Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2016 Volume IV: Physical Science and Physical Chemistry

# Lights and Actions

Curriculum Unit 16.04.09
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## Introduction

The unit I am planning in YNHTI this year is for an elective physics class at Cooperative Arts and Humanities Magnet High School. The class is made up of mostly seniors, with a few juniors. Demographically, the school is diverse in race, ethnicity, socio-economic status, sexual orientation, academic achievement, and artistic ability. Fifty eight percent of the student populous receives free or reduced-price lunch. Thirty-three percent of students are from suburban districts, 67% from the city of New Haven. Sixty-four percent of the students take at least 1 AP or college class prior to graduation, and 98% apply to college.

Most of the students in this physics class are taking it as a prerequisite for entrance into a college nursing program, or are genuinely interested in science. They all plan to graduate and attend four year programs at liberal arts colleges. This unit is designed to be interesting to science and non-science students alike, which is why I have decided to include the search for earthlike extrasolar planets and extraterrestrial life. Everyone thinks aliens are interesting, and everyone wonders if they are out there. It raises philosophical, rhetorical and existential questions, but also some theoretical and empirical science questions, like “How do we measure the properties of a planet 100 light years away?” The answer, as it turns out is with light: intensity, and color.

All my students are currently invested in a four year focused arts curriculum in one of the following disciplines: creative writing, visual art, theatre, music, or dance. As such, I often develop units that have a tie-in to one of the arts disciplines. This unit focuses on wave phenomena (for both light and sound), and has the best cross-curricular connection and real world applications with technical theater. It has many other connections to many other arts, but the core of technical theater is all about controlling various waves and their phenomena to enhance a dramatic performance. The ways in which light and sound technicians and engineers manipulate and use tools to change the way light and sound behave is a direct application of the properties of those waves. The decisions they make will have a huge impact on the environment experienced in the theater, and thusly on the ability of the audience to connect and engage with the performance and its message. These seem like creative choices, and they are, but they are grounded firmly in the soul of physics, in the business of wave mechanics and wave phenomena.

## Background

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**Wave mechanics & wave phenomena in technical theater**

The wave phenomena that apply to lighting a stage of scenery and actors are diffusion, color mixing, thin lenses, and reflection and refraction.  Diffusion is important because the incandescent and halogen bulbs used in theater lighting can be very harsh, and can give very high contract shadows.  Directionality is important when considering shadows.  An actor lit from above will have deep shadows under their eyes and lips, and will appear creepy or evil.  Actors lit head on, almost horizontally will not appear to have any contours to their faces, and appear flat.  Subjects lit from either the left, and right will throw shadows on either side of their face.  A combination of these directions of lighting give appropriate shading and contouring to face, making subjects appear normal and 3D.

In light applications to technical theater, the length of the "can" in which the lightbulb is placed will vary.  The lens that is placed in the can may also vary, and the distance from the bulb to the lens can change to give a larger or smaller spotlight.  The longer the can, and the closer the lens, the narrower the spot. A smaller spot will also be brighter because more light is focused to a smaller area.

Several properties of waves apply directly to technical theater.  Spotlights are often used to illuminate a small area of the stage, a single actor, or small grouping of actors. These are extremely bright, and can have a fuzzy edge or a sharp edge.  Depending upon the size of the spot and the type of edge desired, different types of light boxes, and filters can be used for different effects. Diffusion gels can be used to scatter light in different patterns to create softer light that has a blurry effect.

Color mixing is fundamental to properly lighting a stage.  Several lights are used to mix colors to provide different moods to the stage and the subjects.  Different complexions and colors in costuming also have to be considered when lighting a stage.  Mixing color with light is additive, not subtractive like color mixing in paint or ink.  Additive refers to the spectral lines of the observed light.  Additive color mixing puts more spectral lines in the product of the mixing, subtractive removes them, but color perception is not perfect in the human eye, and some spectra are observed to be brighter with more spectral lines than others.  Intensity is also a large factor in color perception.  Additive color mixing is when the primary colors are darker with more limited spectra, and the mixed color is brighter with broader spectra: for example, adding red light and green light gives yellow light, green and blue gives cyan light, lastly mixing red and blue gives magenta light.  Subtractive color mixing, on the other hand, is the exact opposite, with brighter primary colors that have broad spectra that is diminished (or subtracted) to give darker secondary colors with more limited spectra.  For example, adding cyan ink and yellow ink gives green ink.

Warm or cool themed lighting is the easiest way to convey a mood on stage.  Having a mix of blue light and white light immediately evokes a feeling of melancholy in the audience.  Mixing yellow light and white light, conveys a feeling of hope, of dawn, or new beginnings. On stage, lighting can be mixed wavelength by wavelength, using gel filters over halogen lamps.

**Sound applications to technical theater**

In a theater, full, even sound at all seats is desired so all patrons enjoy the full experience.  This happens by minimizing constructive and destructive interference of the sound output by the speakers used in the sound system. Constructive interference in terms of sound is when two sound waves are played at the same time, and the amplitudes of their waves add up, resulting in a louder sound than originally output. These “hot spots” can create a much louder and vibrating sound in spots. Destructive interference is the opposite, the amplitudes are out of phase, and subtract from each other, creating a loss of sound or a severe decrease in volume, sometimes to the point of a loss of integrity, sometimes making a “cold spot” or making the sound feel “watery” or “squishy” in spots. The placement of these spots will change as the wavelength (or pitch) of the sound varies. Longer wavelengths will produce fewer hot spots and cold spots, and they will be farther apart. Minimizing the number of these spots creates a controllable setting, where every patron gets the sound experience that is the same, and is what the director designed.

There are several strategies to this complex system:

- Having 3D sound system with speakers at the left, right, top, and bottom of the stage that point toward the center of the main sections of the audience, orchestra, back, and balcony.
- Have small speakers at the front for the first few rows of patrons.
- Run the speakers in stereo (or surround sound), so each speaker only puts out certain ranges of frequencies, and they can never line up perfectly to double the amplitude or cancel each other out.
- Have a sound tech and sound board in the audience so they can adjust on the fly.
- Have a microphone in the audience if the soundboard is in a booth.
- Map the theater with a sound engineer.
- Use a shell for vocal choirs and instrumental groups to eliminate the need for microphones and speakers. This bounces the sound forward toward the audience, and fans it out, to reduce the number of waves that cross paths, and reduce interference.
- Have textured sound absorbing walls at the sides and back to prevent ricochet.

## Light applications to astronomy

### Doppler effect

Stars can be determined to be moving toward Earth or away from Earth by the frequency (or wavelength) of light they appear to emit. This is called redshift or blueshift. It is based on the Doppler effect, which says a source point of waves will appear to have a higher frequency when moving toward an observer, or blueshift, and a lower frequency when moving away, or redshift. Since almost all stars in our sky exhibit redshift, it is indicates that the universe is expanding, likely a result of an initial explosion that created the universe (the Big Bang Theory).

### Finding exoplanets as a search for intelligent life

For several decades now, humans have been obsessed with the idea of intelligent aliens existing. This is an area of serious scientific research and discovery. The possibility of intelligent life on another planet was first legitimately estimated by Frank Drake, using a now famous Fermi-style estimation, called the Drake Equation. He estimated the number of planets in the solar system with the potential for intelligent life to be 50,000. The estimate is based on assumption and known values and known ratios, and has been the subject of scientific scrutiny for many years. Some of the assumptions have been discounted, such as the ratio of planets to stars, it was originally estimated as 0.4, but almost every known star has at least one planet, so the value is now known at 1.0. Most of the values ratios have been refined in the past 70 years, such as the fraction of planets that are capable of sustaining life. This has been refined from near zero, to near 0.4 pending the outcome of the search for bacteria on Mars. The overall estimate for the number of planets in the universe that can sustain and grow to intelligent life is in the tens of thousands. The real power of the Drake Equation is that it gave legitimacy to the search for alien life. We now have SETI (Search for Extra Terrestrial Intelligence) with a huge radiotelescope array, and several groups searching for habitable Earthlike planets, as well as Voyager, a probe transmitting evidence and messages of human life on Earth via radiowaves, to any life that can interpret them. These projects would not have been taken seriously, publicly funded, nor exist without Drake and his famous equation. [2]

Exoplanets are planets that exist outside our solar system, and are an area of great research, measurement, and discovery by astronomers. They are looking for Earthlike planets that have the right conditions for life to exist and thrive on a long enough timeline to evolve into intelligent beings. The first step is to find the planets. The next step is to measure their status to see if liquid water can exist. [1]

Based on what we know about water as a compound, it is liquid between 273-373 K at 100 kPa of atmospheric pressure (the atmospheric pressure at sea level). A planet would need to be roughly Earth sized, roughly Earth's mass in order to have a gravitational field and an atmospheric pressure in the appropriate range. It would also need to be located in a similar sweet spot for temperature in terms of distance to its star, and its star's intensity. Bing too close to a star would either make it too warm for liquid water, or burn the atmosphere off completely (for example, Mercury or Venus). Being too far would make it too cold, and only solid water would exist as is the case on Mars. [1,2,3]

**Measuring the intensity with transit photometry**

As planets orbit their suns, there is a period of time where they pass between their sun and us (or our best telescopes out in space). When this happens, the exoplanet will absorb or block a small amount of light emitted by that star. This is similar to an eclipse, but only a tiny amount of light is blocked as the planet moves across the sun. This is called a transit. The transit of Mercury across our sun was visible in May 2016 (unfortunately it was cloudy in New England where I live, and could not be seen.) As the planet blocks some of the sunlight, the observable intensity of that sun diminishes until the planet passes completely, and then the intensity is restored. By measuring the drop in intensity of light, and looking for a cyclical pattern of this observation, we can find stars that have planets very far away. The current range for small stars is within 160 light years (a light year is about 6 trillion miles), and is much farther for large planets orbiting around large suns. [3]

**Measuring the wobble: angular velocity by Doppler spectrography**

Planets are held in orbit by the gravitational attraction between them and their sun. The more massive the sun, the more strongly a planet is attracted to it. This also happens conversely, the more massive a planet, the more the sun is attracted to it. Massive planets exert a small pull on their stars, and often a star with exhibit a very slight wobble as its planet revolves around it (technically, they both rotate around their common center of mass, but the star moves very little). This phenomena can be simulated using the online simulation at phet.colorado.edu: (http://phet.colorado.edu/en/simulation/legacy/my-solar-system.) Since stars are continuously emitting light, we can see them, and we can measure this small periodic wobble using spectrography and the Doppler effect. As the star is pulled away from us, its light shifts slightly toward the red, and when pulled toward us, slightly toward the blue. This is similar to how stars are themselves receding from each other resulting in redshifted spectra as mentioned previously, but the difference between a wobble and the motion of the universe is much smaller in terms of scale, and the wobble is periodic. [3,4]

#### Measuring planetshine or planet emission by photometry

Planetshine is a very simple concept, as planets revolve around a star, they reflect light from that star back toward us, just like our moon does with our sun.  The frequency of the light that is reflected is often in the visible ranges, (which is coincidentally similar to what the Earth reflects from the sun- though we also reflect some UV and infrared light).  This can be measured when the planet is not in transit, and not eclipsed by its star, but is on the outer wings of its orbit, and is facing us. The planet will go through phases, like our moon does, so the intensity of this reflected light will vary in a regular pattern as the percentage of the planet that is both illuminated and facing us wanes or waxes. [3]

Planets will also absorb, use, and re-emit electromagnetic radiation from their stars. The frequency of the light that is re-emitted is lower than that of the star because some of the energy has been converted to internal energy of the planet.  Earth does the same, emitting longwave radiation (infrared light), which causes the dark side of the Earth to cool at night.  When looking for exoplanets, a slight increase in the intensity of lower frequency light can be detected when the planet is within the line of sight, but not when the planet is eclipsed by its star.  Light that is re-emitted should not wax and wane with phases, as it is not depended on the rotating reflective surface, but should merely be constant. [3]

#### Spectral analysis to determine the atmosphere of the planet

Once an exoplanet's existence is confirmed, the question of environment remains.  Is this planet able to sustain life, as we know it?  This is a complicated question to answer, but life on our Earth would not be possible without liquid water, atmospheric oxygen, and complex hydrocarbon compounds.  Modern chemistry allows us to make atmospheric oxygen if liquid water exists, it is fairly simple chemistry, and could be modified to be done on a large scale if necessary.  Hydrocarbons are a bit more complicated to synthesize, but again it could be done, as long as elemental carbon and liquid water exist on a planet.  However, all of the oxygen and hydrocarbons on Earth are the result of photosynthesis (combining water and carbon dioxide using light to form hydrocarbons).  That is why water is so important to life. [3]

The atmosphere of a planet can be detected based on spectral absorption.  Each chemical has a spectral absorption signature, a combination of wavelengths of light that it absorbs.  By measuring the wavelengths of light emitted by the star when the planet is in transit, and is eclipsed, we can subtract the two, and whatever wavelengths are missing while in transit have been absorbed by the planet's atmosphere.  We can then compare those wavelengths to the know spectra for all the elements and compounds on Earth, and have a reasonable estimation of what the atmosphere of the exoplanet is made of.  We can then compare the boiling points of those elements and compounds to estimate ranges of pressure and temperature of the atmosphere of the planet, which is the beginning of the answer to the question: Could this planet support life? [3]

## Teaching strategies

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This unit uses a wide variety of teaching strategies because I think students learn better when they are doing active work themselves. Science concepts also are inherently about experimentation and physics lends itself very well to hands-on learning.  Some strategies employed in this unit are: engaging students with an essential question for each lesson, hands-on inquiry activities that require students to manipulate tactile items with their hands, discuss science concepts with their peers, cooperate with their peers towards a specific goal, and justify their opinions based on data they have gathered.  Students are asked to make and explain models, to ask and evaluate their own questions, develop methods to solve problems, and reflect on their choices in class.

## Classroom activities

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### Wave phenomena in technical theater

**Double slit diffraction & sound applications to technical theater:**

1. Have students come up to the whiteboard in the classroom one at a time, while others are working in groups (and chatting). Have them listen to the whiteboard, and all the sound that is reflected by the smooth ceramic surface.  Then tape a piece of egg crate foam to the opposite end of the board, and have them listen.
2. Run two speakers in mono, give kids blue and yellow post-its. Play a song, or a clip, or a riff on repeat, and have students map out where they hear loud and soft spots. Observe the big picture, and discuss interference patterns.
3. Make paper cones to speak through to simulate an orchestral shell. Have students say different phrases in different ways, with different inflection, and emphasis, with and without the cone. Have them share their observations.

**Diffusion & color mixing:**

1. Put different filters over a strong flashlight and observe how the flashlight's projection appears in different scenarios. (If you can get your hands on old gels, use them, cut them into small squares.)
2. Ask a theater to give your class a short tour, with a lighting tech to show you how the different kinds of lighting gels work together to change the mood or focus of the characters or scenery on a stage.

**Thin lenses:**

1. Pass out thin lenses, and have students write observations about what they see through thin lenses. Use both convex and concave, and have them switch.  Encourage students to look at close and far away objects.
2. Use a candle & optic bench to produce an image of the candle flame on a card: If you don't have an optics bench, you can simulate one with a candle a 3x5 card, and a convex lens or magnifying glass. You can produce the image by moving the candle and the lens back and forth until an upside down image of the candle flame appears on the card.  You need a fairly dark room to do this in.
    1. Calculate the focal length of the lens. You need the distance to from the candle to the lens, and the distance from the lens to the card. You will need, scientific calculators, and the thin lens formula.
    2. Use the focal length of the lenses to create a telescope that can magnify far away objects.

**Reflection of light:**

1. Show students different types of mirrors: flat, concave, convex, and have students observe carefully.

Ask students where they may have seen convex and concave mirrors before. Convex: back of spoon, security mirrors in pharmacies, school bus drivers, side view mirrors on cars, tractor trailers. Concave: front of spoons, funhouses, telescopes.

1. Draw ray diagrams for mirrors and their cases. You will need rulers, pencils, and copy paper. Use these three rays:
    1. Leaves the object parallel to the horizontal center axis, turns to go through the focal point of the mirror
    2. Leaves the object, goes through the center (or the center of curvature) of the mirror, and keeps going straight. (some curved mirrors have the center of curvature at the same point as the focal point, some do not)
    3. Leaves the object, goes through the focal point of the mirror, and turns to go parallel to the horizontal axis of the lens.

#### Refraction of light:

1. Draw ray diagrams for converging and diverging lenses.
    1. Converging (convex) lenses:
        1. Leaves the object parallel to the horizontal center axis, turns to go through the focal point of the lens
        2. Leaves the object, goes through the center of the lens, and keeps going straight.
        3. Leaves the object, goes through the focal point of the lens, and turns to go parallel to the horizontal axis of the lens.
    2. Diverging (concave) lenses have the same 3 rays, except the first one behaves a little differently…
        1. Leaves the object parallel to the horizontal center axis, turns to go up and away from the center line. The angle it turns at can be found by connecting the focal point that’s between the lens and the object, and the spot where the parallel ray hits the lens. Then extend it up and away from the centerline.
        2. Leaves the object, goes through the center of the lens, and keeps going straight.
        3. Leaves the object, goes through the focal point of the lens, and turns to go parallel to the horizontal axis of the lens.
    3. Show “broken pencil” in a beaker of water (index of refraction is different, so the light changes speed and bends, making it to your eye at different times,
    4. Show broken beaker “disappear/reappear” in corn oil (index of refraction is same as borosilicate glass, so light doesn’t bend or reflect at the edges, so you can’t see the glass).

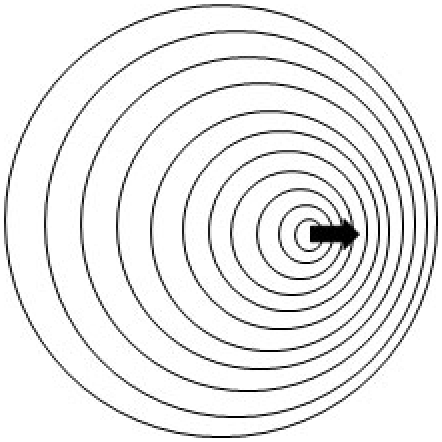
### Light applications to astronomy

#### Doppler effect:

1. Show wavefronts as a source of waves moves:
    1. Use a wavetable: poke the water with your finger as you move your hand slowly in a straight line, you will see the waves crowd each other in front of you, and spread out behind.
    2. Play a YouTube video of an ambulance or police car or fire truck going past the videographer. This works well with students who are musicians, ask students to share what they observe about the sound, specifically about the pitch.
    3. Have students run past a student singing a single note (or a recording of someone singing/playing a single note). This works because the effect is based on relative motion. It does not matter if you

are moving toward the source or the source is moving toward you. The waves are still perceived as a higher frequency, and in terms of sound, a higher pitch.

4. Show a diagram on the board



**Measuring the intensity with transit photometry:**

1. Show a video clip from NASA or YouTube of transit of Mercury May 2016.

**Measuring the wobble: angular velocity by Doppler spectrography:**

1. Use the phet.colorado.edu simulation “My Solar System.” Have students create a solar system with a large sun and a small planet, and observe the wobble.

**Spectral analysis to determine the atmosphere of the planet:**

1. Have students use diffraction gratings or spectrophotometers to observe different colors of light: sunlight, halogen, incandescent, fluorescent.
2. Do flame tests or buy colorflame ™ birthday candles, have student observe the elemental spectra each compound produces while burning.
    1. Compare observed spectra to the spectra cards from LABAIDS™, to figure out what elements are in the burning chemical/candle.
    2. Compare simulated star spectra, find the elements that are missing between the two. This is what was absorbed, and what is in the planet’s atmosphere.

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## Appendix: New Haven District Standards: (state, national & proposed national)

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New Haven Public Schools requires science teachers to use Connecticut state standards, with a special emphasis on inquiry standards, but encourages teachers to consult current national standards that the state derived theirs from, and the likely to be implemented Next Generation Science Standards which have been recently approved by the state.

D INQ.1  Identify questions that can be answered through scientific investigation. [9]

D INQ.2  Read, interpret and examine the credibility and validity of scientific claims in different sources of information. [9]

D INQ.3  Formulate a testable hypothesis and demonstrate logical connections between the scientific concepts guiding the hypothesis and the design of the experiment. [9]

D INQ.4  Design and conduct appropriate types of scientific investigations to answer different questions.

D INQ.5  Identify independent and dependent variables, including those that are kept constant and those used as controls. [9]

D INQ.6  Use appropriate tools and techniques to make observations and gather data. [9]

D INQ.7  Assess the reliability of the data that was generated in the investigation. [9]

D INQ.8  Use mathematical operations to analyze and interpret data, and present relationships between variables in appropriate forms. [9]

D INQ.10  Communicate about science in different formats, using relevant science vocabulary, supporting evidence and clear logic. [9]

CT SCIENCE 9.1 - Energy cannot be created or destroyed; however, energy can be converted from one form to another. [9]

NGSS HS-PS1-3: Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. [6]

NGSS HS-PS4-1.  Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. [6]

NGSS HS-PS4-2. Evaluate questions about the advantages of using a digital transmission and storage of information. [6]

NGSS HS-PS4-3. Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other. [6]

NGSS HS-PS4-4. Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. [6]

NGSS HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. [6]