Explore Your Universe!

Nicole Lloyd-Ronning
lloydronning@gmail.com

A series of labs/experiments introducing concepts in physics and astronomy, and aimed at grades 6-9.

Contents:

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I. ***Powers of 10 and Units in Astronomy***

Objective - This warm-up lab is intended to get students familiar with the large numbers encountered in astronomy (e.g. distances, times, numbers of stars and galaxies in the universe). Students will measure the dimensions of the classroom and/or the distance between objects in the classroom, and report their findings in units of millimeters, micrometers and nanometers.

Background - Students should be reminded of exponential form - for example, 10^2 = 100, 10^6 = 1000000, 10^{-2} = 1/100 = 0.01, 10^{-6} = 1/1000000 = .000001, etc.

Materials

Tape Measure
Paper
Pencil

Procedure

1. Measure various objects in the classroom (in either meters or centimeters) - for example, your science book, your desk, the width of the classroom, the length of your friend's arm, the distance from the floor to the ceiling.

2. Report all measurements in meters, centimeters, millimeters and nanometers. 1 meter = 10^2 cm = 10^3 mm = 10^9 nm (This will help us get used to using large exponents, which we encounter all of the time in astronomy!)

Item Description	Size in m	Size in cm	Size in mm	Size in nm

*For comparison, a human hair or a sheet of paper is about 10^5 nanometers thick. A strand of DNA is about 3 nanometers thick and a single gold atom is about ⅓ nanometer. Your fingernail grows 1 nanometer per second. Can you report your measurements in units of "human hairs"?

Relate our measurements to distances of objects in the universe:

- Distance to Moon: ~10^8 m
- Distance to Sun: ~ 10^{11} m
- Distance to Pluto: ~10^{13} m
- Distance to nearest star (alpha-centauri): 10^{16} m
- Width of galaxy: 10^{21} m
- Distance to nearest galaxy: 10^{22}m
- Distance to edge of visible universe (which is always expanding): ~ 10^{27} m

Question:
Why is using scientific notation important for astronomical units?

Bonus: *Draw dots on a balloon that is not inflated (these represent galaxies in the universe). Measure the distances between dots and compute the average. Now blow up the balloon (this is a rough model of the universe expanding) and compute the average distance between dots.*

***Slide show**: Inventory of the Universe presentation.*

II. ***The Rotation Rate of the Sun***

Objective: Weather permitting, students will observe the sun at the beginning and end of class, over the course of a few days. At each observation, students will record the position of sun spots (they should notice a change in position of each spot with time). From the distance the sunspots move, and the time over which they moved (and given the distance from the Earth to the Sun), students can calculate the rate of rotation of the sun.

Background: Our sun (like Earth, the moon, and almost everything in the universe) rotates and we can observe sunspots as a means of evidence of rotation (sunspots are regions of intense magnetic activity on the surface that appear as dark spots).
If the Sun is rotating, would the spots stay in the same place?

Materials

Telescope
Solar Filter
Pencil and Sun templates/ paper

Procedure

1. On a sunny day at the beginning of class, observe the sun (*Warning: never ever look directly at the sun and ONLY observe the sun with a proper solar filter on the telescope. Serious eye damage and/or blindness can occur otherwise).* Draw the image of the sun on your paper.

2. Try to identify a sunspot. If you can, identify as many as possible. Mark its position on your drawing of the sun.

3. At the end of class, observe the sun again and mark the position of your sun spot(s).

4. In a few days to a week, observe the sun again and mark the position of your sun spot(s) on your drawing (the same spots you originally observed - how can you be sure they are indeed the same spots?).

5. Calculate how far (in cm on your drawing) your sun spot(s) travelled. Measure the effective circumference of your sun in your drawing (for example, if you drew a circle of 12cm, the sun would be 24 cm around). Now calculate the sun's rotation rate:

    Time it takes the sun to rotate once around = (Time between observations)x[(Sun's diameter in drawing)/(distance sunspot moved in time between observations)].

    For example, if in 7 days your sunspot moved 6 cm on a sun drawing that is 12 cm in diameter (so 24cm all the way "around"), the time it takes the sun to do one full rotation is 7days*(24cm/6cm) = 28 days.

Questions: Does you data support that the Sun is rotating? Why or why not? What other celestial objects could you use this method on? What could you observe instead of sunspots?

For support and extra links, see: http://solar-center.stanford.edu/spin-sun/estimate.html

III. Gravity! Measuring g

Objective: In this lab, students will measure the acceleration due to gravity ("*g*") by measuring the rate at which steel balls roll down inclined planes. The distance the balls roll is "x", length of time it takes for them to roll down the inclined plane is "t", and "a" is the acceleration; we will use the relationship $x=½*a*t^2$.

For objects accelerating down an incline plane, a = g*sin(theta), where "theta" is the angle of the inclined plane and "g" is the acceleration due to Earth's gravity (this is what we're after!). The students will measure the length of the plane (x), the angle of the incline (theta) and the time it takes the balls to roll down (t). This will be done for several trials, using different balls and different angles of incline. Using the relationship between distance and acceleration ($x=½*a*t^2$), they will solve for the acceleration "a". Using the measurement of the angle of incline theta and the acceleration "a", they will use the equation (a=g*sin(theta)) to solve for "g" - this is the acceleration due to the pull of Earth's gravity and is (approximately) the same constant value everywhere on Earth!

Materials:

Wooden planks
Books or similar to prop planks at an incline
Balls of different masses (steel balls work well)
Protractors
Timers
Tape measures or meter sticks
Paper and Pencil

Procedure:

1. Set up an incline by propping a wooden plank up on books or some other stable base.

2. Measure the length of the incline (units of meters work well) and record. Measure the height of the incline and record.

3. Determine the angle of the incline: theta = $\sin^{-1}$(height of incline/length of incline). You can also simply measure the angle with a protractor.

4. Hold the ball at the top of the incline. Release (start the timer at this moment) and measure the time it takes to reach the bottom of the incline (stop the timer when it reaches the bottom). Record this value.

5. Repeat several times for the same ball.

6. Repeat for a ball of a different mass (and do several times for this ball).

7. Calculate the acceleration $a = 2*x/(time)^2$. Calculate g ~ a*sin(theta). Does it = 9.8 m/s^2? There is actually an extra complication due to the rolling of the ball that introduces a factor of 5/7 into the second equation. Multiply g by the correction factor of 5/7 due to rolling of ball. Does this match the known value of 9.8 m/s^2?

Questions- Does the angle of the plane effect acceleration? Does the size or weight of the ball affect acceleration?

IV. ***M&M atoms***

Objective: In this lab, students use M&Ms (or similar size candy/objects) to build atoms on the periodic table. M&M's of different sizes and/or colors can be used to represent protons, neutrons and electrons. The students will at first be asked to "build" specific atoms, with the correct number of neutrons, protons and electrons (e.g. Hydrogen, Helium, Carbon). The students are then free to examine the periodic table and build any atom. If time, there can be a short discussion about how when electrons in atoms jump around (from one energy level to the next), they emit light of a very specific energy (spectral lines - see Lab VI).

Materials

M&M's or similar candy/objects of different sizes and colors
Periodic table chart

Procedure

1. Review with the students the basic structure of an atom and how the periodic table tells us how many protons, neutrons and electrons an atom has.

2. Choose M&M's (or whatever object using) to represent protons, neutrons and electrons.

3. Build a model of the hydrogen atom (1 proton, 1 electron). Then helium (2 protons, 2 neutrons, 2 electrons). These are the most abundant elements in the universe.

4. Now, students can have a look at the periodic table and build atoms of their choice (gold? Carbon? Oxygen? Einsteinium?), simply by assembling the correct number of protons, neutrons and electrons according to the periodic table.

Bonus: If there is time, explain how the electrons are confined to certain "shells" or energy levels in the atom. In shell 1, only 2 electrons can fit. In shell 2, 6 electrons. In shell 3, 10 electrons and so on. Have them build their atoms according to the rules confining a certain number of electrons to each shell. What does it mean when there are empty spaces in some of the shells (they can begin to build molecules if there is time)? What happens when an electron jumps from one shell to another?

Questions: How/where are these elements made? Some (like Hydrogen and Helium) were made in the early universe, but most elements (like the gold or silver in our jewelry for example) are made during the violent, energetic deaths of massive stars!

V. ***Visible Light and Beyond - EM spectrum***

Objective: In this lab, students will relate the color of light to its energy and get a sense of how differently objects can appear when we look at them in different energies/wavelengths. They will first explore the colors/energies of the visible spectrum. After breaking white light into its color components using diffraction gratings, students will use color filters to “de-code” color-coded messages, as well as make their own color-coded messages. Students will be able to see how filtering all but one color of the spectrum vastly changes how an object appears. This concept will be extended to the non-visible spectrum - students will solve puzzles, organizing pictures of astronomical objects observed in different wavelengths/energies, according to the wavelength in which they were observed.

Questions: Have you ever seen a rainbow? Where? What colors appeared in the rainbow? What does the color tell you about the light itself?

Background: The energy of light is related to its wavelength by a simple equation $E = (1.24)/L$, where E is the energy of the light (in units of electron volts) and L is the wavelength of light (the distance from one crest of the wave to another) measured in micrometers (10^{-6}m). [Light has pretty tiny wavelengths].

Materials

- Color Paddles (with diffraction gratings)
- Flashlights
- Paper
- Crayons
- Picture sets of astronomical objects observed in different wavelengths

Procedure

1. Using the diffraction grating on the color paddle and a flashlight, “break” white light into its component colors - in other words, make a rainbow! Each color of light is a wave of different energy, with bluer light having more energy and redder light having less. This energy also corresponds to the wavelength of light - the shorter wavelengths have more energy, while the longer have less (see the background section above).

2. Take out the color filters on the color paddles. Try putting them over your flashlight and shine your flashlight on your desk. These filters only allow one color/energy/wavelength through and block out all of the others. *If there is time, you can try to “recombine” the*

colored light by crossing the beams of your flashlights (with different color filters over them). See if you can "make" white light this way.

3. Now let's work with the red (lower energy light) and blue (higher energy light) color filters. Look around the room through the red or blue filter. What color is your desk? Your teacher? Your arm? How about the rainbow you made with the diffraction grating? Record your observations. Again, the color filter blocks out all energies or wavelengths of light *except* that color. *Question: When you put the red and the blue filter together and look through that, will you see purple? No! You should see (almost) nothing (i.e. black). Why?*

4. Now take out a piece of white paper and a red and blue crayon. Write a message in red and color over it in blue (not too darkly). Write a message in blue and color over it in red (don't worry if you're able to see the message). Now observe each message with the red and blue color filters. Which filter allows you to read the first message? The second? If there is time, use other colors to make color-coded messages and observe them with the various color filters. Record your observations. *Questions**:** Imagine living your life with only the red filter over your eyes. What color would the sky appear to you? How about the ocean? In some ways, we are living with a filter over our eyes - we can only see a tiny fraction (just a narrow range of colors or energies) - of the light that exists. What other kind of light do we know of?*

5. Look at the pictures of objects observed in different wavelengths (see slideshow *MultiwavelengthPics)*. How do they differ?

6. Each group should take a puzzle set (*puzzle sets can be made of 2 of the objects in the MultiwavelengthPics presentation - e.g. M33 and CentaurusA; print out, cut up and mix up)*. In the puzzle are 10 pictures, but only 2 different objects. 5 pictures were taken of one object and 5 of the other. Each of the 5 pictures was taken with a telescope that sees a different energy of light. Your challenge is to sort the pictures - put the 5 of one object on the left and 5 of the other on the right. As a bonus, try to sort them according to the energy of light in each picture. How do the pictures in different wavelengths differ? What can you learn about the objects by looking at them in different wavelengths/energies?

   Slides: *MultiwavelengthPics*

VI. ***Spectroscopy - Fingerprinting the Cosmos***

Objective: In this lab, students will learn how astronomers determine the composition of different objects in space (such as stars and galaxies), as well as how the distances to the farthest objects in space are measured. Using gas tubes containing different elements (e.g., hydrogen, helium, oxygen, etc.) and spectrographs, students will try to identify the element by the position of the gas tubes' "spectral lines" (the wavelength where most of the light is emitted). If time, students will be given a spectrum with shifted spectral line, and calculate the distance this object given the spectral line shift (among other things, this is how astronomers measure distances to objects far out in the cosmos!).

Background: Students can review the structure of an atom is (see Lab V), and the energy levels of electrons in atoms (remember electrons can only exist in very specific energy levels - sometimes called shells - around an atom). An electron jumping from a higher to a lower energy gives off a photon of a very specific energy (namely, the energy difference between the two shells). A review or introduction to the Doppler shift is also helpful (the audible Doppler shift can be demonstrated, e.g. through the following video: https://www.youtube.com/watch?v=a3RfULw7aAY ; For light waves: https://www.youtube.com/watch?v=vDvIhiCnatE) .

A reference on spectroscopy:
https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Quantum_Mechanics/09._The_Hydrogen_Atom/Atomic_Theory/Electrons_in_Atoms/Atomic_Spectra

An astronomy oriented discussion of spectroscopy:
http://spiff.rit.edu/classes/phys301/lectures/spec_lines/spec_lines.html

Materials

Gas tubes containing different elements (e.g. hydrogen, helium, oxygen, argon, krypton)
Power source
Spectrographs/ spectroscope *(with a scale/ruler embedded)*
Pencil and paper
A reference guide of atomic spectral lines:
http://www.schaffrath.net/Spectra/Spectral%20Tubes.pdf

Procedure

1. Choose a gas tube and CAREFULLY insert in power source. Turn on power source ONLY when to are ready to observe.
   Warning: Gas tubes get extremely hot and should not be left on for more than about 5 minutes total, please use in 30 second intervals- . They should only be handled by the teacher or careful student wearing insulating gloves.

2. Observe the gas tube with the spectrograph: Look in the small end of the triangular spectrograph. Point the small square window on the large end of the spectrograph toward the gas tube. You should see a line or several lines on the ruler/grid inside the spectrograph.
3. Record the wavelength of each spectral line (where it falls on the "ruler" in the spectrograph) you see. Create a data table to record your results.

4. Have your partner change the gas tube to a different element (without telling you what it is) and repeat. Your goal is to identify the element by the position of its spectral lines without knowing what it is! So first, record the wavelength of each spectral line for a particular gas tube. Then go to the reference chart to find what element that corresponds to.

5. In the end you should have a list of elements and the positions of spectral lines they produce (this can be compared to a table with the known positions of the lines). Have you been able to identify the elements correctly? These elements produce the same spectral lines anywhere and everywhere in our universe. So if we look at a star with a spectrograph, and see a line where we saw the hydrogen line in class, we know that star has hydrogen. (*Cool note: using this technique, astronomers have found some stars that are made of diamonds (squished carbon)!)* The brightness of the line tells us how much of each element the object has.

BONUS*:* If a star or galaxy or some other object is moving away from us or toward us, the spectral line will be shifted to a lower (if moving toward us) or higher (if moving away from us) wavelength (this is often called a Doppler shift). The amount it is shifted tells us how fast it is receding or coming toward us. Objects in our galaxy are moving all around and we can tell how fast by measuring the Doppler shift of their spectral lines. For objects very far out in the universe (billions of light years away), they appear to be receding due to the expansion of space. We can measure how much their spectral lines have shifted and get a distance (called a "redshift") to the object.

- Show a spectrum of an object and see if the class can identify the spectral lines (*See slide #5 in the Spectra/Lines slides)*. If the line is shifted from its laboratory position, you have to identify it by its relative position to the other lines that element makes.
- Measure how much the line shifted: Compute the shift = (wavelength of line in observed spectrum) - (wavelength of line in laboratory).
- The redshift is just this "shift" divided by the wavelength of the line in the laboratory. Calculate the redshift of this object.
- A redshift of 1 corresponds to a distance of about 7.8 billion light years away. A redshift of 0.01 is about 140 million light years away.

BONUS2*:* Consider that light travels 3.0×10^8 m/s (always and everywhere in the universe). If I stood on the moon and turned on a bright flashlight, it would take about 1 second for that light to get to Earth. If the sun suddenly got twice as bright (or went completely dark), it would take 8 minutes before we learned that information. The farther out we look, the further back in time we are looking. When we see a galaxy 1 billion light years away (and we do - lots of them!), we are seeing the galaxy as it looked 1 billion years ago, not as it looks at this moment in time, because that's how long the light took to reach us! So, looking far out in space is also looking far back in time!! (See Inventory of Universe presentation for light travel time slides).

Slides: *Spectra/Lines*

VII. ***Magnetic Forces***

Objective: In this lab, students are given materials and a set of simple challenges to explore the magnetic force. Through simple experiments, students will learn about the polarity of magnets, permanent magnets vs. paramagnets and more. These concepts will be connected to astrophysical objects and students will learn how magnetic forces play a role in the universe.

Background: Magnetic fields are everywhere in our universe - from our Earth (which causes the beautiful northern lights: https://iso.500px.com/northern-lights-photo-tutorial/), our sun, other stars, our galaxy, and even around black holes! They play an important role in producing the light we see from different objects like gamma-ray bursts, active galaxies, microquasars and more. A special kind of star called a neutron star (made in a supernova - see Lab VIII below!) is a tiny, dense star (about the size of the town of Los Alamos but so dense that just about ***1 teaspoon*** of the star weighs as much as about ***20 million large elephants!)***. But maybe even cooler, these neutron stars have really strong magnetic fields (more than a trillion times the Earth's magnetic field). *And* they spin around really fast (about once per second). As this magnetic field whips around, it shines a spinning beacon of light (like a lighthouse) called a pulsar.
Here is a movie illustrating what a pulsar is:
https://www.youtube.com/watch?v=EVbbWrQhwck

Here is a picture of a real neutron star/pulsar that was left over from a supernova that went off in 1054 AD (it's called "the Crab"):
http://chandra.harvard.edu/photo/2002/0052/0052_xray_widefield.jpg

Materials

Circular magnets

Toy cars (with magnet attached to top)
Paper clips
Plastic buckets
Objects in the room
Paper and pencil to record observations

Procedure

1. Students will work in groups of 2 or 3, but each student will have a circular magnet and a paperclip for starters.

2. Using your magnet and a paperclip, consider the following questions:
    a. Can your magnet lift your paper clip off the desk? From how far away (record this distance)? If you attach two circular magnets together and repeat this experiment, how far away can the magnet be to still lift the paper clip off the desk? How about three magnets? Record these observations.
    b. Does the magnetic force work through your desk? Your hand? A book?
    c. What objects in the room are magnetic - that is, what objects will the magnet attract or stick to? Record the properties of the objects in the room that appear to be magnetic (what are they made of?).
    d. Does the magnetic force work through water? Place your paper clip on the bottom of a bucket of water. If so, measure how high your magnet can be to still lift the paper clip off the bottom of the bucket (compare this to what you found in part a)).

3. Each group will take a toy car with a magnet attached to the top. Try to move the car forward and backward with the magnet. Now try to move the car both forward and backward *while keeping the hand holding the magnet in the exact same position relative to the car.* For example, place your hand holding the magnet just behind the car and note what direction the car moves. Now keeping your hand and the car in the exact same position, try to make it move in the *opposite* direction (hint: consider the orientation of the magnet).
    a. This experiment shows us that the orientation of the magnet matters! Magnets have a north and south pole and when north poles are aligned, they repel. When north and south poles come together (so the magnets are “anti-aligned”), they attract.

VIII. ***Supernova Ball Bounce***

Objective: Students will learn about momentum transfer and the basics of how a supernova explodes by dropping two different sized balls - one on top of the other - in unison (the top ball will go flying off!). Students can record the distance their “outer” ball traveled given its mass. ***WARNING: This should probably be done outside with plenty of space.***

Background: When a star uses up all of its fuel, nothing is stopping gravity from trying to squish the star as small as it will go (when it is burning bright, the pressure from the hot particles and radiation keeps it from gravitationally contracting). When this happens, the inner part of the star is squished to a super dense, small star called a neutron star. Very roughly speaking (there are some other effects that come into play) the rest of the infalling gas hits this dense core and roughly “bounces” off, exploding the rest of the star. We will simulate this effect in this lab.

Materials

Bouncy balls of different sizes (3 balls per group)
Paper and pencil
Measuring tape or meter sticks.

Procedure

1. Using three or more bouncy balls, decide with your group a name or label for each ball - for example, *ball1, ball2, ball3 (you can be more creative than this of course!).*

2. Record the properties of each of the three (or more) bouncy balls: 1) it’s weight, 2) it’s circumference, 3) it’s degree of “bounciness” (this is something you will have to decide how to estimate with your group - for example, you can measure how high it bounces when you drop it straight down from waist height).

3. Outside, with plenty of space, hold two balls one on top of the other (touching). Record which ball is on the top and which is on the bottom, and the height at which you are holding the bouncy balls (you can measure this from the point the balls are touching).

4. Now release the balls at the same time (note: from lab IV, you might remember that balls of different masses fall at exactly the same rate). Measure where the top ball landed.

5. Repeat, using all combinations of orderings of the bouncy balls. For example:
    - Ball1 on top of Ball2
    - Ball2 on top of Ball1
    - Ball3 on top of Ball1
    - Ball1 on top of Ball3
    - Ball2 on top of Ball3
    - Ball3 on top of Ball2

   Which ball landed the farthest away? Why? How does it relate to:
    - It’s mass?
    - The mass of the bottom ball?
    - It’s degree of “bounciness”?
    - The degree of bounciness of the bottom ball?

- It’s size?
- The size of the bottom ball?

IX. ***Black Holes***

Objective: Students will be introduced to general relativity and the concept of gravity as curved space by observing the effect of increasingly heavy objects on rubber sheets. The concept will be extended to the limit of curved space - black holes. Several short illustrative videos can be shown to reinforce this concept.

Background: Einstein taught us that we can think of space as sort of an elastic entity with a geometrical shape. A small patch of empty space will be “flat” like a sheet of paper (if we are thinking in two dimensions as opposed to three!). Massive objects like planets and stars and galaxies will cause space to curve (like a bowling ball would cause a trampoline surface to curve or sink in). The more mass an object has, the more space curves around that object (and causes nearby objects to fall toward it). The ultimate limit of gravity is a black hole, in which so much mass is packed into such a tiny volume that it causes a sort of “rip” in space, from which nothing - not even light - can get out (imagine squishing the entire Earth into the size of a marble and putting it on the rubber sheet - it would rip the rubber sheet! And anything that fell into the rip would no longer be able to roll around on the rubber sheet, aka in space).
If time, check out the following black hole movies:

- https://www.youtube.com/watch?v=e-P5IFTqB98
- https://www.youtube.com/results?search_query=black+hole
- https://www.youtube.com/watch?v=366_xfP_PtI (black holes colliding = ripples in space = gravitational waves!).

Materials:

Large rubber sheets
Steel balls of different masses

Procedure

1. In groups of 5 or so, hold the rubber sheet at about waist height, as flat as possible without stretching it at all.

2. Now add a small steel ball to the rubber sheet and observe what happens to the shape of the rubber.

3. Remove the small steel ball and add successively heavier steel balls, each time recording the shape/deformation of the rubber sheet.

4. Now place a medium sized ball in the middle and then gently roll a smaller steel ball to the side of the sheet. What happens to the smaller steel ball? Why?

5. Try different combinations of sizes of steel balls to observe what happens to their motion and the shape of the rubber sheet.

X. ***Centrifugal Force and Angular Momentum***

Objective: In this fun lab/demo, students hold a spinning bicycle wheel and are then spun on a chair. The students are challenged to change the direction of their rotation by changing the orientation of the spinning bicycle wheel.

Background: Angular momentum (which is the momentum associated with spinning objects) is very important in astrophysics. Most stars in the universe are born spinning. When they die (and shed their outer layers - see Lab VIII), they want to conserve their angular momentum. The leftover core is a much smaller object than the original star and so - like the skater who pulls in her arms - is spinning much more rapidly than its parent star. We observe rapidly spinning neutron stars (aka pulsars) and black holes all over the universe!

In the second part of this lab we are looking at the centrifugal force of an object, which is simply its tendency to want to keep going in a straight line - it takes force to keep things spinning in a circle. In this lab, the force keeping the object from flying off is it's friction. The "force" the object feels trying to pull it off the lazy susan is related to its mass (m), velocity (v), and distance from the center (r): mv^2/r. If this force gets bigger than the frictional force, the object will fly off!

Astrophysical objects like stars and galaxies are also spinning. The force that keeps all of the stars in a spinning galaxy from flying off is gravity (as opposed to friction in). The really exciting thing is that the force of gravity required to keep the stars from flying off is much larger than we expect due to the mass that we see - this is the mystery of dark matter, related to our next lab!

Materials

A chair that spins
A bicycle wheel with handles on the axis of rotation (Bradbury has one it loans out).
A rotating flat surface (like a lazy susan)

Objects that sit flat (not rounded) made of different materials that have different amounts of friction with the lazy susan (for example: dice, a wooden block, a metal cube, etc).

Procedure

Part I

1. Sit on a chair that can spin 360 degrees. Have a partner give you one (careful) push and record how many times you spin in a given amount of time (for example, how many full rotations you do in 5 seconds).

2. Now take the bicycle wheel and get it spinning as rapidly as possible (be sure to hold the wheel far away from your body so it doesn't hit you).

3. Holding the spinning bicycle wheel straight in front of you, sit on the chair and have your partner give you a similar push as before.

4. Now rotate the axis of the bicycle wheel - lean it to the right and observe what happens to your motion. Record how many rotations you do in 5 seconds (or your chosen time interval). Now lean it to the left and do the same thing.

5. Can you completely change your direction of motion? Why? (*Nature wants to "conserve" the total angular momentum, so if you change directions of that momentum, your spinning chair will compensate to keep the original amount of angular momentum the same. This is the same reason spinning ice skaters can pull in their arms and spin faster, or throw out their arms to slow their rotation - try that too!!).*

Part II

1. In the second part of this lab, we'll see how much "centrifugal force" an object has when it spins or rotates. Record the mass of each object you are using.

2. Place the various objects (a die, metal block, wooden cube, etc) on the lazy susan and spin the lazy susan. Record how many rotations per second it is spinning.

3. See how fast (how many rotations per second) you have to spin the lazy susan before the object goes flying off. Which object fell off first? Does it depend on the mass? Does it matter how far out you place the object from the center of the lazy susan (i.e. does it fall off as easily if you put it near the center as opposed to the edge?).

XI. ***Missing Mass - Dark Matter***

Objective: In this lab, students will investigate the concept of dark matter by exploring how we can infer the presence of an object - even when we can't see it - by observing its effect on other objects around it.

Background: What is dark matter? Nobody knows, but we know it's there!! When we observe the motion of stars in galaxies or the motions of galaxies in clusters, they are moving *much faster* than they should be given the amount of mass/light we can see (we assume the motion is due to gravity pulling on the stars and galaxies). If we understand the laws of gravity correctly, then there is some sort of "dark" mass there that is causing everything to move around much faster than it should otherwise. Although we have a few ideas, it's anyone's guess what this stuff really is!
Check out these videos explaining dark matter:
https://www.youtube.com/watch?v=sI23cwbbNqs
https://www.youtube.com/watch?v=ttpkto9Cm5c

Materials:

Paper plates
Nickels or quarters
Tape
Pencil

Procedure

1. Working in groups of three or four, punch a hole in the center of two paper plates with a pencil.

2. Tape six quarters spaced equally around the plate and number the positions of each quarter.

3. One student from the group then tapes two extra quarters on top of one of the six quarters already there (the other students in the group should not see where!), and then tapes the other paper plate on top.

4. Put a pencil through the hole of the taped paper plates so they can rotate on the pencil.

5. The other students in the group try to figure out where the extra quarters are taped.

6. Try this several times with different configurations of the quarters. Can you figure out where the extra mass is without seeing it? How did you know? Is it easier to detect the quarters when they are near the center or the edge? Why?

Slides: *Dark Matter*

XII. *Measuring Acceleration - Dark Energy*

Objective: In this outdoor lab, students will measure the acceleration (or deceleration) of fellow students. Teams are spaced at equal intervals, and volunteer student runners are instructed to run from one end to the other, slowly increasing their speed. Timers measure the time it takes between each interval. Back in the class, students plot up the distance between each interval and the time it took for the runners to go between each interval. There should be evidence of a decrease in time between each interval (i.e. acceleration) on the graph. Students can determine the amount of acceleration (is it constant? Is it increasing?). This will be connected to the concept of dark energy and how it is causing the universe to expand at an accelerating rate.

Background

Scientists have done exactly the type of experiment (observation) we do in this lab with bright exploding stars (supernovae) in our universe. We can measure how fast the universe is expanding from how much the light in the supernova is shifted relative to where it should be when it is at rest (see Spectroscopy Lab VII). When we look at supernovae further in the past (meaning at farther distances - See Bonus2 in Spectroscopy Lab VII), space appears to be expanding more slowly than it is in the present universe. This means the *expansion of space is accelerating!* This is a totally unexpected and unexplained result that has been attributed to some unknown "thing" called dark energy, which causes the expansion of the universe to speed up in time.

Materials

Timers
Paper and Pencils
Measuring Tape
Large outdoor space (a track or football field is ideal).

Procedure

1. Measure out 5 equal space intervals over a distance of about 100 meters (this could be done on a football field, where the 10 yard lines work as distance markers - the intervals could be every 20 yards).

2. Station a timer and a recorder at each interval point.

3. Student runners will line up at the starting point. There should be a timer and recorder at each station for *each* student runner.

4. When “go” is yelled, all the timers will start their watches, and student runners will run from one end to the other increasing their speed (so don’t sprint right away - the idea is to get faster and faster from beginning to end).

5. Each timer will call out the time at which their student runner passes them and the recorder will mark this time down.

6. Repeat this several times.

7. Back in class, each group makes a distance vs. time plot of their runner. On the y-axis plot the distance the runner was at (e.g. 0 m, 20m, 40m, 60m, 80m, 100m) vs. the time at which they reached that point. Plot for each trial and also plot the average of the trials.

8. Present the motion of the runner to the class. Is there evidence for acceleration - i.e. does the time between each distance interval decrease? How about deceleration? What else can you learn from the distance versus time plot?

   Slides: *DarkEnergy*

XIII. ***Make a Comet***

Objective: Students will make a realistic replica of a comet, using dry ice, water, and organic materials. Students combine, water, dirt, ammonia, corn syrup and mix well (all elements of real comets). They then add dry ice (frozen carbon dioxide), mix and shape. What emerges after a few minutes is an oddly-shaped, very accurate replica of a comet. This lab requires safety goggles and gloves because of the risk of burns from handling dry ice.

Background: “Comet” means “long-haired star” in Greek, but they are not at all stars - they are pretty much just dirty snowballs! You may notice we’ll put some strange ingredients in our comet, like dirt and sugar. The dirt is made of silicates which are one of the ingredients of actual comets. But what about sugar? And the smelly ammonia? Scientists have observed actual sugar molecules in the solar system and this is one of the components of comets. So is ammonia (in fact, the atmospheres of Jupiter and Saturn are full of ammonia). These ingredients are called “organic” molecules because they contain carbon, oxygen, nitrogen and/or hydrogen (this is not the same as the “organic” food you might buy - that means pesticide-free), and are some of the building blocks of life. Do you think comets could play a role in the creation or destruction of life on planets? How?

Safety Discussion on Dry Ice: Dry ice is awesome and fun, but also dangerous. It is frozen carbon dioxide (the stuff you exhale with every breath, but frozen), and is at a temperature of about -100 degrees Celsius (that's 100 degrees below the temperature water turns to ice!!). This means touching it with your bare skin for even a second can leave you with bad burns that require medical attention. Please keep the safety goggles and gloves on for this experiment!

Something special about dry ice (and the reason they call it "dry") is that it *sublimates* at room temperature. That means that instead of melting, it skips the liquid phase and goes directly from a solid to a gas phase (the ice instantly "boils" and turns to steam).

Materials

Safety goggles
Insulating, waterproof gloves
Buckets
Heavy duty trash bags
Hammer or mallet (to crush dry ice)
Cooler (to hold dry ice)
Water
Dirt
Corn syrup or molasses
Ammonia
Dry Ice
Mixing spoons

Procedure

1. Students should work in groups of 4 and everyone should have gloves and safety goggles on!

2. Have one or two careful people crush up the dry ice with a hammer (keep it in a heavy duty bag as you crush it).

3. Line your bucket with a garbage bag.

4. Add 2 cups of water.

5. Add ¼ cup of dirt and stir.

6. Add a dash of corn syrup.

7. Add ⅛ cup of ammonia.

8. Add 2 cups of crushed dry ice.

9. Stir for 30 seconds (careful not to rip the garbage bag!).

10. Let sit for 1 minute.

11. Now carefully lift the garbage bag and (through the garbage bag), shape the material inside into a ball as best you can. Be careful to let the steam from the dry ice escape so the bag doesn't pop!

12. After a minute or two, pull out your comet (with gloves on!). Don't worry if it's not a perfect ball - real comets aren't either!!

    Questions: Do you think comets could play a role in the creation or destruction of life on planets? How?

    Slides: *Comets*

XIV. ***Exo-solar planets and Life in the Universe***

Objective: Students will design a planet that can support life. They will need to consider the distance to the host star, the size of the planet, what it is made of, what type of life it supports, etc. This lab is intended to have students think about the requirements to sustain living things, but is entirely open ended so the students can be as creative as they want when building their planetary system.

Background: What does it take to support life? A lot of scientists believe liquid water is necessary for life on other planets. But most planets of the planets we've observed so far (there are more than 3000 we've seen orbiting other stars in our galaxy) are too close to the star they orbit to have liquid water (the water would just all boil away!), and in some cases too far away (the water would be frozen, like on the outer planets of our solar system).

Materials:

Paper
Colored Pencils
Your imagination

Procedure

1. Design a planetary system that can support life. You don't have to follow the prerequisite for liquid water, but consider the following questions:
    a. How far away is your planetary system from the star (or stars) it orbits?
    b. How many planets are in your system?
    c. What are they made of (i.e. rock like Earth, gases like Jupiter and Saturn or some other thing entirely? Remind yourself of the elements in the periodic table - see Lab V).
    d. What is the temperature on your planet(s)? Does it have an atmosphere?
    e. Does it have a moon or several moons?
    f. How long does it take your planet to a) spin once around (a day) and b) orbit its star (a year)?
    g. What types of life do you have on your planet? Plant life? Animal life? What do they eat and drink? How long do they live? Are they intelligent life forms that use tools and communicate in some way? Describe and/or draw in as much detail as possible.

XV. ***Mission to Mars***

Objective: In this lab, students will consider what it would take to send a human mission to Mars, including how to get there, how long it will take, how long they will stay the resources they'll need to survive, and how to get back! If there is time and materials, students can build a model of their living space on Mars.

Materials

Paper and pencil
Materials to build a "biodome" on Mars

Procedure

1. Plan a mission to Mars. Consider the following questions:
    a. Assuming you have a rocket that has enough fuel to get there and back, and travels at a speed of 20,000 miles/hour, how long will it take to get to Mars? Mars is 34 million miles away.

    b. Who is going? How many people are on your mission? How long will you stay?

    c. What do you need to pack? Make a list of the resources you will need to survive the total length of the trip (don't forget to include the time it takes to get back). Consider:
        i. Food
        ii. Water
        iii. Clothing

iv. Medical supplies
v. Housing supplies
vi. Tools to make repairs
vii. Air to breathe (you can't breathe the "air" on Mars! It's 100 times thinner than on Earth and mostly carbon dioxide).
viii. Communication equipment
ix. Construction equipment
x. Fuel to return

d. What will you do on Mars while you are there? Plan your experiments and make sure you have the equipment!

e. Plan your return trip. Do you leave anything behind? Will it take as much fuel to get back as it did to get there?

f. If there is time and materials, build a replica of your living space on Mars.

Additional Materials (NASA):
https://www.nasa.gov/sites/default/files/atoms/files/edu_marssurvkit_pdf_2015_0.pdf

XVI. ***Build a Telescope***

Objective: In this lab, students will build their own working telescope. Materials and instructions can be found at: http://www.telescope1609.com/telescope.htm

Kits to build cost about $25/telescope.