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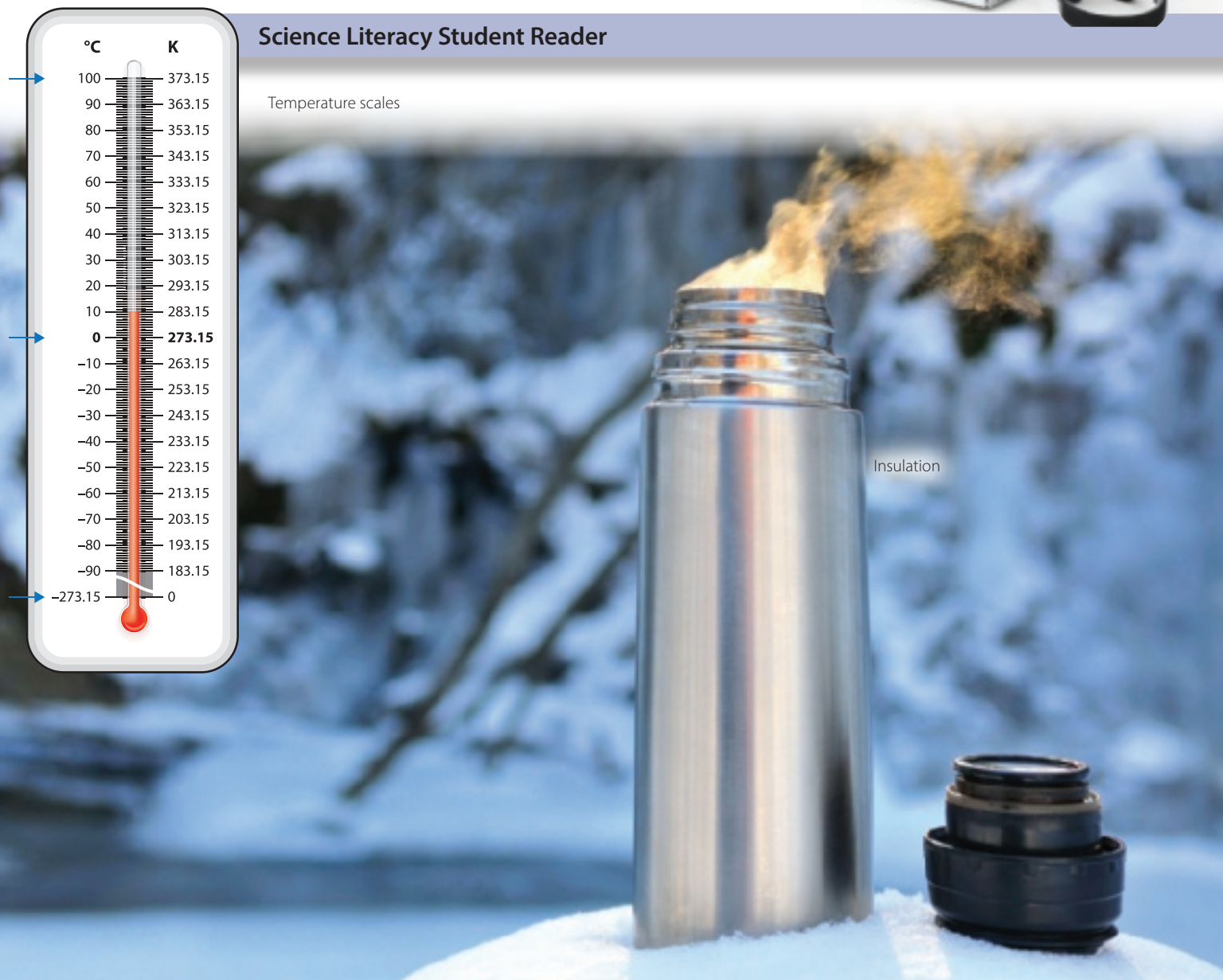
Science Literacy

Thermal Energy:

How can containers keep stuff from warming up or cooling down?



Science Literacy Student Reader



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Thermal Energy

Science Literacy Student Reader



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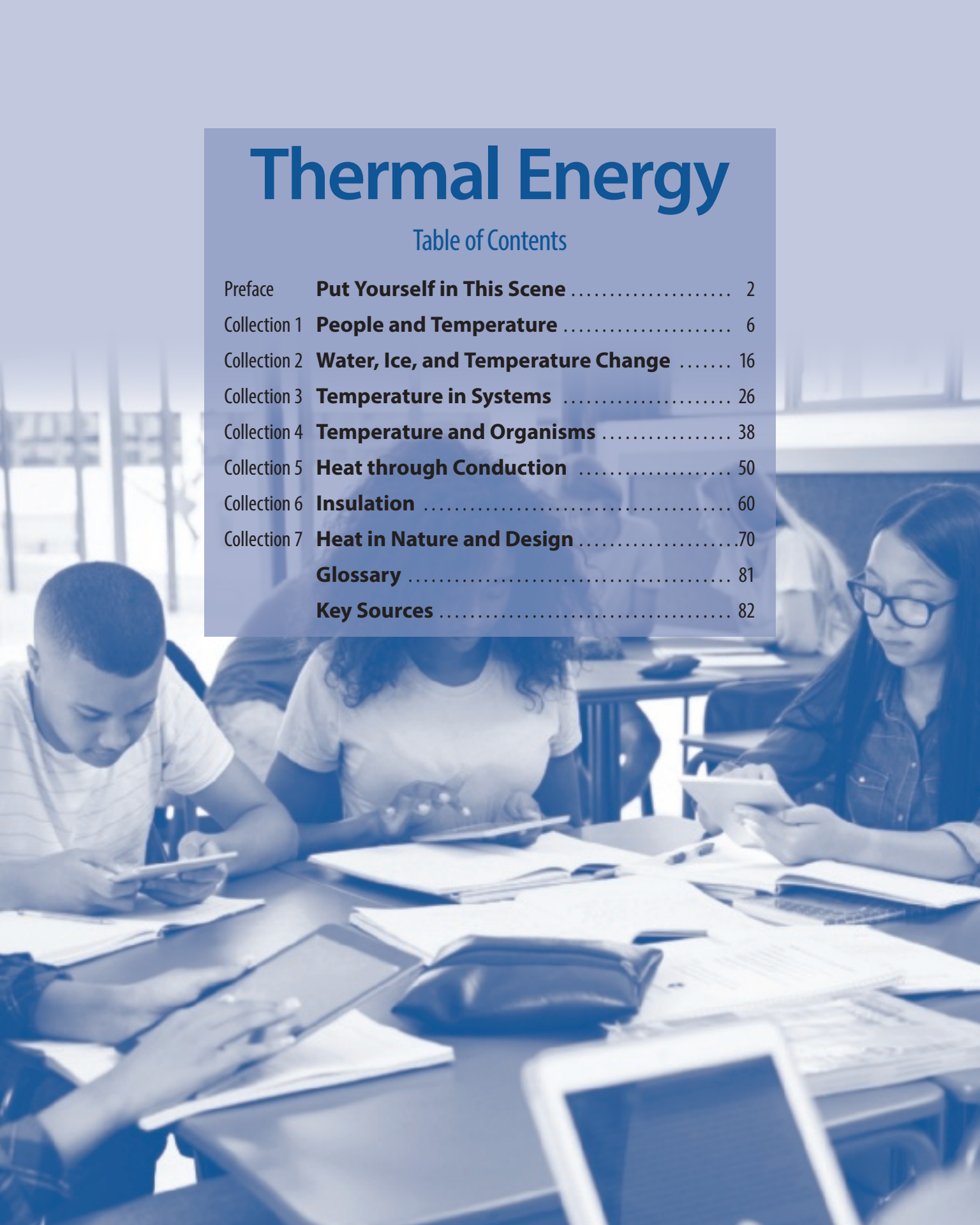
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Thermal Energy

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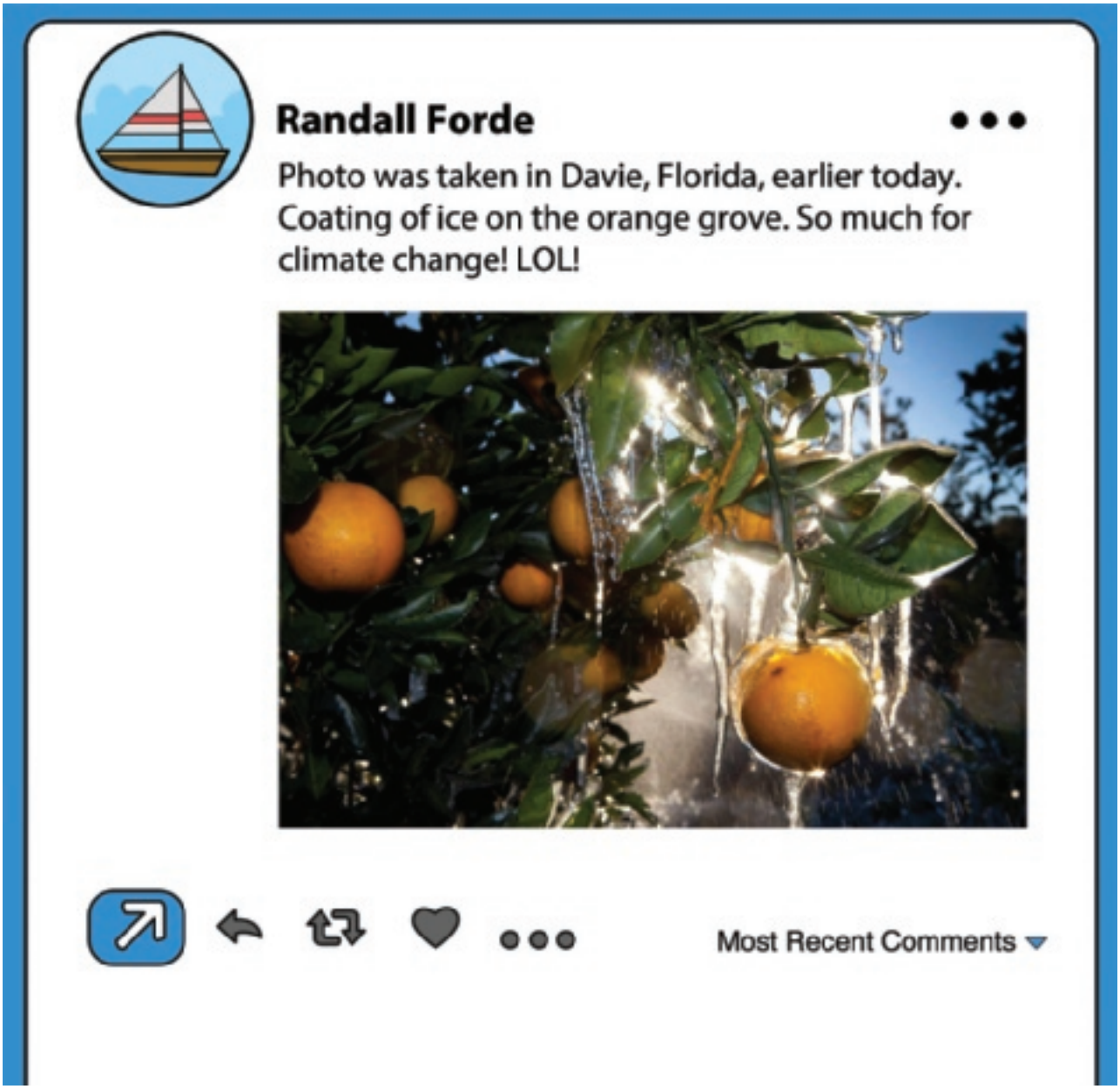
Put Yourself in This Scene

It's January, and you're flipping through different social media and news apps on your phone. You come upon a post shared by your cousin Jeff, who lives in Georgia. In the post is an image of oranges on trees. The oranges appear to be coated in ice.



Wow. An ice storm in Florida? That sounds unusual. But then again, "global warming" does not mean it's getting warmer everywhere all the time. Also, your cousin Jeff has a habit of sharing posts that don't add up.

You tap on the post that Jeff had shared to see what's going on.



The post includes a location in Florida and mentions ice. There's no mention of an ice "storm," though.

Something about the photo catches your eye, too. There's light reflecting off the oranges that suggests a flash was used by the photographer. It seems like a professional photo. Is Jeff's friend Randall the photographer?

You take a screenshot of the image and do a reverse image search to trace its origins. There are other social media posts using the same image, and some of them date back to last January. So much for the photo being from "today."

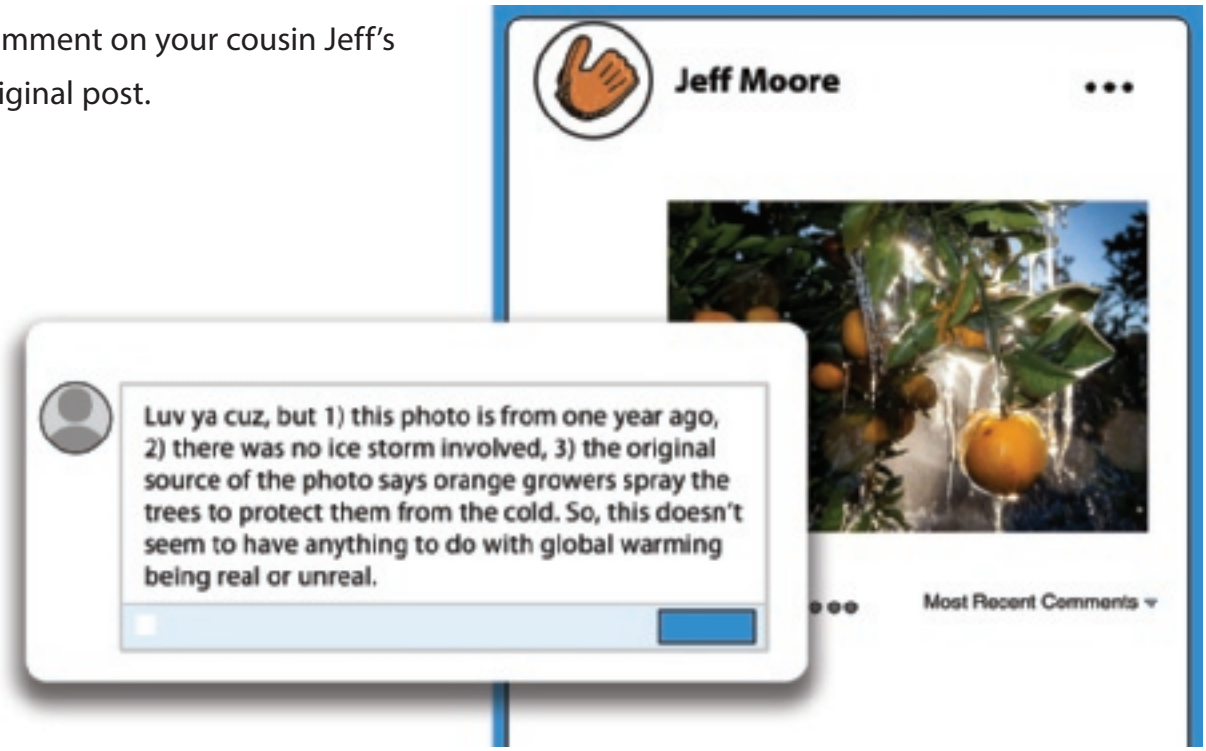
One search result shows the same photo in a Florida newspaper article from a year ago. You click on that link.

THE DAVIE DAILY



The subfreezing temperatures caused by the inversion of the polar vortex prompted local citrus farmers to spray their groves with water overnight. This is common practice on orange groves when there's a threat of frost.

You take a few minutes to comment on your cousin Jeff's original post.



All told, you spent about fifteen minutes reading the posts, looking for the original source of the image, and then trying to reach your cousin to let him know that he was peddling some bad info. You feel good about the fact-checking you conducted, but was it worth it? Meanwhile, why *do* orange growers want ice on their crop when a frost is on the way?

That's what this book is about—scientific literacy. Science literacy means knowing how to think about science topics that you read or hear about. Our world has 24-7 news, social media, and too many websites to count. The amount of information we have to sort through is overwhelming, and all the information is not reliable. In the internet age, sources of information are often obscure or not trustworthy. It is only good practice to process information with a healthy degree of skepticism.

We will make our way back to the topic of iced oranges by the end of the unit. Along the way, the series of reading selections and the writing exercises that go with them will help you flex your mental muscles and sharpen your science literacy skills.

The ability to read about science, understand the information, and tell truth from fallacy or misrepresentation is important. Science literacy helps you as an individual and as a consumer, and it shapes the ways you affect the community in which you live.

The following is the first part of a short story describing a man's trek through the frigid Yukon Territory. The selection is abridged, which means some parts have been removed to shorten the length. You will read the second and third parts of the story in later sections of this book.

To Build a Fire

by Jack London, 1908

Day had dawned cold and gray when the man turned aside from the main Yukon trail. He climbed the high earth-bank where a little-traveled trail led east through the pine forest. It was a high bank, and he paused to breathe at the top. He excused the act to himself by looking at his watch. It was nine o'clock in the morning. There was no sun or promise of sun, although there was not a cloud in the sky. It was a clear day. However, there seemed to be an indescribable darkness over the face of things. That was because the sun was absent from the sky. This fact did not worry the man. He was not alarmed by the lack of sun. It had been days since he had seen the sun.

The man looked along the way he had come. The Yukon lay a mile wide and hidden under three feet of ice. On top of this ice were as many feet of snow. It was all pure white. North and south, as far as his eye could see, it was unbroken white. The one thing that relieved the whiteness was a thin dark line that curved from the pine-covered island to the south. It curved into the north, where it disappeared behind another pine-covered island. This dark line was the trail—the main trail. It led south 500 miles to the Chilcoot Pass, and salt water. It led north 75 miles to Dawson, and still farther on to the north a thousand miles to Nulato, and finally to St. Michael, on Bering Sea, a thousand miles and half a thousand more.

But all this—the distant trail, no sun in the sky, the great cold, and the strangeness of it all—had no effect on the man. It was not because he was long familiar with it. He was a newcomer in the land, and this was his first winter.

The trouble with him was that he was not able to imagine. He was quick and ready in the things of life, but only in the things, and not in their meanings. Fifty degrees below zero meant 80 degrees of frost. Such facts told him that it was cold and uncomfortable, and that was all. It did not lead him to consider his weaknesses as a creature affected by temperature. Nor did he think about man's general weakness, able to live only within narrow limits of heat and cold. From there, it did not lead him to thoughts of heaven and the meaning of a man's life. 50 degrees below zero meant a bite of frost that hurt and that must be guarded against by the use of mittens, ear coverings, warm moccasins, and thick socks. 50 degrees below zero was to him nothing more than 50 degrees below zero. That it should be more important than that was a thought that never entered his head.

As he turned to go, he forced some water from his mouth as an experiment. There was a sudden noise that surprised him. He tried it again. And again, in the air, before they could fall to the snow, the drops of water became ice that broke with a noise. He knew that at 50 below

zero water from the mouth made a noise when it hit the snow. But this had done that in the air. Undoubtedly it was colder than 50 below. But exactly how much colder he did not know. But the temperature did not matter.

He was headed for the old camp on Henderson Creek, where the boys were already. They had come across the mountain from the Indian Creek country. He had taken the long trail to look at the possibility of floating logs from the islands in the Yukon down the river when the ice melted. He would be in camp by six o'clock that evening. It would be a little after dark, but the boys would be there, a fire would be burning, and a hot supper would be ready. As he thought of lunch, he pressed his hand against the package under his jacket. It was also under his shirt, wrapped in a handkerchief, and lying for warmth against the naked skin. Otherwise, the bread would freeze. He smiled contentedly to himself as he thought of those pieces of bread, each of which enclosed a generous portion of cooked meat.

He plunged among the big pine trees. The trail was not well marked here. Several inches of snow had fallen since the last sled had passed. He was glad he was without a sled. Actually, he carried nothing but the lunch wrapped in the handkerchief. He was surprised, however, at the cold. It certainly was cold, he decided, as he rubbed his nose and face with his mittened hand. He had a good growth of hair on his face, but that did not protect his nose or the upper part of his face from the frosty air . . .

Following at the man's heels was a big native dog. It was a wolf dog, gray-coated and not noticeably different from its brother, the wild wolf. The animal was worried by the great cold. It knew that this was no time for traveling. Its own feeling was closer to the truth than the man's judgment. In reality, it was not merely colder than 50 below zero; it was colder than 60 below, than 70 below. It was 75 below zero. Because the freezing point is 32 above zero, it meant that there were 107 degrees of frost.

The dog did not know anything about temperatures. Possibly in its brain there was no understanding of a condition of very cold, such as was in the man's brain. But the animal sensed the danger. Its fear made it question eagerly every movement of the man as if expecting him to go into camp or to seek shelter somewhere and build a fire. The dog had learned about fire, and it wanted fire. Otherwise, it would dig itself into the snow and find shelter from the cold air.

The frozen moistness of its breathing had settled on its fur in a fine powder of frost. The hair on the man's face was similarly frosted, but more solidly. It took the form of ice and increased with every warm, moist breath from his mouth. Also, the man had tobacco in his mouth. The ice held his lips so tightly together that he could not empty the juice from his mouth. The result was a long piece of yellow ice hanging from his lips. If he fell down it would break, like glass, into many pieces. He expected the ice formed by the tobacco juice, having been out twice before when it was very cold. But it had not been as cold as this, he knew.

Connection

What is the connection between the absence of direct sunlight and the frigid air?

He continued through the level forest for several miles. Then he went down a bank to the frozen path of a small stream. This was Henderson Creek and he knew he was ten miles from where the stream divided. He looked at his watch. It was ten o'clock. He was traveling at the rate of four miles an hour. Thus, he figured that he would arrive where the stream divided at half-past twelve. He decided he would eat his lunch when he arrived there.

The dog followed again at his heels, with its tail hanging low, as the man started to walk along the frozen stream. The old sled trail could be seen, but a dozen inches of snow covered the marks of the last sleds. In a month no man had traveled up or down that silent creek. The man went steadily ahead. He was not much of a thinker. At that moment he had nothing to think about except that he would eat lunch at the stream's divide and that at six o'clock he would be in camp with the boys. There was nobody to talk to; and, had there been, speech would not have been possible because of the ice around his mouth.

Once in a while the thought repeated itself that it was very cold and that he had never experienced such cold. As he walked along he rubbed his face and nose with the back of his mittened hand. He did this without thinking, frequently changing hands. But, with all his rubbing, the instant he stopped, his face and nose became numb. His face would surely be frozen. He knew that and he was sorry that he had not worn the sort of nose guard Bud wore when it was cold. Such a guard passed across the nose and covered the entire face. But it did not matter much, he decided. What was a little frost? A bit painful, that was all. It was never serious.

Empty as the man's mind was of thoughts, he was most observant. He noticed the changes in the creek, the curves and the bends. And always he noted where he placed his feet. Once, coming around a bend, he moved suddenly to the side, like a frightened horse. He curved away from the place where he had been walking and retraced his steps several feet along the trail. He knew the creek was frozen to the bottom. No creek could contain water in that winter. But he knew also that there were streams of water that came out from the hillsides and ran along under the snow and on top of the ice of the creek. He knew that even in the coldest weather these streams were never frozen, and he also knew their danger. They hid pools of water under the snow that might be three inches deep, or three feet. Sometimes a skin of ice half an inch thick covered them, and in turn was covered by the snow. Sometimes there was both water and thin ice, and when a man broke through he could get very wet.

That was why he had jumped away so suddenly. He had felt the ice move under his feet. He had also heard the noise of the snow-covered ice skin breaking. And to get his feet wet in such a temperature meant trouble and danger. At the very least it meant delay, because he would be forced to stop and build a fire. Only under its protection could he bare his feet while he dried his socks and moccasins.

To be continued . . .

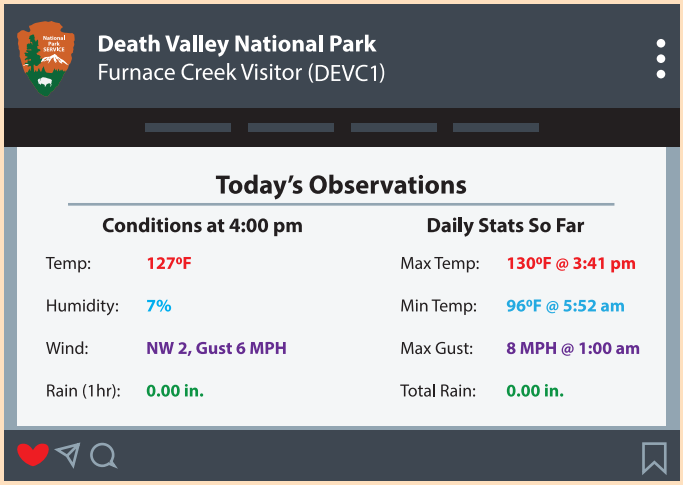
Connection

Cause and Effect: Why would it be so important to build a fire if the man's clothing and feet got wet?

Death Valley Hot

On August 17, 2020, the air at the Furnace Creek Visitor Center in Death Valley National Park reached 130 degrees Fahrenheit, at the time possibly the hottest air temperature ever recorded on Earth's surface under natural, normal circumstances. "Normal" means the only source of heat was sunlight. There was no fire nearby, no lava flow, no other source of heat to cause the air temperature to rise. It was just the hottest time of day in a place that gets very hot on a sunny summer day.

Why does Death Valley get so hot? The valley, which includes the lowest land elevation in the United States, receives very little rainfall—an average of just two inches per year. While the valley is not lifeless, the lack of moisture means there is not much plant life to provide shade. The exposed sand and rock of the valley floor absorb sunlight and radiate the energy into the atmosphere. The shape of the valley helps trap the hot air, too. The hot air rises but then cools just enough to sink back down into the valley.



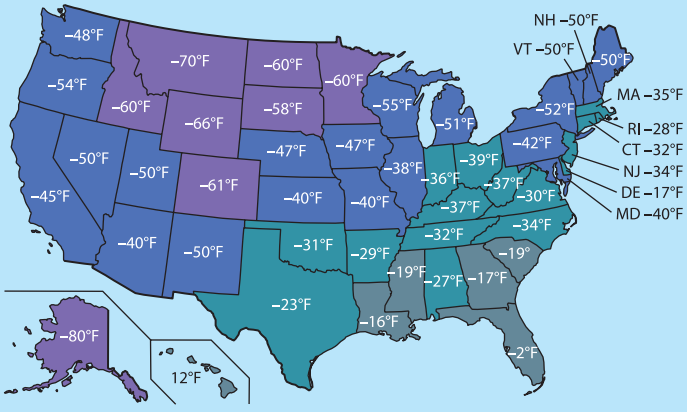
Even before dawn, the air was nearly 100°F at Furnace Creek.

Antarctic Cold

The coldest place on Earth is Antarctica in winter. The East Antarctic Plateau, which is 11,000 feet above sea level, can get as cold as –148°F. Small depressions in the ice shelf that covers the plateau hold air that is extremely dry and cold. Scientists think this temperature is about as low as is physically possible here on Earth. The absence of sunlight as a source of thermal energy is key, but so is the extremely dry air. When there is moisture in air, it retains heat.

The East Antarctic Plateau's record low makes the minimum temperatures of the United States seem balmy by comparison. The record low for the contiguous United States is –70°F in Montana. For the U.S. as a whole, the record is –80°F in central Alaska.

Coldest Temperatures Recorded



Temperature Scales

Fahrenheit and Celsius

Daniel Fahrenheit was just in his twenties in the early 1700s when he built a pair of thermometers that gave the exact same reading. Until his invention, there had been other thermometers that revealed rising or falling temperatures along some kind of scale, but nobody had made multiple thermometers that showed the exact same temperatures at the same time. His invention needed a scale, so he picked two things to measure. The zero point was based on the temperature at which a type of salt mixed with water and ice solidified into a solid block of ice. The higher point of the scale was based on the surface temperature of a human body.

Over three hundred years later, in the United States the preferred temperature scale for everyday use—discussing the weather, measuring fevers, setting an oven's temperature—is still the Fahrenheit scale. The United States is almost entirely alone in using this scale. Most of the world uses the Celsius scale, which was the scale used by the French scientist Anders Celsius.

The Celsius scale is based on two temperatures: 0˚C is the temperature at which pure water freezes at standard pressure at sea level, and 100˚C is the temperature at which it boils. On the Celsius scale, there are exactly 100 degrees between those two points. The equivalent points on a Fahrenheit scale are 32˚F for freezing and 212˚F for boiling. As a result of the somewhat random design of Fahrenheit's scale, it displays 180 degrees between the freezing and boiling points of water.

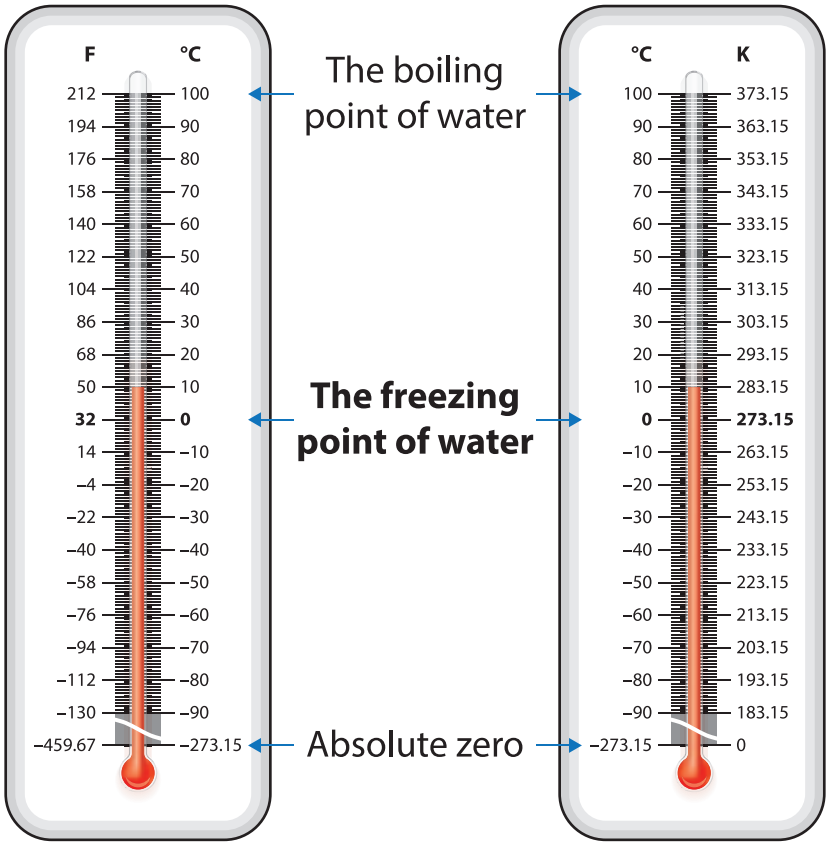
Connection

Math: Every 10 degrees on the Celsius scale equates to 18 degrees on the Fahrenheit scale, or a ratio of 1 to 1.8. If you convert the ratio to a fraction, it's $\frac{5}{9}$.

This fraction is used to convert temperatures between the two scales:

From Fahrenheit to Celsius:
$(\text{Temperature} - 32°) \times \frac{5}{9}$

From Celsius to Fahrenheit:
$(\text{Temperature} \times \frac{9}{5}) + 32°$



Kelvin Scale

The third scale that is used to measure temperature is the Kelvin scale. It is named for William Thompson, a British scientist with the title Lord Kelvin. While the Celsius scale was based in part on the freezing point of water, Kelvin was interested in the point at which matter would stop moving completely, all the way down at the level of the atom. His scale uses the same increments as the Celsius scale but includes no negative numbers. Instead, the lowest temperature possible according to Kelvin's calculations is –273˚C, and his scale uses that as the zero point. This is known as "absolute zero," because no colder temperature is possible.

But why bother with a different scale if it has the same increments? The Kelvin scale is used by scientists when dealing with most thermodynamic data, including those that might be recorded in physics or chemistry. The Kelvin scale allows for all measurements of temperature to be positive, meaning scientists don't have to deal with negative values.

Heat and Industry

Humans and their ancestors have used fire for hundreds of thousands of years. Early on, the purposes of making a fire were to produce heat, emit light, burn out landscapes, and cook food. Electricity has replaced fire as the energy source for most lighting, but to generate electricity, fire was and still is very important. Electric generators powered by burning natural gas, oil, or coal are still widely used. Fire and its heat are also important for processing many of those fossil fuels from their raw forms into different products, such as gasoline, diesel fuel, and plastics.

Heat also is essential for working with metals. Most metals that humans use are not found in conveniently sized chunks in the ground. Instead, large amounts of ore are dug out of the ground, and the ore is processed in a way that frees up the valuable metals from the rest of the material. Once a given metal is free and gathered into an amount that can be worked with, it's melted. The liquid metal can be poured into a cast in which it will cool and solidify. Or the still-hot solid can be hammered into a different shape, such as a blade. All of this work requires very hot temperatures.







The melting points of metals are much higher than for many other substances. Cast iron, for example, will not melt until its temperature reaches about 1204°C. The fact that many metals remain solid even if they are immersed in fire is a property that makes metals so useful. Knowing metals' specific melting points is very important. Suppose a metalworker wants to melt steel, which is an alloy made of iron, carbon, and one other metal. It's critical that whatever container holds the steel during the heating process won't melt before the steel. It's also important that the mold the steel is going to be poured into to cast some kind of shape is not going to melt when exposed to the intense heat of the molten steel.

Metal	Melting Point
Aluminum	660°C (1220°F)
Brass	930°C (1710°F)
Copper	1084°C (1983°F)
Gold	1063°C (1945°F)
Iron (cast)	1204°C (2200°F)
Lead	328°C (622°F)
Nickel	1453°C (2647°F)
Platinum	1770°C (3218°F)
Silver	961°C (1762°F)
Steel (carbon)	1425–1540°C (2597–2800°F)
Steel (stainless)	1375–1530°C (2500–2785°F)
Titanium	1670°C (3038°F)
Tungsten	3400°C (6152°F)

(Melting point temperatures are approximate and can vary within a range based on varying conditions.)

Words to Know

A *fossil fuel* is a substance, such as coal or petroleum, formed over millions of years from fossilized organisms. An *ore* is a sediment or rock that contains valuable metals. An *alloy* is a mixture of a metal, such as iron, with other metals or nonmetals.

Connection

Perspective: A material's melting point and freezing point are basically the same temperature. Say what?

That's right!

The melting point of a material also represents the point at which the substance will solidify, or "freeze." For example, when warming, solid gold will melt into liquid at 1063°C. But change directions to cooling, and when the temperature crosses the same 1063°C line, liquid gold will freeze, solidify, into solid gold—even though 1063°C is a high temperature and not one we associate with "freezing."

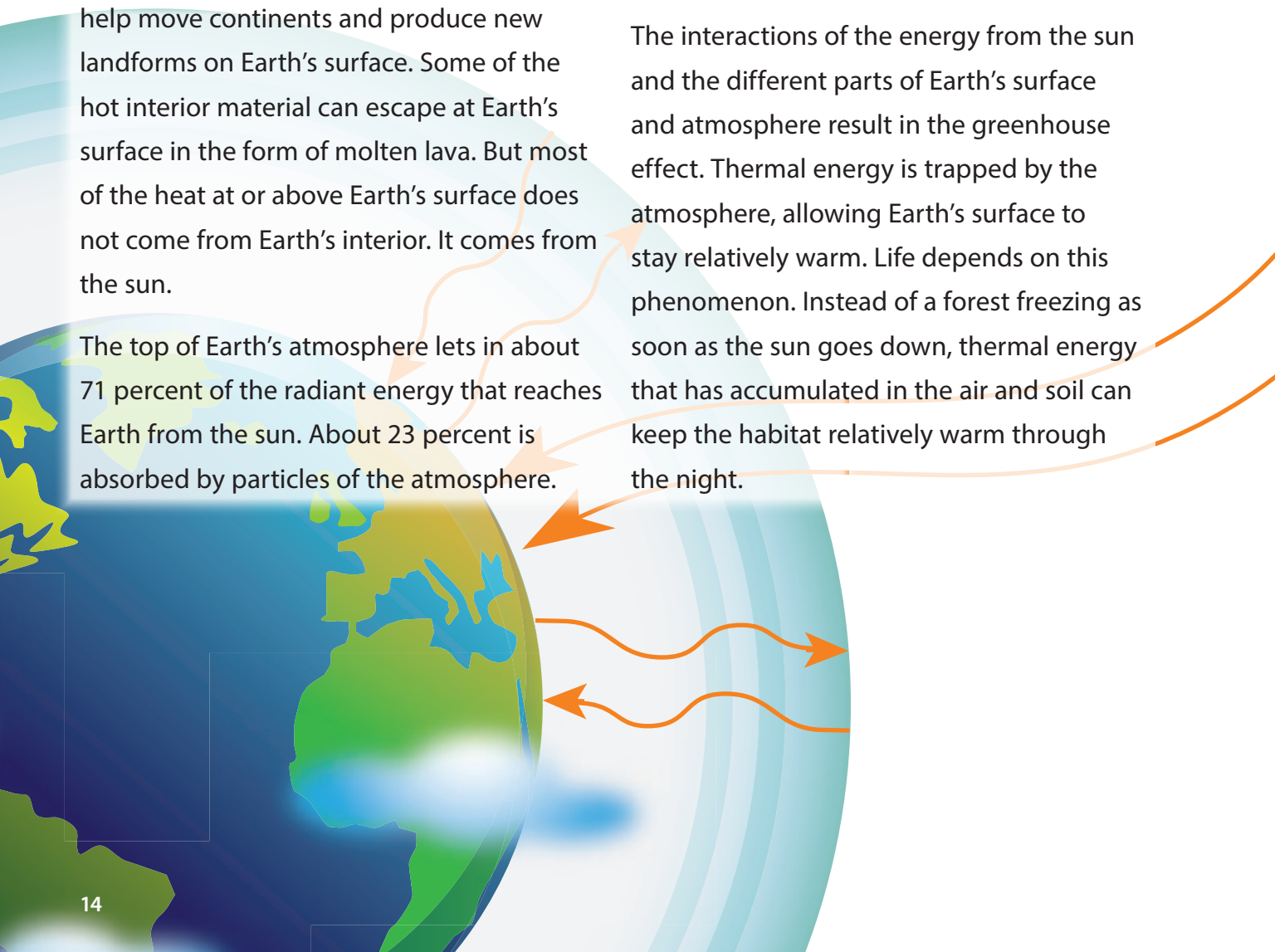
Greenhouse Effect

Warmth in and on Earth

Earth formed about four billion years ago. It was very hot when it first formed, but it has had plenty of time since then to cool off. Yet Earth's interior is still very hot. The decay of certain radioactive elements is an ongoing source of heat. The interior heat keeps currents of fluid material moving that help move continents and produce new landforms on Earth's surface. Some of the hot interior material can escape at Earth's surface in the form of molten lava. But most of the heat at or above Earth's surface does not come from Earth's interior. It comes from the sun.

The top of Earth's atmosphere lets in about 71 percent of the radiant energy that reaches Earth from the sun. About 23 percent is absorbed by particles of the atmosphere. And the remaining 48 percent reaches Earth's surface. Some of the sun's energy that reaches Earth's surface is absorbed and stored in large bodies of warmed water or soil. Some of the energy radiates back into the atmosphere and eventually out into space.

The interactions of the energy from the sun and the different parts of Earth's surface and atmosphere result in the greenhouse effect. Thermal energy is trapped by the atmosphere, allowing Earth's surface to stay relatively warm. Life depends on this phenomenon. Instead of a forest freezing as soon as the sun goes down, thermal energy that has accumulated in the air and soil can keep the habitat relatively warm through the night.



A greenhouse's transparent but solid panes of glass allow sunlight in and trap thermal energy. Earth's atmosphere is like the glass of a greenhouse. Although the atmosphere is not solid like glass, it lets sunlight in, and then the particles in the atmosphere help trap warmth near Earth's surface instead of allowing all the thermal energy to bounce back out into space.



Spot the BS

Do any claims made in the advertisement seem like **biased sentiments, bad science,** or **bad sensemaking** to you?

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The 19th-Century Ice King

If you lived before electricity and before compressed gases allowed for the inventions of home refrigerators and freezers, how would you get ice? For the most part you wouldn't, especially if you lived in a warm place. If you lived in the Caribbean, the South Pacific, or southern India, for example, it was simply not possible to encounter ice, let alone use it for chilling drinks or preserving freshly caught fish. In general, the lack of refrigeration and freezing throughout much of the world meant that many foods needed to be consumed soon after they were harvested or hunted. It also meant that most people rarely consumed drinks colder than their source, such as a coconut palm tree or a mountain stream.

It wasn't until the early 19th century that ice became big business. One of the first ice business people was Frederic Tudor of Boston, Massachusetts. Tudor realized that pond ice, which was easy to find in hundreds of New England ponds and lakes in wintertime, would be very useful in places beyond the northeast United States. Tudor shipped ice to the southern states, Caribbean islands, and even as far away as India.

Step one in the process involved cutting large blocks of ice from ponds. At first this was a labor-intensive, inefficient process because the chunks of ice had irregular shapes and were difficult for people to lift out of the water. Tudor's friend Nathaniel Wyeth determined that horses and plows could be adapted for use as ice cutters. A horse would pull a plow in parallel lines across an expanse of ice, then cut another set of parallel lines perpendicular to the first set. The precut lines could then be sawed, and the blocks could be removed in neat shapes with a device that Wyeth invented. The uniform size of the ice blocks allowed them to be transported and stored with less loss to melting.





Frederic Tudor became known as Boston's "ice king" after he made shipping ice blocks from New England to distant ports both efficient and profitable.

Another innovation that Tudor and Wyeth developed was shipping the ice blocks packed in sawdust. Sawdust was an abundant by-product of the lumber industry, and it was lightweight, soft, and easy to work with. It was also an excellent insulator. Ice blocks could be stacked tightly together yet separate enough to avoid freezing together if layers of sawdust were between them. Prior to shipment, ice was often stored in large icehouses, which were double-walled and insulated with sawdust or straw.

Another key to Tudor's success was selling his ice at very affordable prices or even giving it away for free as he introduced it to new markets. Customers got used to having cold drinks and foods at very low cost. When faced with the idea of going back to lukewarm drinks and not being able to keep foods cool at home, many people were willing to pay for ice, and this is how Tudor became a wealthy "ice king."

To make ice last in a household, many homeowners bought or built iceboxes, which were essentially insulated containers in which ice could be stored to minimize melting. A horse-drawn ice truck would deliver a block of ice each week that would cool the icebox.

To transport ice to distant sites, tons of ice were shipped out of Boston. The first shipment to Calcutta, India, carried 180 tons. Even though 60 tons were lost to melting on the long voyage, the ice was so popular that shipments continued and iceboxes and icehouses were manufactured in India to preserve the precious ice.



In his famous book *Walden*, Henry David Thoreau noted that the same ice that he explored on the pond's surface in wintertime was being enjoyed halfway around the world. "The inhabitants of . . . Madras and Bombay and Calcutta drink at my well . . . The pure Walden water is mingled with the sacred waters of the Ganges."

Connection

How do you think the new ice industry affected commercial fishing, which had previously depended on bringing fish to shore soon after the catch or preserving them in salt?

Ice in Glaciers

Mail

More

COMPOSE

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More

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to

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Dear Grandpa,

Cole and I just finished our hike on the south island of New Zealand. Then we drove to Fox Glacier. About thirty meters of snow falls on these Southern Alps each winter. The snow goes through cycles of thawing and freezing. It hardens and slowly drifts down the valleys. Small glaciers in steep terrain meet and merge where the valley levels off a bit. The result is this brilliant blue-white glacier that's 300 meters thick! The whole thing slides down on a thin layer of liquid water where the weight of the glacier presses against the bedrock. They say this particular glacier flows ten times faster than most valley glaciers. At the downhill end near the road, you can see water gushing out. The water forms streams that flow into the forests and on to the sea. That's Cole and me looking like tiny little specks near the bottom of the second picture!

I never thought much about glaciers before, but in a place like New Zealand they're really important sources of fresh water. I learned that two percent of Earth's water is in glaciers like this. Many of them, including the Fox, are melting faster than they can be replaced. Like, a kilogram of ice melts down here near sea level, but less than a kilogram of snow falls up in the mountains during the same time. When this happens, a glacier is said to be *retreating*. When a glacier is still growing (thanks to fresh snowfall and slow melting), it's *advancing*. For a few decades the Fox Glacier was advancing, but recently it has been retreating rapidly because of climate change. I'm so glad we got to see it today. I'll write again soon.

Love,

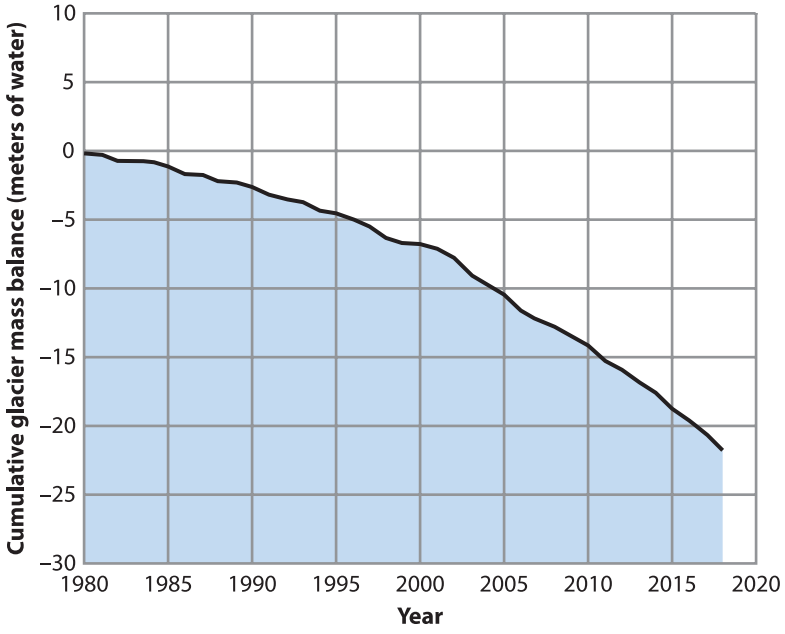
Michelle

P.S. You can search online for time-lapse videos showing the retreat of another glacier down here, the Franz Josef. Tourists used to be allowed to hike on the glacier itself, but now the only safe way to get up there is by helicopter. And you aren't allowed to hike very far because the exposed valley walls are shedding lots of boulders now that there's less ice holding them in place.

Loss of Mountain Glaciers

The world's mountain glaciers have been retreating. This can be perceived visually by simply looking at images or time-lapse videos that show whether glaciers are getting bigger or smaller and how glaciers move downhill. To get more precise measurements of glacial retreat, scientists measure glaciers' thickness and analyze different layers of snow and ice. Because there are hundreds of thousands of glaciers, scientists have focused on 42 specific glaciers to study year after year. They have paid close attention to whether the addition and subtraction of ice to these glaciers has been positive or negative in the balance overall. If the glaciers grew in mass, they would have a positive mass balance. If they shrank, they would have a negative mass balance.

Analysis of the data over time from the 42 reference glaciers, starting with 1980, shows a negative mass balance year after year. It also shows that the loss of ice has gotten faster. The melting of glaciers is a major source of sea-level rise.



Vocabulary

glacier, n. a slow-moving mass or river of ice formed by the accumulation and compaction of snow on mountains or near the poles

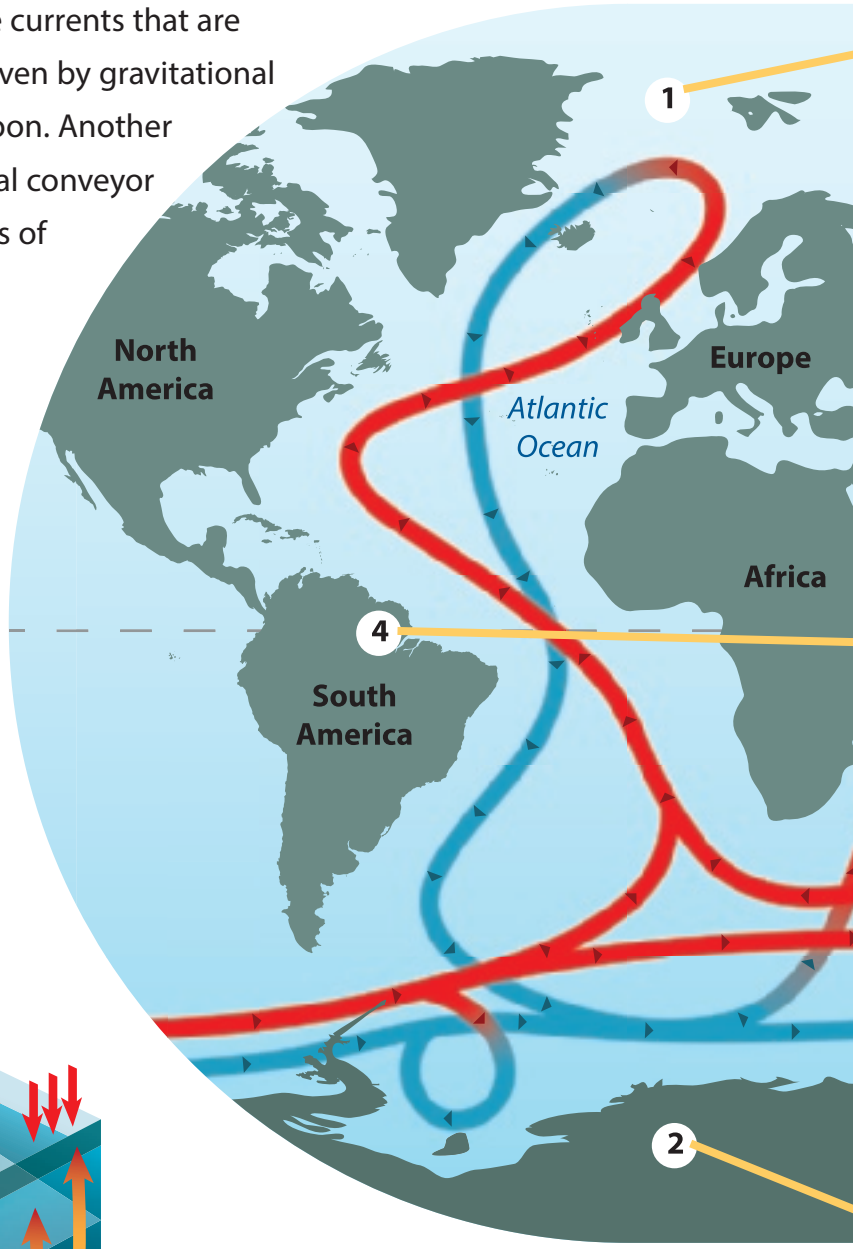
Dig into Data

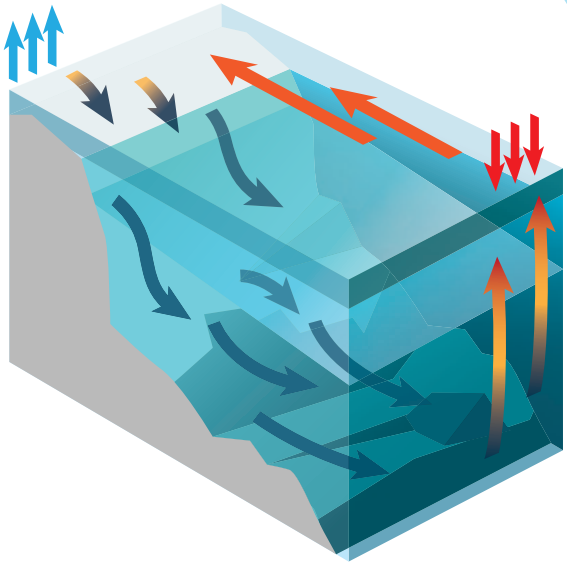
What aspect of the graph indicates that the loss of glacial ice has been faster in recent years?

Global Conveyor Belt Current

One way that seawater moves is in surface currents that are driven by wind. Another way is in tides driven by gravitational forces between Earth, the sun, and the moon. Another system of seawater movement is the global conveyor belt. It circulates seawater over large scales of time and distance, both horizontally and vertically. A molecule of H_2O in a drop of water that trickles into the North Atlantic Ocean from Greenland's melting ice cap will eventually make its way through other oceans' basins thanks to this global series of interconnected currents.

The global conveyor belt helps circulate nutrients as well as oxygen and carbon dioxide throughout the oceans. Without this circulation, ocean ecosystems would be very different.





Word to Know

Upwelling is a process that carries cool, nutrient-rich water from the deep ocean to the surface.

1. We can think of the frigid waters of the North Atlantic as the start of this global current. Around Greenland, evaporation at the surface and cold air temperatures cause seawater to get saltier and denser. The cold, salty water sinks, leaving a void that is filled by warmer, less-salty water from the surface of the Atlantic. The cold water moves south while the warm water moves north.



3. In the Pacific, upwelling brings cool water and nutrients to the surface, and the current passes around the many islands between Asia and Australia before rejoining the current that had veered off around Africa.

4. Surface waters are pulled back into the Atlantic and on toward Greenland, to eventually be chilled and made saltier as they were a thousand years before. Much of this water is part of the Gulf Stream, a major surface current that brings warm water from the Gulf of Mexico up along the east coast of the United States and on toward Greenland and Europe. Some water does not head into the Atlantic and instead is carried around Antarctica, where there's downwelling and upwelling that recharges the conveyor belt. And of course, some water ends up evaporating into the atmosphere, later falling to Earth's surface as snow or rain.

2. The cold water passes South America, then veers east along Antarctica, where it picks up more cold, salty water. The conveyor moves on to the Pacific, while some goes into the Indian Ocean and upwells off the southeast coast of Africa.



The green swirls are plankton blooms.

ASTRONAUT BLOG: Entry 36, Coastal Currents Control Climate

It's amazing, this view I have from the International Space Station, 254 miles above Earth. At over 17,000 miles per hour, we're orbiting Earth in less than one hour. Sometimes I wish we could slow this thing down so I could focus on one point for more than a few seconds!

Just a few minutes ago I could see the fog over San Francisco, my hometown. I think it was Mark Twain who said the coldest winter he ever had was the summer he spent in San Francisco, which isn't too far off the mark (pun intended). The cold California Current that carries water from British Columbia along the West Coast helps generate SF's microclimates, which can make it hard to know what to wear on any given day because the weather can change so much, especially in summer. It also keeps the water pretty cool off the west coast of Mexico, while Mexico's east coast at the same latitude is tropical.

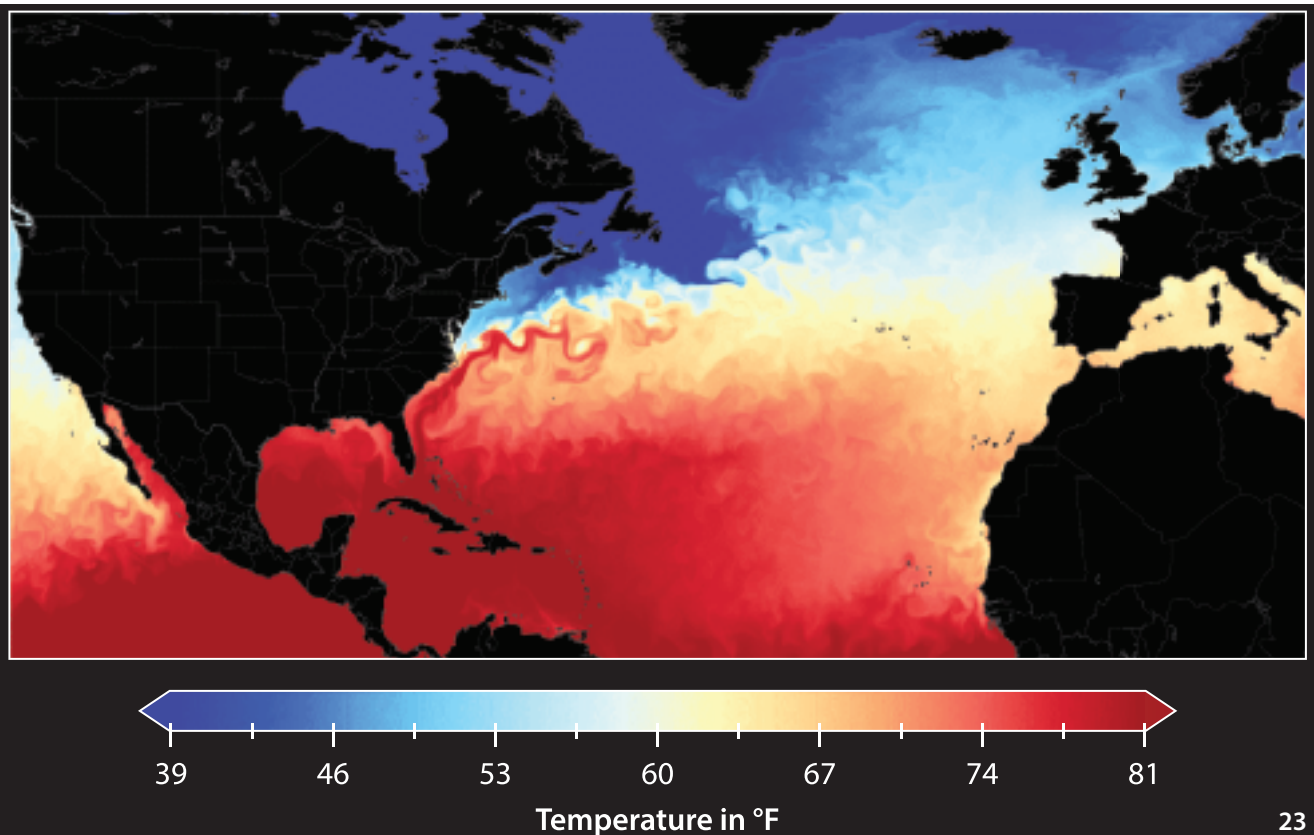
The California Current combines with Earth's rotation and prevailing winds to cause upwelling of cold water from the deep sea. This brings nutrients toward the surface. Phytoplankton bloom show up as vivid green swirls from where I sit. Zooplankton feast on the phytoplankton, small fishes eat the zooplankton, and then the food chain goes from there up to large animals like humpback whales in Monterey Bay and great white sharks circling the Farallon Islands in search of elephant seals. Without that cold current and Earth's rotation, the California coast's marine ecosystems would be very different.

Minutes later I can look down on the Gulf Stream, which runs from south to north along the U.S. East Coast, then becomes the North Atlantic Current. The Gulf Stream's warm water provides heat and moisture to the atmosphere off the East Coast. This source of thermal energy is so powerful that it basically makes England and other countries of northern Europe similar in climate to New England and the Mid-Atlantic states. Based on latitude, they should be similar to Canada.

The current moves so much water and so swiftly that the surface of the Atlantic is lower within the current's span than it is outside the current. It really is like a river flowing within the ocean. Fishers can catch warm-water species such as marlin and yellowfin tuna inside the current, then fish on the outside and be in much greener water, with cold-water species coming up on lines. Near Cape Hatteras, North Carolina, about 80 million cubic meters of water are moving with the current every second. As Arnold Gordon, professor at Columbia University's Lamont-Doherty Earth Observatory, put it, that's like 80 million bathtubs, all of them carrying warm water!

Consider the Source

An astronaut aboard the International Space Station would be highly trained and very well educated. A professor who studies ocean circulation is an expert on currents such as the Gulf Stream.



Eddies

Observer Log, Scalloper F/V Patriot

August 26, 2021

I'm on Day 4 of what's looking like a 14-day scallop trip. We're fishing south of Nantucket, doing half-hour tows in about 250 feet of water. The two steel dredges, equipped with steel-chain bags to capture the scallops after the dredge kicks them off the seafloor, are lowered into the water from the stern. While the dredges are descending, I use a scoop thermometer to sample the surface temperature of the water. I also check the GPS in the wheelhouse to note the starting position of the tow so someone at NOAA can plot the tow later on if they want to. Once the tow starts, everyone gets into the grind of shoveling scallops into baskets from the last tow, dumping the baskets into troughs that are at waist height on the sides of the boat and shucking the scallops. I've learned to shuck them myself, but my rate is probably about one-third that of the fastest shuckers. Each member of the crew has a small bucket into which they shuck the meats of the scallops. Everything else—shells, other organs, roe—stays in the trough for a while and then gets shoved through the scuppers and into the water. Once a small bucket is full, it gets dumped into a basket, and the basket gets rinsed with seawater. Then someone bags the scallops from the basket and puts the bag in the hold, on ice. Some other stuff comes up in the dredges as bycatch—sponges, monkey eels, monkfish, a few big lobsters—but for the most part it all gets shoveled overboard unless someone feels like making lobster rolls for lunch. My job is to sample the scallop catch—measure shell widths, calculate average weights—and identify and weigh the bycatch. If we catch a loggerhead turtle, I'll get busy with tagging it and making sure it gets back in the water.

Consider the Source

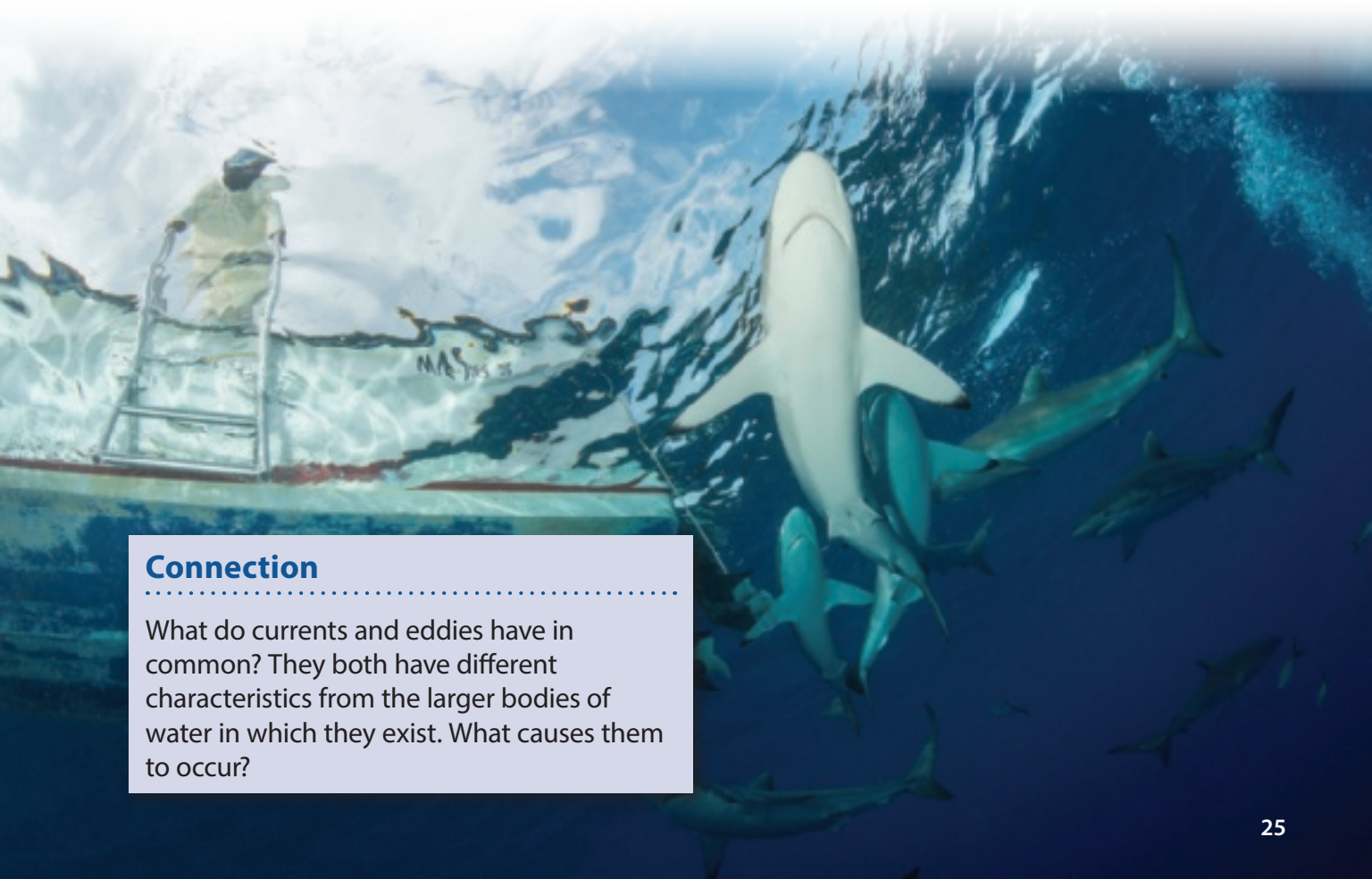
This logbook entry is written from the perspective of a National Marine Fisheries Service observer who works on commercial fishing boats to collect data and samples from various fisheries, including the sea scallop fishery based in New Bedford, Massachusetts.



What's been interesting the last few days is fishing in the eddies. These are moving whirlpools of water that spin off the Gulf Stream and veer toward the coast. The water in the eddies is really different. Instead of being blue-green and about 68ºF, it's clear blue and a full ten degrees warmer. The first time we did a tow in an eddy, I had to double-check my thermometer and check with the captain. "Yeah, the water's a little different, eh? First time in an eddy?" he laughed. I wish I could get in a plane and fly overhead, just to see if the eddy looks like a big blue dot amid a sea of green. The other weird thing about the eddies is the sharks. When the crew is shoveling bycatch off the boat in the green water, there are no sharks coming up to the hull to chow down. But in the eddies, as soon as a skate or a monkey eel hits the water, a silky shark or sandbar shark is right on it, some of them eight to ten feet long. They're basically following the boat, I think, or maybe they can hear the sound of the dredges being hauled up, and it's like a dinner bell to them. I guess it beats having to hunt for food. Just follow the boat and get a free meal. But the sharks seem to be staying within the eddies. I guess they must've come up on the Gulf Stream, and they're not comfortable with the ten-degree drop in temperature outside the eddies. I clamped my little camera to a gaff, pressed record, and stuck it in the water to get some footage of the sharks having their lunch.

I asked the captain if he is fishing in the eddies on purpose, and he said no, they just spin through the area we're fishing and we just happen upon them, like driving into a little storm because the road happens to take you into one. It reminds me of observing on swordfishing boats off California and Hawaii. Navy blue water, clear and warm because the plankton don't like the warmth, and lots of sharks. I'll miss this water when winter hits, and I'm freezing my tail off on these boats. Until tomorrow . . .

M. Cho, NMFS observer #31506



Connection

What do currents and eddies have in common? They both have different characteristics from the larger bodies of water in which they exist. What causes them to occur?

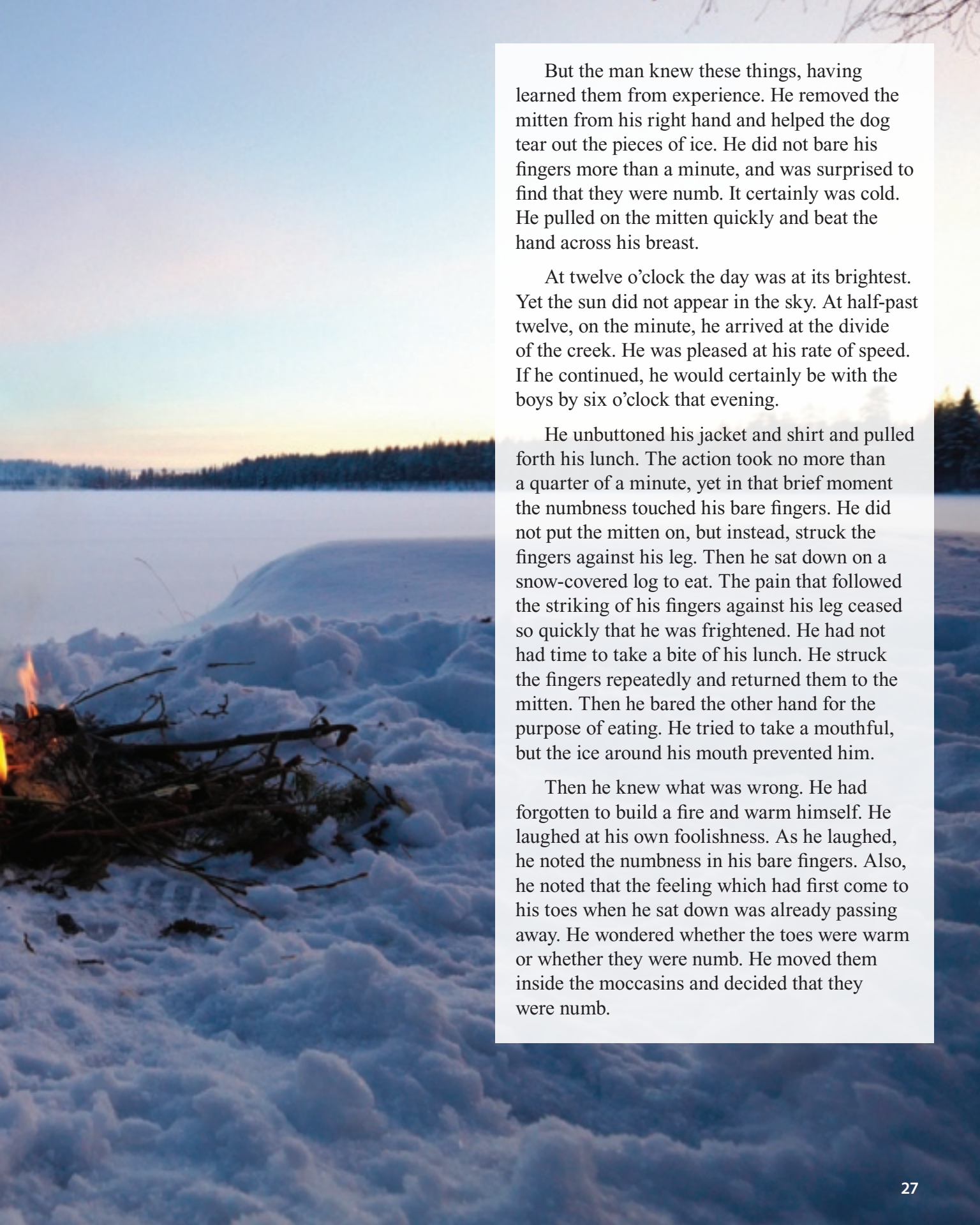
The following is the second part of the short story "To Build a Fire." In an earlier excerpt, you read about the man and his canine companion trekking across the snow-covered Yukon River and streams feeding into it from the surrounding forest.

To Build a Fire

by Jack London, 1908

He stood and studied the creek bottom and its banks. He decided that the flowing stream of water came from the right side. He thought a while, rubbing his nose and face. Then he walked to the left. He stepped carefully and tested the ice at each step. Once away from the danger, he continued at his four-mile pace.

During the next two hours he came to several similar dangers. Usually the snow above the pools had a sunken appearance. However, once again he came near to falling through the ice. Once, sensing danger, he made the dog go ahead. The dog did not want to go. It hesitated until the man pushed it forward. Then it went quickly across the white, unbroken surface. Suddenly it fell through the ice, but climbed out on the other side, which was firm. It had wet its feet and legs. Almost immediately the water on them turned to ice. The dog made quick efforts to get the ice off its legs. Then it lay down in the snow and began to bite out the ice that had formed between the toes. The animal knew enough to do this. To permit the ice to remain would mean sore feet. It did not know this. It merely obeyed the commands that arose from the deepest part of its being.



But the man knew these things, having learned them from experience. He removed the mitten from his right hand and helped the dog tear out the pieces of ice. He did not bare his fingers more than a minute, and was surprised to find that they were numb. It certainly was cold. He pulled on the mitten quickly and beat the hand across his breast.

At twelve o'clock the day was at its brightest. Yet the sun did not appear in the sky. At half-past twelve, on the minute, he arrived at the divide of the creek. He was pleased at his rate of speed. If he continued, he would certainly be with the boys by six o'clock that evening.

He unbuttoned his jacket and shirt and pulled forth his lunch. The action took no more than a quarter of a minute, yet in that brief moment the numbness touched his bare fingers. He did not put the mitten on, but instead, struck the fingers against his leg. Then he sat down on a snow-covered log to eat. The pain that followed the striking of his fingers against his leg ceased so quickly that he was frightened. He had not had time to take a bite of his lunch. He struck the fingers repeatedly and returned them to the mitten. Then he bared the other hand for the purpose of eating. He tried to take a mouthful, but the ice around his mouth prevented him.

Then he knew what was wrong. He had forgotten to build a fire and warm himself. He laughed at his own foolishness. As he laughed, he noted the numbness in his bare fingers. Also, he noted that the feeling which had first come to his toes when he sat down was already passing away. He wondered whether the toes were warm or whether they were numb. He moved them inside the moccasins and decided that they were numb.

He pulled the mitten on hurriedly and stood up. He was somewhat frightened. He stamped forcefully until the feeling returned to his feet. It certainly was cold, was his thought. That man from Sulphur Creek had spoken the truth when telling how cold it sometimes got in this country. And he had laughed at him at the time! That showed one must not be too sure of things. There was no mistake about it, it was cold. He walked a few steps, stamping his feet and waving his arms, until reassured by the returning warmth. Then he took some matches and proceeded to make a fire. In the bushes, the high water had left a supply of sticks. From here he got wood for his fire. Working carefully from a small beginning, he soon had a roaring fire.

Bending over the fire, he first melted the ice from his face. With the protection of the fire's warmth he ate his lunch. For the moment, the cold had been forced away. The dog took comfort in the fire, lying at full length close enough for warmth and far enough away to escape being burned. When the man had finished eating, he filled his pipe with tobacco and had a comfortable time with a smoke. Then he pulled on his mittens, settled his cap firmly about his ears, and started along the creek trail toward the left.

The dog was sorry to leave and looked toward the fire. This man did not know cold. Possibly none of his ancestors had known cold, real cold. But the dog knew and all of its family knew. And it knew that it was not good to walk outside in such fearful cold. It was the time to lie in a hole in the snow and to wait for this awful cold to stop. There was no real bond between the dog and the man. The one was the slave of the other. The dog made no effort to indicate its fears to the man. It was not concerned with the well-being of the man. It was for its own sake that it looked toward the fire. But the man whistled, and spoke to it with the sound of the whip in his voice. So the dog started walking close to the man's heels and followed him along the trail.

The man put more tobacco in his mouth and started a new growth of yellow ice on his face. Again his moist breath quickly powdered the hair on his face with white. He looked around him. There did not seem to be so many pools of water under the snow on the left side of Henderson Creek, and for half an hour the man saw no signs of any. And then it happened. At a place where there were no signs, the man broke through. It was not deep. He was wet to the knees before he got out of the water to the firm snow.

He was angry and cursed his luck aloud. He had hoped to get into camp with the boys at six o'clock, and this would delay him an hour. Now he would have to build a fire and dry his moccasins and socks. This was most important at that low temperature. He knew that much.

So he turned aside to the bank, which he climbed. On top, under several small pine trees, he found some firewood which had been carried there by the high water of last year. There were some sticks, but also larger branches, and some dry grasses. He threw several large branches on top of the snow. This served for a foundation and prevented the young flame from dying in the wet snow. He made a flame by touching a match to a small piece of tree bark that he took from his pocket. This burned even better than paper. Placing it on the foundation, he fed the young flame with pieces of dry grass and with the smallest dry sticks.

He worked slowly and carefully, realizing his danger. Gradually, as the flame grew stronger, he increased the size of the sticks with which he fed it. He sat in the snow, pulling the sticks from the bushes under the trees and feeding them directly to the flame. He knew he must not fail. When it is 75 below zero, a man must not fail in his first attempt to build a fire. This is especially true if his feet are wet. If his feet are dry, and he fails, he can run along the trail for half a mile to keep his blood moving. But the blood in wet and freezing feet cannot be kept moving by running when it is 75 degrees below. No matter how fast he runs, the wet feet will freeze even harder.

All this the man knew. The old man on Sulphur Creek had told him about it, and now he was grateful for the advice. Already all feeling had gone from his feet. To build the fire he had been forced to remove his mittens, and the fingers had quickly become numb. His pace of four miles an hour had kept his heart pushing the blood to all parts of his body. But the instant he stopped, the action of the heart slowed down. He now received the full force of the cold. The blood of his body drew back from it. The blood was alive, like the dog. Like the dog, it wanted to hide and seek cover, away from the fearful cold. As long as he walked four miles an hour, the blood rose to the surface. But now it sank down into the lowest depths of his body. His feet and hands were the first to feel its absence. His wet feet froze first. His bare fingers were numb, although they had not yet begun to freeze. Nose and face were already freezing, while the skin of all his body became cold as it lost its blood.

But he was safe. Toes and nose and face would be only touched by the frost, because the fire was beginning to burn with strength. He was feeding it with sticks the size of his finger. In another minute he would be able to feed it with larger branches. Then he could remove his wet moccasins and socks. While they dried, he could keep his naked feet warm by the fire, rubbing them first with snow. The fire was a success. He was safe.



Connection

Why is it important for the man to remove his wet clothing to warm his frozen feet?

Beebe, Barton, and the Bathysphere

A century ago, humans were just beginning to get a glimpse of what was beneath the ocean's surface. Scuba diving technology was not invented until 1943. But, divers could explore shallow areas by using diving helmets. These were heavy brass or copper devices with glass portholes. The helmet fit over a diver's head and received air through a hose from a boat at the surface. It allowed for viewing through the glass while providing a protective bubble of air around the diver's head.

The air from the surface had to be pressurized to make sure the hose wasn't squeezed shut by the water pressure around it. A valve released exhaled air from the helmet into the water to prevent the diver from rebreathing too much of their own air. This semiclosed system provided the diver with essential oxygen, removed some carbon dioxide, and allowed the diver to see the surroundings. Divers wore suits made of heavy canvas, but these did not provide much insulation from the cold of the deep sea.

William Beebe was a famous naturalist and explorer of the early 20th century, and he loved to dive. But he wanted to go deeper than he could in a diving helmet.



Otis Barton was an engineer and amateur underwater explorer. In 1928, Barton brought his considerable wealth and his design for a deep-sea submersible he called the bathysphere to Beebe. The two formed a partnership aimed at breaking the world record for deepest dive to see what was down in the darkness of the deep unexplored sea.

The challenges the deep sea posed were numerous. The craft needed to be absolutely watertight. Even a slight hole or crack would allow water in. If this occurred at great depth, where pressure is immense, a laser-like blast of water could cut right through a diver inside and, of course, fill the submersible with water. The cast iron sphere that Barton



devised resolved some of the challenges. A sphere was the best shape for distributing the water pressure evenly around the whole vessel; 18-inch steel walls would withstand pressure and run-ins with large objects. On the other hand, Barton and Beebe needed to get inside the sphere, to see out some kind of window, and to operate a telephone line from within the sphere to communicate with people at the surface. They also needed a source of oxygen inside the sphere itself, because a hose from the surface would be too compressed by water pressure at the half-mile depth Beebe and Barton hoped to reach.

Three small porthole windows were built into the sphere to allow the passengers to see into the water. A "stuffing box" atop the sphere allowed a telephone line and electrical line into the sphere, without allowing water in. Tanks of compressed oxygen gas were taken into the bathysphere. The bathysphere's interior would surely get somewhat cool during a dive, but its thick walls and the body heat of the divers would keep things warm enough for a few hours.

On August 15, 1934, after test dives that got deeper and deeper, Beebe and Barton made their record-breaking descent. At a depth of 3,028 feet, the bathysphere withstood over 1,360 pounds of pressure per square inch. The designers' solutions for keeping air in and water out, while allowing light and electrical signals in and out, worked well. Since then, submersibles have reached much greater depths, including the deepest points of the Mariana Trench—over 35,000 feet down.

Connection

The bathysphere was a closed system in terms of matter. Nothing that had mass could get in or out of it while it was in the water. However, forms of energy—electrical, thermal, and light—could get in and out.

Biosphere 2

In the fall of 1991, eight people were sealed inside an airtight, three-acre structure known as Biosphere 2. The $150-million facility was designed to allow for the study of closed systems that mimic Earth's environment. Earth itself is a closed system, with little to no matter entering or leaving the planet. By building and living inside a miniature version of Earth, scientists hoped to learn more about the interactions of smaller systems and their interrelated processes.

Vacuum pumps were set up to create waves in a miniature ocean. Water had to be distributed to different biomes in the correct amounts and at the right times. Water also had to be filtered and recycled for the people and other organisms, all without piping in any new water.

It was essential that Biosphere 2 support life without involving too many machines or other forms of technology that might have



Ocean and rain forest area of Biosphere II. Glass walls allowed sunlight into the otherwise closed system.

unintended consequences. Even small objects had to be screened before being allowed into Biosphere 2, in case they might be carrying harmful bacteria or likely to emit harmful gases that could affect the closed atmosphere. Unfinished wood and wool were used for flooring and walls. Fire was also outlawed.

The experiment began on September 26, 1991, when the eight humans entered Biosphere 2 and closed the doors. Life was busy inside. Farming, research and maintenance, writing reports, cooking, biome management, and taking care of animals took up more than 90 percent of their waking hours. The occupants grew edible plants and raised and slaughtered livestock for consumption. The Biosphere 2 "crew" did not have much farming experience, but they quickly got better at it because their lives depended on it. They grew 83 percent of their food and wasted nothing—sometimes eating peanuts whole, shell included.

Several months into the experiment, the scientists realized that the oxygen level had dropped from 20.9 percent to 14.2 percent, the equivalent of living at a 15,000-foot elevation. Some of the crew suffered symptoms of altitude sickness. The physician living among them discovered one day that he couldn't add a column of numbers. The alarming discovery prompted a decision to pump pure oxygen into Biosphere 2. The effect was immediate. The crew began to laugh and run around. Prior to that, observers said watching the crew work was like viewing a slow-motion dance. This was a reminder of how much Earth's organisms depend on oxygen in the atmosphere and water and that the only source of this substance is Earth and its functional systems.

What had caused the oxygen level to crash? Microbes in the enriched soil had converted oxygen into carbon dioxide. The plants could have converted some of that carbon dioxide into oxygen, but instead the carbon dioxide was absorbed by unsealed concrete in Biosphere 2. This was an example of an unintended consequence of a type of technology in the closed system.

The eight occupants left Biosphere 2 on September 26, 1993, having completed their mission.

Connection

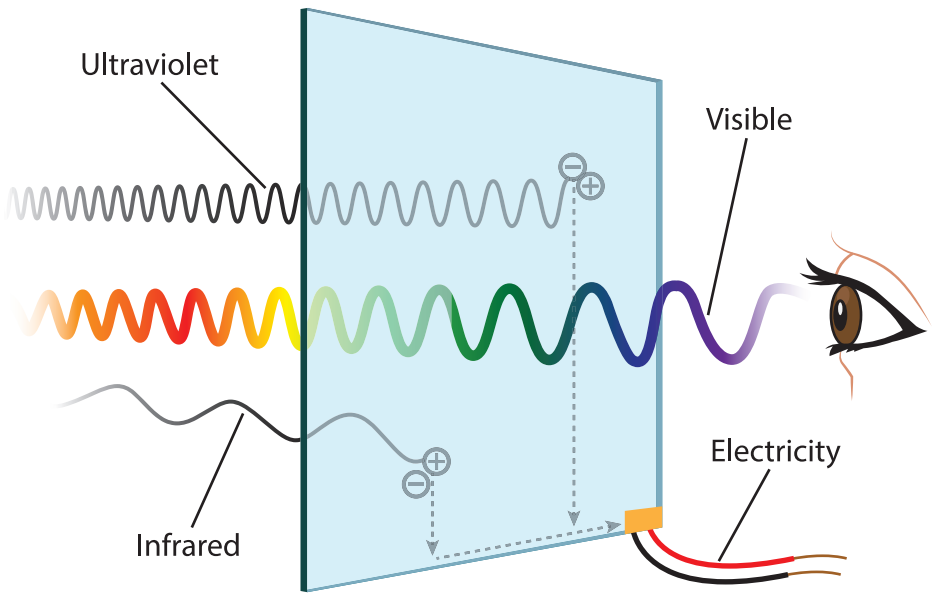
Earth has natural systems and systems that humans have invented. Some are intertwined, such as a hydroelectric dam and a river. These systems can be open in some ways and closed in others. Understanding what is closed and open—and what the interactions are—is important for scientists but also urban planners, homeowners, farmers, and many others.

Turning Windows into Solar Cells

Want to sleep late? Use blackout shades in your windows. Want privacy but don't want to oversleep? Use shades that block about half the light. Is the sun too bright for your eyes while you hike? A hat can block direct rays from your face, and sunglasses can filter the rays bouncing off the environment all around you. Feeling chilled after a long swim in a lake? Lie in the sun to soak up heat. In general, we treat sunlight as one thing that we try to absorb, block, or reflect. But sunlight actually consists of different types of light, or radiation.

Ultraviolet (UV) light accounts for only about 1 percent of the light that reaches Earth's surface. You might wear sunscreen to block the UV light that reaches your skin. About 45 percent of sunlight is visible light, which interacts with different types of matter to produce color and other properties that your eyes perceive. The remaining 54 percent of radiation is infrared. Infrared radiation is the type you feel as warmth when you stand in sunlight on a clear day.

Visible light has wavelengths that are longer than infrared light and shorter than ultraviolet light. All three are forms of electromagnetic radiation.



Windows helpfully allow visible light indoors. However, sometimes the amount of infrared radiation that windows allow in makes the inside of a building or vehicle too hot. To reduce the need for costly cooling by air conditioning, some glass is coated to block out a portion of the infrared radiation. This prevents an interior space from getting too warm, but that energy is just redirected on the exterior. Instead of merely blocking out infrared radiation, engineers have found a way to convert it into a useful form of energy—electricity.

New, transparent solar cells work like photovoltaic solar panels seen on rooftops and in solar farms. Energy in the form of electromagnetic waves is converted into electricity. Traditional photovoltaic solar cells are not transparent. These new cells, however, are transparent and allow most of the visible light to pass right through.

The new transparent cells are still too expensive to make for them to become commonplace. But the technology is worth developing. Windows that help generate electricity do two jobs at once. A large skyscraper, for example, could have thousands of electricity-generating windows to lower its energy costs. Instead of allowing too much infrared radiation into a building in a warm location, excess energy could instead become transformed to electricity and help power air conditioning systems.

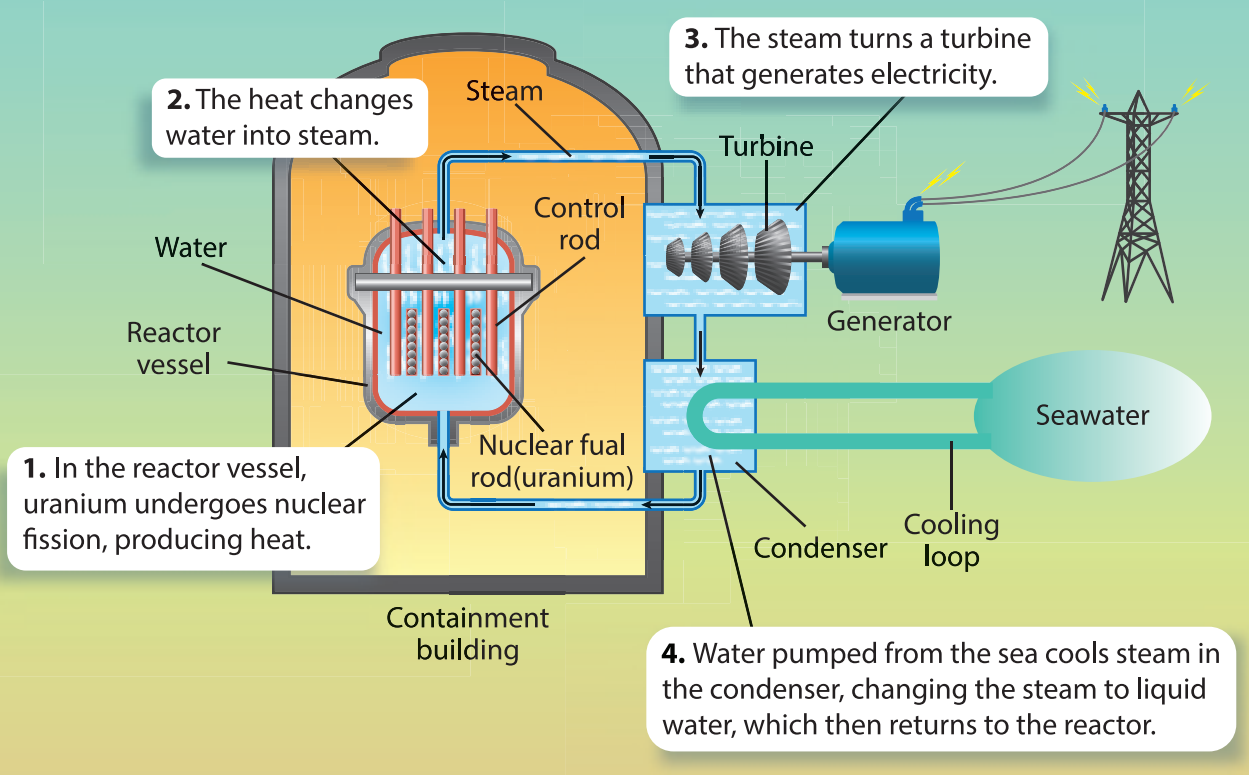


In the near future, cities could have silicon-based solar panels on rooftops and carbon-based solar cells embedded in windows.

Heat Too Powerful to Control

On March 11, 2011, at 2:46 p.m., a massive earthquake rocked the ocean floor just off the east coast of Japan's main island, Honshu. The magnitude-9.0 earthquake caused a large area of seafloor to heave upward, displacing the ocean and producing a tsunami. The tsunami swept ashore, flooding harbors and low-lying coastal areas with seawater and debris. Over 20,000 people were killed, towns were destroyed, farms were buried in mud, and boats were ripped from their moorings and left on top of buildings.





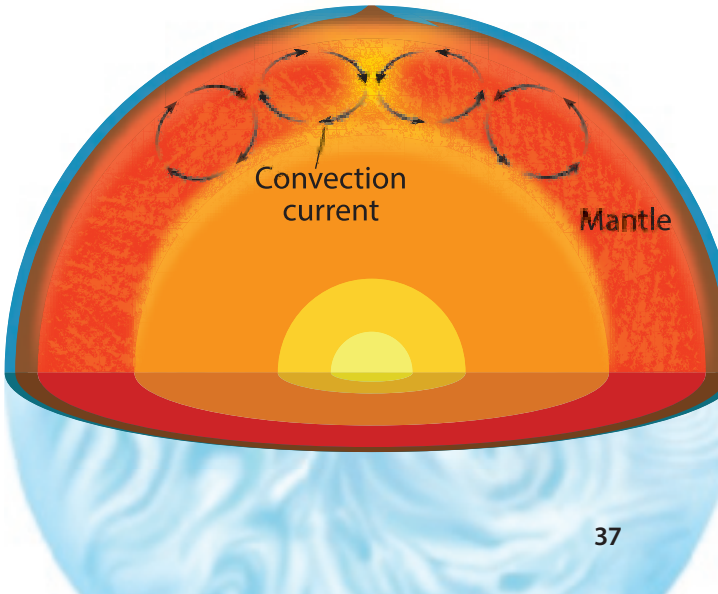
A second disaster was triggered by the tsunami. The Fukushima Daiichi nuclear power facility was in the path of the tsunami. When the earthquake occurred, safeguard mechanisms shut down the nuclear reactors. However, the source of electricity to control the plant was disabled by the tsunami. Backup batteries to power the plant's controls could only last so long, and diesel-powered generators that were supposed to be the second backup were flooded by the tsunami, making them useless. This proved to be disastrous because without electricity to control the reactors, the heat given off by the nuclear fuel rods kept building up.

Continuously pumping water through the system is vital in a nuclear power plant. Heat from the nuclear reactions warms water and turns it to steam. The steam turns turbines that generate electricity. Water also serves as a coolant to condense the steam back into liquid water so it can go back into the reactor and remove more thermal energy.

With Fukushima's reactors still producing large amounts of heat in their cores and no way for that heat to be removed from the system by pumped water, steam built up, along with explosive hydrogen gas. In time, the mixture of steam and gas exploded, blowing the roofs off three of the six reactors. The closed system was now open, allowing dangerous radioactive steam to escape into the environment.

Uncontrollable heat was also at the source of the earthquake that triggered the tsunami in the first place, which led, in turn, to the nuclear disaster at Fukushima. Below Earth's crust is the mantle, a layer of soft rock heated by Earth's core. Heated rock in the mantle moves in convection currents. The rock nearest the core is hottest, which makes it less dense. The hot rock floats toward the crust, and cooler rock sinks down toward the core. These convection currents carry the plates that make up Earth's crust as if the plates were on a conveyor belt. For example, because of convection currents, the Pacific Plate is moving toward (and pushing under) the plate that carries Japan.

The interactions of some plates are sticky and stop-and-go. When the plate edges are stuck, stress builds up. Eventually the stress becomes too great, and the plate edges lurch into motion, producing an earthquake.



The following is the final part of the short story "To Build a Fire." By this point the man has gotten dangerously cold and wet, but he has managed to build a fire to warm his freezing hands and feet and dry his wet clothes.



To Build a Fire

by Jack London, 1908
(This section has been abridged.)

He remembered the advice of the old man on Sulphur Creek, and smiled. The man had been very serious when he said that no man should travel alone in that country after 50 below zero. Well, here he was; he had had the accident; he was alone; and he had saved himself. Those old men were rather womanish, he thought. All a man must do was to keep his head, and he was all right. Any man who was a man could travel alone. But it was surprising, the rapidity with which his face and nose were freezing. And he had not thought his fingers could lose their feeling in so short a time. Without feeling they were, because he found it very difficult to make them move together to grasp a stick. They seemed far from his body and from him. When he touched a stick, he had to look to see whether or not he was holding it.

All of which mattered little. There was the fire, promising life with every dancing flame. He started to untie his moccasins. They were coated with ice. The thick socks were like iron almost to the knees. The moccasin's strings were like ropes of steel. For a moment he pulled them with his unfeeling fingers. Then, realizing the foolishness of it, he grasped his knife.

But before he could cut the strings, it happened. It was his own fault, or instead, his mistake. He should not have built the fire under the pine tree. He should have built it in an open



space. But it had been easier to pull the sticks from the bushes and drop them directly on the fire.

Now the tree under which he had done this carried a weight of snow on its branches. No wind had been blowing for weeks and each branch was heavy with snow. Each time he pulled a stick he shook the tree slightly. There had been just enough movement to cause the awful thing to happen. High up in the tree one branch dropped its load of snow. This fell on the branches beneath. This process continued, spreading through the whole tree. The snow fell without warning upon the man and the fire, and the fire was dead. Where it had burned was a pile of fresh snow.

The man was shocked. It was like hearing his own judgment of death. For a moment he sat and stared at the spot where the fire had been. Then he grew very calm. Perhaps the old man on Sulphur Creek was right. If he had a companion on the trail he would be in no danger now. The companion could have built the fire. Now, he must build the fire again, and this second time he must not fail. Even if he succeeded, he would be likely to lose some toes. His feet must be badly frozen by now, and there would be some time before the second fire was ready.

Such were his thoughts, but he did not sit and think them. He was busy all the time they were passing through his mind. He made a new foundation for a fire, this time in the open space, where no tree would be above it. Next, he gathered dry grasses and tiny sticks. He could not bring his fingers together to pull them out of the ground, but he was able to gather them by the handful. In this way he also got many pieces that were undesirable, but it was the best he could do. He worked carefully, even collecting an armful of the larger branches to be used later when the fire gathered strength. And all the while the dog sat and watched him. There was an anxious look in its eyes, because it depended upon him as the fire provider, and the fire was slow in coming.

When all was ready, the man reached in his pocket for the second piece of tree bark. He knew the bark was there, although he could not feel it with his fingers. He tried again and again, but he could not grasp it. And all the time, in his mind, he knew that each instant his feet were freezing. This thought alarmed him, but he fought against it and kept calm.

He pulled on his mittens with his teeth, and began swinging his arms. Then he beat his hands with all his strength against his sides. He did this while he was sitting down. Then he stood up to do it. All the while the dog sat in the snow, its tail curled warmly over its feet and its sharp wolf ears bent forward as it looked at the man. And the man, as he waved his arms and hands, looked with longing at the creature that was warm and secure in the covering provided by nature.

After a time, he began to notice some feeling in his beaten fingers. The feeling grew stronger until it became very painful, but the man welcomed the pain. He pulled the mitten from his right hand and grasped the tree bark from his pocket. The bare fingers were quickly numb again. Next, he brought out his pack of matches. But the awful cold had already driven the life out of his fingers. In his effort to separate one match from the others, the whole pack fell in the snow. He tried to pick it out of the snow, but failed. The dead fingers could neither touch nor hold.

Now he was very careful. He drove the thought of his freezing feet, and nose, and face, from his mind. He devoted his whole soul to picking up the matches. He followed the movement of his fingers with his eyes, using his sense of sight instead of that of touch. When he saw his fingers on each side of the pack, he closed them. That is, he willed to close them, because the fingers did not obey. He put the mitten on the right hand again, and beat it fiercely against his knee. Then, with both mittened hands, he lifted up the pack of matches, along with much snow, to the front of his jacket. But he had gained nothing.

After some struggling he managed to get the pack between his mittened hands. In this manner he carried it to his mouth. The ice broke as he opened his mouth with a fierce effort. He used his upper teeth to rub across the pack in order to separate a single match. He succeeded in getting one, which he dropped on his jacket. His condition was no better. He could not pick up the match. Then he thought how he might do it. He picked up the match in his teeth and drew it across his leg. Twenty times he did this before he succeeded in lighting it. As it flamed he held it with his teeth to the tree bark. But the burning smell went up his nose, causing him to cough. The match fell into the snow and the flame died.

The old man on Sulphur Creek was right, he thought in the moment of controlled despair that followed. After 50 below zero, a man should travel with a companion. He beat his hands, but failed to produce any feeling in them. Suddenly he bared both hands, removing the mittens with his teeth. He caught the whole pack of matches between his hands. His arm muscles were not frozen and he was able to press the hands tightly against the matches. Then he drew the whole pack along his leg. It burst into flame, 70 matches at once!

There was no wind to blow them out. He kept his head to one side to escape the burning smell, and held the flaming pack to the tree bark. As he so held it, he noticed some feeling in his hand. His flesh was burning. He could smell it. The feeling developed into pain. He continued to endure it. He held the flame of the matches to the bark that would not light readily because his own burning hands were taking most of the flame.

Finally, when he could endure no more, he pulled his hands apart. The flaming matches fell into the snow, but the tree bark was burning. He began laying dry grasses and the tiniest sticks on the flame. He could not choose carefully because they must be pieces that could be lifted between his hands. Small pieces of green grass stayed on the sticks, and he bit them off as well as he could with his teeth. He treated the flame carefully. It meant life, and it must not cease.

The blood had left the surface of his body and he now began to shake from the cold. A large piece of a wet plant fell on the little fire. He tried to push it out with his fingers. His shaking body made him push it too far and he scattered the little fire over a wide space. He tried to push the burning grasses and sticks together again. Even with the strong effort that he made, his trembling fingers would not obey and the sticks were hopelessly scattered. Each stick smoked a little and died. The fire provider had failed. As he looked about him, his eyes noticed the dog sitting across the ruins of the fire from him. It was making uneasy movements, slightly lifting one foot and then the other.

The man looked down at his hands to locate them and found them hanging on the ends of his arms. He thought it curious that it was necessary to use his eyes to discover where his hands were. He began waving his arms, beating the mittened hands against his sides. He did this for five minutes. His heart produced enough blood to stop his shaking. But no feeling was created in his hands.

A certain fear of death came upon him. He realized that it was no longer a mere problem of freezing his fingers and toes, or of losing his hands and feet. Now it was a problem of life and death with the circumstances against him. The fear made him lose control of himself and he turned and ran along the creek bed on the old trail. The dog joined him and followed closely behind. The man ran blindly in fear such as he had never known in his life. Slowly, as he struggled through the snow, he began to see things again—the banks of the creek, the bare trees, and the sky.

The running made him feel better. He did not shake any more. Maybe, if he continued to run, his feet would stop freezing. Maybe if he ran far enough, he would find the camp and the boys. Without doubt, he would lose some fingers and toes and some of his face. But the boys would take care of him and save the rest of him when he got there. And at the same time, there was another thought in his mind that said he would never get to the camp and the boys. It told him that it was too many miles away, that the freezing had too great a start and that he would soon be dead. He pushed this thought to the back of his mind and refused to consider it. Sometimes it came forward and demanded to be heard. But he pushed it away and tried to think of other things.

It seemed strange to him that he could run on feet so frozen that he could not feel them when they struck the earth and took the weight of his body. He seemed to be flying along above the surface and to have no connection with the earth.

His idea of running until he arrived at the camp and the boys presented one problem: he lacked the endurance. Several times he caught himself as he was falling. Finally, he dropped to the ground, unable to stop his fall. When he tried to rise, he failed. He must sit and rest, he decided. Next time he would merely walk and keep going.

As he sat and regained his breath, he noted that he was feeling warm and comfortable. He was not shaking, and it even seemed that a warm glow had come to his body. And yet, when he touched his nose or face, there was no feeling. Running would not bring life to them. Nor would it help his hands and feet. Then the thought came to him that the frozen portions of his body must be increasing. He tried to keep this thought out of his mind and to forget it. He knew that such thoughts caused a feeling of fright in him and he was afraid of such feelings. But the thought returned and continued, until he could picture his body totally frozen. This was too much, and again he ran wildly along the trail. Once he slowed to a walk, but the thought that the freezing of his body was increasing made him run again.

And all the time the dog ran with him, at his heels. When he fell a second time, the dog curled its tail over its feet and sat in front of him, facing him, curiously eager. The warmth and security of the animal angered him. He cursed it until it flattened its ears. This time the shaking because of the cold began more quickly. He was losing his battle with the frost. It was moving into his body from all sides. This thought drove him forward. But he ran no more than 100 feet, when he fell head first.

It was his last moment of fear. When he had recovered his breath and his control, he sat and thought about meeting death with dignity. However, the idea did not come to him in exactly this manner. His idea was that he had been acting like a fool. He had been running around like a chicken with its head cut off. He was certain to freeze in his present circumstances, and he should accept it calmly. With this newfound peace of mind came the first sleepiness. A good idea, he thought, to sleep his way to death. Freezing was not as bad as people thought. There were many worse ways to die.

He pictured the boys finding his body the next day. Suddenly he saw himself with them, coming along the trail and looking for himself. And, still with them, he came around a turn in the trail and found himself lying in the snow. He did not belong with himself any more. Even then he was outside of himself, standing with the boys and looking at himself in the snow. It certainly was cold, was his thought. When he returned to the United States he could tell the folks what real cold was.

His mind went from this to the thought of the old man of Sulphur Creek. He could see him quite clearly, warm and comfortable, and smoking a pipe.

"You were right, old fellow. You were right," he murmured to the old man of Sulphur Creek.

Then the man dropped into what seemed to him the most comfortable and satisfying sleep he had ever known. The dog sat facing him and waiting. The brief day ended in a long evening. There were no signs of a fire to be made. Never in the dog's experience had it known a man to sit like that in the snow and make no fire. As the evening grew darker, its eager longing for the fire mastered it. With much lifting of its feet, it cried softly. Then it flattened its ears, expecting the man's curse. But the man remained silent. Later, the dog howled loudly. And still later it moved close to the man and caught the smell of death. This made the animal back away. A little longer it delayed, howling under the stars that leaped and danced and shone brightly in the cold sky. Then it turned and ran along the trail toward the camp it knew, where there were the other food providers and fire providers.

Connection

Why did the loss of the use of his hands and feet spell doom for the man? And why were his hands and feet among the first parts of his body to succumb to the cold?

Too Cold, Too Hot

Temperature ranges in which organisms can live vary, but with any organism there are points that are too cold and too warm to survive. Cold can kill if ice crystals form in an organism's tissues, causing cells to rupture. (Remember: Water expands when it freezes.) Before this even occurs, organs and systems can shut down as the body attempts to protect itself from the cold. This shutting down of body systems is a dangerous state called *hypothermia*.

In mammals, one of the first responses to an overheating body is to cool the body through evaporation. Furry mammals can do this by panting. A dog, for example, pants with its mouth open. Warmth in the mouth heats watery saliva, which leads to evaporation. The rapid panting is like a breeze that increases the rate of evaporation. The same basic process occurs when humans sweat, and the warm skin causes the sweat to evaporate. Sitting in front of a fan or finding a breeze increases the rate of evaporation.

So, why does evaporation lower the temperature of a sweating human or a panting dog? Heat from the body moves into the watery fluid. Some of the water particles gain enough thermal energy to break away into the air as water vapor. When water changes from a liquid to a gas state, heat is released. Evaporation continues if the body is too warm and for as long as there is enough water supplied to the surface of the body.

Heat can become deadly, especially for mammals. A person who is too hot for hours can lose enough water sweating to become dehydrated. At that point, the body can't afford to lose any more water to sweating, because it needs water for so many other processes—including maintaining blood volume and flow. Unless there's an external source of water for evaporative cooling, the body can get dangerously hot, and heat stroke can occur. Excessive heat can lead to *hyperthermia* and cause breakdowns of bodily functions.

Animals and Body Temperature

Animals in nature don't throw on a coat when it's cold or crank up the air conditioning when it's hot. They have structures and behaviors that help them deal with the temperature in the environment in different ways. Here's a look at thermoregulation in animals that live primarily on land.

Some birds migrate to completely avoid cold weather. Ones that don't migrate have behaviors and physical traits that allow their feathers to fluff. The fluffing increases the thickness of the insulating layer of downy feathers. When they're warm, birds compress these feathers, forcing out trapped air and decreasing the insulating effect.

Some newly hatched chicks are born with fuzzy down that allows them to start foraging for food alongside their parents. Others hatch naked and must huddle in the nest with a parent for warmth.



Finch with feathers fluffed for warmth



Cygnet (baby swan) with downy feathers



Robin hatchlings

Word to Know

Thermoregulation is a body's ability to maintain a temperature within a certain range for survival. Since the temperature in the environment often differs from an organism's body temperature, its body needs ways to warm up or cool off.

Land mammals that live in cold climates tend to be furry. They can also have large stores of fat that act as additional insulation beneath the fur and skin. Fur is such a good insulator that humans have long hunted animals such as beavers, mink, bears, and deer for their pelts. Mammals that live in warm environments, such as zebras, tend to have shorter fur.

Unlike birds and mammals, reptiles are not warm-blooded. They don't produce enough heat internally to maintain a steady, warm body temperature. Instead, reptiles must find external sources of warmth; the sun is their primary source of warmth. Many reptiles must come out from water, leaf piles, or burrows and bask in direct sunlight to achieve a warmer body temperature. A reptile may also seek out a sun-warmed rock after the sun has gone down. If a reptile is too warm, it can seek shade from plants, return to an underground burrow, or move into water.



Long, thick musk ox fur provides insulation in the cold.



Zebras live in warm climates and have short hair.



The saltwater crocodile can hunt and idle in the water—but once too much thermal energy has been lost, it will need to find a sunny place on land to warm up. On land, the croc might hold its mouth open so heat near the brain is released while the rest of the body continues to warm up from the sunlight.

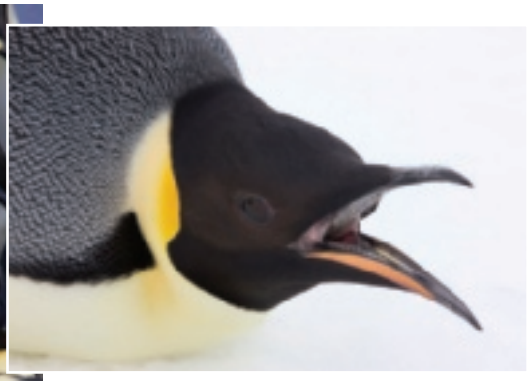
Water and Blubber

Comfortable "room temperature" in air is about 68°F, but your body gets chilled in 68°F water. Animals that are exposed to or submerged in water lose heat more quickly than those in air of the same temperature. Organisms that live all or part of the time in cold water must have adaptations to the cold. This is especially true of marine mammals and birds, which are warm-blooded animals that can't survive lengthy drops in body temperature. Insulation in the forms of fat, feathers, and fur are adaptations that help these animals survive in cold places. Organisms that live in warm water and don't migrate to colder water typically don't have such adaptations to cold temperatures.

Penguins have dense layers of overlapping feathers that repel water and air. The layered feathers serve well as insulation, even though they are useless for flight. When a penguin is cold, its feathers are fluffed, increasing the thickness of the feather layer. When a penguin is too warm, further fluffing allows air to escape the feathers, like opening the zipper in a winter coat.

Penguins also have **blubber,** a layer of dense, insulating fat that prevents body heat from escaping. Up to 30 percent of a penguin's body weight can be blubber. The blubber and feathers are less effective in water, so many penguins enter the water very briefly only to hunt for food. When penguins are on land and the air temperature is dangerously cold, they huddle together to conserve body heat. The penguins' dark-colored feathers also help them absorb warmth from the sun. Their feathers and blubber can hang down over their feet, eggs, and newly hatched chicks.





Emperor penguins in Antarctica protect their young from cold by huddling around them.



A humpback whale calf drinks milk from its mother in the warm waters off Hawaii.

Whales that spend most or all their time in very cold waters have extra-thick layers of blubber. The bowhead whale, for example, has 17 to 19 inches of blubber, allowing it to survive the icy waters of the Arctic.

Migratory whales, such as the humpback, feast in cold waters near the poles in summer. Their bodies store much of the food energy as blubber. The blubber provides insulation in the cold water while the whale continues to feed but then also serves as a store of energy for later.

Humpbacks migrate to tropical waters where the females birth their young. In the warmer waters there is less food for the humpbacks, but then there is no need for the insulation of the blubber. The energy stored in her blubber is chemically broken down to sustain a pregnant female humpback and soon her calf, as her own body produces milk to feed the calf until it is about a year old.

Seals, sea lions, and walruses have layers of blubber and, in some species, fur. Insulation protects those species that spend their time in cold regions. But it is also important for those that live in warmer places, because sometimes they need to dive hundreds or thousands of feet into the ocean to find food. At those depths the ocean is very cold. The Weddell seal can dive 2,000 feet below the sea surface and needs blubber to conserve body heat during the frigid dive.

Similar to whales, a mother seal's blubber is also a backup source of energy when food is scarce or she must spend weeks on shore nursing her young.



Weddell seal

Vocabulary

blubber, n. a layer of dense fat that provides thermal insulation

Arctic Ground Squirrel

Wonder Lake, Denali National Park, Alaska
April 29, 2021



Counted 44 ground squirrels in the study area. They look skinny, especially the females, which is to be expected after eight months of hibernation. Plant life is blooming now that there's abundant sunlight, and the squirrels are foraging throughout the day when they aren't mating. The males are working so hard at finding mates and defending their territory, they are probably burning twice as many calories as the females. In about a month the females will be giving birth. Imagine being asleep more than half the year, the hunger you'd feel upon waking! The male squirrels make it easier on themselves by stashing food in their burrows so they have something to eat when they wake up weeks earlier than the females.

May 5, 2021

Torrential rain today, so I'm in the tent, reviewing temperature sensor data and camera footage from the squirrel burrows over the winter. The pattern is becoming clearer. As is well known, the squirrels freeze. Their body temperatures drop from 37°C to as low as –3°C. And yet, they don't actually freeze like an ice cube. Their bodies contain plenty of water, yet no ice crystals form. It seems there are several antifreeze adaptations at work. The first is the one I can see in the camera footage:

Every few weeks, the squirrels shiver and shake. This physical activity warms them up to about 34°C for a day or two. Then they shut down again and drop back down to a subfreezing temperature. What's still a mystery is how their tissues don't freeze when below zero. I hope our team can figure this out in the coming winter.

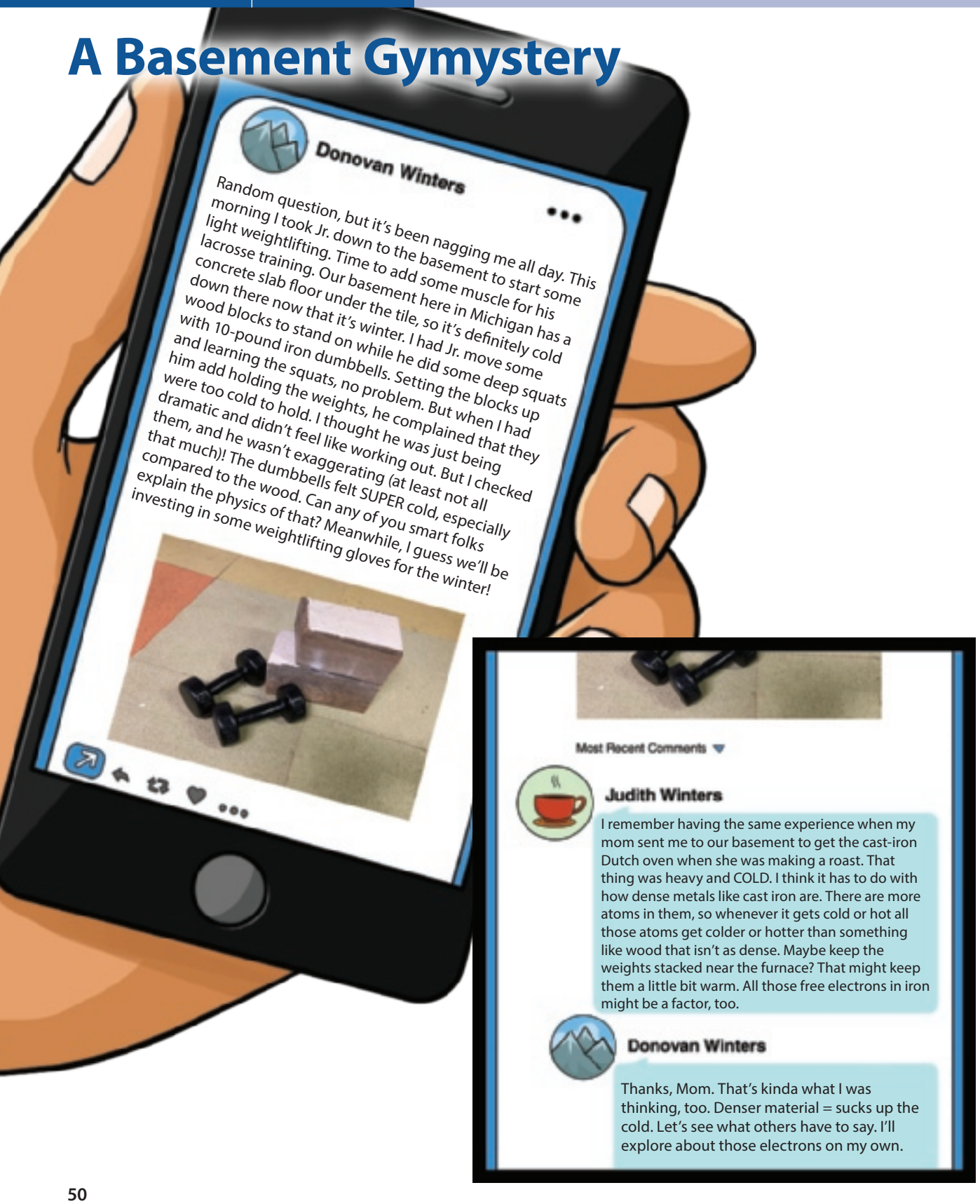
July 11, 2021

The newborns are out and about from their parents' burrows and starting to dig their own for the coming winter. I found a few adult males dead in the grass, with clear signs of starvation. They expend so much energy waking from hibernation, mating, and defending their territory, it's tough for them to eat enough to stay alive. But they probably passed on their genes before dying, so "in the game of life they are still winners," as Prof. Kim used to say. The other squirrels are plumping up nicely, getting ready for the long winter. Grizzlies, foxes, and eagles continue to pick off some squirrels, especially at the water's edge.

November 22, 2021

Temperature sensors and cameras are live and working in most of the burrows. (Camera glitched out in Burrow #13.) I'm again seeing a pattern of deep, subfreezing hibernation punctuated by 1–2-day periods of shivering, shaking, and almost-normal body temperatures. My colleagues back at the lab just ran an experiment with a hibernating squirrel in a wind tunnel. They lowered the air temperature all the way to –26°C, and only at that point did the squirrel shiver and shake to the point of waking up. Maybe that's the lowest temperature it can survive in a state of deep hibernation? Thermal imaging showed the head and neck regions warmed up first. This suggests that brown fat is another piece of the puzzle. Brown fat can be burned by cold mammals to generate heat, without the body needing to expend energy to shiver. Aside from nonshivering thermogenesis, it's unclear how the squirrels avoid actual freezing. My colleagues think they might have some way of cleansing their bodies of particles that ice crystals typically form around, called ice nucleators. Without nucleators present in the blood and other water-rich tissues, the squirrel can be well below freezing without freezing.

A Basement Gymystery





Consider the Sources

Of the three responders, who constructs theories primarily from observations of personal experience? And who provides science-backed documentation for their reasoning and explanation?



Hot Mug as Hand Warmer: How Does It Work?

Why does a warm drink in a ceramic mug heat up your hands?

For starters, the warm drink in the mug releases heat through the ceramic material to your hands. If the material of your mug conducts heat poorly, your hands won't be warmed. But be aware that if the mug material conducts heat too well, your hands might get too much heat too fast—to the point that you drop the drink!

The warm cup of cocoa provides heat to your body in a second way, too. When you drink anything warmer than your own body, you're swallowing a hot liquid, which will raise the temperature of your stomach. Raising your stomach temperature tells your cardiovascular system to dilate blood vessels that may have been constricted during that cold walk you just took in the snow. Your cold, numb fingers and toes are now getting more warming blood. If the drink isn't warm, it won't warm your core at all. In fact, if a cool drink is cooler than your body, then your core temperature will be somewhat lowered (but not likely enough that you really notice it).

Okay, so what's going on here at the level of particles?

Let's start with the mug in the hands. The warm liquid within the mug has particles that are moving around a lot. This is partly because of the state of matter—it's liquid—but it's also because of the high temperature of the particles in the liquid. Temperature is a measure of the average kinetic energy, or energy of motion, of the particles in matter. More motion equals more kinetic energy. More kinetic energy means more collisions among particles.

The busy particles in hot cocoa strike the particles in a solid ceramic mug. The mug remains solid, but its particles vibrate in place. And they vibrate more rapidly when they are being struck by active particles in an adjacent liquid. Vibrating particles on the inside of the mug vibrate against their neighbor particles and so on, until the particles in the skin of your hands are also vibrating more than before. Your body's temperature receptors detect this change and signal your nervous system that your hands are absorbing thermal energy. Your brain perceives the warmth.

If there's too much heat for your skin to handle, your nervous system will set off an alarm that says, "Pain! Hot!" And you'll either drop the mug or look for a place to set it down very quickly. Interestingly, our bodies perceive intense heat and cold in pretty much the same way. A very cold object will feel like something that's burning. In both cases, the amount of heat that's being conducted is dangerously high. It's just the direction of the conduction that differs.

The vibrating-particle phenomenon is also what makes a warm drink warm your body's core. The warm liquid is swallowed. As it passes through your esophagus and lands in your stomach, the energized particles of the liquid collide with the particles in the lining of these organs, causing them to vibrate more than before. The vibrations continue, conducting heat from the liquid to the digestive system tissues and then onto the other tissues in the torso. This is why hot soup and other warm foods and drinks feel like they warm you up on a cold day—because they do!

Words to Know

When something *dilates*, it opens wider, usually in a circular shape or opening. For example, if blood vessels dilate, they are opening up and allowing more blood flow. The opposite occurs when something *constricts*.

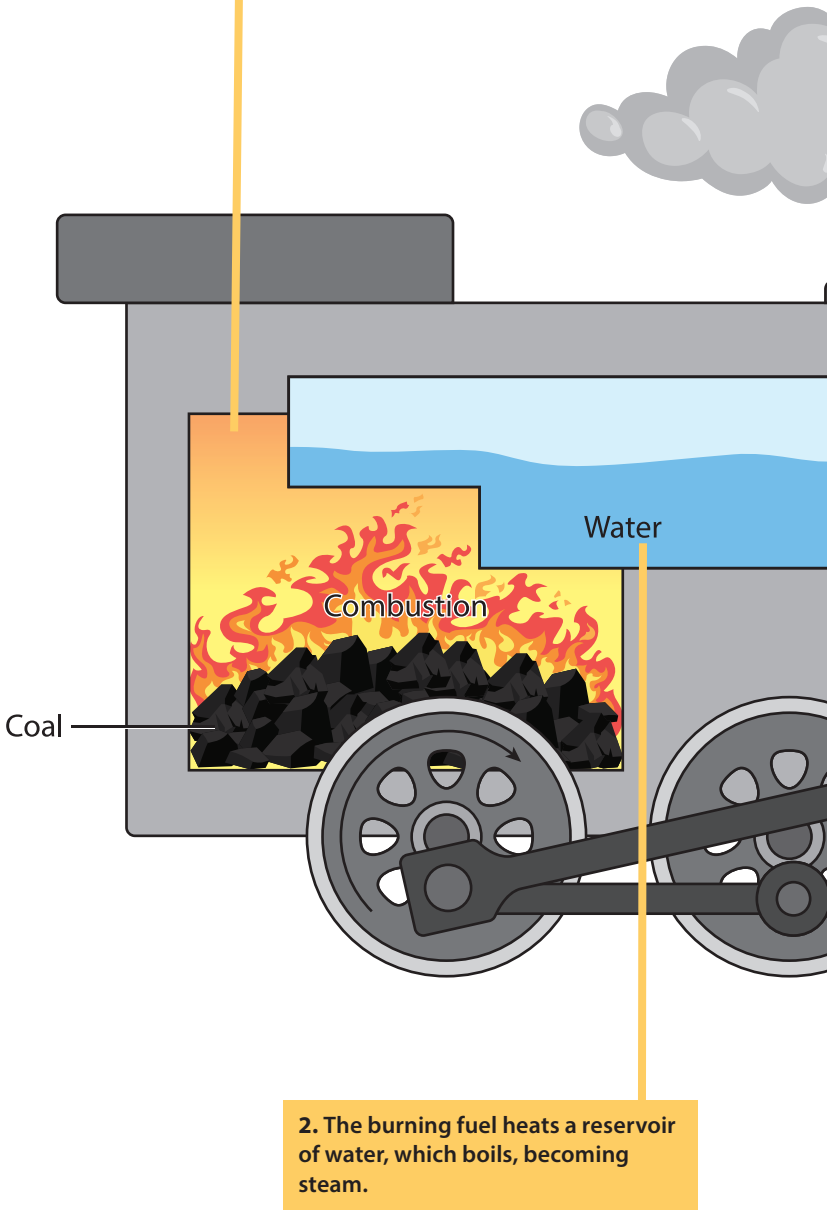
Steam Power

What is steam power? Steam is hot water vapor. If it can be contained and controlled, steam can be used to transform thermal energy into mechanical energy.

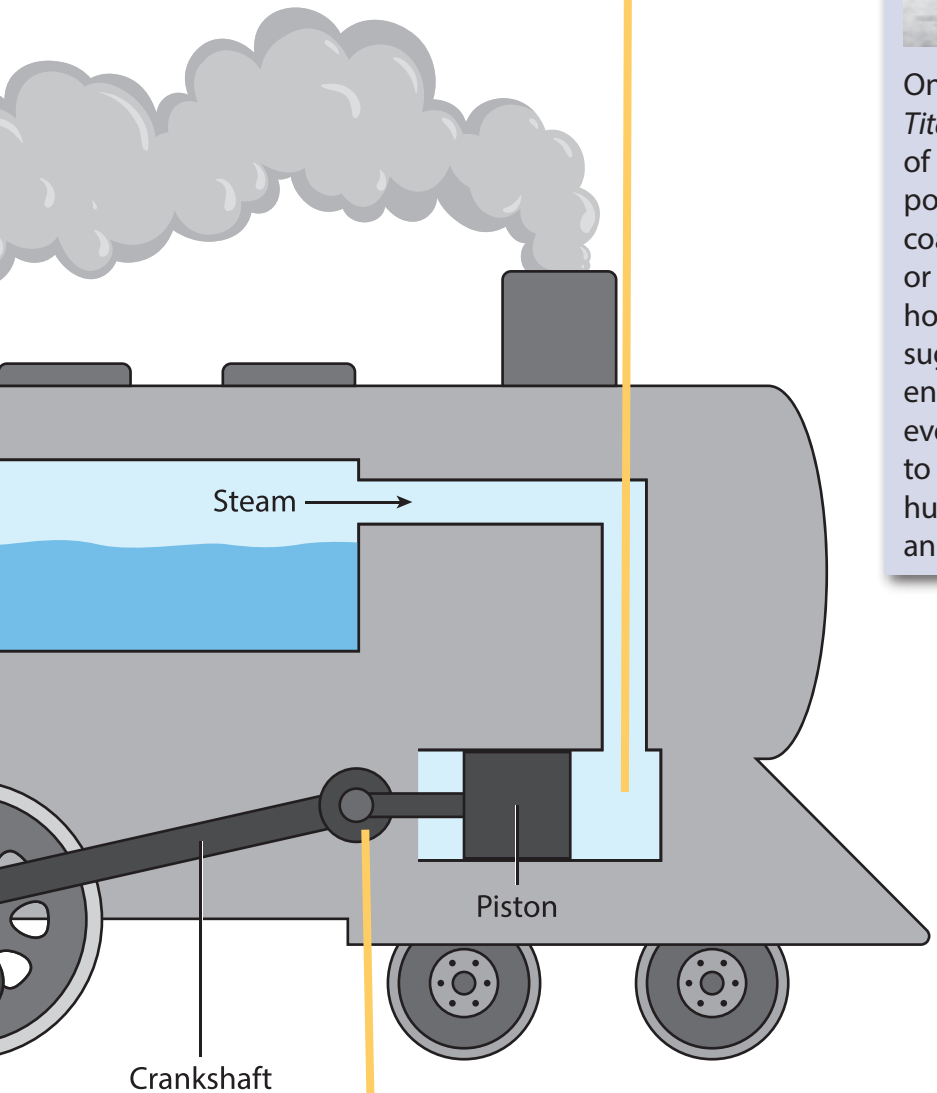
In certain places on Earth, usually near geysers and hot pools, steam can be tapped from underground pockets and directed into a turbine. The steam produces rotation in the turbine, mechanical energy, which then can be used to generate electrical energy, aka electricity. Nuclear power plants also work by producing steam that powers a generator.

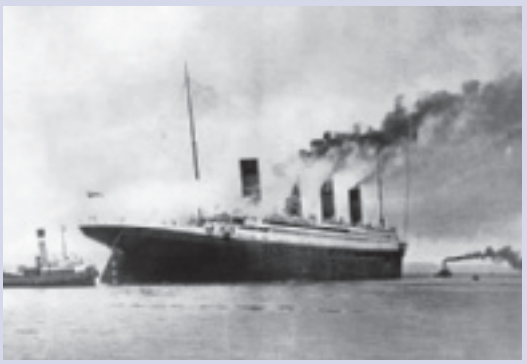
More common is steam power that starts with the heat from burning a fossil fuel, such as coal or wood. Burning coal produced the steam of the early steam engines that powered the trains, ships, and factories of the Industrial Revolution.

The process and technology can be boiled down—pun intended ☺—to four steps.



3. The expanding steam flows into an engine and pushes against a piston. Once the piston chamber has expanded, the steam then condenses, allowing the piston to move back into the chamber. The condensed steam is forced backward toward the boiler, where it is reheated, forcing the piston back out.





On a large steamship such as the *Titanic*, workers would shovel tons of coal into the 162 fireboxes that powered the massive ship. The tons of coal allowed an 882-foot ship to travel, or "steam," at more than 25 miles per hour. One theory about the *Titanic* suggests that a large coal fire in the engine room weeks before the ship even departed on its fateful voyage to America had weakened its steel hull, making it more vulnerable to an iceberg strike.

4. The in-and-out action of the piston moves a crankshaft, which is connected by gears to something that will do the work of the engine—turn a train's wheels, rotate a shaft bearing a ship's propeller, or some other mechanical action.

Cold Water, Cold Feet

Observer Log, Bottom Longliner F/V Tenacious II

December 25, 2021

Okay, when I get back to shore, I need some new boots because my feet are FREEZING out here. The combo of the cold air, the steel deck, and me standing in a few inches of seawater at the stern when the deck is loaded with haddock is bone-chilling. These boots worked fine back in August and September. Not now. I'm buying some insulated boots as a holiday present to myself as soon as we hit the dock.

The air temperature has been around 35°F, but with the wind it feels like 15°F. The water temp. is in the fifties, but when it's pooled around my boots when I'm standing at the stern to count fish, I'm still losing heat to the water even with the heavy rubber material and a pair of good wool socks insulating my feet. The steel deck is also sucking body heat through the soles of my boots. The thin felt insoles are just not very insulative. And the colder my feet get, the less my body allows blood to flow to them to warm them up!

The other thing I need to buy is some boot warmers. Once we get into January, the water will be in the forties. The water will be colder, and I can expect freezing temperatures and plenty ice on the rails and deck. The new boots will help, but the boot warmers will be a boost on the coldest days.

Plenty of haddock caught today, along with a lone porbeagle shark. It's one of several sharks that can maintain a slightly warm body temperature, allowing it to hang around in New England waters even in winter.



Benthic Offshore Crew Boots

The best deck footwear for today's commercial fishers



The new Offshore Crew Boot is a 15-inch, insulated boot that has the traction to keep you upright, working, and safe on the slickest, coldest steel decks on those 18-hour shifts through the toughest weather. These have top-notch slip resistance, a steel-toe insert to protect you from dropped traps, and, for those dark days and nights on the North Atlantic, a quarter-inch of felt insulation to envelop your foot in dry warmth. The rubber outsole adds another layer of insulation that will not crack in intense cold or heat. The felt inserts can be removed for the dog days of summer.



Exothermos boot warmers provide eight hours of heat for your cold feet. This patented technology relies on a simple chemical reaction between a few safe reactants and air. The reaction is exothermic, meaning it releases heat—the opposite of a cold pack. Just open the sealed packet, slide a warmer into the toe area of each boot, and your feet will thank you through the long haul back on the crab grounds.

Connection

Chemical reactions can be used to conduct heat into or out of the body. A chemical cold pack does the opposite of the boot warmers. The reaction in the cold pack absorbs heat from the body.

Freezing in Space

At the Movies

Review by Laura Torres

We see it over and over again. We're at or near the climax of the movie. The hero or villain is about to be blasted out of a spacecraft's airlock. For whatever reason, there's a deliberate removal of a helmet or spacesuit. And in an instant the being's face is frozen, even iced over. The body petrifies as if the astronaut or alien whose "time is up" has met the gaze of Medusa.

Moreover, we sometimes *hear* this process, which is impossible because there is no sound



in space. (The original *Alien* had the tagline "In space no one can hear you scream," which is admirably true! The sequel, *Aliens*, includes a queen alien screaming loudly upon being blasted through an airlock into space—notably sketchy science in that there science fiction!) But what's getting in my craw about these scenes is the freezing part itself. Yes, space is cold. Its temperature is 2.7 kelvin, near absolute zero. But that's because it's space. It's a vacuum. There's nothing there, no particles to bounce around with kinetic energy and have any kind of temperature. It's as cold as cold can be, yes, but with space's absence of matter, it's impossible for a warm body to conduct heat into space.

Think about being relatively unclothed in air at room temperature. You might feel a little cool, especially if the air is moving. Your body is conducting heat to the air around you, and convection via moving air can accelerate the removal of heat. But you survive, because air is relatively thin and there aren't that many particles in it to collide with you and basically bounce away with a smidgen of your body's heat as energy.

Now, think about being in water of the same temperature. Feels pretty cold, right? That's because water is much denser than air, meaning there are many more particles making contact with you. More particles, more contact, more conduction. Within a few minutes you'd surely be wishing you were back on the beach, absorbing radiation from the sun. Or wearing a wet suit, at least.

In space, it's just you and . . . nothing. Without matter around you, you can't conduct heat away fast enough to instantaneously freeze in the way Hollywood would have us believe.

So, would you eventually freeze in space, given its temperature of absolute zero? Sure, but it would take a while. Without conduction and convection, your body would lose heat via radiation, in the form of infrared waves. (Think of that heat lamp warming the popcorn at the movie concession counter. You're the lamp, only with much less infrared energy radiating from your body.)

The more rapidly deadly factor would be the vacuum of space depriving you of oxygen and allowing your body to unsurvivably expand. Your very quick death would make you less warm by shutting down your metabolic processes—digestion, muscle movement, basic cellular processes—and eliminating the sources of heat within your own body. But the loss of your warmth to space would be very slow.

No doubt, exposure to space would be . . . pretty bad. Can't deny that. But you would not instantly turn into a brittle freeze-pop. This reality makes for less exciting cinema, however, so we can expect the next round of space action films to include at least one scene in which someone or something freezes, crackles, and shatters in a matter of seconds.

Suiting Up for Water

You're planning to go snorkeling in Florida in February. Or maybe you are itching to surf the California coast or use your new stand-up paddleboard on the local lake just after the ice thaws. You need thermal protection from the cold, but what kind? This guide will help you think it through.



Want to wear a suit over your jeans and wool sweater for a casual paddle on an iceberg? A dry suit might be for you.

Dry Suits

As you might have guessed, a dry suit keeps you dry. Whether it also keeps you warm depends on what you wear under the suit. The suit acts as a waterproof layer all over your body, typically with only the hands and face or head exposed to the environment. Most dry suits are made of a trilaminate material—meaning three inseparable layers. The outermost shield layer is tough nylon. The middle layer is butyl, a waterproof synthetic rubber. This is the layer that keeps the dry suit dry. The innermost layer is another nylon or polyester layer that adds comfort and protects the butyl from the inside. Tight latex cuffs at the wrists and neck of a dry suit are designed to be so snug that water can't enter the suit. But overall, a dry suit fits more loosely than a wet suit, providing a layer of air inside to serve as insulation for your body. The loose fit permits you to wear pants, a sweater, or whatever type of insulating clothing you want to wear inside the suit. This is one advantage of the dry suit—you can wear your clothing and not deal with suit rash or suit squeeze, which can be issues with tight-fitting wet suits. The challenge to wearing a dry suit, especially while scuba diving, is dealing with moving pockets of air inside the suit. If the air ends up around your legs and feet, you can get stuck in an upside-down position. Adhesive straps and belts built into the suit can help lock pockets of air in place to prevent such accidental inversions. Of course, ballooning air is less of a concern if the suit is worn at or above the surface, where there's little or no water pressure to put a squeeze on you.



Word to Know

If something is physically *buoyant*, it has a lower density than its surroundings, causing it to rise or float upward.

Wet Suits

Wet suits are the most common type of thermal protection for divers, surfers, and others who are going to be immersed in water during their activity. Wet suits work in part by making the wearer wet. They fit snugly while also allowing a bit of space between the wearer's skin and the synthetic rubber neoprene of the suit. When the wearer gets in the water, they should lean into the water, use their hands to pull open the collar, and let water into the suit. In a few minutes, body heat will warm the trapped water. The neoprene acts as an insulating boundary between the environment outside the suit and the warmed water inside it. The thicker the neoprene, the more insulation. Wet suits have their downsides. Neoprene is buoyant. This means the suit could keep a diver stuck at the surface unless they wear a weight belt. Thicker neoprene means more weight on the belt. Thick neoprene also makes it harder to move freely. A wet suit can also get smelly after being used many times, and the neoprene rubbing or squeezing against the skin can cause suit rash. On the other hand, beneath a wet suit you wear a bathing suit and don't need to worry about getting your clothing wet. Also, the thick neoprene acts as a cushiony barrier between your skin and things that might hurt you, including barnacle-covered rocks, stinging jellyfish, or even the occasional bump from a shark.

Extreme Heat Protection

Molten materials such as melted steel or volcanic lava are extremely hot and radiate tremendous amounts of heat. Steelworkers must protect themselves from this heat by wearing personal protective equipment, or PPE. Aluminized PPE is coated with aluminum, which reflects the infrared energy radiated by molten material. It also protects the wearer from the danger of molten metal splashes. Beneath the layer of aluminum is an insulating fabric made of fiberglass or some other material that resists conduction. PPE for workers exposed to high heat needs to strike a balance between insulating the worker from heat in their environment and not trapping so much of their own body heat that they suffer from heat stress.



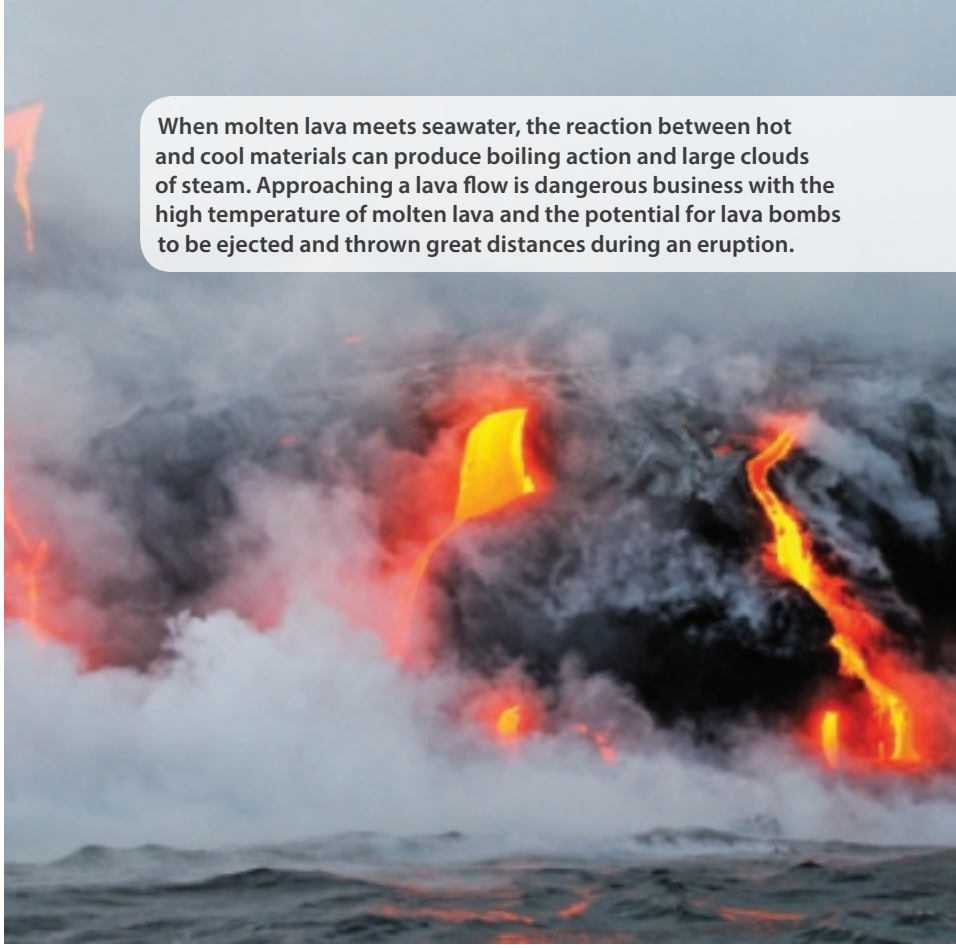
This steelworker wears aluminized PPE to reflect heat and guard against any splashes of molten steel. The worker also wears a protective face shield that filters out some of the light emitted by the material.

The PPE worn by metal workers is like the PPE worn by some volcanologists when they study eruptions up close. Like molten steel, molten lava is hot, viscous, and dangerous. Pockets of gas trapped in lava can cause explosions and splashes that carry lava long distances. Depending on the size of a launched lump of lava and the distance it travels, it can return to Earth's surface as a dangerously hot lava bomb or a cooled piece of rock.

Lava cools very quickly once it is exposed to the atmosphere. As it cools, it darkens, eventually becoming black or brown. The color of lava can be evaluated to estimate its temperature. Yellow lava is about 1,000–1,200°C. Orange indicates 800–1,000°C. Red is cooler, around 600–800°C.

Word to Know

A *viscous* substance is one that is sticky and thick, such as hot lava or honey.



When molten lava meets seawater, the reaction between hot and cool materials can produce boiling action and large clouds of steam. Approaching a lava flow is dangerous business with the high temperature of molten lava and the potential for lava bombs to be ejected and thrown great distances during an eruption.



Approaching a fresh lava flow or active volcanic crater can be made less dangerous by wearing PPE that reflects heat and protects the wearer from ejected material.

Down Jackets

One of the most reliable and popular insulating materials for winter coats is down. Down is the fluffy, short feathers of waterfowl—birds that spend much of their time swimming in water. For winter coats, goose down is often used. What makes down so useful is its light weight, its insulating properties, and its ability to be compressed but then fluff back into a larger shape. This allows down coats to be compressed when packed in a backpack or squeezed into a closet of other coats but later expand to maximize the insulation of the down-filled coat again. Unlike flight feathers, down does not have quills or a relatively flat, 2-D shape. From a distance, a cluster of down resembles a clump of cotton.

If you've ever shopped for a down coat or down comforter, you might have noticed specs about down's "loft" or its "fill power." Fill power is a measurement of how much down resists compression and therefore how well it stays fluffed so it can provide the most insulation. An actual lab test determines fill power. A cylinder gets a single ounce of down, and then a weighted disk of the same diameter as the cylinder is gently placed on top of the down and allowed to sink in the cylinder. After one minute, the position of the disk is recorded, and the volume of the compressed down is calculated. A measurement of, say, 500 cubic inches would yield a fill power value of 500. The higher the number, the better. The maximum known fill power for down is about 900.

Down garment performance is also a function of how much down is involved. If a coat has 500 grams of 500-fill-power down, it will probably provide more insulation than a coat with 500 grams of 400-fill-power down, or 300 grams of 600-fill-power down. So, a very warm down coat will have high-fill-power down *and* quite a bit of it.



Lämmin 900-Fill Down Jacket—$449

The new down coat by Lämmin features 800 grams of 900-fill goose down distributed evenly from the mid-thigh hem all the way to the hood. This coat is loaded with down, yet it can be compressed and tucked into the hood, making it no larger than a football. This can be done thanks to the breakthrough Joustava ripstop nylon that is incredibly thin yet tough and water resistant. This coat puffs up to three inches to keep you warm on the chilliest days yet easily squeezes into your carry-on when you only need the coat to get to and from the airport for that much-deserved trip to Bora Bora! What's more, it can be paired with a waterproof shell to add durability for mountain climbing, skiing, or snowboarding.



Vela 500-Fill Down Jacket—$199

Don't fall for fancy companies' overpriced coats. You're paying for expensive trips and photography to make glossy catalogs, not better-quality garments. Vela is all about getting back to the basics. You need a warm coat. Down is the best natural thermal insulation for clothing. We are offering you a 500-fill down coat for less than half the cost of those other guys. What's more, our down is compressed so it takes up less space at all times and doesn't make you look like a Saturday-morning cartoon character. Why walk around with a thick, heavy coat when you could be just as warm while looking slim and trim? The Vela weighs just 500 grams in total, making it the perfect insulating layer for hiking the Appalachian Trail or walking from the subway station.



Spot the BS

There is **bad sensemaking** in here. The two ads make claims about their products. Can you detect where the math and the claims don't quite add up?

Home Insulation Timeline

Before humans began to construct homes, they relied on caves or other natural structures to provide some protection from hot and cold weather. This was particularly important in regions of Earth that go through freezing winters. Long before fiberglass, foam, and other materials were invented, humans built homes with whatever was available in their environments: stone, mud, wood, clay, soil, straw. This timeline shows some important advances in home building and insulation.

Ancient Egypt, 5000 years ago

Egyptians collect clay-rich mud from the banks of the Nile River. Mud is mixed with reeds from the papyrus plant, pressed into wooden molds to provide a uniform shape, then removed from the mold and dried in the sun. The sturdy, moveable bricks are stacked to build homes, and the mud-based material proves to be good insulation from the hot environment.

Ancient Rome, 2000 years ago

Romans use sheets of cork to insulate roofs and water pipes. This allows some plumbing to carry hot water without losing too much heat along the way. They also use cork as insulation in shoes.

Arizona, 1000 years ago

People who live in what is now Arizona mixed clay, sand, grass, and straw into material called adobe, which is molded and dried into stackable bricks. Pueblo homes are built from these bricks and sometimes incorporated into natural shelters such as caves and overhangs. In the desert environment, adobe provides the right balance of blocking the extreme heat of the daytime while trapping enough heat to make cold nights less uncomfortable.





In northern Europe, many homes are made of stone, with mud and straw packed into gaps to prevent drafts. Roofs are often made of thick mats of straw. Animal skins and furs are used on walls and floors as insulation. In warmer regions such as the South Pacific and Caribbean, eelgrass is harvested from shallow seas, dried, and packed into walls to provide some insulation from cool weather. Dried coconut palm fronds are woven into mats that block cool breezes.

Middle Ages, 1500 to 500 years ago

1800s, Great Plains

In Nebraska, straw bales were used to build homes for settlers, as there was not much timber to harvest. Nearby, the Sioux, a Native American tribe, continued to live in moveable homes called tipis, made of wood and buffalo skins. Tipis had an opening at their tops to release smoke if fires were built inside.

1930s

Fiberglass insulation is invented and becomes a common form of insulation. The fiberglass is sold in thick blankets called batts, which can be unrolled directly into gaps between studs and joists of buildings.

1980s to present

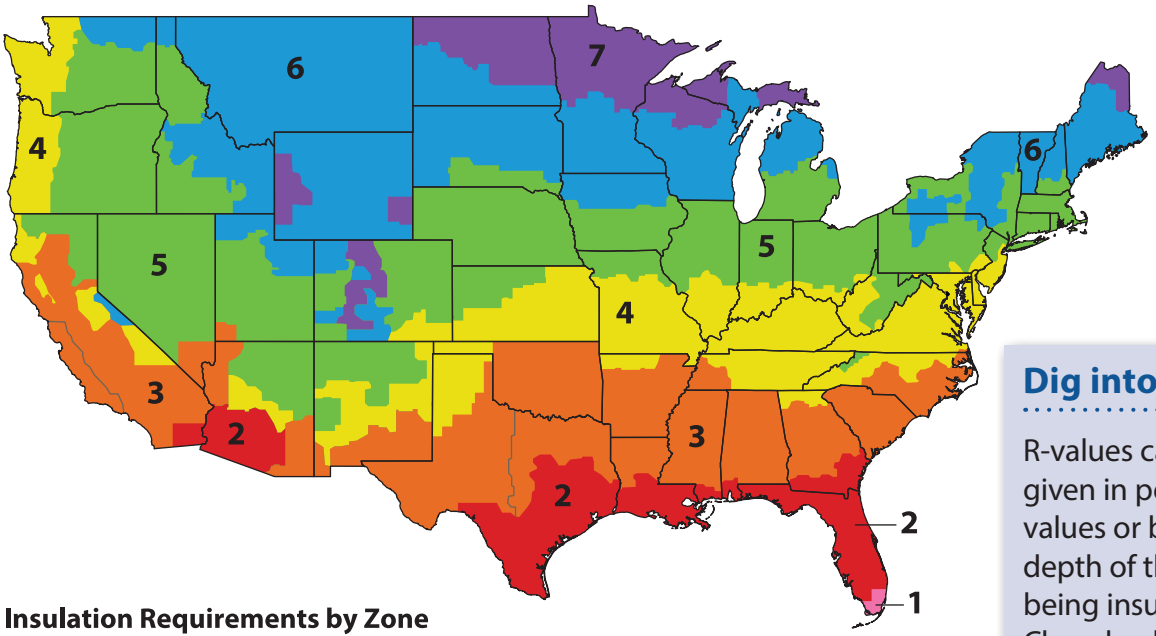
Cellulose—usually made of recycled newspaper—is used as blown-in insulation in home walls and ceilings. Spray foam is also a popular and highly efficient form of insulation. Foam can be sprayed in virtually any space, where it will expand to fill gaps before curing into a relatively hard, stable layer of bubble-filled insulation.





Insulation and R-Values

Insulating materials are designed to resist conductive heat flow. Resistance is measured in a material's R-value—"R" for "resistance." The greater the R-value, the more effective the insulation is at preventing conduction of heat. In general, thicker insulation means greater R-value, but it depends on the insulation and how it behaves once it is installed. For example, cellulose—mostly bits of recycled newspaper—that is blown into a wall can settle over time, leaving a dense, compacted area at the base of the wall and loosely packed or even empty space toward the ceiling. Likewise, thick fiberglass that is compressed to fit into a tight space will have a lower R-value than the same fiberglass that is not compressed in another space. R-values can change over time, too, as materials age, lose or gain moisture, or have the gases inside them exchanged with regular air.



Insulation Requirements by Zone

Zone	Attic	Floor	Walls (2x4)
1	R30 to R49	R13	R13 to R15
2	R30 to R60	R13 to R19	R13 to R15
3	R30 to R60	R19 to R25	R13 to R15
4	R38 to R60	R25 to R30	R13 to R15
5	R49 to R60	R25 to R30	R13 to R15
6	R49 to R60	R25 to R30	R13 to R15
7	R49 to R60	R25 to R30	R13 to R15

Dig into Data

R-values can be given in per-inch values or by the depth of the space being insulated. Closed-cell foam has the best R-value per inch: R7. Cellulose, fiberglass, and open-cell foam have similar R-values per inch, around R3.5.

All of these factors explain why it's important to consider the size, conditions, and locations of spaces that need insulation before purchasing and installing specific materials.

The U.S. Department of Energy provides a map that puts different parts of the United States into zones based on climate and likely use of energy for heating and cooling. The different zones have recommended R-values for insulation as shown in the table. Alaska is in Zones 7 and 8, while Hawaii is in Zone 1.

Fiberglass—R11 to R21

You can have fiberglass installed in rolled batts. The batts are manufactured to fit into standard spaces between joists and studs. They are not meant to be compressed or flattened, as this reduces their efficiency. The fiberglass strands hold air, and the combination acts as a layer of resistance to thermal conduction. High-density fiberglass made for two-by-four studs has an R-value of 15, or "R15," whereas low-density batts for the same space are R11. For two-by-six construction, meaning six-inch depth, high-density fiberglass is R21. Fiberglass can also be blown in as loose-fill insulation to achieve similar R-values.

Cellulose—R3.5

Cellulose insulation consists mainly of cut-up bits of newsprint and other recycled paper. It is packed in bags that can be carried into a space and then installed in several ways. For installation in vertical spaces, such as behind walls, holes are drilled in three places in the wallboard—near the floor, midway up the wall, and near the ceiling. A special blower sends cellulose into the lower hole until the bottom third of the space is full. The hole is plugged, then the blowing moves up to the middle hole, and so on, until the space is filled from floor to ceiling. The process is repeated in the next space between studs and wallboard. As long as the cellulose is installed at the correct density, it should not settle over time or leave gaps near the ceiling. For horizontal spaces such as those between ceiling joists, the material can be packed by hand. Cellulose has an R-value of 3.5 per inch, or R3.5.

Spray Foam—R3.5 to R7

Polyurethane foam insulation comes in several forms. Closed-cell foam is sprayed with a gas that forms closed bubbles. When this product cures, it is fairly rigid. Open-cell foam uses regular air, and its bubbles break very easily, causing the cured product to be spongy and flexible. Closed-cell foam is denser and has an R-value of 6.7 to 7. Open-cell foam is about R3.5.

The Albedo Effect



On the morning after a snowfall, Darren walks to the corner bus stop past three houses. The residents of the first house have completely removed all the snow from their sidewalk.



The residents of the second house have not shoveled their walk at all. It's covered with six inches of white powder, into which Darren leaves a trail of white footprints.



The residents of the third house have cleared a narrow path in the snow on their walk, pushing away the snow to expose a strip of sidewalk just the width of their snow shovel.



After a few hours, the day remains cold, but it's been sunny. Darren returns to find that the sidewalk is now clear of snow along the section where the narrow path had been shoveled.

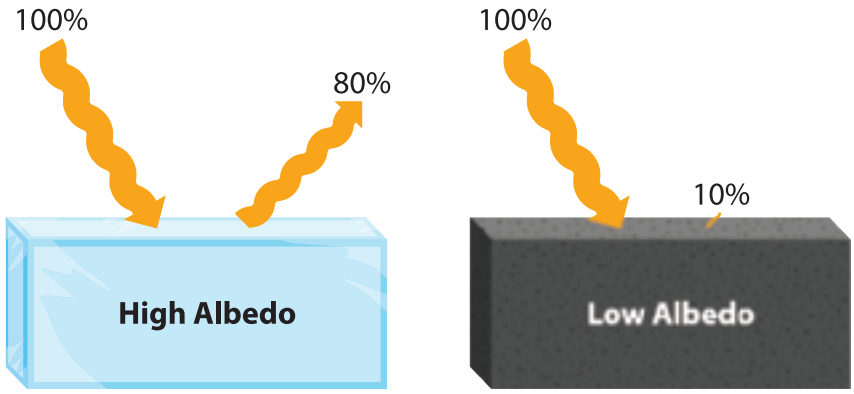


The unshoveled section of sidewalk remains covered in snow. Many people have walked on it, though, leaving too many compressed white footprints to count.



And the walk that had previously been completely shoveled now reveals exposed grass along both sides where the snow has melted away. Darren has just noted a small demonstration of the albedo effect.

Albedo refers to the portion of sunlight reflected from a surface, as opposed to absorbed by surfaces. It is especially important to astronomers when discussing the reflected light of a planet or moon. Climatologists use it when describing reflection from various surfaces of Earth. White, lighter-colored, and reflective surfaces, such as snow, bounce a greater percentage of radiation from the sun back out toward the atmosphere. Clouds, ice, and snow are highly reflective bodies. They are said to have a high albedo. Darker-colored surfaces, such as soil or pavement, reflect less sunlight. Those surfaces are said to have a lower albedo.



Loss of Sea Ice Is Fuel for Climate Change

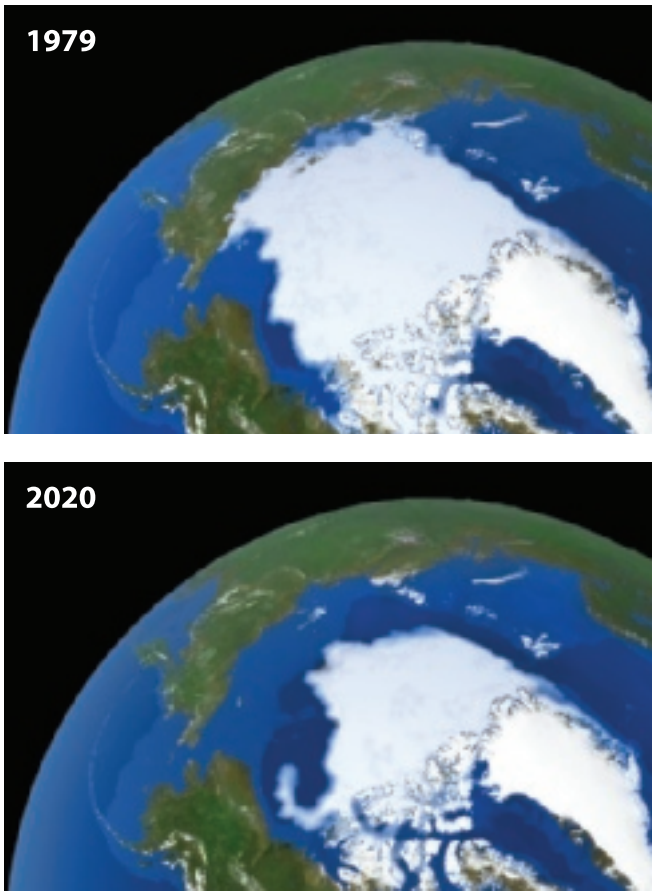
Where snow blankets Earth's surfaces in white, much of the sunlight is reflected back into the atmosphere. But if you shovel part of a sidewalk, exposing pavement to the sun, the sidewalk will absorb more sunlight and heat the air above it. This can increase the melting of nearby snow, in turn exposing more sunlight-absorbing surface. This is a **positive feedback loop**. Clearing a sidewalk of light-reflecting snow causes the sidewalk to get warmer, which results in more snowmelt, which allows even more light absorption, which further warms surfaces and air.

In the Arctic, the albedo effect occurs on a vast scale thanks to the presence of snow and sea ice. In winter, when the North Pole gets little to no sunlight for months, the Arctic's seawater gets colder, and the air temperature plummets.

Much of the Arctic Ocean is frozen, and by the time summer arrives there is so much ice that much of it remains solid even through the summer when the North Pole has sunshine around the clock. This is why oceangoing ships have not sailed from Europe to Asia across the Arctic Ocean.

But all of that is changing. With climate change and global warming, there is less sea ice enduring the summer months. A positive feedback loop has kicked in. Because there is less of the reflective sea ice in summer, more of the Arctic Ocean receives sunlight during the sunny months. This makes the sea considerably warmer than it would be if it were covered by ice. By the time the air is colder again and the sunlight is absent, less of the warmer-than-usual sea is likely to freeze. And the sea ice will be less abundant and thinner in the spring. This, in turn, allows more of the sea to be warmed in summer, which spells less sea ice formed the following winter. And so on.

The scale of this phenomenon is so large that it will have effects on global climate. The warming Arctic Ocean emits heat into the atmosphere. The global conveyor belt of ocean currents might slow down. Some nations are already planning to reroute cargo ships through the Arctic once the sea ice is sparse and thin enough for ships to pass through.



In summer, there is now far less sea ice than there was four decades ago, and the positive feedback loop suggests the Arctic could have very little summer sea ice in the decades to come.

Vocabulary

positive feedback loop, n. a phenomenon in nature in which the more something occurs, the stronger or more likely that thing's effect becomes

Newburyville Gazette

Hotels, Horse Tracks, and the Heat Island Effect

Editorial

Earth's many surface types absorb and reflect solar radiation in different ways. It all depends on variables—the properties of the materials that are struck by sunlight, as well as how much sunlight gets through the atmosphere and reaches the surface. Humankind's impact should not be overlooked. Whenever we convert, say, a meadow or forest into an asphalt parking lot or high-rise building with a black tar roof, we are changing the fate of the thermal energy in sunlight. In general, many of our activities on Earth have made the planet absorb more sunlight, which means more heat in the thin layer of air in which we live.



Heron Pond is a complex wetland ecosystem that provides cooling and other ecosystem services.

Editorial (continued)

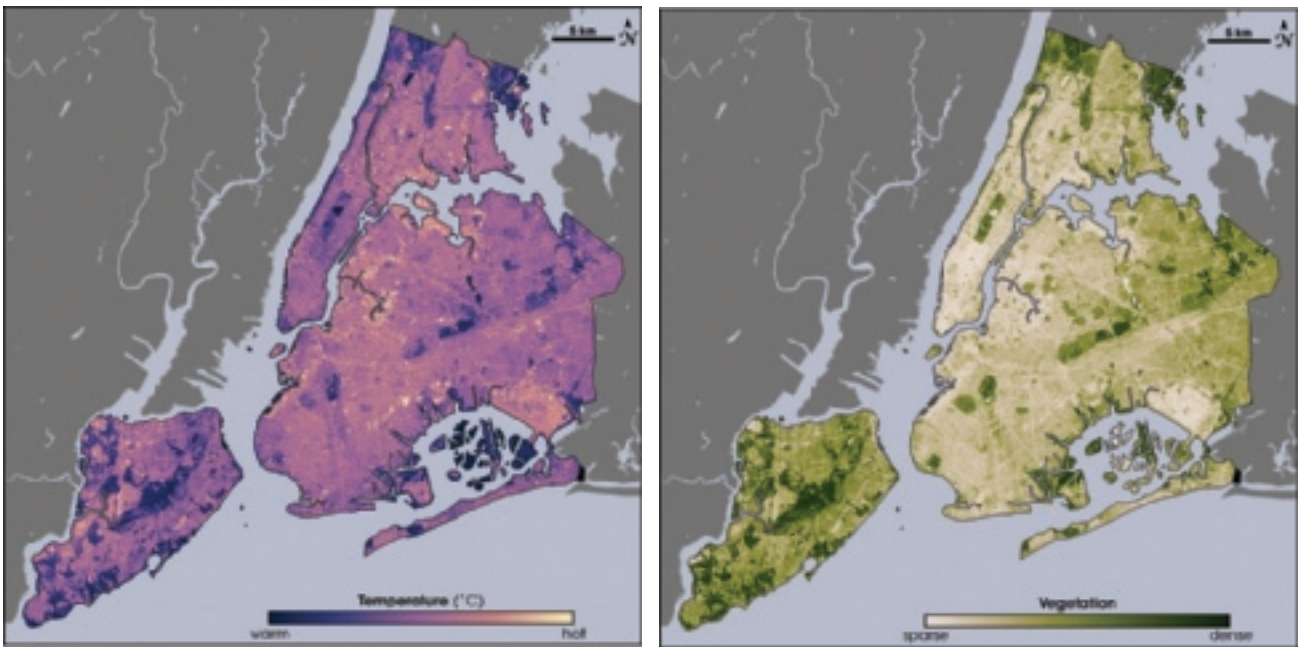
Let's consider the case of the proposed development of a horse-racing track and resort hotel at the marsh we know as Heron Pond. The marsh is warmed by the sun, but it does not radiate all that much heat back into the air. Asphalt and other materials that would compose the horse track facility, on the other hand, would radiate heat into the air. This is known as the heat island effect, where a specific location becomes hotter than surrounding areas despite no difference in the amount of sunlight received. You have probably experienced this when you have walked across a parking lot on a warm, sunny day.

With climate change making the atmosphere warmer, the heat island effect will be amplified. Urban areas that lack vegetation and are covered with concrete and asphalt will get even hotter in the summer, and heat waves will be deadlier.

Even at Heron Pond, the conversion of the marsh into the proposed horse track and resort could alter the microclimate of Newburyville. The massive parking lots, surfaces of the racetrack, and rooftops will have a high albedo, which means they will radiate increased heat into the atmosphere. The heated air will also rise, creating a void that will draw in air from nearby. This will produce some refreshing breezes.

We suggest that Newburyville say no to the proposed resort unless, at the very least, the plans are altered. Responsible plans should provide shade in the form of large arrays of solar panels to prevent the location from becoming a solar oven. However, the Board's opinion is that the best plan seems to be to leave the marsh alone, allowing it to provide the ecosystem services it has been providing for several thousand years.

—The Newburyville Gazette Editorial Board



These images from NASA show the connection between vegetation-free areas of Manhattan island of New York City and extra-warm air temperatures.

Ice as Insulator

Ice performs an unexpected but similar role in two very different places on the same day.

January 29
White Pond, Concord, Massachusetts
An Ice Fisher's Journal

It's counterintuitive, but ice keeps this pond alive. To be more specific, how water behaves when it freezes prevents most of the pond from turning into a solid block of ice, which would kill just about every fish, crawfish, plant, and frog in it. Water's an unusual substance in that it gets less dense when it changes from liquid to solid. When water freezes, its molecules become stacked and arranged in an orderly way that takes up more space than the molecules' arrangement in liquid water. Because the solid is less dense than the liquid, ice floats on top of liquid water.

Where the air temperature is continuously very cold, ice keeps getting thicker as liquid water freezes against the bottom surface of the ice layer. For more water to keep freezing into ice, heat has to be conducted out of the water, through the ice, and into the cold air above. But compared to a lot of materials, water and ice are fairly poor conductors of thermal energy. And at a certain point, the ice becomes so thick that the liquid can't lose enough of its kinetic energy into the ice to pass the tipping point and freeze.

At this point, the ice is as thick as it is going to get, and it's acting as a very efficient insulator between the water below and the frigid air above. So, the water below remains liquid.

If you think about it, if ice sank instead of floating, a pond like this could freeze completely as ice built up from the bottom. Instead, the ice forms a layer of insulation on top of the liquid below, allowing fish to survive the winter—and get hooked on my ice-fishing line!



Ice can be strong enough to support people, and even houses and trucks, yet its low density means it floats on top of liquid water.

January 29
Heggerick Orange Groves, Davie, Florida
An Orange Farmer's Journal

The forecast is calling for subfreezing temperatures here in central Florida tonight and tomorrow night, so I'm preparing the sprinklers. If I lose 50 acres' worth of oranges, I'll be in a world of hurt. (On the other hand, if I don't lose mine but my competition loses theirs, I'll be able to sell my crop for a better price!) The key is to keep enough water on the oranges to form a thin ice layer. Surprisingly, the ice on the fruit and leaves will insulate them. It's also good to get the ground beneath the trees pretty soaked, too. A thin layer of ice on the ground will provide some temporary insulation for the soil and roots

Freezing all that water also gives a tiny, unexpected boost of heat to the plants and to the air surrounding them. It's kind of tricky to think about, but my local professor friend explained it like this:

A glass full of liquid water has more energy than the same glass full of ice after a night in the freezer. Why? Because in the liquid, the particles are moving around more. There's more kinetic energy.

So, when the liquid water approaches freezing, it takes a while; and the temperature doesn't change from 32°F until all of the water has frozen. During that cooling period, thermal energy is leaving the water as heat. A freezer is designed to remove thermal energy. It dumps the heat outside the freezer compartment.

But in my orange grove, the process of freezing those thin layers of water moves a little bit of heat into the fruit, the leaves, and the surrounding air. So, in a weird way, making things wet and frozen heats the oranges a bit. The process makes the air a little warmer, and then the ice acts as an insulator, too. If the air temperature drops well below freezing overnight, the ice should protect the fruit and trees for a short time until the morning sun rises to warm things back up again.



Heat in Turf and Grass Athletic Fields: A Local Study

By Jordan Agnew, Elsie DiForio, Tevita Lolohea, and Hector Cabral
Mrs. Nann's Grade 9 Science Class, Nelson H.S.

Introduction

The town of Nelson is building a new high school in the next two years. A debate over whether the new athletic fields should consist of grass sod or artificial turf is ongoing. Turf has lower maintenance costs, as it does not require watering, mowing, or fertilizer. However, there are concerns about the impacts of artificial turf on the health of local wetlands and waterways and also on the health of participants and spectators on the fields. Our hypothesis: Artificial turf consisting of plastic grass and black rubber crumb fill will absorb more sunlight and conduct more heat into the feet of players and into the air around them, making a turf field much hotter and potentially more uncomfortable than a field of grass sod would be.



Turf consists of plastic blades of artificial grass embedded in a thick layer of black rubber crumb fill made from used automobile tires.



Natural grass sod consists of Kentucky bluegrass or fescue rooted in well-drained soil consisting of loam, sand, clay, and stone.

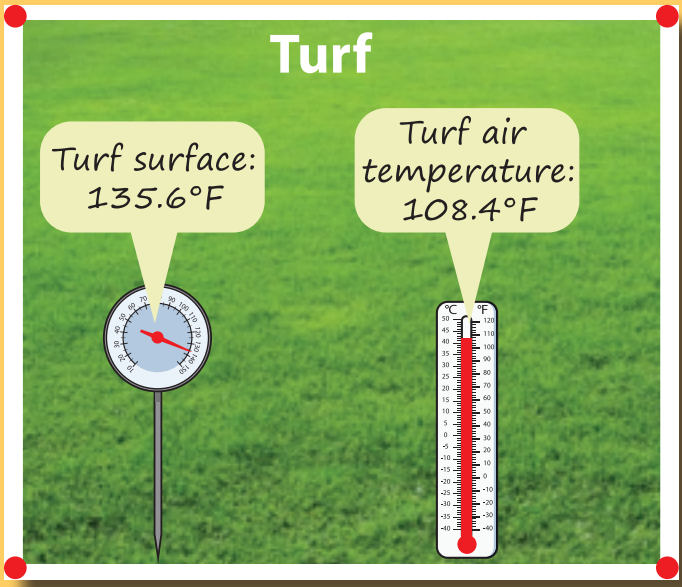
Methods and Materials

We used two existing sites: the natural grass field at the existing high school and the turf field at the local community college. These sites are less than one mile apart and experience the same weather and amount of incoming sunlight. Both sites have a depth of at least six inches of their respective fills: tire crumb for the turf, loamy soil for the grass. Our team split up so we could measure midday temperatures in the top inch of the turf and grass and in the air three feet above these surfaces at the same times every day. For five straight days in early May, we took readings to approximate what each type of athletic fields would experience in a spring or fall season of soccer, lacrosse, football, or other field activities.

Weather conditions were recorded for each day of our study, including the morning (9:00 a.m.) conditions and the conditions at midday (12:30 p.m.), when temperature data were recorded.



We used a meat thermometer to measure the temperature within the topmost layer of rubber crumb fill and soil and a standard thermometer to measure the air temperature at waist height (3 feet) at each site at midday. We used the U.S. customary units of measurements for temperature (°F) and distances (ft).

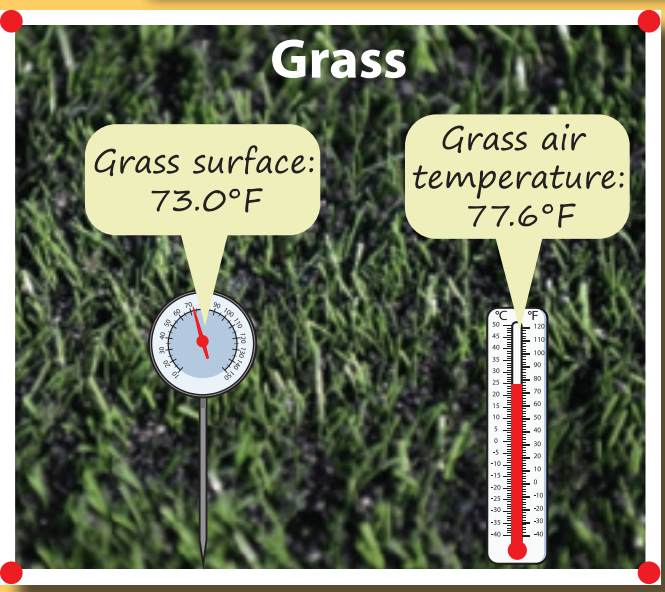


Results

The data table contains our results.

	May 5		May 6		May 7		May 8		May 9	
	Turf	Grass	Turf	Grass	Turf	Grass	Turf	Grass	Turf	Grass
a.m. weather	Mostly sunny		Clear, sunny, breezy		Partly cloudy, drizzling rain		Clear, sunny		Partly cloudy, humid	
Temp. high/ low (°F)	78/64		83/66		65/54		79/66		84/69	
12:30 surface temp. (1" depth)	145	75	155	79	103	65	130	68	145	78
12:30 air temp. (3' height)	125	82	108	80	73	68	118	78	118	80

Our data show a clear pattern: Days that were relatively warm and sunny made the turf field's surface hotter than natural grass, and in turn the air above the hot turf was much warmer at midday than the air above the natural grass. In both sites, the presence of moisture via rainfall provided relief from heat, and this made the two surfaces closer in temperature, but even then the turf surface was nearly forty degrees warmer than the grass because there was enough sunlight to provide significant warmth to the rubber crumb fill and the amount of precipitation was not enough to remove the heat through conduction to the water or evaporative cooling. On average, the turf surface at midday was 135.6°F while the grass surface was 73.0°F. The difference in air temperatures at waist height was less extreme: 108.4°F to 77.6°F.



Discussion

Our study supports our hypothesis. It showed that artificial turf absorbs much more energy on sunny days than does natural grass. Precipitation or irrigation (e.g., sprinklers) reduces this effect by providing evaporative cooling, but that was the only circumstance in which the turf was close to 100°F or less at midday. The potential effects of the hot turf surface on the health of participants in field sports are significant, as any type of fall, sliding, or skidding against the hot rubber crumb and plastic grass could result in a skin burn, and certain types of bacteria might thrive in the warmth. It is even possible that some participants' footwear would fall apart or melt, depending on the soles and the heat conducted from the rubber crumb material. Secondly, the hot air directly above the turf could lead to heat stress and heat stroke unless the activities themselves are modified to increase opportunities for hydration and rest. Intense air temperatures could also lead to fatigue and poor decision-making, both of which are contributing factors in athletic injuries such as sprained knees and strained muscles.

The supposed savings offered by artificial turf would likely be offset in a number of ways. First, such a field could be made cooler and somewhat safer if it were regularly watered, but then that means whatever savings on irrigation are wiped out. While it's true that plastic grass does not need to be mowed or fertilized, the costs associated with dehydration, heat stress, and injuries that occur because athletes are overheated are difficult to predict but could be considerable.

Given our findings, we strongly urge the town of Nelson to rebuild the existing grass fields and not invest in artificial turf fields. Should the town vote for turf, we suggest investigating the use of a lighter type of fill that would absorb less energy from sunlight and be less likely to turn the athletic fields into solar ovens.

Vocabulary

hypothesis, n. an idea or claim that can be tested through an investigation or experiment

Dig into Data

Given that the study recorded the turf and grass site temperatures at midday but most school athletics occur after school, what would you suggest for a follow-up study?

Glossary

alloy, n. a mixture of a metal, such as iron, with other metal or nonmetal elements

blubber, n. a layer of dense fat that provides thermal insulation

buoyant, adj. the characteristic of an object or material that rises upward as a result of its having lower density than its surrounding medium

climate change, n. a change in global or regional climate patterns revealed by data diverging from averages in continuous trends

closed system, n. a set of factors working together into which no new matter or energy is introduced and from which no matter or energy is removed

compression, n. reduction in volume (which causes increase in pressure)

constrict, v. to make narrower; the opposite of *dilate*

dehydrate, v. to cause to lose water

dilate, v. to make wider or more open

downwelling, n. the sinking of higher-density fluid in a surrounding fluid

fluid, n. matter that does not hold a fixed shape and is able to flow; gases and liquids

fossil fuel, n. a substance, such as coal or petroleum, formed over millions of years from fossilized organisms

glacier, n. a slow-moving mass or river of ice formed by the accumulation and compaction of snow on mountains or near the poles

global warming, n. the long-term heating of Earth's climate system observed since the pre-industrial period (between 1850 and 1900) due to human activities

hyperthermia, n. the condition of having a body temperature above normal

hypothermia, n. the condition of having a body temperature below normal

hypothesis, n. a proposed, unproven explanation made as the basis to start an investigation

insulation, n. material that reduces the transfer of energy

open system, n. a set of factors working together into or out of which some new matter or energy can move

ore, n. a sediment or rock that contains valuable metals

polar vortex, n. a body of cold, rotating air encircling either of Earth's polar regions

positive feedback loop, n. a phenomenon in nature in which the more something occurs, the stronger or more likely that thing's effect becomes

radiate, v. to send out in a straight line from a center

reverse image search, n. the function of an internet search engine to identify the source of a digital image file

scale, n. a graduated series of measurements; a proportion between two sets of measurements

science literacy, n. the ability to read, hear, and comprehend information about scientific topics and demonstrate understanding in discussion and through writing

social media, n. websites and applications that allow users to participate in sharing content on the internet

system, n. a set of factors that work together

temperature, n. the measure of the average kinetic energy of the particles that make up a substance or material

thermoregulation, n. a body's ability to maintain a temperature within a certain range for survival

upwelling, n. the rising of lower-density fluid in a surrounding fluid

viscous, adj. the stickiness or thickness of a liquid

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