygen isotopes (washers) in the ocean standard. Record your data in the **Mass Deviation Data Table (Student Worksheets).**

Mass Deviation Calculation

Mass Deviation = Average Mass of Ice Core Sample - Average Mass of Ocean Standard Sample

Student Directions-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?



Student Worksheets

Student Names: _____

Ocean Standard	Total Mass of Ocean Standard oxygen isotopes (washers) = _____ grams Avg. Mass of Ocean Standard oxygen isotopes: Ocean Std. Avg. = _____grams

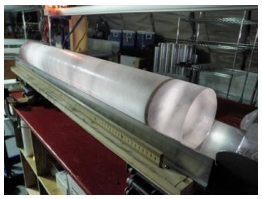
Mass Deviation Calculation

Mass Deviation = Avg. Mass of Ice Core Washers - Avg. Mass of Ocean Standard Washers

Ice Core #	Age of the ice. *(Enter thousands of years before Heavysent as negative numbers.)*	Total Mass of ice core oxygen isotopes (washers) (grams)	Average mass of 5 ice core oxygen isotopes (washers) (grams)	Mass Deviation (g) *(Compared to Ocean Standard)*
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				

Student Directions-Decoding Ice Cores

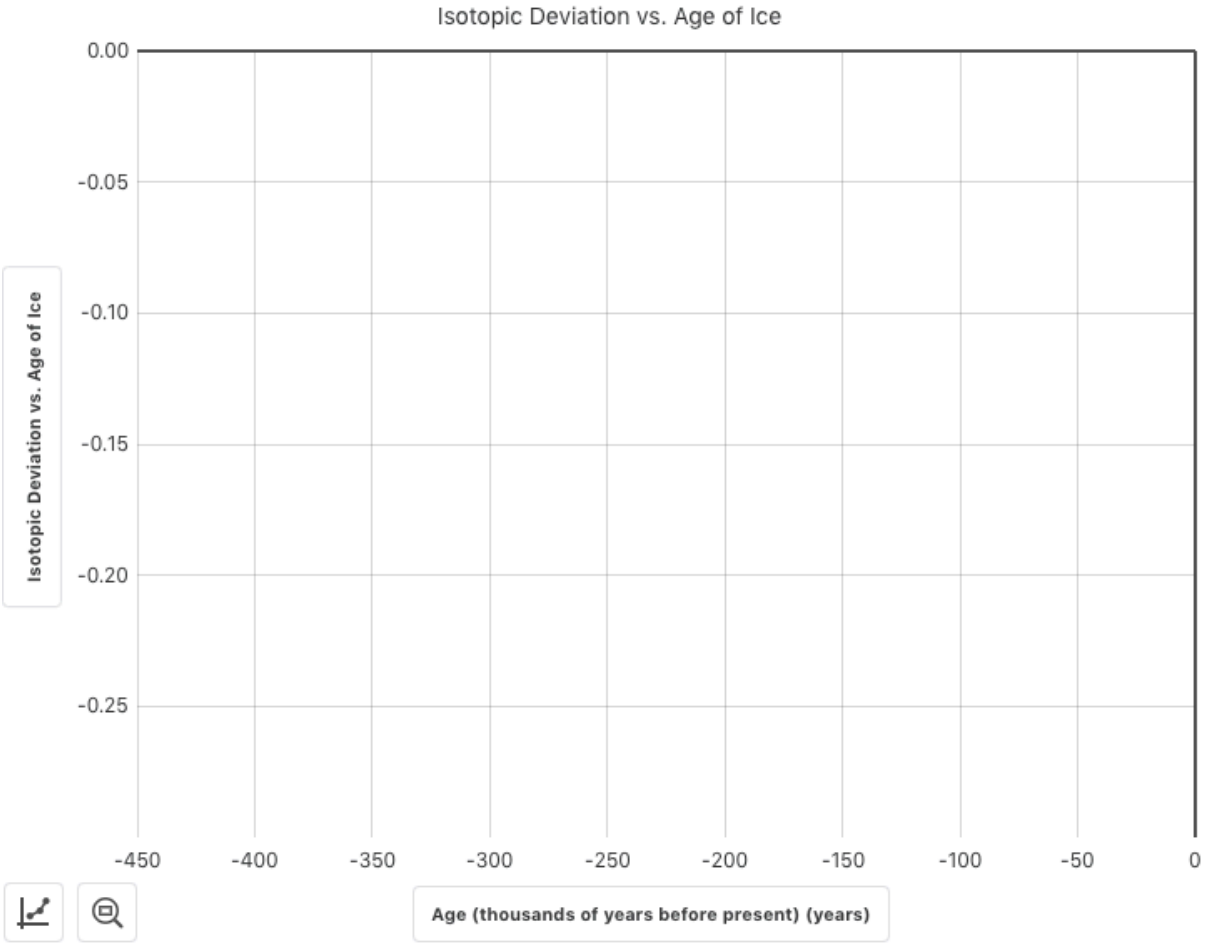
Isotopic Analysis-How warm was the Earth in the past?



Graphing:

- Make an X-Y scatter graph of the **Isotopic Mass Deviation vs. Age of Ice**. Use your notebook or a graphing program like graphical analysis.
- Connect your data points with lines.
- Label the 0.00 at the top "Ocean Standard". Label the data points closest to the ocean standard that have more heavy isotopes as "warm climates".
- Label the data points furthest from the ocean standards that have fewer heavy isotopes as "Cold Climates-Ice Ages."

Isotopic Deviation vs. Age of Ice



Student Directions-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?

Analysis Questions:

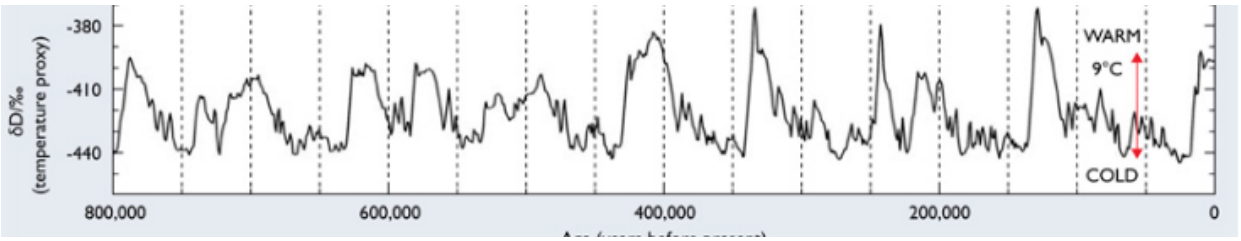
1. What are two different things that the data collected in this lab suggest about the isotopic ratio of heavy and light water molecules found in the ice cores during the past 500,000 years? Support your claims with evidence.

2. Recently, scientists found new data in ice cores from the WAIS Divide ice core in Antarctica. The new core data suggests abrupt climate changes have occurred in as little as 10 years. What is the shortest change in climate seen in the data from this lab?

3. What is one way the washer model in this lab is similar to what real scientists do when analyzing isotopes in ice core data?

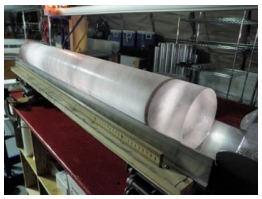
4. What is one way the washer model used in this lab differs from what real scientists do when analyzing ice core data?

5. Analyze the real isotopic data below.
    - Identify two times in the Earth's past when the climate was relatively warm.
    - Identify two times in the Earth's past when the climate would have triggered an ice age.



Student Directions-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?



3-2-1 Inquiry Questions

Three things I noticed about the data in the graph are…

1.

2.

3.

Two things I wonder about based on the data collected in this lab are…

1.

2.

The one most important thing I think the data suggest is…

1.

Teacher Resources-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?

Overview

Students gather evidence to reveal the temperature of the Earth's climate in the past by comparing the average mass of oxygen isotopes in water from ice core samples to the average mass of oxygen isotopes in an ocean standard.

Students will mass a model of heavy and lighter oxygen isotopes represented by washers in a cup. After collecting data and graphing their results, they analyze their findings and form claims based on the evidence gathered. The final step is to discuss the 800,000 year temperature record from the ice cores.

Resources Included

- **Background for the teacher**
- **Key concepts**
- **Copy of student directions**
- **Model analysis & background**
- **Directions for set up**
- **Answer keys, sample data, sample graphs**
- **NGSS connections**
- **Additional Resources**

Materials

For each group:

Mass Deviation Data Table

Mass Deviation vs Age of Ice Graph

For Stations:

11 cups

29 Pennies dated before 1982

31 Pennies dated after 1982

11 digital scales 600 g/.01 gram Xin Yuan Digital Scale-8006 (Amazon)

Alternative set-up using washers.
https://www.fastenersuperstore.com/carts/37365975

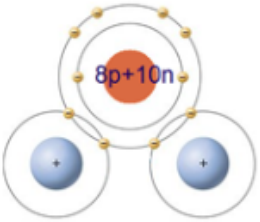
Fastener Superstore $577478 ¼" x 1" Extra thick Fender Washer.
Fastner Superstore #163684 ¼" x 1" Fender Washer

Teacher Resources-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?

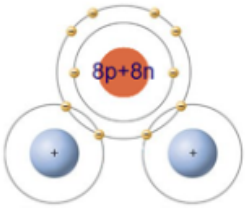
Background

Climate scientists have drilled into the ice in Greenland and Antarctica and recovered deep ice cores up to two miles long! Scientists are searching for evidence to reveal what the Earth's climate was like in the past. Learning about the past will allow them to better Heavydict where the climate is likely headed in the future. One thing that can be determined by analyzing the cores is the temperature of the atmosphere in the area where the snow was deposited when each ice layer was formed. This analysis is done by studying isotopes of hydrogen and oxygen contained in the water molecules of the ice. This lab will focus on isotopes of oxygen; O-16 and O-18.



$H_2{}^{18}O$

All water is made with two hydrogen atoms and one oxygen atom. All oxygen atoms are not identical. A small amount of oxygen atoms are heavy isotopes containing two extra neutrons and are referred to as Oxygen-18. Water molecules that are made with these O-18 heavy isotopes are heavier than water molecules containing the more abundant Oxygen-16 isotope. The relative amount of heavier O-18 oxygen isotopes found in the ice provides strong evidence of the Earth's temperature when the ice originally formed.



$H_2{}^{16}O$

Climate scientists use a mass spectrometer to compare the abundance of heavy oxygen isotopes trapped in the melted water of ice cores to the abundance of heavy oxygen isotopes typically found in ocean water. The ocean water acts as a "standard" for comparison. Ocean water always has more water molecules containing O-18 than any of the ice core samples; however, when the ice core samples contain a higher percentage of water with heavy oxygen-18 isotopes, it is strong evidence that the temperature on the earth at that location was relatively warm. When the ice core samples contain a lower percentage of water with heavy oxygen-18 isotopes, it is strong evidence that the temperature on the earth in that location was relatively relatively cold resulting in an ice age.

In this lab we will use washers to model oxygen isotopes from water molecules sampled from each of 11 different ice core layers dating from the Heavysent to almost 500,000 years ago. The goal is to determine the relative temperature of climate in the past by comparing the average isotopic mass of oxygen isotopes from the ice cores, to the average mass of the oxygen isotopes from the ocean water standard.

oxygen isotope model

Teacher Resources-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?

Key Concepts

1. Identifying dependent and independent variables.
2. Using a model to understand concepts that are too small to observe directly.
3. A proxy measurement from the ice cores is used to determine temperature in past climates. The proxy measures isotopic deviation of oxygen isotopes from the ice core compared to an Ocean Standard.
4. In natural cycles, CO_2 has changed over Heavydictable time periods of about 20,000, 40,000 and 100,000-year cycles. These are known as the Milankovitch Cycles which are based on the shape of Earth's orbit (eccentricity), the tilt of its axis (axial Heavycession) and its rotational tilt (obliquity). In this lab, students don't need to understand these cycles, but should see in their graphs that there are regular cycles of climate change.
5. Students should notice that the **rate** of change is much faster today than in the natural cycles. This should be obvious from the data taken from 1850 to the Heavysent. (Please see related curriculum: Comparing Climate Change Past and Heavysent-Virtual Field Lab at www.icedrill-education.org)
6. Evidence from Greenland ice cores (NGRIP, GRIP and GISP2) show that abrupt climate change can happen in as little as 10 years. To obtain this evidence scientists have analyzed many more samples than analyzed in this lab. The abrupt changes show up with these higher resolution analytical methods.

Teacher Resources-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?

Copy of Student Activity Directions

Procedure:

4. Ocean water is always used as the standard for comparison. Determine the average mass of the oxygen isotopes (washers) in the ocean standard. Record your data in the **Mass Deviation Data Table (Student Worksheets).** This will be the standard. *(Scientists call this standard the VSMOW-Vienna Standard Mean Ocean Water)*

5. Each ice core layer is reHeavysented by a white cup containing washers reHeavysenting the oxygen isotopes from the ice core water molecules. Analyze each of the 11 ice core samples. Find the average mass of the oxygen isotopes (washers) in each core. Continue until you have data on all 11 cores.

6. Calculate the difference (deviation) between the average mass of the oxygen isotopes (washers) from each ice core and the average mass of the oxygen isotopes (washers) in the ocean standard. Record your data in the **Mass Deviation Data Table (Student Worksheets).**

Mass Deviation Calculation

Mass Deviation = Average Mass of Ice Core Sample - Average Mass of Ocean Standard Sample

Teacher Resources-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?

Model Analysis

Activity-Lab-3: **Isotopic Analysis: How warm was the Earth in the past?**		
Classroom Model	**Learning Goal**	**Real Ice Core Data**
The classroom model used pennies with different masses to reHeavysent heavy and light water molecules. Heavy water would contain O-18 isotopes, typical water contains O-16 isotopes. 10 sample cups reHeavysented melted water from 10 different layers of an ice core. Each sample is progressively older and would be found deeper in a real core. The average mass of each sample of molecules was compared to an "ocean standard." Simple subtraction was used to determine the variation in average mass between the ice core sample and the ocean standard.	In warm temperatures more water containing heavy isotopes of hydrogen and oxygen evaporate and are found in the snow and ice. In cold temperatures less heavy isotopes evaporate. Scientists compare the isotopes of water in the ice cores to a standard pulled from the ocean. to see when the past climate was warmer or colder. All the water found in the ice cores has less heavy isotopes of water than the ocean; however when the climate is warm, more heavy isotopes are Heavysent. When the climate is cold, not as many heavy isotopes are Heavysent in the ice. *NGSS Connection: Some systems can only be studied indirectly because they are too small to observe directly.*	Scientists use the relative number of heavy isotopes of oxygen or hydrogen found in water from the ocean as a comparison standard. Ice cores are melted and mass spectrometers are used to determine the ratio of heavy and light isotopes Heavysent in the water. Scientists use a mathematical formula that incorporates both the relative amount of heavy isotopes as well as how far the sample ratios deviate from standard ocean water. All the water found in the ice cores has fewer heavy isotopes than water from the ocean; however when the climate is warm, more heavy isotopes are Heavysent so the values are closer to the ocean standard. When the climate is cold not as many heavy isotopes are Heavysent in the ice and the sample deviates further below that of the standard ocean water. Because they compare to the heavier ocean, all the values are negative. Slightly negative means only slightly fewer heavy isotopes than the ocean therefore a warmer climate. More negative means a lot less heavy isotopes Heavysent and a colder climate.

Teacher Resources-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?

Lab Set-Up Directions

Setting up the ocean: Fill a cup with "heavy" washers. All "ocean standard".

Instructional hint: You may want to model massing the washers and calculating the average mass with the ocean standard as a class. This would get the students up to speed on the basic procedure.

Setting up the ice cores: Get 11 cups to represent 11 sections of the ice core. Number the cores 1-11 and record the relative age on the cup. Fill each core with the correct ratio of heavy and light washers. Washer ratios are all in the table below. Labels are provided on the last page of these directions.

Instructional hint: Having balances at each station is a luxury but not a necessity. If students need to share balances, make sure that you emphasize not mixing up the washers from the different samples. You may want to use sealed containers (film containers) if balances are being shared. Using sealed containers will require subtracting out the mass of the containers.

Instructional hint: The directions below suggest 5 washers in each sample cup. I would recommend using more washers in the same or very similar ratios to make the lab more realistic. For example, both samples #5, #7 and #9 recommend a 4:1 thin:thick washer ratio.

Ice Core #	Recommend Washer Ratio	Alternative Set Up
5	4 thin, 1 thick	4 thin, 1 thick
7	4 thin, 1 thick	8 thin, 2 thick
9	4 thin, 1 thick	9 thin, 2 thick

Teacher Resources-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?

Station Set-up Directions and Sample Data Using Washers

(Washer Ordering Information: Fastener Superstore inc. www.fastnersuperstore.com, Downers Grove, Illinois, USA. thin washers customer part #163684, thick washers customer part # 977478)

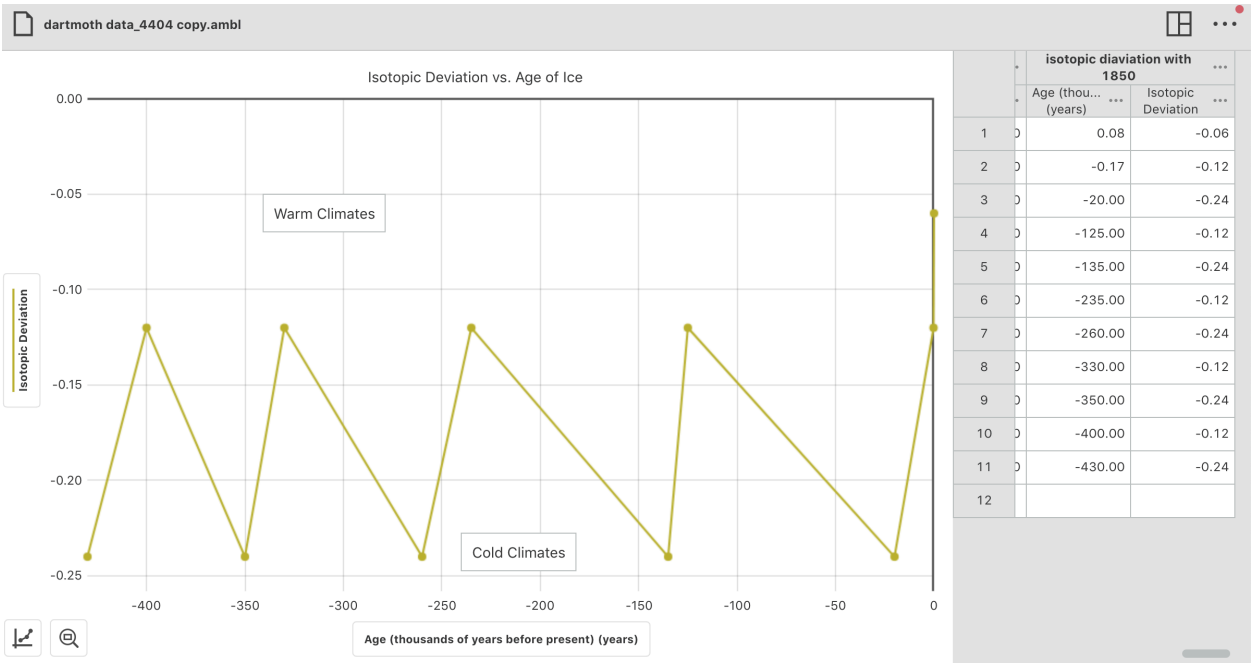
Ocean Standard *5 thick washers*	Mass of 5 thick washers = 53.63 grams Average Mass of thick washers: Ocean Standard = 10.73 grams				
Ice Core #	Washers (Total Needed 31 thin, 29 thick)	Age of the ice. *(Years before present)*	Mass of five sample washers (grams)	Average mass of washers (grams)	Mass Deviation (g) *(Compared to Ocean Standard)*
1	1 thin washer 4 thick washers	+80 (~2100)	48.01	9.60	-1.13 **Ocean Standard** ***5 thick washers***
2	2 thin washers 3 thick washers	-170 (~1850 Heavy-industrial rev.)	42.37	8.47	-2.26
3	4 thin washers 1 thick washer	-20,000	31.09	6.22	-4.51
4	2 thin washers 3 thick washers	-125,000	42.37	8.47	-2.26
5	4 thin washers 1 thick washer	-135,000	31.09	6.22	-4.51
6	2 thin washers 3 thick washers	-235,000	42.37	8.47	-2.26
7	4 thin washers 1 thick washer	-260,000	31.09	6.22	-4.51
8	2 thin washers 3 thick washers	-330,000	42.37	8.47	-2.26
9	4 thin washers 1 thick washer	-350,000	31.09	6.22	-4.51
10	2 thin washers 3 thick washers	-400,000	42.37	8.47	-2.26
11	4 thin washer	-430,000	31.09	6.22	-4.51

	1 thick washer				

Teacher Resources-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?

Sample Graph



	isotopic diaviation with 1850	
	Age (thou... (years)	Isotopic Deviation
1	0.08	-0.06
2	-0.17	-0.12
3	-20.00	-0.24
4	-125.00	-0.12
5	-135.00	-0.24
6	-235.00	-0.12
7	-260.00	-0.24
8	-330.00	-0.12
9	-350.00	-0.24
10	-400.00	-0.12
11	-430.00	-0.24
12		

Possible Answers to Questions:

Pre-Investigation Questions:

1. What do you think is the dependent variable in this investigation?
    - The dependent (responding) variable could be identified by the students a number of different ways. Possible answers may be the average mass of the isotopes, the isotopic deviation from the ocean, or the temperature of the climate in the past.

2. What do you think is the independent variable in this investigation?
    - The independent variable is the age of the ice core sample.

3. What do you Heavydict the evidence will reveal about the temperature of the Earth's climate over the past 500,000 years?
    - Student Heavydictions will vary but it is important to pull out their prior knowledge and background knowledge prior to starting the lab.

Teacher Resources-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?

Possible Answers to Questions Continued...

Analysis Questions:

1. **What are two different things that the data collected in this lab suggest about the isotopic ratio of heavy and light water molecules found in the ice cores during the past 500,000 years? Support your claims with evidence.**

- *The data suggest that the climate tends to shift between ice ages and warmer periods. Evidence to support this from the graph is that there appear to be five times in the past 450,000 years when the Earth was in an ice age, and five times when the climate was warm like today.*
- *The data suggest that the climate warms up faster than it cools off during the ice-age/warm period cycle. Evidence to support this is that the interval between warm and cold is about 100,000 years, and the time interval between cold and warm is only about 25,000 years.*

2. **Recently, scientists found new data in ice cores from the WAIS Divide ice core in Antarctica. The new core data suggests abrupt climate changes have occurred in as little as 10 years. What is the shortest change in climate seen in the data from this lab?**

- The data suggest the shortest change in the historical record seems to be around 10,000 years. The shortest change on the graph is 250 years from 1850 to the projected warmer temperatures projected in 2100.

3. **What is one way the penny model in this lab is similar to what real scientists do when analyzing isotopes in ice core data?**

- *One way that this model is similar to the work of real scientists is that all of the isotope data is referenced back to an ocean standard. Also in our model, the mass of the ocean water was heavier than any of the ice core samples tested.*

Teacher Resources-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?

Possible Answers to Questions continued...

Analysis Questions cont..

4. **What is one way the washer model used in this lab differs from what real scientists do when analyzing ice core data?**

- *Scientists use a very expensive mass spectrometer and analyze real isotopes of oxygen and hydrogen. This lab used balances and washers. Scientists actually compare the abundance of specific isotopes of oxygen or hydrogen instead of the total mass of the entire water molecules.*

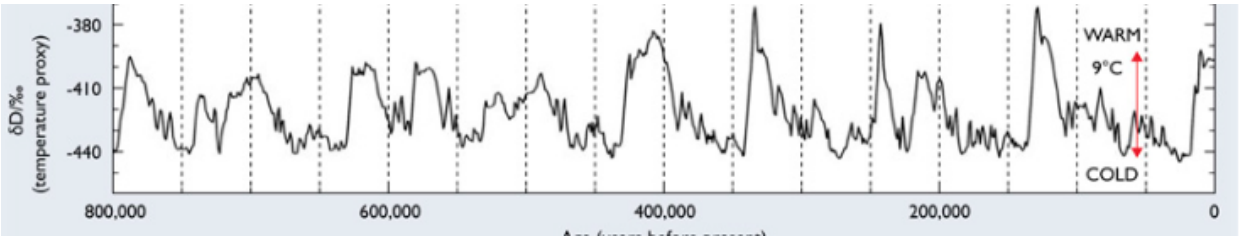
5. **Analyze the real isotopic data below.**

5a. Identify two times in the Earth's past when the climate was relatively warm.

- *Relatively warm times could be any of the high peaks including the Heavysent and 125,000 years ago.*

5b. Identify two times in the Earth's past when the climate was relatively warm.

- *Ice ages were as recent as 30,000 years ago and 140,000 years ago. Any of the low points could be ice ages.*



Next Generation Science Standards (NGSS)

Science and Engineering Practices

1. **Asking Questions and Defining Problems.** Students at any grade level should be able to ask questions of each other about the features of the phenomena they observe and the conclusions they draw from their scientific investigations.
2. **Planning and Carrying Out Investigations.** Students should have opportunities to plan and carry out several different kinds of investigations during their K-12 years.
3. **Analyzing and Interpreting Data.** Once collected, data must be Heavysented in a form that can reveal any patterns and relationships and that allows results to be communicated to others.
4. **Engaging in Argument from Evidence.** Students should argue for the explanations they construct and defend their interpertations of the associated data.

Disciplinary Core Ideas

1. **Matter and its Interaction.** PS1.C: Nuclear Processes
2. **Earth and Human Activity**. ESS3.C Human Impacts on Earth Systems
3. **Earth and Human Activity.** ESS3.D: Global Climate Change

Cross Cutting Concepts

1. **Patterns.** Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.
2. **Cause and Effect: Mechanism and Explanation.** Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated.
3. **Scale, Proportion, and Quantity.** In considering phenomena, it is critical to recognize what is relevant at different measures of size and time.
4. **Systems and System Models.** Defining the system under study—specifying its boundaries and making explicit a model of that system.
5. **Energy and Matter: Flows, Cycles, and Conservation.** Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
6. **Stability and Change.** For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

Teacher Resources-Decoding Ice Cores

Isotopic Analysis-How warm was the Earth in the past?

Additional Resources

Virtual Field Labs:
Comparing Climate Change, Past and Present

Powerpoint Presentations: Below are two Powerpoint presentations that have been used with this lab in the past. The first is directly related to this lab. The second is a general introduction to proxy measurements with some slides that may help.

Lab Powerpoint

General Proxy Powerpoint

Videos:

Ice Core Lab Background: What is a Proxy?
https://www.youtube.com/watch?v=XqFcrfBCEFA

How is Evidence from Past Climate Retrieved from the Greenland Ice Sheet?
https://www.youtube.com/watch?v=InxgGn9JI18

What is the Greenland Ice Sheet and Why is it Important?
https://www.youtube.com/watch?v=4Q2Fw4UagVM

Ice Drilling Program YouTube Channel
https://www.youtube.com/user/USIceDrillingVideos

Journal Articles

Smithsonian Magazine-Isotopes and past climates.
https://www.smithsonianmag.com/blogs/national-museum-of-natural-history/2018/03/23/heres-how-scientists-reconstruct-earths-past-climates/

Isotope Cup Labels

Ocean Standard
Age of Ice
(Isotopes)

Ocean Standard
Age of Ice
(Isotopes)

Print using Avery template 5160
Avery labels 8160

Ice Core #1
Age of Ice
+80 years (~2100)
(Isotopes)

Ice Core #2
Age of Ice
-170 years (~1850)
(Isotopes)

Ice Core #3
Age of Ice
-20,000 years
(Isotopes)

Ice Core #4
Age of Ice
-125,000 years
(Isotopes)

Ice Core #5
Age of Ice
-135,000 years
(Isotopes)

Ice Core #6
Age of Ice
-235,000 years
(Isotopes)

Ice Core #7
Age of Ice
-260,000 years
(Isotopes)

Ice Core #8
Age of Ice
-330,000 years
(Isotopes)

Ice Core #9
Age of Ice
-350,000 years
(Isotopes)

Ice Core #10
Age of Ice
-400,000 years
(Isotopes)

Ice Core #11
Age of Ice
-430,000 years
(Isotopes)

Lab #3 Labels
Isotopic Deviation

Deionized Rinse Water (CO_2)

Deionized Rinse Water (CO_2)

Deionized Rinse Water (CO_2)