MAIN MENU

ICE FLOWS

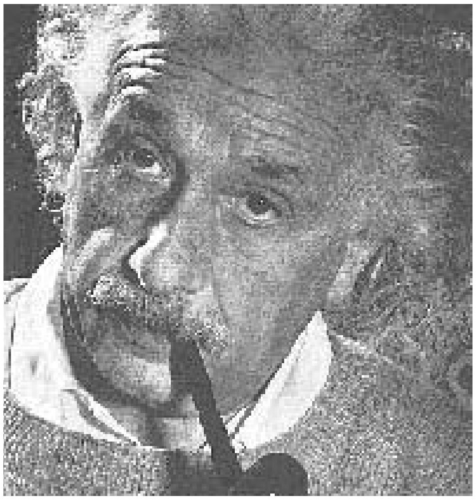
LESSON DIRECTORY

PHOTO GALLERY

This lesson develops precursor understanding about how and why ice flows, especially as a large mass, such as a glacier.

SCIENCE & LITERATURE

> “All bodies are elastically deformable and alter in volume with change in temperature.”
>
> —Albert Einstein (1954/1982)



> “When polycrystalline ice is subjected to stress, it immediately deforms elastically, followed by transient creep, and finally steady viscous flow called secondary creep is reached.”
>
> —Hermann Engelhardt,
> Discoverer of Ice IV (2005)

In other words, ice flows. This is most evident in a large body of ice, such as a glacier, subjected to the stress of its own weight.

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CONCEPT OVERVIEW

This lesson develops precursor understanding about how and why ice flows, especially as a large mass, such as a glacier.

Concepts:

- Flowing
- Elasticity
- Stress and Strain

This activity provides a concrete experience of:

- Qualities of *viscoelastic* materials.
- Observing pictures and videos about what happens when glacial ice flows.

PRE K–GRADE 2 CONCEPTS

- Materials can be categorized by how they respond to different kinds of stress, such as pushing, stretching, twisting, squeezing, and gravity.
- Under stress, ice flows.
- A glacier is a large accumulation of ice that flows under the stress of gravity due to its own mass.

GRADE 3–5 CONCEPTS

- Materials can be categorized by how they respond to different kinds of stress, such as pushing, stretching, squeezing, twisting, and the effect of Earth's gravity.
- A material that flows slowly is called *viscous*. A material that can rebound to its original shape after being stressed is called *elastic*. Ice has both qualities, so it is *viscoelastic*.
- Large masses of ice exist on Earth in the polar regions and high in the mountains. Under the stress of gravity and its own mass, glacial ice can creep, or flow, like a slow moving river. Sometimes, faster surges occur.
- Earth has experienced periods known as ice ages, when massive glaciers flowed farther south than they ever do today. We can find evidence of glacial erosion in the landforms, caused by ice creeping and flowing like slow-motion rivers over long periods of time.

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LESSON SUMMARY & OBJECTIVES

Young students have already a great deal of everyday experience of playing with the flowing properties of water, honey, syrup, and other familiar materials. This lesson aims to connect that personal experience to the world of science, making distinctions among the different ways materials flow and to think about how things flow—and then to apply those distinctions to understand how ice flows.

Objective 1: Notice that water and other materials flow differently under stress

Flowing occurs as a fluid moves from higher elevation to lower elevation, affected by the downward pull of gravity. We can compare how different substances flow and deform differently under stress.

Objective 2: Notice from pictures and videos of glaciers that ice flows

Ice flows, but it is difficult to observe directly. While we might not be able to visit glaciers directly, we can view pictures and videos, and we can learn from measurements that ice scientists have made. We can examine evidence that glacial ice flows slowly and in surges.

Objective 3: Notice from pictures and videos of places where glaciers have been that flowing ice can leave effects on the land

Large-scale glacial movement can affect the landscape and global climate conditions. Earth has experienced periods of glacial activity known as ice ages.

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STANDARDS

BENCHMARKS:

11C Common Themes: Constancy and Change

GRADES K–2, PAGE 272

- Things can change in different ways, such as size, weight, color and movement. Some small changes can be detected by taking measurements.

4C The Physical Setting: Processes that Shape the Earth

GRADES 6–8, PAGE 73

- Some changes in the earth's surface are abrupt (such as earthquakes and volcanic eruptions) while other changes happen very slowly (such as uplift and wearing down of mountains). The earth's surface is shaped in part by the motion of water and wind over very long times, which act to level mountain ranges.

4F The Physical Setting: Motion

GRADES K–2, PAGE 89

- The way to change how something is moving is to give it a push or a pull.

GRADES 3–5, PAGE 89

- How fast things move differs greatly. Some things are so slow that their journey takes a long time; others move too fast for people to even see them.

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NSES:

Content Standard B Physical Science: Position and motion of objects

GRADES K–4, PAGE 127

- An object's motion can be described by tracing and measuring its position over time.

GRADES 5–8, PAGE 154

- The motion of an object can be described by its position, direction of motion and speed. The motion can be measured and can be represented on a graph.

Content Standard D Earth and Space Science: changes in the Earth and sky

GRADES K–4, PAGE 134

- The surface of the earth changes. Some changes are due to slow processes, such as erosion and weathering, and some changes are due to rapid processes such as landslides, volcanoes, and earthquakes.

Content Standard F Science in personal and Social Perspectives: Changes in environments

GRADES K–4, PAGE 140

- Some environmental changes occur slowly, and others occur rapidly. Students should understand the different consequences of changing environments in small increments over long periods as compared with changing environments in large increments over short periods.

Content Standard D Earth and Space Science: Changes in the Earth and sky

GRADES 5–8, PAGE 160

- Land forms are the result of a combination of constructive and destructive forces. Constructive forces include crustal deformation, volcanic eruption, and deposition of sediment, while destructive forces include weathering and erosion.

Content Standard B Physical Science: Position and motion of objects

GRADES K–4, PAGE 127

- The position and motion of objects can be changed by pushing or pulling. The size of the change is related to the strength of the push or pull.

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ESSENTIAL QUESTION

How do materials flow?

What can we observe about how materials flow under different conditions? How do we categorize materials that flow? How can we apply this to understand how ice flows? What can we say, draw, write about flowing that we look at, touch, and examine in class?

ACTIVITY QUESTION

How does ice flow?

How can we explain how ice creeps or flows? How does glacial ice flow? What can we learn from viewing pictures of glaciers moving and their effects on the land? What can we say, draw, or write about ice as a *viscoelastic* material?

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BACKGROUND

ScienceTalk: What does is mean to say that ice is a viscoelastic material?

When scientists make up new words, they are trying to communicate a precise meaning to describe the details of a phenomenon. While scientific terms often seem to complicate matters, once you understand what the scientist means, the new words make sense.

Stress and Strain

When scientists talk about stress, they are referring to forces acting upon an object, such as: compression (pushing, squeezing), tension (pulling, stretching), shear (twisting, distorting). Strain is the response of a material to stress, such as: fluidity (flow), elasticity (rebound), plasticity (malleability), and fracturing (brittleness, breaking).

Ice is Viscous

A scientist might want a way of describing these properties of materials more precisely. *Fluidity* is a measure of how easily a fluid flows. *Viscosity* describes resistance to flowing. A thick, sticky fluid is slow-to-flow or viscous.

Ice is Elastic

Elasticity is a measure of how easily a substance rebounds after being under stress. An elastic material may be stretched out of shape, and then bounces back. Similarly, an elastic material can be squeezed, and can still bounce back to its original shape. Its spring-like molecular bonds have the capability of stretching and rebounding, or of breaking and re-forming so that the rebound effect is the same. The hydrogen bonds in the crystalline structure of ice are strong, flexible, and capable of re-crystallizing in response to stress. Ice turns out to be elastic.

Ice is Viscoelastic

Although ice is frozen solid, it flows slowly and it can rebound to its former shape after being stressed, even at the scale of a single ice crystal. When a material has both of these qualities, we need a special word to describe it. Scientists use the word *viscoelastic* to describe that ice both flows and rebounds. Here's how a glaciologist, an ice scientist, tells it:

> Ice is a viscoelastic material with a nonlinear flow law. When shear stress is applied to a single crystal of ice, it undergoes plastic shear strain easily parallel to the basal plane, which is perpendicular to the hexagonal c-axis. In other directions the stress needed to produce plastic shear deformation is much higher. When polycrystalline ice is subjected to stress, it immediately deforms elastically, followed by transient creep, and finally steady viscous flow called secondary creep is reached…. Several physical processes are responsible for these deformations: movement of dislocations, sliding along grain boundaries, and recrystallization.
>
> —Hermann Engelhardt,
> Glaciologist and
> Discoverer of Ice IV (2005)

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How do glaciers form?

A glacier is a massive accumulation of ice. The life of a glacier begins in a place where the temperature is nearly always below the freezing point. On Earth, this includes the Arctic, the Antarctic, and high mountain areas. It all begins as snow that never melts. As more and more snow accumulates, it becomes heavier and more densely packed. The actual snow crystals begin to merge into larger crystals that we call "firn." Firn is 4 to 16 times larger than snow crystals. As firn continues to accumulate, the glacier keeps growing, becoming thicker and heavier.

The pressure tends to push out the air trapped in between ice crystals, which gives glacial ice its "crystal clear" appearance. It takes a very long time to attain such thickness. When the ice reaches a critical thickness of about 18 meters (about 60 feet) the glacier is capable of flowing. Some glaciers in Antarctica are over 4000 meters (13,000 feet) thick, preserving a history of about 80,000 years.

As glaciers move, they scrape the ground and the sides of mountains and move rocks, boulders, dust, and dirt. Glaciers preserve a history of global climate change in the layers of ice. Earth has experienced periods of global climate change when freezing temperatures moved beyond the poles—the ice ages. We can see the remnants of the ice ages in glaciated land.

How do glaciers flow?

Scientists are still exploring exactly how glaciers flow. They propose possible explanations, such as:

1. Is the ground frozen beneath it?
    - If it is, the glacier would tend to adhere and move more slowly.
2. Is there melting near the base?
    - If there is, the glacier would tend to slip at the base and flow more rapidly.
3. Is there an ice stream?
    - If there is, the glacier can surge, moving up to twice the normal rate of flow.
4. What is the slope of the land?
    - Where it is steeper, the glacier would flow at a greater rate due to gravity.

When polycrystalline ice reaches a thickness of about 50 meters (150 feet) the sheer weight causes it to deform and spread out. Like a slowly moving river, a glacier flows over land and leaves its abrasive effects, most notably during the ice ages. The rate at which a glacier flows depends on its thickness, its connectedness to the frozen ground below, and to what extent there is melting as a result of the high pressures involved.

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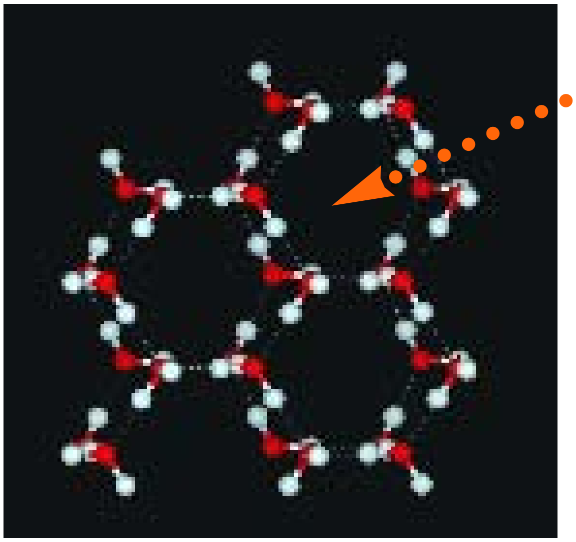
Generally, the gravitational pull on a massively thick glacier creates shear deformation of its crystalline structure. You can think of an ice crystal as "a stack of crinkled molecular sheets, each having hexagonal symmetry and lying perpendicular to the *c*-axis" (Fletcher, 1970, p 185)

As we look through the open hexagonal spaces, we are looking in the direction of the *c-axis* (shown by the orange arrow).



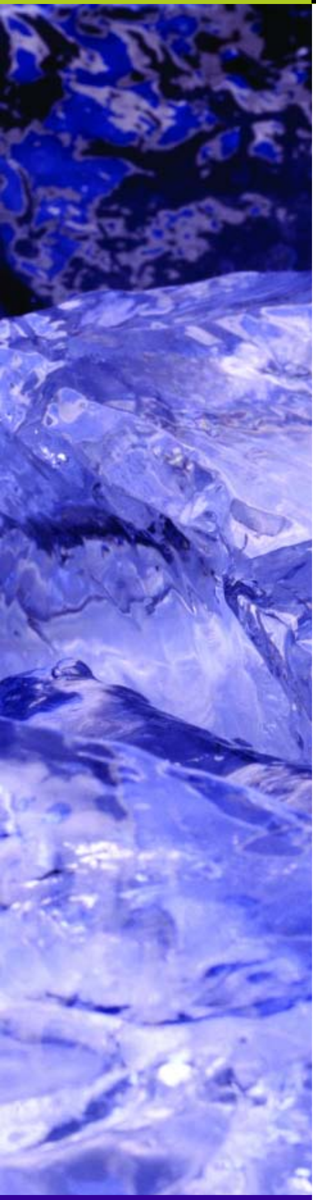
(image source: http://www.edinformatics.com/math_science/info_water.htm)

Crystals tend to form more rapidly *perpendicular* to the *c-axis*, forming hexagonal rings in crinkled, slightly twisted sheets. For any given sheet, about half the hydrogen bonds connect to the sheet above and about half to the sheet below. When push comes to shove, the main type of plastic deformation is the gliding of sheets over one another, called basal glide.

Even though the hydrogen bonds are just as strong in each direction, it is the disordered nature of the arrangement that allows ice to creep, or flow, as stress forces the bonds to shift or break and reform. Ice can dislocate, it can slide along grain boundaries, and it can recrystallize, resulting in the effect of a flow.

Sometimes, the high pressure can cause melting, either at the base, resulting in a basal slip, or as an ice stream at depth, causing rapidly moving surges up to twice the usual flow rate of a glacier.

Like a river, the flow motion tends to be more rapid at the upper surface. The lower the depth the more lag there is. Glacial ice creeps along like massive slow-motion rivers, pulled by gravity from higher elevations toward sea level.



ACT OUT THE SCIENCE

Whole Group Mime Activity: *Movement Integration Mediating Experience*

Narrative	Movement	Concept
This is a story of How Greenland Got Its Glaciers. This story begins in a very cold and beautiful place in the Arctic called Greenland. Only Greenland is not a green land now. It's icy and snowy white.	The idea is to create a sequence of actions that illustrates the life of a glacier and its effects.	A glacier builds up over long periods of geologic time.
In Greenland, one ice age long ago, on top of a mountain, it began to snow. Every winter it snowed and snowed and snowed and it never melted away. It stayed there all year round. As more and more snow fell, it became heavier and more densely packed.	Let the hands represent the falling snow. Let the hands pack the snow	Snow is the source of ice for a glacier.
The actual ice crystals of the snow began to merge into larger crystals we call firn. A snowflake is just a little thing. You can hold it in your hand. Firn is 4 times, 8 times, 16 times larger than snow. As the firn kept firning, it packed down even more, and a stack of ice began to stack up high and higher still, it grew and kept growing, becoming thicker and heavier.	Let everyone show a tiny snowflake in their hands, then let it grow exponentially, and pack down even more.	Firn is an intermediate form of ice.
At the top, the snow kept falling, in the middle the firn kept packing, and down below the pressure continued to build, pushing out the air trapped in between the ice crystals, making the ice crystal blue clear.	Let students show more packing, pushing down.	The weight of the upper layers pushes out air between ice crystals, making the ice extraordinarily clear, so that it appears blue for the same reason the sky is blue.

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Narrative	Movement	Concept
After a long winter count, winter after winter after winter, the ice grew as tall as a palace, six-stories tall, atop the mountain in Greenland. At that moment the snow, the firn, the deep crystal clear ice wakened to become a glacier and it started to move.	Let students invent ways to illustrate the increasing pressure and the release of air, for example, rapid arm movements, or sounds of air escaping.	
The top tipped like the leading edge of a great flood. The middle layers followed behind, and slowly, ever so slowly, the glacier began to creep down the mountain, carving out a valley that meandered like a slowly moving river, down to the sea.	As a team, demonstrate an ultra slow motion flow, moving inexorably, carrying rocks and scraping the ground and the sides of mountains	The crucial understanding is the weight of the growing thickness of the ice produces the pressure (not a function of temperature)
Where the mountain slope was steep the glacier would glide along, scraping the land and rolling over rocks and debris. In some places along the way, the ground was frozen beneath and it held the glacier slow. In some places, the pressure would build so greatly at the base, that the ice would melt, and suddenly start the glacier sliding. Sometimes, an ice stream would form, and the glacier would surge like a rising surf, at twice the normal pace.	The students can show the dynamics as the narration proceeds: As a group, gliding slowly with increasing speed. The group slows down. A sudden sliding. A rapid surging.	There are different conditions of glacial flow. The crystalline structure holding in frozen ground tends to hold the glacier more in place. Basal slip, one of the ways glaciers glide. Ice streams are rivers of meltwater running through some glacial areas.
As the glacier flowed down through the valley, it scraped the ground and the sides of the mountain and it moved rocks, boulders, dust, and dirt. And when it reached the ocean, like a thirsty giant, a glacial tongue of ice extended out into the sea. Sometimes icebergs would break off and float away.	Slowing down, some break off as icebergs.	As a glacier meets the sea, it flows out and breaks off to form icebergs.
You can see that glacier and many more, even today, from the mountaintop to the mouth of the deep blue bay. Its layers of snow and firn and crystal ice so blue tell the flow of icy history and of Earth's climate change so true.	Recap all the motions of the process.	Glaciers can be viewed in many places in the world today.

Small Group Mime Activity: *Movement Integration Mediating Experience*

Invite students to form small groups (about four to seven students), have them select from any aspect of the activity and create their own mime and narrated story about ice flowing. Encourage students to act out a sequence that communicates new understanding about how ice flows.

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MATERIALS

For all activities, to record reflections, observations, calculations, etc.
Science Notebooks and writing and drawing utensils.

Demonstration
A couple of reams of paper.
A big atlas-sized book.

Main Activity
A selection of variety of familiar materials that enables students to compare and contrast the properties of viscosity and elasticity:

- Playdough or modeling clay
- honey
- molasses
- peanut butter
- pancake batter
- cake frosting
- chocolate syrup
- ice cream
- canola oil
- ketchup
- toothpaste
- a variety of candy bars (at different temperatures)
- rubber bands, elastic tape
- plush toys
- sponge
- chocolate bars (warm and frozen)

Requires a flat surface at a slight incline that empties into a pan, plate, or bowl.

Glacial erosion
Select a place outside to show effect of ice flowing. Find a small hill or an incline, with dirt, sand, or gravel.

- At least one 10, 20, or 25-pound block of ice.
- Work gloves.

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DEMONSTRATION

A direct experience of ice flowing is difficult to create in a classroom setting. This demonstration provides a basis for discussing the *viscoelastic* properties of other familiar materials and then applying it to ice, especially as students explore how glaciers move and how glaciers leave their mark.

PRE K–2

Modeling how ice flows

To help provide a concrete experience that connects the crystalline structure of ice and the problem of explaining how ice flows:

1. Ask students to draw a picture of an ice crystal. It could be a snowflake, or any six-sided, hexagonal shape.
2. Refer to the block of ice and tell students that scientists think of a block of ice as "a stack of crinkled molecular sheets."
3. Ask students in a fun way to crinkle up their sheets of paper and then uncrinkle them. Now we have a whole bunch of "crinkled sheets."
4. In a central area where everyone can see, have students gather the "crinkled sheets" next to an atlas-sized book.
5. Ask students to imagine that the book is the ground in a high mountain or a cold place in the Arctic or Antarctica.
6. Start with one crinkled sheet; show how it floats down like a snowflake onto the book. Ask students to think of each sheet as a whole winter season of snow, until all the crinkled sheets are stacked. Remind students that this "stack of crinkled sheets" is an analogy of a massive accumulation of ice, having formed over many cold winter years.
7. Explain that right now it is flat and still. Ask students to consider what would happen if we were to create a stress on the system? Specifically, what would happen if we were to lift one end of the atlas, as if to create the slope of a hill or mountain?
8. Ask students to predict what will happen? Guiding questions might include:
   - Will the crinkled sheets stay in place?
   - Will they glide downward?
   - Will all the sheets move together?
   - Will the lower sheets move faster and further than the upper sheets?
   - Or will the upper sheets move faster and further than the lower sheets?
   - Why do you think so? (What do you base your prediction on?)

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9. Then, after students predict, lift one end of the atlas slowly: *Ok, let's do it… What did you see happen?*

    - Note: With as few as six crinkled sheets, the upper sheets glide faster, the middle sheets lag slightly behind, and the lower sheets lag further behind. This corresponds to how glacial ice flows.
    - Do it several times so that everyone sees what happens.

Close off by explaining to the students that ice flows in a similar way. A glacier moves like the paper: the upper crinkled layers move a bit faster, the lower layers lag behind. But that is only part of the story. To learn more about that we need to explore how some other materials flow.

3–5

Modeling a glacier in motion

To help provide a concrete experience that connects the crystalline structure of ice and the problem of explaining how ice flows:

1. Tell students that scientists think of a block of ice as "a stack of crinkled molecular sheets."
2. Remind students of the hexagonal symmetry of ice. Have each student draw as many hexagons as they can, using all the space on a sheet of paper.
3. Ask students to crinkle up their sheets of paper and then uncrinkle them. Point out that at the molecular scale, some hydrogen bonds are longer, others are shorter, so bonding is not exactly flat and even—they're "crinkled."
4. In a central area where everyone can see, have students gather and stack the "crinkled sheets" on top of an atlas-sized book.
5. Ask students to imagine that this "stack of crinkled sheets" is not just $8\frac{1}{2}$ by 11 inches and 20 or 30 sheets high, but that it is an analogy of a massive accumulation of ice, having formed this lattice of hexagonal ice over many cold winter years.
6. Explain that right now it is flat and still. There is no unbalanced stress. Gravity is balanced by the structure of the materials. Ask students to consider what would happen if we were to create a stress on the system.

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7. Ask students to predict what would happen if we were to lift one end of the atlas, as if to create the slope of a hill or mountain. What would be likely to happen to the crinkled sheets? Guiding questions might include:
   - Will they stay in place?
   - Will they glide downward?
   - Will all the sheets move together?
   - Will the lower sheets move faster and further than the upper sheets?
   - Or will the upper sheets move faster and further than the lower sheets?
   - What stress comes into play when the “crinkled sheets” are on a sloping hill or mountain?
   - Why do you think so? (What do you base your prediction on?)
8. Then, after students predict, lift one end of the atlas slowly: *Ok, let’s do it…What did you see happen?*

   Note: With as few as six crinkled sheets, the upper sheets glide faster, the middle sheets lag slightly behind, and the lower sheets lag further behind. This corresponds to how glacial ice flows.
9. Have students form active inquiry teams of six or seven and stack their crinkled sheets, and do it themselves, record the details in their science notebooks. Invite students to discuss among themselves about what they observed and to propose explanations.
10. After a few minutes of exploration, ask students to come together again as a whole group to share thoughts.
11. Close off by reminding students that the analogy of the crinkled sheets of paper—even with the hexagons drawn on them—is only part of the story.

Under stress, the hydrogen bonds holding ice together begin to stretch, bend, shift, break, and rejoin in such a way that the ice flows slowly and rebounds to its shape. Ice is a viscoelastic material. To learn more about that we need to play with some other analogies.

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MAIN ACTIVITY

PREPARATION

This activity involves observing substances that flow under a variety of conditions, connecting to the flow of glaciers.

Set up a series of three kinds of exploratory zones that allow students to categorize, compare, and contrast the flowing and elastic properties of different materials, and an area dedicated to glaciers.

- Viscosity Zone: Select several examples of materials of varying viscosity at different temperatures (warmed, room temperature, refrigerated, or frozen) and set up one or more exploratory zones for students to experience how different substances flow.
- Elasticity Zone: Select several examples of materials of varying elasticity and set up one or more exploratory zones for students to experience how different items rebound to their original shape after experiencing stress.
- Glacier Zone: Create a gallery of pictures, videos, or presentations of glacial ice, so that students can examine evidence of ice flowing.

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TEACHING TIPS

Explore

While large-scale ice is solid, it also flows. But the rate of flow is so gradual that it is difficult to perceive directly, even more so in the classroom setting. Exploring analogous experiences of flowing can give a sense of the phenomenon of glaciers flowing. Video footage of glaciers and computer animations can help provide an additional framework for understanding.

Diagnose

Listen to students' ideas about materials that flow. What implications do students draw from their observations of how different materials flow? What comparisons do they make? How can observing analogous materials draw out accurate understanding about ice? Listen to student ideas about glaciers. How do students conceptualize what glaciers are and how they move? Draw students toward inquiry about how to test out their ideas.

Design

Invite students to devise ways to test out their own ideas about flow, especially with respect to explaining how ice flows. Guide students toward the notion of using analogies to test out ideas about how ice flows. While the flowing motion of a glacier is difficult to re-create in the classroom, carefully constructing an apt analogy can lead to understanding.

Discuss

Discuss ice flow and glaciers. Discuss the flow of other substances compared to glacial flow. Discuss the evidence of the abrasive effects of glaciers and the history of ice ages.

Use

Extend the new knowledge about how glacial ice flows to inquire about other flowing phenomena on Earth and other places in the Solar System.

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WARM-UP AND PRE-ASSESSMENT

Categories of Materials that Flow

Flowing is a property that we usually associate with a liquid under "normal" conditions. Water flows. Some liquids are thicker and slow-to-flow.

Let's make up some different words for different ways that stuff flows.

Select five to seven materials with different consistencies. Talk about *fluidity*, how easily a material flows and *viscosity*, how slowly a material flows. Show what different kinds of flowing looks like.

- water
- pancake syrup
- honey
- molasses
- chocolate syrup, warm
- chocolate syrup, cold
- toothpaste

For each example, invite students to invent words that describe the different consistencies of flowing.

- runny
- gooey
- syrupy
- sticky
- gummy

Record students' own word inventions as well. Then let students know that scientists invent words, too. Like *viscoelastic* to describe the way ice flows, to be explored…

PROCEDURES

PART 1.

Viscosity Zone: Observe how a variety of different materials flow

Opening thought: *Water flows. Other liquids much thicker than water also flow, but they flow more slowly. A material that flows slowly is called viscous.*

To get students started in the exploratory zones, explain that they are to select two or three different materials that may have viscoelastic qualities under stress.

Lead a discussion that might go like this (adapt accordingly): *Let's take the idea of flowing. When we stop and think about it, lots of stuff flows. Fluids flow. Some fluids flow flast—I mean flow fast and easily. Like water (pour some water). Water flows fleetingly flast…I mean fast and easily. Some fluids flow pretty fast and pretty easily. Like pancake syrup. Pancake syrup flows pretty fast and easily. Honey flows slowly and thickly.*

You get the idea. At the exploratory zones, traveling with your active inquiry team, see how different materials flow. Have your science notebooks out and ready, so that you can keep track of what you do.

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At the exploratory zones that you have set up, students:

1. Pour some water. *Water clearly flows. Now, what other materials flow?* (Have students record their questions, speculations, and explanations.)
2. Select two or three examples from materials on hand. In their midst, guide students to ask questions and discuss ideas (or post such questions around each exploratory zone):
    - *How does the flow of these materials compare to the way water flows? What's the same about it? What's different?*
    - *Honey! Let's see! Yes, it flows!*
    - *Let's take a closer look at how this honey flows. Does it seem thicker than the water? Does it flow more slowly?*
    - *What happens if we put pressure on the honey, by squeezing the container around it? Can we make it flow more? Is squeezing a kind of stress?*
    - *What words can we use to describe how honey flows?*
    - *Does temperature affect viscosity? If we warm up honey, what happens?*
    - *What about chocolate syrup?*
    - *If we pour refrigerated chocolate syrup, what happens?*
    - *Take chocolate syrup, at room temperature or warmer, it flows fast and easily; but if it's been in the refrigerator, it flows slowly and thickly.*

For example, of the following, which is more fluid, which is more viscous?

- Chocolate syrup—flows easily, at room temperature or warmer
- Chocolate syrup—slow-to-flow, refrigerated
- Chocolate frosting—flows when squeezed through a plastic bag funnel

Invite students to pose questions in their science notebooks:

Draw/say/write how you think something flows differently when it is warm or cold. How does water and ice flow compared with other substances?

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Viscosity: This table describes a range of likely exploratory zone observations

Exploratory Zone Conditions	Observation
• Liquid water flows	• Pouring, water moves from higher to lower elevation • Gravity explains flow
• Compare water flow to other flowing substances (honey, molasses)	• Other liquids flow differently • Thicker liquids flow more slowly than water
• Compare warm and cold	• Colder temperature makes things flow more slowly • Warmer temperature makes things flow more easily
• Compare water and ice	• Water flows • Ice does not appear to flow (hmm)—or does it?

Bring students together to share and discuss results.

PART 2:

Elasticity Zone: Observe how elasticity varies

Opening thought: *When we bend something and it breaks easily, we call it brittle. When we bend something and it doesn't break as easily, and then it springs back to its original shape, we say that it is elastic.*

Categories of Elastic Materials

Move the discussion toward the idea of elasticity (adapt accordingly):

Then let students know that they will be able to explore more about these qualities in the exploratory zones.

1. Let's explore a variety of materials by creating stress by bending or squeezing, and seeing how the materials respond.
2. How does temperature affect elasticity? For example, let's explore what happens when you bend a chocolate candy bar kept in the refrigerator, a candy bar at room temperature, and a candy that has been warmed up.

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Elasticity: This table describes a range of likely exploratory zone observations

Exploratory Zone Conditions	Observation
• Rubber band, elastic band	• Stretches, snaps back • Bonds stretch
• Plush toys	• Squeezes, bounces back • Bonds stretch and rebound
• Sponge	• Squeezes, rebounds to original shape
• Cold chocolate bar (e.g. Hershey's bar)	• Brittle • Dreaks easily when stressed by bending
• Chocolate bar at room temperature	• Deforms to a certain extent under stress of bending • Rebound elastically when stress is removed
• Warm chocolate bar	• Bends easily • Doesn't bounce back into shape

After students have had a chance to explore on their own, bring them together to share and discuss results.

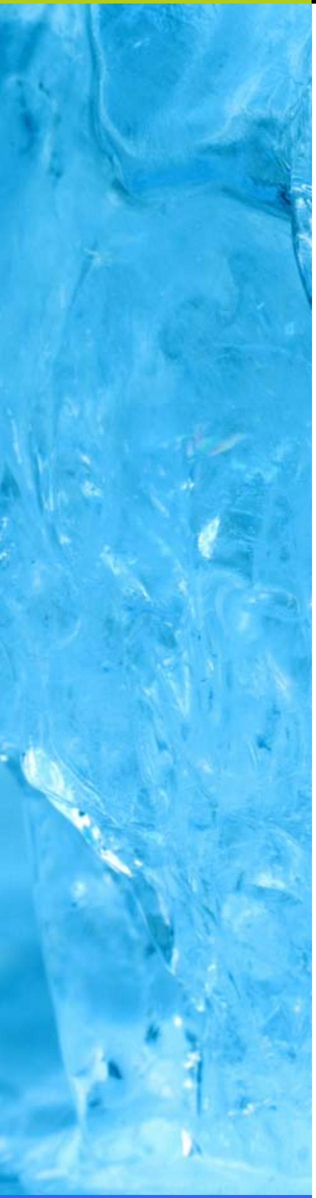
Based on the activities, have students write and illustrate a story of ice flowing and share it dynamically with both a small group and the whole group.

PART 3.

Glacial Zone: View Gallery of Pictures and Videos of Glacial Ice

Ice flows so slowly that we cannot observe it directly in a short period of time—to see ice flow, we need to look at the evidence of scientific measurements, pictures, and videos.

1. View the gallery of glacier images and videos.



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This table connects exploratory zone learning experiences to scientific data and imagery about glaciers.

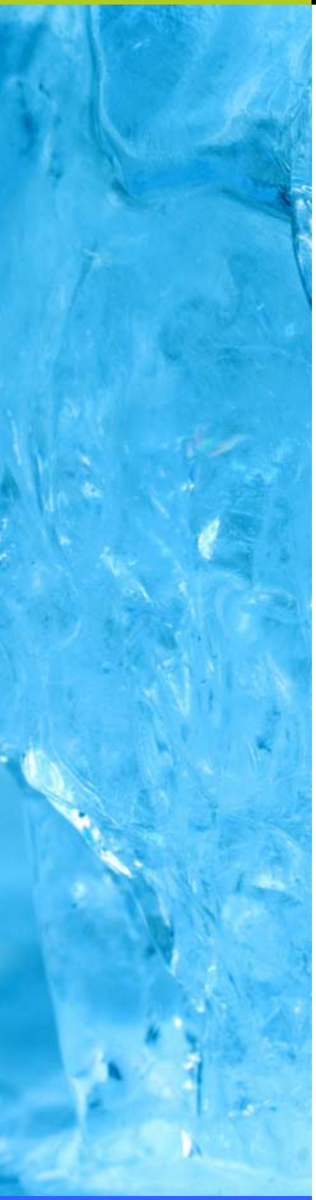
Figural analogy	Evidence
• Glaciers flow like rivers	• Velocity at upper surface faster than at lower depths • Measuring movement at depth by drilling lines deep • Effect on landforms
• Compare glacial flow to other flowing substances (lava, molasses, water)	• Obtain existing data or devise experiment • Ice volcanism

PART 4.

Glacial Zone: Effects of Glacial Flow

1. Say to students: *Let's find a place outside for this exploration.*
2. Find a small hill or an incline, with dirt, sand, or gravel. *Here's a big block of ice. Who would like to put on these work gloves and create downward pressure on this block of ice?* (Pick two volunteers)
3. What will likely happen when you push on this block of ice? Invite discussion.
4. *Go ahead; do it. What did you see happen?*
    - Lead a discussion with these points in mind: *Yes, it scrapes the ground and leaves a mark. And not just a little mark! Of course, here, we pushed the whole block of ice ourselves. What is it that pushes and pulls a glacier?*
    - *Would you call what we did, seeing the ice "flow"? No, not really…what we are looking at is the effect of ice moving, when we push it.*
    - *In our exploration, we pushed the ice ourselves…what makes glacial ice move? How can we infer a flowing action? How can we explain how solid ice flows?*

Let's keep these things in mind as we explore more about how glaciers move.



DISCUSSION & REFLECTION

How can we apply an analogy to our understanding of a science concept?
Just as scientists discuss the aptness of a scientific analogy, invite students to consider how closely the analogies in this lesson explain how ice flows.

Guide students in the discussion of the crinkled sheets demonstration with the following explanation in mind.

"Ice is a stack of crinkled molecular sheets…"
One of the most important science communication skills is to analyze the fit of an analogy, often constructed as a physical or a computer model, but most often as figural language. In this case, how well does the "crinkled sheets of paper" physical analogy fit as an experience of the figural analogy "ice as crinkled molecular sheets" to explain part of the picture of how ice flows?

Each of these sheets of paper represents a crinkled molecular sheet of ice. If we stack up the sheets of paper, we have a physical analogy of a section of a block of ice, just like the block of ice sitting over here. But of course the sheets of paper are not really molecular sheets of ice. It's an analogy that works in some respects, but not in others.

The sheets of paper glide easily over one another. If we stack these sheets on an incline, you can see that the sheets of paper glide over one another, and that the top sheets glide ahead, while the lower sheets lag behind. The stress is the effect of a slight shift of the center of gravity that overcomes the friction between the crinkled sheets of paper. This aspect of the analogy fits well to explain what happens when ice flows. Under the stress of gravity on a mass of ice situated on an incline, the upper layers move faster and further than the lower layers, as it flows from higher to lower elevation.

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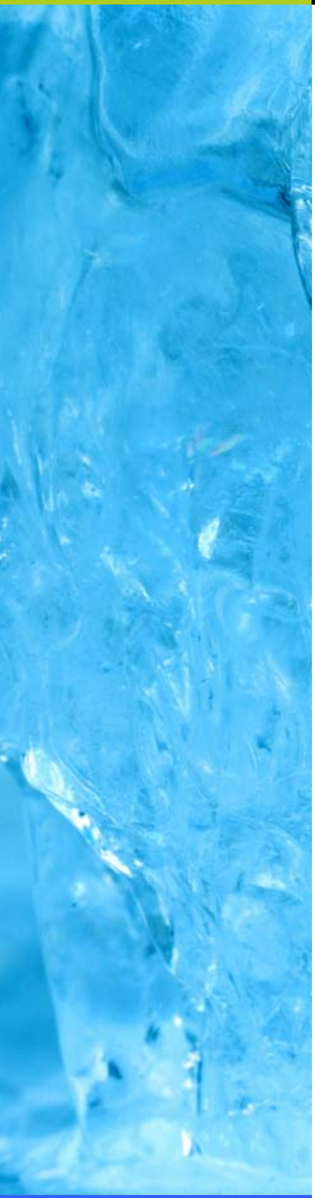

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But there the aptness ends. Ice does not separate neatly like loose sheets of paper. One big difference between sheets of paper and molecular sheets of ice is that the friction of the paper against each other is much weaker than the interwoven hydrogen bonds that hold the molecular sheets of ice together.

Remember that we drew the hexagons on the paper as a graphic analogy of the hexagonal, six-sided, symmetry of ice crystals. The molecular sheets are also connected above and below, not by friction, but by hydrogen bonds in four-sided symmetry. The crystal structure is a 3-D interwoven latticework. The hydrogen bonds themselves experience the stress. They stretch, bend, shift, break and rejoin in such a way that the ice flows slowly and rebounds to its shape—ice is a viscoelastic material—we didn't show all that part of the story. To learn more about that, we need to play with some other analogies.

After exploring viscous materials and elastic materials, how can we construct apt analogies to describe our understanding of how ice flows?

CURRICULUM CONNECTIONS

The Flow of Language: Ice and Poetry

Explore the imagery of ice in literature. The literature, mythology, and art of peoples who live in cold climates are rich with ice stories.

The German poet Paul Celan uses snowfall imagery in this poem,

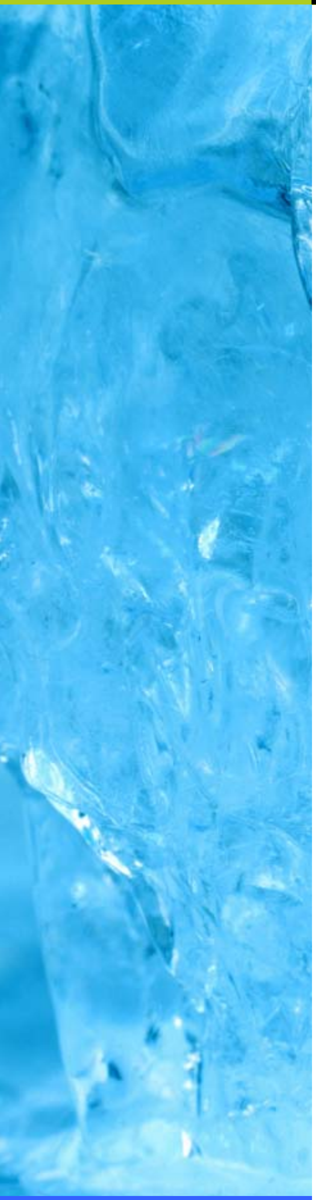
Homecoming:

Snowfall, denser and denser,
dove-coloured as yesterday,
snowfall, as if even now you were sleeping.

White, stacked into distance.
Above it, endless,
the sleigh track of the lost.

Below, hidden,
presses up
what so hurts the eyes,
hill upon hill,
invisible.
On each,
fetched home into its today,
an I slipped away into dumbness:
wooden, a post.

There: a feeling,
blown across by the ice wind
attaching its dove- its snow-
coloured cloth as a flag.



Samuel Taylor Coleridge described the frozen seas:

And now there came both mist and snow,
And it grew wondrous cold:
And ice, mast-high, came floating by,
As green as emerald.
The land of ice, and of fearful sounds where no living thing was to be seen.
And through the drifts the snowy clifts
Did send a dismal sheen:
Nor shapes of men nor beasts we ken—
The ice was all between.

The ice was here, the ice was there,
The ice was all around:
It cracked and growled, and roared and howled,
Like noises in a swound!

—Samuel Taylor Coleridge, *Rime of the Ancient Mariner*

Have students look for poetry with ice and snow imagery.

Invite students to write their own ice poems.

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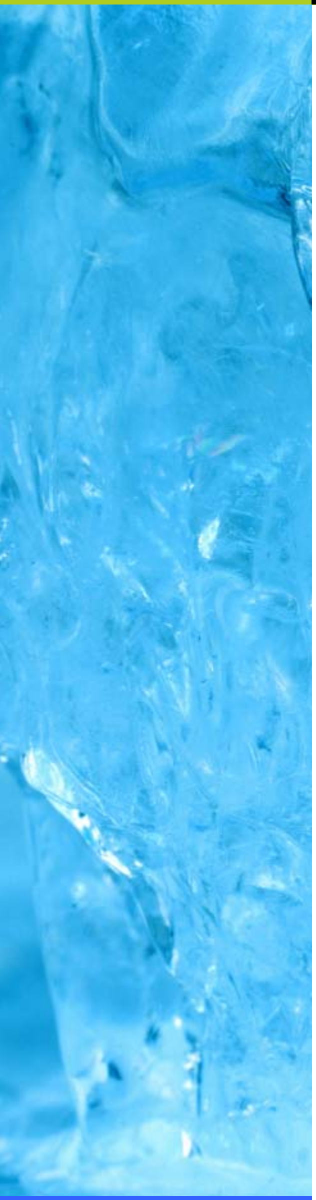

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ASSESSMENT CRITERIA

Exemplary

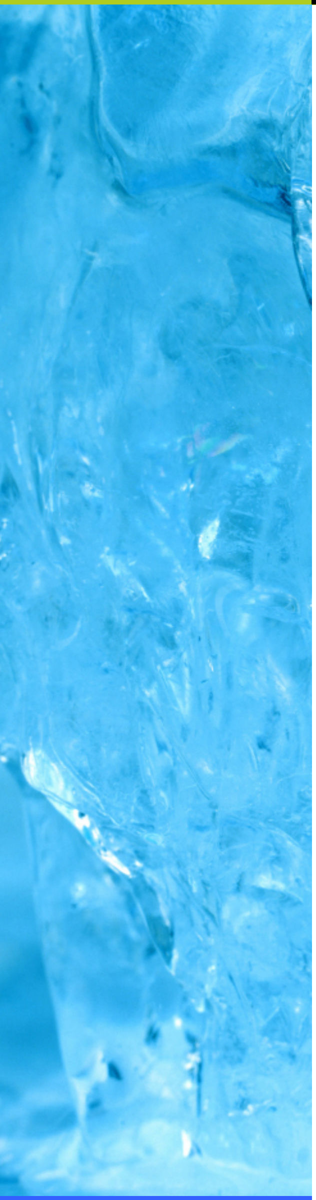
- Students write and illustrate a story of ice flowing and share it dynamically with both a small group and the whole group.
- Students display drawings, constructions, and dynamic models drawn from their science notebooks and web-based research.
- Students identify and extend science questions drawn from direct observation and extended research about ice flow.
- Students explore a rich range of information about glaciers and relate it to prior shared experiences.
- Students ask a rich and extensive range of questions about ice flow.
- Students extend learning by considering implications of ice flow on other worlds.
- Students relate ideas to whole context of exploring ice in the solar system.

Emerging

- Students write and illustrate a description of ice flow, such as occurs with glaciers, sharing it with both a small group and the whole group.
- Students pose basic science questions drawn from the concept of ice flow.
- Students view images of glaciers and the physics of ice flow.
- Students display results using a variety of ways to represent ice flow. Students succeed in asking a rich range of questions about glaciers and ice flow.
- Students make speculations about implications of glaciers and ice flow.

Formative

- Students recognize that ice flows.
- Students identify the basic categories of flowing and related motions of different materials.
- Students pose science questions drawn out of the context of exploring glaciers and ice flow.
- Students observe glaciers through videos and other visual representations.



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RESOURCES

Einstein, Albert (1954/1982). *Relativity and the Problem of Space (1954)* in **Ideas and Opinions** (1982), p. 365. New York: Three Rivers Press.

Engelhardt, Hermann (2005). *Glaciology* website, http://skua.gps.caltech.edu/hermann/engelhardt.html

N. H. Fletcher. The Chemical Physics of Ice. Cambridge University Press. Cambridge, 1970. (An intermediate to advanced text that illustrates many aspects of solid-state physics using ice as an example.)

Links to glaciology-related sites: http://skua.gps.caltech.edu/hermann/glaciolinks.html

Catalog the rich selection of glacier images provided by Hermann Engelhardt, and list a selection of the many web sites and curriculum activities related to glaciers.

Other Ways to Research Glaciers

- Explore ice scientists' websites; ask them questions. Many glaciologists welcome thoughtful student questions and will often take the time to share their own knowledge.
- Interview people who have visited glaciers by contacting Teachers Exploring the Arctic and Antarctica:
  http://www.arcus.org/TREC/index.php
  http://tea.armadaproject.org/tea_meetteachers.html
- Investigate ice ages.
- Look at maps of where glacial ice exists on Earth.

Images

Link to image gallery