WEATHER and WATER

READINGS

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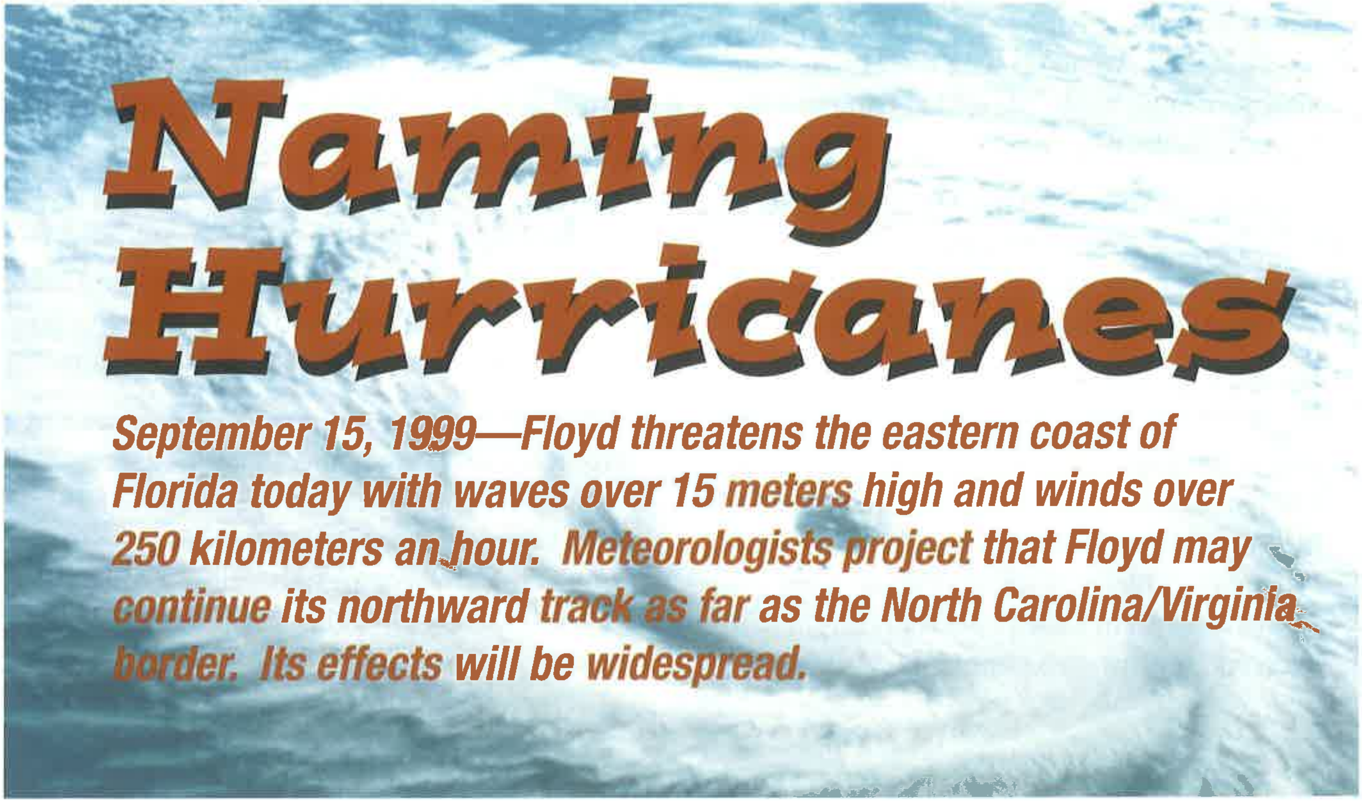
Naming Hurricanes



September 15, 1999—Floyd threatens the eastern coast of Florida today with waves over 15 meters high and winds over 250 kilometers an hour. Meteorologists project that Floyd may continue its northward track as far as the North Carolina/Virginia border. Its effects will be widespread.

Who is Floyd? And who are Camille, Hugo, Agnes, and Andrew? They're hurricanes! Throughout human history hurricanes have caused destruction. Some of the most powerful hurricanes to come on land in the United States were those named above. How did these storms get names and why?

Because they have reputations as troublemakers, hurricanes are under the watchful eye of meteorologists from the time they first take form as tropical storms. In order to refer to them over a period of days and weeks, they are given names. It's much easier to talk about what Gertie did today than "that hurricane 18°N, 55°W." It also helps reduce confusion when more than one hurricane is brewing in the same area.

Naming hurricanes has undergone a number of changes over the years. In the West Indies (perhaps for reasons of protection), hurricanes were first named after the saint whose day fell closest to the day of arrival of the hurricane. Early in the 20th century an Australian forecaster started naming hurricanes for politicians. People thought this was funny because news reports could include headlines like "Dundee causing great distress," or "Gibson wandering aimlessly, but could be dangerous."

For a few years, the international phonetic alphabet (Able, Baker, Charlie...) was used to name hurricanes. The first hurricane of the season was Able, Baker was second, and so on. During World War II, U.S. Air Force and Navy meteorologists named the Pacific storms for their wives or girlfriends. Starting in 1953 the United States used whatever names they liked...as long as they were women's names, and the first hurricane of the season had a name starting with A.

In 1977 the World Meteorological Organization, a United Nations group, decided on the official naming system used today. They came up with 6 years' worth of names for storms in the Atlantic Ocean. After 6 years, they start over at the beginning. The six lists are alphabetical, and the letters Q, U, X, Y, and Z aren't used. It hasn't happened yet, but if all 21 names on a year's list are used up, additional storms would be assigned

Greek letters, like Alpha and Beta. The first forecaster who came up with the 21 names used a baby-naming book. He added names of his relatives to the list, too.

The first lists contained only female names. In 1978, the lists were changed to include both male and female names. They also include French and Spanish names for Atlantic storms.

Fourteen countries of the western North Pacific and South China Sea have approved new lists of names for tropical storms in the South Pacific. The names derive from many languages, and include Nakri (a type of flower in Cambodia), Haishen (a Chinese sea god), Pabuk (a big freshwater fish in Laos), Parma (a dish of ham, liver, and mushrooms popular in Macao), Ewinlar (a Chuuk storm god in Micronesia), Cimaron (a Philippine wild ox), Durian (a Thai fruit), and Conson (a mountain in northern Vietnam).

The names of the most severe storms are taken off the list for at least 10 years. At this time the exiled names include Fran, Andrew, and Hugo. The country that suffered the most destruction from the hurricane gets to add a new name.

When do storms get a name? Hurricanes and tropical storms are named once they start rotating and reach a wind speed above 65 kilometers (km) per hour (39 miles per hour). A tropical storm becomes a hurricane when it reaches speeds of 123 km per hour (74 miles per hour) or more.

Storm Names for 2002–2007 (Atlantic Storms)

2002	2003	2004	2005	2006	2007
Arthur	Ana	Alex	Arlene	Alberto	Andrea
Bertha	Bill	Bonnie	Bret	Beryl	Barry
Cristobal	Claudette	Charley	Cindy	Chris	Chantal
Dolly	Danny	Danielle	Dennis	Debby	Dean
Edouard	Erika	Earl	Emily	Ernesto	Erin
Fay	Fabian	Frances	Franklin	Florence	Felix
Gustav	Grace	Gaston	Gert	Gordon	Gabrielle
Hanna	Henri	Hermine	Harvey	Helene	Humberto
Isidore	Isabel	Ivan	Irene	Isaac	Ingrid
Josephine	Juan	Jeanne	Jose	Joyce	Jerry
Kyle	Kate	Karl	Katrina	Kirk	Karen
Lili	Larry	Lisa	Lee	Leslie	Lorenzo
Marco	Mindy	Matthew	Maria	Michael	Melissa
Nana	Nicholas	Nicole	Nate	Nadine	Noel
Omar	Odette	Otto	Ophelia	Oscar	Olga
Paloma	Peter	Paula	Philippe	Patty	Pablo
Rene	Rose	Richard	Rita	Rafael	Rebekah
Sally	Sam	Shary	Stan	Sandy	Sebastien
Teddy	Teresa	Tomas	Tammy	Tony	Tanya
Vicky	Victor	Virginie	Vince	Valerie	Van
Wilfred	Wanda	Walter	Wilma	William	Wendy

Weather Tools

Thermometer

A thermometer measures temperature. Temperature is measured in degrees. This thermometer uses the Celsius scale (°C). You would read the temperature as 21°C in the example above.

Some thermometers use the Fahrenheit scale (°F).

Compass

A compass is used to determine the direction from which the wind is coming.

- Stand facing the wind.
- Hold the compass in front of you.
- Rotate the compass body until the N lines up with the needle.
- A line running from the center of the compass needle straight into the wind tells you the wind direction.

Anemometer

An anemometer measures wind speed.

- Face into the wind.
- Hold the meter in front of you straight up and down, scale toward you. Don't cover the holes at the bottom.
- The height of the ball indicates the wind speed. This picture shows 7 miles per hour.

If the wind is strong, cover the top hole with your finger to read the high scale on the right.

Hygrometer

A hygrometer measures relative humidity. Relative humidity is a measure of the amount of water vapor in the air. It is a percentage. On the hygrometer above, relative humidity is 63%.

Barometer

A barometer measures air pressure. Air pressure on this barometer is measured in millibars (mb). The barometer above indicates a pressure of 985 mb.

What's in the Air?

Air? Can't see it. Can't taste it. Can't smell it. If you pay attention, you might feel it as a gentle breeze brushing across your skin. Because we are so insensitive to air, it is difficult to understand what it is. Is it one thing, or a mixture of things? And where is it? Is it everywhere or just in some places?

As we go about our everyday business, we usually travel with our feet on the solid Earth and our heads in the atmosphere. The atmosphere completely surrounds us, pressing firmly on every square centimeter of our bodies—top, front, back, and sides. Even if we attempt to get out of the atmosphere by locking ourselves inside a car or hiding in a basement, the atmosphere is there, filling every space we enter.

An **atmosphere** is the layer of gases that surrounds a planet or star. All planets and stars have an atmosphere around them. The Sun's atmosphere is hydrogen. Mars has a thin atmosphere of carbon dioxide with a bit of nitrogen and a trace of water vapor. Mercury has almost no atmosphere at all. Each planet is surrounded by its own mixture of gases.

Earth's atmosphere is composed of a mixture of gases we call **air.** Air is mostly nitrogen (78%) and oxygen (21%), with some argon (0.93%), carbon dioxide (0.03%), ozone, water vapor, and other gases (less than 0.04% together).

Nitrogen (N_2) is the most abundant gas in our atmosphere. It is a stable gas, which means it doesn't react easily with other substances. When we breathe air, the nitrogen goes into our lungs and then back out unchanged. We don't need nitrogen gas to survive.

Oxygen (O_2) is the second most abundant gas. It takes up about 21% of the air's volume, and, because the oxygen atom is larger than the nitrogen atom, it accounts for 23% of air's mass. Oxygen is a colorless, odorless, tasteless gas. It is the most plentiful element in the rocks of Earth's crust. Oxygen combines with hydrogen to form water. Without oxygen, life as we know it would cease to exist on Earth.

Oxygen and nitrogen are called **permanent gases.** The amount of oxygen and nitrogen in the atmosphere stays constant. The other gases in this chart are also permanent gases, but are found in much smaller quantities.

Permanent Gases of the Atmosphere

Gas	Percentage by volume
Nitrogen	78.08
Oxygen	20.95
Argon	0.93
Neon	0.002
Helium	0.0005
Krypton	0.0001
Hydrogen	0.00005
Xenon	0.000009

Air also contains **variable gases.** The amount of a variable gas changes in response to activities in the environment.

Water vapor (H_2O) is the most abundant variable gas. It makes up about 0.25% of the atmosphere's mass. The amount of water vapor in the atmosphere changes constantly. Water cycles between Earth's surface and the atmosphere through evaporation, condensation, and precipitation. You can get a feeling for the changes in atmospheric water vapor by observing clouds and noting the stickiness you feel on humid days.

Carbon dioxide (CO_2) is another important variable gas. It makes up only about 0.036% of the atmosphere. You can't see or feel changes in the amount of carbon dioxide in the atmosphere.

Carbon dioxide plays an important role in the lives of plants and algae. Carbon dioxide is removed from the air during **photosynthesis.** Plants and algae convert light energy into chemical energy by making sugar (food) out of carbon dioxide and water. In the process, oxygen is released to the atmosphere. When living organisms use the energy in food to stay alive, oxygen is removed from the air and carbon dioxide is returned to the air.

Variable Gases of the Atmosphere

Gas	Percentage by volume
Water vapor	~ 0.25
Carbon dioxide	~ 0.036
Ozone	~ 0.01

There are other gases that you may have heard about. **Ozone (O_3)** is a variable gas. It is a form of oxygen that forms a thin layer in the stratosphere. Ozone is absolutely essential to life on Earth because it absorbs deadly ultraviolet radiation from the Sun. But ozone in high concentration can cause lung damage. In the lower atmosphere, ozone is an air pollutant.

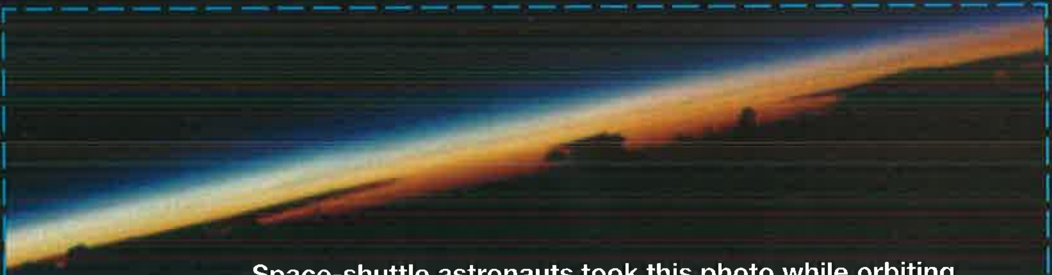
Methane (CH_4) is a variable gas that is increasing in concentration in the atmosphere. Scientists are trying to figure out why this is happening. They suspect several things. Cattle produce methane in their digestive processes. Methane also comes from coal mines, oil wells, and gas pipelines, and is a by-product of rice cultivation. Methane absorbs heat coming up from Earth's surface.

These gases are all mixed together, so that any sample of air is a mixture of all of them. If you rise higher in the atmosphere, there are fewer molecules, but the ratio of each gas to the other is the same. The mixing is caused by the constant movement of the air in the part of the atmosphere near Earth's surface. Above about 90 kilometers, there is much less mixing. Very light gases (hydrogen and helium, in particular) are more abundant above that level.

Think Questions

1. **What is the difference between permanent gases and variable gases in the atmosphere?**
2. **During the daylight hours, plants and algae take in carbon dioxide and release oxygen. If humans continue to destroy rain forests, what might happen to the balance between these gases?**

A Thin Blue Veil



Space-shuttle astronauts took this photo while orbiting Earth. You can see a side view of Earth's atmosphere. The black bumps pushing into the troposphere are tall cumulus clouds.

The crew of Apollo 17 took this photograph of Earth in December 1972, while on their way to the Moon. The small box at the top of this image shows an area equal to the atmosphere image above taken by the space-shuttle astronauts.

It is cold in deep space. The temperature is in the neighborhood of –270°C. That's nearly 200°C colder than it has ever been on Earth. Near stars, like the Sun, it's hot—outlandishly hot—reaching thousands of degrees. There are, however, a few places here and there in the universe where the temperature is between the extremes. Earth is one of those places. In fact, the average temperature on Earth is just about the temperature of Baby Bear's porridge—not too hot and not too cold, but just right.

On a typical day, the temperature range on our planet is only about 100°C, from maybe 45°C in the hottest place to –55°C at one of the poles. The measured extremes are 58°C in El Azizia, Libya, recorded on September 13, 1922, and –89°C in Vostok, Antarctica, on July 21, 1983. That's a range of temperature on Earth of 147°C.

It's not only because we are at the right distance from the Sun that Earth has tolerable temperatures. Earth is wrapped in a blanket of gases—the atmosphere. Earth's atmosphere keeps the temperature within a narrow range that is suitable for life.

From space, Earth's atmosphere looks like a thin blue veil. Some people like to think of the atmosphere as an ocean of air covering Earth. The depth of this "ocean" is about 600 kilometers (km). The atmosphere is densest right at the bottom where it rests on Earth's surface. It gets thinner and thinner (less dense) as you move away from Earth's surface. There is no real boundary between the atmosphere and space. The air just gets thinner and thinner until it disappears.

Imagine a column of air that starts on Earth's surface and extends up 600 km to the top of the atmosphere. Scientists have discovered several distinct layers in this column of air. Each layer has a different temperature. Here's how it stacks up.

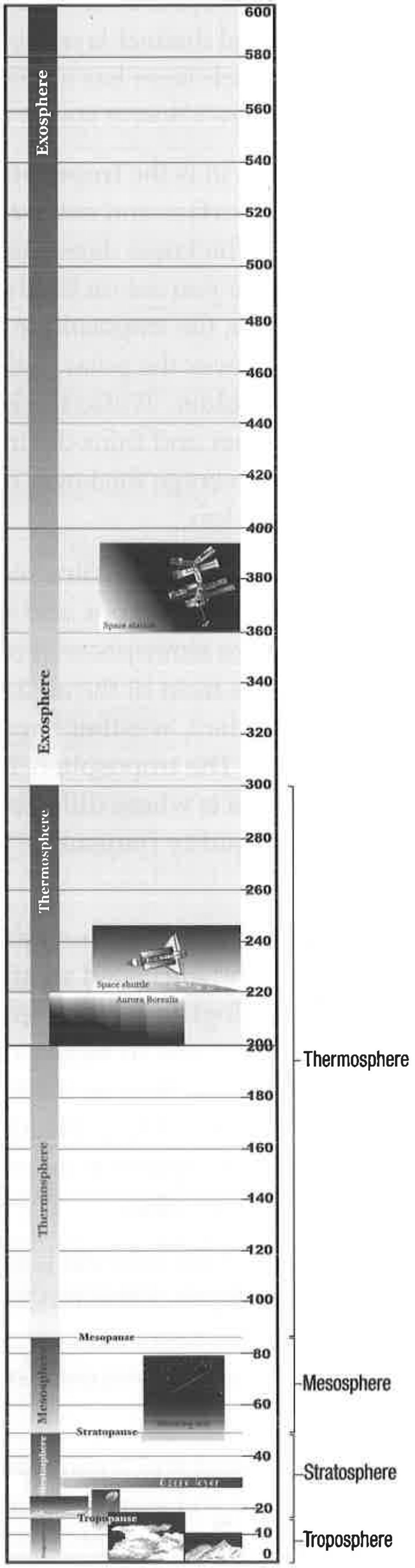
The layer we live in is the **troposphere.** It starts at Earth's surface and extends upward for 9–20 km. Its thickness depends on the season and where you are on Earth. Over the warm equator, the troposphere is a little thicker than it is over the polar regions, where the air is colder. It also thickens during the summer and thins during the winter. A good average thickness for the troposphere is 10 km.

This ground-floor layer contains most of the organisms, dust, water vapor, and clouds found in the entire atmosphere. For that matter, it contains most of the air as well. And, most important, weather happens in the troposphere. The troposphere is where the action is. This is where differences in air temperature, humidity (moisture), pressure, and wind occur.

These properties of temperature, humidity, pressure, and wind are called **weather factors.** Meteorologists launch weather balloons twice each day to monitor weather factors. The balloons float up through the troposphere to about 18 km. Weather factors will be investigated in detail as we continue to study weather.

The troposphere is the thinnest layer—only about 2% of the depth of the atmosphere. It is the densest layer, however, containing four-fifths (80%) of the total mass of the atmosphere.

Earth's surface (land and water) absorbs heat from the Sun and warms the air above it. Because air in the troposphere is heated



mostly by Earth's surface, the air is warmest close to the ground. The air temperature drops as you go higher. At its upper limit, the temperature of the troposphere is about –60°C. The average temperature of the troposphere is about 25°C.

Mount Everest, located in Nepal and Tibet, is the highest landform on Earth, rising 8.848 km into the troposphere. The air temperature at the top of the mountain is well below freezing most of the time. There is also less air to breathe at the top of Mount Everest. Climbers usually bring oxygen along to help them survive the thin air.

The **stratosphere** is the layer above the troposphere. It is 10–50 km above Earth's surface and contains almost no moisture or dust. It does, however, contain a layer of ozone (O_3), a form of oxygen, that absorbs high-energy ultraviolet (UV) radiation from the Sun. The temperature stays cold until you reach the upper reaches of the stratosphere, where energy absorption by ozone warms the air to about 0°C.

The jet stream, a fast-flowing river of wind, travels generally west to east in the region between the lower stratosphere and the upper troposphere. Many military and commercial jet aircraft take advantage of the jet stream when flying from west to east.

The **mesosphere** is above the stratosphere, 50–80 km above Earth's surface. The temperature plunges again, reaching its coldest temperature of around –90°C in the upper mesosphere. This is the layer in which meteors burn up while entering Earth's atmosphere, producing what we call shooting stars.

Beyond the mesosphere, 80–300 km above Earth, is the **thermosphere.** The thermosphere is the least-understood layer of the atmosphere and the most difficult to measure. The air is extremely thin. The thermosphere is the region of the atmosphere that is first heated by the Sun. A small amount of energy coming from the Sun can result in a large temperature change. When the Sun is extra active with sunspots or flares, the temperature of the thermosphere can surge up to 1500°C or higher!

Within the thermosphere is a layer noted for its chemistry, the **ionosphere.** The ionosphere contains a large number of electrically charged ions. Ions form when intense radiation from the Sun hits atoms and molecules. The ionosphere is responsible for the aurora borealis, or northern lights, and the aurora australis, or southern lights.

The identification of these four layers is based on temperature. There are no sharp boundaries or abrupt changes in gas composition between them. As average temperatures change with the seasons, the boundaries between layers may move up or down a little.

Beyond the thermosphere, Earth's atmosphere makes a transition into space. This area is the **exosphere** where atoms and molecules escape into space. It extends from 300 to 600 km above Earth. In this region, the temperature plunges to the extreme –270°C of outer space, and the concentration of atmospheric gases fades to nothing.

That 600-km column of air pushes down on the surface of Earth with a lot of force. We call the force **air pressure,** or **atmospheric pressure.** We are not aware of it because we are adapted to live under all that pressure, but there is a mass of about 1 kilogram (kg) pushing down on every square centimeter of surface on Earth. Your head has a surface area of about 150 cm^2. This means you have about 150 kg of air parked on your head. That's about like having a kitchen stove or a motorcycle pushing down on your head all the time!

Another way to look at it...if all the air were replaced with solid gold, the entire planet would be covered by a layer of gold a little more than half a meter deep. The mass of the entire atmosphere is about equal to half a meter of gold, but the atmosphere is much more valuable.

Think Questions

1. How is Earth's atmosphere like an ocean? How is it unlike an ocean?
2. Why do you think airplanes don't fly high in the stratosphere?

Wendy and Her Worldwide Weather Watchers

Wendy loves weather. She watches weather come across the Potomac River outside her kitchen window while she eats breakfast and watches weather forecasts on the TV. On her bookcase is a weather atlas, and she follows reports of severe weather on the World Wide Web. Wendy is planning to be a meteorologist.

It's no accident that weather is of interest to Wendy—she's seen a lot of it. Her dad is an agricultural consultant for the government, so Wendy's family has traveled around the world. She's been rained on in the rain forest, baked in the desert, blown over on the open plains, and nearly frozen in the tundra.

As a result of her travels, Wendy has made a lot of friends around the world. And she keeps in touch with them by e-mail all the time. They have formed a little weather study group and often share information about the weather in their local areas. They like to call themselves the Worldwide Weather Watchers. Some people put a finger in the air to figure out which way the wind is blowing; Wendy puts a finger on her keyboard.

On June 20, Wendy listened to a TV weather report. The meteorologist announced that the summer solstice would be tomorrow, on June 21. He said it would be the longest day of the year. You can count on more daylight on the solstice than you will see again for a whole year.

"Summer solstice...longest day of the year...I need to find out more about this," Wendy thought. "I think I need some help from the Worldwide Weather Watchers." She went to her computer and sent out a message to all of her friends. It said,

Here in Virginia it is the summer solstice on June 21. It is going to be the longest day of the year. What I want to know is if it is going to be summer solstice in your town, and if it is the longest day of the year for you, too. I'm also wondering, if it is the longest day of your year, how long is it?

What I would like you to do is find out when sunrise and sunset are in your town. If you give me those two pieces of information, I can figure out the rest. I plan to be up the whole day. I'm setting my clock to get up early so I won't miss a minute of the longest day of the year.

Thanks for helping me with this project. Wendy

Before going to sleep that night, Wendy rechecked her clock radio to make sure it was set for 5:30 a.m. As she pushed her clock back into place, her computer beeped. It was her first report—her friend Shawn from Auckland, New Zealand. The message didn't seem right, though. Shawn reported that the Sun rose at 7:48 a.m. and would set at 4:55 p.m.! That was just over 9 hours of daylight. How could that be the longest day of the year? Had she heard the TV meteorologist right? Had Shawn reported his numbers incorrectly? Wendy climbed into bed, pulled the covers up around her chin, and let the questions turn over in her mind as she drifted off to sleep.

Wendy awoke to "a 40% chance of thunder showers by late afternoon, clearing by nightfall. Winds from the southeast at 10 knots...." She bounced out of bed and pulled back the curtain. Dark! Yes, up before the Sun. She checked her e-mail and found three more reports from the Weather Watchers: Hiroko from Sendai, Japan; Seeta in New Delhi, India; and Makindu in Nairobi, Kenya.

Wendy hurried down to the kitchen for breakfast. The kitchen window had the best view to the east. Already the darkness on the horizon was yielding to the first suggestion of sunrise. By the time Wendy took her first bite of toast, a line of orange had pushed between the horizon and the darkness above. The kitchen clock showed 5:40 a.m. Sunrise had to be pretty soon. Wendy peeled an orange. The sunrise intensified and color moved across the bottoms of the clouds. She could see the brightest place on the horizon clearly now. Night had been replaced by the gray of early morning. Then the very tip-top of the red orange Sun peeked over the horizon. Wendy glanced at the clock. It was 5:44 a.m.—sunrise on the summer solstice.

Wendy watched as the complete disk of the Sun glided free of the horizon and hung suspended in the sky. Then she returned to her bedroom to check her computer for more messages. Justin from Punta Arenas, Chile; Maria from Quito, Ecuador; Billy from Barrow, Alaska; and Elke in Stockholm, Sweden. She read through the reports quickly, but the information was all a blur. There didn't seem to be a pattern to the data. How could she make sense of them?

She wrote down the sunrise and sunset times and returned to the kitchen. Her dad was opening the paper and eating yogurt. "Dad, I got up to see the sunrise because this is the longest day of the year. I'm going to see all of it. The Sun first appeared at 5:44, and I plan to see it go down, too."

"Good for you. Where will you go to watch the sunset? Our apartment has a great sunrise view, but no sunset view."

Wendy gulped. She hadn't thought of that. "I don't know," she admitted.

"How about this for a plan. I'll make sure I'm home in time for us to go up on top of the building to see old Sol set. What time will the Sun be setting?"

Again, Wendy was caught off guard. Her dad tossed her the paper and said, "Look it up. I need to gather a few papers before I head off. Give me the time on my way out."

"Of course," breathed Wendy, "the weather page." She dove into the paper, threw it open to the weather page, and quickly found the information she wanted. June 21, summer solstice, sunrise at 5:44 a.m., sunset at 8:37 p.m.

"Sunset is at 8:37 p.m.," Wendy called up to her dad, "but could you be here a little early? I don't want to miss this."

"I'll be here in plenty of time."

Wendy returned her attention to the e-mail data. She decided to organize the numbers in a chart. After thinking about it for a while, she put the cities in order from east to west, starting with New Zealand. This is the chart she produced.

City and country	Sunrise	Sunset	Length of day
Auckland, New Zealand	7:48	4:55	9:07
Sendai, Japan	4:18	7:06	14:48
New Delhi, India	5:22	7:18	13:56
Nairobi, Kenya	6:34	6:34	12:00
Stockholm, Sweden	2:48	8:59	18:11
Punta Arenas, Chile	8:00	3:32	7:32
Alexandria, VA, USA	5:44	8:37	14:53
Quito, Ecuador	6:22	6:22	12:00
Barrow, AK, USA	None	None	24:00

Wendy studied the chart. The hours of daylight varied widely, from less than 8 hours to 24 hours. More information would be needed to make sense of the data. She went to her weather atlas, opened to the map of the world, and located the countries in which her Worldwide Weather Watchers lived. She particularly wanted to see what might account for the huge difference in daylight between Justin's home in Chile and Billy's in Alaska.

"Hmmm," Wendy thought, "Justin lives way down in the southern tip of South America, and Billy is close to the North Pole in Alaska. I think I need to add latitude to my chart and put the cities in order from northernmost location to southernmost location." When Wendy added latitude to her chart and reorganized, this is what she saw.

June 21

City and country	Latitude	Sunrise	Sunset	Length of day
Barrow, AK, USA	71°N	None	None	24:00
Stockholm, Sweden	59°N	2:48	8:59	18:11
Sendai, Japan	38°N	4:18	7:06	14:48
Alexandria, VA, USA	38°N	5:44	8:37	14:53
New Delhi, India	28°N	5:22	7:18	13:56
Quito, Ecuador	0°	6:22	6:22	12:00
Nairobi, Kenya	1°S	6:34	6:34	12:00
Auckland, New Zealand	37°S	7:48	4:55	9:07
Punta Arenas, Chile	53°S	8:00	3:32	7:32

One thing became clear to Wendy. Latitude did relate to the length of the day. But why did locations in the northern latitudes have longer days than locations in the southern latitudes? And did northern locations always have longer days, or were days longer in the south at a different time of the year? More data would be needed to answer these new questions.

The U.S. Naval Observatory maintains lots of information related to Earth motions in the Solar System. Wendy had used their website in the past to check on the phases of the Moon. She thought she might find sunrise and sunset data there. To her delight, she could call up the sunrise and sunset data for any location on Earth for any day she chose. What a great resource! But what should she look up?

Some little voice inside told her to check the sunrise and sunset data for a date exactly half a year earlier. It took almost an hour to get the data, but it was worth the effort. This is the table she produced for sunrise and sunset on the winter solstice, December 21, for the previous year.

"Very interesting!" Wendy commented to herself. "The locations that have the longest days today had the shortest days half a year ago. And vice versa; the places with short days today had long days half a year ago. But look at Nairobi and Quito. Their days stayed the same all the time—equal amounts of daylight and darkness."

It *was* interesting. Wendy thought about day length all afternoon. She discovered that, if she added together the summer solstice day lengths for her town, Alexandria, and Shawn's town, Auckland, the sum was just about 24 hours. Alexandria and Auckland are almost the same latitude, but one is north and the other south. She also found that, when she added together the length of the day on the summer solstice and the winter solstice for any city, the sum was very close to 24 hours. What did it all mean?

December 21

City and country	Latitude	Sunrise	Sunset	Length of day
Barrow, AK, USA	71°N	None	None	00:00
Stockholm, Sweden	59°N	9:53	16:03	6:10
Sendai, Japan	38°N	7:00	4:32	9:32
Alexandria, VA, USA	38°N	7:23	4:50	9:27
New Delhi, India	28°N	7:03	5:31	10:28
Quito, Ecuador	0°	6:14	6:22	12:08
Nairobi, Kenya	1°S	6:24	6:35	12:11
Auckland, New Zealand	37°S	4:56	7:37	14:41
Punta Arenas, Chile	53°S	3:50	8:46	16:56

Right on the stroke of 8:00 p.m., Wendy's dad came through the door. "What a day! This feels like the longest day of my life. I'm bushed."

"It *is* the longest day...at least of the year...at least for us. Did you know this is the shortest day of the year for Shawn and Justin?" asked Wendy. Her dad raised his eyebrows. "Come on, Dad, let's go up on the roof. It's been a busy day for me, too, but it isn't over yet. I still need to see the curtain go down on the year's longest day."

From the roof, they had an unrestricted view in all directions. They could look north across the river to the nation's capital, Washington, DC, and west across rolling woods. The Sun peeked through spaces in the quickly dispersing clouds. The day was nearing sunset.

"Dad, I've been thinking all day about the different lengths of daylight that are happening around the world today. Billy says the Sun has been up since the middle of May and won't set at all until August. Makindu reports nothing surprising about today, 12 hours of daylight followed by 12 hours of darkness, just like every other day. Justin gets only 8 hours of sunlight today, but Hiroko has a day just about the same as ours. It's pretty hard to figure out."

At that moment, the disk of the Sun touched the horizon. Wendy and her dad watched in silence until there was just one brilliant sliver remaining. "Going...going...gone," she whispered. "It must be 8:37 p.m."

As they started back down to their apartment, Wendy asked, "What causes days to get longer in some places, shorter in other places, and stay the same in still other places?"

"The answer to that question is also the key to understanding the seasons. Look for the answer not in what the Sun is doing, but what Earth is doing. You can shed a little light on the subject by looking closely at the revolution of Earth around the Sun and the rotation of Earth on its axis."

"Very funny, Dad, but thanks for the tip."

Think Questions

1. Which locations have the greatest number of hours of daylight on June 21? The fewest hours of daylight?

2. Which locations have the longest hours of daylight on December 21? The shortest hours of daylight?

3. Alpena, Michigan, is located 45° north of the equator. How much daylight do you estimate they have on June 21? On December 21?

4. Boulder, Colorado, has a latitude of 40°N. Wellington, New Zealand, has a latitude of 41°S. Which city has the longest amount of daylight on June 21?

Seasons

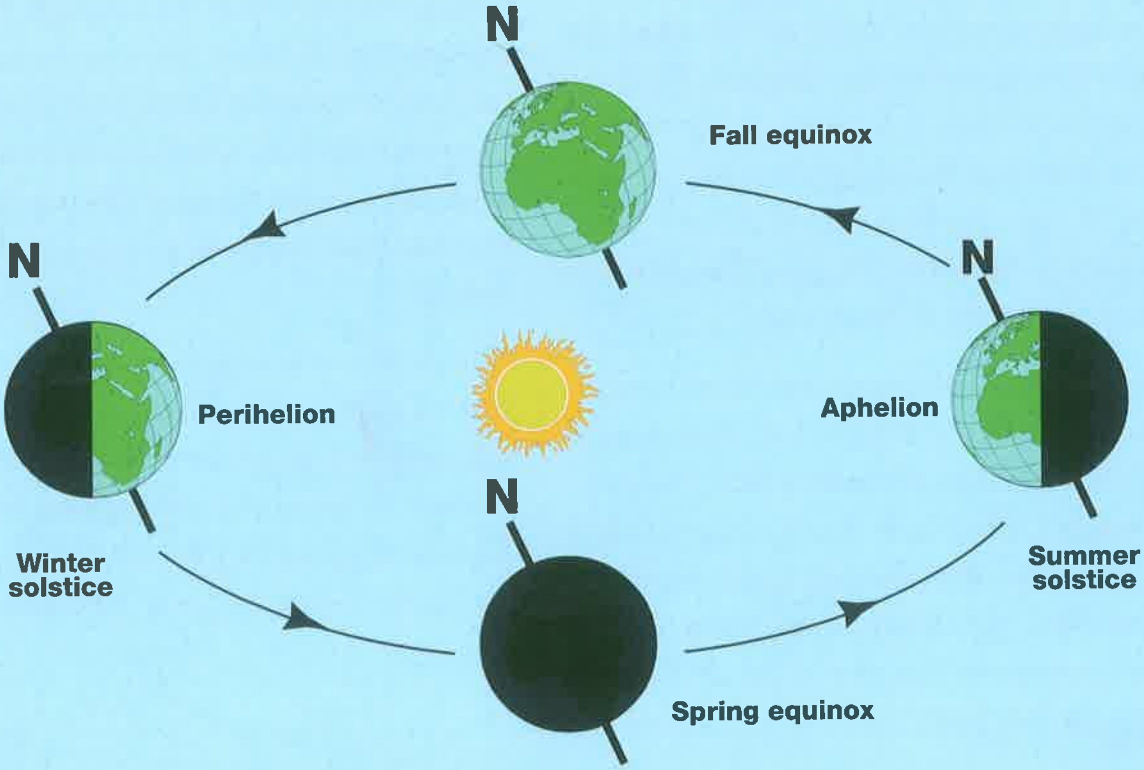
What do you picture in your mind when you read these words? Summer. Fall. Winter. Spring.

Most of us come up with a mental picture or two—summer means shorts and T-shirts, swimming, and fresh fruits and vegetables. Winter means heavy coats and short days with, perhaps, a blanket of snow on everything. Seasons are pretty easy to tell apart in most parts of the country. The amount of daylight, the average temperature, and the behavior of plants and animals are a few familiar indicators of the season. But what causes the predictable change of season? Have you ever stopped to think about why the seasons happen?

As Earth Tilts

Let's start with a quick review of some basic information about our planet.

- Earth spins on an imaginary axle called an **axis.** The axis passes through the North and South Poles. This spinning is called **rotation.** It takes 24 hours for Earth to make one rotation on its axis.
- Earth travels around the Sun. Traveling around something is called **revolution.** Earth's path around the Sun is not exactly round, but is slightly oval. One revolution takes 365 and 1/4 days, which is 1 year.



- Earth doesn't sit straight up and down on its axis as it revolves around the Sun. It is tipped at a 23.5° angle.
- The average distance between the Sun and Earth is about 150 million kilometers. Because Earth's orbit is an ellipse (oval), Earth is sometimes farther away from and sometimes closer to the Sun. **Perihelion** is when Earth and the Sun are closest to each other. Perihelion happens each year around January 3. The distance is 147 million kilometers. **Aphelion** is when Earth and the Sun are farthest apart. It happens each year around July 4. The distance is 152 million kilometers.

It would seem logical that summer would be during perihelion, when Earth is closest to the Sun. Wrong. Here in the Northern Hemisphere, we are in the middle of winter at the time of perihelion. Because Earth is closest to the Sun in January, it receives more energy in January than at any other time of year. But that energy doesn't make it warm in the United States. The reason for seasons is linked to Earth's tilt.

Think about Earth revolving around the Sun. As Earth revolves, it also rotates on its axis, one rotation every 24 hours. Here's something important: Earth's North Pole *always* points at a reference star called the North Star. No matter where Earth is in its orbit around the Sun, the North Pole always points at the North Star, day and night.

Tilt Equals Season

Look at the illustration on page 17. It shows where Earth is in its orbit around the Sun at each season. You will also see that the North Pole points toward the North Star in all four seasons.

Study the Earth image in the summer solstice position. Because of the tilt, Earth is "leaning" toward the Sun. When the North Pole is leaning toward the Sun, it is summer in the Northern Hemisphere. Days are longer, and the angle at which light hits that part of Earth is more direct. Both of these factors result in more solar energy falling on the Northern Hemisphere in summer (thus more heat) even though the planet is actually farther away from the Sun.

Look at the position of Earth 6 months later (winter solstice). Just the opposite is true. Even though Earth is closer to the Sun at this time, the Northern Hemisphere is leaning *away from* the Sun. Days are shorter, and sunlight does not come as directly to the Northern Hemisphere, so it gets less solar energy.

Four days in the year have names based on Earth's location around the Sun. **Summer solstice** (June 21 or 22) is the day when the North Pole leans toward the Sun. **Winter solstice** happens on December 21 or 22 when the North Pole leans away from the Sun.

The 2 days when the Sun's rays shine straight down on the equator are the **equinoxes.** Earth's axis is tilted neither away from nor toward the Sun. *Equinox* means "equal night." Daylight and darkness are equal (or nearly equal) all over Earth. There are two equinoxes each year, **spring equinox** (March) and **fall equinox** (September).

Daily Dose of Sunshine

We take night and day for granted. They always happen. The Sun comes up; the Sun goes down. This cycle has happened as long as humans have been on Earth. It will most likely continue for millions of years.

Because Earth tilts, the length of day and night changes as the year passes. This table shows how hours of daylight change by latitude during the year. When it's summer in the Northern Hemisphere, the North Pole leans toward the Sun. At the North Pole, the Sun never sets. Above the Arctic Circle (66.5° north), daylight can last all 24 hours of the day.

LENGTH OF DAYLIGHT IN THE NORTHERN HEMISPHERE

Latitude (°N)	Summer solstice	Winter solstice	Equinoxes
0	12 hr.	12 hr.	12 hr.
10	12 hr. 35 min.	11 hr. 25 min.	12 hr.
20	13 hr. 12 min.	10 hr. 48 min.	12 hr.
30	13 hr. 56 min.	10 hr. 04 min.	12 hr.
40	14 hr. 52 min.	9 hr. 08 min.	12 hr.
50	16 hr. 18 min.	7 hr. 42 min.	12 hr.
60	18 hr. 27 min.	5 hr. 33 min.	12 hr.
70	24 hr. 00 min.	0 hr. 00 min.	12 hr.
80	24 hr. 00 min.	0 hr. 00 min.	12 hr.
90	24 hr. 00 min.	0 hr. 00 min.	12 hr.

THERMOMETER:
A Device to Measure Temperature

Is the oven ready for this pie? You look flushed—do you have a fever? The fish are not eating. Is it warm enough in the aquarium? The ice cream is soft. Is that freezer working?

To answer these questions, we reach for a thermometer. And these days, there are lots of different kinds to reach for.

All thermometers work the same way on a basic level: some property of a material changes as it gets hot. You may already be familiar with several kinds of thermometers. The old standby is the glass tube filled with alcohol or mercury. This is how it works.

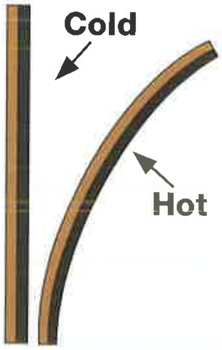
A thin, heat-tolerant, glass tube with a bulb at one end is filled with alcohol or mercury. The liquid extends partway up the tube. The tube is then sealed and attached to a backing that has a scale written on it.

When the bulb touches something hot, the liquid inside expands. The volume of liquid increases. The only place the added volume of liquid can go is into the tube. The distance the liquid pushes up the tube indicates the temperature of the material touching the thermometer bulb.

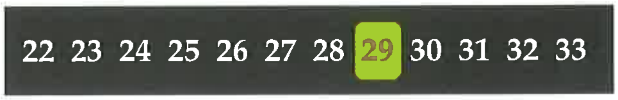
The first closed-tube thermometer, like the one described above, was invented by Grand Duke Ferdinand II in 1641. He used alcohol in the tube. During the 18th century, more precise closed-tube thermometers made it possible to conduct experiments involving fairly accurate temperature measurements.

In 1714, German physicist Daniel Gabriel Fahrenheit made a mercury thermometer and developed the Fahrenheit temperature scale. On the Fahrenheit scale, 32°F is the freezing point of water and 212°F is the boiling point of water. In 1742, Swedish astronomer and physicist Anders Celsius devised a temperature scale on which 0°C is the freezing point of water and 100°C is the boiling point. This used to be called the centigrade scale, which means "hundred steps." But in 1948, it was renamed the Celsius scale in honor of Anders Celsius.

There are other types of thermometers. Oven thermometers and some wall thermometers look a little like pocket watches. Inside is a **bimetallic strip.** Bimetallic strips are made of two metals stuck together. The two metals expand at different rates when they get hot. When the heat is turned up, the copper-colored part of the strip expands (lengthens) more than the other. The strip bends. A pointer attached to the bending metal strip points to the temperature.



Tropical-fish fanciers keep thermometers right in the aquarium. One efficient kind is a thin, flat strip of plastic, like a piece of black plastic ribbon, that has **liquid crystals** packaged inside. Liquid crystals change color within a very narrow temperature range. A liquid-crystal thermometer has a series of little pockets in the strip, each filled with a different mix of liquid crystals to indicate one temperature only. So all you have to do is look at the strip to see which number is surrounded by a green glow, and that's the temperature.



The last time you went to the doctor for a checkup, you may have had your temperature taken with a digital thermometer. These recent arrivals on the thermometer scene are very accurate and easy to use. You slip the probe end under your tongue for a few seconds. Inside the probe is a circuit with electricity flowing through it. Part of the circuit flows through a piece of wire that changes resistance as the temperature increases. When the electronic circuitry detects that the current flowing in the probe circuit has stabilized, that means the temperature is no longer changing. The electronic thermometer measures the amount of current flowing in the circuit and displays the temperature on a little digital screen.

That's just a small sampling of the many different thermometers found in common and specialized applications.

Galileo *invented one of the first functional thermometers in 1596. He filled a number of small glass balls partway with colored water and sealed them shut. The balls of colored water all floated in water.*

Galileo knew that water expands as it warms up. Warm, expanded water is less dense than cold water. He then attached a weight to each ball. The weights were adjusted to give each ball a slightly different buoyancy. The result was that when the water was cold (at its densest), all of the balls floated . As the water warmed up, becoming less dense, balls would sink.

By placing the balls in a column of water in order of their buoyancy, with the least dense on the top, Galileo produced a thermometer. If all of the balls were on the bottom of the cylinder, it was really hot.

Modern versions of the Galileo thermometer have temperatures printed on the weights. The number on the lowest floating ball shows the temperature of the system.

Heating the Atmosphere

You may have had an experience like this one. The campfire has burned down to a bed of hot coals, perfect for toasting some marshmallows. The only stick available is about a meter long, but you go for it. You can hardly stand the heat from the coals because the stick is short, but after a minute the marshmallow is brown and gooey. You pop it into your mouth. Yikes! Didn't wait long enough for it to cool.

This story includes a couple of intense heat experiences. But have you ever stopped to think about what heat really is? What is the heat that you felt coming off the coals and the heat in the marshmallow that burned your tongue?

Heat = Movement

Objects in motion have energy. The faster they move, the more energy they have. Energy of motion is called **kinetic energy.**

Matter, like nails, soda bottles, water, and air, is made of atoms and molecules. Atoms and molecules, even in steel nails and glass bottles, are in motion. In solids, the molecules vibrate back and forth. In liquids and gases, the molecules move all over the place. The faster molecules vibrate or move, the more energy they have.

Molecular motion is molecular kinetic energy, and that is heat. The amount of kinetic energy in the molecules of a material determines how much heat it has. The molecules in hot materials are moving fast. The molecules in cold material are moving slowly.

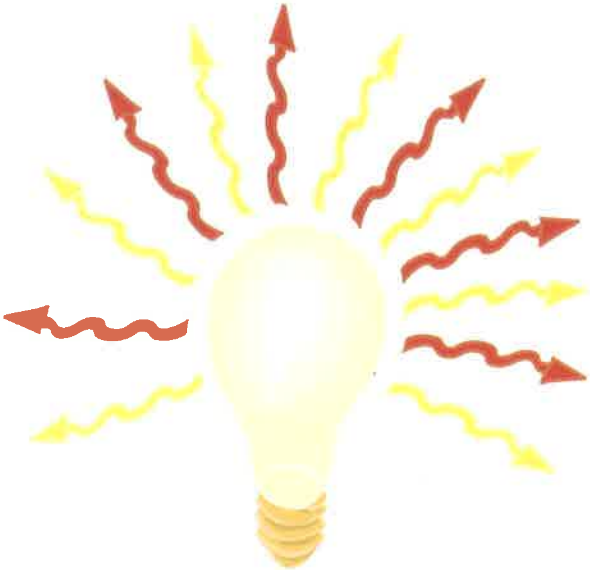
Heat Transfer

Heat can move, or transfer, from one place to another. Scientists sometimes describe heat transfer as heat flow, as though it were a liquid. Heat is not a liquid, but flow is a pretty good way to imagine its movement.

Heat flows from a hotter location (more energy) to a cooler one (less energy). For example, if you add cold milk to your hot chocolate, heat flows from the hot chocolate to the cold milk. The hot chocolate cools because heat flows away; the cold milk warms because heat flows in. Soon the chocolate and the milk arrive at the same temperature, and you gulp them down.

Heat Transfer by Radiation

There are many different forms of energy, including heat and light. If you heat an object, like the burner on a stove, to a high enough temperature, it will get red hot. When this happens, the burner is giving off two forms of energy, heat and light. If you put your hands near a lightbulb, you can see light and feel heat, even though you are not touching the bulb. This kind of energy that travels right through air is **radiant energy.**



Radiant energy travels in the form of **rays.** Heat and light rays radiate from sources like the intensely hot campfire coals, lightbulbs, and the Sun.

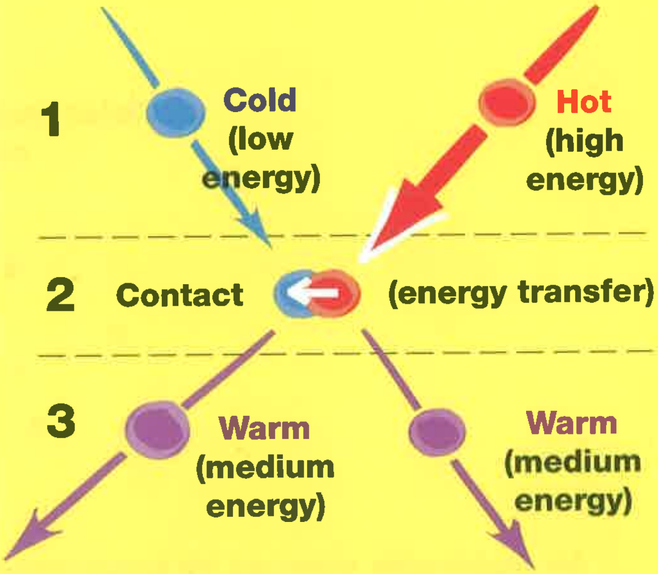
Energy rays from the Sun pass through Earth's atmosphere. We call this **solar energy.** When solar energy hits a molecule, such as a gas molecule in the air, a water molecule in the ocean, or a molecule in the soil, the energy can be **absorbed.** Absorbed energy increases the kinetic energy (movement) of the molecules in the air, water, or soil. Increased kinetic energy equals increased heat.

Radiation is one way energy moves from one place to another. Materials don't have to touch for energy to transfer from one to the other.

Heat Transfer by Conduction

Think about that hot toasted marshmallow or maybe a slice of pizza straight from the oven going into your mouth. This kind of memorable experience is another kind of energy transfer. When energy transfers from one place to another *by contact*, it is called **conduction.**

The fast-moving molecules of the hot pizza bang into the slower molecules of your mouth. The molecules in your tongue gain kinetic energy. At the same time, molecules of the hot pizza lose kinetic energy, so the pizza cools off. Some of the pizza kinetic energy is conducted to heat receptors on your tongue, causing them to send a message to your brain that says "Hot!"



A "hot" molecule with a lot of kinetic energy collides with a "cold" molecule with little kinetic energy. Energy transfers at the point of contact. The cold molecule then has more energy, and the hot molecule has less energy.

When you heat water in a pot, the water gets hot because it comes in contact with the hot metal of the pot. Kinetic energy transfers from the hot metal molecules to the cold water molecules by contact, which is conduction.

Heat Transfer to the Atmosphere

The atmosphere is heated by radiant energy from the Sun—solar energy. Lots of different kinds of rays are sent out by the Sun, but the most important ones are visible light and invisible light called infrared radiation. It seems pretty straightforward. The molecules in the air absorb the incoming radiation to increase their kinetic energy. But that's not what happens.

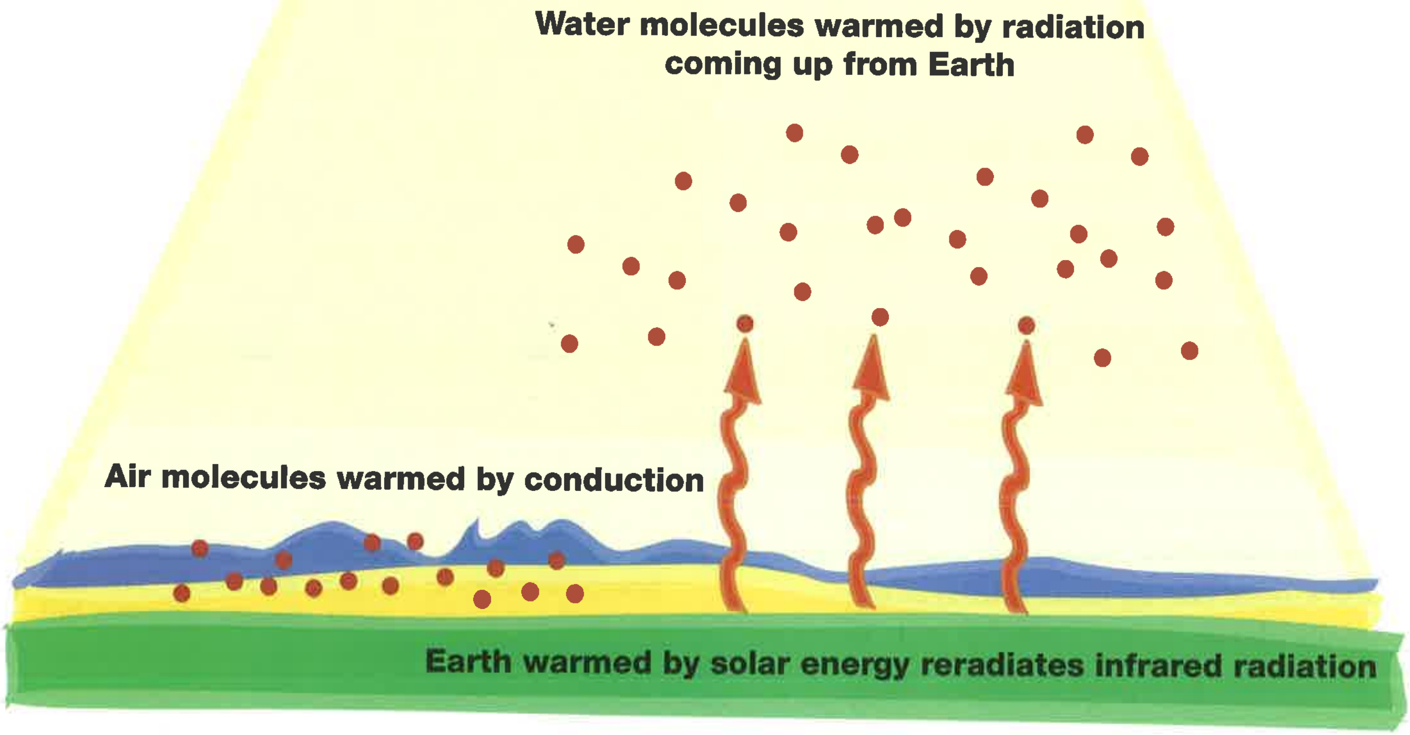
Air is 99% nitrogen and oxygen molecules. Neither of these molecules absorbs visible light or infrared radiation. It just doesn't happen. Only water vapor and carbon dioxide absorb significant amounts of radiant energy, and this is mostly infrared rays, not visible light.

If only a tiny part of the atmosphere gets hot from incoming solar energy, how does the rest of the atmosphere get hot?

Visible light *is* absorbed by Earth's surface. The land and seas warm up. The air molecules that come in contact with the warm land and water molecules gain energy by conduction. But there is more.

The warm land and seas also **reradiate** energy. This is a very important idea. Earth actually gives off infrared radiation that can be absorbed by water molecules (mostly) and carbon dioxide molecules in the atmosphere. The energy absorbed by the small number of water molecules is transferred throughout the atmosphere by conduction when hot water molecules bang into oxygen and nitrogen molecules.

The atmosphere is not heated from above; it is heated from below.



Temperature and Thermometers

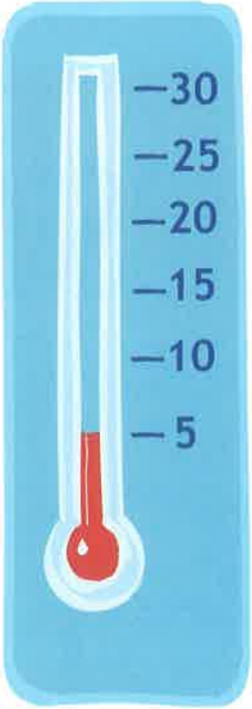
How can you find out just how much heat is in the part of the atmosphere where you are? With a thermometer.

A thermometer measures temperature. **Temperature** is a measure of the average kinetic energy of the molecules in a material. If a thermometer is surrounded by air, it measures the average kinetic energy of the air molecules. If it is surrounded by water, it measures the kinetic energy of the water molecules. If you hold the thermometer bulb between your fingers, the thermometer measures the average kinetic energy of the molecules on the surface of your fingers.

If you stick a thermometer in a cup of cocoa, under your tongue, or in a freezer, it will measure the average kinetic energy of the molecules touching it in those places.

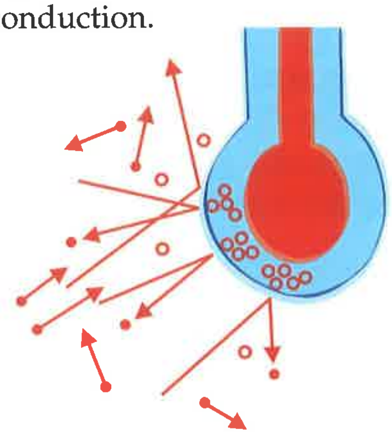
How Does a Thermometer Work?

Think about an alcohol thermometer on the wall in a cold cabin. The kinetic energy in the air molecules is low. The kinetic energy in the glass and alcohol molecules is low. The air molecules and the glass thermometer bulb have the *same* kinetic energy. The top of the column of alcohol is at 5°C. Brrrr, it's cold, so you turn on the heater.

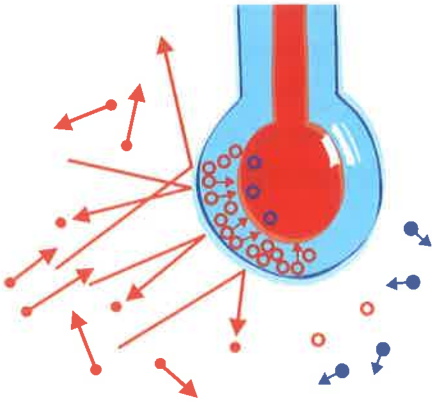


Pretty soon warm air is flowing into the room. Warm air has more kinetic energy than cooler air. The energy added to the room in the form of fast-moving air molecules starts a chain of events.

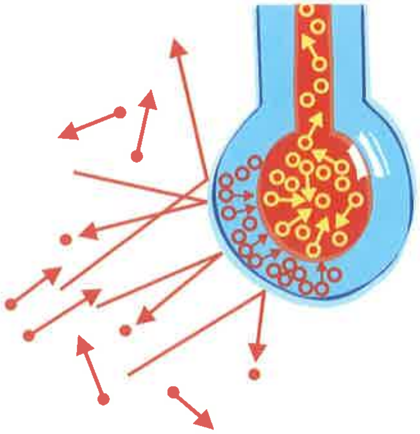
- Molecules in the warm air collide more often with the glass thermometer bulb. Energy transfers to the molecules of glass by conduction.



- Kinetic energy transfers by conduction from molecule to molecule in the glass bulb until all of the glass molecules are warm.

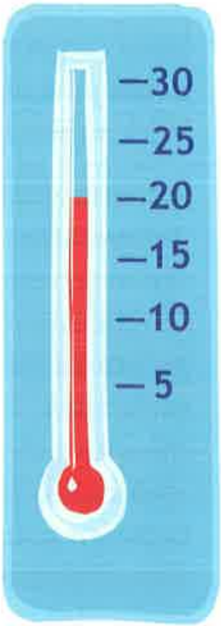


- Energy transfers by conduction from the glass molecules to the alcohol molecules inside the bulb. Kinetic energy transfers throughout the alcohol by conduction—collisions between alcohol molecules.



- The alcohol molecules push on one another more forcefully because of the increased kinetic energy. The molecules push farther apart, expanding the volume of alcohol. As the volume of alcohol gets bigger, the only place it can go is into the tube.
- The alcohol will continue to expand as long as more and more energy is transferred to the alcohol. The alcohol will continue to push up the tube.

When the room is warm, you turn off the heater. In a few minutes, all the molecules in the room are at the same level of kinetic energy. The alcohol stops rising. The top of the column of alcohol is right next to the 20°C mark on the thermometer. Nice and warm.



As long as the kinetic energy of the alcohol molecules stays the same, the level of the column of alcohol will stay the same, and we say the temperature is steady at 20°C.

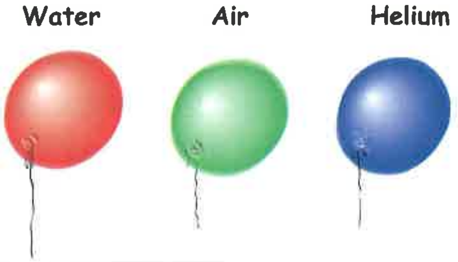
What happens if you open the window? The whole process goes into reverse. Molecules in cool air have less kinetic energy. Heat energy transfers by conduction from the glass tube to the air. Heat then transfers from the alcohol to the now-cooler glass. The alcohol molecules lose kinetic energy and slow down, and the alcohol contracts. The liquid level gets lower in the tube. Kinetic energy will transfer from the molecules in the room to the molecules outside through the open window. The chill of low kinetic energy will set in once again. The thermometer will once again dip to 5°C. Brrrr.

Think Questions

1. What is heat?
2. What heats Earth's atmosphere?
3. What are the two ways energy can transfer from one material to another?
4. Explain two ways that Earth's atmosphere gets heated.
5. Thermometers measure temperature. What is temperature?
6. Explain why the alcohol level in a thermometer goes down when the weather gets cold.

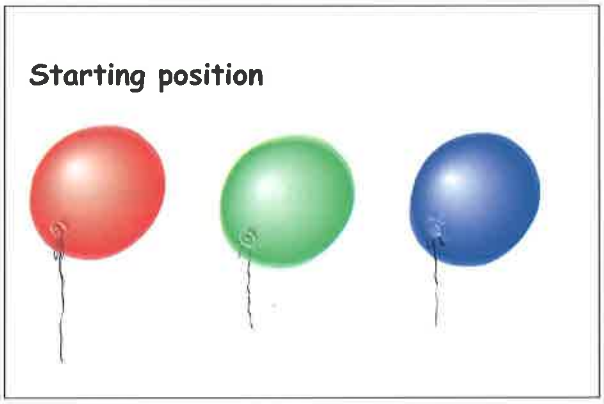
DENSITY

Make believe you have a package of regular rubber balloons. Fill one with water, tie it off, and give it to a friend. Fill a second, identical balloon with air until it is the same size as the water balloon. Tie it off and give it to a second friend to hold. Fill a third balloon with helium, same size as the other two, and tie it off.

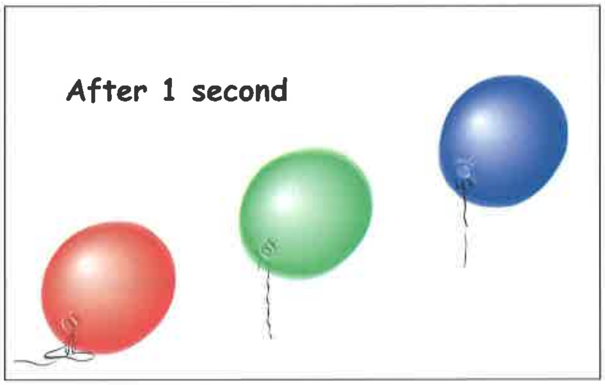


Review the balloons—three identical balloons, all filled to exactly the same volume, each tied off so nothing can get in or out. What's different? The kind of material in the three balloons. Ready to try a little experiment?

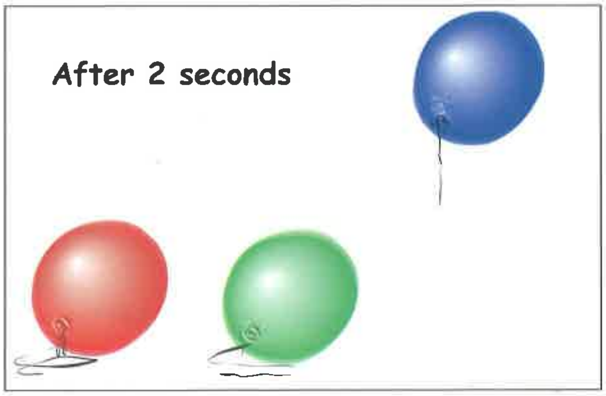
You and your friends hold the balloons at the same height above the floor. On the count of three, you will all release your balloons and observe what happens.



The water balloon will plunge to the floor, the air balloon will drift slowly to the floor, and the helium balloon will float up to the ceiling. Why?



It comes down to how much stuff there is in each balloon. The scientific word for stuff is **matter.** The amount of matter in an object is its **mass.** Matter is made out of atoms. So the mass of an object depends on *how many* atoms there are in the object and *how big* the atoms are.



The atoms in solids (glass, steel) and liquids (water, alcohol) are packed together as close as they can get. This means there are lots of atoms in a volume of water. That makes water pretty heavy.

In gases, the atoms are not packed as close together as they can get. There is a lot of space between atoms. Air and helium are gases, so they are pretty light.

Air atoms (mostly nitrogen and oxygen) are fairly large, but helium atoms are small. Generally speaking, small atoms weigh less than large atoms. So helium is much lighter than air.

DENSITY

The amount of matter in a volume of material determines the material's density. **Density** is defined as mass per volume of an object. When you have equal volumes of a bunch of different materials, you can find out which one is densest and which one is least dense by weighing them. The heaviest one is the densest; the lightest is the least dense.

The important idea in this discussion is that you need to compare the weight of *equal volumes* of different materials to determine which one is densest.

DENSITY OF LIQUIDS

Mr. Dey's students had several salt solutions. They wanted to find out which one was densest.

Group 1 put 25 milliliters (ml) of the blue solution on a scale and found that it had a mass of 25 grams (g). They measured 25 ml of green solution into another cup. Its mass was 30 g.

The students announced, "We weighed equal volumes of two solutions. The green solution is heavier, so it is denser. It has more mass per volume than the blue solution."

Group 2 put 25 ml of blue solution on a scale and found that it had a mass of 25 g. But then they made a little mistake. They put 50 ml of yellow solution in a cup and found that it had a mass of 55 g.

When they realized what they had done, Reggie said, "Oh-oh, we didn't measure equal volumes. We have to start over."

"Maybe not," said Yolanda. "We weighed twice as much yellow solution as we should have. If we had used half as much, it would have weighed half as much. All we have to do is divide the mass by two to find out the mass of 25 ml of yellow solution."

They did the math and found that 25 ml of yellow solution had a mass of 27.5 g.

The two groups put their data together in a table.

Solution	Volume	Mass
Blue	25 ml	25 g
Green	25 ml	30 g
Yellow	25 ml	27.5 g

Students could now easily compare equal volumes of the three solutions to see which one was heaviest and, therefore, densest. They determined that green was densest, blue least dense, and yellow in the middle.

Mr. Dey had a question. "What is the mass of 1 ml of each of the solutions?"

Reggie offered, "Twenty-five milliliters of blue solution has a mass of 25 g, so 1 ml of blue has a mass of 1 g."

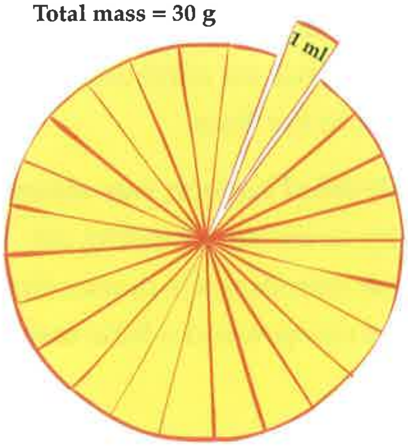
"And the green solution?" asked Mr. Dey.

Reggie's group thought about it this way.

- Twenty-five milliliters of green has a mass of 30 g. That's more than 1 g for each milliliter.
- They drew a pie chart to help them think about the problem. Each slice of pie represented 1 ml, or 1/25 of the total volume.

Total volume = 25 ml

Total mass = 30 g



- One milliliter is 1/25 of the total volume. Each milliliter must have 1/25 of the total mass.
- They divided 30 g by 25 ml to find the mass of 1 ml of green solution.

The students discovered the definition of density. **Density is the mass, in grams, of 1 ml of material.**

The usual way of stating density is *mass per volume*. The word *per* means "divided by."

Density can be written as an equation.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{\text{g}}{\text{ml}}$$

The equation can be used to calculate the density of the green solution.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{30\text{ g}}{25\text{ ml}} = 1.2\text{ g/ml}$$

Density equals mass divided by volume. If you remember "mass per volume," you will always know how to set up your equation when it comes time to calculate a density.

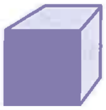
What's the density of the yellow solution? Remember, mass per volume. The original mass of the yellow solution was 55 g, and the volume was 50 ml.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{55\text{ g}}{50\text{ ml}} = 1.1\text{ g/ml}$$

DENSITY INTERACTIONS

Density is a number that tells you how much matter there is in a milliliter or **cubic centimeter (cc)** of material. One milliliter is exactly the same volume as one cubic centimeter.

1 cubic centimeter = 1 milliliter →



Liquids are generally measured in milliliters, and solids and gases are measured in cubic centimeters.

If there is a lot of matter in a cubic centimeter of something, it is dense. If there is very little matter in a cubic centimeter of material, it is not dense.

Water has a density of 1 g/ml. Materials with densities greater than 1 g/ml are denser than water; materials with densities less than 1 g/ml are less dense than water.

What will happen if you put a rock with a density of 3 g/cc in a tub of water? It will sink like, well, a rock. And if you put a cork, with a density of 0.45 g/cc in the tub of water? Yes, it will float.

Materials that are denser than water sink in water. Materials that are less dense than water float in water. That's the way it always works.

When salt dissolves in water, it forms a solution. The more salt dissolved in a volume of water, the greater the solution's density.

If you carefully pour a little bit of each of the colored solutions from Mr. Dey's class into a vial, what do you think would happen? Can you describe the result?

Solution	Density
Blue	1.0 g/ml
Yellow	1.1 g/ml
Green	1.2 g/ml

DENSITY OF GASES

Back to the balloons. We know the density of water, but what about the air and the helium?

Material	Density
Water	1.0 g/ml
Air	0.0013 g/ml
Helium	0.0002 g/ml

The chart shows that air and helium are not very dense. There is very little mass in a milliliter of gas.

When the three balloons were released, the dense water-filled balloon pushed through the less-dense air surrounding it. It fell straight to the floor.

The air-filled balloon was almost the same density as the surrounding air. The rubber-balloon membrane is denser than air, and the air was compressed a little inside the balloon, making the air-filled balloon a little denser than the surrounding air. It drifted slowly to the floor.

The helium-filled balloon was quite a bit less dense than the surrounding air. Just like a cork in water, the less-dense helium balloon floated up to the ceiling.

DENSITY OF AIR

Air is gas. The molecules in gases are not bonded to other molecules. Gas molecules move around freely in space.

When energy transfers to matter, the kinetic energy (movement) of the atoms and molecules increases. The increased motion causes most matter to expand. When matter expands, the atoms and molecules do not get bigger—they get farther apart. This is a very important point: It is the distance between molecules that increases, not the size of the molecules.

When matter expands, the molecules get farther apart. What do you think that does to the density of the material? The density gets lower. When the molecules get farther apart, each cubic centimeter (which is the same as a milliliter) has fewer molecules. Fewer molecules per milliliter means lower density.

This is a general rule of matter. When matter gets hot, it expands, and the density goes down.

Air is matter. Air expands when it gets hot. Air gets less dense when it gets hot. When energy transfers from Earth's surface to the air by conduction (contact between surface molecules and air molecules) or reradiation, the air temperature goes up and the air expands. The low-density, warm air rises, just like the helium balloon in air.

DENSITY AND WEATHER

Weather happens in the atmosphere. Energy transfers into and out of the atmosphere in the form of heat. As air heats up and cools down, its density changes. Warm air tends to go up, and cold air tends to go down. When masses of air move, things happen in the weather.

The idea of density will be an important concept in our investigation of weather and the processes that cause it.

THINK QUESTIONS

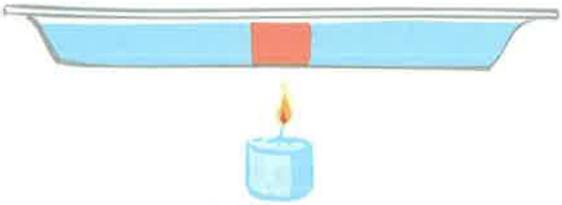
1. **What do you think the density of a person might be? Explain.**
2. **Why do you think hot-air balloons are able to rise into the air? How do hot-air-balloon pilots get their balloons back to Earth?**

CONVECTION

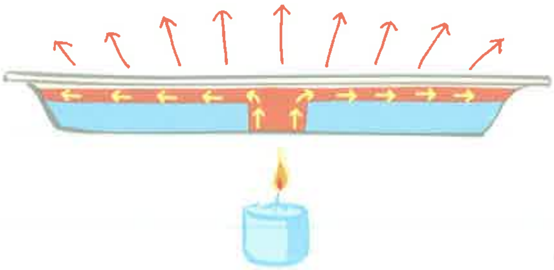
If you put a couple of centimeters of water in a metal pie pan and support it over a candle, you can slowly heat the water. The energy from the flame will heat a small area of the pan, and the heat will conduct to the water in contact with the hot metal.

A small mass of water will heat up. The question is, what happens to the hot water?

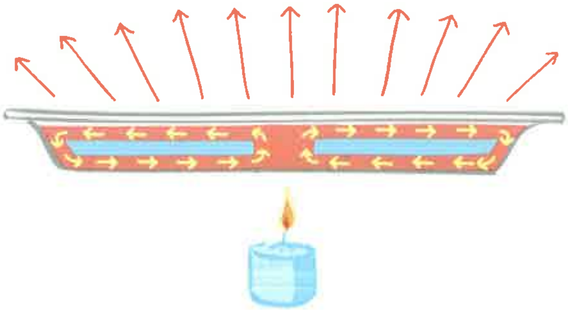
The water expands as the water molecules gain kinetic energy and push farther apart. The expanding water is less dense than the surrounding water. The warm water rises upward.



When the warm water reaches the surface, it spreads out. Water at the surface cools by radiation and conduction.



When the cool water reaches the edges of the pie pan, the water is dense. It flows down the sides of the pan, across the bottom, and back toward the center of the pan. As the water nears the hot metal, it begins to warm again. The hot water rises to repeat the cycle.



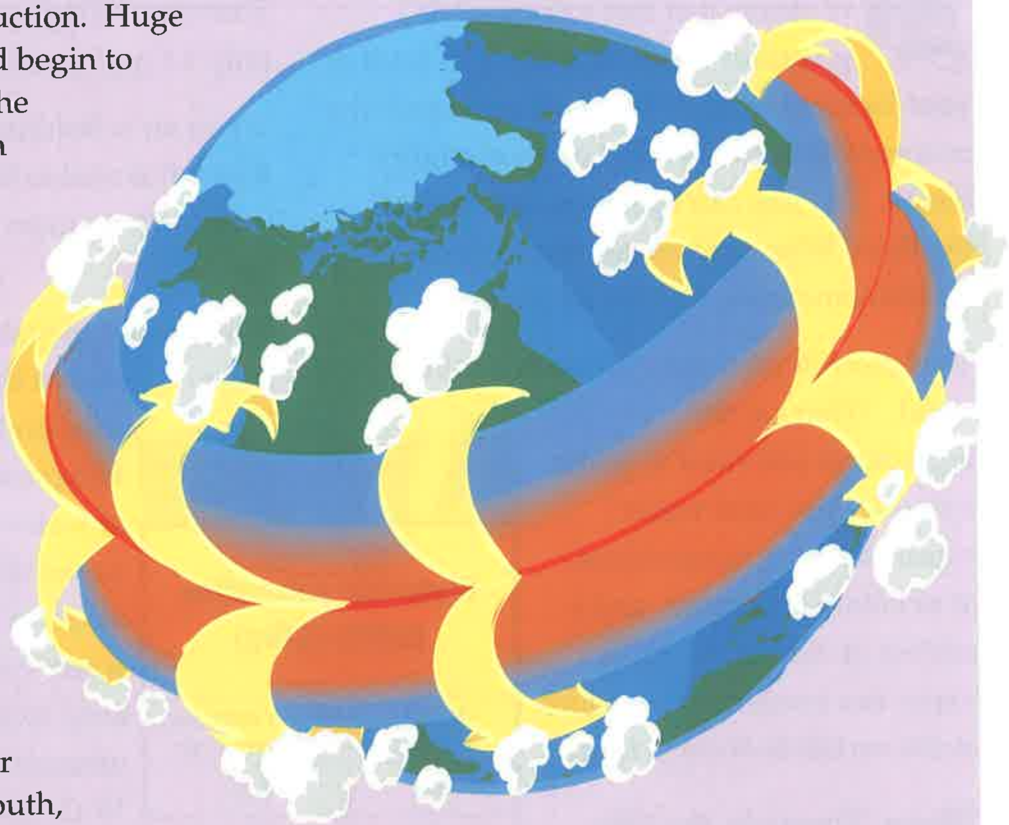
The movement of water in the pan, driven by a localized heat source, is **convection.**

Convection happens only in fluids. Fluid near an energy source heats up and expands. The hot fluid becomes less dense and rises. The energy in the molecules of hot fluid is carried to a new location. As the energy in the hot fluid transfers away from the fluid, it cools and contracts, making it denser. The cool fluid flows downward again.

The mass of fluid flowing in a circle is called a **convection cell.**

Air is a fluid. Energy can transfer to air, causing it to expand. When air expands, it becomes less dense. Less-dense air will rise in the atmosphere.

This is exactly what happens in the real world. Earth's surface is always warm in the tropics, the part of the planet near the equator. Water in the tropical oceans absorbs a lot of solar energy. Air in contact with the tropical seas receives a lot of energy by reradiation and conduction. Huge masses of air heat up and begin to rise. This is the start of the largest convection cell on Earth.



The equatorial convection cells circle the globe like two bicycle inner tubes. Because much of the energy transfer occurs over the ocean, large amounts of water vapor rise high into the atmosphere, riding along in the convection cell. The warm, moist air spreads out north and south, and it cools. When the air cools, water vapor condenses into droplets of liquid water. Large numbers of little droplets of water form clouds. And we all know what happens after clouds form—rain.

In the next few investigations, we will see how the process of convection helps redistribute water around the planet and affects wind, everything from gentle breezes to powerful, dangerous storms.

Dragon's Breath

Did you ever breathe out a big breath of steam, just like a dragon? It's great fun to exhale a cloud in front of your face and pretend that you can scorch the countryside with one blast of your mighty breath. But you can't perform this trick all the time. Why can you see these breath clouds sometimes, but not all the time?

That short-lived dragon's breath is a little cloud. What are the ingredients you need to make a cloud? You need water vapor in the air, temperature at or below dew point, and a surface on which the water vapor can condense. Let's look at the variables one at a time.

Water Vapor in the Air

There is always water vapor in the air. Sometimes there is very little water vapor, and sometimes there is a lot. Water vapor in the air is called **humidity.**

Temperature plays an important role in humidity. The rule is, the warmer the air, the more water vapor it can hold. At 35°C, a kilogram (kg) of air can hold 35 grams (g) of water vapor. That same kilogram of air at 0°C can hold only 3.5 g of water vapor.

Water/air saturation points (g/kg)

Air temp. (°C)	Grams water per kilogram of air
–40	0.1
–30	0.3
–20	0.8
–10	2.0
0	3.5
5	5.0
10	7.0
15	10.0
20	14.0
25	20.0
30	26.5
35	35.0
40	47.0

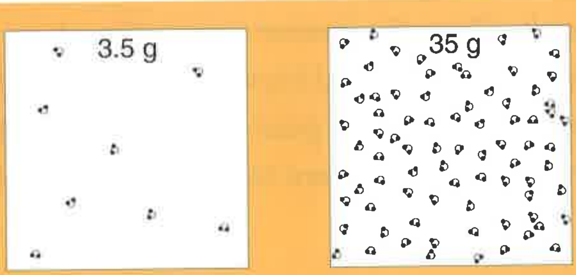
When air is holding as much water vapor as it can, it is said to be **saturated.** When air is saturated, no more water vapor can enter the air.

The amount of water needed to saturate a mass of air is not the same at all temperatures. Let's think about a kilogram of air that is holding 3.5 g of water vapor. The 3.5 g of water vapor will saturate the kilogram of air at 0°C. That same 3.5 g of water vapor, however, represents only 10% of the 35 g needed to saturate the kilogram of air at 35°C. The amount of water vapor in the air compared to the amount of water vapor *needed to saturate the air at a given temperature* is **relative humidity.** Relative humidity is reported as a percentage.

The relative humidity of the kilogram of air holding 3.5 g of water vapor at 0°C is 100%. When the same kilogram of air with the same 3.5 g of water vapor is heated to 35°C, the relative humidity is only 10%.

Dew Point

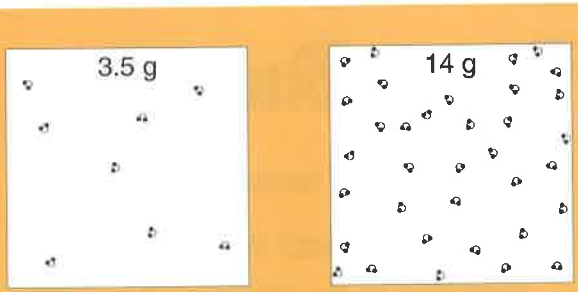
Picture the kilogram of warm 35°C air holding 3.5 g of water vapor. That's 10% relative humidity. This is a cartoon of 3.5 g of water vapor in the air compared to the 35 g of water vapor needed to saturate the air at 35°C.



10% relative humidity at 35°C

100% relative humidity at 35°C

As the kilogram of air cools off to 20°C, there are still 3.5 g of water vapor in the kilogram of air, but at 20°C a kilogram of air is saturated when it is holding 14 g of water vapor.

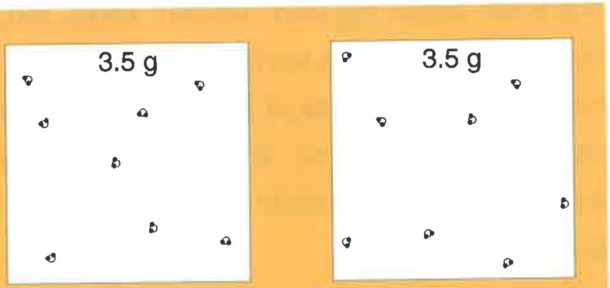


25% relative humidity at 20°C

100% relative humidity at 20°C

At 10°C, a kilogram of air is saturated when it is holding 7 g of water vapor. When our kilogram of air with its 3.5 g of water vapor cools to 10°C, the relative humidity is now up to 50%.

If the mass of water vapor in a kilogram of air doesn't change, its relative humidity goes up and up as it cools. When it gets to 0°C, an interesting thing happens. Without changing the mass of the water vapor in the air, the air becomes saturated. The kilogram of air can hold only 3.5 g of water vapor at 0°C, and that's the amount in our air.



100% relative humidity at 0°C

100% relative humidity at 0°C

What happens when the air gets even colder? The table shows that a kilogram of air at –10°C can hold only 2 g of water vapor. Our kilogram has 3.5 g of water vapor. What happens to the extra 1.5 g of vapor? It condenses into ice crystals.

The temperature at which a volume of air is saturated with water vapor is known as **dew point.** When the temperature drops even a tiny bit below the dew point, water condenses as ice crystals, dew, fog, or clouds.

Condensation Surface

Water vapor needs a surface on which to condense. When the air reaches dew point, water will condense on grass, leaves, and windows as dew. Dew is a thin layer of tiny drops of water. Dew forms on large surfaces.

But what about fog and clouds? Here, too, water vapor needs a surface on which to condense. In the case of fog and clouds, the surface is microscopic. It can be as small as a piece of dust, a particle of smoke, or a tiny crystal of salt.

Small particles on which vapor condenses are called **condensation nuclei.** The air is full of tiny things that can act as the nucleus around which condensation starts. Once a droplet is started, more water vapor can condense on the surface of the water droplet.

Back to Dragon's Breath

Air in your lungs is warm—close to 35°C—and humid. In fact, the humidity of an exhaled breath is at or very near 100% relative humidity. Most of the time the water vapor in the exhaled humid air enters the atmosphere and just adds to the humidity of the air. When the warm air from your body is exhaled on a cold day, it cools rapidly. Cold air holds less water vapor. Your breath air quickly drops to dew point and becomes saturated with water vapor. The water vapor from your breath instantly condenses on invisible dust particles present in the air, and you let out a blast of cold dragon breath!

The colder the air temperature, the easier it is to saturate the air with the water vapor from your breath. So where could you go today to breathe out a cloud? Your face would have to be in the cold even if the rest of you wasn't. Open the freezer compartment on your refrigerator and blow a blast of dragon breath on the frozen peas and carrots. But be careful, you don't want to defrost the freezer by accident.

Think Questions

1. **What is relative humidity?**
2. **What is dew point? What does dew point have to do with dragon's breath?**
3. **Why does fog form on bathroom mirrors and car windows?**
4. **On what kind of day would it be possible to create frozen dragon's breath?**