ASTRONOMY 3

PARENT/TEACHER'S GUIDE

A comprehensive course that teaches the big ideas behind Newton and Einstein's groundbreaking work. Students will discover how to design and build reflector and refractor telescopes, investigate how gravity curves spacetime, detect black holes, build a calibrated spectrometer, play with the electromagnetic spectrum, and uncover the mysterious forces that shape the incredible universe we call home.

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This curriculum is aligned with the California State Standards and STEM for Science.

Introduction

Greetings, and welcome to the unit on astronomy. I hope you will find this helpful in preparing to teach your students, exhaustively thorough in content and a whole lot of fun, because that's when students and teachers do their best work.

This curriculum course has been prepared to be completed over several weeks, completing 1-2 lessons per week. You will find that there are 14 lessons outlined to take you from an introduction of astronomy on through several advanced projects which are complex enough to win a prize at the science fair (and I've also included a sample of this at the back of this book). If you complete this course and send your kids off, you'll find their high school teachers entirely blown away by their mastery of the subject. Each lesson has a Teacher Page and a Student Worksheet.

The following features are on each set of the Teacher Pages:

- Overview: This is the main goal of the lesson.
- Suggested Time: Make sure you have enough for completing this lesson.
- Objectives : These are the core principles covered with this lesson.
- Materials: Gather these before you start
- Lab Preparation: This outlines any preparation you need to do ahead of time.
- Lesson: This outlines how to present the topic to the students, stirs up interest and gets the students motivated to learn the topic.
- Lab Time & Worksheets: This includes activities, experiments, and projects that reinforce the concepts and really bring them to life. You'll also find worksheets that make up their Scientific Journal.
- Background Lesson Reading: This is optional additional reading material you can utilize ahead of time to help you feel confident when the students ask questions during the Lab Time. I don't recommend giving this reading to the kids beforehand. If you must share it with them, then do so *after* the students have gotten a chance to roll around with the activities. Doing this teaches kids to ask their own questions by getting curious about the concepts through the experiments, the way real scientists do in the real world.
- Exercises & Answer Key: How well did you teach? How well did they learn? Time to find out.
- Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Immediately following the Teacher Pages are "Student Worksheets" for each of the activities. Each set of student worksheets has the following sections:

- Overview
- What to Learn
- Materials
- Lab Time & Worksheets
- Exercises

In addition to the lessons, we have also prepared the following items you'll find useful:

- Scientific Method Guide
- Master Materials and Equipment List
- Lab Safety Sheet
- Written Quiz (with Answer Key)
- Lab Practical Test (with Answer Key)
- Science Fair Project Sample Report

Master Materials List for All Labs

This is a brief list of the materials that you will need to do *all* of the activities, experiments and projects in each section. The set of materials listed below is just for one lab group. If you have a class of 10 lab groups, you'll need to get 10 sets of the materials listed below. For 10 lab groups, an easy way to keep track of your materials is to give each group a number from 1 to 10, and make up 10 separate lab kits using small plastic tubs or baskets. Put one number on each item and fill each tub with the materials listed below. Label the tubs with the section name, like *Astronomy Study Kit* and you will have an easy way to keep track of the materials and build accountability into the program for the kids. Copy these lists and stick them in the bin for easy tracking. Feel free to reuse items between lessons and unit sections. Most materials are reusable year after year.

Aluminum foil
Aluminum pie pan
Baader film (www.dracoproductions.net)
Balloons (2)
Binoculars (optional)
Bouncy ball
Bowl
Buckets (2)
Bungee cords (2)
CD or DVD
Clothespins (4)
Concave mirror (www.hometrainingtools.com)
Diffraction grating
Double-convex lenses (2) (www.hometrainingtools.com)
Drinking straws
Dry ice
Fabric (3 squares of stretchy material)
Feather
Felt (black)
Film canister or M&M container
Fire extinguisher
Fishing bobber
Fishing line
Flashlight
Foam cup
Foam plate
Garbage bag (black)
Glass jar
Goggles
Hair from your head
Heavy gloves for handling the dry ice (adults only)
Hot glue gun
Index cards (5)
Laser pointer (cheap is best)
Magnets (2 rare earth type)
Magnets (4 doughnut)
Magnifying glass
Marbles (3 sizes)
Masking tape
Measuring tape (25-100')
Metal ball (like a ball bearing) or a magnetic marble
Nail (needs to be a little longer than the film canister)
Nylon filament (thin nylon thread works, too)
Paper clip (large)
Pencil
Pennies (10)
Plastic baggie
Popsicle sticks
Rubber band
Rubbing alcohol
Ruler
Saran wrap
Scissors
Small mirrors (2)
Softball
Stopwatch
String (5')
Tack
Tennis ball
Thread (12")
Wax paper
Weight (0.5 lb)
Weight (2.5 lb)
Wool cloth or sweater
Yard or meter sticks (2)

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Unit Prep

This is a short list of things that you may want to consider as you prepare for this unit.

Student Lab Books: If you're the kind of teacher who likes to prepare lab books for your kids, now is a good time to do this. You can copy the *Introduction for Kids* and the *Student Worksheets* for each of the experiments, 3-hole punch them, and stick them in a binder. You'll want one binder per student.

Science Journals: One of the best things you can do with your students is to teach them how to take notes in a journal as you go along. This is the same way scientists document their own findings, and it's a lot of fun to look back at the splattered pages later on and see how far you've come. I always jot down my questions that didn't get answered with the experiment across the top of the page so I can research these topics more.

Master Set of Materials: If you plan on doing all the labs in this unit, you'll want to start gathering your materials together. There's a master materials list so you'll have everything you need when you need it.

Test Copies: Students will take two tests at the end of each section. There are quizzes and lab practical tests you can copy and stash away for when you need them.

Classroom Design: As you progress through the units, you'll be making demos of the experiments and kids will be making posters. You can hang these up on your bulletin boards, string them from the ceiling, or display them in a unique way. I always like to snap photos of the kids doing their experiments and hang those up along with their best labs so they can see their progress as we go along.

Lab Safety

Goggles: These should be worn when working with chemicals, heat, fire, or projectiles. These protect your eyes from chemical splatter, explosions, and tiny fast-moving objects aimed at the eyes. If you wear glasses, you can find goggles that fit over them. Don't substitute eyeglasses for goggles, because of the lack of side protection. Eyeglasses don't provide this important protection.

Clean up Messes: Your lab area should be neat, organized, and spotless before you start, during your experiment, and when you leave. Scientists waste more time hunting for lost papers, pieces of an experiment, and trying to reposition sensitive equipment… all of which could have easily been avoided had they been taught organizational skills from the start.

Dispose of Poisons: If a poisonous substance was used, created, or produced during your experiment, you must follow the proper handling procedures for disposal. You'll find details for this in the experiments as needed.

Special Notes on Batteries: Do not use alkaline batteries with your experiments. Find the super-cheap kind of batteries (usually labeled "Heavy Duty" or "Super Heavy Duty") because these types of batteries have a carbon-zinc core, which does not contain the acid that alkaline batteries have. This means when you wire up circuits incorrectly (which you should expect to do because you are learning), the circuits will not overheat or leak. If you use alkaline batteries (like Energizer and Duracell) and your students short a circuit, their wires and components will get super-hot and leak acid, which is very dangerous.

No Eating or Drinking in the Lab: All foods and drinks are banned from your classroom during science experimentation. When you eat or drink, you run the very real risk of ingesting part of your experiment. For electricity and magnetism labs, always wash your hands after the lab is over to rinse off the lead from the electrical components.

No Horse Play: When you goof around, accidents happen, which means chemicals spill, circuits short, and all kinds of hazards can occur that you weren't expecting. Never throw anything to another person and be careful where you put your hands – it could be in the middle of a sensitive experiment, especially with magnetism and electricity. You don't want to run the risk of getting shocked or electrified when it's not part of your experiment.

Fire: If you think there's a fire in the room (even if you're not sure), let your teacher know right away. If they are not around (they always should be), smother the fire with a fire blanket or use a fire extinguisher and send someone to find an adult. Stop, drop, and roll!

Questions: If you're not sure about something stop and ask, no matter what it's about. If you don't know how to properly handle a chemical, do part of an experiment, ask! If you're not comfortable doing part of the experiment, then don't do it.

Teaching Science Right

These activities and experiments will give you a taste of how science can be totally cool AND educational. But teaching science isn't always easy. There's a lot more to it than most traditional science books and programs accomplish. If your students don't remember the science they learned last year, you have a problem.

What do kids really need to know when it comes to science? Kids who have a solid science and technology background are better equipped to go to college, and will have many more choices once they get out into the real world.

Learning science isn't just a matter of memorizing facts and theories. On the contrary, it's developing a deep curiosity about the world around us, AND having a set of tools that lets kids explore that curiosity to answer their questions. Teaching science in this kind of way isn't just a matter of putting together a textbook with a few science experiments and kits.

Science education is a three-step process (and I mean teaching science in a way that your students will really understand and remember).

Here are the steps:

1. Get kids genuinely interested and excited about a topic.

2. Give them hands-on activities and experiments to make the topic meaningful.

3. Teach the supporting academics and theory.

Most science books and curriculum just focus on the third step, and may throw in an experiment or two as an afterthought. This just isn't how students learn. When you provide your students with these three keys (in order), you can give them the kind of science education that not only excites them, but that they remember for many years to come.

So what do you do? First, don't worry. It's not something that takes years and years to do. It just takes commitment.

What if you don't have time? What I'm about to describe can take a bit of time as a teacher, but it doesn't have to. There is a way to shortcut the process and get the same results! But I'll tell you more about that in a minute. First, let me tell you how to do it the right way:

Putting It into Action

Step one: Get students genuinely interested and excited about a topic. Start by deciding what topic you want your students to learn. Then, you're going to get them really interested in it. For example, suppose I want my fifth-grade students to learn about aerodynamics. I'll arrange for them to watch a video of what it's like to go up in a small plane, or even find someone who is a pilot and can come talk with the kids. This is the kind of experience that will really excite them.

Step two: Give your students hands-on activities and experiments to make the topic meaningful. This is where I take that excitement and let them explore it. I have flying lesson videos, airplane books, and real pilots interact with my students. I'll also show videos on how pilots plan for a flight. My students will learn about navigation, figuring out how much fuel is needed for the flight, how the weight the plane carries affects the aerodynamics of it, and so much more. (And did I just see a spot for a future math lesson also?) I'll use pilot training videos to help us figure this out (short of a live demo, a video is incredibly powerful for learning when used correctly).

My students are incredibly excited at this point about anything that has to do with airplanes and flying. They are all positive they want to be pilots someday and are already wanting flying lessons (remember - they are only fifth-graders!).

Step three: Teach the supporting academics and theory. Now, it's time to introduce academics. Honestly, I have my pick of so many topics, because flying includes so many different fields. I mean my students use angles and math in flight planning, mechanics and energy in how the engine works, electricity in all the equipment on board the plane, and of course, aerodynamics in keeping the plane in the air (to name just a few).

I'm going to use this as the foundation to teach the academic side of all the topics that are appropriate. We start with aerodynamics. They learn about lift and drag, make paper and balsa-wood gliders and experiment by changing different parts. They calculate how big the wings need to be to carry more weight (jelly beans) and then try their models with bigger wings. Then we move on to the geometry used in navigation. Instead of drawing angles on a blank sheet of paper, our workspace is made of airplane maps (free from the airport). We're actually planning part of the next flight my students will "take" during their geography lesson. Suddenly, angles are a lot more interesting. In fact, it turns out that we need a bit of trigonometry to figure out some things.

Of course, a 10-year-old can't do trigonometry, right? Wrong! They have no idea that it's usually for high school and learn about cosines and tangents. Throughout this, I'm giving them chances to talk with the pilot in class, share what they've learned with each other, and even plan a real flight. How cool is that to a kid?

The key is to focus on building interest and excitement first, and then the academics are easy to get students to learn. Try starting with the academics and ... well, we've all had the experience of trying to get kids do something they don't really want to do.

The Shortcut: Okay, so this might sound like it's time-intensive. If you're thinking, "I just don't have the time to do this!" Or maybe "I just don't understand science well enough myself to teach it to my students at that level." If this is you, you're not alone.

The good news is, you don't have to. The shortcut is to find someone who already specializes in the area you want your students to learn about and expose them to the excitement that the person gets from the field. Then, instead of you being the one to invent an entirely new curriculum of hands-on activities and academics, use a solid science program or curriculum (live videos, not cartoons). This will provide them with both the hands-on experiments and the academic background they need.

If you use a program that is self-guided (that is, it guides you and your students through it step-by-step), you don't need to be hassled with the preparation. That's what this unit is intended to do for you and your students. This program uses these components and matches your educational goals set by state standards.

This unit implements the three key steps we just talked about and does this all for you. My hope is that you now have some new tools in your teaching toolbox to give your students the best start you can. I know it's like a wild roller coaster ride some days, but I also know it's worth it. Have no doubt that that the caring and attention you give to your students' education today will pay off manifold in the future.

Educational Goals

Astrophysics combines the knowledge of light (electromagnetic radiation), chemical reactions, atoms, energy, and physical motion all into one. The things we're going to study in this unit border on sci-fi weird, but I assure you it's all the same stuff real scientists are studying.

Here are the scientific concepts:

- Objects in the sky move in regular and predictable patterns. The patterns of stars stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons.
- The Earth is one of several planets that orbit the Sun, and the Moon orbits the Earth.
- The solar system consists of planets and other bodies that orbit the Sun in predictable paths.
- The appearance, general composition, relative position and size, and motion of objects in the solar system, including planets, planetary satellites, comets, and asteroids.
- The path of a planet around the Sun is due to the gravitational attraction between the Sun and the planet.
- Telescopes magnify the appearance of the Moon and the planets.
- The Sun, an average star, is the central and largest body in the solar system and is composed primarily of hydrogen and helium. The Sun uses nuclear reactions to generate its energy.
- Telescopes magnify the appearance of the Sun using special lenses and make it possible to locate sunspots and solar flares.
- White light is a mixture of many wavelengths (colors), including infrared, ultra-violet, visible, and more. Different instruments detect and measure different wavelengths of light.
- The number of stars that can be seen through telescopes is dramatically greater than can be seen by the unaided eye.
- The structure and composition of the universe can be learned from the study of stars and galaxies.
- Galaxies are clusters of billions of stars, and may have different shapes. The Sun is one of many stars in our own Milky Way galaxy. Stars may differ in size, temperature, and color.
- Black holes are objects where the escape velocity is greater than the speed of light. They are the leftovers of a BIG star explosion. There is nothing to keep it from collapsing, so it continues to collapse forever. It becomes so small and dense that the gravitational pull is so great that light itself can't escape.
- Gravitational lensing occurs when black holes and other massive objects bend light.
- Mass causes spacetime to curve. The amount of curvature depends on how massive the object is and your distance from the massive object.

By the end of the labs in this unit, students will be able to:

- Design and build a telescope using optical equipment such as mirrors and lenses.
- Know how to demonstrate how the position of objects in the sky changes over time.
- Know the celestial objects in the solar system and how they relate and interact with each other.
- Understand how to determine the structure and composition of celestial objects.
- Differentiate observation from inference (interpretation) and know scientists' explanations come partly from what they observe and partly from how they interpret their observations.
- Measure and estimate the length and volume of objects.

- Formulate and justify predictions based on cause-and-effect relationships.
- Conduct multiple trials to test a prediction and draw conclusions about the relationships between predictions and results.
- Construct and interpret graphs from measurements.
- Follow a set of written instructions for a scientific investigation.

Lesson #1: Kepler's Swinging System

Teacher Section

Overview: Today the students will learn first-hand how the orbital speeds of the planets differ, and why. They are again making a real scale model of the solar system, but the focus today is on orbital speeds.

Suggested Time: 30-45 minutes

Objectives: Students will get introduced to Kepler's Laws of Planetary Motion by making a scale model of the solar system and tracking orbital speeds. They will also get introduced to the idea of how to use astronomical units as measures of distance between the Sun, stars, and Earth. For advanced students, you can add in the conservation of angular momentum and conservation of energy to your discussion during the demonstration.

Materials (per lab group OR entire class)

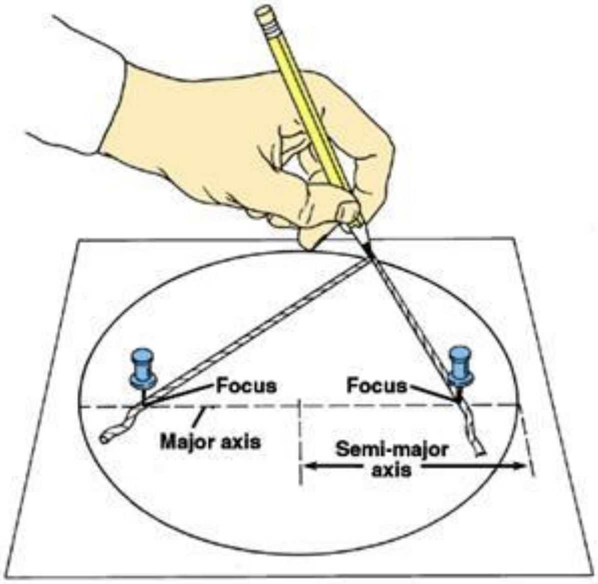
- Print outs of the planets (see Lab Preparation)
- 100' measuring tape
- Stopwatch

Lab Preparation

1. Cut out photos of the planets and objects you plan to use (refer to Lab Time for complete instructions). You'll find a complete set from NASA here: http://photojournal.jpl.nasa.gov/
2. If you can't find this long of a measuring tape, I've provided smaller versions of this lab using different measuring tape sizes. Refer to the student worksheet.
3. Print out copies of the student worksheets.
4. Read over the Background Lesson Reading before teaching this class.
5. Watch the video for this experiment to prepare for teaching this class.

Background Reading

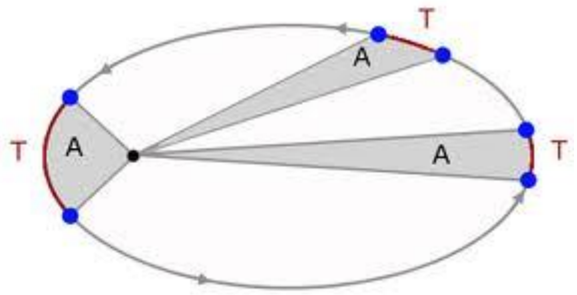
Johannes Kepler, a German mathematician and astronomer in the 1600s, was one of the key players of his time in astronomy. Among his best discoveries was the development of three laws of planetary motion. He worked for Tycho Brahe, who had logged huge volumes of astronomical data, which was later passed on to to Kepler. Kepler took this information to design and develop his ideas about the movements of the planets around the Sun.



Kepler's 1st Law states that planetary orbits about the Sun are not circles, but rather ellipses. The Sun lies at one of the foci of the ellipse. Well, almost. Newton's Laws of Motion state that the Sun can't be stationary, because the Sun is pulling on the planet just as hard as the planet is pulling on the Sun. They are yanking on each other. The planet will move more due to this pulling because it is less massive. The real trick to understanding this law is that both objects orbit around a common point that is the center of mass for both objects. If you've ever swung a heavy bag of oranges around in a circle, you know that you have to lean back a bit to balance yourself as you swing around and around. It’s the same principle, just on a smaller scale.

In our solar system the Sun has 99.85% of the mass, so the center of mass between the Sun and any other object actually lies inside the Sun (although not at the center).

Kepler's 2nd Law states that a line connecting the Sun and an orbiting planet will sweep out equal areas for a given amount of time. The planet’s speed decreases the further from the Sun it is located (actually, the speed varies inversely with the square-root of the distance, but you needn't worry about that). You can demonstrate this to the students by tying a ball to the end of a string and whirling it around in a circle. After a few revolutions, let the string wind itself up around your finger. As the string length shortens, the ball speeds up. As the planet moves inward, the planet’s orbital speed increases.



Embedded in the second law are two very important laws: conservation of angular momentum and conservation of energy. Although those laws might sound scary, they are not difficult to understand. Angular momentum is distance multiplied by mass multiplied by speed. The angular momentum for one case must be the same for the second case (otherwise it wouldn’t be conserved). As the planet moves in closer to the Sun, the distance decreases. The speed it orbits the Sun must increase because the mass doesn’t change. Just like you saw when you wound the string around your finger.

Energy is the sum of both the kinetic (moving) energy and the potential energy (this is the “could” energy, as in a ball dropped from a tower has more potential energy than a ball on the ground, because it “could” move if released). For conservation of energy, as the planet’s distance from the Sun increases, so does the gravitational potential energy. Again, since the energy for the first case must equal the energy from the second case (that’s what *conservation* means), the kinetic energy must decrease in order to keep the total energy sum a constant value.

Kepler’s 3rd Law is an equation that relates the revolution period with the average orbit speed. The important thing to note here is that mass was not originally in this equation. Newton came along shortly after and did add in the total mass of the system, which fixed the small error with the equation. This makes sense, as you might imagine a Sun twice the size would cause the Earth to orbit faster. However, if we double the mass of the Earth, it does not affect the speed with which it orbits the Sun. Why not? Because the Earth is soooo much smaller than the Sun that increasing a planet’s size generally doesn’t make a difference in the orbital speed. If you’re working with two objects about the same size, of course, then changing one of the masses absolutely has an effect on the other.

Lesson

Planet/Object	Distance from the Sun
Mercury	0.39 AU
Venus	0.72 AU
Earth	1.0 AU
Mars	1.5 AU
Ceres	2.8 AU
Jupiter	5.2 AU
Saturn	9.6 AU
Uranus	19.2 AU
Neptune	30.1 AU
Pluto	39.4 AU
Haumea	43.3 AU
Makemake	45.8 AU
Eris	67.7 AU

1. Ask your students to draw the solar system on the board. Don't correct any mistakes just yet (if any). If they still draw the planets evenly spaced apart as they did in *Lesson 3*, ask them what they learned about planet spacing from the last lab. Allow them to correct their mistakes now.
2. Here's how you get the entire solar system up on the board: Ask: "What's the largest object in the solar system"? Draw the Sun as a large circle and label it *Sun.*
3. Ask: "What are the planets in our solar system starting closest to the Sun?" Have the student write down a planet and label it with the name. Do this for each of the eight planets.
    a. Mercury is 0.39 AU (in a rocket it would take 2.7 months to go straight to Mercury from the Sun)
    b. Venus is 0.72 AU
    c. Earth is 1 AU (in a rocket it would take 7 months to go straight to Earth from the Sun)
    d. Mars is 1.5 AU
    e. Jupiter is 5.2 AU
    f. Saturn is 9.6 AU
    g. Uranus is 19.2 AU
    h. Neptune is 30.1 AU (in a rocket it would take 18 years to go straight to Neptune from the Sun)
    i. Of course, we don't travel to planets in straight lines – we use curved paths to make use of the gravitational pull of nearby objects to slingshot us forward and save on fuel.
4. Ask "Where is the asteroid belt?" and ask a student to draw and label it (between Mars and Jupiter).
5. Ask "Where is the Kuiper Belt?" and ask a student to draw and label it (beyond Neptune).
6. Ask "Where are the five dwarf planets?" Label Ceres (in the Asteroid Belt, closer to Jupiter than Mars), Pluto (is 39.44 AU from the Sun), Haumea (43.3 AU), Makemake (45.8 AU), and Eris. (67.7 AU).

Lab Time

1. Review the instructions on their worksheets and then assign students to work together so you have at least one student for each planet, one for the Sun, and two for the asteroid belts, and five for the dwarf planets. You can assign additional students to be moons of Earth (Moon), Mars (Phobos and Deimos), Jupiter (assign only 4 for the largest ones: Ganymede, Callisto, Io, and Europa), Saturn (again, assign only 4: Titan, Rhea, Iapetus, and Dione), Uranus (Oberon, Titania), and Neptune (Triton). If you still have extra students, assign one to Charon (Pluto's binary companion) and one each to Hydra and Nix, which orbit Pluto and Charon. While you ask the students to walk around in step 9, the moons can circle in orbit.
2. Walk the students outside to a very large area.
3. Hand the Sun student the measuring tape.

4. Ask Kuiper Belt student(s) to take the end of the measuring tape and begin walking slowly away from the Sun.
5. Using the data table below, with each student assigned to the distance shown, have them grab the measuring tape and walk along with it. Please be careful – measuring tapes can have sharp edges! You can also ask the Sun to call out the distances periodically so the students know when it's time to come up.
6. Ask the class what they notice about the distances between the planets.
7. Let the students know that the nearest star is 114.5 miles away!

Planet/Object	Distance from the Sun	Distance from the Sun
Mercury	10.4 inches	0.264 m
Venus	1 foot 7.4 inches	0.493 m
Earth	2 feet 2.9 inches	0.682 m
Mars	3 feet 4.9 inches	1.039 m
Jupiter	11 feet 7.76 inches	3.649 m
Saturn	21 feet 4.3 inches	6.51 m
Uranus	42 feet 11.5 inches	13.094 m
Neptune	67 feet 4.2 inches	20.529 m
Pluto (dwarf planet)	88 feet 6 inches	36.975 m
Nearest Star: Alpha Centauri	114.5 miles	184.2 km

8. Ask the students to let go of the measuring tape, except for Neptune and the Sun. Everyone else gathers around you (a safe distance away, as Neptune is going to orbit the Sun).
9. Using a stopwatch, show the students how to time as Neptune walks around the Sun while holding the measuring tape taut. How long did it take for one revolution? Record it in the data table.
10. Now ask Mercury to take their position on the tape at the appropriate distance. Time their revolution as they walk around the Sun. How long did it take? Record this in your data table.
11. Demonstrate Kepler's 2nd Law to the students by tying a ball to the end of a string and whirling it around in a circle. After a few revolutions, let the string wind itself up around your finger. As the string length shortens, the ball speeds up. As the planet moves inward, the planet's orbital speed increases. The planet's speed decreases the further from the Sun it is located. Ask them how this relates to the data you just recorded for Neptune and Mercury. They should notice that the speeds the kids were walking at were probably nearly the same, but the time was much shorter for Mercury. Let them know that if you could swing them around (instead of having them walk), they could see how this would make Mercury orbit at a faster speed than Neptune.
12. Now ask one of the bigger students to take their position with the measuring tape, reminding them to keep the tape taut no matter what happens. When they start to walk around the Sun, have the Sun move with them a bit (a couple of feet is good). Let the students know that the planet also yanks on the Sun just as hard as the Sun yanks on the planet. Since the planet is much smaller than the Sun, you won't see as much motion with the Sun.
13. Take a heavy bag (I like to use oranges) and ask a kid to spin it around as they whirl around in a circle. Ask the rest of the kids if they notice the student leaning back a bit to balance themselves as they swing around and around. Let them know that it's the same principle, just on a smaller scale. The two objects (the bag and

the student) are orbiting around a common point, called the center of mass. In our real solar system, the Sun has 99.85% of the mass, so the center of mass lies inside the Sun (although not at the exact center).

14. You can now break the students into their lab groups to complete the rest of this activity. While you ask the students to walk around in step 9, the moons (if you have assigned them) can circle in orbit (although this may affect your data). If you prefer, you can assign one student to record the data while you all proceed to complete the data table together.

Solar System Measuring Tape Data Tables

Planet/Object	Distance from the Sun	Distance from the Sun	Time for 1 Revolution *(seconds)*
Mercury	10.4 inches	0.264 m	
Venus	1 foot 7.4 inches	0.493 m	
Earth	2 feet 2.9 inches	0.682 m	
Mars	3 feet 4.9 inches	1.039 m	
Jupiter	11 feet 7.76 inches	3.649 m	
Saturn	21 feet 4.3 inches	6.51 m	
Uranus	42 feet 11.5 inches	13.094 m	
Neptune	67 feet 4.2 inches	20.529 m	
Pluto (dwarf planet)	88 feet 6 inches	36.975 m	

Exercises

1. If the Sun is not stationary in the center but rather gets tugged a couple of feet as the planet yanks on it, how do you think this will affect the planet's orbit? (In reality, the planets do not travel in a circle, but rather an ellipse, and the Sun is actually not at the center but at one of the foci of the ellipse. The Sun also moves around due to the planets yanking on it. The result is that the orbiting planet will speed up as it gets closer to the Sun and slow down when it moves away from the Sun.)
2. If we double the mass of Mars, how do you think this will affects the orbital speed? (Not at all. If we doubled the mass of the Sun, Mars *would* orbit faster. However, if we double the mass of Mars, it does not affect the speed that it orbits the Sun with because Mars is much smaller than the Sun.)
3. If Mercury's orbit is normally 88 Earth days, how long do you estimate Neptune's orbit to be? (165 Earth years.)

Closure Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Lesson #1: Kepler's Swinging System

Student Worksheet

Name____

Overview Kepler's Laws of Planetary Motion explain why the planets move at the speeds they do. You'll be making a scale model of the solar system and tracking orbital speeds.

What to Learn Kepler's 1st Law states that planetary orbits about the Sun are not circles, but rather ellipses. The Sun lies at one of the foci of the ellipse. Kepler's 2nd Law states that a line connecting the Sun and an orbiting planet will sweep out equal areas in for a given amount of time. Translation: the further away a planet is from the Sun, the slower it goes.

Materials

- 100' measuring tape
- Stopwatch

Lab Time

1. Look at the length of your measuring tape. Find the data table you need to use in the tables below. Circle the one you're going to use or cross out the ones you're not. Copy the distance from the Sun into the first data table below.
2. Your teacher will do the first part of this lab with you. Complete this before moving to the next step.
3. When you're asked to finish the data recording, figure out who is going to be Venus and who's going to be the Sun.
4. Using a stopwatch, time Venus as they walk around the Sun while holding the measuring tape taut. How long did it take for one revolution? Write this in the data table below. (Make sure the Sun doesn't move much during this process like they did for the demonstration. We're assuming the Sun is at the center when we take our data.)
5. Continue this for all the planets.

Solar System Measuring Tape Data Tables

Planet/Object	**Distance from the Sun** (inches)	**One Revolution Time** (sec)
Mercury		
Venus		
Earth		
Mars		
Jupiter		
Saturn		
Uranus		
Neptune		
Pluto (dwarf planet)		

Solar System Measuring Tape Data Tables

For 100 foot / 50 m measuring tapes:

Planet/Object	Distance from the Sun	Distance from the Sun
Mercury	10.4 inches	0.264 m
Venus	1 foot 7.4 inches	0.493 m
Earth	2 feet 2.9 inches	0.682 m
Mars	3 feet 4.9 inches	1.039 m
Jupiter	11 feet 7.76 inches	3.649 m
Saturn	21 feet 4.3 inches	6.51 m
Uranus	42 feet 11.5 inches	13.094 m
Neptune	67 feet 4.2 inches	20.529 m
Pluto (dwarf planet)	88 feet 6 inches	36.975 m
Nearest Star: Alpha Centauri	114.5 miles	184.2 km

For 35+ foot/ 10+ m measuring tapes (note the fractions for the US unit system):

Planet/Object	Distance from the Sun	Distance from the Sun
Mercury	4 ⅛ inches	0.105 m
Venus	7 ¾ inches	0.197 m
Earth	10 ¾ inches	0.272 m
Mars	1 foot 4 ⅜ inches	0.415 m
Jupiter	4 feet 8 inches	1.419 m
Saturn	8 feet 6 ½ inches	2.604 m
Uranus	17 feet 2 ¼ inches	5.237 m
Neptune	26 feet 11 ¼ inches	8.211 m
Pluto (dwarf planet)	35 feet 11 ¼ inches	10.79 m
Nearest Star: Alpha Centauri	45.8 miles	73.7 km

For 25 foot / 10 m measuring tapes:

Planet/Object	Distance from the Sun	Distance from the Sun
Mercury	2.9 inches	0.074 m
Venus	5.4 inches	0.138 m
Earth	7.5 inches	0.191 m

Mars	11.5 inches	0.291 m
Jupiter	3 feet 3.1 inches	0.993 m
Saturn	5 feet 11.8 inches	1.822 m
Uranus	12 feet 0.4 inches	3.666 m
Neptune	18 feet 10.3 inches	5.748 m
Pluto (dwarf planet)	24 feet 9.4 inches	7.553 m
Nearest Star: Alpha Centauri	32 miles	51.6 km

For yard-sticks / meter-sticks (This chart is not recommended for this experiment, but really just to demonstrate the planetary spacing).

Planet/Object	Distance from the Sun	Distance from the Sun
Mercury	0.37 inches	9 mm
Venus	0.69 inches	17 mm
Earth	0.96 inches	24 mm
Mars	1.47 inches	37 mm
Jupiter	5.03 inches	0.127 m
Saturn	9.22 inches	0.234 m
Uranus	1 foot 6.55 inches	0.471 m
Neptune	2 feet 5.06 inches	0.739 m
Pluto (dwarf planet)	3 feet 2.23 inches	0.971 m
Nearest Star: Alpha Centauri	4.1 miles	6.6 km

For rulers (This chart is not recommended for this experiment, but really just to demonstrate the planetary spacing).

Planet/Object	Distance from the Sun	Distance from the Sun
Mercury	0.11 inches	2 mm
Venus	0.21 inches	5 mm
Earth	0.30 inches	7 mm
Mars	0.45 inches	11 mm
Jupiter	1.56 inches	3.9 cm
Saturn	2.87 inches	7.2 cm
Uranus	5.77 inches	14.6 cm
Neptune	9.05 inches	22.9 cm
Pluto (dwarf planet)	11.89 inches	30.2 cm
Nearest Star: Alpha Centauri	1.2 miles	2 km

Exercises Answer the questions below:

1. If the Sun is not stationary in the center but rather gets tugged a couple of feet as the planet yanks on it, how do you think this will affect the planet's orbit?
2. If we double the mass of Mars, how do you think this will affects the orbital speed?
3. If Mercury's orbit is normally 88 Earth days, how long do you estimate Neptune's orbit to be?

Lesson #2: Earth's Magnetic Pulse

Teacher Section

This is a Bonus Lab, meaning that it's in addition to the experiments the kids get to do throughout the course. Feel free to skip this lab if the materials are out of your budget, or save it as a treat for the end of the year. You can also just make one and use it as a demo piece to keep in your classroom, because once it's set up, it goes forever.

Overview: When you stare at a compass, the needle that indicates the magnetic field from the Earth appears to stand still, but we're going to find how it fluctuates and moves by creating a super-sensitive instrument using everyday materials (for comparison, you would spend more than $100 for a scientific instrument that does the same thing).

Suggested Time: 30-45 minutes

Objectives: Kids will learn how to amplify tiny pulses in the Earth's magnetic field using a laser.

Materials (per lab group)

- Index card or scrap of cardboard
- 2 small mirrors
- 2 rare earth magnets
- Nylon filament (thin nylon thread works, too)
- 4 doughnut magnets
- Laser pointer (any kind will work – even the cheap key-chain type)
- Clean glass jar (pickle, jam, mayo, etc… any kind of jar that's heavy so it won't knock over easily)
- Wooden spring-type clothespin
- Hot glue gun, scissors and tape

Lab Preparation

1. Print out copies of the student worksheets.
2. Watch the video for this experiment to prepare for teaching this class.
3. Read over the Background Lesson Reading before teaching this class.
4. Precut the nylon twine into 12" pieces, one for each lab group.

Background Lesson Reading

The reason this project works is because of tiny magnetic disturbances caused by the ripples in the ionosphere. Although these disturbances happen all the time and on a very small scale (usually only 1/10,000th of the Earth's magnetism strength), we'll be able to pick them up using this incredibly simple project. Your reflected laser beam acts like an amplifier and picks up the movement from the magnet in the glass.

Construction tip for experiment: You need to use a filament that doesn't care how hot or humid it is outside, so using one of the hairs from your head definitely won't work. Cotton tends to be too stretchy as well. Professionals use fine quartz fibers (which are amazingly strong and really don't care about temperature or humidity). Try extracting a single filament from a multi-stranded nylon twine length about 30″ long. If you happen to have a fine selection of nylon twine handy, grab the one that is about 25 microns (0.01″) thick. Otherwise, just get the thinnest one you can find.

Also, note that big, powerful magnets will not respond quickly, so you need a lightweight, powerful magnet. Try finding a set of rare earth magnets from Radio Shack or the hardware store.

You can walk around with your new instrument and you'll find that it's as accurate as a compass and will indicate north. You probably won't see much oscillation as you do this. Because the Earth has a large magnetic field, you have to "tare" the instrument (set it to "zero") so it can show you the smaller stuff. Use the doughnut magnets about 30 centimeters away as shown in the video.

Lesson

1. You can tape a wooden clothespin down to the table and insert your laser pointer inside – the jaws will push the button of the laser down so you can watch your instrument and take your measurements. When you're ready, tape a sheet of paper to the wall where your reflected beam (reflected from the mirror, not the glass … there will be two reflected beams!) hits the wall and mark where it hits. Over periods of seconds to minutes, you'll see deflections and oscillations (wiggles back and forth) – you are taking the Earth's magnetic pulse!
2. In order for this experiment to work properly, ALL magnets (including the penny described below) need to be in the same plane. That is, they all need to be the same height from the ground. You can, of course, rotate the entire setup 90 degrees to investigate the magnetic ripples in the other planes as well!
3. To make this instrument even *more* sensitive, glue a copper penny (make sure it's minted before 1982, or you'll get an alloy, not copper, penny) to the glass jar just *behind* the magnets (opposite the laser). When your magnets move now, they will induce eddy currents in the penny that will induce a (small) magnetic field opposite of the rotation of the magnets to dampen out "noise" oscillation. In short, add a penny to the glass to make your instrument easier to read.

Lab Time

1. Review the instructions on their worksheets and then break the students into their lab groups. Hand each group their materials.
2. Watch the video first and make a sample. Here are the steps from the video:
3. Sandwich the twine between the two rare earth magnets. These are the stronger magnets.
4. Use a tiny dab of glue on one of the magnets and attach a mirror to the magnet. Do this on the other side for the second magnet and mirror.
5. Lower the mirror-magnets into the container, leaving it hanging an inch above the bottom of the jar. Cut the twine at the mouth level of the container.
6. Glue the top of the twine to the bottom of the lid, right in the center.
7. When the glue has dried, place your mirror-magnets inside the jar and close the lid. Make sure that the mirror-magnets don't touch the side of the jar, and are free to rotate and move.
8. You've just built a compass! The small magnets will align with the Earth's magnetic field. Slowly rotate the jar, and watch to see that the mirror-magnets inside always stay in the same configuration, just like the needle of a standard compass.
9. Set your new compass aside and don't touch it. You want the mirror-magnets to settle down and get very still.
10. You are going to build the magnet array now. Stack your four doughnut magnets together in a tall stack.

11. Fold your index card in half, and then open it back up. On one side of the crease you're going to glue your magnets. When the magnets are attached, you'll fold the card over so that it sits on the table like a greeting card with the magnets facing your glass jar.
12. Tape your index card down to the table as you build your magnet array. (Otherwise the paper will jump up midway through and ruin your gluing while you are working.)
13. Place a strip of glue on the bottom magnet of your stack and press it down onto the paper, gluing it into place.
14. Lift the stack off (the bottom magnet should stay put on the paper) and place glue on the bottom magnet. Glue this one next to the first.
15. Continue with the array so you have a rectangle (or square) arrangement of magnets with their poles oriented the same way. Don't flip the magnets as you glue them, or you'll have to start over to make sure they are lined up right.

Since we live in a gigantic magnetic field that is 10,000 times more powerful than what the instrument is designed to measure, we have to "zero out" the instrument. It's like using the "tare" or "zero" function on a scale. When you put a box on a scale and push "zero," then the scale reads zero so it only measures what you put in the box, not including the weight of the box, because it's subtracting the weight of the box out of the measurement. That's what we're going to do with our instrument: We need to subtract out the Earth's magnetic field so we just get the tiny fluctuations in the field.

16. Place your instrument away from anything that might affect it, like magnets or anything made from metal.
17. Fold the card back in half and stand it on the table. We're normally going to keep the array away from the jar, or the magnet array will influence the mirror-magnets just like bringing a magnet close to a compass does. But to zero out our instrument, we need to figure out how far away the array needs to be in order to cancel out the Earth's field.
18. Bring the array close to your jar. You should see the mirror-magnets align with the array.
19. Slowly pull the magnet array away from the compass to a point where if it were any closer, the mirror-magnets would start to follow it, but any further away and nothing happens. It's about 12 inches away. Measure this for your experiment and write it on your array or jar so you can quickly realign if needed in the future.
20. Insert your laser pointer into the clothespin so that the jaws push the button and keep the laser on. Place it at least the same distance away as the array. You might have to prop the laser up on something to get the height just right so you can aim the laser so that it hits the mirror inside. (Note that you'll have a reflection from the glass as well, but it won't be nearly as bright.)
21. Find where the laser beam is reflected off the mirror and hits the wall in your room. Walk over and tape a sheet of paper so that the dot is in the middle of the paper. Use a pen and draw right on top of the dot, and mark it with today's date.
22. Do you notice if it moves or if it stays put? Sometimes the dot will move over time, and other times the dot will wiggle and move back and forth. The wiggles will last a couple of seconds to a couple of minutes, and those are the oscillations and fluctuations you are looking for!
23. Tape a ruler next to the dot so you can measure the amount of motion that the dot makes. Does it move a lot or a little when it wiggles? Two inches or six?

Exercises

1. Does the instrument work without the magnet array? (Yes, but only as a compass.)
2. Why did we use the stronger magnets inside the instrument? (Small lightweight magnets are needed to be used to move the mirrors and detect the fluctuations.)
3. Which planet would this instrument probably not work on? (Venus and Mars)

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Lesson #2: Earth's Magnetic Pulse

Student Worksheet

Name____

Overview: When you stare at a compass, the needle that indicates the magnetic field from the Earth appears to stand still, but we're going to find how it fluctuates and moves by creating a super-sensitive instrument using everyday materials (for comparison, you would spend more than $100 for a scientific instrument that does the same thing).

What to Learn: Today you get to learn how to amplify tiny pulses in the Earth's magnetic field using a laser and a couple of magnets. It's a very cool experiment, but it does take patience to make it work right. Deep breath … are you ready?

Materials

- Index card or scrap of cardboard
- 2 small mirrors
- 2 rare earth magnets
- Nylon filament (thin nylon thread works, too)
- 4 doughnut magnets
- Laser pointer (any kind will work – even the cheap key-chain type)
- Clean glass jar (pickle, jam, mayo, etc… any kind of jar that's heavy so it won't knock over easily)
- Wooden spring-type clothespin
- Hot glue gun, scissors and tape

Lab Time

1. Sandwich the twine between the two rare earth magnets. These are the stronger magnets.
2. Use a tiny dab of glue on one of the magnets and attach a mirror to the magnet. Do this on the other side for the second magnet and mirror.
3. Lower the mirror-magnets into the container, leaving it hanging an inch above the bottom of the jar. Cut the twine at the mouth level of the container.
4. Glue the top of the twine to the bottom of the lid, right in the center.
5. When the glue has dried, place your mirror-magnets inside the jar and close the lid. Make sure that the mirror-magnets don't touch the side of the jar, and are free to rotate and move.
6. You've just built a compass! The small magnets will align with the Earth's magnetic field. Slowly rotate the jar, and watch to see that the mirror-magnets inside always stay in the same configuration, just like the needle of a standard compass.
7. Set your new compass aside and don't touch it. You want the mirror-magnets to settle down and get very still.
8. You are going to build the magnet array now. Stack your four doughnut magnets together in a tall stack.
9. Fold your index card in half, and then open it back up. On one side of the crease you're going to glue your magnets. When the magnets are attached, you'll fold the card over so that it sits on the table like a greeting card with the magnets facing your glass jar.

10. Tape your index card down to the table as you build your magnet array. (Otherwise the paper will jump up midway through and ruin your gluing while you are working.)
11. Place a strip of glue on the bottom magnet of your stack and press it down onto the paper, gluing it into place.
12. Lift the stack off (the bottom magnet should stay put on the paper) and place glue on the bottom magnet. Glue this one next to the first.
13. Continue with the array so you have a rectangle (or square) arrangement of magnets with their poles oriented the same way. Don't flip the magnets as you glue them, or you'll have to start over to make sure they are lined up right.

Since we live in a gigantic magnetic field that is 10,000 times more powerful than what the instrument is designed to measure, we have to "zero out" the instrument. It's like using the "tare" or "zero" function on a scale. When you put a box on a scale and push "zero", then the scale reads zero so it only measures what you put in the box, not including the weight of the box, because it's subtracting the weight of the box out of the measurement. That's what we're going to do with our instrument: we need to subtract out the Earth's magnetic field so we just get the tiny fluctuations in the field.

14. Place your instrument away from anything that might affect it, like magnets or anything made from metal.
15. Fold the card back in half and stand it on the table. We're normally going to keep the array away from the jar, or the magnet array will influence the mirror-magnets just like bringing a magnet close to a compass does. But to zero out our instrument, we need to figure out how far away the array needs to be in order to cancel out the Earth's field.
16. Bring the array close to your jar. You should see the mirror-magnets align with the array.
17. Slowly pull the magnet array away from the compass to a point where if it were any closer, the mirror-magnets would start to follow it, but any further away and nothing happens. It's about 12 inches away. Measure this for your experiment and write it on your array or jar so you can quickly realign if needed in the future.
18. Insert your laser pointer into the clothespin so that the jaws push the button and keep the laser on. Place it at least the same distance away as the array. You might have to prop the laser up on something to get the height just right so you can aim the laser so that it hits the mirror inside. (Note that you'll have a reflection from the glass as well, but it won't be nearly as bright.)
19. Find where the laser beam is reflected off the mirror and hits the wall in your room. Walk over and tape a sheet of paper so that the dot is in the middle of the paper. Use a pen and draw right on top of the dot, and mark it with today's date.
20. Do you notice if it moves or it is stays put? Sometimes the dot will move over time, and other times the dot will wiggle and move back and forth. The wiggles will last a couple of seconds to a couple of minutes, and those are the oscillations and fluctuations you are looking for!
21. Tape a ruler next to the dot so you can measure the amount of motion that the dot makes. Does it move a lot or a little when it wiggles? Two inches or six?

Exercises

Answer the questions below:

1. Does the instrument work without the magnet array?

2. Why did we use the stronger magnets inside the instrument?

3. Which planet would this instrument probably not work on?

Lesson #3: Retrograde Motion

Teacher Section

Overview: Three planets, Mars, Mercury, and Venus, appear to move backward in the sky when tracked night after night. This motion is called "retrograde motion" and has baffled scientists for years. Students are going to learn first-hand how this motion is possible by dipping into orbital mechanics.

Suggested Time: 30-45 minutes

Objectives: The planets move at different rates and each have their own orbit path, no two of which are the same size. Because of this, planets play catch-up with each other, and when they speed past quickly, the other planet appears to stop and move backward. The bottom line: It's just an illusion.

Materials (per lab group)

- Pencil
- Ruler

Lab Preparation

1. Start this lab as a demonstration, with you demonstrating and showing the kids the videos shown here.
2. Print out copies of the student worksheets.
3. Read over the Background Lesson Reading before teaching this class.
4. Watch the video for this experiment to prepare for teaching this class.

Background Lesson Reading

If you watch the Moon, you'd notice that it rises in the east and sets in the west. This direction is called "prograde motion." The stars, Sun, and Moon all follow the same prograde motion, meaning that they all move across the sky in the same direction.

However, at certain times of the orbit, certain planets move in "retrograde motion," the opposite way. Mars, Venus, and Mercury all have retrograde motions that have been recorded for as long as we've had something to write with. While most of the time, they spend their time in the "prograde" direction, you'll find that sometimes they stop, go backward, stop, and then go forward again, all over the course of several days to weeks.

It's like going down a racetrack on the inside curve. You pass the outside car quickly, and from your point of view, they seem to be moving backward as you pass them.

Here are videos I created that show you what this would look like if you tracked their position in the sky each night for a year or two.

Mercury and Venus Retrograde Motion

This is a video that shows the retrograde motion of Venus and Mercury over the course of several years. Venus is the dot that stays centered throughout the video (Mercury is the one that swings around rapidly), and the bright dot is the Sun. Note how sometimes the trace lines zigzag, and other times they loop. Mercury and Venus never get far from the Sun from Earth's point of view, which is why you'll only see Mercury in the early dawn or early evening.

Retrograde Motion of Mars

You've probably heard of epicycles people used to use to help explain the retrograde motion of Mars. Have you ever wondered what the fuss was all about? Here's a video that traces out the path Mars takes over the course of several years. Do you see our Moon zipping by? The planets, Sun, and Moon all travel along a line called the "ecliptic," as they all are in about the same plane.

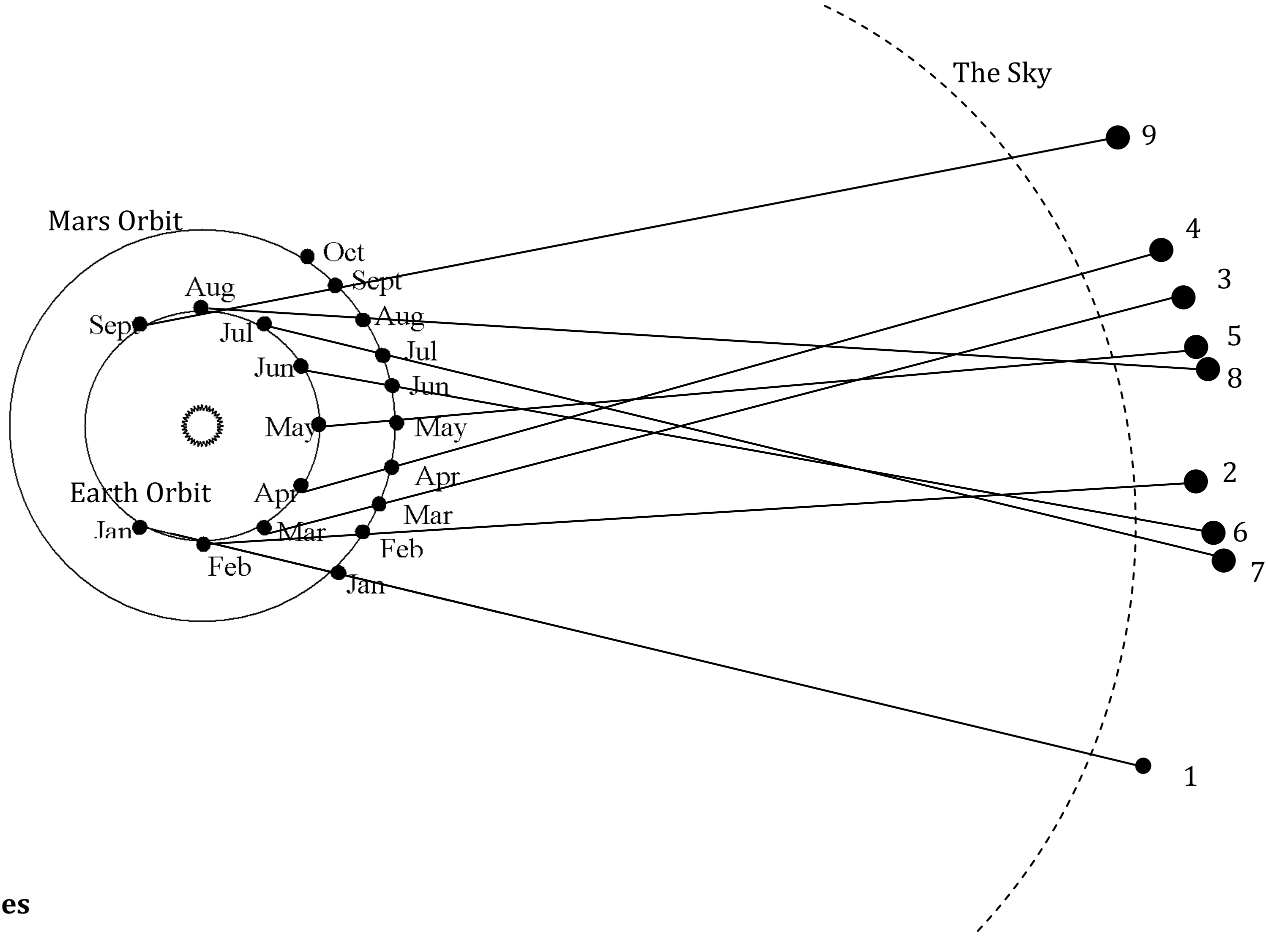
Several planets found outside our solar system (called extrasolar planets) have backward orbits. This isn't retrograde motion, just plain old backward … something we've never seen before in our search for extrasolar planets!

Lesson

1. Share the videos with your students and explain to them what they are watching from the Background Reading section.
2. Mars retrogrades for 72 days every 25.6 months, Jupiter for 121 days every 13.1 months, Saturn for 138 days every 12.4 months, Uranus for 151 days every 12.15 months, and Neptune for 158 days every 12.07 months.

Lab Time

1. Review the instructions on their worksheets and then break the students into their lab groups.
2. Hand each group their materials and give them time to perform their experiment and write down their observations.
3. Look at the diagram below. The tiny center circle (without any dots) is the Sun. The inner circle is the Earth's orbit, and the other circle is the orbit of Mars. The dots show where Mars and the Earth are each month. The dashed line is the sky we'd see on Earth.
4. I've already drawn a line with my ruler connecting the two January dots. (I know it also went through February, but that's because it just happened to be there.)
5. Take your ruler and connect the two dots for February. Make sure to extend your lines a little past the sky before labeling the end of the line with a 2.
6. Do this for each month, connecting the dots starting with the inner Earth circle month to the corresponding Mars circle month. The March months should have a 3 label at the end.
7. If you find that your lines cross, make the lines a little longer and make the dots further away so you can tell which number goes with which line.
8. Now for the fun part: play "connect the dots" with the numbered dots in the sky. Start with the 1, and carefully connect your dots in order. This line is the path that Mars will follow when you look at it from Earth.



Exercises

1. During which months does Mars move in retrograde? (Between April and July)
2. Why does Mars appear to move backward? (As the Earth passes Mars more quickly, Mars appears to slow down, stop, and reverse direction.)
3. Which planets have retrograde motion? (All planets.)

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Lesson #3: Retrograde Motion

Student Worksheet

Name____

Overview: Three planets, Mars, Mercury, and Venus, appear to move backward in the sky when tracked night after night. This motion is called "retrograde motion" and has baffled scientists for years.

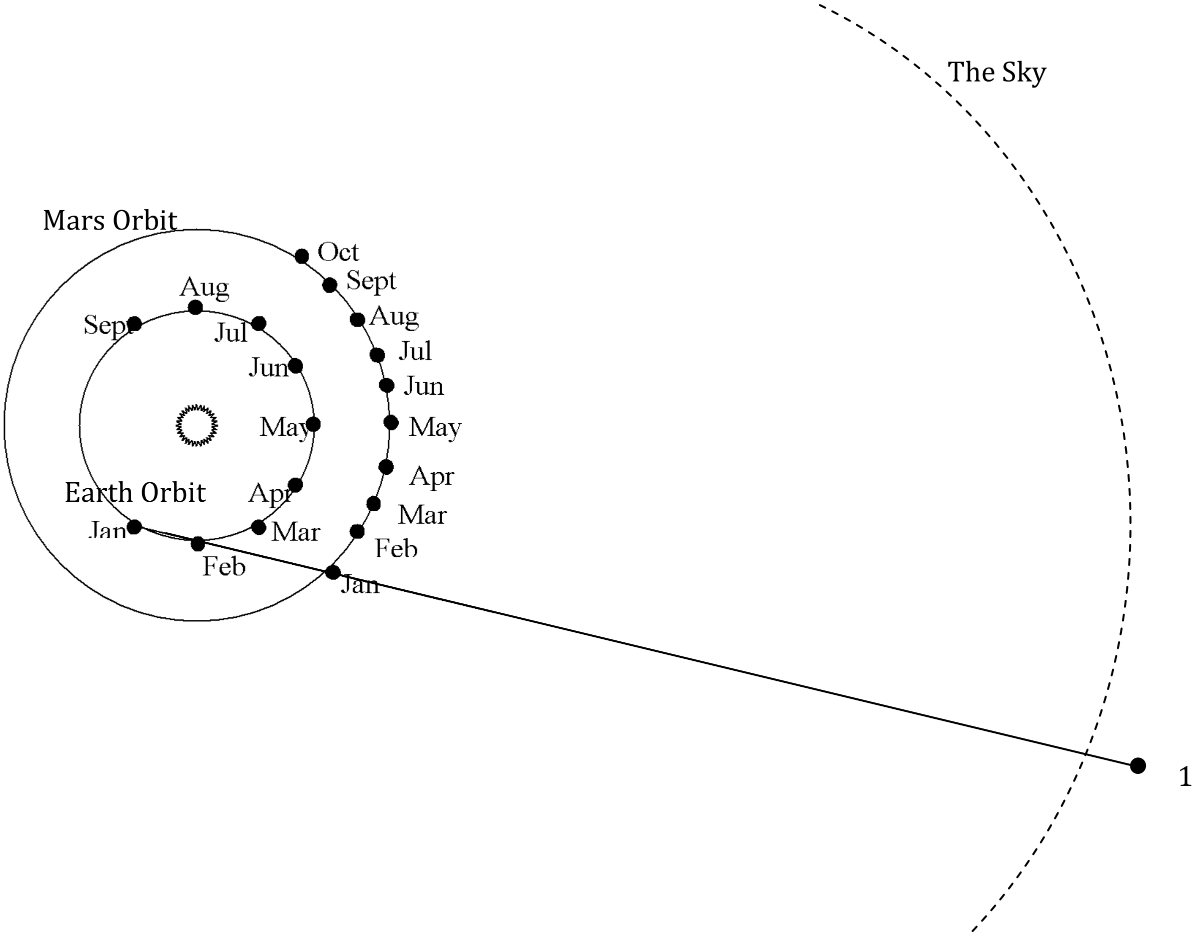
What to Learn: From a top view of the solar system, the planets appear to move around the Sun in an orderly fashion. The real chaos comes in when you place yourself on one of these planets and try to watch the path that the others take while you're orbiting the Sun. It's predictable chaos, though, with enough math and physics under your belt (like in college). Today you're just going to get a sneak peek at the wild world of orbital mechanics.

Materials

- Pencil
- Ruler

Lab Time

1. Review the instructions on their worksheets and then break the students into their lab groups.
2. Hand each group their materials and give them time to perform their experiment and write down their observations.
3. Look at the diagram on the next page. The tiny center circle (without any dots) is the Sun. The inner circle is the Earth's orbit, and the other circle is the orbit of Mars. The dots show where Mars and the Earth are each month. The dashed line is the sky we'd see on Earth.
4. I've already drawn a line with my ruler connecting the two January dots. (I know it also went through February, but that's because it just happened to be there.)
5. Take your ruler and connect the two dots for February. Make sure to extend your lines a little past the sky before labeling the end of the line with a 2.
6. Do this for each month, connecting the dots starting with the inner Earth circle month to the corresponding Mars circle month. The March months should have a 3 label at the end.
7. If you find that your lines cross, make the lines a little longer and make the dots further away so you can tell which number goes with which line.
8. Now for the fun part: Play "connect the dots" with the numbered dots in the sky. Start with the 1, and carefully connect your dots in order. This line is the path that Mars will follow when you look at it from Earth.



Exercises Answer the questions below:

1. During which of the months does Mars appear to move in retrograde?
2. Why does Mars appear to move backward?
3. Which planets have retrograde motion?

Lesson #4: Rocket Math

Teacher Section

Overview: Launching rockets requires a lot complicated math, but it all starts with Newton's Laws of Motion. We're going to get a taste of the math behind the real rocket science.

Suggested Time: 30-45 minutes

Objectives: Using math with rocket science experiments allow scientists to figure out important information about the rocket structure, flight, and performance before it ever leaves the ground.

Materials

- Pencil
- Paper
- Rocket or ball
- Measuring tape
- Stopwatch

Lab Preparation

1. Print out copies of the student worksheets.
2. Read over the Background Lesson Reading before teaching this class.
3. Watch the video for this experiment to prepare for teaching this class.
4. This lab is best done outdoors, since kids are throwing balls in the air.

Background Reading: Rockets are more complicated than it might first seem. For example, as a rocket burns through its fuel, it gets lighter, which makes it easier to move through the atmosphere. Also the pressure inside the combustion chamber must be higher than the outside pressure in order for the gases to escape and push out through the nozzle, which is helped by the fact that as a rocket moves up through the atmosphere, there's less and less atmosphere for it to move through (which also means the drag force decreases). All of these things increase the acceleration (how fast speed changes when moving in a straight line) of the rocket.

Newton's Second Law can be formally stated as the acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

Whew… that's a lot to remember, isn't it? Let's try a math equation instead that says the same thing: $\mathbf{F_{net} = m\ a}$

> $\mathbf{F_{net}}$ **are the forces acting on the rocket.** This includes weight, drag, thrust and lift for flying objects.
>
> **m is the mass of the rocket.** Remember, this is changing as the rocket burns through its fuel.
>
> **a is the acceleration of the rocket.** That's how fast the rocket is changing speed if it's going in a straight line.
>
> **Note:** If you've never heard of net force before, know that it is the vector sum of all the forces acting on the object. A rocket has a force on it due to its weight, which points toward the center of the Earth. There's also

a force on the rocket from the atmosphere called drag, and it acts in the opposite direction to the motion of the rocket. There's another force due from the gases exiting the nozzle, and those act in the direction of the motion of the rocket. This part isn't really important for today's lesson, but keep it in mind for later.

The equations that describe Newton's Laws of Motion can be used to figure out how fast your rocket traveled based on the distance and the time you measure during its flight. You can also find out how high your rocket flew by using another set of equations. While normally these equations are reserved for high school physics students who usually have to figure out where they came from, I'm going to give you a taste of what it's really like to use math during a science experiment.

Don't worry too much about these questions or where they came from. Just use them as I've described below and in the video so you can see how a real scientist uses math to model what's going on with their rocket.

Lab Time:

Kids are about to do learn how to use math to find the speed and forces on rockets.
IMPORTANT: use the same rocket for the entire data table!

Also important: measure in meters for distance and measure seconds for time.

1. Have the kids find their best rocket (or ball) and practice launching it a couple of times.
2. Launch the rocket horizontally. Use a measuring tape and find how far the rocket flew and a stopwatch to time how long it was in flight. Record this in the data table. They are going to estimate the speed of the rocket by using the equation: speed = distance ÷ time.
3. Now launch the rocket vertically. (Make sure they are lying flat on their back on the ground when launching.) Use a stopwatch to find out how long it took the rocket to hit the ground. They are going to estimate how high the rocket flew by taking the time measured, dividing it by two (since the rocket went both up and down, we cut that time in half to find the time it took to go from its greatest height to hit the ground), and using the question: distance = $\frac{1}{2} gt^2$. The term "g" is 9.81 m/s^2.
4. Use the data table to track results and analyze the rocket, just like a real scientist!

Tip: There is a simple test you can do to test to see if your rocket is stable. Tie a string around the body at the center of gravity (CG) point. (For a model rocket, make sure you've prepared it for launch, so the engine, wadding and parachute are on board.) Swing the rocket around your head in a circle. The nose points in the direction of rotation for a stable rocket. Unstable rockets will wobble, spin sideways, or go tail-first. You can fix any stability problems by lowering the center of pressure (make the fins bigger) or by moving the CG forward (adding weight to the nose).

Going Further: If you're a real math nut like I am, here's Newton's Second Law rewritten for a rocket moving through the atmosphere: $F_{net} = m_{exit}V_{exit} + (P_{exit}-P_{ambient})\, A_{exit}$

The "A" in the above equation is the area of the engine "throat" or the smallest area of the nozzle where gases are rushing through. The "P" terms are the difference in pressure between the outside air and the pressure of the gases exiting the nozzle. When the rocket finally reaches space, the difference in pressure goes to zero, so the equation then becomes: $F_{net} = m_{exit}V_{exit}$

Things to think about: Looking at rocketry from the math side of things, how could you generate enough thrust so that the amount of thrust is greater than the weight of the rocket? How big would that rocket need to be? What happens when the rocket burns through its tanks unevenly? How does the CG change in a rocket that is burning fuel? How can you make the rocket go where you want it to, and return the parts you need safely back to earth?

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Lesson #4: Rocket Math

Student Worksheet

Name____

Overview: Launching rockets requires a lot complicated math, but it all starts with Newton's Laws of Motion. We're going to get a taste of the math behind the real rocket science.

What to Learn: Using math with rocket science experiments allow scientists to figure out important information about the rocket structure, flight, and performance before it ever leaves the ground.

Materials

- Pencil
- Paper
- Rocket or ball
- Measuring tape
- Stopwatch

Background Reading: Rockets are more complicated than it might first seem. For example, as a rocket burns through its fuel, it gets lighter, which makes it easier to move through the atmosphere. Also the pressure inside the combustion chamber must be higher than the outside pressure in order for the gases to escape and push out through the nozzle, which is helped by the fact that as a rocket moves up through the atmosphere, there's less and less atmosphere for it to move through (which also means the drag force decreases). All of these things increase the acceleration (how fast speed changes when moving in a straight line) of the rocket.

Lesson:

Newton's Second Law can be formally stated as the acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

Whew… that's a lot to remember, isn't it? Let's try a math equation instead that says the same thing: $\mathbf{F_{net} = m\ a}$

F_{net} are the forces acting on the rocket. This includes weight, drag, thrust and lift for flying objects.

m is the mass of the rocket. Remember, this is changing as the rocket burns through its fuel.

a is the acceleration of the rocket. That's how fast the rocket is changing speed if it's going in a straight line.

Note: If you've never heard of net force before, know that it is the vector sum of all the forces acting on the object. A rocket has a force on it due to its weight, which points toward the center of the Earth. There's also a force on the rocket from the atmosphere called drag, and it acts in the opposite direction to the motion of the rocket. There's another force due from the gases exiting the nozzle, and those act in the direction of the motion of the rocket. This part isn't really important for today's lesson, but keep it in mind for later.

The equations that describe Newton's Laws of Motion can be used to figure out how fast your rocket traveled based on the distance and the time you measure during its flight. You can also find out how high your rocket flew by using another set of equations. While normally these equations are reserved for high school physics students who usually have to figure out where they came from, I'm going to give you a taste of what it's really like to use math during a science experiment.

Don't worry too much about these questions or where they came from. Just use them as I've described in the video so you can see how a real scientist uses math to model what's going on with their rocket.

Lab Time:

You're about to do learn how to use math to find the speed and forces on one of your rockets.
IMPORTANT: use the same rocket for the entire data table!

Also important: measure in meters for distance and measure seconds for time.

1. Find your best rocket and practice launching it a couple of times.
2. Launch your rocket horizontally. Use your measuring tape and find how far your rocket flew and a stopwatch to time how long it was in flight. Record this in your data table. You are going to estimate the speed of the rocket by using the equation: speed = distance ÷ time.
3. Now launch your rocket vertically. (Make sure you're lying flat on your back on the ground when you launch.) Use your stopwatch to find out how long it took your rocket to hit the ground. You are going to estimate how high your rocket flew by taking the time you measured, dividing it by two (since the rocket went both up and down, we cut that time in half to find the time it took to go from its greatest height to hit the ground), and using the question: distance = $\frac{1}{2} gt^2$. The term "g" is 9.81 m/s^2.
4. Use the data table to track your results and analyze your rocket, just like a real scientist!

Rocketry Data Table: Horizontal Flight

Trial #	**Distance Traveled** *(meters)*	**Time Aloft** *(seconds)*	**Average Speed** speed = distance ÷ time *(meters/second)*
1			
2			
3			
4			
5			
6			

Rocketry Data Table: Vertical Flight

Trial #	**Time Aloft** *(seconds)*	***Divide Time by 2:*** *(seconds)*	**Calculated Maximum Rocket Flight Height** Distance = $\frac{1}{2} \cdot g \cdot t^2$ *(meters)*
1			
2			
3			
4			
5			
6			

Tip: There is a simple test you can do to test to see if your rocket is stable. Tie a string around the body at the center of gravity (CG) point. (For a model rocket, make sure you've prepared it for launch, so the engine, wadding and parachute are on board.) Swing the rocket around your head in a circle. The nose points in the direction of rotation for a stable rocket. Unstable rockets will wobble, spin sideways, or go tail-first. You can fix any stability problems by lowering the center of pressure (make the fins bigger) or by moving the CG forward (adding weight to the nose).

Going Further: If you're a real math nut like I am, here's Newton's Second Law rewritten for a rocket moving through the atmosphere: $F_{net} = m_{exit}V_{exit} + (P_{exit}-P_{ambient})\ A_{exit}$

The "A" in the above equation is the area of the engine "throat" or the smallest area of the nozzle where gases are rushing through. The "P" terms are the difference in pressure between the outside air and the pressure of the gases exiting the nozzle. When the rocket finally reaches space, the difference in pressure goes to zero, so the equation then becomes: $F_{net} = m_{exit}V_{exit}$

Things to think about: Looking at rocketry from the math side of things, how could you generate enough thrust so that the amount of thrust is greater than the weight of the rocket? How big would that rocket need to be? What happens when the rocket burns through its tanks unevenly? How does the CG change in a rocket that is burning fuel? How can you make the rocket go where you want it to, and return the parts you need safely back to earth?

Lesson #5: What’s in the Sky?

Teacher Section

Overview: Students will learn how to read an astronomical chart to find out when the Sun sets, when twilight ends, which planets are visible, when the next full moon occurs, and much more.

Suggested Time: 30-45 minutes

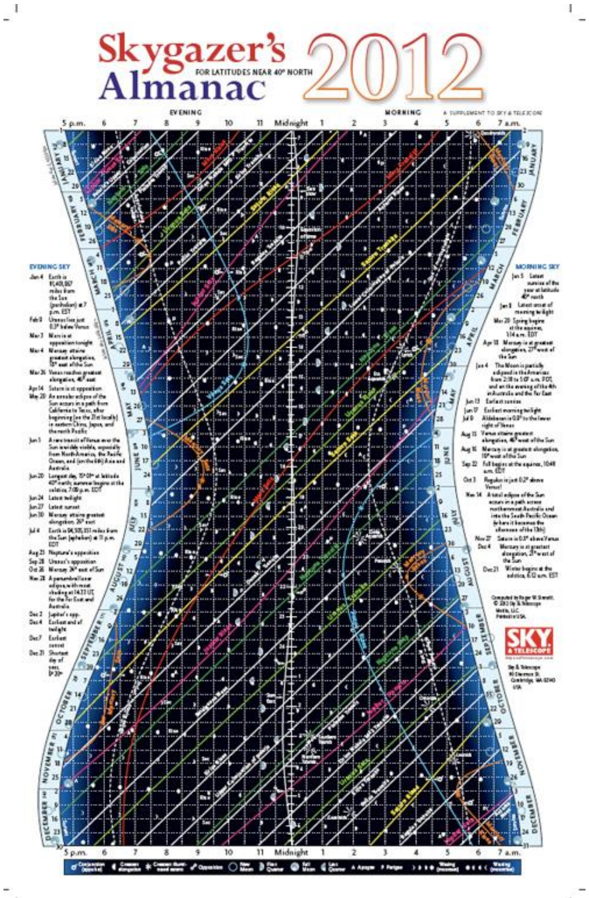
Objectives: Students learn that the patterns of stars stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons.

Materials (per lab group)

- Printout of Stargazer’s Almanac
- Pencil
- Tape and scissors (optional)
- Ruler

Lab Preparation

1. Print out copies of the student worksheets.
2. Print out copies of the almanac by clicking the image of the Skygazer’s Almanac. You can print it full-size on two pages, or size it to fit onto a single page. Since there’s a ton of information on it, it’s best read over two pages. This is an expired calendar for kids to practice with. Click here for the current year at your latitude.
3. Read over the Background Lesson Reading before teaching this class.
4. Watch the video for this experiment to prepare for teaching this class.



CLICK HERE FOR HIGH-RESOLUTION.

Background Lesson Reading

This is one of the finest charts I’ve ever used as an astronomer, as it has so much information all in one place. You’ll find the rise and set times for all eight planets, peak times for annual meteor showers, moon phases, sunrise and set times, and it gives an overall picture of what the evening looks like over the entire year. Kids can clearly see the planetary movement patterns and quickly find what they need each night. I keep one of these posted right by the door for everyone to view all year long.

Lesson

1. Work with the students at first so they get the hang of how to read the chart. Do the following steps together (answers given in parentheses).
2. Hand out the chart to the students. If you've opted for the two-page printouts, then you'll need to cut the borders off at the top and bottom and tape them together so they fit perfectly. Do this first so you have one large chart.
3. First, note the "hourglass" shape of the chart. Do you see how it's skinnier in the middle and wider near the ends? Since it's an astronomical chart that shows what's up in the sky at night, the nights are shorter during the summer months, so the number of hours the stars are visible is a lot less than during the winter. You'll find the hours of the night printed across the top and bottom of the chart (find it now) and the months and days of the year printed on the right and left side.
4. Can you find the summer solstice on June 20? Use your finger and start on the left side between June 17 and June 24. The 20th is between those two dates somewhere. Here's how you tell exactly…
5. Look at the entire chart – do you see the little dots that make up little squares all over the chart, like a grid? Each dot in the vertical direction represents one day. There are eight dots on the vertical side of the box.
6. Let's say you want to find out what time Neptune rises on June 17. Go back to June 17, which has its own little set of dots. Follow the dots with your finger until you hit the line that says *Neptune Rises*. Stop and trace it up vertically to the top scale to read just after 11 p.m.
7. Look again at the dot boxes. Each horizontal dot is 5 minutes apart, and every six dots there is a vertical line representing the half-hour. The line crosses between the second and third dot, so if you lived in a place where you can clearly see the eastern horizon and looked out at 11:07, you'd see Neptune just rising. Since Uranus and Neptune are so far away, though, you'd need a telescope to see them. So let's try something you can find with your naked eye.
8. Look at Oct 21. What time does Saturn set? (5:30p.m.).
9. What other two planets set right afterward? (Mercury at 6:03 p.m. and Mars sets at 7:12 p.m.).
10. When does Jupiter rise? (7:32 p.m.).
11. What is Neptune doing that night of Oct. 21? (Neptune transits, or is directly overhead, at 8:07 p.m. and sets at 1:30 a.m.)
12. What other interesting things happen on Oct. 21? (Betelgeuse, one of the bright stars in the constellation *Orion*, rises at 9:23 p.m. Sirius, the dog star, rises at 11:06 p.m. The Pleiades, also known as the *Seven Sisters*, are overhead at 1:42 a.m.)
13. Let's find out when the Moon rises on Oct. 21. You'll find a half circle representing the Moon centered on 11:05 p.m. Which phase is the Moon at? First or third quarter? (First. You can tell if you look at the next couple of days to see if the Moon waxes or wanes. Large circles indicate one of the four main phases of the Moon.)
14. When does the Sun rise and set for Oct. 21? First, find the nearest vertical set of dots and read the time (5:30 p.m.). Now subtract out the 5-minute dots until you get to the edge. You should read three dots plus a little extra, which we estimate to be 17 minutes. Sunset is at 5:13 p.m. on Oct 21.
15. Note the fuzzy, lighter areas on both sides of the hourglass. That represents the twilight time when it's not quite dark, but it's not daylight either. There's a thin dashed line that runs up and down the vertical, following the curve of the hourglass offset by about an hour and 35 minutes. That's the official time that twilight ends and the night begins.
16. Can you find a meteor shower? Look for a starburst symbol and find the date right in the center. Those are the peak times to view the shower, and it's usually in the wee morning hours. The very best meteor showers are when there's also a new Moon nearby.

17. Notice how Mercury and Venus stay close by the edges of the twilight. You'll find a half-circle symbol representing the day that they are furthest from the Sun as viewed from the Earth, which is the best date to view it. For Venus, the * indicates the day that it's the brightest.
18. What do you think the open circle means at sunset on May 20? (New moon)
19. Students who spot the "Sun slow" or "Sun fast" marks on the chart always ask about it. It's actually rather complicated to explain, but here's the best way to think about it. Imagine that the vertical timeline running down the center means noon, not midnight. Do you see a second line weaving back and forth across the noon line throughout the year? That's the line that shows the when the Sun crosses the meridian. On Feb 5, the Sun crosses that meridian at 12:14, so it's "running slow," because it "should have" crossed the meridian at noon. This small variation is due to the axis tilt of the Earth. Note that it never gets much more than 15 minutes fast or slow. The wavy line that represents this effect is called the *Equation of Time*. We'll be using that later when we make our own sundials and have to correct for the Sun not being where it's supposed to be.
20. Look at Mars and Saturn both setting around the same time on Aug. 14. When two event lines cross, you'll find nearby an open circle with a line coming from the top right side, accompanied by a set of arrows pointing toward each other. This means *conjunction*, and is a time when you can see two objects at once. Usually the symbol isn't right at the intersection, because one of the objects is rising or setting and isn't clearly visible. On Aug. 14, you'll want to view them a little before they set, so the symbol is moved to a time where you can see them both more clearly.
21. Important to note: If your area uses daylight savings time, you'll need to add one hour to the times shown on the chart.
22. *Time corrections for advanced students:* This chart was made for folks living on the 40° north latitude and 90° west longitude lines (which is Peoria, Ill.).
    a. If you live near the standardized longitudes for Eastern Time (75°), Central (90°), Mountain (105°) or Pacific (120°), then you don't have to correct the chart times you read. However, if you live a little west or east of these standardized locations, you need a correction, which looks like this:
        i. For every degree west, add four minutes to the time you read off the chart.
        ii. For every degree east, subtract four minutes from the time.
        iii. For example, if you lived in Washington, D.C. (which is 77° longitude), note that this is 2° west of the Eastern Time, so you'd add 8 minutes to the time you read off the chart.
        iv. Memorize your particular adjustment and always use it.
    b. If your latitude isn't 40° north, then you need to adjust the rise and set times like this:
        i. If you live north of 40°, then the object you are viewing will be in the sky for longer than the chart shows, as it will rise earlier and set later.
        ii. If you live south of 40°, then the object you are viewing will be in the sky for less time than the chart shows, as it will rise later and set earlier.
        iii. The easiest way to calculate this is to note what time an object *should* rise, and then watch to see when it actually appears against a level horizon. This is your correction for your location.
23. Fill out the table below (note answers are given with the table below).

“What’s in the Sky?” Data Table

Question	Answer (date and/or time)
What time does Venus set on April 22?	10:35 p.m.
When does Mars set on August 12?	9:30 p.m.
When is the full moon in March?	March 8
When is the best date and time to view both Jupiter and Saturn?	(answers vary, but Sept. 9 is a choice)
When is the best meteor shower for the entire year?	(answers vary, but Lyrids and Leonids are great choices with nearly no moon)
Which day is the longest?	Dec. 21
When do two planets rise at the same time?	4:30 a.m. on Nov. 27
If this calendar was for this year at your exact location, what would you be looking forward to tonight?	(answers vary)

Lab Time

1. Review the instructions on their worksheets and then break the students into their lab groups.
2. Hand each group their materials and give them time to perform their experiment and write down their observations.
3. Fill out the data table below.

Exercises

1. Is Mercury visible during the entire year? (No, only for a couple of months.)
2. In general, when and where should you look for Venus? (Near the eastern or western sky during twilight during certain months of the year, because it’s always rising or setting, never transiting.)
3. When is the best time to view a meteor shower? (Look for a starburst symbol that is close to a new moon symbol. The skies will be dark enough to view the meteors.)
4. Which date has the most planets visible in the sky? (Feb. 12 has all 7 planets visible sometime during the night, although Nov. 11 is a better night to view, since Mercury and Neptune won’t be lost in the sunset.)

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Lesson #5: What's in the Sky?

Student Worksheet

Name____

Overview: Today you get to learn how to read an astronomical chart to find out when the Sun sets, when twilight ends, which planets are visible, when the next full moon occurs, and much more. This is an excellent way to impress your friends.

What to Learn: The patterns of stars and planets stay the same, although they appear to move across the sky nightly, and different stars and planets can be seen in different seasons.

Materials

- Printout of Stargazer's Almanac
- Pencil
- Tape and scissors (optional)
- Ruler

Lab Time

1. If your chart comes on two pages, you'll need to cut the borders off at the top and bottom and tape them together so they fit perfectly.
2. Use your ruler as a straight edge to help locate items as you read the chart with your teacher.
3. Your teacher is going to walk you through the first set of steps. When you're done, fill out the data table below.

"What's in the Sky?" Data Table

Question	Answer (date and time)
What time does Venus set on April 22?	
When does Mars set on August 12?	
When is the full moon in March?	
When is the best date and time to view both Jupiter and Saturn?	
When is the best meteor shower for the entire year?	
Which day is the longest?	
When do two planets rise at the same time?	
If this calendar was for this year at your exact location, what would you be looking forward to tonight?	

Exercises Answer the questions below:

1. Is Mercury visible during the entire year?
2. In general, when and where should you look for Venus?
3. When is the best time to view a meteor shower?
4. Which date has the most planets visible in the sky?

Lesson #6: Jupiter's Jolts

Teacher Section

Overview: Jupiter not only has the biggest lightning bolts we've ever detected, it also shocks its moons with a charge of 3 million amps every time they pass through certain hotspots. Some of these bolts are caused by the friction of fast-moving clouds. Kids will make their own sparks and simulate Jupiter's turbulent storms.

Suggested Time: 30-45 minutes

Objectives: Kids will see, hear, and feel the electrostatic spark that forms with this experiment. Students will also know how friction builds up in the planet's atmosphere, producing lightning bolts.

Materials (per lab group)

- Foam plate
- Foam cup
- Wool cloth or sweater
- Aluminum pie pan
- Plastic baggie
- Aluminum foil
- Film canister or M&M container
- Nail (needs to be a little longer than the film canister)
- Hot glue gun or tape
- Water

Lab Preparation

1. Print out copies of the student worksheets.
2. Blow up a balloon for a demonstration during class.
3. Set up a hot glue gun station if you don't have enough room for everyone to have their own.
4. Read over the Background Lesson Reading before teaching this class.
5. Watch the video for this experiment to prepare for teaching this class.

Background Lesson Reading

Blow up a balloon. If you rub a balloon on your head, the balloon becomes filled up with extra electrons, and now has a negative charge. Try the following experiment to create a temporary charge on a wall: Bring the balloon close to the wall until it sticks.

Opposite charges attract right? So, is the entire wall now an opposite charge from the balloon? No. In fact, the wall is not charged at all. It is neutral. So why did the balloon stick to it?

The balloon is negatively charged. It created a temporary positive charge when it got close to the wall. As the balloon gets closer to the wall, it repels the electrons in the wall. The negatively charged electrons in the wall are repelled from the negatively charged electrons in the balloon.

Since the electrons are repelled, what is left behind? Positive charges. The section of wall that has had its electrons repelled is now left positively charged. The negatively charged balloon will now “stick” to the positively charged wall. The wall is temporarily charged because once you move the balloon away, the electrons will go back to where they were and there will no longer be a charge on that part of the wall.

This is why plastic wrap, Styrofoam packing popcorn, and socks right out of the dryer stick to things. All those things have charges and can create temporary charges on things they get close to.

If you rub a balloon all over your hair, the *Triboelectric Effect* causes the electrons to move from your head to the balloon. But why don’t the electrons go from the balloon to your head? The direction of electron transfer has to do with the properties of the material itself. And the balloon-hair combination isn’t the only game in town.

Electrons move differently depending on the materials that are rubbed together. A balloon takes on a negative charge when rubbed on hair. Today, the kids are going to find when a foam plate is rubbed with wool, the plate takes on electrons and creates a negative charge on the plate. To give the plate a positive charge, kids can rub it with a plastic bag.

The *Triboelectric Series* is a list that ranks different materials according to how they lose or gain electrons. A rubber rod rubbed with wool produces a negative charge on the rod, however an acrylic rod rubbed with silk creates a positive charge on the rod. A foam plate often has a positive charge when you slide one off the stack, but if you rub it with wool it will build up a negative charge.

Near the top of the list are materials that take on a positive charge, such as air, human skin, glass, rabbit fur, human hair, wool, silk, and aluminum. Near the bottom of the list are materials that take on a negative charge, such as amber, rubber balloons, copper, brass, gold, cellophane tape, Teflon, and silicone rubber. Scientists developed this list by doing a series of experiments, very similar to the ones we’re about to do.

Lesson

1. Hold up a balloon and announce that you’re looking for the kid with best hair. Find someone with a head of fine, shoulder-length hair that doesn’t have any goop in it, like mousse, hair spray or gel. This experiment works best on a dry day. If it’s raining outside, shut the door and crank up the heat to dry out the air… or just wait for the clouds to clear up.
    a. As you rub the hair, lift the balloon up a couple of inches and watch for the hair to follow. If you’re patient, you’ll figure out how to make the hair stand up all over the head and have the kids roaring with laughter.
    b. Ask the kids: *“What’s going on?”* as you spike the hair up.
    c. They will invariably answer: *“Static electricity!”* Nod your head sagely and challenge them with: *“Great! What is static electricity?”* Get them to describe exactly what it is. Ask them to explain it to you as if you were only six.
    d. As they struggle to give you a definition, take a walk around the room and find things that the charged balloon sticks to, like a wool sweater, the wall, a sheet of paper, or the ceiling. Continue to ask: *“What’s going on?”*
    e. If they continue to repeat *“Static electricity!”* say: *“That’s a fancy word. What does it mean?”*
2. Hold up an electrical device or point to the overhead lights and remind the students that although you can't see electricity, you can certainly detect its effects. Blenders, washing machines, vacuum cleaners, airplanes - all of these use electricity. While you don't need to understand electricity to turn on a light, you *do* need to understand the basics. First, we’re going to investigate what static electricity is and how it works.

3. The proton has a positive charge, and the electron has a negative charge. In the hydrogen atom, which has one proton and one electron, the charges are balanced. If you steal the electron, you now have an unbalanced, positively charged atom and stuff really starts to happen. The flow of electrons is called electricity. We're going to move electrons around and have them stick, not flow, so we call this "static electricity." Like charges repel (two negative charges will repel each other) and opposites attract (a positive and negative will be attracted to each other).
4. Ask the kids which they think the balloon is: positive or negative. After the guesses come in, tell them that the balloon steals the electrons from your head, and now has a negative charge. Ask them what the charge of your head now is … it's a positive charge because your head was electrically balanced (same number of positive and negative charges) until the balloon stole your negative electrons, leaving you with an unbalanced positive charge.
5. What happens if you rub a wool sweater on a plate? Do you think you can build up a charge? That's what we're about to find out.

Lab Time

1. Review the instructions on their worksheets and then break the students into their lab groups.
2. Hand each group their materials and give them time to perform their experiment and write down their observations.
3. Lay the aluminum pie pan in front of you, right-side up.
4. Glue the foam cup to the middle of the inside of the pan.
5. Lay the plate on the table, upside down. Place the pie pan (don't glue it!) on top of the plate, back-to-back. Set aside.
6. Insert the nail through the middle of the film canister lid. Wrap the bottom of the film canister with aluminum foil. Tape the foil into place.
7. Fill the canister nearly full of water.
8. Snap on the lid, making sure that the nail touches the water.
9. Rub the foam plate with the wool for at least a minute to really charge it up. Place the plate upside down carefully on the table.
10. Put the pie pan back on top of the foam plate. The plate has taken on the charge from the foam plate.
11. Touch the pie pan with a finger … did you feel anything?
12. Use the cup as a handle and lift the pie pan up.
13. Touch the pan with your finger, and you should feel and see a spark (turn down the lights to make the room dark).
14. Charge the foam plate again and set the pie pan back on top to charge it up. (Make sure you're lifting the pie pan only by the foam cup, or you'll discharge it accidentally.)
15. Hold the film canister by the aluminum foil and touch the charged pie pan to the nail.
16. Rub the foam plate with the wool again to charge it up. Set the pie pan on the foam plate to charge the pan. Now lift the pie pan and touch the pan to the nail. Do this a couple of times to really get a good charge in the film canister.
17. Discharge the film canister by touching the foil with one finger and the nail with the other. Did you see a spark?
18. The wool gives the plate a negative charge. You can use a plastic bag instead of the wool to give the foam plate a positive charge.

Exercises

1. What happens if you hold the nail and charge the aluminum foil? (It also works to charge up the film canister.)
2. Can you see electrons? Why or why not? (No – they are too small!)

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Lesson #6: Jupiter's Jolts

Student Worksheet

Name____

Overview: Jupiter not only has the biggest lightning bolts we've ever detected, it also shocks its moons with a charge of 3 million amps every time they pass through certain hotspots. Some of these bolts are caused by the friction of fast-moving clouds. Today you get to make your own sparks and simulate Jupiter's turbulent storms.

What to Learn: Electrons are too small for us to see with our eyes, but there are other ways to detect something's going on. The proton has a positive charge, and the electron has a negative charge. Like charges repel and opposite charges attract.

Materials

- Foam plate
- Foam cup
- Wool cloth or sweater
- Plastic baggie
- Aluminum pie pan
- Aluminum foil
- Film canister or M&M container
- Nail (needs to be a little longer than the film canister)
- Hot glue gun or tape
- Water

Lab Time

1. Lay the aluminum pie pan in front of you, right-side up.
2. Glue the foam cup to the middle of the inside of the pan.
3. Lay the plate on the table, upside down. Place the pie pan (don't glue it!) on top of the plate, back-to-back. Set aside.
4. Insert the nail through the middle of the film canister lid. Wrap the bottom of the film canister with aluminum foil. Tape the foil into place.
5. Fill the canister nearly full of water.
6. Snap on the lid, making sure that the nail touches the water.
7. Rub the foam plate with the wool for at least a minute to really charge it up. Place the plate upside down carefully on the table.
8. Put the pie pan back on top of the foam plate. The plate has taken on the charge from the foam plate.
9. Touch the pie pan with a finger … did you feel anything?
10. Use the cup as a handle and lift the pie pan up.
11. Touch the pan with your finger, and you should feel and see a spark (turn down the lights to make the room dark).
12. Charge the foam plate again and set the pie pan back on top to charge it up. (Make sure you're lifting the pie pan only by the foam cup, or you'll discharge it accidentally.)
13. Hold the film canister by the aluminum foil and touch the charged pie pan to the nail.

14. Rub the foam plate with the wool again to charge it up. Set the pie pan on the foam plate to charge the pan. Now lift the pie pan and touch the pan to the nail. Do this a couple of times to really get a good charge in the film canister.
15. Discharge the film canister by touching the foil with one finger and the nail with the other. Did you see a spark?
16. The wool gives the plate a negative charge. You can use a plastic bag instead of the wool to give the foam plate a positive charge.
17. Fill out the table below.

Jupiter's Jolts Data Table

For the first column, describe which object you are charging and how. For example, is it the foam plate with wool, or is it the jar with the plate? For the second column, if you're charging the plate with wool, then time yourself to see how long you rubbed it for and write this down. If you're charging the jar, then write in how many times you touched the plate to the jar and record it.

Item/Object	**How long did you charge it for?** *(measure in seconds or number of times)*	**Did it spark?**

Exercises Answer the questions below:

1. What happens if you hold the nail and charge the aluminum foil?

2. Can you see electrons? Why or why not?

Lesson #7: Moons of Jupiter

Teacher Section

Overview: On a clear night when Jupiter is up (which you learned how to find in the lesson entitled: *What's in the Sky?*) you'll be able to view the four moons of Jupiter (Europa, Ganymede, Io, and Callisto) and the largest moon of Saturn (Titan) with only a pair of binoculars. The question is: Which moon is which? This lab will let you in on the secret to figuring it out.

Suggested Time: 30-45 minutes

Objectives: Students will learn how to locate a planet in the sky with a pair of binoculars, and also be able to tell which moon is which in the view. Students will know the position of the moons change over the course of the night and from week to week.

Materials (per lab group)

- Printout of corkscrew graph
- Pencil
- Binoculars (optional)

Lab Preparation

1. Print out copies of the student worksheets.
2. Read over the Background Lesson Reading before teaching this class.
3. Watch the video for this experiment to prepare for teaching this class.

Background Lesson Reading

Jupiter's Rings and Moons

Jupiter's moons are threadlike when compared with Saturn's. Also, unlike Saturn's rings, Jupiter's rings come from ash spewed out from the active volcanoes of its moons. Since Jupiter is so large, its gravity likes to catch things. When a volcano shoots its ash-snow up, Jupiter grabs it and swirls it in on itself. The moons are constantly replenishing the rings, which is why they are so much smaller than Saturn's and much harder to detect (you won't see them with binoculars or a backyard telescope).

If you're doing the binocular portion of this lab in the evening, the numbers on binoculars refer to the magnification and the lens at the end. For example, 7×50 means you're viewing the sky at 7X, and the lenses are at 50mm. Most people can easily hold up to 10x50s before their arms get tired. Remember, you're looking *up*, not out or down as in normal terrestrial daytime viewing.

Saturn's Rings and Moons

Galileo Galilei was the first to point a telescope at the sky, and the first to glance at the rings of Saturn in 1610. In the 1980s, the Voyager 1 and Voyager 2 spacecraft flew by, giving us our first real images of the rings of Saturn. Some of the biggest mysteries in our solar system are: What are the rings made up of, and why?

The Cassini-Huygens Mission answered the first question: The rings are made of billions of particles ranging from dust-sized icy grains to a couple of mountain-sized chunks. Actually, Saturn's rings are an optical illusion. They are not solid, but rather a blizzard of water-ice particles mixed with dust and rock fragments, and each piece orbits Saturn like a little a moon. These billions of particles race around Saturn in tracks, and are herded into position by moons that also orbit within the rings ("shepherd" moons). Shepherd moon Pan orbits in the Encke gap, Daphnis orbits in the Keeler gap, Atlas orbits in the A ring, Prometheus in the F ring, and Pandora in the F ring. These moons keep the gaps open with their gravity.

The second question is harder to answer, but the latest news is that the rings are pieces of comets, asteroids or shattered moons that broke apart before they ever reached Saturn. Although each ring orbits at a different speed around the planet, the Cassini spacecraft had to *slow down* to 75,000 mph before it dropped into the rings to orbit around the planet.

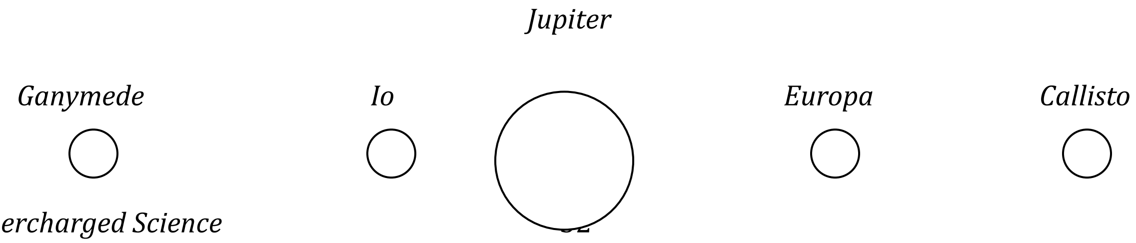
While the rings are wide enough to see with a backyard telescope, the main rings (A, B and C) are paper-thin, only 10 meters (33 feet) thick.

Cassini found that a great plume of icy material blasting from the moon Enceladus is a major source of material for the expansive E ring. Additionally, Cassini has found that most of the planet's small, inner moons appear to orbit within partial or complete rings formed from particles blasted off their surfaces by impacts of micrometeoroids.

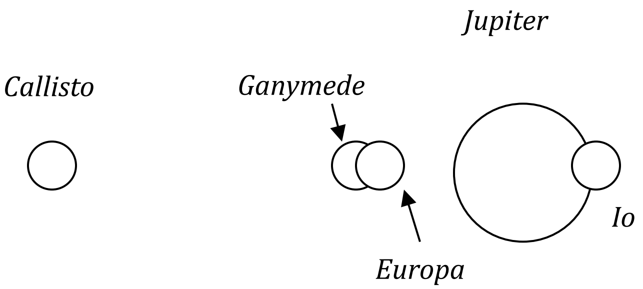
Lesson

1. Hand out the corkscrew graphs to the students and walk them through the first couple of examples so they get the hang of it. Answers are in (parentheses).
2. Look at your corkscrew satellite graph. These are common among astronomers for both Saturn and Jupiter. Notice how Saturn has a lot more wavy lines than Jupiter. We're going to focus on Jupiter for the first part of this lab. Jupiter's graph is the one on the left with Ganymede as one of the moons.
3. The wavy lines represent four of Jupiter's biggest moons: Ganymede, Callisto, Europa, and Io. The central two lines for a band is the width of Jupiter itself. If you see any gaps in the wavy lines, those are times when the moon is behind Jupiter. Each bar across that corresponds to a number is an entire day. The width of the column represents how far away each moon is from Jupiter. Notice at the top it says *East* and *West.*

4. Draw a circle on the board that represents Jupiter.
5. Notice the largest waves are made by Callisto. What makes the smallest waves? (Io.)
6. Look at Dec 4th. Which moons are on which side of Jupiter? (Ganymede is the furthest east, and Io is closer to the planet, still on the east side. On the west, Europa is closer to Jupiter than Callisto.)
7. Draw the moons on the board around Jupiter:



8. Look at Dec 24. Draw the diagram of Jupiter and its moons (ask the kids to help you):



Lab Time

1. Review the instructions on their worksheets and then break the students into their lab groups.
2. Hand each group their materials and give them time to perform their experiment and write down their observations.
3. Answer the questions below using the corkscrew graph on the next page:

Moons of Jupiter Data Table

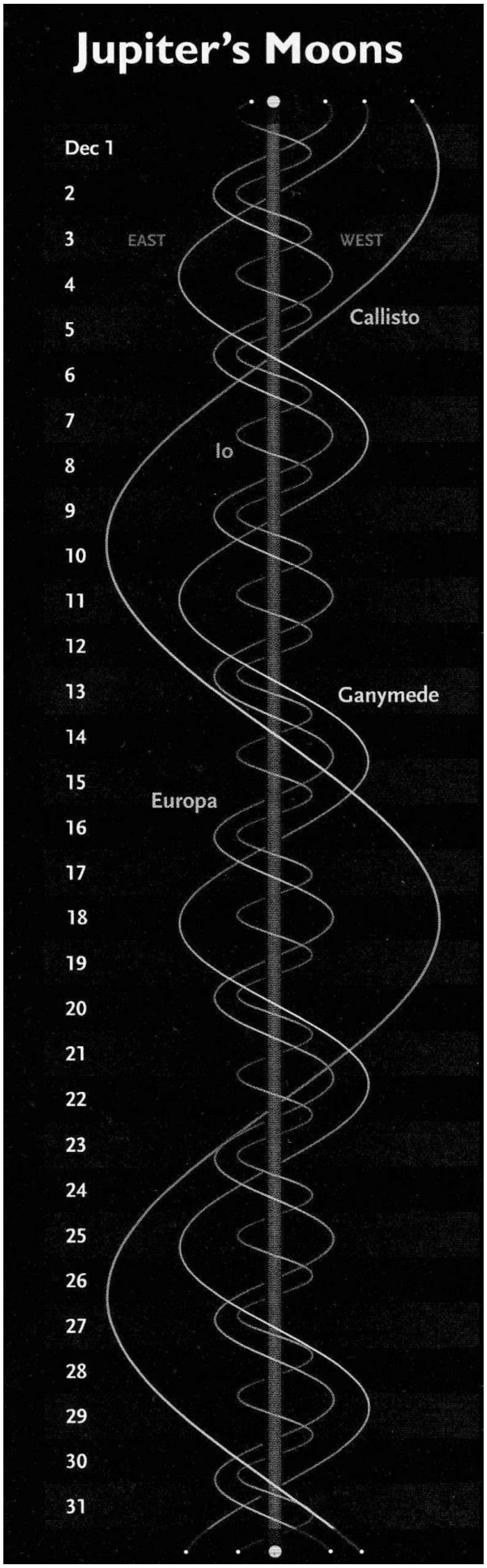
Date	Draw Jupiter and its four moons:
Dec 11	
Dec 18	
Dec 13	
Dec 22	

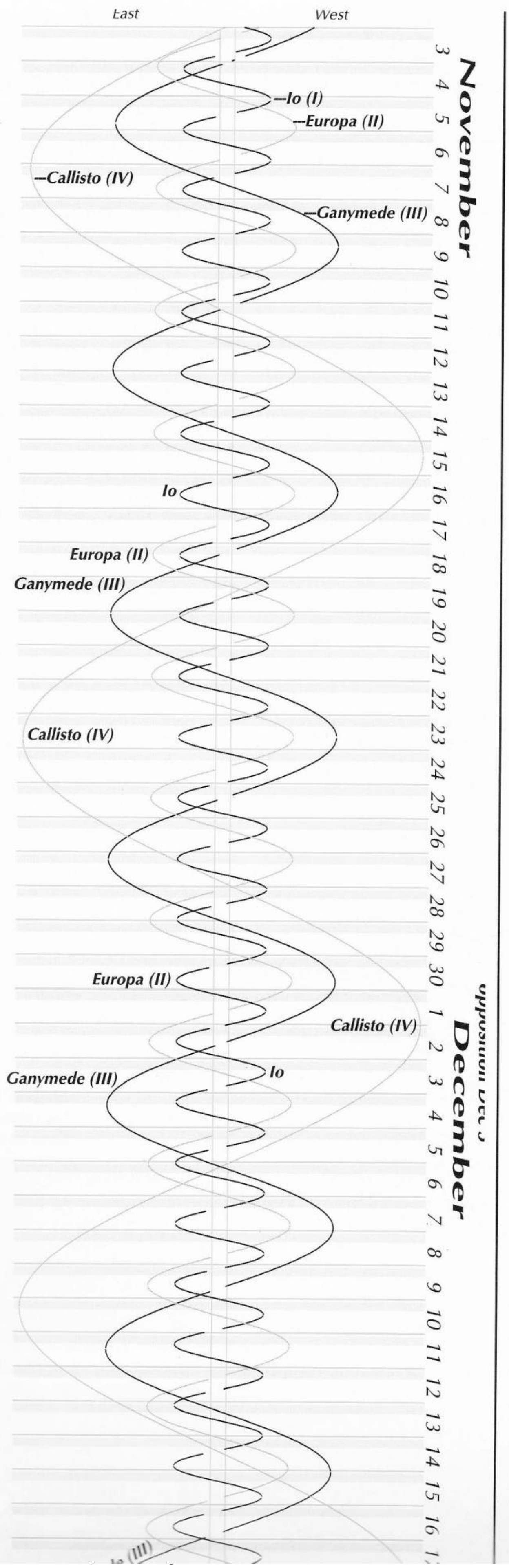
Exercises

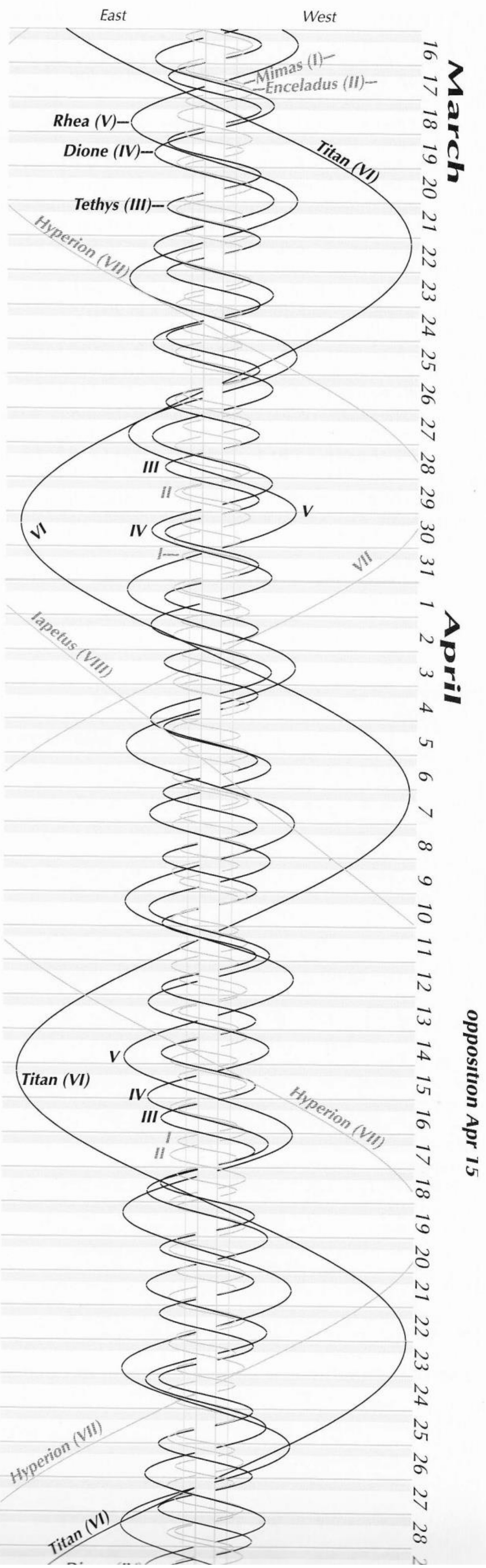
1. Find a date that has all four moons on one side of Jupiter. (Early on Dec. 13)
2. When is Callisto in front of Jupiter and Io behind Jupiter at the same time? (Dec. 14)
3. Are the images you've drawn in the table what you'd expect to see in binoculars, or are they upside down, mirrored, or inverted? (They are exactly what I'd expect to see.)

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Note: For advanced students, the next page has two corkscrew satellite graphs: the left is for Jupiter and the right is for Saturn.




East
West
November
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
December
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
opposition Dec 3
Io (I)
Europa (II)
Callisto (IV)
Ganymede (III)
Io
Europa (II)
Ganymede (III)
Callisto (IV)
Europa (II)
Callisto (IV)
Ganymede (III)
Io


East
West
March
16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
April
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
opposition Apr 15
Mimas (I)
Enceladus (II)
Rhea (V)
Dione (IV)
Titan (VI)
Tethys (III)
Hyperion (VII)
III
II
V
VI
IV
I
VII
Iapetus (VIII)
V
Titan (VI)
IV
III
I
II
Hyperion (VII)
Hyperion (VII)
Titan (VI)

Lesson #7: Moons of Jupiter

Student Worksheet

Name____

Overview: On a clear night when Jupiter is up (which you learned how to find in the lesson entitled: *What's in the Sky?*) you'll be able to view the four moons of Jupiter (Europa, Ganymede, Io, and Callisto) and the largest moon of Saturn (Titan) with only a pair of binoculars. The question is: Which moon is which? This lab will let you in on the secret to figuring it out.

Suggested Time: 30-45 minutes

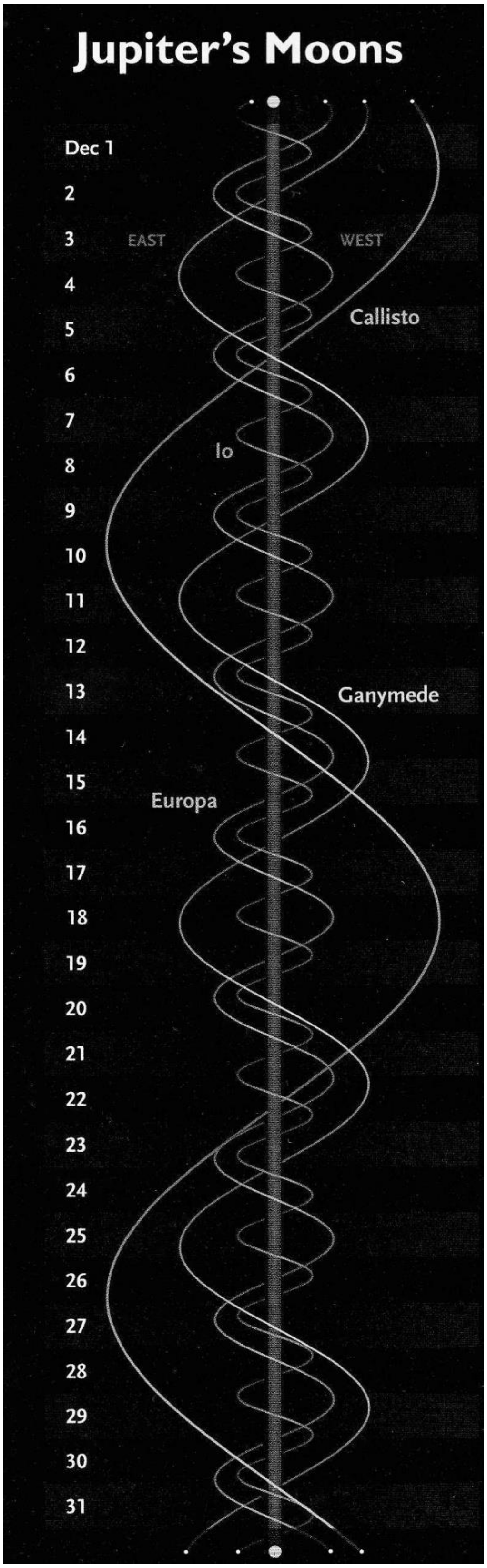
What to Learn: You get to learn how to locate a planet in the sky with a pair of binoculars, and also be able to tell which moon is which in the view.

Materials (per lab group)

- Printout of corkscrew graph
- Pencil
- Binoculars (optional)

Lab Time

1. Your teacher is going to walk you through how to read the satellite corkscrew graph. Once you've completed the steps with your teacher, proceed to filling out the table below using the corkscrew graph.
2. The wavy lines represent four of Jupiter's biggest moons: Ganymede, Callisto, Europa, and Io. The central two lines for a band is the width of Jupiter itself. If you see any gaps in the wavy lines, those are times when the moon is behind Jupiter. Each bar across that corresponds to a number is an entire day. The width of the column represents how far away each moon is from Jupiter. Notice at the top it says *East* and *West.*



Moons of Jupiter Data Table

Date	Draw Jupiter and its four moons:
Dec 11	
Dec 18	
Dec 13	
Dec 22	

Exercises Answer the questions below:

1. Find a date that has all four moons on one side of Jupiter.

2. When is Callisto in front of Jupiter and Io behind Jupiter at the same time?

3. Are the images you've drawn in the table what you'd expect to see in binoculars, or are they upside down, mirrored, or inverted?

Lesson #8: Solar Viewers

Teacher Section

Overview: Students are going to start observing the Sun and tracking sunspots across the Sun using their viewers. They will use this information to determine how fast the Sun rotates.

Suggested Time: 30-45 minutes total, over the course of two weeks

Objectives: Sunspots are dark, cool areas with highly active magnetic fields on the Sun's surface that last from hours to months. They are dark because they aren't as bright as the areas around them, and they extend down into the Sun as well as up into the magnetic loops.

Materials (per lab group)

- Tack
- 2 index cards (any size)
- Baader film from Draco Productions

Lab Preparation

1. If the Sun is not available, you can use images from a satellite that's pointed right at the Sun while orbiting around the Earth called "SOHO." SOHO gets clear, unobstructed views of the Sun 24 hours a day, since it's above the atmosphere of the Earth. Download the very latest image of the Sun from NASA's SOHO page (choose the SDO/HMI Continuum filter for the best sunspot visibility) and hand them out to the students to track the sunspots.
2. Print out copies of the student worksheets.
3. Read over the Background Lesson Reading before teaching this class.
4. Watch the video for this experiment to prepare for teaching this class.

Background Lesson Reading

You know you're not supposed to look at the Sun, so how can you study it safely? I'm going to show you how to observe the Sun safely using a very inexpensive filter. I actually keep one of these in the glove box of my car so I can keep track of certain interesting sunspots during the week!

The visible surface of the Sun is called the photosphere, and is made mostly of plasma (electrified gas) that bubbles up hot and cold regions of gas. When an area cools down, it becomes darker (called sunspots). Solar flares (massive explosions on the surface), sunspots, and loops are all related the Sun's magnetic field. While scientists are still trying to figure this stuff out, here's the latest of what they do know…

The Sun is a large ball of really hot gas – which means there are lots of naked charged particles zipping around. And the Sun also rotates, but the poles and the equator move at different speeds (don't forget – it's not a solid ball but more like a cloud of gas). When charged particles move, they make magnetic fields (that's one of the basic laws of physics). And the different rotation rates allow the magnetic fields to "wind up" and cause massive magnetic loops to eject from the surface, growing stronger and stronger until they wind up flipping the north and south poles of the Sun (called "solar maximum"). The poles flip every 11 years.

The Sun rotates, but because it's not a solid body but a big ball of gas, different parts of the Sun rotate at different speeds. The equator (once every 27 days) spins faster than the poles (once every 31 days). Sunspots are a great way to estimate the rotation speed.

Sunspots usually appear in groups and can grow to several times the size of the Earth. Galileo was the first to record solar activity in 1613, and was amazed how spotty the Sun appeared when he looked at the projected image on his table.

There have been several satellites especially created to observe the Sun, including Ulysses (launched 1990, studied solar wind and magnetic fields at the poles), Yohkoh (1991-2001, studied X-rays and gamma radiation from solar flares), SOHO (launched 1995, studies interior and surface), and TRACE (launched 1998, studies the corona and magnetic field).

Lesson

1. You might be curious about how to observe the Sun safely without losing your eyeballs. There are many different ways to observe the Sun without damaging your eyesight (which we'll talk about more in the lesson entitled: *Fire and Optics)*.
2. We're going to learn two different ways to view the Sun. First is the pinhole projector and the second is using a special film called a Baader filter. The quickest and simplest way to do this is to build a super-easy pinhole camera that projects an image of the Sun onto an index card for you to view.

Lab Time

1. Review the instructions on their worksheets and then break the students into their lab groups.
2. Hand each group their materials and give them time to perform their experiment and write down their observations.

Solar Pinhole Projector

1. With your tack, make a small hole in the center of one of the cards.
2. Stack one card about 12″ above the other and go out into the Sun.
3. Adjust the spacing between the cards so a sharp image of the Sun is projected onto the lower paper.
4. The Sun will be about the size of a pea.
5. You can experiment with the size of the hole you use to project your image.
6. What happens if your hole is really big? Too small?
7. What if you bend the lower card while viewing? What if you punch two holes? Or three?

Baader Filter

1. Using a Baader filter, you're going to look straight through the filter right at the Sun.
2. Put the filter between you and the Sun, right up close to your eye, and look *through* it. It takes a little while to get the hang of seeing the Sun through this filter, but it's totally worth it.

Taking Data:

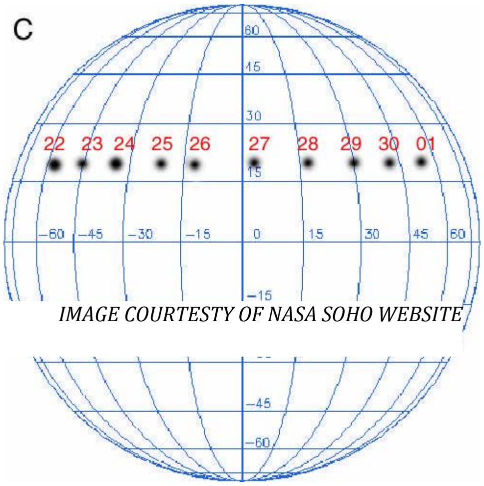


IMAGE COURTESTY OF NASA SOHO WEBSITE

1. Using either the Baader filter or the solar pinhole projector (or both), you will track the sunspot activity using the mapping grid. You will be charting the Sun for 24 days using the mapping grid.
2. Each day, step outside at the same time each day (just before lunchtime is great) and look at the Sun using one of the two filter methods. Draw what you see on the mapping grid. If the Sun isn't visible one day, simply skip a day and wait for the next. Or use the printouts from NASA's SOHO website.
3. See image *right* to see how to draw the sunspots with the date of the month next to them.
4. For example, on March 13, write a "13" right next to the sunspot picture you drew. If there's more than one sunspot, pick the largest one to track. If you'd like to track *all* of them, label them A-13, B-13, C-13…etc. The next day, label the set A-14, B-14, C-14. For multiple sunspots, use one mapping grid per day.
5. At the end of the time period (you can expect to see a sunspot travel across the face of the Sun in about 14 days), record your data in the Data Table.

Exercises

1. How many longitude degrees per day does the sunspot move? (About 12° per day, and when you divide 360° by 12° per day you get 30 days for a sunspot to move all the way around the Sun. But the Earth is also moving around the Sun in the same direction, but it does this at about 1° per day, so it makes the Sun seem like it's rotating less than it really is. So we need to add 1° per day to the 12, so we get 13 degrees per day, or 360° ÷13° per day = 28 days.)
2. Do all sunspots move at the same rate? (No. Sunspots at the poles move slower than at the equator, about once every 31 days.)
3. Did some of the sunspots change size or shape, appear or disappear? (Yes, all the time!)

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Lesson #8: Solar Viewers

Student Worksheet

Name____

Overview: You are going to start observing the Sun and tracking sunspots across the Sun using one of two different kinds of viewers so you can figure out how fast the Sun rotates.

What to Learn: Sunspots are dark, cool areas with highly active magnetic fields on the Sun's surface that last from hours to months. They are dark because they aren't as bright as the areas around them, and they extend down into the Sun as well as up into the magnetic loops.

Materials

- Tack
- 2 index cards (any size)
- Baader film from Draco Productions

Lab Time

Solar Pinhole Projector

1. With your tack, make a small hole in the center of one of the cards.
2. Stack one card about 12″ above the other and go out into the Sun.
3. Adjust the spacing between the cards so a sharp image of the Sun is projected onto the lower paper.
4. The Sun will be about the size of a pea.
5. You can experiment with the size of the hole you use to project your image.
6. What happens if your hole is really big? Too small?
7. What if you bend the lower card while viewing? What if you punch two holes? Or three?

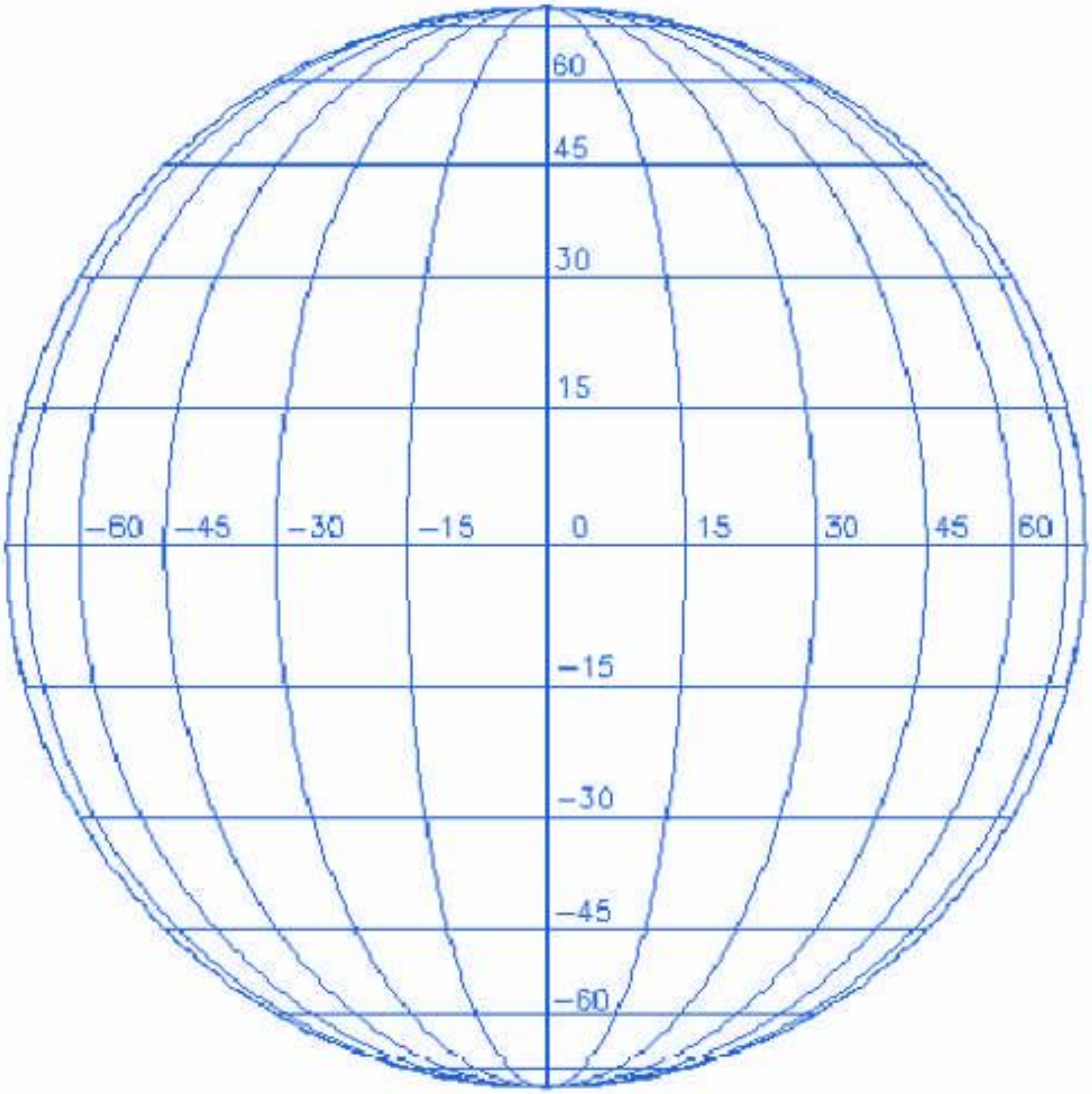
Baader Filter

1. Using a Baader filter, you're going to look straight through the filter right at the Sun. Put the filter between you and the Sun, right up close to your eye and look *through* it. It takes a little while to get the hang of seeing the Sun through this filter, but it's totally worth it.

Taking Data:

1. Using either the Baader filter or the solar pinhole projector (or both), you will track the sunspot activity using the mapping grid. You will be charting the Sun for two weeks using the mapping grid.
2. Each day, step outside at the same time and look at the Sun using one of the two filter methods.
3. Draw what you see on the mapping grid.
4. Draw the sunspot(s) with the date of the month next to it. For example, on March 13, write a "13" right next to the sunspot picture you drew. If there's more than one sunspot, pick the largest one to track. If you'd like to track *all* of them, label them A-13, B-13, C-13…etc. The next day, label the set A-14, B-14, C-14. For multiple sunspots, use one mapping grid per day.

Mapping Grid



At the end of the time period transfer your data to the Data Table.

Solar Viewers Data Table

Sunspot (A, B, C…)	Date	Longitude

Exercises Answer the questions below:

1. How many longitude degrees per day does the sunspot move?
2. Do all sunspots move at the same rate?
3. Did some of the sunspots change size or shape, appear or disappear?

Lesson #9: Cosmic Ray Detector

Teacher Section

This is a Bonus Lab, meaning that it's in addition to the experiments the kids get to do throughout the course. Feel free to skip this lab if the materials are out of your budget, or save it as a treat for the end of the year. You can alternatively make a single one of these and keep it in your classroom as a demo all year long.

Overview: A cosmic ray is not like a ray of sunshine, but rather is a super-fast particle slinging through space. Think of throwing a grain of sand at a 100 mph - that's what a "cosmic ray" is. The Cosmic Ray Detector is a great device for finding cosmic rays because it's going to catch negatively charged particles (electrons, also called "beta particles") *and* positively charged particles (called "alpha particles"). A lot of these particles come from the Sun. You'll actually get to see the thin, threadlike vapor trails appear and disappear, marking the path left by the particles. This type of detector was created by Charles Wilson in 1894, and he later received a Nobel Prize (along with Arthur Compton) for their work on cloud chambers.

Suggested Time: 30-45 minutes

Objectives: Kids will build a special cloud chamber that will make these invisible particles visible. This cloud chamber works because it's filled with a super-saturated alcohol-water vapor mix. The alpha particles (ions) turn the vapor into microscopic clouds the kids can see.

Materials (per lab group)

- Rubbing alcohol
- Clean glass jar
- Black felt
- Hot glue gun
- Magnet
- Flashlight
- Scissors
- Dry ice
- Goggles
- Heavy gloves for handling the dry ice (adults only)

Lab Preparation

1. Since this is a tricky project, you'll want to build one yourself and get the kinks worked out *before* teaching this project to your class.
2. Print out copies of the student worksheets.
3. Watch the video for this experiment to prepare for teaching this class.
4. Read over the *Background Lesson Reading* before teaching this class.

Background Lesson Reading

Cosmic rays have a positive charge, as the particles are usually protons, though one in every 100 is an electron (which has a negative charge) or a muon (also a negative charge, but 200 times heavier than an electron). On a good day, your cosmic ray indicator will blip every 4-5 seconds. These galactic cosmic rays are one of the most important problems for interplanetary travel by crewed spacecraft.

Most cosmic rays zoom to us from extrasolar sources (stars that are *outside* our solar system but *inside* our galaxy) such as high-energy pulsars, grazing black holes, and exploding stars (supernovae). We're still figuring out whether some cosmic rays started from outside our own galaxy. If they are from outside our galaxy, it means that we're getting stuff from quasars and radio galaxies, too!

Cosmic rays are fast-moving, high-energy, charged particles. The particles can be electrons, protons, the nucleus of a helium atom, or something else. In our case, the cosmic rays we're detecting are "alpha particles." Alpha particles are actually high-speed helium nuclei (helium nuclei are two protons and two neutrons stuck together). They were named "alpha particles" long before we knew what they were made of, and the name just kind of stuck.

Did you know that your household smoke alarm emits alpha particles? Most smoke detectors contain a small bit (around 1/5,000th of a gram) of Americium-241, which emits an alpha particle onto a detector. As long as the detector sees the alpha particle, the smoke alarm stays quiet. However, since alpha particles are easy to block, when smoke gets in the way and blocks the alpha particles from reaching the detector, you hear the smoke alarm scream.

Alpha particles are pretty heavy and slow, and most get stopped by just about anything, like a sheet of paper or your skin. Because of this, alpha particles are not something people get very excited about, unless you actually eat the smoke detector and ingest the material (which is not recommended).

Both brick buildings as well as people emit beta particles. Beta particles are actually high-speed electrons or positrons (a positron is the antimatter counterpart to the electron), and they are quick, fast, and light. When an electron hit the foil ball, it traveled down and charged the foil leaves, which deflected a tiny bit inside the electroscope. A beta particle has a little more energy than an alpha particle, but you can still stop it in its tracks by holding up a thin sheet of plastic (like a cutting board) or tinfoil.

Important Project Considerations:

After creating your detector: You can bring your alpha particle detector near a smoke alarm, an old glow-in-the-dark watch dial or a Coleman lantern mantel. You can go on a hunt around your house to find where the particles are most concentrated. If you have trouble seeing the trails, try using a flashlight and shine it on the jar at an angle.

You will also be working with dry ice. The dry ice works with the alcohol to get the vapor inside the jar at just the right temperature so it will condense when hit with the particles. Note that you should **NEVER TOUCH DRY ICE WITH YOUR BARE HANDS.** Always use gloves and tongs and handle very carefully. **Keep out of reach of children** - the real danger is when kids think the ice is plain old water ice and pop it in their mouth.

If your dry ice comes in large blocks, the easiest way to break a large chunk of dry ice into smaller pieces is to insert your hands into heavy leather gloves, wrap the dry ice block in a few layers of towels, and hit with a hammer. Make sure you wrap the towels well enough so that when the dry ice shatters, it doesn't spew pieces all over. Use a metal pie plate to hold the chunks while you're working with them. Store unused dry ice in a paper bag in a cooler or the coldest part of the freezer. Dry ice freezes at -109 degrees Fahrenheit. Most freezers don't get that cold, so expect your dry ice to disappear soon.

Lesson

1. Hold up your detector and show it to the kids, explaining how it works. You will be making a special cloud chamber that holds alcohol gas inside. When you hold the jar in your hands, you warm it slightly and cause the air inside to get saturated with alcohol vapor. When the alpha particles (cosmic rays) zip through this portion of the jar, they quickly condense the alcohol and create spider-webby vapor trails. Kind of like when a jet flies through the air – you can't always see the jet, but the cloud vapor trails streaming out behind stay visible for a long time. In our case, the vapor trails are visible for only a couple of seconds.

Lab Time

1. Review the instructions on their worksheets and break the class into their groups and get started.
2. Walk the kids through the steps to building their detectors. Here are the main steps from the video:
3. Cut your felt to the size of the bottom of your jar. Glue the felt to the bottom of the jar.
4. Cut out another felt circle the size of the lid and glue it to the inside surface of the lid.
5. Cut a third felt piece, about 2 inches wide, and line the inside circumference of the jar, connecting it with the bottom felt. Glue it into place.
6. Very carefully pour a tablespoon or two of the highest concentration of rubbing alcohol onto the felt in the jar. You don't need much. Swirl it around to distribute it evenly. If the kids are doing this part, be sure to strap goggles on their eyes. Do the same for the lid. All the felt pieces should be thoroughly saturated. Cap the jar and leave it for ten minutes while you explain about dry ice (see safety precautions above under *Important Project Considerations*.
7. Put on your gloves, remove the lid and place a small piece of dry ice right on the lid. Invert the jar right over the lid. Leave the jar upside down.
8. **DO NOT SCREW ON THE CAP TIGHTLY!** Leave it loose to allow the pressure to escape.
9. Sit and wait and watch carefully for the tiny, thin, threadlike vapor trails.
10. If no vapor trails form in one of the jars, add more felt and alcohol. The jar might be too large for the amount of alcohol used. You need a thick cloud of air mixed with alcohol vapor for this experiment to work. You can also try a larger piece of dry ice, though usually the trouble is not enough alcohol molecules.
11. If you're still having trouble seeing the particles, remove the dry ice from the jar, screw on the lid to make an air-tight seal, and stick the entire jar right on a big block of dry ice, lid-side down for 15 minutes. Make sure you've got enough light to detect the trails. If things still aren't working right, use a different-sized container.
12. Alpha particles are heavy and create straight, thick trails. Beta particles, which are light, will leave light, wispy trails. You'll have way more alpha than beta trails in your cloud chamber. Bring a smoke detector close to the jar to test the experiment, as cosmic rays are often very tiny and spider-webby, and can be difficult to detect if you don't know what you are looking for.
13. You can use a magnet to deflect the cosmic rays if the magnet is strong enough and positioned just right.

Exercises

1. How does this detector work? (When the particle enters the chamber, it smacks into the alcohol vapor and makes free ions. The vapor in the chamber condenses around these ions, forming little droplets which form the cloud trail.)

2. Do all particles leave the same trail? (No. Different types of particles leave different trails. Alpha particles are heavy and create straight, thick trails. Beta particles, which are light, will leave light, wispy, trails. If you see any curly trails or straight paths that take a sharp turn, those are particles that have smacked into each other.)
3. What happens when the magnet is brought close to the jar? (You can use a magnet to deflect the cosmic rays if the magnet is strong enough and positioned just right.)

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Lesson #9: Cosmic Ray Detector

Student Worksheet

Name____

Safety Alert! You'll be working with *hot* glue guns, toxic chemicals, glassware that can shatter, and finger-burning-cold dry ice. This is no time to mess around in the lab. Stay alert and work carefully to get your experiment to work.

Overview: Your teacher has detected an alien invasion of cosmic insects. Your mission? Build a detector so you know where to aim your anti-alien bug spray.

What to Learn: These "alien insects" are cosmic rays which have a positive charge, as the particles are usually protons, though one in every 100 is an electron (which has a negative charge). These galactic cosmic rays are one of the most important problems for interplanetary travel by crewed spacecraft. Your job is to learn how to make the invisible *visible* so you can do something about it.

Materials

- Rubbing alcohol
- Clean glass jar
- Black felt
- Hot glue gun
- Magnet
- Flashlight
- Scissors
- Dry ice
- Goggles
- Heavy gloves for handling the dry ice (adults only)

Lab Time

1. Cut your felt to the size of the bottom of your jar. Glue the felt to the bottom of the jar.
2. Cut out another felt circle the size of the lid and glue it to the inside surface of the lid.
3. Cut a third felt piece, about 2 inches wide, and line the inside circumference of the jar, connecting it with the bottom felt. Glue it into place.
4. Strap goggles on your face. No exceptions.
5. Very carefully pour a tablespoon or two of the highest concentration of rubbing alcohol onto the felt in the jar. You don't need much. Swirl it around to distribute it evenly. Do the same for the lid. All the felt pieces should be thoroughly saturated. Cap the jar and leave it for ten minutes while your teacher explains about dry ice (see safety precautions above under *Important Project Considerations*.
6. Your teacher is coming around with the dry ice. Remove the lid and your teacher will place a small piece of dry ice right on the lid. Invert the jar right over the lid. Leave the jar upside down.
7. **DO NOT SCREW ON THE CAP TIGHTLY!** Leave it loose to allow the pressure to escape.
8. Sit and wait and watch carefully for the tiny, thin, threadlike vapor trails.
9. What do you think the magnet is for? (Hint: Keep it *outside* the jar.)

Draw a picture of your experiment and describe how it works and label each part:

Exercises

Answer the questions below:

1. How does this detector work?

2. Do all particles leave the same trail?

3. What happens when the magnet is brought close to the jar?

Lesson #10: Spectroscopes

Teacher Section

Overview: Spectrometers are used in chemistry and astronomy to measure light. In astronomy, we can find out about distant stars without ever traveling to them, because we can split the incoming light from the stars into their colors (or energies) and “read” what they are made up of (what gases they are burning) and thus determine what they are made of.

Suggested Time: 30-45 minutes

Objectives: Stars are the source of light for all bright objects in outer space. The Sun, an average star, is the central and largest body in the solar system and is composed primarily of hydrogen and helium. The Sun is one of many stars in our own Milky Way galaxy. Stars may differ in size, temperature, and color.

SPECIAL NOTE: This instrument is NOT for looking at the Sun. Do NOT look directly at the Sun. But you can point the tube at a sheet of paper that has the Sun’s reflected light on it.

Materials (per lab group)

Easy Spectrometer

- Old CD
- Razor
- Index card
- Cardboard tube at least 10 inches long

Advanced Spectrometer (Calibrated)

- Cardboard box (ours is 10″ x 5″ x 5″, but anything close to this will work fine)
- Diffraction grating (try a science store, like Edmund Scientific)
- 2 razor blades (with adult help)
- Masking tape
- Ruler
- Photocopy of a ruler (or sketch a line with 1 through 10 cm markings on it, about 4cm wide)

Lab Preparation

1. Decide which spectrometer you’d like to do.
2. Print out copies of the student worksheets.
3. Read over the Background Lesson Reading before teaching this class.
4. Watch the video for this experiment to prepare for teaching this class.
5. Right before class, set up your various light sources around the room. Students will rotate between different stations and record their results. Some ideas are: computer screens, laptops, night lights, neon lights, candles, campfires, fluorescent lights, incandescent lights, LEDs, stoplights, street lights, and any other light sources you can find. The students will rotate as they did in the previous lesson.

Background Lesson Reading

Diffraction gratings are found in insect (including butterfly) wings, bird feathers, and plant leaves. While I don't recommend using living things for this experiment, I do suggest using an old CD. That's how we're going to build the *Easy Spectrometer.*

CDs are like a mirror with circular tracks that are very close together. The light is spread into a spectrum when it hits the tracks, and each color bends a little more than the last. To see the rainbow spectrum, you've got to adjust the CD and the position of your eye so the angles line up correctly (actually, the angles are perpendicular).

You're looking for a spectrum (the rainbow image at left) – this is what you'll see right on the CD itself. Depending on what you look at (neon signs, chandeliers, incandescent bulbs, fluorescent bulbs, Christmas lights …), you'll see different colors of the rainbow.

For the *Advanced Spectrometer,* we're actually going to calibrate it by plotting information on a graph and using a diffraction grating to make it more precise. It's much more like the instrument that scientists use in their labs.

Lesson

1. Scientists use spectroscopes (spectrometers) to collect a small sample of light and test it to see what made the light. As the light passes through the diffraction grating, it gets split into different bands of light, and you'll see these as different wavelengths, or colors of light.

2. Scientists can figure out what fuel a star is burning, the age of the star, the composition of the star, how fast it's moving, and whether it's moving toward or away from Earth. For example, when hydrogen burns, it gives off light, but not in all the colors of the rainbow, only very specific colors in red and blue. It's like hydrogen's own personal fingerprint, or light signature.

3. While the spectrometers we're about to make aren't powerful enough to split starlight, they're perfect for using with the lights in your house, and even with an outdoor campfire. Next time you're out on the town after dark, bring this with you to peek different types of lights – you'll be amazed how different they really are.

4. **SPECIAL NOTE: This instrument is NOT for looking at the Sun. Do NOT look directly at the Sun.** But you can point the tube at a sheet of paper that has the Sun's reflected light on it.

5. If you're completing the *Advanced Spectrometer*, you'll find additional content to discuss during the lesson part of your class discussion in that section (see below).

Lab Time

1. Review the instructions on their worksheets and then break the students into their lab groups.
2. Hand each group their materials and give them time to perform their experiment and write down their observations.

Easy Spectrometer:

1. A CD has a diffraction grating built into it. We're going to use a CD instead of a diffraction grating for this experiment.
2. Cut a clean slit less than 1 mm wide in an index card or spare piece of cardboard.
3. Tape it to one end of the tube.
4. Align your tube with the slit horizontally, and on the top of the tube at the far end cut a viewing slot about one inch long and ½ inch wide.
5. Cut a second slot into the tube at a 45-degree angle from the vertical away from the viewing slot.
6. Insert the CD into this slot so that it reflects light coming through the slit into your eye (viewing slot).
7. Aim the 1 mm slit at a light source such as a fluorescent light, neon sign, light bulb, computer screen, television, night light, candle, fireplace… any light source you can find EXCEPT THE SUN.
8. Look through the open hole at the light reflected off the compact disk (look for a rainbow in most cases) inside the cardboard tube.
9. Complete the table below.

Advanced Spectrometer (Calibrated)

1. Using a small box, measure 4.5 cm from the edge of the box. Starting here, cut a hole for the double-razor slit that is 1.5 cm wide 3 cm long.
2. From the other edge (on the same side), cut a hole to hold your scale that is 11 cm wide and 4 cm tall.
3. Print out the scale and attach it to the edge of the box.
4. Very carefully line up the two razors, edge-to-edge, to make a slit and secure into place with tape.
5. On the opposite side of the box, measure over 3 cm and cut a hole for the diffraction grating that is 4 cm wide and 3 cm tall.
6. Tape your diffraction grating over the hole.
7. Aim the razor slit at a light source such as a fluorescent light, neon sign, sunset, light bulb, computer screen, television, night light, candle, fireplace … any light source you can find. Put the diffraction grating up to your eye and look at the inner scale. Move the spectrometer around until you can get the rainbow to be on the scale inside the box.

How to Calibrate the Spectrometer with the Scale

8. Inside your box is a scale in centimeters. Point your slit to a fluorescent bulb, and you'll see three lines appear (a blue, a green, and a yellow-orange line). The lines you see in the fluorescent bulb are due to mercury superimposed on a rainbow continuous spectrum due to the coating. Each of the lines you see is due to a particular electron transition in the visible region of Hg (mercury).
    1. **blue line (435 nm)**
    2. **green line (546 nm)**,
    3. **yellow orange line (579 nm)**

    If you look at a sodium vapor street light you'll see a yellow line (actually 2 closely spaced) at 589 nm.

9. Line the razor slits along the length of the fluorescent tube to get the most intense lines. Move the box laterally (the lines will move due to parallax shift).

10. Take scale readings at the extreme of these movements and take the average for the scale reading. For instance, if the blue line averages to the 8.8 cm value, this corresponds to the 435 nm wavelength. Do this for the other 2 lines.
11. On graph paper, plot the cm (the ruler scale values) on the vertical axis and the wavelength (run this from 400-700 nm) on the horizontal axis.
12. Draw the best straight lines through the 3 points (4 lines if you use the Na (sodium) street lamp). You've just calibrated the spectrometer!
13. Line the razor slits up with another light source. Notice which lines appear and where they are on your scale. Find the value on your graph paper. For example, if you see a line appear at 5.5 cm, use your finger to follow along to the 5.5 cm until you hit the best-fit line, and then read the corresponding value on the wavelength axis. You now have the wavelength for the line you've just seen!

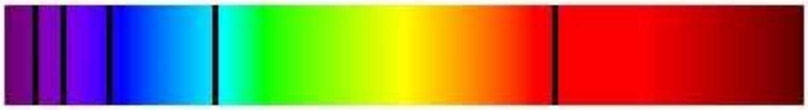
Notes on Calibration and Construction: If you swap out different diffraction gratings, you will have to re-calibrate. If you make a new spectrometer, you will have to re-calibrate to the Hg (mercury) lines for each new spectrometer. If you do remake the box, use a scale that is translucent so you can see the numbers. If you use a clear plastic ruler, it may let in too much light from the outside, making it difficult to read the emission line.

How to Tell Which Elements are Burning

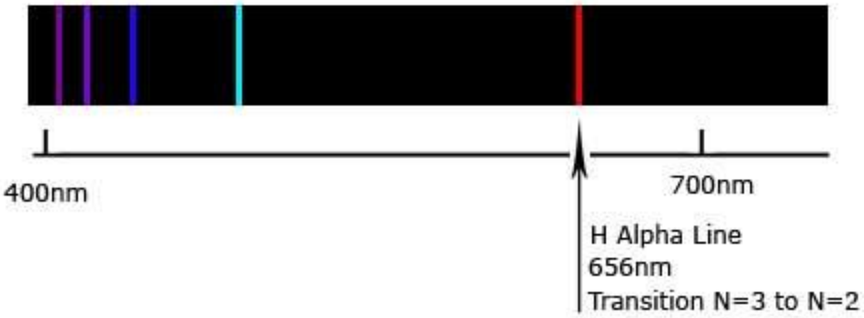
For example, if you were to view hydrogen burning with your spectroscope, you'd see the bottom appear in your spectrometer:

Notice how one fits into the other, like a puzzle. When you put the two together, you've got the entire spectrum.

Hydrogen Absorption Spectrum



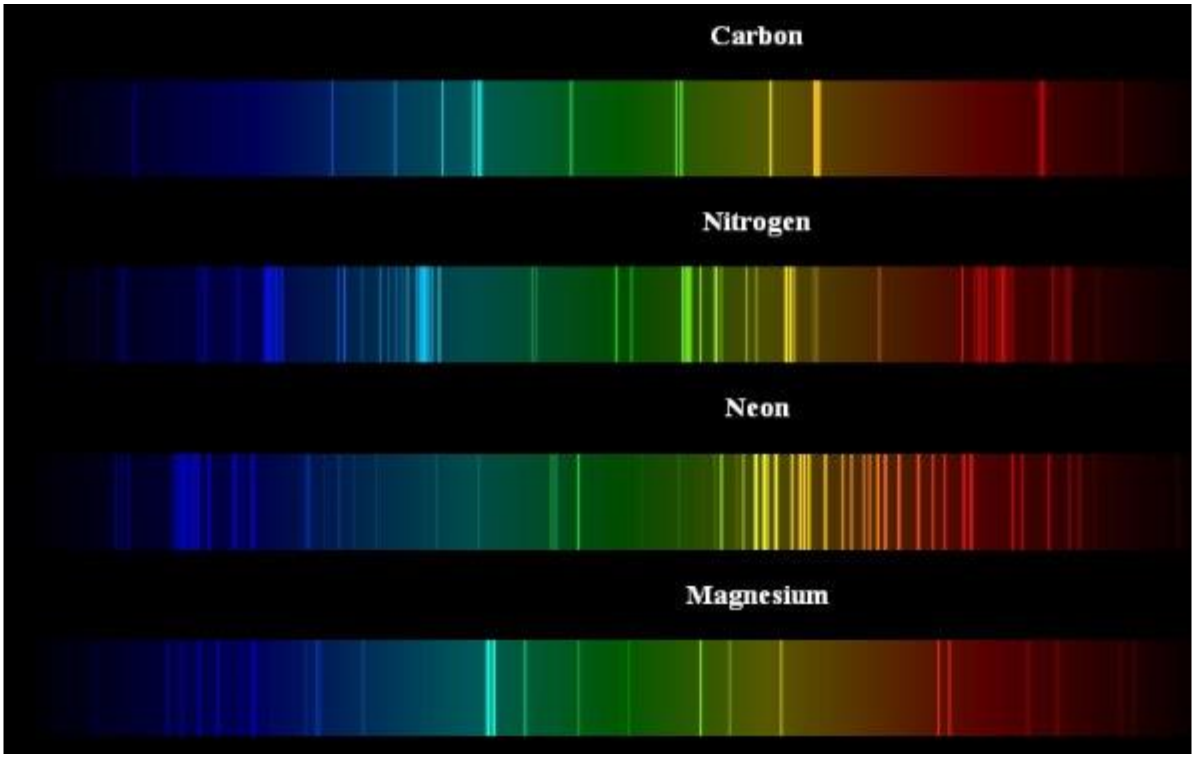
Hydrogen Emission Spectrum



What's the difference between the two? The upper picture (absorption spectrum of hydrogen) is what astronomers see when they use their spectrometers on distant stars when looking through the earth's atmosphere (a cloud of gas particles). The lower picture (emission spectrum of hydrogen) is what you'd see if you were looking directly at the source itself.

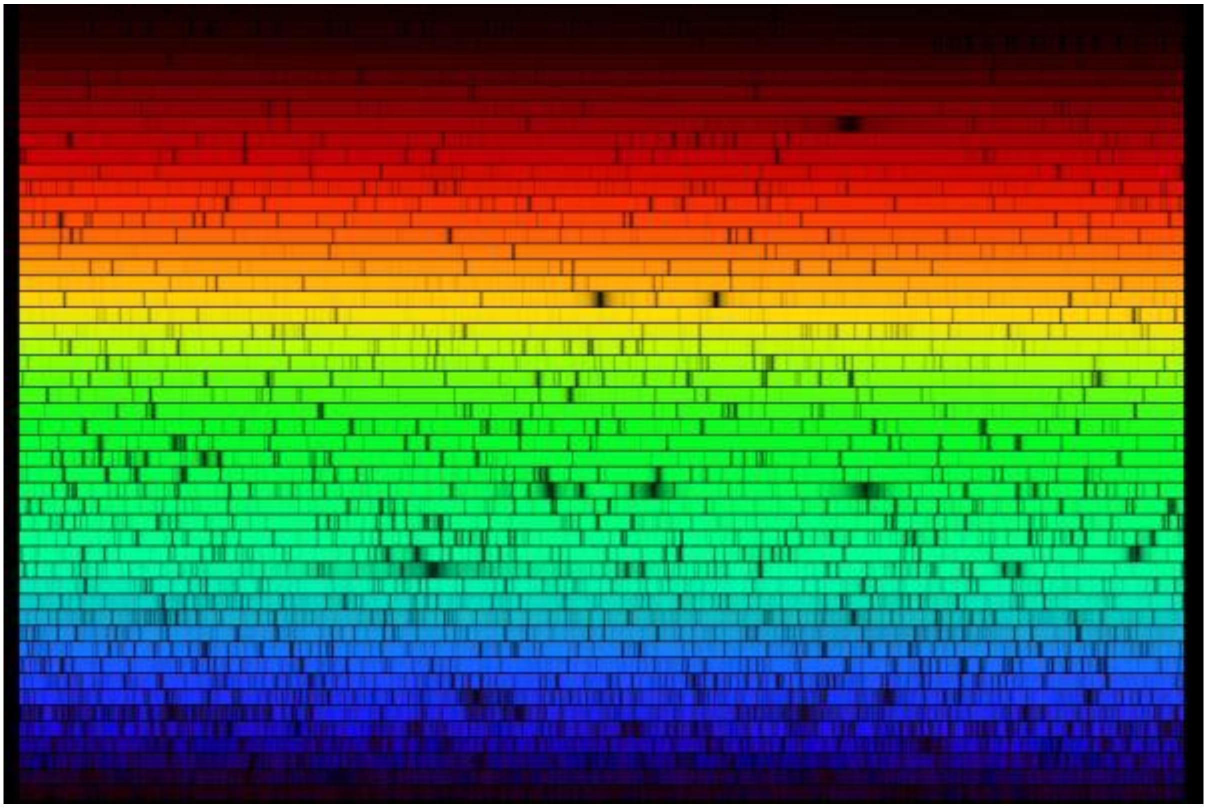
Note - Do NOT use your spectrometer to look at the Sun! When astronomers look at stars, they have computers look for them - they aren't putting their eye on the end of a tube.

Each element has its own special "signature," unique as a fingerprint, that it leaves behind when it burns. This is how we can tell what's on fire ***in*** a campfire. For example, here's what you'd see for the following elements:



Just get the feel for how the signature changes depending on what you're looking at. For example, a green campfire is going to look a lot different from a regular campfire, as you're burning several elements in addition to just carbon. When you look at your campfire with your spectroscope, you're going to see ***all*** the signatures at the same time. Imagine superimposing all four sets of spectral lines above (carbon, neon, magnesium, and nitrogen) into one ***single*** spectrum ... it's going to look like a mess! It takes a lot of hard work to untangle it and figure out which lines belong to which element. Thankfully, these days, computers are more than happy to chug away and figure most of it out for us.

Here's the giant rainbow of absorption lines astronomers see when they point their instruments at the Sun:



Do you see all the black lines? Those are called emission lines, and since astronomers have to look through a lot of atmosphere to view the Sun, there's a lot of the spectrum missing (shown by the black lines), especially corresponding to water vapor. The water absorbs certain wavelengths of light, which corresponds to the black lines.

Click here for more information on Spectra of the Elements. You'll find a lot of great details by clicking on the spectrum you want to know about. Go ahead and check out the different spectral lines with your colored campfires. Have fun!

Exercises

1. Name three more light sources that you think might work with your spectroscope.
2. Why is there a slit at the end of the tube instead of leaving it open? (The light that strikes the end of the tube gets mostly reflected away, and only a tiny amount of light gets inside the tube to the diffraction grating. If you had too much light, you wouldn't be able to see the spectrum.)

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time**.**

Lesson #10: Spectroscopes

Student Worksheet

Name____

Overview: Spectrometers (spectroscopes) are used in chemistry and astronomy to measure light. In astronomy, we can find out about distant stars without ever traveling to them, because we can split the incoming light from the stars into their colors (or energies) and "read" what they are made up of (what gases they are burning) and thus determine what they are made of.

What to Learn: In this experiment, you'll make a simple cardboard spectrometer that will be able to detect all kinds of interesting things!

SPECIAL NOTE: This instrument is NOT for looking at the Sun. Do NOT look directly at the Sun. But you can point the tube at a sheet of paper that has the Sun's reflected light on it.

Materials:

Easy Spectrometer

- Old CD
- Razor
- Index card
- Cardboard tube at least 10 inches long

Advanced Spectrometer (Calibrated)

- Cardboard box (ours is 10″ x 5″ x 5″, but anything close to this will work fine)
- Diffraction grating
- 2 razor blades (with adult help)
- Masking tape
- Ruler
- Photocopy of a ruler (or sketch a line with 1 through 10 cm markings on it, about 4cm wide)

Lab Time *Your teacher will let you know which one to complete!*

Easy Spectrometer:

1. A CD has a diffraction grating built into it. We're going to use a CD instead of a diffraction grating for this experiment.
2. Cut a clean slit less than 1 mm wide in an index card or spare piece of cardboard.
3. Tape it to one end of the tube.
4. Align your tube with the slit horizontally, and on the top of the tube at the far end cut a viewing slot about one inch long and ½ inch wide.
5. Cut a second slot into the tube at a 45-degree angle from the vertical away from the viewing slot.
6. Insert the CD into this slot so that it reflects light coming through the slit into your eye (viewing slot).

7. Aim the 1 mm slit at a light source such as a fluorescent light, neon sign, light bulb, computer screen, television, night light, candle, fireplace… any light source you can find that your teacher has set out for you at different stations. **EXCEPT THE SUN.**
8. Look through the open hole at the light reflected off the compact disk (look for a rainbow in most cases) inside the cardboard tube.
9. Complete the table below.

Spectrometer Data Table

Light Source	**Draw what you see:**	**Wavelength** *For Advanced Spectrometers Only!*

Exercises Answer the questions below:

3. Name three more light sources that you think might work with your spectroscope.

4. Why is there a slit at the end of the tube instead of leaving it open?

Advanced Spectrometer (Calibrated)

1. Using a small box, measure 4.5 cm from the edge of the box. Starting here, cut a hole for the double-razor slit that is 1.5 cm wide 3 cm long.
2. From the other edge (on the same side), cut a hole to hold your scale that is 11 cm wide and 4 cm tall.
3. Print out the scale and attach it to the edge of the box.
4. Very carefully line up the two razors, edge-to-edge, to make a slit and secure into place with tape.
5. On the opposite side of the box, measure over 3 cm and cut a hole for the diffraction grating that is 4 cm wide and 3 cm tall.
6. Tape your diffraction grating over the hole.
7. Aim the razor slit at a light source such as a fluorescent light, neon sign, sunset, light bulb, computer screen, television, night light, candle, fireplace … any light source you can find. Put the diffraction grating up to your eye and look at the inner scale. Move the spectrometer around until you can get the rainbow to be on the scale inside the box.

How to Calibrate the Spectrometer with the Scale

8. Inside your box is a scale in centimeters. Point your slit to a fluorescent bulb, and you'll see three lines appear (a blue, a green, and a yellow-orange line). The lines you see in the fluorescent bulb are due to mercury superimposed on a rainbow continuous spectrum due to the coating. Each of the lines you see is due to a particular electron transition in the visible region of Hg (mercury).
    1. **blue line (435 nm)**
    2. **green line (546 nm)**,
    3. **yellow orange line (579 nm)**

    If you look at a sodium vapor street light, you'll see a yellow line (actually 2 closely spaced) at 589 nm.

9. Line the razor slits along the length of the fluorescent tube to get the most intense lines. Move the box laterally (the lines will move due to parallax shift).
10. Take scale readings at the extreme of these movements and take the average for the scale reading. For instance, if the blue line averages to the 8.8 cm value, this corresponds to the 435 nm wavelength. Do this for the other 2 lines.
11. On graph paper, plot the cm (the ruler scale values) on the vertical axis and the wavelength (run this from 400-700 nm) on the horizontal axis.
12. Draw the best straight lines through the 3 points (4 lines if you use the Na (sodium) street lamp). You've just calibrated the spectrometer!
13. Line the razor slits up with another light source. Notice which lines appear and where they are on your scale. Find the value on your graph paper. For example, if you see a line appear at 5.5 cm, use your finger to follow along to the 5.5 cm until you hit the best-fit line, and then read the corresponding value on the wavelength axis. You now have the wavelength for the line you've just seen!

Notes on Calibration and Construction: If you swap out different diffraction gratings, you will have to re-calibrate. If you make a new spectrometer, you will have to re-calibrate to the Hg (mercury) lines for each new spectrometer. If you do remake the box, use a scale that is translucent so you can see the numbers. If you use a clear plastic ruler, it may let in too much light from the outside making it difficult to read the emission line.

Lesson #11: Fire & Optics

Teacher Section

Overview: You're going to demonstrate what happens if you concentrate the energy from the Sun through optical lenses. Since magnifying lenses, telescopes, and microscopes all use lenses to magnify images, students often wonder why they should never look at the Sun. This demonstration will cure their curiosity for good.

Suggested Time: 30-45 minutes

Objectives: Students will learn the real reason why they are NEVER to look through anything that has lenses in it at the Sun, including binoculars or telescopes.

Because this activity involves fire, make sure you do this on a flame-proof surface and not your dining room table! Good choices are your driveway, cement parking lot, the concrete sidewalk, or a large piece of ceramic tile. Don't do this experiment in your hand, or you're in for a hot, nasty surprise.

Materials (per lab group)

- Sunlight
- Glass jar
- Nail that fits in the jar
- 12" thread
- Hair from your head
- 12" string
- 12" fishing line
- 12" yarn
- Paperclip
- Magnifying glass
- Fire extinguisher
- Adult help

Lab Preparation

1. Print out copies of the student worksheets.
2. Read over the Background Lesson Reading before teaching this class.
3. There are two videos for this lab. The burning leaf experiment is the one *you* get to do as a demonstration. The second video is the one the kids get to do, because there's less flammable material and less chance of them starting fires and getting into trouble. Watch the video for this experiment to prepare for teaching this class.
4. You'll need a magnifier and a dead leaf for your demonstration for the kids.
5. Ask the kids to bring in their jars ahead of time so you can prepare the lids before class. No water bottles – you want something that doesn't melt, like a glass jar from the pickles or the mayo.
6. When you have all the jars, remove the lids and punch a hole in the center of each lid. Use a drill with a ¼" drill bit or smaller, or a hammer and nail.

Background Lesson Reading

Magnifying lenses, telescopes, and microscopes use this idea to make objects appear different sizes by bending the light. When light passes through a different medium (from air to glass, water, a lens…) it changes speed and usually the angle at which it's traveling. A prism splits incoming light into a rainbow because the light bends as it moves through the prism. A pair of eyeglasses will bend the light to magnify the image.

Lesson

1. This lab is in two parts. The demonstration you do with the kids is not the one they do for their activity. You're going to concentrate the power of the Sun on a flammable surface.
2. Please do this on a fireproof surface! This experiment will damage tables, counters, carpets, and floors. Do this experiment on a fireproof surface, like concrete or blacktop.
3. Hold the magnifier above the leaf and bring it down toward the leaf until you see a bright spot form on its surface. Adjust it until you see the light as bright and as concentrated as possible. First, you'll notice smoke, then a tiny flame as the leaf burns.
4. You are concentrating the light, specifically the heat, from the Sun into a very small area. Normally, the sunlight would have filled up the entire area of the lens, but you're shrinking this down to the size of the dot that's burning the leaf.
5. Thermoelectric power plants use this principle to power entire cities by using this principle of concentrating the heat from the Sun.
6. Never look through anything that has lenses in it at the Sun, including binoculars or telescopes, otherwise what's happening to the leaf right now is going to happen to your eyeball.

Lab Time

1. Review the instructions on their worksheets and then break the students into their lab groups.
2. Hand each group their materials and give them time to perform their experiment and write down their observations.
3. Screw the lid on the jar.
4. Tie one end of the thread to the paperclip.
5. Poke the other end of the thread inside the hole on the lid.
6. Unscrew the lid and tie a nail to the other end of the thread. You want the nail to be hanging above the bottom of the jar by an inch or two, so adjust the height as needed.
7. Bring your jar outside.
8. Question: *Without breaking the glass or removing the lid, how can you get the nail to drop to the bottom of the jar?*
9. Once you've successfully got the nail to drop, substitute a hair from your head for the thread and do the experiment again and time it. Complete the table below.

Exercises

1. What happened to the leaf? Why? (You are concentrating the light, specifically the heat, from the Sun into a very small area. Normally, the sunlight would have filled up the entire area of the lens, but you're shrinking this down to the size of the dot that's burning the leaf.)
2. How did you get the nail to drop? (By concentrating the energy from the Sun using the magnifier.)
3. Which material ignited the quickest? (Refer to data table.)

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Lesson #11: Fire and Optics

Student Worksheet

Name____

Overview: Today you get to concentrate light, specifically the heat, from the Sun into a very small area. Normally, the sunlight would have filled up the entire area of the lens, but you're shrinking this down to the size of the dot.

What to Learn: Magnifying lenses, telescopes, and microscopes use this idea to make objects appear different sizes by bending the light. When light passes through a different medium (from air to glass, water, a lens …) it changes speed and usually the angle at which it's traveling. A prism splits incoming light into a rainbow because the light bends as it moves through the prism. A pair of eyeglasses will bend the light to magnify the image.

Materials

- Sunlight
- Glass jar
- Nail that fits in the jar
- 12" thread
- Hair from your head
- 12" string
- 12" fishing line
- 12" yarn
- Paperclip
- Magnifying glass
- Fire extinguisher
- Adult help

Lab Time

1. Screw the lid on the jar.
2. Tie one end of the thread to the paperclip.
3. Poke the other end of the thread inside the hole on the lid.
4. Unscrew the lid and tie a nail to the other end of the thread. You want the nail to be hanging above the bottom of the jar by an inch or two, so adjust the height as needed.
5. Bring your jar outside.
6. Question: *Without breaking the glass or removing the lid, how can you get the nail to drop to the bottom of the jar?*

Fire & Optics & Eyes Data Table

Material for Suspending Nail	**How Long Did It Take to Drop?** *(measure in seconds)*

Exercises Answer the questions below:

1. What happened to the leaf? Why?

2. How did you get the nail to drop?

3. Which material ignited the quickest?

Lesson #12: Reflector and Refractor Telescopes

Teacher Section

This is a Bonus Lab, meaning that it's in addition to the experiments the kids get to do throughout the course. Feel free to skip this lab if the materials are out of your budget, or save it as a treat for the end of the year.

Overview: Telescopes aren't nearly as complicated as they seem. We're going to build two different kinds of telescopes: the refractor (which has only lenses) and the reflector (which has lenses and mirrors) telescopes.

Suggested Time: 30-45 minutes

Objectives: Your lenses are curved pieces of glass or plastic designed to bend (refract) light. A simple lens is just one piece, and a compound lens is when you stack two or more together, like inside a camera. You can arrange your lenses in different ways to get different types of magnification.

Materials (per lab group)

- Index card
- 3 clothespins
- Popsicle sticks
- 2 meter sticks
- Bright light source
- Two double-convex lenses
- Concave mirror
- Small flat mirror (like a mosaic mirror)
- Large paper clip
- Black garbage bag
- Rubber band
- Waxed paper
- Masking tape
- Hot glue gun
- Scissors

Lab Preparation

1. Print out copies of the student worksheets.
2. Instead of reading the Background Lesson Reading, watch all the videos for this lab *before* teaching this class. They give a good overview of light and lenses.

Lesson

1. The videos for these labs are longer than usual, as I've included bonus content about building optical benches that include complete instructions for mounting lenses and mirrors to the rail. Watch the videos first and then build a demonstration model to share with your students.
2. If you opt for your students to build one of these, have a model working in advance on the main table so they can come up and look when they get stuck. If you build it together slowly, you'll succeed more quickly.

Lab Time

1. Review the instructions on their worksheets and then break the students into their lab groups.
2. Hand each group their materials and give them time to perform their experiment and write down their observations.
3. In the video, I used a simulated crescent moon as a light source for the telescopes. To make this moon light source, stretch a section of a garbage bag over the head of the flashlight as shown in the video. You can cut out a crescent moon and line the cut section with waxed paper on the inside. Attach the garbage bag to the flashlight with a rubber band with the waxed paper on the inside.
4. Mount a double-convex lens to a clothespin as shown in the Optical Bench video. You need two of these for the refractor telescope. Make sure your two lenses magnify about the same amount.
5. Make an optical rail and mount one of the lenses near one end of the rail. You'll adjust it soon when you bring the moon shape into focus.
6. Place an index card near the middle of the optical rail. Don't attach it to the meter stick itself.
7. Place your flashlight about six feet away from the table so it shines through the lens and onto the index card.
8. Adjust the distance the lens is from the index card and bring the moon into focus.
9. At this point, if you have different-sized lenses, you can hold the second one near the first so you have two moons on the card. Do you notice the difference in brightness in moons? If your lenses are different sizes, the larger lens will make a brighter image because it's got more light-gathering ability. Remove the second lens - we were just demonstrating this concept with it.
10. Slide the optical rail around so that the moon on the index card is right over the meter stick.
11. Take the second lens and insert it into the rail on the *other side* of the index card.
12. Look through the second lens and bring the moon that shines through the card into focus.
13. As you still look through the second lens, remove the card and look through both lenses. Make any tiny adjustments, if needed. You're looking for the moon to be in focus and magnified. You just made a refractor telescope, exactly like Galileo did 400 years ago!
14. Draw a diagram of your telescope and include the following:
    a. Label the two lenses
    b. Label the light source
    c. Measure the distance between the light source and the first lens and draw it in your diagram
    d. Measure the distance between the first and second lens and draw it in your diagram
    e. Title your image – what kind of telescope is it?
    f. What is the magnification of your telescope? Add this to your drawing under the title.

15. Now, we're going to replace one of the lenses with a curved mirror to make a reflector telescope.
16. Mount the mirror at the far end of the optical rail. The light source is still at the opposite end.
17. Move the index card into position to catch the reflection of the moon. Adjust the mirror so that the moon is right over the rail and in focus. Make sure the index card is not attached to the optical rail.
18. Pick up your double-convex lens and place it on the opposite side of the card from the mirror and look through it to focus the image as we did before.
19. Uh-oh! Did you find a problem? That's right – your *head* got in the way of the light source, didn't it?
20. What if we use a tiny mirror to change the direction of the light and then we can focus it?
21. Open up the paperclip into an L-shape and hot glue or tape one side of the L to the back of your mirror.
22. The other end of the paperclip attaches to the popsicle stick so you can insert it into the optical rail.
23. Hold the popsicle stick and paper clip junction as you rotate the mirror into position. You need to flip it 90 degrees down and over at 45 degrees.
24. Insert the secondary mirror (the tiny one we just mounted on a popsicle stick) into the optical rail.
25. Adjust your rail so that the moon is right over the rail and at the edge of the index card.
26. Adjust the image of the moon by moving the mirror so that the moon is the same height as the tiny mirror.
27. When you've got it, remove the card and the image should be right on your card. Look right at the tiny mirror with your eye and see if you can spot the crescent moon.
28. Take your magnifier and hold it up to your eye to see if you can make that focused image even larger. The magnifier is your *eyepiece*. The curved mirror is your *primary mirror*. The tiny flat mirror is your *secondary mirror.*
29. Draw a diagram of your telescope and include the following:
    a. Label the two mirrors
    b. Label the lens (what kind is it?)
    c. Label the light source
    d. Measure the distance between the light source and the first (primary) mirror and draw it in your diagram
    e. Measure the distance between the first and second mirrors and draw it in your diagram
    f. Measure the distance between the second mirror and your magnifier and draw it in your diagram
    g. Title your image – what kind of telescope is it?
    h. What is the magnification of your telescope? Add this to your drawing under the title.

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Lesson #12: Reflector and Refractor Telescopes

Student Worksheet

Name____

Overview: Telescopes aren't nearly as complicated as they seem. We're going to build two different kinds of telescopes: the refractor (which has only lenses) and the reflector (which has lenses and mirrors) telescopes.

What to Learn: Your lenses are curved pieces of glass or plastic designed to bend (refract) light. A simple lens is just one piece, and a compound lens is when you stack two or more together, like inside a camera. You can arrange your lenses in different ways to get different types of magnification.

Do not use this telescope to look at the Sun! *This telescope is for looking at the moon, distant terrestrial objects, and flashlights with their light intensity stepped down and passed through a wax filter.*

Materials

- Index card
- 3 clothespins
- Popsicle sticks
- 2 meter sticks
- Bright light source
- Two double-convex lenses
- Concave mirror
- Small flat mirror (like a mosaic mirror)
- Large paper clip
- Black garbage bag
- Rubber band
- Waxed paper
- Masking tape
- Hot glue gun
- Scissors

Lab Time

1. To make a moon light source, stretch a section of a garbage bag over the head of the flashlight. You can cut out a crescent moon and line the cut section with waxed paper on the inside. Attach the garbage bag to the flashlight with a rubber band with the waxed paper on the inside.
2. Mount a double-convex lens to a clothespin as shown in the Optical Bench video. You need two of these for the refractor telescope. Make sure your two lenses magnify about the same amount.
3. Make an optical rail and mount one of the lenses near one end of the rail. You'll adjust it soon when you bring the moon shape into focus.
4. Place an index card near the middle of the optical rail. Don't attach it to the meter stick itself.
5. Place your flashlight about six feet away from the table so it shines through the lens and onto the index card.
6. Adjust the distance the lens is from the index card and bring the moon into focus.

7. At this point, if you have different-sized lenses, you can hold the second one near the first so you have two moons on the card. Do you notice the difference in brightness in moons? If your lenses are different sizes, the larger lens will make a brighter image because it's got more light-gathering ability. Remove the second lens - we were just demonstrating this concept with it.
8. Slide the optical rail around so that the moon on the index card is right over the meter stick.
9. Take the second lens and insert it into the rail on the *other side* of the index card.
10. Look through the second lens and bring the moon that shines through the card into focus.
11. As you still look through the second lens, remove the card and look through both lenses. Make any tiny adjustments, if needed. You're looking for the moon to be in focus and magnified. You just made a refractor telescope, exactly like Galileo did 400 years ago!
12. Draw a diagram of your telescope and include the following:
    a. Label the two lenses
    b. Label the light source
    c. Measure the distance between the light source and the first lens and draw it in your diagram
    d. Measure the distance between the first and second lens and draw it in your diagram
    e. Title your image – what kind of telescope is it?
    f. What is the magnification of your telescope? Add this to your drawing under the title.

13. Now, we're going to replace one of the lenses with a curved mirror to make a reflector telescope.
14. Mount the mirror at the far end of the optical rail. The light source is still at the opposite end.
15. Move the index card into position to catch the reflection of the moon. Adjust the mirror so that the moon is right over the rail and in focus. Make sure the index card is not attached to the optical rail.
16. Pick up your double-convex lens and place it on the opposite side of the card from the mirror and look through it to focus the image as we did before.
17. Uh-oh! Did you find a problem? That's right – your *head* got in the way of the light source, didn't it?
18. What if we use a tiny mirror to change the direction of the light and then we can focus it?
19. Open up the paperclip into an L-shape and hot glue or tape one side of the L to the back of your mirror.
20. The other end of the paperclip attaches to the popsicle stick so you can insert it into the optical rail.
21. Hold the popsicle stick and paper clip junction as you rotate the mirror into position. You need to flip it 90 degrees down and over at 45 degrees.
22. Insert the secondary mirror (the tiny one we just mounted on a popsicle stick) into the optical rail.
23. Adjust your rail so that the moon is right over the rail and at the edge of the index card.
24. Adjust the image of the moon by moving the mirror so that the moon is the same height as the tiny mirror.
25. When you've got it, remove the card and the image should be right on your card. Look right at the tiny mirror with your eye and see if you can spot the crescent moon.
26. Take your magnifier and hold it up to your eye to see if you can make that focused image even larger. The magnifier is your *eyepiece*. The curved mirror is your *primary mirror*. The tiny flat mirror is your *secondary mirror.*
27. Draw a diagram of your telescope and include the following:
    a. Label the two mirrors
    b. Label the lens (what kind is it?)
    c. Label the light source
    d. Measure the distance between the light source and the first (primary) mirror and draw it in your diagram
    e. Measure the distance between the first and second mirrors and draw it in your diagram
    f. Measure the distance between the second mirror and your magnifier and draw it in your diagram
    g. Title your image – what kind of telescope is it?
    h. What is the magnification of your telescope? Add this to your drawing under the title.

Lesson #13: Black Holes

Teacher Section

Overview: We're ready to deal with the topic you've all been waiting for! Join me as we find out what happens to stars that wander too close, how black holes collide, how we can detect super-massive black holes in the centers of galaxies, and wrestle with the question: What's down there, inside a black hole?

Suggested Time: 30-45 minutes

Objectives: We're going to take a sneak peek at the laws of physics that govern these and more in our adventure through black holes. You can totally relax, because I am going to do all the teaching for you, as you will be playing a video for your class for the lab today.

Materials (per lab group)

- Marble
- Metal ball (like a ball bearing) or a magnetic marble
- Strong magnet
- Small bouncy ball
- Tennis ball and/or basketball
- Two balloons
- Bowl
- 10 pennies
- Saran wrap (or cut open a plastic shopping bag so it lays flat)
- Aluminum foil (You'll need to wrap inflated balloons with the foil, so make sure you have plenty of foil.)
- Scissors

Lab Preparation

1. Print out copies of the student worksheets.
2. Read over the Background Lesson Reading before teaching this class.
3. Watch the video for this lab to prepare for this class so know what the students will be learning.
4. Get a couple of different sizes of balls, like a tennis ball and a bouncy ball, or a tennis ball and a basketball so you can demonstrate the supernova explosion.

Background Lesson Reading

Question: What is a black hole? It's **BLACK** because does not emit or reflect light. Black holes are the darkest black in the universe – no matter how powerful a light you shine on it, even if it's a million-watt flashlight, no light ever bounces back, because it's truly a "hole" in space.

HOLE means nothing entering can escape. Anything that crosses the edge is swallowed forever. Scientists think of black holes as the edge of space, like a one-way exit door. What's a black hole made of? Black holes are made of nothing but space and time, and they are the strangest things in nature.

One of the biggest myths about black holes: Black holes are not vacuum cleaners with infinite-sized bags. They do not roam around the universe sucking up everything they can find. They will grow gradually as stars and matter fall into them, but they do not seek out prey like predators. A black hole just sits there with its mouth open, waiting for dinner.

It's actually more like a basketball hoop – think about a hoop: it just sits there waiting for you to put a ball through, right? I mean, you wouldn't expect a basketball hoop to chase you around the court, would you? So a black hole just sits there waiting for stuff to fall in, kind of like an invisible trap.

So what IS a black hole?

Here's an example of what a black hole is: Hold out your hand in front of you, and place in your hand an imaginary ball. Don't use a real one, or someone might be upset with what we're going to do with it. Now take that ball and toss it up in the air… does it come back down to you? Sure!

Toss it up even higher now… and it still comes back, right? Pretend you're outside and really toss it up hard – higher than the house! Does it STILL come back down?

What if you toss it up so fast that it exceeds the escape velocity of earth? (7 miles per second) Will it ever come back? No. The escape velocity depends on the gravitational pull of an object. The escape velocity of the Sun is 400 miles per second. A black hole is an object that has an escape velocity greater than the speed of light. That's exactly what a black hole is.

Let me say that again – a black hole is an object that requires objects to go faster than light to escape the gravitational pull. That's all there is to it. The rest is all on the video, including the three ways to detect black holes, what happens if you were to fall into a black hole, and the most famous black hole scientists.

Lesson

1. Today you, the teacher, have a choice to make: You can have me teach your students directly or you can watch the video in advance and teach it to your kids. You can let the students watch the video while they work through the experiments that we'll do during the video. If you prefer to teach this class yourself, simply watch it in advance, take notes as to the experiments to have the kids do, and enjoy the fun.
2. When we get to the supernova question: ""Why do supernovas explode at all if they are shrinking and collapsing?" pull out the two different sizes of balls that you set aside and demonstrate this for the kids.

Here's how you do it:

3. Tell the kids: "I want to you grab your two different sizes of balls – either a tennis ball and a bouncy ball, or a tennis ball and a basketball. Either one will work. If you don't have any, just do this in your mind as we go along."
4. "First, I want you to hold out the larger ball at arm's length in front of you. You'll want to do this over a flat surface – something without any rugs or carpet. Drop (don't throw and don't bounce) your larger ball on the floor. Do you see how high it bounces on its own?"
5. "Now drop your smaller ball (this can be a bouncy ball or a tennis ball if you're using a basketball) on the ground and notice how far it bounces back up. Got it?"
6. "Okay, now place the smaller ball on top of the larger ball like it shows here in the picture and let them BOTH drop at the same time so that they fall together and hit the ground with the smaller ball still on top. You've got to make sure that the smaller ball stays on top when it hits the ground. If it falls off, you've got to do it again."
7. So - what happened? Give them time to get this experiment right.
8. When the two balls hit the floor, the smaller ball suddenly rebounds with enough energy to hit the ceiling!
9. How high did the larger ball bounce? More or less than when you dropped it by itself? The larger ball transferred its energy to the smaller ball and didn't bounce much (if at all).
10. This is exactly what happens in a supernova. When the core of a star collapses, it smacks together so HARD that it rebounds – it bounces back. When it rebounds and bounces back out, it collides with the rest of the gas that is still falling inward. When the rebounding core hits the in-falling gas, the core blasts everything out into space… and this makes a giant explosion!
11. This idea is just like the experiment with the tennis ball we just did – the bigger ball is the core collapsing, and the small ball is the outer gas layers that take longer to collapse. When the core (big ball) rebounds, it hits the gases (small ball) with enough energy to blow the gas layers away from the star. That's why supernovas explode.

Lab Time

1. Review the instructions on their worksheets and then break the students into their lab groups.
2. Hand each group their materials before the video starts. They will be doing the experiments while the video is playing. You can have a set for yourself to demonstrate as we go along.

Exercises

1. What are three different ways to detect a black hole? (Look for X-rays from actively feeding black holes, gravitational lensing, and stars that appear to orbit something that's not there.)
2. How many ways can a black hole kill you? Can you name them? (You can get killed by a black hole by: falling in, spaghettification, being near when it forms, being near when it evaporates, being near when two black holes smack into each other, fried by the X-ray light coming out)
3. What happens if you get close to a black hole, but not close enough to get sucked in? (Remember your magnet-marble experiment! Your path appears to be straight (to you), but in follows the curve of space and deflects.)
4. What's the most interesting thing you learned from the video about black holes?
5. What causes a black hole to form? (When the biggest stars run out of fuel, they explode and what's left over is a black hole as the core collapses forever.)
6. Does a black hole search for its next victim? (No – it just sits there waiting.)

7. Where is the closest super-massive black hole? (At the center of our galaxy.)
8. What is gravitational lensing and why does it work? (When gravity from a black hole bends light, we can see the effects in photographs. Although we can't actually "see" a black hole, we can see the light being bent around it.)

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Lesson #13: Black Holes

Student Worksheet

Name____

Overview: We're ready to deal with the topic you've all been waiting for! Join me as we find out what happens to stars that wander too close, how black holes collide, how we can detect super-massive black holes in the centers of galaxies, and wrestle with the question: What's down there, inside a black hole?

What to Learn: We're going to take a sneak peek at the laws of physics that govern these and more in our adventure through black holes. You'll have a set of materials so you can do the activities as we learn about black holes in our video class together.

Materials

- Marble
- Metal ball (like a ball bearing) or a magnetic marble
- Strong magnet
- Small bouncy ball
- Tennis ball and/or basketball
- Two balloons
- Bowl
- 10 pennies
- Saran wrap (or cup open a plastic shopping bag so it lays flat)
- Aluminum foil (you'll need to wrap inflated balloons with the foil, so make sure you have plenty of foil)
- Scissors

Exercises Answer the questions below:

1. What are three different ways to detect a black hole?

2. How many ways can a black hole kill you? Can you name them?

3. What happens if you get close to a black hole, but not close enough to get sucked in? (Remember your magnet-marble experiment!)

4. What's the most interesting thing you learned from the video about black holes?

5. What causes a black hole to form?

6. Does a black hole search for its next victim?

7. Where is the closest super-massive black hole?

8. What is gravitational lensing and why does it work? (Remember your marble-bowl experiment!)

Lesson #14: Black Hole Bucket

Teacher Section

Overview: What comes to mind when you think about empty space? (You should be thinking: "*Nothing!"*) One of Einstein's greatest ideas was that empty space is not actually nothing – it has energy and can be influenced by objects in it. It's like the T-shirt you're wearing. You can stretch and twist the fabric around, just like black holes do in space.

Suggested Time: 30-45 minutes

Objectives: Students will get introduced to the idea that gravity is the structure of spacetime itself. Massive objects curve space. How much space curves depends on how massive the object is, and how far you are from the massive object.

Materials (per lab group)

- Two buckets (They need two holes in the bottom, one on each side. The buckets that plants come in from the nursery work perfectly. The ones in the video are 1.5 liter, about 13" across.)
- 2 bungee cords
- 3 different sizes of marbles
- 2.5 lb weight (you can use a lead weight if it's coated or sealed so that the kids can't touch it)
- 0.5 lb weight
- 3 squares of stretchy fabric
- Rubber band
- 4 feet of string
- Fishing bobber
- Drinking straws
- Softball
- Playdough (optional)

Lab Preparation

1. Print out copies of the student worksheets.
2. Read over the Background Lesson Reading before teaching this class.
3. Watch the video for this experiment to prepare for teaching this class.
4. You'll be showing four short animations of black holes, so you'll need a way to play them for students to see.

Background Reading

Here are some of the most-asked questions when I give a class on black holes:

Question: *Does time slow down when you approach a black hole?* Yes! Great questionv… Gravity does affect time – in fact, the stronger the gravity field, the slower time passes as viewed from an outside observer. In fact, in the 1960s, a very sensitive experiment was done at Harvard that had two identical clocks: one at the base and one at the tip of a 74-foot tower. The experiment verified that time did pass a different rate for both clocks! Which clock do you think ran slower? That's right – the one closer to the Earth (it was in a slightly stronger gravitational field). This is very important with the GPS systems. Without correcting for this, our GPS satellite system would be way off! It's called gravitational time dilation. That's why black holes are called frozen stars, because time passes extremely slowly near a black hole.

Question: *Do black holes make time-travel or galaxy-travel possible?* Maybe, but not for humans just yet. Black holes can help wormholes form, we think. A wormhole is a bridge from one part of space to another. Think about it this way: If you put a dot at the upper corner of a sheet of paper, and another dot at the lower corner, and drew a line connecting the dots, that's how you'd travel to get from one star to another. But if you folded the paper so that the two dots line up on top of each other, a wormhole would be a bridge that connects one to another *through* the paper. However, scientists think that wormholes are very unstable, and they collapse very quickly, unless they are held up by something. It might be possible to figure out how to keep a wormhole open, and then use it for traveling through space and time, but not today.

Question: *If light doesn't have mass, how does it get sucked into a black hole?* Wow – that's a really good question, and by piecing together everything we talked about, you can figure this out. OK, so in a black hole, we've already talked about how if you shine a light at the black hole, it gets trapped in the black hole, but it's not because it has mass but because the gravity of the black hole bends the space around it – do you remember the experiment we did with the bowl and the marble? The plastic wrap bends around the marble, right? Space bends around an object and that's why light can't escape… it has nothing to do with mass. And we already know through gravitational lensing that the photon is affected by gravity – gravity can bend light and distort the images we see.

Question: *How does gravity escape a black hole?* That's a REALLY brilliant question … because there are two points of view for gravity. According to Einstein, gravity doesn't have to get out of the black hole, because gravity is the structure of space itself, like we saw with the marble-bowl experiment when the plastic wrap indented under the marble – space does the same thing with big, heavy objects. However, when you look at stuff at the quantum level – that's when we look at what's inside atoms (the small little dots that stuff is made up of); this is a problem, because we don't know how yet. The best answer here is that gravity has a get-out-of-a-black-hole-free-card.

Question: *How can time change when you travel fast, like near the speed of light?* That's a really good question. To answer this, I have to ask you something first: So if I were to ask you how far California is from New York, what would you say? Is there more than one way to get there? Do you think you'd get a different answer if you were taking the scenic route on twisting highways or flying straight across in an airplane? Sure you would! When you go from California to New York, you could take the shortest route, which is the great circle distance which is about 2,000 miles or the most scenic, which is over 5,000 miles. The distance you'd travel depends on the path you take, right?

Okay, now what if you noticed that it was 3 o'clock now on your watch, and I asked you what time it would be in one hour… what would you say? 4 o'clock, right? Not only for you, but for me, kids in Japan, and the space aliens on the other side of the galaxy. All our watches always tick at the same rate, so in one hour all our watches should say 4 o'clock (ignore the time zone difference - that's not what we're talking about here) ... The point is that all our watches would indicate one hour later than we see now, right (regardless of what time zone you are in)?

But Einstein came along and said – "Wait! That's not right. Time is like space… the rate that it ticks by depends on the path you take …" With time, time passes at different rates depending on if you're moving around or standing still. For example, if you have two watches that are perfectly synchronized (like in spy movies) and one stays put and the other goes zooming all over the planet and then back again, the one that moved will have experienced *less* time, meaning that the moving watch's ticks go more slowly than the stationary watch. We've done this experiment hundreds of times, where we have one clock race around the Earth in a jet and compare it with one that stayed put on the ground, and the one moving about is slightly slower than the one on the ground.

Time doesn't pass at the same rate for both, and here's the real kicker … they are both right. There's not one point of view that's the "right" one, which is why when you study this kind of physics, you always have to say what it's compared to. You already know this is true - think about it: When you fly in an airplane, you're moving at 600 mph. Are you worried when the stewardess tries to fill up your cup with soda? No, not really … Are you concerned at all when you open up the bag of peanuts? No – why should you be? Right – that's because physics is working like it normally does at 600 mph, as it would if you were sitting still on the ground. If it didn't, meaning that there was only one right point of view, then when you opened up the bag of peanuts, they'd go flying everywhere because they were moving at 600 mph! And you'd totally miss the cup if you were trying to pour it from a can traveling at 600 mph, wouldn't you?

Right – so it doesn't matter if you're pouring coffee in an airplane, tossing a ball on a train, playing tennis on a cruise ship or playing soccer at the park, physics works the same in every situation, and everyone thinks that their point of view is normal. When you're in a jet, you don't notice your watch slowing down, or see things suddenly moving in slow motion… everything appears normal to you. The same is true for the watch that stays put on the surface of the Earth. The difference appears when one point of view peeks into the other's world – that's when you notice a difference. If you have a see-through airplane, the observer on the ground might be surprised to see peanuts flying through the air at 600 mph and not spilling everywhere. If I'm standing on the Earth, I can see your watch in the jet tick by at a slower rate than my watch, but both our watches are working fine in their own situations. It's just one of the laws of the universe Whew! Okay… I hope that made a little sense… if not, well, that's why we're sending out a replay of this class.

Lesson

1. Massive objects are truly massive. If our solar system was the size of a quarter, the Milky Way would be the size of North America.
2. The Milky Way has an estimated 100 billion stars. That's hard to imagine, so try this: Imagine a football field piled 4' deep in birdseed. Now scatter those seeds over North America and space them 25 miles deep. Each seed is a Sun. Stars are very far apart!
3. If the mass of the Sun was one birdseed, then the mass of a black hole would be 22 gallons of birdseed shoved into the volume of a single birdseed.
4. It's time to explore how black holes interact with the universe. There are four animations to watch. Let the students know that these are scientific simulations which used actual data to create them – they are not artist's concepts or fantasy. They are based on solid physics. The reason they are animations is because these videos happen over such a long period of time, and our view is limited in some cases.
5. Tidal Disruption (video below) shows a yellow star that wanders too close to a black hole. The black hole is in the center of a galaxy. Notice how when the yellow star nears the black hole, the star gets stretched, squeezed, and then shredded and torn apart. Kids will get to do this with their rocket ship during their lab activity.

6. SGR (Sagittarius) Flare (video below) demonstrates X-ray flares are produced when matter falls into an accretion disk that circles around a supermassive black hole, like the one we have in the center of our own Milky Way galaxy.

7. X-ray binary sequence (video below) shows a binary system where one of the stars has exploded as a supernova and dumped its mass onto its companion star. The supernova then turned into a black hole, as in Cygnus X-1 (the first black hole we ever discovered). The remaining star is having its outer atmosphere drawn toward the black hole. As gas falls into the black hole, it emits a flood of X-ray light.

8. Here's an animation (video below) of two galaxies colliding, each with their own supermassive black holes in their centers. The last image is what we actually see today, and scientists figured out what had to happen in order to create what we see today. Both black holes are actively feeding and producing X-rays. These images were observed by the Chandra Observatory.

Lab Time

1. Review the instructions on their worksheets and then break the students into their lab groups.
2. Hand each group their materials and give them time to perform their experiment and write down their observations.
3. What is gravity? How does it work? That's what today's lab is all about.

Making the Buckets Ready for the Lab

4. Stretch the bungee cord around the circumference of the bucket. Do this for both buckets.
5. On one bucket, tuck in the stretchy fabric under the cord. If your cords are loose, tie another knot near the end so they fit snugly around the bucket. The fabric is stretched like a drum head. This is the "fabric of space" – it's around us everywhere.
6. Push the bottom of the bobber so the hook opens on the other end. Push your string in.
7. Place it in the center of the squares of fabric. Fasten it with your rubber band.
8. Thread the ends of your string through the bottom holes of your second bucket and tie it securely on the bottom.
9. Tuck in your corners under the bungee cord. This is your black hole bucket.
10. The first lab uses two buckets, neither of which is a black hole. We're going to convert the black hole bucket to a regular spacetime fabric bucket. For now, place a second piece of fabric over the black hole bucket and tuck it under the cord so that it looks like the first bucket you used.
11. Now, we're ready for our lab.

Exploring How Space Curves

12. Place a mid-sized weight in the middle of one of the buckets. What happens to the fabric when you put a weight on the fabric? (It curves.)
13. Place the heavy 2.5-lb. lead weight in the center of the fabric of the second bucket. Did it curve more or less than the first weight? (More.)
14. The heavier weight is like the Sun, and the lighter weight is like the Earth. Which has more mass? (The Sun.)
15. Which has more gravitational attraction? (The Sun.)
16. Is space more or less curved further from the object? (less)
17. Where is space curved the most? (nearest the object)
18. Grab your marbles. These are your space probes. If we place one probe at the edge of each bucket, which do you expect to fall toward the middle faster? (the one with the more massive weight)
19. Why? (More mass = more curve = more gravity)
20. This is what we mean when we say the force of gravity depends on how much mass something has, since mass curves space. More massive objects curve space more, so the gravitational attraction is more with more massive objects.
21. Take two marbles of different sizes and drop them at the same time onto the edge of the bucket. You can drop them on opposite sides so they don't knock into each other. What happened? (They fall straight in quickly instead of sitting on the surface.)
22. The moon is like a giant marble. Why doesn't it fall to Earth?
23. Why is it orbiting?

24. Remove all weights from the fabric. Roll a marble across the surface (do it slowly without bouncing – planets don't bounce!). Does it roll straight or curved?
25. Place the heavy weight on the fabric. Try to make the marble go in a straight line. Did it work?
26. Can you roll the marble so that it escapes from the weight that represents the Sun?
27. In the second bucket, place a smaller weight and try step 25-26 again. How is this different?
28. Planets orbit the Sun because space is curved around the Sun. The Moon orbits the Earth without falling in because space is curved around Earth. How fast the Moon moves through space and how much the Earth curves space depends on the Earth's mass and how far away the moon is.
29. If the Moon was in closer to the Earth, would it have to move faster or slower to maintain its orbit? (Faster) Let's find out: Place two marbles, one closer to the weight and one near the edge of the bucket, and make them orbit the weight. Which one orbits faster? (The one closer in). Why? (because space is more curved nearer to the object)
30. Replace the weight in the second bucket with a lightweight mass. Now, what if Earth was less massive? How would this change the Moon's orbit? (The moon orbits slower.)
31. Notice this: When you roll a ball in orbit around a weight, do you see the weight move slightly also? All orbiting objects yank on each other. The Moon pulls on the Earth just as the Earth pulls on the Moon. All massive objects cause space to move: planets, stars, black holes, comets, etc.

Exploring Black Holes

32. Place a weight in each bucket, one representing the Earth and the other representing the Moon.
33. Place a marble next to each weight. These marbles are your rocket ships. Do you think that you can launch your rockets and escape the pull of gravity? Grab a straw and try to blow the marble away from the weight (launch the rocket off the Earth and moon). What happened? (It's nearly impossible to do!)
34. What if we start the rockets in space? Do you think you can escape the pull of the objects now? Start the marbles orbiting and then blow them with the straws. Can you fire your rockets at the right time to get them to escape the orbit?
35. Let's launch a probe out of a black hole! Remove the fabric from the black hole bucket and place a marble in the black hole. Can you use your straw to blow the marble out of the black hole?
36. Let's see the difference between the Sun and a black hole. Grab an 8-ounce weight and the softball. These have the same mass, but they are different sizes. The softball is the Sun, and the weight is the black hole. Which is going to curve space more when you place it on the fabric? Guess before you try it!
37. Replace the fabric over the black hole bucket.
38. Place the softball on one of the buckets, and the 8-ounce weight on the other bucket.
39. Roll a marble near the edge of each bucket. This is where our Earth would be orbiting. Notice that although the weight curves space more near it, at the edge, the curvature is the same. So if the Sun were suddenly replaced by a black hole of the same mass, the Earth wouldn't notice it (gravitationally, at least. It would get dark and cold, though.),
40. Remove the second fabric from the black hole bucket so you have the vortex exposed.
41. Take two marbles and start them orbiting at the edge of the black hole. What happens? Why?
42. Make a rocket shape out of clay or playdough. Bring the rocket close to the black hole bucket and get prepared to show your teammates what happens if it goes into the black hole. First, it stretches (pull the rocket into a longer shape), then it gets shredded (crumple it up) and finally added to the black hole's mass (shove it into the bucket).

Exercises

1. What is the event horizon? (If you fall into a black hole, you'll never get out again, because falling into a black hole is a lot like falling over Niagara Falls – there's no way of getting back the same way you came. The edge of a black hole is called the "event horizon," and it's like the edge of a waterfall. Do you see the water that's about to fall over the edge? Once you pass the edge, there's no turning back. That's called the "point of no return.")
2. Does a more massive object curve space more or less than a smaller object? What does this mean for the gravitational field? (More massive objects curve the fabric of space more than a smaller object. More mass = more curvature = more gravitational attraction.)
3. Does an object feel more or less gravitational attraction as the object moves closer to a massive object? (As the distance decreases from the center of an object to a massive object, the curvature increases, and the gravitational attraction also increases.)
4. Where is space most curved? (Space is curved most nearest the object and less curved out near the edge.)
5. What is mass? (Mass is the amount of stuff (atoms) in an object.)

Closure: Before moving on, ask your students if they have any recommendations or unanswered questions that they can work out on their own. Brainstorming extension ideas is a great way to add more science studies to your class time.

Lesson #14: Black Hole Bucket

Student Worksheet

Name____

Overview: What comes to mind when you think about empty space? (You should be thinking: "*Nothing!"*) One of Einstein's greatest ideas was that empty space is not actually nothing – it has energy and can be influenced by objects in it. It's like the T-shirt you're wearing. You can stretch and twist the fabric around, just like black holes do in space.

What to Learn: Today, you will get introduced to the idea that gravity is the structure of spacetime itself. Massive objects curve space. How much space curves depends on how massive the object is, and how far you are from the massive object.

Materials

- Two buckets with holes in the bottom
- 2 bungee cords
- 3 different sizes of marbles
- 2.5 lb weight
- 0.5 lb weight
- 3 squares of stretchy fabric
- Rubber band
- 4 feet of string
- Fishing bobber
- Drinking straws
- Softball
- Playdough (optional)

Lab Time

Making the Buckets Ready for the Lab

1. What is gravity? How does it work? That's what today's lab is all about.
2. Stretch the bungee cord around the circumference of the bucket. Do this for both buckets.
3. On one bucket, tuck in the stretchy fabric under the cord. If your cords are loose, tie another knot near the end so they fit snugly around the bucket. The fabric is stretched like a drum head. This is the "fabric of space" – it's around us everywhere.
4. Push the bottom of the bobber so the hook opens on the other end. Push your string in.
5. Place it in the center of the squares of fabric. Fasten it with your rubber band.
6. Thread the ends of your string through the bottom holes of your second bucket and tie it securely on the bottom.
7. Tuck in your corners under the bungee cord. This is your black hole bucket.
8. The first lab uses two buckets, neither of which is a black hole. We're going to convert the black hole bucket to a regular spacetime fabric bucket. For now, place a second piece of fabric over the black hole bucket and tuck it under the cord so that it looks like the first bucket you used.

9. Now, we're ready for our lab.

Exploring How Space Curves

Write the answers in the spaces provided after each question as you play with your buckets and work through the activities.

10. Place a mid-sized weight in the middle of one of the buckets. What happens to the fabric when you put a weight on the fabric?

11. Place the heavy 2.5-lb lead weight in the center of the fabric of the second bucket. Did it curve more or less than the first weight?

12. The heavier weight is like the Sun, and the lighter weight is like the Earth. Which has more mass?

13. Which has more gravitational attraction?

14. Is space more or less curved further from the object?

15. Where is space curved the most?

16. Grab your marbles. These are your space probes. If we place one probe at the edge of each bucket, which do you expect it to fall toward the middle faster?

17. Why?

18. This is what we mean when we say the force of gravity depends on how much mass something has, since mass curves space. More massive objects curve space more, so the gravitational attraction is more with more massive objects.

19. Take two marbles of different sizes and drop them at the same time onto the edge of the bucket. You can drop them on opposite sides so they don't knock into each other. What happens?

20. The Moon is like a giant marble. Why doesn't it fall to Earth?

21. Why is it orbiting?

22. Remove all weights from the fabric. Roll a marble across the surface (do it slowly without bouncing – planets don't bounce!). Does it roll straight or curved?

23. Place the heavy weight on the fabric. Try to make the marble go in a straight line. Did it work?

24. Can you roll the marble so that it escapes from the weight that represents the Sun?

25. In the second bucket, place a smaller weight and do steps 23 and 24 again. How is this different?

26. Planets orbit the Sun because space is curved around the Sun. The Moon orbits the Earth without falling in because space is curved around Earth. How fast the moon moves through space and how much the Earth curves space depends on the Earth's mass and how far away the moon is.
27. If the Moon was in closer to the Earth, would it have to move faster or slower to maintain its orbit?

28. Let's find out: Place two marbles, one closer to the weight and one near the edge of the bucket, and make them orbit the weight. Which one orbits faster? Why?

29. Replace the weight in the second bucket with a lightweight mass. Now, what if Earth was less massive? How would this change the Moon's orbit?

30. Notice this: When you roll a ball in orbit around a weight, do you see the weight move slightly also? All orbiting objects yank on each other. The Moon pulls on the Earth just as the Earth pulls on the Moon. All massive objects cause space to move: planets, stars, black holes, comets, etc.

Exploring Black Holes

31. Place a weight in each bucket, one representing the Earth and the other representing the Moon.
32. Place a marble next to each weight. These marbles are your rocket ships. Do you think that you can launch your rockets and escape the pull of gravity? Grab a straw and try to blow the marble away from the weight (launch the rocket off the Earth and moon). What happened? Why?

33. What if we start the rockets in space? Do you think you can escape the pull of the objects now? Start the marbles orbiting and then blow them with the straws. Can you fire your rockets at the right time to get them to escape the orbit?

34. Let's launch a probe out of a black hole! Remove the fabric from the black hole bucket and place a marble in the black hole. Can you use your straw to blow the marble out of the black hole?

35. Let's see the difference between the Sun and a black hole. Grab an 8-ounce weight and the softball. These have the same mass, but they are different sizes. The softball is the Sun, and the weight is the black hole. Which is going to curve space more when you place it on the fabric? Guess before you try it:

36. Replace the fabric over the black hole bucket.
37. Place the softball on one of the buckets, and the 8-ounce weight on the other bucket.
38. Roll a marble near the edge of each bucket. This is where our Earth would be orbiting. Notice that although the weight curves space more near it, at the edge, the curvature is the same. So if the Sun were suddenly replaced by a black hole of the same mass, the Earth wouldn't notice it (gravitationally, at least. It would get dark and cold, though.),
39. Remove the second fabric from the black hole bucket so you have the vortex exposed.
40. Take two marbles and start them orbiting at the edge of the black hole. What happens? Why?

41. Make a rocket shape out of clay or playdough. Bring the rocket close to the black hole bucket and get prepared to show your teammates what happens if it goes into the black hole. First, it stretches (pull the rocket into a longer shape), then it gets shredded (crumple it up) and finally added to the black hole's mass (shove it into the bucket).

Exercises Answer the questions below:

1. What is the event horizon?
2. Does a more massive object curve space more or less than a smaller object? What does this mean for the gravitational field?
3. Does an object feel more or less gravitational attraction as the object moves closer to a massive object?
4. Where is space most curved?
5. What is mass?

Astronomy 3 Evaluation

Teacher Section

Overview Kids will demonstrate how well they understand important key concepts from this section.

Suggested Time 45-60 minutes

Objectives Students will be tested on the key concepts of astronomy:

- Objects in the sky move in regular and predictable patterns. The patterns of stars stay the same, although they appear to move across the sky nightly, and different stars can be seen in different seasons.
- The position of the Moon changes during the course of the day and from season to season.
- The phases of the Moon and the lunar cycle.
- The tilt of the Earth and its location in orbit are the reasons for the seasons.
- The Earth is one of several planets that orbit the Sun, and the Moon orbits the Earth.
- The solar system consists of planets and other bodies that orbit the Sun in predictable paths.
- Our solar system includes rocky terrestrial planets (Mercury, Venus, Earth, and Mars), gas giants (Jupiter and Saturn), ice giants (Uranus and Neptune), and assorted chunks of ice and dust that make up various comets and asteroids.
- Two planets (Ceres and Pluto) have been reclassified after astronomers found out more information about their neighbors.
- The Oort Cloud holds an estimated 1 trillion comets. The Kuiper Belt holds chunks of ice and dust, like comets and asteroids as well as larger objects like dwarf planets Eris and Pluto.
- The appearance, general composition, relative position and size, and motion of objects in the solar system, including planets, planetary satellites, comets, and asteroids.
- How to use astronomical units and light years as measures of distance between the Sun, stars, and Earth.
- The path of a planet around the Sun is due to the gravitational attraction between the Sun and the planet.
- Telescopes magnify the appearance of the Moon and the planets.

Materials

- Print out of the Skygazer's Almanac
- Paper and pencil

Lab Preparation

1. Print out copies of the student worksheets, lab practical, and quiz.
2. Have materials in front of you at a desk so kids can demonstrate their knowledge using these materials.

Lesson: The students are taking two tests today: the quiz and the lab practical. The quiz takes about 20 minutes, and you'll find the answer key to make it easy to grade.

Lab Practical: Students will demonstrate individually that they know how the moon's appearance changes during the lunar cycle and explain the size of planets and their distance from the Sun. While other kids are waiting for their turn, they will get started on their homework assignment. You get to decide whether they do their assignment individually or as a group.

Astronomy 3 Evaluation

Student Worksheet

Overview: Today, you're going to take two different tests: the quiz and the lab practical. You're going to take the written quiz first, and the lab practical at the end of this lab. The lab practical isn't a paper test – it's where you get to show your teacher that you know how to do something.

Lab Test & Homework

1. Your teacher will ask you to share how much you understand about astronomy. Since science is so much more than just reading a book or circling the right answer, this is an important part of the test to find out what you really understand.
2. While you are waiting to show how much of this stuff you already know, you get to choose which homework assignment you want to complete. The assignment is due tomorrow, and half the credit is for creativity and the other half is for content, so really let your imagination fly as you work through it. Choose one:
    a. Write a short story or skit about gravity from the perspective of the planet or object (like a sun or moon). You'll read this aloud to your class.
    b. Make a poster that teaches one of the main concepts of astronomy you enjoyed most. When you're finished, you'll use it to teach to a class of younger students and demonstrate the principles that you've learned.
    c. Write and perform a poem or song about astronomy, telescopes, gravity, space, or black holes. This will be performed for your class.

Astronomy 3 Quiz

Teacher's Answer Key

1. If we doubled the mass of the Earth, what would happen to its orbital speed? *Kepler's 3rd Law states that a Sun twice the size would cause the Earth to orbit faster. However, if we double the mass of the Earth, it does not affect the speed that it orbits the Sun with. Why not? Because the Earth is soooo much smaller than the Sun that increasing a planet's size generally doesn't make a difference in the orbital speed. If you're working with two objects about the same size, of course, then changing one of the masses absolutely has an effect on the other.*
2. Why do the planets stay in orbit? *The path of a planet around the Sun is due to the gravitational attraction between the Sun and the planet.*
3. How fast does the Sun rotate? *27 days at the equator, 31 days at the poles.*
4. How does the Sun make energy? *The Sun uses nuclear reactions to generate its energy.*
5. Why does Mars appear to move backward? *As the Earth passes Mars more quickly, Mars appears to slow down, stop, and reverse direction.*
6. Is Saturn always in the same place every night? Why or why not? *All objects except the North Star, Polaris, move in regular and predictable patterns that appear to move across the sky nightly.*
7. Does the moon change position, appearance, or both from night to night? *Both. The position of the moon changes during the course of the day and from season to season, as do the phases of the moon.*
8. Name two astronomical instruments astronomers use and what they are for. *Answers vary, but you'll usually get something about telescope and how they allow us to study incoming light from distant stars, spectroscopes to determine the fuel a distance star is burning, satellites to study planets around distant stars, and so forth.*
9. Can you see electrons? If not, how can you detect them? *No, they are too small, but there are several ways to detect them, including making a cosmic ray detector, building a circuit that lights a light bulb, or gathering a charge on a balloon by rubbing it on your head and zapping something with the charge.*
10. What does a telescope do? *It magnifies the appearance of planets and the moon, and also star patterns in the night sky.*
11. Is the number of stars that can be seen through telescopes greater or less than can be seen by the unaided eye? Why? *Much greater. Telescopes use lenses to magnify images from far away and make them appear larger.*
12. How do scientists currently find other planets around distant stars? *Scientists look for stars to "wobble" as the orbiting planet yanks on the star.*
13. Name three ways a black hole can kill you. *You can get killed by a black hole by: falling in, spaghettification , being near when it forms, being near when it evaporates, being near when two black holes smack into each other, fried by the X-rays coming out.*
14. Name two ways you can find a black hole. *Look for X-ray emissions or stars that appear to orbit something that isn't there.*
15. What is a galaxy? *Galaxies are clusters of billions of stars, and may have different shapes. The Sun is one of many stars in our own Milky Way galaxy.*
16. Do stars differ in size, temperature, and color? *If so, how? The hottest stars are blue and white and tend to be larger in size. Cooler stars are red. Blue stars measure above 10,000K (17,540°F or 9,727°C) at the surface. Red stars are about 2500K (4,040°F or 2,227°C). Our Sun, a white star, is 6,000K (10,340°F or 5,727°C.*
17. What is a black hole? *You can pick from any of these: Black holes are objects where the escape velocity is greater than the speed of light. They are the leftovers of a BIG star explosion. There is nothing to keep it from collapsing, so*

it continues to collapse forever. It becomes so small and dense that the gravitational pull is so great that light itself can't escape They are objects who has an escape velocity greater than the speed of light

18. Does a more massive object curve space more or less? *Mass causes spacetime to curve. The amount of curvature depends on how massive the object is and your distance from the massive object.*

Astronomy 3 Quiz

Student Quiz Sheet

Name____

1. If we doubled the mass of the Earth, what would happen to its orbital speed?
2. Why do the planets stay in orbit?
3. How fast does the Sun rotate?
4. How does the Sun make energy?
5. Why does Mars appear to move backward?
6. Is Saturn always in the same place every night? Why or why not?
7. Does the moon change position, appearance, or both from night to night?
8. Name two astronomical instruments astronomers use and what they are for.

9. Can you see electrons? If not, how can you detect them?

10. What does a telescope do?

11. Is the number of stars that can be seen through telescopes greater or less than can be seen by the unaided eye? Why?

12. How do scientists currently find other planets around distant stars?

13. Name three ways a black hole can kill you.

14. Name two ways you can find a black hole.

15. What is a galaxy?

16. Do stars differ in size, temperature, and color?

17. What is a black hole?

18. Does a more massive object curve space more or less?

Astronomy 3 Lab Practical

Teacher's Answer Key

This is your chance to see how well your students have picked up on important key concepts, and if there are any holes. Your students also will be working on their homework assignment as you do this test individually with the students.

Materials:

- Print out of the Skygazer's Almanac
- Sheet of paper, pencil

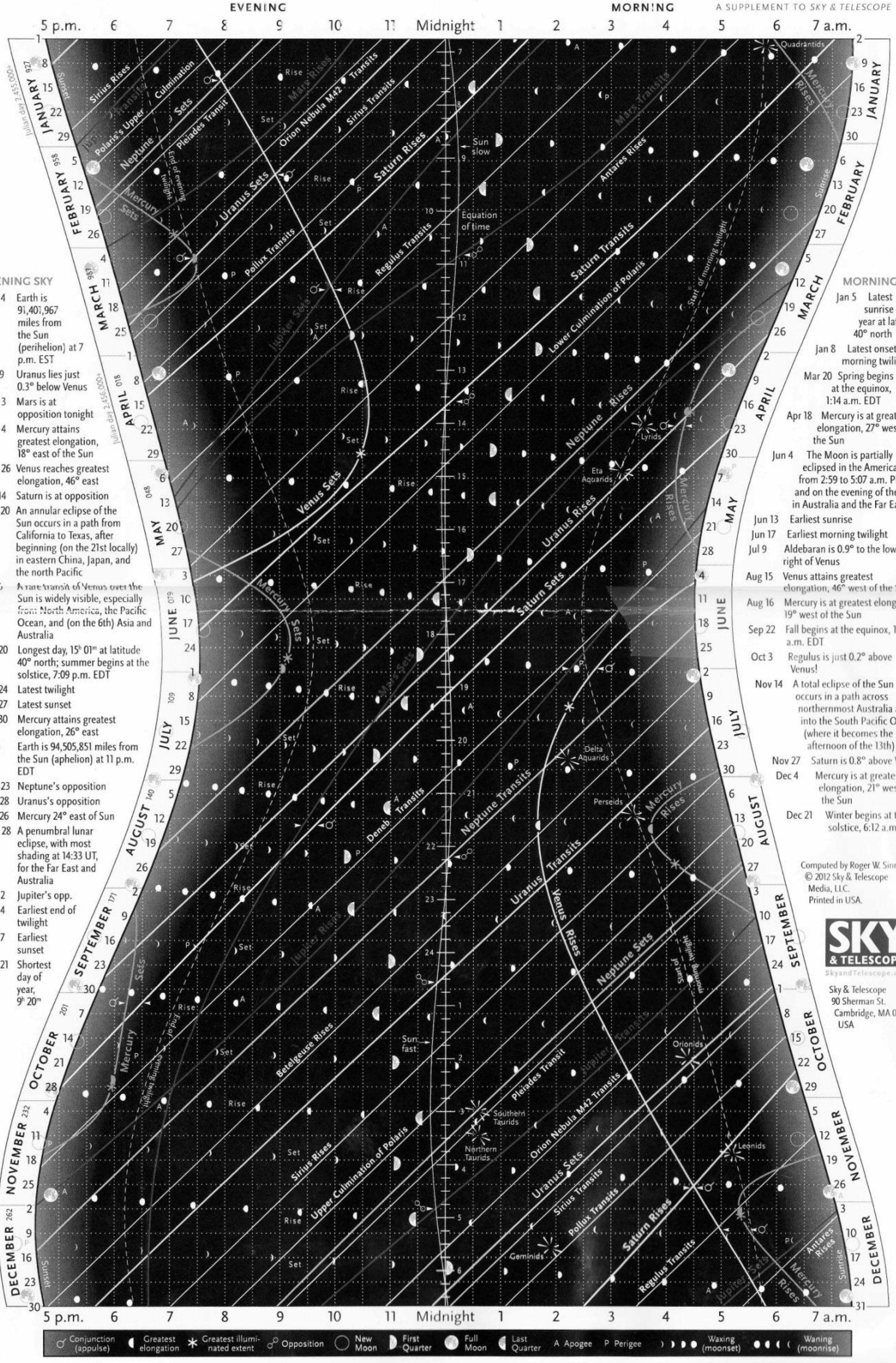
Lab Practical: Ask the student *Note: Answers given in italics!*

- Using the Skygazer's Almanac, (use the current year, or print out the one on the next page and pretend it's the current year), show which planets are up tonight, and when the next meteor shower is expected.
- Explain why you should never look at the Sun through anything with lenses. Design and draw an experiment on paper, teaching your instructor what would happen if they did. *Student will explain how a magnifier focuses and concentrates the Sun's light (specifically heat) from a large area down to a point, and if you were to look at the Sun at this point, you'd burn your eye.*
- Explain how satellites are not stationary in orbit. *The student can place a weight on the fabric to represent the Earth. Roll a marble around the outer edge to be the satellite. They will explain how satellites need to orbit at a particular speed to keep from flying out of orbit and being lost forever (too fast), or crashing down onto the planet (too slow).*

Skygazer's Almanac 2012

FOR LATITUDES NEAR 40° NORTH

A SUPPLEMENT TO *SKY & TELESCOPE*



EVENING SKY

Jan 4	Earth is 91,401,967 miles from the Sun (perihelion) at 7 p.m. EST
Feb 9	Uranus lies just 0.3° below Venus
Mar 3	Mars is at opposition tonight
Mar 4	Mercury attains greatest elongation, 18° east of the Sun
Mar 26	Venus reaches greatest elongation, 46° east
Apr 14	Saturn is at opposition
May 20	An annular eclipse of the Sun occurs in a path from California to Texas, after beginning (on the 21st locally) in eastern China, Japan, and the north Pacific
Jun 5	A rare transit of Venus over the Sun is widely visible, especially from North America, the Pacific Ocean, and (on the 6th) Asia and Australia
Jun 20	Longest day, 15ʰ 01ᵐ at latitude 40° north; summer begins at the solstice, 7:09 p.m. EDT
Jun 24	Latest twilight
Jun 27	Latest sunset
Jun 30	Mercury attains greatest elongation, 26° east
Jul 4	Earth is 94,505,851 miles from the Sun (aphelion) at 11 p.m. EDT
Aug 23	Neptune's opposition
Sep 28	Uranus's opposition
Oct 26	Mercury 24° east of Sun
Nov 28	A penumbral lunar eclipse, with most shading at 14:33 UT, for the Far East and Australia
Dec 2	Jupiter's opp.
Dec 4	Earliest end of twilight
Dec 7	Earliest sunset
Dec 21	Shortest day of year, 9ʰ 20ᵐ

MORNING SKY

Jan 5	Latest sunrise of the year at latitude 40° north
Jan 8	Latest onset of morning twilight
Mar 20	Spring begins at the equinox, 1:14 a.m. EDT
Apr 18	Mercury is at greatest elongation, 27° west of the Sun
Jun 4	The Moon is partially eclipsed in the Americas from 2:59 to 5:07 a.m. PDT, and on the evening of the 4th in Australia and the Far East
Jun 13	Earliest sunrise
Jun 17	Earliest morning twilight
Jul 9	Aldebaran is 0.9° to the lower right of Venus
Aug 15	Venus attains greatest elongation, 46° west of the Sun
Aug 16	Mercury is at greatest elongation, 19° west of the Sun
Sep 22	Fall begins at the equinox, 10:49 a.m. EDT
Oct 3	Regulus is just 0.2° above Venus!
Nov 14	A total eclipse of the Sun occurs in a path across northernmost Australia and into the South Pacific Ocean (where it becomes the afternoon of the 13th)
Nov 27	Saturn is 0.8° above Venus
Dec 4	Mercury is at greatest elongation, 21° west of the Sun
Dec 21	Winter begins at the solstice, 6:12 a.m. EST

Computed by Roger W. Sinnott.

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SAMPLE PROJECT: MEASURING THE SPEED OF LIGHT

How to Use the Scientific Method for a Science Fair Project

This is a step-by-step guide on how to do a complete science fair project, from a spark of an idea through to the final presentation to the judges.

Your first step: Doing Research. Why do you want to do this project? What originally got you interested in light waves? Is it the idea of high-speed waves? Or does the name of the project just *sound* cool? Do you like the idea of finding the speed of light with a bar of chocolate?

Take a walk to your local library, flip through magazines, and surf online for information you can find about electromagnetic spectrum, frequency, wavelength, and how light travels in outer space. Learn what other people have already figured out before you start re-inventing the wheel!

Flip open your science journal and write down things you've found out. Your journal is just for you, so don't be shy about jotting ideas or interesting tidbits down. Also, keep track of which books you found interesting. You'll need these titles later in case you need to refer back for something, and also for your bibliography, which needs to have at least three sources that are not from the Internet.

Your next step: Define what it is that you really want to do. In this project, we're going to walk you step by step through measuring the speed of light right in your own kitchen, using only parts from the grocery store. Go shopping and gather your equipment together now, picking up a few extra chocolate bars so you can run a few trial runs before taking data. (*You'll be able to eat the chocolate after the experiment!)*

Materials: Before we start the real experiment, you'll need to gather items that may not be around your house right now. Take a minute to take inventory of what you already have and what you'll need.

- Ruler for measuring
- Large (dark, milk, and white) chocolate bar, two raw eggs, mini and big marshmallows, cheese and crackers, bread and butter, chocolate chips, and anything else that melts easily in the microwave
- Microwave
- Calculator, pencil
- Camera to document project
- Composition or spiral-bound notebook to take notes
- Display board (the three-panel kind with wings), about 48" wide by 36" tall
- Paper for the printer (and photo paper for printing out your photos from the camera)
- Computer and printer

Playing with the experiment: First, you'll need to find the "hot spots" in your microwave. Remove the turntable from your microwave and place a naked bar of chocolate on a plate inside the microwave.

Make sure the chocolate bar is the BIG size – you'll need at least 7 inches of chocolate for this to work. Turn the microwave on and wait a few seconds until you see small parts of the chocolate bar start to bubble up, and then quickly open the door (it will start to smoke if you leave it in too long).

Look carefully at the chocolate bar without touching the surface… you are looking for TWO hotspots, not just one – they will look like small volcano eruptions on the surface of the bar. If you don't have two, grab a fresh plate and chocolate bar and try again, changing the location of the place inside the microwave. You're looking for the place where the microwave light hits the chocolate bar in two spots so you can measure the distance between the spots. Those places are the peaks of the microwave light wave.

Formulate your Question or Hypothesis: You'll need to nail down ONE question or statement you want to test. Be careful with this experiment - you can easily have several variables running around and messing up your data if you're not careful. Here are a few possible questions:

- "Which food gives the most accurate speed of light measurement?"
- "Does the power setting matter?"
- "Does dish location matter?"
- "Which type of chocolate gives the most accurate results?"
- "Does it matter if the food starts out as hot, warm, cold, or frozen?"

Once you've got your question, you'll need to identify the *variable.* For the question: *"Which food gives the most accurate speed of light measurement?"* your variable is the type of food you are using, keeping everything else constant (plate location inside the microwave, temperature of food, etc...)

If you wanted to ask the question: "Does it matter how powerful the microwave is?" your hypothesis might be: *"A microwave twice the power will give the same light speed."*

For testing different kinds of microwave ovens, you could visit friends' houses and perform the same experiment over and over (keeping the type of food constant – always using a chocolate bar, for example).

Taking Data: An example of *how* to record your data:
Question *"Which food gives the most accurate speed of light measurement?"*
Hypothesis: "*I think a milk chocolate bar gives the most accurate speed of light measurement."*

Here's how to record data. Grab a sheet of paper, and across the top, write down your background information, such as your name, date, time of day, type and frequency of microwave, and anything else you'd need to know if you wanted to repeat this experiment *exactly* the same way on a different day. Include a photograph of your invention also, so you'll see exactly what your project looks like.

Open up the door or look on the back of your microwave for the technical specifications. You're looking for a frequency in the 2,000-3,000 MHz range… usually about 2450 MHz. Write this number down at the top of your data sheet – this tells you the microwave radiation frequency that the oven produces, and will be used for calculating the speed of light.

Get your paper ready to take data… and write across your paper these column headers, including the things in ( ): (Note – there's a sample data sheet following this section).

- Trial #
- Food type – the independent variable
- Hotspot distance (inches or cm) – the dependent variable
- Speed of light (meter/second or feet/second) – a calculated dependent variable

Be sure to run your experiment a few times before taking actual data, to be sure you've got everything running smoothly. Have someone snap a photo of you getting ready to test, to enter later onto your display board.

When you're ready, pop in the first food type on a plate (without the turntable!) into the best spot in the microwave, and turn it on. Remove when both hotspots form, and being careful not to touch the surface of the food, measure the center-to-center distance using your ruler. Record the first trial in your data log. Run your experiment again and again, changing the food type each time for at least 8 trials.

TIP: If you're using mini-marshmallows or chocolate chips (or other smaller foods), you'll need to spread them out in an even layer on your plate so you don't miss a spot that could be your hotspot!

For older students: Also measure the furthest-edge to furthest-edge distance, which you can transform into your +/- error margins for your measurements.

How to Calculate the Speed of Light from your Data: Note that when you measure the distance between the hotspots, you are only measuring the peak-to-peak distance of the wave … which means you're only measuring *half* of the wave. We'll multiply this number by two to get the actual length of the wave. If you're using cm or inches, you'll also need to convert those to meters or miles.

1 inch = 2.54 cm
1 mile = 5,280 feet = 63,360 inches
1 meter = 100 cm

So, if you measure 2.1 inches between your hotspots, and you want to calculate the speed of light and compare to the published value which is in meters per second, here's what you do:

2,450 MHz is really 2,450,000,000 Hz or 2,450,000,000 cycles per 1 second

Find the length of the wave (in cm): 2 * 2.1 inches = 4.2 inches * 2.54 cm/inch = 10.67 cm

Convert cm to meters: 10.67 cm = 0.1067 m

Multiply the wavelength by the microwave oven frequency:
0.1067 m * 2,450,000,000 Hz = 261,400,000 m/s

Published value for light speed is 299,792,458 m/s = 186,000 miles/second = 671,000,000 mph

Enter in your data in Excel and calculate the speed of light for each trial run.

Analyze your data. Time to take a hard look at your numbers! What did you find? Does your data support your original hypothesis, or not?

Make yourself a grid (or use graph paper), and plot the *Speed of Light* versus the *Food Type*. In this case, the *Food Type* goes on the horizontal axis (independent variable), and *Speed of Light* (dependent variable) goes on the vertical axis. You can also make another graph showing *Hotspot Location* (vertical) and *Food Type* (horizontal).

Using a computer, enter in your data into an Excel spreadsheet and plot a graph. Label your axes and add a title.

Conclusion: So - what did you find out? What is the best food to use? Does it matter? Which type of microwaves gave the best results? Does a larger microwave give more hotspots? Is it what you originally guessed? Science is one of the only fields where people actually *throw a party* when stuff works out differently than they expected! Scientists are investigators, and they get *really* excited when they get to scratch their heads and learn something new.

Hot Tip on Being a Cool Scientist: One of the biggest mistakes you can ever make is to fudge your data so it matches what you wanted to have happen. Don't *ever* be tempted to do this … science is based on observational fact. Think of it this way: The laws of the universe are still working, and it's your chance to learn something new!

Recommendations: This is where you need to come up with a few ideas for further experimentation. If someone else was to take your results and data, and wanted to do more with it, what would they do? Here are a few spins on the original experiment:

- Vary the food thickness
- Change the size of the microwave

Make the display board. Fire up the computer, stick paper in the printer, and print out the stuff you need for your science board. Here are the highlights:

- Catchy Title: This should encompass your basic question (or hypothesis).

- Purpose and Introduction: Why study this topic?
- Results and Analysis (You can use your actual data sheet if it's neat enough, otherwise print one out.)
- Methods & Materials: What did you use and how did you do it? (Print out photos of you and your experiment.)
- Conclusion: One sentence tells all. What did you find out?
- Recommendations: For further study.
- References: Who else has done work like this?

Outline your presentation. People are going to want to see you demonstrate your project, and you'll need to be prepared to answer any questions they have. We'll detail more of this in the later section of this guidebook, but the main idea is to talk about the different sections of your display board in a friendly, knowledgeable way that gets your point across quickly and easily. Test drive your presentation on friends and relatives beforehand and you'll be smoothly polished for the big day.

Sample Data Sheet

Measuring the Speed of Light

Name	Microwave Frequency	
Date		
Time		

Trial #	Food Type	Hotspot Distance	Calculated Light Speed	% Difference
		(inches)	(meters / second)	
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Create this table yourself using Microsoft Excel. You can download your free 60-day trial copy from Microsoft at this link:

http://office.microsoft.com/en-us/excel/default.aspx

Sample Report

In this next section, we've written a sample report for you to look over and use as a guide. Be sure to insert your own words, data, and ideas in addition to charts, photos, and models!

Title of Project

(Your title can be catchy and clever, but make sure it is as descriptively accurate as possible. Center and make your title the LARGEST font on the page.)

by Aurora Lipper

123 Main Street,
Sacramento, CA 10101

Carmel Valley Grade School
6th grade

Table of Contents

Abstract

This is a *summary* of your entire project. Always write this section LAST, as you need to include a brief description of your background research, hypothesis, materials, experiment setup and procedure, results, and conclusions. Keep it short, concise, and less than 250 words.

Here's a sample from Aurora's report:

Which type of food most accurately measures the speed of light? After researching the electromagnetic spectrum, microwave ovens, frequency, wavelength, and substances that easily melt, I realized I had all the basics for measuring the speed of light. But which type of food would produce the best measurement results?

I hypothesized that the chocolate bar would have the smallest percent error when compared with the published value for the speed of light. My best guess is that a substance with a melting point near room temperature would be easiest to visualize the results needed for finding the hotspots in a microwave. After raiding the grocery store for chocolate bars, chocolate chips, marshmallows, butter, and cheese, I created a super-simple project for determining the speed of light by melting different substances in the microwave. I ran nine trials, varying the type of food melted, and measured the distance between the hotspots and calculated the speed of light using frequency information from the microwave oven itself.

I found that my initial hypothesis (chocolate gives the lowest percent error for measuring the speed of light) was supported by the data, but not in the way I expected. **White chocolate has the most accurate measurement (298,704,000 meters/second) with a difference of 0.36% from the published value.**

For further study, I recommend running an experiment to test the various types of microwaves, as well as testing different foods based on water content. This experiment was tasty and a whole lot of fun!

Introduction/Research

This is where all your background research goes. When you initially wrote in your science journal, what did you find out? Write down a few paragraphs about interesting things you learned that eventually led up to your main hypothesis (or question).

Here is a sample from Aurora's report:

Which type of food most accurately measures the speed of light? After researching the electromagnetic spectrum, microwave ovens, frequency, wavelength, and substances that easily melt, I realized I had all the basics for measuring the speed of light. But which type of food would produce the best measurement results?

Microwave ovens use dielectric heating (or high-frequency heating) to heat your food. Basically, the microwave oven shoots light beams that are tuned to excite the water molecule. Foods that contain water will step up a notch in energy levels as they heat. (The microwave radiation can also excite other polarized molecules in addition to the water molecule, which is why some plates also get hot.)

One of the biggest challenges with measuring the speed of light is that the photons move *fast …* too fast to watch with our eyeballs. So instead, I planned to watch the effects of microwave light and base the measurements on the effects the light has on different kinds of food. Light with a wavelength of 0.01 to 10 cm is in the microwave part of the electromagnetic spectrum.

When designing the experiment, I had to take into account the finer details, such as the frequency of the microwave oven (found inside the door), where I placed the food inside the oven, and how long to leave it in for.

Purpose

Why are you doing this science fair project at all? What got you interested in this topic? How can you use what you learn here in the future? Why is this important to you?

Come up with your own story and ideas about why you're interested in this topic. Write a few sentences to a few paragraphs in this section.

Hypothesis

This is where you write down your speculation about the project – what you think will happen when you run your experiment. Be sure to include *why* you came up with this educated guess. Be sure to write at least two full sentences.

Here's a sample from Aurora's report:

I hypothesized that the chocolate bar would have the smallest percent error when compared with the published value for the speed of light. My best guess is that a substance with a melting point near room temperature would be easiest to visualize the results needed for finding the hotspots in a microwave.

Materials

What did you use to do your project? Make sure you list *everything* you used, even equipment you measured with (rulers, stopwatch, etc.) If you need specific amounts of materials, make sure you list those, too! Check with your school to see which unit system you should use. (Metric or SI = millimeters, meters, kilograms. English or US = inches, feet, pounds.)

Here's a sample from Aurora's report:

- Ruler for measuring
- Large (dark, milk, and white) chocolate bar, two raw eggs, mini and big marshmallows, cheese and crackers, bread and butter, chocolate chips, and anything else that melts easily in the microwave
- Microwave
- Calculator, pencil
- Camera to document project
- Composition or spiral-bound notebook to take notes
- Display board (the three-panel kind with wings), about 48" wide by 36" tall
- Paper for the printer (and photo paper for printing out your photos from the camera)
- Computer and printer

Procedures

This is the place to write a highly detailed description of what you did to perform your experiment. Write this as if you were telling someone else how to do your exact experiment and reproduce the same results you achieved. If you think you're overdoing the detail, you're probably just at the right level. Diagrams, photos, etc. are a great addition (NOT a substitution) to writing your description.

Here's a sample from Aurora's report:

First, I became familiar with the experiment and setup. After raiding the grocery store for chocolate bars, chocolate chips, marshmallows, butter, and cheese, I created a super-simple project for determining the speed of light by melting different substances in the microwave. I ran nine trials, varying the type of food melted, and measured the distance between the hotspots and calculated the speed of light using frequency information from the microwave oven itself.

I made myself a data logger in my science journal. I placed the food in the perfect spot in the microwave oven such that two hotspots formed when turned on. As soon as the spots bubbled up, I quickly opened the door and measured the center-to-center distance and recorded it in my data sheet. I continued this process, testing different food types for each trial. I later transformed the half-wavelength information (hotspot measurement) into a speed of light calculation using the formula c = l f, where c = speed of light in m/s, l = wavelength in meters, and f = frequency in cycles per second.

Results

This is the data you logged in your Science Journal. Include a chart or graph – whichever suits your data the best, or both if that works for you. Use a scatter or bar graph, label the axes with units, and title the graph with something more descriptive than "Y vs. X or Y as a function of X". On the vertical (y-axis) goes your dependent variable (the one you recorded), and the horizontal (x-axis) holds the independent variable (the one you changed).

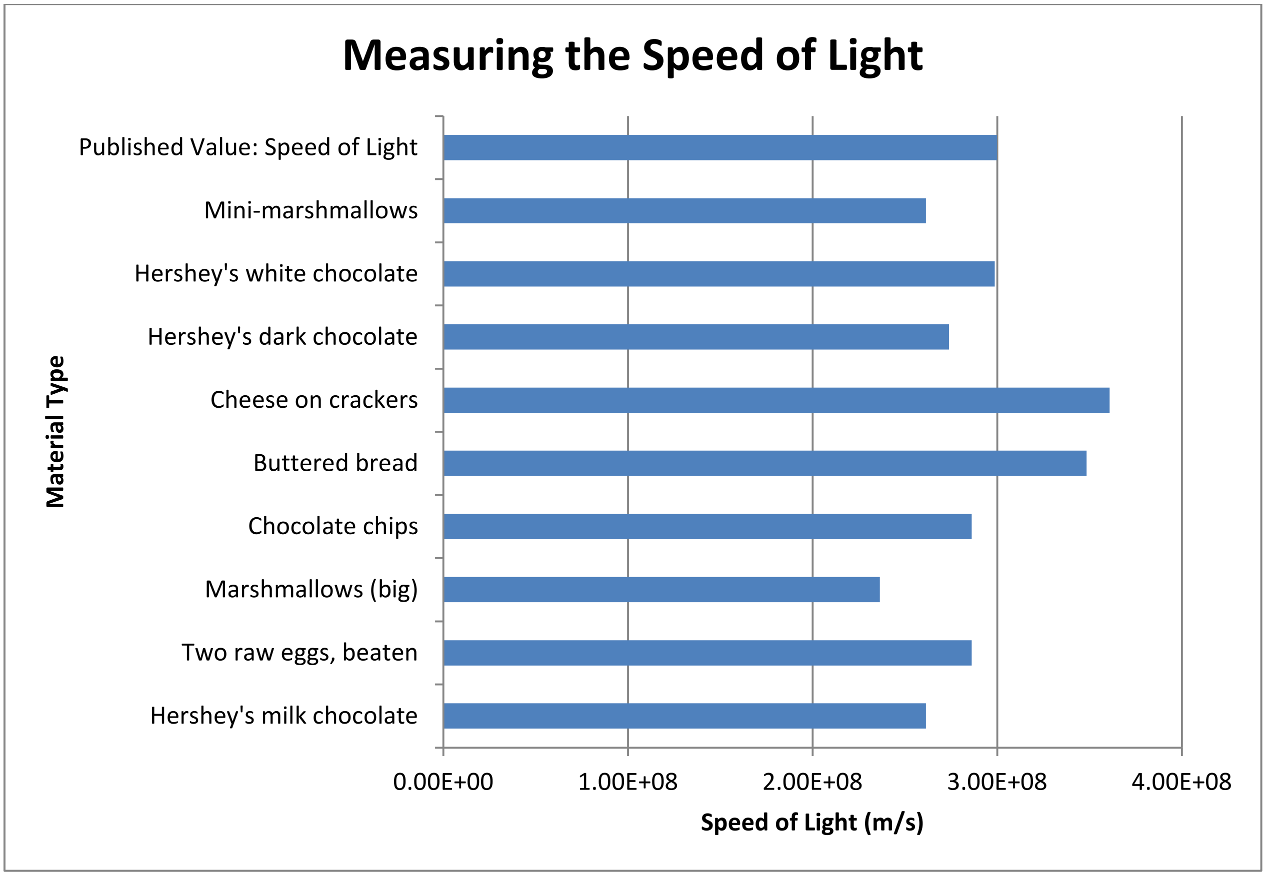
Measuring the Speed of Light

Name *Aurora Lipper*
Date *Nov. 12, 2009*
Time *12:36pm*

Microwave Frequency *2450 MHz*

Trial #	Food Type	Hotspot Distance	Calculated Light Speed	% Difference
		(inches)	(meters / second)	
1	Hershey's milk chocolate	2.1	261,366,000	12.82
2	Two raw eggs, beaten	2.3	286,258,000	4.51
3	Marshmallows (big)	1.9	236,474,000	21.12
4	Chocolate chips	2.3	286,258,000	4.51
5	Buttered bread	2.8	348,488,000	16.24
6	Cheese on crackers	2.9	360,934,000	20.39
7	Hershey's dark chocolate	2.2	273,812,000	8.67
8	Hershey's white chocolate	2.4	298,704,000	0.36
9	Mini-marshmallows	2.1	261,366,000	12.82
10	White chocolate chips	2.3	286,258,000	4.51

NOTE: The numbers above are NOT real! Be sure to input your own.



NOTE: The numbers above are NOT real! Be sure to input your own.

Conclusion

Conclusions are the place to state what you found. Compare your results with your initial hypothesis or question – do your results support or not support your hypothesis? Avoid using the words "right," "wrong," and "prove" here. Instead, focus on what problems you ran into as well as why (or why not) your data supported (not supported) your initial hypothesis. Are there any places you may have made mistakes or not done a careful job? How could you improve this for next time? Don't be shy – let everyone know what you learned!

Here's a sample from Aurora's report:

I found that my initial hypothesis (chocolate gives the lowest percent error for measuring the speed of light) was supported by the data, but not in the way I expected. **White chocolate has the most accurate measurement (298,704,000 meters/second) with a difference of 0.36% from the published value.**

For further study, I recommend running an experiment to test the various types of microwaves, as well as testing different foods based on water content. This experiment was tasty and a whole lot of fun!

Bibliography

Every source of information you collected and used for your project gets listed here. Most of the time, people like to see at least five sources of information listed, with a maximum of two being from the Internet. If you're short on sources, don't forget to look through magazines, books, encyclopedias, journals, newsletters… and you can also list personal interviews.

Here's an example from Aurora's report on Rocketry:
(The first four are book references, and the last one is a journal reference.)

Fox, McDonald, Pritchard. Introduction to Fluid Mechanics, Wiley, 2005.

Hickam, Homer. Rocket Boys, Dell Publishing, 1998.

Gurstelle, William. Backyard Ballistics, Chicago Review Press, 2001.

Turner, Martin. Rocket and Spacecraft Propulsion. Springer Praxis Books, 2001.

Eisfeld, Rainer. "The Life of Wernher von Braun." Journal of Military History Vol 70 No. 4. October 2006: 1177-1178.

Acknowledgements

This is your big chance to thank anyone and everyone who have helped you with your science fair project. Don't forget about parents, siblings, teachers, helpers, assistants, friends…

Formatting notes for your report: Keep it straight and simple: 12 point font in Times New Roman, margins set at 1" on each side, single or 1.5 spaced, label all pages with a number and total number of pages (see bottom of page for sample), and put standard information in the header or footer on every page in case the report gets mixed up in the shuffle (but if you bind your report, you won't need to worry about this). Create the table of contents at the end of the report, so you can insert the correct page numbers when you're finished.

Add a photo of your experiment in action to the title page for a dynamic front page!

Exhibit Display Board

Your display board holds the key to communicating your science project quickly and efficiently with others. You'll need to find a tri-fold cardboard or foam-core board with three panels or "wings" on both sides. The board, when outstretched, measures three feet high and four feet long.

Your display board contains *all* the different parts of your report (research, abstract, hypothesis, experiment, results, conclusion, etc.), so it's important to write the report *first*. Once you've completed your report, you'll take the best parts of each section and print it out in a format that's easy to read and understand. You'll need to present your information in a way that people can stroll by and not only get hooked into learning more, but can easily figure out what you're trying to explain. Organize the information the way museums do, or even magazines or newspapers.

How to Write for your Display Board: Clarity and neatness are your top tips to keep in mind. The only reason for having a board is to communicate your work to the rest of the world. Here are the simple steps you need to know:

Using your computer, create text for your board from your different report sections. You'll need to write text for the title, a purpose statement, an abstract, your hypothesis, the procedure, data and results with charts, graphs, analysis, and your conclusions. And the best part is - it's all in your report! All you need to do is copy the words and paste into a fresh document so you can play with the formatting.

The title of your project stands out at the very top, and can even have its own "shingle" propped up above the display board. The title should be in Times New Roman or Arial, at least 60 point font ... something strong, bold, and easy to read from across the room. The title has to accurately describe your experiment *and* grab people's attention. Here are some ideas to get you started:

- Light Speed: Measuring the speed of light using a chocolate bar.
- Microwave Radiation: Studying the Effect of Focused Power
- How to Turn Food into Scientific Instruments: Capturing Light Waves Using Microwave Radiation Hotspots

On the left panel at the top, place your abstract in 16-18 pt. font. Underneath, post your purpose, followed by your hypothesis in 24 pt. font. Your list of materials or background research can go at the bottom section of the left panel. If you're cramped for space, put the purpose in the center of the board under the title.

In the central portion of the board, post your title in large lettering (24-60 pt. font). (You can alternatively make the title on a separate board and attach to the top of the display board… which is *great* if you really want to stand out!) Under the title, write a one-sentence description of what your project is really about in smaller font size (24-48 pt. font) Under the title, you'll need to include highlights from your background research (if you haven't put it on the left panel already) as well as your experimental setup and procedures. Use photos to help describe your process.

The right panel holds your results with prominent graphs and/or charts, and clear and concise conclusions. You can add tips for further study (recommendations) and acknowledgements beneath the conclusions in addition to your name, school, and even a photo of yourself doing your project.

Use white copy paper (*not* glossy, or you'll have a glare problem) and 18 pt. Times New Roman, Arial, or Verdana font. Although this seems obvious, spell-check and grammar-check each sentence, as sometimes the computer does make mistakes! Cardstock (instead of white copy paper) won't wrinkle in areas of high humidity.

Cut out each description neatly and frame with different colored paper (place a slightly larger piece of paper behind the white paper and glue in place. Trim border after the glue has dried. Use small amounts of white glue or hot glue in the corners of each sheet, or tape together with double-sided sticky tape. Before you glue the framed text descriptions to your board, arrange them in different patterns to find the best one that works for your work. Make sure to test out the position of the titles, photos, and text together before gluing into place!

In addition to words, be sure to post as many photos as is pleasing to the eye and also help get your point across to an audience. The best photos are of *you* taking real data, doing real science. Keep the pictures clean, neat, and with a matte finish. Photos look great when bordered with different-colored paper (stick a slightly larger piece of paper behind the photo for a framing effect). If you want to add a caption, print the caption on a sheet of white paper, cut it out, and place it near the top or bottom edge of the photo, so your audience clearly can tell which photo the caption belongs to. Don't add text directly to your photo (like in Photoshop), as photos are rich in color, and text requires a solid color background for proper reading.

Check over your board as you work and see if your display makes a clear statement of your hypothesis or question, the background (research) behind your experiment, the experimental method itself, and a clear and compelling statement of your results (conclusion). Select the text you write with care, making sure to add in charts, graphics, and photos where you need to in order to get your point across as efficiently as possible. Test drive your board on unsuspecting friends and relatives to see if they can tell you what your project is about by just reading over your display board.

How to Stand Out in a Crowd: Ever try to decide on a new brand of cereal? Which box do you choose? All the boxes are competing for your attention … and out of about a hundred, you pick one. This is how your board is going to look to the rest of the audience – as just one of the crowd. So, how do you stand out and get noticed?

First, make sure you have a BIG title – something that can be clearly seen from across the room. Use color to add flair without being too gaudy. Pick two colors to be your "color scheme," adding a third for highlights. For example, a black/red/gold theme would look like: a black cardboard display board with text boxes framed with red, and a title bar with a black background with red lettering highlighted with gold (using two sets of "sticky" letters offset from each other). Or a blue/yellow scheme might look like: royal blue foam core display board with textboxes framed with strong yellow. Add color photographs and color charts for depth. Don't forget that the white in your textboxes is going to add to your color scheme, too, so you'll need to balance the color out with a few darker shades as you go along.

It's important to note that while stars, glitter, and sparkles may attract the eye, they may also detract from displaying that you are about "real science." Keep a professional look to your display as you play with colors and shades. If you add something to your board, make sure it's there to help the viewer get a better feel for your work.

For a speed of light exhibit, you can add zooming photons or lightning up the edges of your display board and around the top of your board in gold or blue. Add a test specimen (something with hardened hotspots) at the top of your board as an attention-getter. Have a tiny microwave on display (if you're allowed to bring one in and plug it in) with a stack of chocolate bars … so people can see your experiment in action.

If you're stuck for ideas, here are a few that you might be able to use for your display board. Be sure to check with your local science fair regulations, to be sure these ideas are allowed on your board:

- Your name and photo of yourself taking data on the display board
- Captions that include the source for every picture or image
- Acknowledgements of people who helped you in the lower right panel
- Your scientific journal or engineer's notebook
- The experimental equipment used to take data and do real science
- Photo album of your progress (captions with each photo)

Oral Presentation

You're now the expert of the Light Speed Science Experiment … you've researched the topic, thought up a question, formulated a hypothesis, done the experiment, worked through challenges, taken data, finalized your results into conclusions, written the report, and built a display board worthy of a museum exhibit. Now all you need is to prep for the questions people are going to ask. There are two main types of presentations: one for the casual observer, and one for the judges.

The Informal Talk: In the first case, you'll need quick and easy answers for the people who stroll by and ask, "What's this about?" The answers to these questions are short and straightforward – they don't want a highly detailed explanation, just something to appease their curiosity. Remember that people learn new ideas quickly when you can relate it to something they already know or have experience with. And if you can do it elegantly through a story, it will come off as polished and professional.

The Formal Presentation: The second talk is the one you'll need to spend time on. This is the place where you need to talk about everything in your report without putting the judges to sleep. Remember, they're hearing from tons of kids all day long. The more interesting you are, the more memorable you'll be.

Tips & Tricks for Presentations: Be sure to include professionalism, clarity, neatness, and "real-ness" in your presentation of the project. You want to show the judges how you did "real" science – you had a question you wanted answered, you found out all you could about the topic, you planned a project around a basic question, you observed what happened and figured out a conclusion.

Referring back to your written report, write down the highlights from each section onto an index card. (You should have one card for each section.) What's the most important idea you want the judges to realize in each section? Here's an example:

Research Card: Which type of food most accurately measures the speed of light? After researching the electromagnetic spectrum, microwave ovens, frequency, wavelength, and substances that easily melt, I realized I had all the basics for measuring the speed of light. But which type of food would produce the best measurement results?

Question/Hypothesis Card: I hypothesized that the chocolate bar would have the smallest percent error when compared with the published value for the speed of light. My best guess is that a substance with a melting point near room temperature would be easiest to visualize the results needed for finding the hotspots in a microwave.

Procedure/Experiment Card: After raiding the grocery store for chocolate bars, chocolate chips, marshmallows, butter, and cheese, I created a super-simple project for determining the speed of light by melting different substances in the microwave. I ran nine trials varying the type of food melted and measured the distance between the hotspots and calculated the speed of light using frequency information from the microwave oven itself.

Results/Conclusion Card: I found that my initial hypothesis (chocolate gives the lowest percent error for measuring the speed of light) was supported by the data, but not in the way I expected. **White chocolate has the most accurate measurement (298,704,000 meters/second) with a difference of 0.36% from the published value.**

Recommendations Card: For further study, I recommend running an experiment to test the various types of microwaves, as well as testing different foods based on water content. This experiment was tasty and a whole lot of fun!

Acknowledgements Card: I want to express my thanks to mom for clearing out the kitchen so I could have enough floor space for testing, for my teacher who encourages me to go further than I really think I can go, for my friends for helping chase the balls down, and for dad for helping me unstick the magnets when I knocked them together accidentally.

Putting it all together… Did you notice how the content of the cards were already in your report, in the abstract section? The written report is such a vital piece to your science fair project, and writing it first makes the rest of the work a lot easier. You can do the tougher pieces (like the oral presentation) later because you took care of the report upstream.

As you practice your oral presentation, try to get your notes down to only one index card. Shuffling through papers onstage detracts from your clean, professional look. While you don't need to memorize exactly what you're going to say, you certainly can speak with confidence because you've done every step of this project yourself.

You're done! Congratulations!! Be sure to take lots of photos, and send us one! We'd love to see what you've done and how you've done it. If you have any suggestions, comments, or feedback, let us know! We're a small company staffed entirely human beings, and we're happy to help you strive higher!

The Scientific Method

Throughout this course, you'll see embedded videos, like the one below. You'll find the videos in each experiment include step-by-step explanations and quick demonstrations you can do with your students. These videos are a great way to help you introduce the topic in a kid-friendly way.

One of the problems kids have is how to experiment with their great ideas without getting lost in the jumble of result data. So often students will not have any clear ideas about what change caused which effect in their results! Students often have trouble communicating their ideas in ways that not only make sense but are also acceptable by science fairs or other technical competitions designed to get kids thinking like a real scientist. Another problem they face is struggling to apply the scientific method to their science project in school, for scout badges, or any other type of report where it's important that other folks know and understand their work.

The scientific method is widely used by formal science academia as well as scientific researchers. For most people, it's a real jump to figure out not only how to do a decent project, but also how to go about formulating a scientific question and investigate answers methodically like a real scientist. Presenting the results in a meaningful way via "exhibit board"… well, that's just more of a stretch that most kids just aren't ready for. There isn't a whole lot of useful information available on how to do it by the people who really know how. That's why I'm going to show you how useful and easy it is.

The scientific method is a series of 5 steps that scientists use to do their work. But, honestly, you use it every day, too! The five steps are Observation, Hypothesis, Test, Collect Data, and Report Results. That sounds pretty complicated, but don't worry, they are just big words. Let me tell you what these words mean and how to play with them.

Step 1: Observation means what do you see, or hear, or smell, or feel? What is it that you're looking at? Is that what it usually does? Is that what it did last time? What would happen if you tried something different with it? Observation is the beginning of scientific research. You have to see or touch or hear something before you can start to do stuff with it, right?

Step 2: Once you observe something, you can then form a hypothesis. All hypothesis really means is "guess." A hypothesis is an educated guess. Tonight at dinner, when someone asks you, "Do you want peas or carrots?" Say, "I hypothesize that I would like the carrots." Everyone will think you're a genius! Basically you're saying "I guess that I would like the carrots." Hypotheses aren't right or wrong, they are just your best guess.

Step 3: To see if your guess is correct, you need to do the next step in the scientific method: test. The test is just what it sounds like: running experiments to see whether or not your hypothesis is correct.

Step 4: As you do your tests, you need to collect data. That means collecting the numbers, the measurements, the times, the data of the experiment. Once you collect your data, you can take a look at it, or in other words, analyze it.

Step 5: Once you analyze your data you can report your results. That basically means tell someone about it. You can put your data in a chart or a graph or just shout it from the rooftops!

Here's a great way to remember the 5 steps. Remember the sentence "Orange Hippos Take Classes Regularly." The first letter in each word of that goofy sentence is the same as the first letter in each step of the scientific method. That's called a mnemonic device. Make up your own mnemonic devices to remember all sorts of stuff.

“OK, so that’s what the words mean. How do I use that every day?”

Well, I’m glad you asked that question. If you had cereal for breakfast this morning, you did the scientific method. On the table you had a bowl of cereal with no milk in it. As you looked at your dry cereal, you made an observation, “I need milk!” At that point, you made a hypothesis, “There’s milk in the fridge.” You can’t be sure there’s milk in the fridge. Someone might have used it up. It might have gone bad. Aliens may have used it to gas up their milk-powered spaceship. You just don’t know! So you have to do a test.

What would be a good test to see if there is milk in the fridge? Open the fridge! Now once you move the week-old spaghetti and the green Jell-O (at least you hope it’s Jell-O) out of the way, you can see if there is milk or not. So you collect your data. There is milk or there isn’t milk. Now you can finally report your results. If there is milk, you can happily pour it on your cereal. If there isn’t any milk, you report your results by shouting, “Hey, Mom ...We need milk!” Scientific method, not so hard is it?

You’ll get familiar with the scientific method by doing the activities and experiments in your lessons. Most scientists don’t use the *full* version of the scientific method, which actually includes several additional steps to the ones I’ve outlined above. You’ll find the full-blown version of the scientific method in the back of this book. I’ve included a copy of a special project which won first prize at a science fair. You’ll find this complete project explains every detail and how it uses the full version of the scientific method so you can see how to do it for yourself on any project you choose.

Vocabulary for the Unit

Asteroid. Object in orbit around the Sun, intermediate in size between meteoroids and planets.

Asteroid belt. The region of the solar system in which most asteroids have their orbits, between Mars and Jupiter.

Black holes. The leftovers of a BIG supernova. When a star explodes, it collapses down into a white dwarf or a neutron star. However, if the star is large enough, there is nothing to keep it from collapsing, so it continues to collapse forever. It becomes so small and dense that the gravitational pull is so great that light itself can't escape.

Center of mass. Mean position of the masses that comprise a system or larger body: for two bodies, the center of mass is a point on the line joining them. For a binary star system, the motion of each star can be computed about the center of mass.

Comet. Small body in the solar system, in orbit around the Sun. Some of its frozen material vaporizes during the closer parts of its approach to the Sun to produce the characteristic tail, right behind the head.

Conjunction. Closest apparent approach of two celestial objects. Planetary conjunctions were once considered important omens for events on Earth.

Constellation. A group of stars that seemed to suggest the shape of some god, person, animal or object. Now a term used to designate a region of the sky. There are 88 constellations.

Dark matter: Matter in the cosmos that is undetectable because it doesn't glow. Dark matter, some of it in the form of as-yet-undiscovered exotic particles, is thought to comprise most of the universe.

Eclipse. Blocking of light from one body by another that passes in front of it. Eclipses can be total or partial.

Eclipse path. Narrow path on the Earth's surface traced by the Moon's shadow during an eclipse.

Eclipsing binary star. Binary star whose mutual orbit is viewed almost edge-on so that light observed is regularly decreased each time one star eclipses the other.

Ecliptic. Path that the Sun appears to follow, against the stars on the celestial sphere, during the course of a year.

Ecliptic plane. Plane defined by the Earth's orbit around the Sun.

Electromagnetic wave: A structure consisting of electric and magnetic fields in which each kind of field generates the other to keep the structure propagating through empty space at the speed of light, c. Electromagnetic waves include radio and TV signals, infrared radiation, visible light, ultraviolet light, X-rays, and gamma rays.

Ellipse. Type of closed curve whose shape is specified in terms of its distance from one or two points. A circle is a special form of ellipse. In appearance, an ellipse is oval-shaped.

Escape speed: The speed needed to escape to infinitely great distance from a gravitating object. For Earth, escape speed from the surface is about 7 miles per second; for a black hole, escape speed exceeds the speed of light.

Equinox. Two days each year when the Sun is above and below the horizon for equal lengths of time.

Event horizon: A spherical surface surrounding a black hole and marking the "point of no return" from which nothing can escape.

Field: A way of describing interacting objects that avoids action at a distance. In the field view, one object creates a field that pervades space; a second object responds to the field in its immediate vicinity. Examples include the electric field, the magnetic field, and the gravitational field.

Galaxies are stars that are pulled and held together by gravity.

Globular clusters are massive groups of stars held together by gravity, using housing between tens of thousands to millions of stars (think New York City).

Gravitational lensing is one way we can "see" a black hole. When light leaves a star, it continues in a straight line until yanked on by the gravity of a black hole, which bends the light and change its course and shows up as streaks or multiple, distorted images on your photograph.

Gravitational time dilation: The slowing of time in regions of intense gravity (large spacetime curvature).

Gravitational waves: Literally, "ripples" in the fabric of spacetime. They propagate at the speed of light and result in transient distortions in space and time.

Gravity: According to Newton, an attractive force that acts between all matter in the universe. According to Einstein, a geometrical property of spacetime (spacetime curvature) that results in the straightest paths not being Euclidean straight lines.

Latitude. Coordinate used to measure (in degrees) the angular distance of a point or celestial objects above or below an equator.

Light year. Distance that light travels in 1 year.

Longitude. Coordinate used to specify the position of a point or direction around (or parallel to) an equator.

The **Kuiper Belt** is an icy region that extends from just beyond Neptune (from 3.7 billion miles to 7.4 billion miles from the Sun). This is where most comets and asteroids from our solar system hang out.

Neutron stars with HUGE magnetic fields are known as **magnetars**.

Magnetic field. Region surrounding a magnet or electric current, in which magnetic force can be detected in such a region, high-speed electrically charged particles will generally move along curved paths and radiate energy.

Magnetic pole. One of the two regions on Earth to which a compass needle will point. Poles also exist on magnets, and the magnetic fields of some electric currents can have an equivalent behavior.

Magnetosphere. Region surrounding a star or planet (including Earth) in which a magnetic field exists.

Meridian. Great circle, on the celestial sphere or the Earth, that passes through both north and south poles and an observer's zenith or location.

Meteor. Glowing trail in the upper atmosphere, produced by meteoroid burning up as it moves at high speed.

Meteor shower. Numerous meteors seen in a short time span as the Earth moves through a cloud of meteoroids, probably remnants of a comet and still following the comet's orbit.

Meteorite. Remnant of a meteoroid that has been partially eroded in passage through the Earth's atmosphere before hitting the surface. Term now also applied to similar bodies that collide with the surfaces of the other planets and their satellites, producing craters.

Meteoroid. Large rock (but much smaller than minor planets) moving in an orbit in the solar system. Meteoroids that enter in the Earth's atmosphere are termed meteors or meteorites, depending on their behavior.

Neutron stars are formed from stars that go supernova, but aren't big and fat enough to turn into a black hole.

The **Oort Cloud** lies just beyond the Kuiper belt, housing an estimated 1 trillion comets.

Orbit. Path traced out by one object around another.

The visible surface of the Sun is called the **photosphere**, and is made mostly of plasma (remember the plasma grape experiment?) that bubbles up hot and cold regions of gas.

Dying stars blow off shells of heated gas that glow in beautiful patterns called **planetary nebula**.

Pulsars are a type of neutron star that spins very fast, spews jets of high-energy X-ray particles out the poles, and has large magnetic fields.

Our **solar system** includes **rocky terrestrial planets** (Mercury, Venus, Earth, and Mars), **gas giants** (Jupiter and Saturn), **ice giants** (Uranus and Neptune), and assorted chunks of ice and dust that make up various **comets** (dusty snowballs) and asteroids (chunks of rock).

Spacetime: The four-dimensional continuum in which the events of the universe take place. According to relativity, spacetime breaks down into space and time in different ways for different observers.

Spacetime curvature: The geometrical property of spacetime that causes its geometry to differ from ordinary Euclidean geometry. The curvature is caused by the presence of massive objects, and other objects naturally follow the straightest possible paths in curved spacetime. This is the essence of general relativity's description of gravity.

Spacetime interval: A four-dimensional "distance" in spacetime. Unlike intervals of time or distance, which are different for observers in relative motion, the spacetime interval between two events has the same value for all observers.

Special theory of relativity: Einstein's statement that the laws of physics are the same for all observers in uniform motion.