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Beyond the Rainbow: Investigating the Characteristics of Stars

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by Joanna Minott

Introduction

At a very early age, children across the globe gaze with wonderment at the sighting of a rainbow in the sky. These colors of the rainbow are nature's example of a spectrum of light. This band of familiar colors is nicknamed, “ROY G. BIV,” which stands for red, orange, yellow, green, blue, indigo, and violet (Image 1). In this Earth and Space Science Curriculum Unit, students will deepen their understanding of how astronomers analyze the light of a star to determine its chemical composition, color, temperature, motion, luminosity, distance, and evolutionary stage. In this unit, students will see “beyond the rainbow” and enter the world of spectroscopy. Spectroscopy is the technique used by astrophysicists and astrochemists to determine the characteristics of stars. The ease with which students can recollect not only the colors but more importantly, the sequence of these colors in the rainbow will enable them to engage in more complicated content material that shows how scientists unlock the mysteries of the cosmos. Students will “see the rainbow” throughout this unit as they analyze blackbody curves, categorize stars using the Hertzsprung-Russell (HR) diagram, determine the motion of stars using the Doppler effect, identify the chemical composition of stars from absorption spectra and investigate the sun’s surface features as seen under different wavelengths of the electromagnetic spectrum using satellite imagery from the Solar Dynamic Observatory (SDO).

Image 1: Colors of the Rainbow.

Photo Credit: Gringer, Public Domain, via Wikimedia Commons

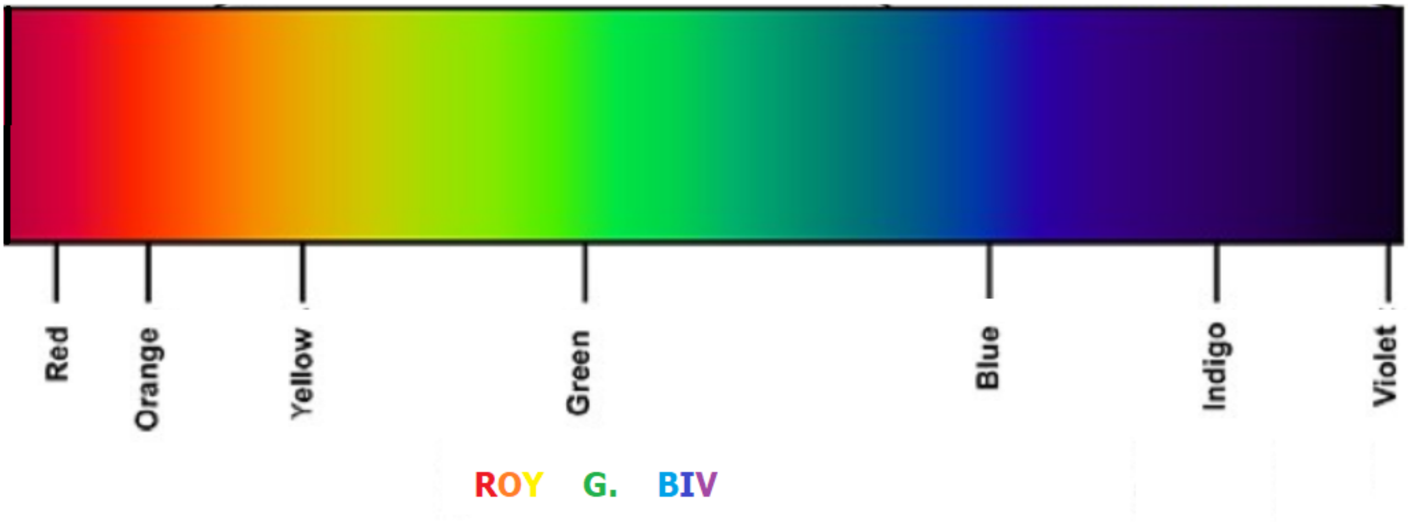


Image 1: This band of colors represents a continuous spectrum of visible light in the electromagnetic spectrum. It also shows the sequential order of the colors in a rainbow.

This curriculum unit is designed for Earth Science students with limited exposure to Algebra. However, each activity can be modified for advanced coursework in Physics, Chemistry, Astronomy, and Environmental Science. The curriculum unit is aligned to the standards of learning as outlined in the Virginia Department of Education (VDOE) Earth Science Curriculum Framework.[1]

Rationale

Huguenot High School is a Title (I) school, located in Richmond, Virginia. Our school is identified as a Title (I) school and therefore qualifies for federally funded educational programs because over 40% of their student population is below the poverty level. These funds are allocated to provide robust academic supports to help ensure that all children even from low-income households meet challenging state academic standards.[2] Based on the data from the Virginia Department of Education School Quality Report for 2020, approximately 1200 students are enrolled at Huguenot High School. Forty-Nine percent (49%) come from economically disadvantaged homes. Our dropout rate is a staggering 29%, and 22% of our students are coded for chronic school absenteeism. 14% are students with learning disabilities 21% of the student population are English-Language Learners and mandated to enroll in our Limited English Instruction Program (LEIP).[3]

My student population consists predominantly of African American and Central American immigrant youths. Over the years that I have taught this course, I realized that my students come alive during the astronomy portion of my Earth Science class. In response to my students' interest in astronomy, I developed this curriculum unit to foster their curiosity and provide more opportunities for them to deepen their knowledge of how scientists study the Universe. In fact, an astronomy class is an excellent opportunity to highlight the contributions of Mesoamerican civilizations and African Americans to the collective knowledge and information about the cosmos. By including contributions from other cultures and peoples, allows students of color to see themselves reflected in the coursework. My Latinx students should know that the Mayans were avid astronomers. Since 500 BCE, the Mayan calendar approximated 365 days in a year. Mayans also described the planetary motions of Venus, Mars, Jupiter, and Saturn. With ancient instruments, Mayans meticulously recorded Venus' orbital revolution as 584 days. Modern technology has measured Venus' revolution to be 583.92 days.[4]

The iconic NASA Apollo 11 Mission cemented America's domination in the Great Space Race with the former USSR. Neil Armstrong, Buzz Aldrin, and Alan Shepard became household names. In the 2017 academy the blockbuster movie *"Hidden Figures"* introduced the world to three African American female mathematicians in the segregated south, Katherine Johnson, Mary Jackson, and Dorothy Vaughan. They were instrumental in solving the trajectory of astronaut John Glenn's space capsule.[5] Other African Americans of note that students can research include self-educated astronomer Benjamin Banneker, astrophysicist Neil DeGrasse Tyson, and astronauts Guion Bluford, Mae C. Jemison, Leland Melvin, and Victor J. Glover. My students will be thrilled to learn about these amazing contributions by African Americans.

In addition, our school shares the same home state location as the world-renowned NASA Langley Research Center. NASA's outreach programs have a vested interest in providing educational programs and internships for students to gain real exposure and provide training for the next generation of space scientists.

This curriculum unit will align with the Virginia Department of Education standards of learning, foster multicultural delivery of instruction, and demonstrate to students the nature of science, whereby science continuously builds upon or disproves the previous knowledge and advancements of others. This unit is quite timely, as we are currently experiencing a resurgence in space travel and exploration from both the public and private sectors. In this unit, students will learn techniques that will deepen their understanding of the cosmos and hopefully inspire some to pursue careers in the space sciences.

Unit Content

Brief History of Spectroscopy

Spectroscopy is by far the single most powerful tool for astronomers to characterize stars, planets, asteroids, comets, galaxies, and other celestial objects of great distances away.By analyzing the spectra of stars, scientists can determine their chemical composition, relative motion, luminosity, mass, temperature, density, and color. The lessons developed for this curriculum unit will introduce the students to this groundbreaking technique and its applications. They will recognize the "colors of the rainbow" in these activities. But first, let us identify some significant scientific contributions to the field of spectroscopy.

In 1672, Sir Isaac Newton described his rainbow experiment in his first paper submitted to the Royal Society. Newton passed a beam of sunlight through a prism. This white light characteristic of sunlight emerged from the prism in the colors of the rainbow. The rainbow forms because as white light enters the prism, the medium changes from air to solid and the light bends and undergoes refraction. Not all the colors are bent by the same amount and separate by wavelengths, each wavelength corresponds to a given color in the visible light range. Newton then passes the rainbow of colors through a second prism. Amazingly all the colors recombined, and white light reemerged. He demonstrated that white light is in fact, made up of all the colors.[6][7]

Similarly, as rain falls, each water droplet acts as a tiny prism. As sunlight enters a water droplet, it slows down and undergoes refraction and dispersion, then it reflects off the inner wall of the rain droplet as it reemerges into the air, and it is refracted again and is separated into a rainbow of colors.[8]

In 1802, British scientist, William Hyde Wollaston, built a spectrometer and was the first to observe dark lines in the spectrum of the sun.[9] Twelve years later, in 1814, German optician, Joseph von Fraunhofer, independently rediscovered these dark lines using a diffraction grating device that disperses light more effectively than a prism.[10] He found and labeled over five hundred dark lines crossing the Sun’s spectra. These spectral lines are known today as Fraunhofer lines. Fraunhofer concluded that the relative positions of the lines are constant whether the spectra are produced by the direct rays of the Sun or by the reflection of light by the Moon, planets, or heated by metals in the laboratory. Between 1838 and 1846, Robert Bunsen, who created the Bunsen burner for use in flame tests for various metals and salts, teamed up with Gustav Kirchhoff. They noticed that several of the spectral lines produced on an absorption spectrum coincided with characteristic emission lines identified in the spectra of heated elements. Bunsen and Kirchhoff recognized they had a powerful tool since each element had its unique absorption and emission spectrum. This distinct “fingerprint” can then confirm the chemical composition of the Sun and fixed stars.[11] By 1859, Bunsen and Kirchhoff identified many of the known elements’ spectra. And the solar eclipse of 1868 allowed for the discovery of the Helium lines in the Sun’s spectrum by the French scientist Janssen, though it took some time for scientists to accept that the lines were from a then-unknown substance, Helium.[12] Janssen and an English scientist Lockyer independently proposed that the lines were from a new element, but it took about thirty years before their results were accepted – they had to wait until helium was discovered inside a uranium ore by Scottish scientist William Ramsay.[13]

Kirchhoff’s Three Laws

Rainbows are an excellent example of a continuous spectrum. In 1860, German physicist Gustav Kirchhoff was the first person to use spectroscopy to identify an element from sunlight. Kirchhoff’s experiments showed the three conditions that gave rise to the creation of the three general types of spectra: continuous, absorption, and emission (Image 2).[14] Kirchhoff’s First Law states that a hot, opaque light source will produce a continuous spectrum with all colors present. Kirchhoff’s Second Law states that when a cool gas cloud is placed in front of a light source, the cloud’s atoms will absorb and produce a spectrum with dark lines – this is an absorption spectrum. The dark lines indicate the areas where the gas was absorbed for specific wavelengths of light. Kirchhoff’s Third Law states that when a hot gas cloud is placed in the absence of a light source, only bright lines appear and form an emission spectrum. These bright lines are the areas where the gas emits energy.

Image 2: Kirchhoff’s Law for Spectral Analysis

Photo Credit: Penn State University Department of Astronomy and Astrophysics, Creative Commons

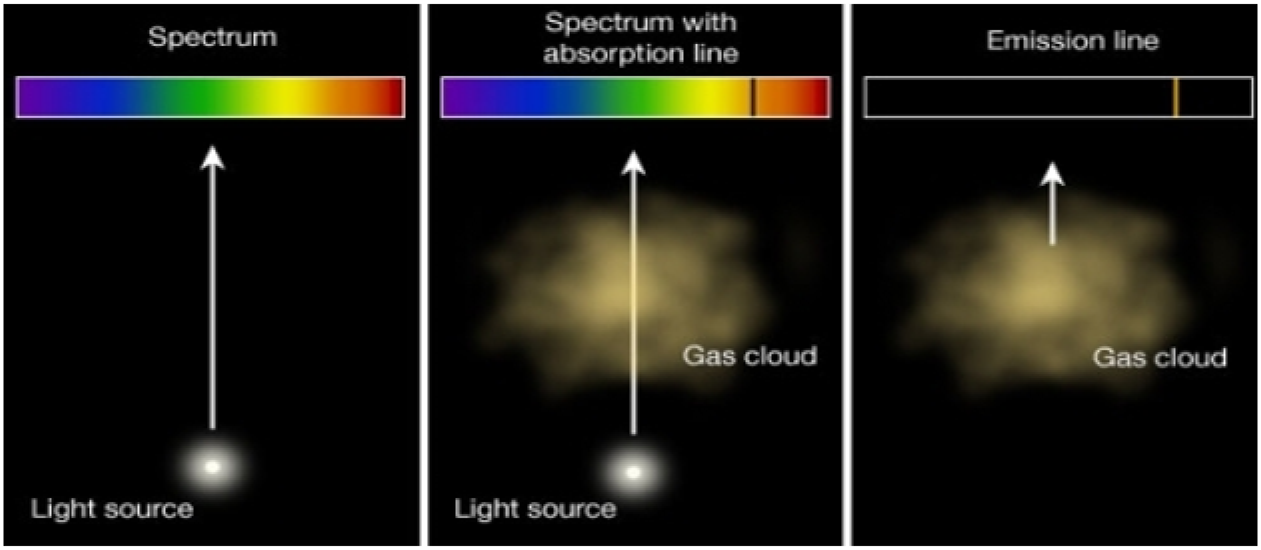


Image 2: Kirchhoff's Three Laws of Spectral Analysis for the creation of a continuous, absorption, and emission spectrum. A continuous spectrum forms when only a source of continuous radiation is present. This results in all the colors are present. When the continuous spectrum is viewed through the presence of relatively cool gas, absorption "dark" lines appear to form an absorption spectrum. When the hot cloud is seen without a light source behind it, then an emission spectrum appears.

The Dawn of Quantum Theory

At the start of the 20th century, more sophisticated experiments revealed the wave-particle duality of light. In some experiments, light behaves like a wave, and for others, it behaved like a particle. This particle or packet of energy is called a photon.[15] German theoretical physicist, Max Karl Ernst Ludwig Planck discovered that energy comes in bundles called quanta for which he won the Nobel Prize in 1918. Planck proposed that energy radiated in very minute and discrete quantized amounts. He was able to determine that the energy of each quantum is equal to the frequency of the radiation multiplied by a universal constant that he derived, now known as the Planck constant, *h.*[16] Planck was also able to explain the wavelength distribution of energy from black body radiation. For his work, Planck is considered the Father of Quantum Theory.

In 1905, Albert Einstein used Planck's quantum theory to describe the particle properties of light. Einstein used it to explain the photoelectric effect.[17] This Planck-Einstein relationship is a formula that states that quanta have a specific amount of energy, that only depends on the wavelength ($E = h\,c/\,\lambda$, where E is energy, h is the Plank constant, c is the speed of light and λ is wavelength).[18] Einstein's photoelectric is a phenomenon in which electrons are ejected from a metal when photons of light are incident upon it. The photoelectric effect demonstrated the quantum nature of light and electrons. It was this work on the photoelectric effect that awarded him the 1921 Nobel Prize in Physics.

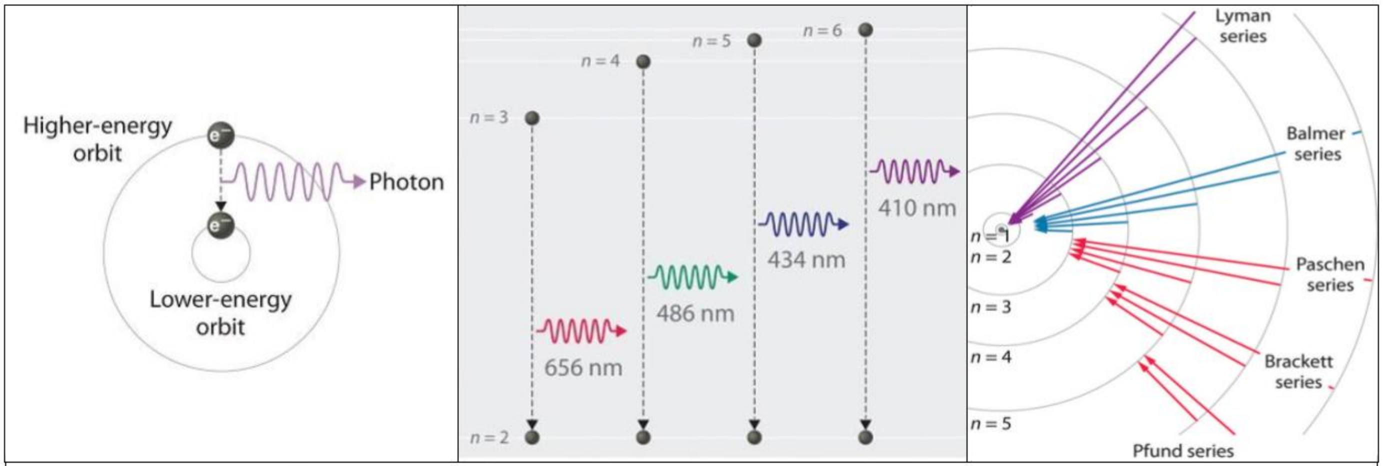
The Bohr Model

In 1922, Danish physicist Niels Bohr won the Nobel prize for his work that led to our understanding that electrons in an atom reside in specific energy levels around a nucleus and how that leads to radiation or absorption. Bohr developed a model of the atom that would explain certain regularities using the spectrum of hydrogen. As an electron moves from one energy level to the next, that difference in energy requires that it either emits a photon (when it moves from a higher-energy orbit to a lower-energy one) and produces an emission spectrum. When an electron absorbs a photon (when moving from a lower-energy orbit to a higher energy one) a photon is absorbed and an absorption spectrum is absorbed.[19] The wavelength at which the photon is emitted corresponds to a color found in the visible light, as illustrated in (Image 3a).[20]

Using Image 3c, if an electron from hydrogen jumps from the sixth orbital to the second orbital, the energy difference corresponds to a wavelength of 420nm, this would give off a photon that has the color violet because light with wavelengths between 380-450nm is in the range for the color violet. Since it went to a lower energy level, this would produce a violet spectral line. If an electron goes jumps from the second energy level to the third, it went higher and so it would have to absorb this energy. If that energy difference corresponds to a wavelength of 656 nm, the spectrum would have a dark line in the red, because the wavelengths for the red-light area are between 620-750nm.

Image 3: Bohr Model of a Photon Emission and Hydrogen Spectral Lines

Photo Credit: ChemWiki, Creative Commons



(a) Electron Emission Transition **(b) Balmer Series** **(c) Hydrogen Spectral Series**

Image 3a*:* The emission of light by a hydrogen atom in an excited state when it transitions from a higher orbital energy level to a lower orbital energy level**. Image 3b:** Bohr sought to explain the Balmer series. Using this Bohr model, he explained that electrons are quantized. Balmer Series shows is specific for electrons that transition from the second orbital level. The difference in energy between the orbital energy levels corresponds to light in the visible portion of the electromagnetic spectrum. **Image 3c:** Hydrogen Spectral Lines are named after the scientists that observed them. Each series shows the electron transitions from a specific orbital level observed in the emission spectrum of hydrogen.

As students learn about the contributions of scientists to the development of spectroscopy and quantum mechanics, they should see that one pillar of the nature of scientific knowledge is that it builds upon the work of others and in the process, previous work can be built upon, refined, or debunked. For instance, Kirchhoff showed that each element had a unique spectrum, but his attempts to predict the frequencies of these spectral lines were unsuccessful until Swiss mathematician, Johann Jakob Balmer proposed an empirical formula for the wavelengths of four hydrogen spectral lines in the visible region.[21] Balmer's prediction was very successful, but he could not explain why his prediction worked. Niels Bohr sought to explain the Balmer series and in doing so he assumed that electrons orbit the nucleus at discrete or quantized orbits each with associated energy.[22] As electrons transition to different orbital energy levels, they release or absorb electromagnetic radiation at a given wavelength that obeys the Planck-Einstein relationship.[23]

The Spectral Lines of Hydrogen

The spectrum of hydrogen is an important piece of evidence to show the quantized electronic structure of an atom.[24] Hydrogen has the simplest atomic structure as it only has one electron in its outer shell. The atomic spectrum of hydrogen consists of several lines which have been grouped in five series. Each series is named after the scientist who observed it: Lyman, Blamer, Paschen, Brackett and Pfund [See Image 3c]. When hydrogen gas is heated to a high temperature or an electric discharge is passed, emission of electromagnetic radiation is initiated by the energetically excited hydrogen atoms.[25] As an electron absorbs energy, they get excited and jump from a lower energy level to a higher energy level. Conversely, when they emit radiation, they return to their original state. This happens for any element, but hydrogen's structure is the simplest with one electron in the outer shell, while others have more electrons and it gets complicated, which produces more complex spectra.[26]

Using hydrogen, these five scientists studied the different series of spectral lines that hydrogen has in different regions of the electromagnetic spectrum. For the Lyman series, electrons transition to and from higher orbits and the lowest orbital energy level which is also known as the ground state. This ground state is denoted, n=1. For the Balmer Series, electrons transition between higher orbits and the second orbital energy level n=2. For the Paschen series, electrons transition between higher orbital levels and the third orbital level, n=3. For the Brackett series, electrons transition between higher orbital levels and the fourth orbital energy level, n=4. Then for the Pfund Series, electrons transition between higher orbital levels and the fifth orbital level, n=5. The Lyman series of lines lie in the ultraviolet region of the spectrum, the Balmer series in the visible part, and the others in the infrared.[27] Image 3c, illustrates how the emission spectra lines are produced as photons are emitted. Conversely, when the gas absorbs photons, the arrows in the diagram will reverse direction, and produce the dark lines of an absorption spectrum.

Spectral Lines: How to determine the chemical composition of stars

Like the unique pattern of a snowflake, each element also has its unique and identifiable emission spectral lines. Students will be given a sheet of Periodic Table of elements, unlike one that they have ever seen before. This Periodic Table of Elements will show the specific emission spectral lines of each element.

Students will be given copies of spectra of known elements such as hydrogen, helium, carbon, magnesium, and iron which are elements. They will then be put in groups. Each group will be given a star and asked to determine the chemical composition of the given stars. An online version of this activity called Star Spectra Gizmo by Explore Learning provides more in-depth activities to create more opportunities for students to explore, discover and apply new concepts.[28] In the interactive Star Spectra Gizmo, students will determine the elements that a represented in each spectrum, use this information to infer the classification and temperature of the star. Once they have determined the elements present in their stars, they will share their information with the class. This is also an opportunity for the teacher to answer any questions and clear up any misconceptions.

Blackbody Radiation

The term blackbody radiation is used to describe the relationship between an object's temperature and the wavelength emitted.[29] All objects emit electromagnetic radiation, but a blackbody is an idealized model in which all light falling on it is absorbed.[30] However, to stay in thermal equilibrium, a blackbody must emit radiation at the same rate as it absorbs and so it is a “perfect” absorber and a “perfect” emitter of radiation at all wavelengths.[31] A German theoretical physicist, Max Planck, explained that a blackbody will completely absorb all radiant energy falling on it, then reach equilibrium and re-emit that energy. Experiments showed that the color of the radiation emitted was related to the temperature of the object. Think about a metal coil on your stove. As you increase the temperature on your stove, the coil gets hotter and glows from red to orange, to yellow and at even higher temperatures, this is not attained with ordinary stoves, you may even see the metal bright yellow or blueish white.[32] No object is an ideal blackbody, but stars behave approximately like blackbodies, and as such using black body curves, astronomers can explain the temperatures associated with different colors.[33] Most stars emit most of their energy in visible light, the dominant color of a star’s appearance is a rough indicator or “thermometer” of its temperature.[34] See Image 4.

In 1911, German physicist, Wilhelm Wein, won the Nobel Prize in Physics, for his deduction of a blackbody radiation law, now called Wein’s Law. Wein’s displacement law formulated at what peak wavelength (λ_{max}) is most intense at a given temperature.[35] The blackbody radiation curve for different temperature peaks at a wavelength that is inversely proportional to the temperature. At cooler temperatures, the blackbody curve flattens, and the wavelengths increase (Image 4). Students will look closely and observe that cooler temperatures have a distribution peak at a higher wavelength and tend toward red (λ_{max} ~700 nm at 4000K), while hotter temperatures, have shorter wavelengths and tend towards blue (λ_{max} ~ 400 nm at 7000K).

This relationship is called Wein’s displacement laws and it helps determine the temperature of radiant objects such as stars.[36] Humans also give off radiation, but we most strongly radiate in the infrared parts of the spectrum. With special infrared filtered cameras, because we most strongly radiate in the infrared parts of the spectrum, you can see then see our radiation.[37] Max Planck explained why the black-body spectrum looks the way it does and why it depends on temperature. Stefan-Boltzmann Law states that the total power output of a body across all wavelengths is directly proportional to the temperature of the object raised to the fourth power (Intensity = σT^4).[38] Together, all three laws related to black body curves will be investigated using the Colorado PhET Blackbody Spectrum Simulation.[39] At the end of this lesson, students will understand how astronomers use blackbody curves to understand the color, temperature, size, and luminosity of stars, and how this is used to categorize stars in the Hertzsprung-Russell Diagram.

Image 4: Blackbody Radiation Curves

Photo Credit: University Physics Volume 3

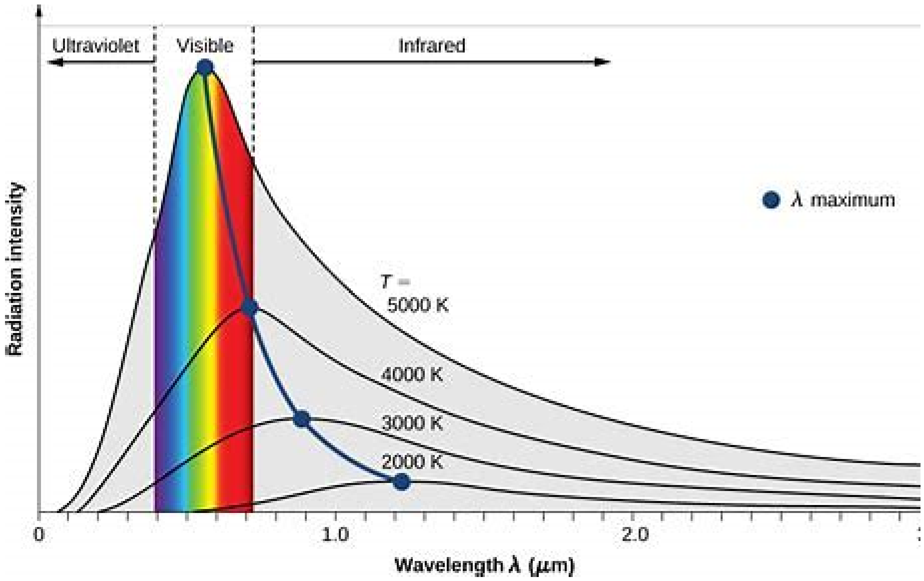


Image 4: The intensity of blackbody radiation versus the wavelength of the emitted radiation. The wavelengths corresponding to visible light are shown by colored bands. At lower temperatures, less energy is emitted, and the curve flattens. However, notice that at hotter temperatures, more photons/energy is emitted at all wavelengths.

The Doppler Effect

When you are at a stoplight, if you hear or see the flashing lights and sounds of an emergency vehicle, your sense of sight and sound helps you determine if the vehicle is moving towards or away from you. This is known as the Doppler Effect.[40] The Doppler effect is the apparent change in frequency of light or sound waves due to the relative motion between the source of the wave and the observer. The Doppler effect is used in astronomy to determine if objects in the cosmos are moving towards or away from Earth.

Students should recall that longer wavelengths tend to the red region of the EM spectrum, while shorter wavelengths tend to the blue region of the EM spectrum. When the source of the wave moves, astronomers observe a shift in spectral lines. When an object is observed by astronomers to be moving towards the observer, the frequency increases and the wavelengths decrease, and they shift towards the blue end of the spectrum. This is called “blueshift”. When an object is moving away, the distance increases, which reduces the frequency, and the wavelengths increase and shift towards the red end of the spectrum. This is called “redshift”. Astronomers use the Doppler Effect to track the movements of stars, galaxies, meteorites, asteroids, and other cosmic debris by analyzing the color shift of spectral lines.

Observing Features of Our Sun

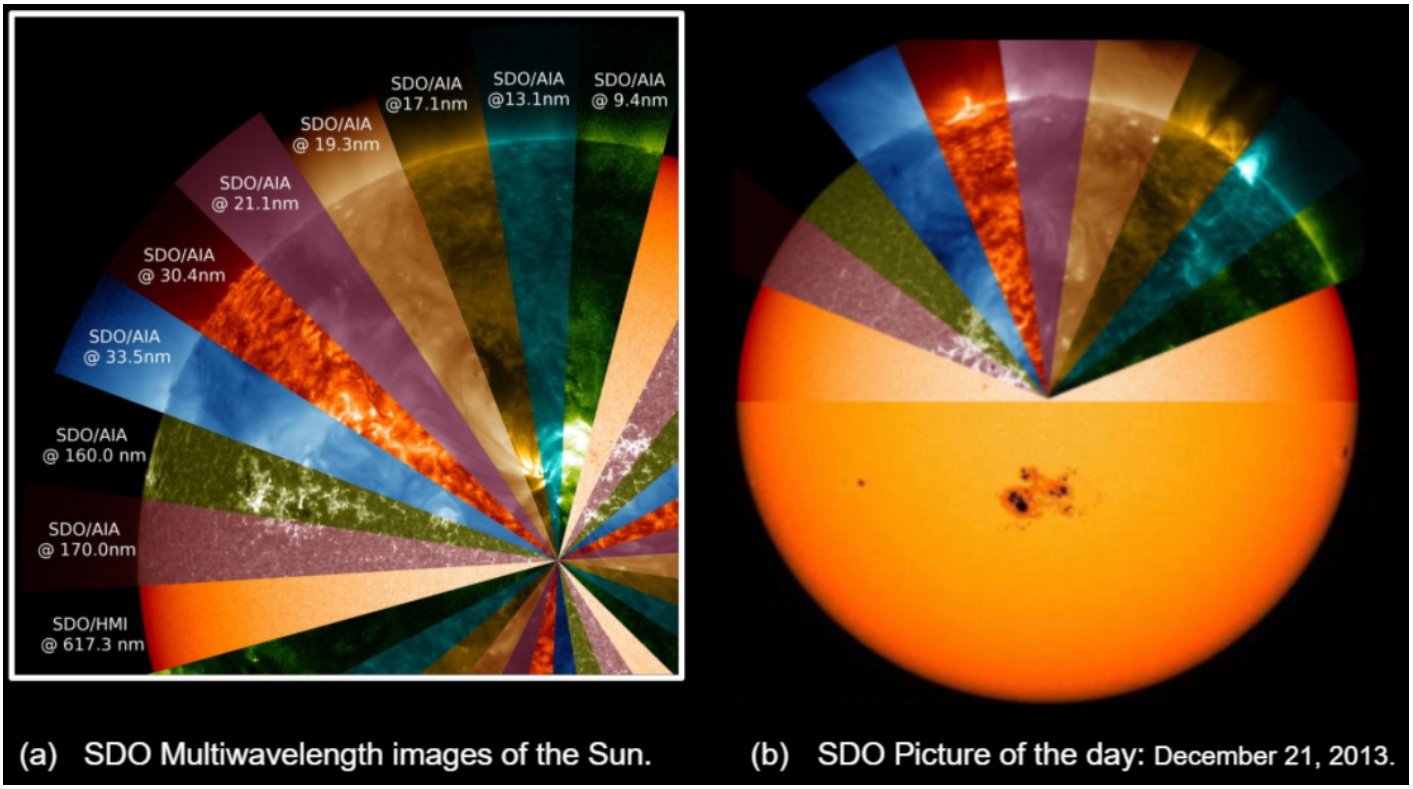
Most would describe the Sun as a hot yellow circle in the sky. The color of the sun may also be observed with red or orange hues, depending on the time of day, atmospheric conditions, and the presence of an eclipse.[41] All their observations are done in the visible spectrum. But the Sun is seen, much differently when observed under different wavelengths of light that the human eye cannot see. In Feb 2010, NASA launched the Solar Dynamic Observatory (SDO), equipped with a suite of instruments to capture ultra-high-definition imagery of the Sun in 13 different wavelengths.[42] [See Image 5]. Near-simultaneous images of the Sun are taken in each wavelength. Each wavelength is used to highlight a particular part of the Sun’s atmosphere, from the solar surface to the upper levels of the Sun’s corona. The SDO is designed to help us better see features of the Sun and understand the Sun’s influence on Earth and Near-Earth space by studying the solar weather, solar magnetic field, and on small scales of space and time in many wavelengths simultaneously. The SDO is equipped with three powerful instruments: The Atmospheric Imaging Assembly (AIA), Helioseismic and Magnetic Imager (HMI), and the Extreme Ultraviolet Experiment (EVE).

Atmospheric Imaging Assembly

The Atmospheric Imaging Assembly (AIA) images the outer layer of the Sun’s corona, at all temperatures from 20,000 -20,000,000 million degrees.[43] of the sun using multi-wavelength filters on telescopes and cameras. These different wavelengths reveal remarkable high-definition (HD) features of the sun Each filter simultaneously captures images of the physical properties of the sun every 10 seconds, significantly improving our understanding of the 11-year solar cycle, solar flares, sunspots, magnetic fields, solar storms, and coronal mass ejections (CMEs).[44] The image shows dark-colored sunspots in visible light (yellow backdrop), shows sunspots as bright glowing ribbons of looping magnetic fields in ultraviolet light (green wedge). In the far-ultraviolet light, the photosphere appears dark because a black-body spectrum at a temperature of 5700 Kelvin emits very little light in this wavelength. If we compare these filters from 170 nm to 9.3nm, we see that the “edge” of the sun’s atmosphere is captured in more detail and appears at different heights.

Image 5: Solar Dynamics Observatory Multiwavelength Images of the Sun.

Photo Credit: Brian Dunbar, NASA



(a) SDO Multiwavelength images of the Sun. (b) SDO Picture of the day: December 21, 2013.

Image 5a. The Solar Dynamics Observatory (SDO) Multiwavelength images of the Sun in the visible, extreme ultraviolet, and x-rays (617.3nm - 9.13nm). **Image 5b.** Against a base image of the sun, the wedge-shaped segments this was the NASA SDO Picture of the day on December 21, 2013. This image comparatively shows the increase in ultra-high-definition imagery that able to see solar flares, magnetic fields, and other features of the sun.

Helioseismic and Magnetic Imager

A second instrument called the Helioseismic and Magnetic Imager (HMI) on the Solar Observatory, is designed to measure oscillations and the magnetic field at the solar surface, or photosphere. HMI looks at the outside of the sun and tries to determine what goes on the inside.[45] Billions of ripples caused by the Sun’s convection zone are little, but like shocks from an earthquake. The HMI will measure the ripples on and magnetic field on the photosphere. HMI carefully analyzes the sound of seismic waves to understand what happens under the surface of the sun. Another function of HMI is to then produce a map of the Sun’s magnetic field. The Sun has numerous and extremely complicated magnetic fields, and when they combine, they create active regions. It is important to study the magnetic field of the Sun because it affects our climate and its space weather. Space weather event from the Sun puts out dangerous radiation to our astronauts, interfering with satellites.A region of strong magnetic fields can result in a coronal mass ejection and solar flares which can cripple power grids and communication systems.[46]

Extreme Ultraviolet Experiment

SDO’s Extreme Ultraviolet Experiment (EVE) measures the solar radiance at the ultraviolet (UV) sand extreme ultraviolet radiation wavelengths. These are extremely short wavelengths. They are usually absorbed in the upper layers of the Earth’s atmosphere where the ozone layer traps UV radiation. EVE measures the amount of solar irradiance and provide warnings about the dangers of flares to astronauts, and communications on earth that there will be problems with their equipment.[47]

The Daniel K. Inouye Solar Telescope

The surface of the sun is boiling! The Daniel K. Inouye Solar Telescope (DKIST) captured first of its kind images of the sun's granular surface.[48] The DKIST is a four-meter-diameter solar telescope located on the island of Maui, Hawaii. In July 2020, DKIST captured high-resolution images showing real images of revealing convection granules the size of Texas on the surface of the sun. These images are remarkable, but of particular interest to scientists are the magnetic fields, which can result in powerful solar storms capable of knocking out power grids.[49] Scientists hope that by understanding solar storms, they can develop an early warning system to warn of possible obstruction to our technological systems.

Teaching Strategies

My “Beyond the Rainbow '' curriculum unit covers 4 of the standards of learning from the Virginia Department of Education Earth Science Curriculum. Students will carry out engaging investigations, demonstrate mastery of the content and build on the skill sets of data analysis, critical thinking, experimentation, and formulating valid conclusions based on scientific inquiry. The three teaching strategies for this curriculum unit applied for this unit are the 5E Teaching Module, a robust English Language Learners (ELLs) approach, and Storytelling.

The 5E Model Strategy

The 5E Model is a student-led inquiry-based learning method. The 5E Model takes students through five (5) distinct learning phases. Students will have opportunities to engage, explore, explain, elaborate, and evaluate the material while learning. This inquiry-based learning strategy allows students to go through a process of gaining answers to their questions. In the Engage portion, they may question how a rainbow forms, how is it related to the sun? What is the sun? How can we study the sun? and what instruments are used to observe the sun? The teacher has activities, research materials, online resources, manipulatives, and laboratory experiments for students to derive answers to their questions. Using the 5E model students collaborate, modify their claims, clear up misconceptions, and create authentic experiences to better understand the phenomena, processes, and characteristics of our sun and other stars.

English Language Learner Strategies

Vocabulary is a major academic hindrance for English Language Learners (ELL). To provide equitable learning opportunities for all students in the classroom, this curriculum unit can be modified with several ELL supports and techniques. Front loading of vocabulary means that the teacher will expose the science words and images prior to the concept being taught.[50] Clearly state the objectives of the class, and then to check for understanding students will complete “I can” statements and share with the teacher and class what they can now do and demonstrate the learning objectives were met. Provide scaffolding by breaking up the material and using tools such as show and tell, sentence stems and graphic organizers. Scaffolding encourages the student to independently self-regulate and problem-solve as they learn.[51] The Frayer Model is a vocabulary graphic organizer that is usually segmented into a definition, pictures, examples and synonyms. This Frayer Model layout will be modified to include a section for the student to write the vocabulary in their native language. Students can compare the vocabulary words used in different languages. Some may be fascinated by how the words sun, rainbow, light, and stars are written and spoken in other languages. In addition, to make my classroom culturally inclusive we can share stories, mythologies, and folklore about the sun and stars. This is a great way to start and pique interest in the topics of the day. This would loop back into the 5E Model of engaging and exploring.

Classroom Activities

The student learning objectives at the end of this curriculum unit are to demonstrate their understanding of how scientists analyze and characterize stars using blackbody curves, emission and absorption spectra, Doppler effect, and Hertzsprung-Russel diagram. With a vault of information from NASA’s various programs such as, living with a Star, and the findings from powerful instruments such as Solar Dynamic Observatory and the Daniel K. Inouye Solar Telescope students can explore surface features of the sun, and discuss how the Sun’s solar weather affects human activities on Earth and in space.

Blackbody Radiation Curve Activity: Star Temperature, Color, and Radiance

In the PhET Colorado Black Body Spectrum Activity, students will describe what happens to the blackbody spectrum when the temperature is increased or decreases and what observations they make about the shape of the curve.[52] In this activity, students will be able to determine the temperature and color of the stars. They will explain the relationship between the temperature and the peak wavelength. This is an online virtual simulation activity.

Periodic Table of Spectra: Chemical Composition of Stars

Students will be given a standard Periodic table of elements and a Periodic Table of Spectra. In this whole-class activity, students will compare how each chart represents the elements and explain the information that each of the documents provides. Regarding the Periodic Table of Spectra, students will observe that each element has its unique spectral lines.[53] Using the unique "fingerprint" of each element, students will understand how scientists can identify the chemical composition of celestial bodies and the evolutionary stage of a star from their spectral lines. At this point, students may want to know how each element has its unique spectrum. The teacher can provide resources to explain the Bohr Model and the particle nature of light as photons.

Stellar Spectral Lines Analysis: Star Composition and Temperature

In the Explore Learning Star Spectra activity, students will determine the elements that are present in a star by comparing its absorption spectrum to known spectra of elements such as carbon, hydrogen, helium, sodium, magnesium, calcium, and iron. Use the information to infer the approximate temperature of the star. In this activity, students will see how astronomers use spectroscopy, and how powerful this technique is in the classification of stars.[54]

Hertzsprung-Russell Diagram: Temperature, Luminosity, Size, Color, and Evolutionary Stage

Students will be given a worksheet of a Hertzsprung-Russell diagram.[55] As students read and interpret the HR diagram, which is a graphical representation of the relationship between a star's absolute temperature and its luminosity. Students will recognize that unlike conventional associations of color and temperature, for stars cooler stars are red and hotter stars are blue-white. Students will use the chart to classify stars by temperature, color, luminosity, evolutionary stage, and size.

Doppler Effect with Demos: Observing Stellar Motion using Blueshifts and Red Shifts

Students will be shown a video explaining the Doppler effect.[56] In this video, they will see how light, and sound have an apparent change in pitch as it approaches or moves away from them as the observer. While they might not have known the term, Doppler effect, they will now as they have experienced emergency vehicles with flashing lights and blaring sirens motion towards or away from them. You can demonstrate the Doppler effect in the classroom in several ways. One way is by having a speaker with sound on and spin it around your head. A Doppler ball consists of a foam ball with a battery-powered buzzer inside. Students will throw the ball back and forth and recognize the frequency shift as they through it away to their partner, a redshift. When we catch the approaching ball, the pitch should sound higher. This is a blue shift. A third option is to use a long sound tube and spin it around.[57]

Frayer Model: Vocabulary Building for English Language Learners

In addition to other vocabulary-building techniques, students will be given a modified Frayer Model to include the vocabulary words in their language. Numerous Frayer Models are available online, for one of the segments students will write the word in their native language. In this exercise, students may already know the word, and if not then they can use a translation dictionary.

Appendix on Implementing District Standards

In this curriculum, students will plan and investigate two of the 12 Earth Science (E.S.) standards of learning stated in the 2018 Virginia Department of Education Earth Science Curriculum Framework.[58]

Standard ES.1: Scientific Investigation and the Nature of Science

The student will demonstrate an understanding of scientific and engineering practices by asking questions and defining problems, planning and carrying out investigations, interpreting, analyzing, and evaluating data, constructing and critiquing conclusions and explanations, developing and using models, and obtaining, evaluating, and communicating information.

Standard ES.2: Cosmology, Origins and Time

The student will demonstrate an understanding that there are scientific concepts related to the origin and evolution of the universe. Key concepts in this standard include that the big bang theory is the current scientific explanation of the origin of the universe; stars, star systems, and galaxies change over long periods of time; characteristics of the sun, planets, and their moons, comets, meteors, asteroids, and dwarf planets are determined by materials found in each body; and evidence attained through space exploration has increased our understanding of the structure and nature of our universe.

Bibliography

Ariel, Balter. "*How Did Bohr's Model Explain the Balmer Lines of Hydrogen's Emission Spectrum?*" Education - Seattle PI, November 21, 2017. https://education.seattlepi.com/did-bohrs-model-explain-balmer-lines-hydrogens-emission-spectrum-5972.html. Online Newspaper. An easy-to-read article that explains the link between the Bohr Model, the Balmer Series of the Hydrogen's emission spectrum, and how this laid the foundation for quantum mechanics.

Buick, Tony. *The Rainbow Sky: An Exploration of Colors in the Solar System and Beyond*. New York; London: Springer, 2010. Springer, 2010. Book. This book explores the colorfulness of the universe. In analyzing these colors scientists unlock information about other celestial bodies.

ByJus Learning Program "S*pectral Series- Explained along with Hydrogen Spectrum, Rydberg Formula.*" BYJUS, August 28, 2020. https://byjus.com/physics/spectral-series/. This online tutoring resource provides literature on the topic and shows worked problems. This is helpful in thinking about materials to assign as well as providing resources that students can access outside of class to improve their understanding.

ByJus Learning Program. "*Hydrogen Spectrum - Balmer Series, Definition, Diagram, Spectrum.*" BYJUS, March 25, 2021. https://byjus.com/chemistry/hydrogen-spectrum/#:~:text=The%20hydrogen%20spectrum%20is%20an%20important%20piece%20of. This online tutoring resource also provides great explanations and free tutorials to break down the material and improve student understanding.

Chemistry LibreTexts. “6*.3: Line Spectra and the Bohr Model.*” Chemistry LibreTexts, September 18, 2019. https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_Chemistry_-_The_Central_Science_(Brown_et_al.)/06._Electronic_Structure_of_Atoms/6.3%3A_Line_Spectra_and_the_Bohr_Model. Online Textbook. This comprehensive online textbook covers a broad scope and sequence of chemistry topics for an introductory, undergraduate-level course. Its search bar allows you to go directly to the section you need more information. It provides content background, graphic organizers, illustrations, diagrams, and worked problem sets.

Chemistry LibreTexts. “*The Particle Nature of Light.*” Chemistry LibreTexts, 2020. https://chem.libretexts.org/Courses/City_College_of_San_Francisco/Chemistry_101A/Topic_E%3A_Atomic_Structure/07%3A_Electronic_Structure_of_Atoms/7.02%3A_Quantized_Energy_and_Photons. Online Textbook. This Undergraduate, introductory-level textbook covers a broad scope and sequence of chemistry topics. It includes helpful annotated diagrams, sample problems, key vocabulary words, summary and recommends activities for further exploration. This textbook is also available online.

Cheung, Mark. “*The Atmospheric Imaging Assembly: Science Highlights, Analysis Techniques and Instrument Status*.” www.youtube.com, February 23, 2021. https://www.youtube.com/watch?v=V-d0uf5u9hQ. Video. Mark Cheung is part of the Solar Dynamic Observatory team. In this video, he provides an update on the highlights and instrument status of the Atmospheric Imaging Assembly.

Colorín Colorado. “*What Is ‘Scaffolding’ and How Does It Help ELLs?*” Colorín Colorado, May 2015. https://www.colorincolorado.org/faq/what-scaffolding-and-how-does-it-help-ells. Online Article. This online article explains what is meant by the term scaffolding and lists the benefits of using this teaching strategy to support English Language Learning students.

Dunbar, Brian. “NASA - Infrared Light.” Nasa.gov, 2009. https://www.nasa.gov/audience/forstudents/5-8/features/F_Infrared_Light_5-8.html. This online article explains what scaffolding is and lists its benefits to English Language Learners. Online Article. As students carry the Blackbody curve simulation, they will see that peaks occur in the visible, infrared, or ultraviolet, this article explains what infrared is and explains how people “glow” in infrared.

Enterprise in Space. “*Project: Spectroscopy.”* July 2016.” https://www.eisacademy.org/course/view.php?id=61. Website. An online resource that explains the history and timeline for spectroscopy. Website. An online article resource that explains the history and timeline for spectroscopy.

Explore Learning. *“Star Spectra Gizmo: Lesson Info: Explore Learning.”* Explore Learning: Get hands-on, minds-on in math and science. Accessed June 3, 2021. https://gizmos.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=558. Online Simulation. Explore Learning Gizmos is an award-winning math and science simulation program. The Star Spectra Gizmo activity is an inquiry-based online simulation that allows students to determine the elements present in a star’s spectrum, approximate the temperature, classify stars and decipher the movement of stars using blueshifts and redshifts.

Field Tested Systems. *“Periodic Table of Spectra – Field Tested Systems.”* Field Tested Systems, 2010. https://www.fieldtestedsystems.com/ptable/. Poster. This poster is a wonderful teaching tool because unlike the traditional Periodic Table of elements that students are familiar with, this poster has the same layout but the elements in the table are shown with their unique spectrum.

Fraknoi, Andrew, David Morrison, Sidney C Wolff, and Openstax College. "*Astronomy*." Houston, Texas: Openstax, 2016. Textbook. This comprehensive online textbook covers a broad scope and sequence of astronomy topics suitable for an introductory, undergraduate-level course. It includes helpful annotated diagrams, sample problems, key vocabulary words, chapter summaries, and activities for further exploration. This textbook is also available online.

"*HR Diagram Worksheet.*" http://velascience.weebly.com/uploads/4/8/5/5/48550801/hr-diagram-worksheet-23cncab.pdf. PDF Document. This worksheet has a great image of the HR Diagram. In this activity, students will determine how stars are classified by temperature, size, luminosity, and shows the evolutionary path of the Sun in the main sequence.

HyperPhysics. "*Star Temperatures.*" Gsu.edu, 2019. http://hyperphysics.phy-astr.gsu.edu/hbase/wien.html. Website. HyperPhysics was extremely helpful in explaining blackbody curve diagrams and also had practice problems for Wien's Displacement Law.

Las Cumbres Observatory. "*Black-Body Radiation* | *Las Cumbres Observatory.*" Lco.global, 2019. https://lco.global/spacebook/light/black-body-radiation/. Online Resource. The Las Cumbres Observatory global telescope network believes that science and technology should be accessible to and equitable for all and has made available its data and welcomes visitors to its operation sites. This website was a great resource for understanding why stars are considered black bodies and how that information is used by astrophysicists. In addition to literature, it provides animations and diagrams.

Ling, Samuel J, Jeff Sanny, and William Moebs. "*Blackbody Radiation*." Opentextbc.ca. OpenStax, September 2016. Online Textbook. In chapter 44 of this online textbook, it provides background information, worked sample problems, learning objectives, a chapter summary and many illustrations to help to explain the Photoelectric Effect. https://opentextbc.ca/universityphysicsv3openstax/chapter/blackbody-radiation/.

Ling, Samuel J, Jeff Sanny, and William Moebs. "*Photoelectric Effect*." Opentextbc.ca. OpenStax, September 2016. Online Textbook. In chapter 44 of this online textbook, it provided background information, worked sample problems, learning objectives, a chapter summary, and many illustrations to help to explain the Photoelectric Effect. https://opentextbc.ca/universityphysicsv3openstax/chapter/photoelectric-effect/.

Merriam-Webster. "*Helium: This Word Brought to You by a Solar Eclipse.*" www.merriam-webster.com. Accessed August 5, 2021. https://www.merriam-webster.com/words-at-play/helium-this-word-brought-to-you-by-a-solar-eclipse. Online Encyclopedia. This article highlights the importance of the solar eclipse of 1868 by French astronomer Pierre Janssen in discovering the element, Helium.

Meyers, Catherine. *"Exploring the Math in 'Hidden Figures."* Inside Science, February 24, 2017. https://www.insidescience.org/news/exploring-math-hidden-figures. Online Movie Review. In this movie review, Meyers breaks down the contributions of three African American women in making the Apollo 11 mission a success in the movie, "Hidden Figures.".

NASA. "*SDO Spacecraft & Instruments*." NASA, 2011. https://www.nasa.gov/mission_pages/sdo/spacecraft/index.html. Website. In this article, NASA describes the purpose and instruments onboard the Solar Dynamic Observatory.

NASA Goddard. *"NASA* | *SDO's Instruments: EVE."* www.youtube.com, September 22, 2009.

https://www.youtube.com/watch?v=lkQDqG61qtQ. Video. This video explains the function and importance of the Extreme Ultraviolet Variability Experiment of the Solar Dynamics Observatory.

National Center for Education Statistics. *"The NCES Fast Facts Tool Provides Quick Answers to Many Education Questions (National Center for Education Statistics)."* Ed.gov. National Center for Education Statistics, 2009. https://nces.ed.gov/fastfacts/display.asp?id=158. Website. This online website provided fast facts. It is managed by the National Center for Education Statistics (NECS). NECS is the primary federal entity for collecting and analyzing data related to education in the U.S. and other nations.

Optical Microscopy Division of the National High Magnetic Field Laboratory. *"Molecular Expressions: Science, Optics and You - Timeline - Max Planck."* Fsu.edu, December 24, 1999. https://micro.magnet.fsu.edu/optics/timeline/people/planck.html. Website. A great article that information of Max Planck's quantum theory.

Palmer, Christopher. *"Kirchoff's Laws and Spectroscopy | Astronomy 801: Planets, Stars, Galaxies, and the Universe."* Psu.edu, 2018. https://www.e-education.psu.edu/astro801/content/l3_p6.html. Image. This website created by the Professors at Penn State University provided explanations of Kirchhoff's Three Laws and was the creator of Image is 2 in this curriculum unit.

Pesnell, Dean. *"NASA | SDO's Helioseismic and Magnetic Imager (HMI)."* www.youtube.com, July 9, 2009. https://www.youtube.com/watch?v=vSSs7-O5IqY. Video. This video explains the function and importance of the SDO's Helioseismic and Magnetic Imager.

PhET Interactive Simulations. *"Blackbody Spectrum."* PhET, July 6, 2019. https://phet.colorado.edu/en/simulation/blackbody-spectrum. Online Simulation. Students will complete this activity and learn how astronomers use blackbody curves to determine the temperature, color, and luminosity of stars.

Rice, Richard E. *"Johann Jakob Balmer - Chemistry Encyclopedia - Name, Equation, Atom."* www.chemistryexplained.com. Accessed July 17, 2021. http://www.chemistryexplained.com/Ar-Bo/Balmer-Johann-Jakob.html. Website. This article provides a brief description of Johann Balmer's work and background.

Rodgers, Griffen. *"Starlight's Story: What Can the Light We See in the Night Sky Tell Us about the Universe?"* Berkeley Scientific Journal 17, no. 1 (2013). https://doi.org/10.5070/bs3171016150. Journal. This is a great resource. One of the first articles read and gives an overview of many components of this curriculum unit.

Shift, Alt. *"The Doppler Effect: What Does Motion Do to Waves?"* YouTube Video. June 6, 2013. https://www.youtube.com/watch?v=h4OnBYrbCjY. Video. This video does a great job at explaining the Doppler Effect and how it is used to determine if an object is moving towards (blueshift) or away from the observer (redshift).

Starr, Michelle. *"Staggering New Images of the Sun Are the Most Detailed Ever Taken." ScienceAlert,* 2020. https://www.sciencealert.com/these-new-images-of-the-sun-are-the-most-detailed-ever-taken. Website. This article discusses the remarkable achievement of the Daniel K. Inouye Solar Telescope that took the most detailed pictures of the Sun's surface ever.

Swinburne University of Technology. *"Blackbody Radiation | COSMOS."* astronomy.swin.edu.au. Accessed July

20, 2021. https://astronomy.swin.edu.au/cosmos/B/Blackbody+Radiation. Website. This article explains how the three laws by Planck, Wein, and Stephan-Boltzman were used to describe the characteristics of black body diagrams.

Taylor Redd, Nola. *"World's Largest Solar Telescope Produces Never-Before-Seen Image of Our Star."* Space.com, January 29, 2020. https://www.space.com/first-sun-image-from-massive-solar-telescope.html. Website. This article highlights the incredible achievement of the Daniel K. Inouye Solar Telescope that took the most detailed pictures of the Sun's surface ever.

Teachings In Education. *"ELL & ESL Teaching Strategies."* YouTube Video. *YouTube*, September 2, 2019. https://www.youtube.com/watch?v=SyJ_pNaazso. Video. This video gives numerous teaching strategies that are easy to implement. It provides great visuals and the rationale for each strategy used to support English Language Learners.

The Editors of Encyclopedia Britanica. "*Joseph von Fraunhofer | German Physicist | Britannica*." In Encyclopedia Britannica, July 20, 1998. https://www.britannica.com/biography/Joseph-von-Fraunhofer. Online Encyclopedia. This online article summarized the significant contributions of Joseph Fraunhofer. It is written in an easy-to-read language about dark lines found in the absorption spectrum of the Sun that enabled spectroscopy to become a powerful and precise scientific technique.

The Nobel Prize. *"Wilhelm Wein-the Lecture."* NobelPrize.org, https://www.nobelprize.org/prizes/physics/1911/wien/facts/. Website. This curriculum unit features many scientists whose pioneering work won them the distinguished Nobel Prize. Their work included the Bohr Model, Photoelectric Effect, Analysis of Hydrogen Spectral Lines, and other theories and discoveries related to Quantum Mechanics and its applications. Many scientists such as Einstein are known for many discoveries but not all of their work won them a Nobel Prize, so this website is great for keeping track of the winners and their work.

ThoughtCo. *"How Does Ancient Mayan Astronomy Portray the Sun, Moon and Planets?"* ThoughtCo, 2012. https://www.thoughtco.com/ancient-maya-astronomy-2136314. Online Article. This article broadened my knowledge of Mayan's knowledge of the cosmos.

TSG Physics. *"C 57: Doppler Effect Using a Sound Tube."* www.youtube.com, July 27, 2015. https://www.youtube.com/watch?v=Yb7ulVRlnuM. Video. This video shows how the Doppler effect is demonstrated in the classroom.

U.S. Department of Education. *"The NCES Fast Facts Tool Provides Quick Answers to Many Education Questions (National Center for Education Statistics)."* Ed.gov. National Center for Education Statistics, 2009. https://nces.ed.gov/fastfacts/display.asp?id=158. Website. This article provides the criteria required for schools to qualify for Title I status and federal funding.

Virginia Department of Education. "*Huguenot High." Virginia School Quality Profiles."* September 30, 2020. https://schoolquality.virginia.gov/schools/huguenot-high. A quick graphical snapshot of my school's demographics, accreditation status, teacher quality, enrollment, and other school quality indicators. This helped provide reasons for Huguenot High's status as a Title I school.

Virginia Department of Education. *"Science Standards of Learning Curriculum Framework 2010 Earth Science."*, 2010.

https://www.doe.virginia.gov/testing/sol/standards_docs/science/2010/curriculum_framewk/earth_science.pdf. PDF Document. This is a document that gives a quick graphical snapshot of my school's demographics, accreditation status, teacher quality, enrollment, and other school quality indicators. Using these indicators, Huguenot High qualified as a Title I school.

Voss, David. *"August 18 and October 20, 1868: Discovery of Helium."* www.aps.org, August 2014. https://www.aps.org/publications/apsnews/201409/physicshistory.cfm. Newsletter. A great article on the work of various scientists that lead to the discovery of helium, which is the second most abundant element in the universe.

Notes

[1] Virginia Department of Education, "Science Standards of Learning Curriculum Framework 2010 Earth Science" (2010), https://www.doe.virginia.gov/testing/sol/standards_docs/science/2010/curriculum_framewk/earth_science.pdf.

[2] U.S. Department of Education, "The NCES Fast Facts Tool Provides Quick Answers to Many Education Questions (National Center for Education Statistics)," Ed.gov (National Center for Education Statistics, 2009), https://nces.ed.gov/fastfacts/display.asp?id=158.

[3] Virginia Department of Education, "Huguenot High," Virginia School Quality Profiles, September 30, 2020, https://schoolquality.virginia.gov/schools/huguenot-high.

[4] ThoughtCo, "How Does Ancient Mayan Astronomy Portray the Sun, Moon and Planets?" ThoughtCo, 2012, https://www.thoughtco.com/ancient-maya-astronomy-2136314.

[5] Catherine Meyers, "Exploring the Math in 'Hidden Figures,'" Inside Science, February 24, 2017, https://www.insidescience.org/news/exploring-math-hidden-figures.

[6] Andrew Fraknoi et al., *Astronomy* (Houston, Texas: OpenStax, 2016)., pg 161-163

[7] Enterprise in Space, "Project: Spectroscopy," www.eisacademy.org, July 2016, https://www.eisacademy.org/course/view.php?id=61.

[8] Andrew Fraknoi et al., *Astronomy*, pg 161-163

[9] Enterprise in Space, "Project: Spectroscopy," July 2016,

[10] The Editors of Encyclopedia Britannica, "Joseph von Fraunhofer | German Physicist | Britannica," in *Encyclopædia Britannica*, July 20, 1998, https://www.britannica.com/biography/Joseph-von-Fraunhofer.

[11] Norriss S. Hetherington and W. Patrick McCray, "A Cosmic Journey: A History of Scientific Cosmology," history.aip.org, accessed July 28, 2021, https://history.aip.org/exhibits/cosmology/tools/tools-spectroscopy.htm.

[12] Merriam-Webster, "Helium: This Word Brought to You by a Solar Eclipse," www.merriam-webster.com, accessed August 5, 2021, https://www.merriam-webster.com/words-at-play/helium-this-word-brought-to-you-by-a-solar-eclipse.

[13] David Voss, “August 18 and October 20, 1868: Discovery of Helium,” www.aps.org, August 2014, https://www.aps.org/publications/apsnews/201409/physicshistory.cfm.

[14] Christopher Palmer, “Kirchoff’s Laws and Spectroscopy | Astronomy 801: Planets, Stars, Galaxies, and the Universe,” Psu.edu, 2018, https://www.e-education.psu.edu/astro801/content/l3_p6.html.

[15] Andrew Fraknoi et al., *Astronomy*, pg 151

[16] Optical Microscopy Division of the National High Magnetic Field Laboratory, “Molecular Expressions: Science, Optics and You - Timeline - Max Planck,” Fsu.edu, December 24, 1999, https://micro.magnet.fsu.edu/optics/timeline/people/planck.html.

[17] Samuel J. Ling, Jeff Sanny, and William Moebs, “Photoelectric Effect,” Opentextbc.ca (OpenStax, September 2016), https://opentextbc.ca/universityphysicsv3openstax/chapter/photoelectric-effect/.

[18] Ariel Balter, “How Did Bohr’s Model Explain the Balmer Lines of Hydrogen’s Emission Spectrum?” Education - Seattle PI, November 21, 2017, https://education.seattlepi.com/did-bohrs-model-explain-balmer-lines-hydrogens-emission-spectrum-5972.html.

[19] Andrew Fraknoi et al., *Astronomy*, pg 158.

[20] Chemistry LibreTexts, “6.3: Line Spectra and the Bohr Model,” Chemistry LibreTexts, September 18, 2019, https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_Chemistry_-_The_Central_Science_(Brown_et_al.)/06._Electronic_Structure_of_Atoms/6.3%3A_Line_Spectra_and_the_Bohr_Model.

[21] Richard E Rice, “Johann Jakob Balmer - Chemistry Encyclopedia - Name, Equation, Atom,” www.chemistryexplained.com, accessed July 17, 2021, http://www.chemistryexplained.com/Ar-Bo/Balmer-Johann-Jakob.html.

[22] Balter Ariel, “How Did Bohr’s Model Explain the Balmer Lines of Hydrogen’s Emission Spectrum?”.

[23] Balter Ariel, “How Did Bohr’s Model Explain the Balmer Lines of Hydrogen’s Emission Spectrum?” 2017.

[24] BYJUS, March 25, 2021, https://byjus.com/chemistry/hydrogen-spectrum/#:~:text=The%20hydrogen%20spectrum%20is%20an%20important%20piece%20of.

[25] BYJUS, August 28, 2020, https://byjus.com/physics/spectral-series/., BYJUS Learning Program, “Hydrogen Spectrum - Balmer Series, Definition, Diagram, Spectrum,”.

[26] Andrew Fraknoi et al., *Astronomy*, page 173.

[27] BYJUS, “Spectral Series- Explained along with Hydrogen Spectrum, Rydberg Formula.,” BYJUS, August 28, 2020, https://byjus.com/physics/spectral-series/.

[28] Explore Learning, “Star Spectra Gizmo: Lesson Info: ExploreLearning,” ExploreLearning: Get hands-on,

minds-on in math and science, accessed June 3, 2021, https://gizmos.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=558.

[29] Las Cumbres Observatory, “Black-Body Radiation | Las Cumbres Observatory,” Lco.global, 2019, https://lco.global/spacebook/light/black-body-radiation/

[30] Las Cumbres Observatory, “Black-Body Radiation | Las Cumbres Observatory,”

[31] Swinburne University of Technology, “Blackbody Radiation | COSMOS,” astronomy.swin.edu.au, accessed July 20, 2021, https://astronomy.swin.edu.au/cosmos/B/Blackbody+Radiation

[32] Andrew Fraknoi et al., *Astronomy*, page 158

[33] Andrew Fraknoi et al., *Astronomy*, pages 157-158

[34] Andrew Fraknoi et al., *Astronomy*, page158

[35] The Nobel Prize, “Wilhelm Wein-the Lecture,” NobelPrize.org, n.d., https://www.nobelprize.org/prizes/physics/1911/wien/facts/.

[36] HyperPhysics, “Star Temperatures,” Gsu.edu, 2019, http://hyperphysics.phy-astr.gsu.edu/hbase/wien.html.

[37] Brian Dunbar, “NASA - Infrared Light,” Nasa.gov, 2009, https://www.nasa.gov/audience/forstudents/5-8/features/F_Infrared_Light_5-8.html.

[38] Andrew Fraknoi et al., *Astronomy*, page160

[39] PhET Interactive Simulations, “Blackbody Spectrum,” PhET, July 6, 2019, https://phet.colorado.edu/en/simulation/blackbody-spectrum.

[40] Andrew Fraknoi et al., *Astronomy*, pages 176-180

[41] Daniel V Schroeder, “Understanding Astronomy: The Sun and the Seasons,” Weber.edu, 2010, https://physics.weber.edu/schroeder/ua/SunAndSeasons.html.

[42] NASA, “SDO Spacecraft & Instruments,” NASA, 2011, https://www.nasa.gov/mission_pages/sdo/spacecraft/index.html.

[43] NASA, “SDO Spacecraft & Instruments,” NASA, 2011

[44] Mark Cheung, “The Atmospheric Imaging Assembly: Science Highlights, Analysis Techniques and Instrument Status,” www.youtube.com, February 23, 2021, https://www.youtube.com/watch?v=V-d0uf5u9hQ.

[45] NASA, “SDO Spacecraft & Instruments,” NASA, 2011

[46] Dean Pesnell, “NASA | SDO’s Helioseismic and Magnetic Imager (HMI),” www.youtube.com, July 9, 2009, https://www.youtube.com/watch?v=vSSs7-O5IqY.

[47] NASA Goddard, “NASA | SDO’s Instruments: EVE,” www.youtube.com, September 22, 2009, https://www.youtube.com/watch?v=lkQDqG61qtQ.

[48] Nola Taylor Redd, “World’s Largest Solar Telescope Produces Never-Before-Seen Image of Our Star,” Space.com, January 29, 2020, https://www.space.com/first-sun-image-from-massive-solar-telescope.html.

[49] Michelle Starr, “Staggering New Images of the Sun Are the Most Detailed Ever Taken,” ScienceAlert, 2020, https://www.sciencealert.com/these-new-images-of-the-sun-are-the-most-detailed-ever-taken.

[50] Teachings In Education, “ELL & ESL Teaching Strategies,” YouTube Video, *YouTube*, September 2, 2019, https://www.youtube.com/watch?v=SyJ_pNaazso.

[51] Colorín Colorado, “What Is ‘Scaffolding’ and How Does It Help ELLs?,” Colorín Colorado, May 2015, https://www.colorincolorado.org/faq/what-scaffolding-and-how-does-it-help-ells.

[52] PhET Interactive Simulations, “Blackbody Spectrum,” PhET, July 6, 2019

[53] Field Tested Systems, “Periodic Table of Spectra – Field Tested Systems,” Field Tested Systems, 2010, https://www.fieldtestedsystems.com/ptable/.

[54] TSG Physics, “C 57: Doppler Effect Using a Sound Tube,” www.youtube.com, July 27, 2015, https://www.youtube.com/watch?v=Yb7ulVRlnuM.

[55] “HR Diagram Worksheet” http://velascience.weebly.com/uploads/4/8/5/5/48550801/hr-diagram-worksheet-23cncab.pdf.

[56] Alt Shift, “The Doppler Effect: What Does Motion Do to Waves?” YouTube Video, *YouTube*, June 6, 2013, https://www.youtube.com/watch?v=h4OnBYrbCjY.

[57] Explore Learning, “Star Spectra Gizmo.”

[58] Virginia Department of Education, “Science Standards of Learning Curriculum Framework 2010 Earth Science.”
