Part II: What is Electromagnetic (EM) Radiation? How is it created in atoms? What units are used to characterize EM radiation?

From: X-ray Spectroscopy and the Chemistry of Supernova Remnants

A Series of Lesson Plans by
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Objectives

Students will read and write about the chemistry and spectroscopy of stars and supernova remnants, as well as understand their relevance and impact on human life. Students will also learn about cutting edge technology that will help us to build better instruments with which to study the Universe.

Each section has several pages of background material relevant to the associated activities and the lesson plan as a whole. The background sections include short exercises or thought questions developed to help the student reach a better understanding of the material presented. Each section also has activities developed by real teachers - designed to bring important concepts in astronomy right into the classroom. Each activity is correlated to national science and math standards for grades 9 - 12. These activities show how interrelated chemistry, physics, and astronomy really are.

Outline of Unit

Part I: How and Where are Elements Created?

- **Background:** *The Life Cycles of Stars: How Supernovae Are Formed* – Describes the life of a high-mass star - as well as its death in a giant supernova explosion.
- **Background**: *The Dispersion of Elements* – Describes how supernova explosions not only disperse the elements created inside a star, they create new elements.
- **Activity**: *Fusion Reactions* – In this activity, each student is given a card with an element produced inside stars on it - the students then form fusion reactions that occur within stars.

Part II: What is Electromagnetic (EM) Radiation? How is it created in atoms? What units are used to characterize EM radiation?

- **Background**: *How Do the Properties of Light Help Us to Study Supernovae and Their Remnants?* – Students learn about the electromagnetic spectrum.
- **Activity**: *Calculation Investigation* – Students learn about unit analysis by converting energies to wavelengths to frequencies.
- **Background**: *Atoms and Light Energy* – Describes how atoms emit light, and how we can use this to learn about astronomical objects.
- **Activity**: *Calculate the Energy!* – Students will calculate the energy differences in different energy states of the Bohr atom of Hydrogen.

Part III: What tools are used to identify elements? What importance do X-rays have to astronomy?

- **Background**: *Introduction to Spectroscopy* – Everything you ever wanted to know about spectroscopy but were afraid to ask!
- **Activity**: *Graphing Spectra* – Practice drawing graphs of spectra, and understanding the different ways spectra can be represented, as well as what each representation can tell us.
- **Activity**: *Flame Test* – A chemistry experiment that shows how heated elements emit different colors of light.
- **Activity**: *Design an Element Poster Advertisement* – Students will discuss what they have learned about atoms and elements in their own words, designing a poster advertisement for their chosen element. Students will use more than just their right brain to think about science!

Part IV: How does the newest technology help us to understand the Universe?

- **Background**: *All About The Microcalorimeter* – All about microcalorimeter technology, the next generation X-ray spectrometer.
- **Activity**: *Identifying Light Energy by Temperature Changes* – Learn first hand how a microcalorimeter really works
- **Activity**: *Identifying Elements in Supernova Remnants using Spectra* – Now the students get to take all they have learned and really apply it. Students will identify the elements present in a supernova remnant by analyzing its spectrum.
- **Background**: *A Plethora of X-ray Telescopes* – Learn about existing and future X-ray telescopes and what they hope to accomplish.
- **Activity**: *Satellite Venn Diagram* – Students will organize the information about X-ray observatories into a Venn diagram.
- **Activity**: *Writing Assignment* – As a closing activity, students will demonstrate the ability to use text information and data to persuade a reading audience of the benefits of using calorimeter detectors to do X-ray astronomy.

Part II: What is Electromagnetic (EM) Radiation? How is it created in atoms? What units are used to characterize EM radiation?

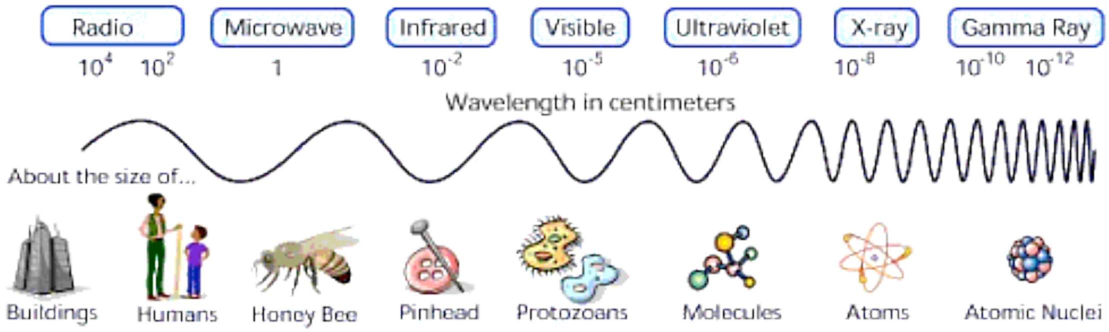
How Do the Properties of Light Help Us to Study Supernovae and Their Remnants?

There are special properties of light that we can take advantage of to understand even objects that are millions and billions of light years away. In this section we explore some of these properties and how we can use them to understand our Universe. In the previous section of this unit, you were told that superheated material created by the supernova explosion gives off X-rays and gamma-rays. X-rays and gamma-rays are really just light (electromagnetic radiation) that has very high energy.

What is Electromagnetic (EM) Radiation?

Although it would seem that the human eye gives us a pretty accurate view of the world, we are literally blind to much of what surrounds us. A whole Universe of color exists, only a thin band of which our eyes are able to detect; an example of this visible range of color is the familiar rainbow (an example of a "spectrum"). The optical spectrum ranges in color from reds and oranges up through blues and purples. Each of these colors actually corresponds to a different energy of light. The colors or energies of light that our eyes cannot see also have names that are familiar to us. We listen to radios, we eat food heated in microwaves, we have X-rays taken of our broken bones. Yet many times we do not realize that radio, X-ray, and microwave are really just different energies of light!

The entire range of energies of light, including both light we can see and light we cannot see, is called the electromagnetic spectrum. It includes, from highest energy to lowest: gamma-rays, X-rays, ultraviolet, optical, infrared, microwaves, and radio waves.



Because light is something that is given off, or radiated from an object, we can call it radiation. That's why we often talk about X-ray radiation - it's the same thing as saying X-ray light. When we refer to the whole spectrum of light, we can call it electromagnetic radiation.

Because we can see only visible light, we are put at a disadvantage because the Universe is actively emitting light at all different energies.

Light has different colors because it has different energies. This is true whether we are talking about red and blue visible light, or infrared (IR) and X-ray light. Of all the colors in the visible spectrum, red light is the least energetic and blue is the most. Beyond the red end of the visible part of the spectrum lie infrared and radio light, both of which have lower energy than visible light. Above the blue end of the visible spectrum lies the higher energies of ultraviolet light, X-rays, and finally, gamma-rays.

What Units are Used to Characterize EM Radiation?

Light can be described not only in terms of its energy, but also its wavelength, or its frequency. There is a one-to-one correspondence between each of these representations. X-rays and gamma rays are usually described in terms of energy, optical and infrared light in terms of wavelength, and radio in terms of frequency. This is a scientific convention that allows the use of the units that are the most convenient for describing whatever energy of light you are looking at. For example, it would be inconvenient to describe both low energy radio waves and high-energy gamma rays with the same units because the difference in their energies is so great. A radio wave can have an energy on the order of 4×10^{-10} eV as compared to 4×10^{9} eV for gamma rays. That's an energy difference of 10^{19}, or ten million trillion eV!

Wavelength is the distance between two peaks of a wave, and it can be measured with a base unit of meters (m) (such as centimeters, or Ångstroms). Frequency is the number of cycles of a wave to pass some point in a second. The basic unit of frequency is cycles per second, or Hertz (Hz). Energy in astronomy is often measured in electron volts, or eV or its multiples (such as kilo electron volts, or 1,000 eV) .

Wavelength and frequency are related by the speed of light ($c=3.00 \times 10^{8}$ m/s), a fundamental constant. Energy is also directly proportional to frequency (the constant of proportionality is Planck's constant, $h=6.626 \times 10^{-34}$ m^2 kg/s) and inversely proportional to wavelength. It was Max Planck who demonstrated that light sometimes behaves as a particle by showing that its energy (E) divided by its frequency (usually denoted using the Greek letter ν) is a constant. Since we know that frequency is equal to the speed of light (c) divided by wavelength (the Greek letter λ), we also know the relationship between energy and wavelength. The energy (or wavelength or frequency) of light can give important clues into how the light was produced, and it is this characterization of light emission that allows us to understand objects in the distant universe.

Since light can act like both a particle and a wave, we say that light has a particle-wave duality. We call particles of light photons. Low-energy photons (i.e. radio) tend to behave more like waves, while higher energy photons (i.e. X-rays) behave more like particles. This is an important difference because it affects the way we build instruments to measure light (telescopes!).

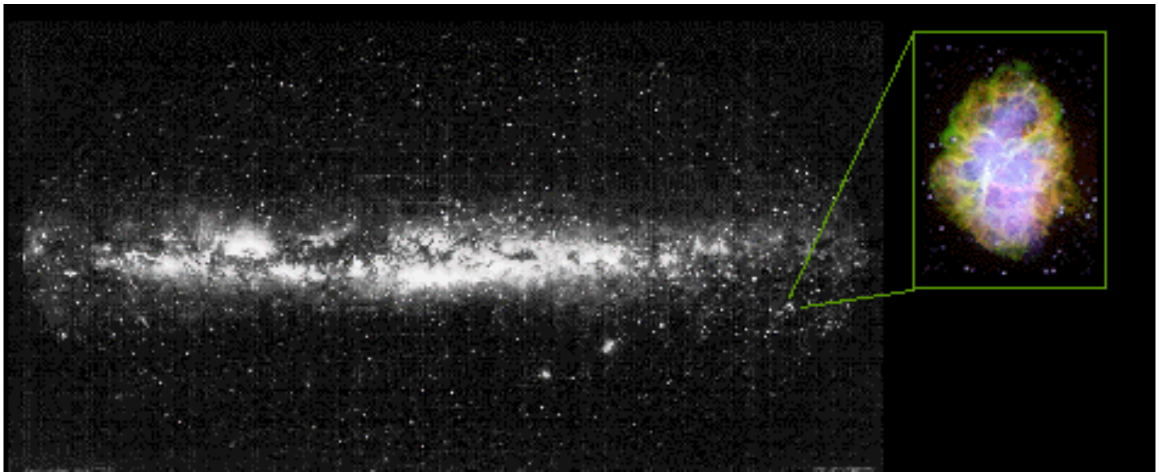
You are familiar with light in many forms, like sunlight, which you see every day. But how is this light created? Further, how can we use the properties of light to understand objects in the Universe?

Observing Supernovae and Their Remnants at Different Energies

It pays to make multiple observations of astronomical objects because they emit light of different energies. Supernovae remnants can give off visible light, ultraviolet light, radio waves and X-rays. Each observation of a supernovae remnant can give us different information about it.

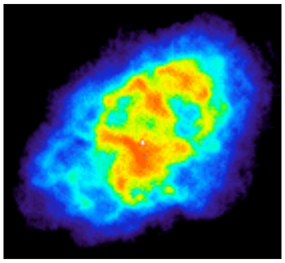
Let's examine the Crab Nebula; it is unique in that it contains one of only a few pulsars that are observable at so many different energies.

The Crab Nebula's creation was witnessed in July of 1054 A.D. when Chinese astronomers and members of the Native American Anasazi tribe separately recorded the appearance of a new star. Although it was visible for only a few months, it was bright enough to be seen even during the day! In the 19th century, French comet hunter Charles Messier recorded a fuzzy ball of light near the constellation Taurus. This fuzzy ball turned out not to be a comet after all, but the remains of a massive star whose explosive death had been witnessed centuries before by the Chinese and the Anasazi.



The location of the Crab Nebula (inset) in the Milky Way Galaxy.

Scientists now believe the Crab Nebula is the remains of a star that suffered a supernova explosion. The core of the star collapsed and formed a rapidly rotating, magnetic neutron star, releasing energy sufficient to blast the surface layers of the star into space with the strength of a 10^{28}-megaton bomb or a hundred million nuclear warheads. Nestled in the nebulous cloud of expelled gases, the rotating neutron star, or pulsar, continues to generate strobe-like pulses that can be observed at radio, optical, and X-ray energies. The Crab Nebula was one of the first sources of X-rays identified in the early 1960s when the first X-ray astronomy observations were made.

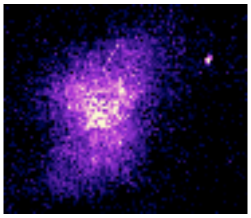


Crab Nebula in Radio

At radio wavelengths, the Crab Nebula, seen to the left, displays two distinctive physical features. The nebulous regions hide radio emission coming from unbound electrons spiraling around inside the nebula. The pulsar at the heart of the Crab Nebula generates pulses at radio frequencies roughly 60 times a second. In this image, the pulsar's flashes are blurred together (since the image was "exposed" for much longer than 1/60 s) and it appears as the bright white spot near the middle of the nebula.

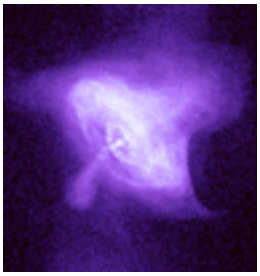
Crab in optical

In the optical, both a web of filaments at the outer edges of the nebula and a bluish core become apparent. The blue core is from electrons within the nebula being deflected and accelerated by the magnetic field of the central neutron star. The red filaments surrounding the edges of the nebula are the remnants of the original outer layers of the star.



Crab in UV

In the ultraviolet (or UV) the nebula is slightly larger than when seen in X-rays. Cooler electrons (responsible for the UV emission) extend out beyond the hot electrons near the central pulsar. This supports the theory that the central pulsar is responsible for energizing the electrons.



Crab in X-ray

X-ray observations reveal a condensed core near the central pulsar, which is the bright dot visible slightly left and below center in the image to the right. The Crab Nebula appears smaller and more condensed in X-rays because the electrons, which are primarily responsible for the X-ray emission, exist only near the central pulsar. Scientists believe that the strong magnetic field near the surface of the neutron star "heats up" the electrons in it and that these "hot" electrons are responsible for the X-ray emission.

For the Student

Using the text and any external references, define the following terms: radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays, light energy, photon, electromagnetic spectrum, electromagnetic radiation, Hertz, wave peak, frequency, and wavelength.

Reference URLs:

The EM Spectrum

http://imagine.gsfc.nasa.gov/docs/introduction/emspectrum.html

Activity: Calculation Investigation

Days needed: 1
Grade Level: 11 - 12

Objective

In this activity, students will learn how white light, such as that from an overhead projector, is broken up into its component colors by a diffraction grating. They will learn the relationships between wavelength, frequency, and energy and how to convert between any of these characterizations of a particular color of light. Background information includes general information on the electromagnetic spectrum and the nature of light.

Science and Math Standards

NCTM

- Content Standard 1:
  - Mathematics as problem Solving
  - Structure of Atoms
- Content Standard 2:
  - Mathematics as Communication
- Content Standard 4:
  - Mathematical Connections
- Content Standard 6:
  - Functions

NSES

- Content Standard B:
  - Light, heat, energy and magnetism

Pre-requisites

- **Science Students** should read the background material on the Electromagnetic Spectrum
- **Math Students** should have a basic understanding of algebra and should have read the background material on the Electromagnetic Spectrum

Introduction

Light can be described in many ways, by its energy, its wavelength, or its frequency. All three terms are equally important, and all are interrelated. Each color in the spectrum, for example red, has a distinct energy, but also has a specific wavelength and frequency. The convention is that infrared light and visible light (the rainbow of colors our eyes can see) are usually described by wavelength, radio waves in terms of frequency, and high-energy X-rays and gamma-rays in terms of energy. This scientific convention allows the use of the units that are the most convenient for that energy of light. For example, it would be inconvenient to describe both low-energy radio waves and high-energy gamma rays with the same units because the difference between their energies is so great. A radio wave can have an energy on the order of 4×10^{-10} eV, as opposed to 4×10^{9} eV for gamma rays. That's an energy difference of 10^{19}, or ten million trillion, eV!

Engagement

Using the overhead projector, prism, diffraction grating, and two sheets of cardboard, the students will set up the apparatus as illustrated below to project the spectrum of white light on a screen. Students will then pose questions about what they are observing, and what they are going to do to answer these questions.

Using an Overhead Projector to Project a Spectrum

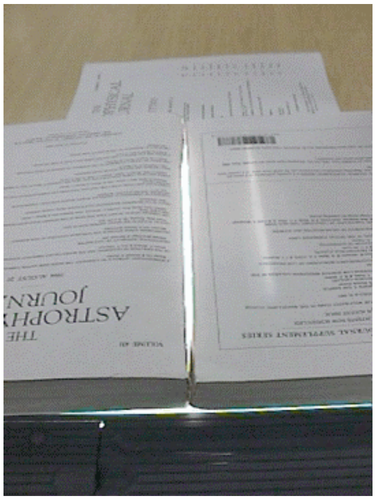
We (and two of our teacher interns) have tried this recently. We had very good success with the overhead projector method of generating a good, large spectrum. This idea was originally published by Dr. Philip M. Sadler in the article "Projecting Spectra for Classroom Investigations," The Physics Teacher, 29(7), 1991, pp. 423-427.

You will need:

- an overhead projector and a source of power
- two or three books or pieces of 8×10 dark construction paper
- diffraction grating - (a film with thousands of microscopic grooves per inch that break up white light) - this is available from Edmund Scientific. Use one about the size of a 35mm slide.
- white wall or screen

1. To make a visible light spectrum, plug in the projector, and turn on the lamp. Set up the projector so it is projecting at a white screen or wall.

Set-up for the experiment, including the overhead, books to create a slit of light, and the diffraction grating (at top of overhead)



Close-up of creating the slit of light from the overhead.

2. Use books on the base plate of the projector to completely block all but a single slit of light no larger than an 1" wide from being projected on the screen. Focus the projector.
3. Place a diffraction grating over the lens at the top of the "projection stack". Rotate the grating (if necessary) until the spectrum appears on both sides of the projected slit on the wall or screen.
4. Turn off the lights, lower blinds, whatever you can do to make the room dark. You should now have a nice spectrum projected onto the screen/wall.

The image on the screen shows the central white band of light coming from the projector, plus a spectrum on both sides.

Close-up showing the placement of the diffraction grating on the overhead lens.

Exploration

Print out the "Student Worksheet: Calculation Investigation" for the class. Have the students complete it.

Evaluation

Formative assessment and observation should be evident throughout the lesson. The worksheet, final questions during closure or a future quiz may serve as summative assessment.

Closure

If students have been keeping a lab journal, direct students to write for ten minutes in their journals summarizing the lab and all procedures in this lesson. Encourage students to then share their findings and what they might have written in their journals. Otherwise, have students create a lab report for this lesson, summarizing their findings. The format of the lab report would then be up to the teacher.

Extension

Using a supply of diffraction gratings, students can make their own spectroscope (either making "spectroscope glasses" using two gratings or a "spectroscope telescope" using one grating and a hollow tube). Students can then look at different light sources. (Caution students that they should not look a the Sun!)

Student Worksheet:
Calculation Investigation

You are given the following two equations that express the relationships between the speed, the wavelength, the energy and the frequency of light:

$$c = \lambda\nu$$

speed = wavelength × frequency

$$E = h\nu$$

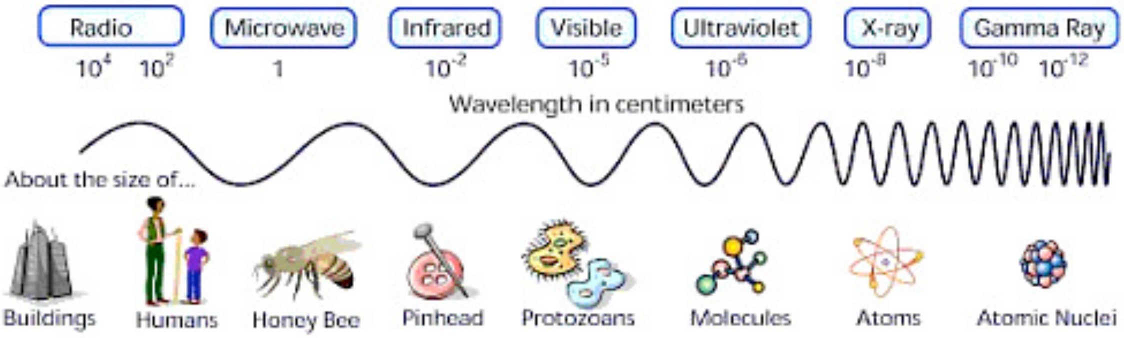
energy = Planck's constant × frequency

Where $h=6.626 \times 10^{-34}\ \mathrm{m^2\ kg/s}$.

Answer This!

1. Check the equations above and show that the units match on each side of the equations.
2. Manipulate both equations to solve for energy (E) as a function of wavelength (l) and fundamental constants. Show each step. Show that the units match on each side of the resulting equations.
3. Given a photon's wavelength, frequency or energy in the chart below, use the above equations to solve for the other two (in the units indicated). Use the useful constants below if you need to. Use the chart of the electromagnetic spectrum (below the table) to fill in the part of the electromagnetic radiation range for each row.

Wavelength (m)	Frequency (Hz)	Energy (J)	Electromagnetic Radiation Range
0.001			
	7.0×10^{13}		
5.0×10^{-7}			
		2.0×10^{-15}	
	1.2×10^{22}		



Thought Questions

In three minutes, summarize what you have learned about light and the relationship between its energy, frequency and wavelength. Write an unanswered question you still have.

KEY

Solution: Student Worksheet
EM Spectrum - A Calculation Investigation

You are given the following two equations that express the relationships between the speed, the wavelength, the energy and the frequency of light:

$$c = \lambda \nu$$

speed = wavelength × frequency

$$E = h\nu$$

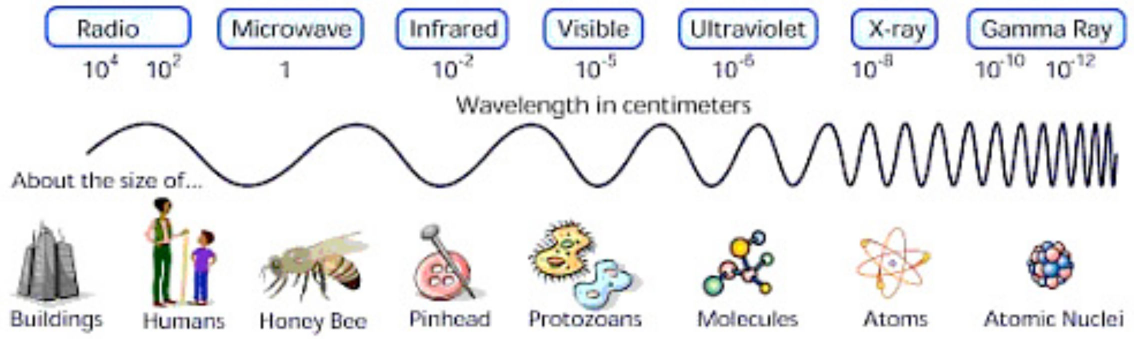
energy = Planck's constant × frequency

Where $h = 6.626 \times 10^{-34}\ m^2\ kg/s$.

Answer This!

4. Check the equations above and show that the units match on each side of the equations.
5. Manipulate both equations to solve for energy (E) as a function of wavelength (l) and fundamental constants. Show each step. Show that the units match on each side of the resulting equations.
6. Given a photon's wavelength, frequency or energy in the chart below, use the above equations to solve for the other two (in the units indicated). Use the useful constants below if you need to. Use the chart of the electromagnetic spectrum (below the table) to fill in the part of the electromagnetic radiation range for each row.

Wavelength (m)	Frequency (Hz)	Energy (J)	Electromagnetic Radiation Range
0.001	3.0×10^{11}	2.0×10^{-22}	microwave
4.3×10^{-6}	7.0×10^{13}	4.6×10^{-20}	infrared
5.0×10^{-7}	6.0×10^{14}	4.0×10^{-19}	visible
1.0×10^{-10}	3.0×10^{18}	2.0×10^{-15}	X-ray
2.5×10^{-14}	1.2×10^{22}	8.0×10^{-12}	gamma ray



Thought Questions

Students should note the inverse relationship between wavelength and frequency: as wavelength increases, frequency decreases or as wavelength decreases, frequency increases. They should note a similar inverse relationship between wavelength and energy. Students should also note the linear, correlated relationship between frequency and energy: as frequency increases, energy increases.

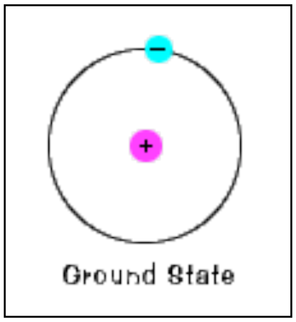
Students might also compare the size of the wavelength of various waves to the sizes of common objects, as illustrated in the above figure. They might also note how small the energies are.

Atoms and Light Energy

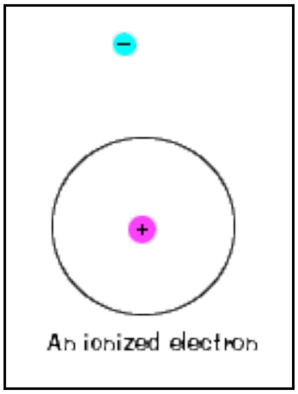
The study of atoms and their characteristics overlap several different sciences. Chemists, Physicists, and Astronomers all must understand the microscopic scale at which much of the Universe functions in order to see the "bigger picture."

Inside the Atom

Just like bricks are the building blocks of a home, atoms are the building blocks of matter. Matter is anything that has mass and takes up space (volume). All matter is made up of atoms. The atom has a nucleus, which contains particles of positive charge (protons) and particles of neutral charge (neutrons). Surrounding the nucleus of an atom are shells of electrons - small negatively charged particles. These shells are actually different energy levels and within the energy levels, the electrons orbit the nucleus of the atom.

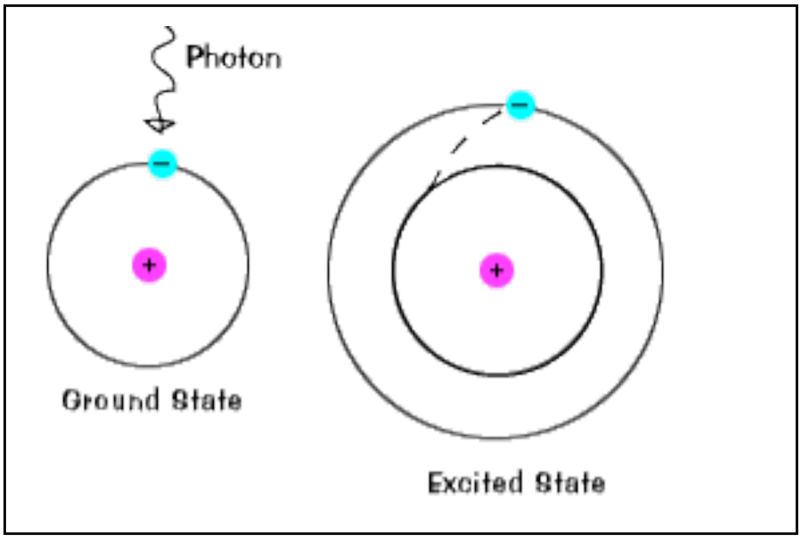


The ground state of an electron, the energy level it normally occupies, is the state of lowest energy for that electron.

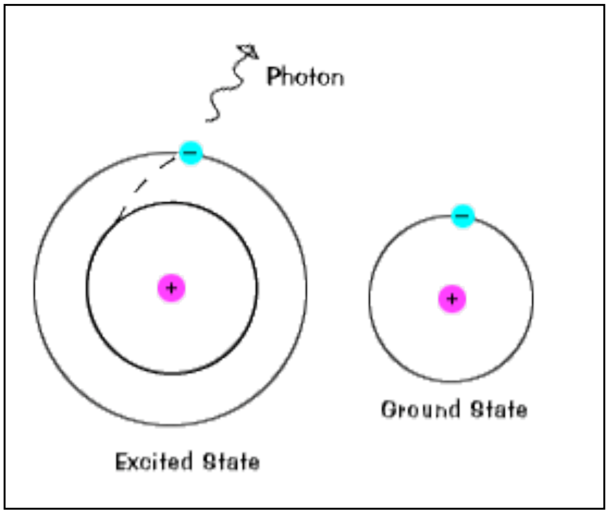


There is also a maximum energy that each electron can have and still be part of its atom. Beyond that energy, the electron is no longer bound to the nucleus of the atom and it is ionized.

When an electron temporarily occupies an energy state greater than its ground state, it is in an excited state. An electron can become excited if it is given extra energy, such as if it absorbs a photon, or packet of light, or collides with a nearby atom or particle.



Light Energy



Each orbital has a specific energy associated with it. For an electron to be boosted to an orbital with a higher energy, it must overcome the difference in energy between the orbital it is in, and the orbital to which is is going. This means that it must absorb a photon that contains precisely that amount of energy, or take exactly that amount of energy from another particle in a collision.

The illustrations on this page are simplified versions of real atoms, of course. Real atoms, even relatively simple ones like hydrogen, have many different orbitals, and so there are many possible energies with different initial and final states. When an atom is in an excited state, the electron can drop all the way to the ground state in one go, or stop on the way in an intermediate level.

Electrons do not stay in excited states for very long – they soon return to their ground states, emitting a photon with the same energy as the one that was absorbed.

Identifying Individual Types of Atoms

Transitions among the various orbitals are unique for each element because the protons and neutrons in the nucleus uniquely determine the energy levels. We know that different elements have different numbers of protons and neutrons in their nuclei. When the electrons of a certain atom return to lower orbitals from excited states, the photons they emit have energies that are characteristic of that kind of atom. This gives each element a unique fingerprint, making it possible to identify the elements present in a container of gas, or even a star.

We can use tools like the periodic table of elements to figure out exactly how many protons, and thus electrons, an atom has. First of all, we know that for an atom to have a neutral charge, it must have the same number of protons and electrons. If an atom loses or gains electrons, it becomes ionized, or charged. The periodic table will give us the atomic number of an element. The atomic number tells us how many protons an atom has. For example, hydrogen has an atomic number of one - which means it has one proton, and thus one electron - and actually has no neutrons.

For the Student

Based on the previous description of the atom, draw a model of the hydrogen atom. The "standard" model of an atom is known as the Bohr model.

Different forms of the same chemical element that differ only by the number of neutrons in their nucleus are called isotopes. Most elements have more than one naturally occurring isotope. Many more isotopes have been produced in nuclear reactors and scientific laboratories. Isotopes usually aren't very stable, and they tend to undergo radioactive decay until something that is more stable is formed. You may be familiar with the element uranium - it has several unstable isotopes, U-235 being one of the most commonly known. The "235" means that this form of uranium has 235 neutrons and protons combined. If we looked up uranium's atomic number, and subtracted that from 235, we could calculate the number of neutrons that isotope has.

Here's another example - carbon usually occurs in the form of C-12 (carbon-12), that is, 6 protons and 6 neutrons, though one isotope is C-13, with 6 protons and 7 neutrons.

For the Student

Use the periodic table and the names of the elements given below to figure out how many protons, neutrons and electrons they have. Draw a model of an atom of the following element: silicon-28, magnesium-24, sulphur-32, oxygen-16, and helium-4.

For the Student

Using the text, define the following terms: energy levels, absorption, emission, excited state, ground state, ionization, atom, element, atomic mass, atomic number, isotope.

A Optional Note on the Quantum Mechanical Nature of Atoms

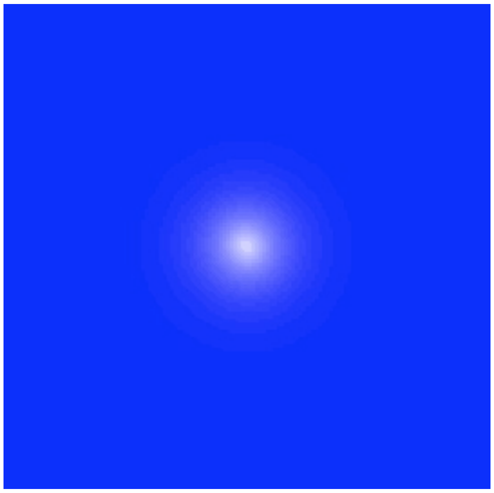
While the Bohr atom described above is a nice way to learn about the structure of atoms, it is not the most accurate way to model them.

Although each orbital does have a precise energy, the electron is now envisioned as being smeared out in an "electron cloud" surrounding the nucleus. It is common to speak of the mean distance to the cloud as the radius of the electron's orbit. So just remember, we'll keep the words "orbit" and "orbital", though we are now using them to describe not a flat orbital plane, but a region where an electron has a probability of being.

Electrons are kept near the nucleus by the electric attraction between the nucleus and the electrons. Kept there in the same way that the nine planets stay near the Sun instead of roaming the galaxy. Unlike the solar system, where all the planets' orbits are on the same plane, electrons orbits are more three-dimensional. Each energy level on an atom has a different shape. There are mathematical equations, which will tell you the probability of the electron's location within that orbit.

Let's consider the hydrogen atom, which we already drew a Bohr model of.

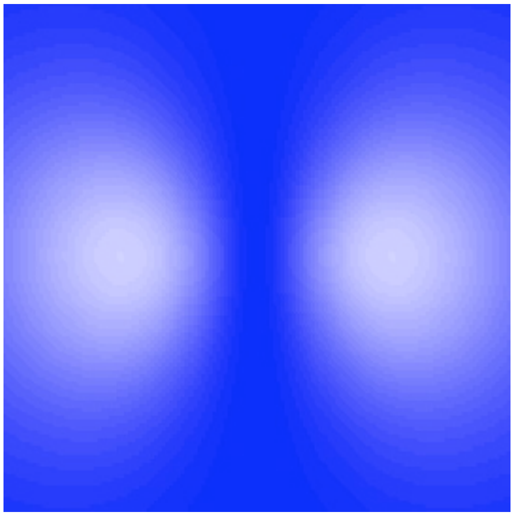
What you're looking at in these pictures are graphs of the probability of the electron's location. The nucleus is at the center of each of these graphs, and where the graph is lightest is where the electron is most likely to lie. What you see here is sort of a cross section. That is, you have to imagine the picture rotated around the vertical axis. So the region inhabited by this electron looks like a disk, but it should actually be a sphere. This graph is for an electron in its lowest possible energy state, or "ground state."



Probable locations of the electron in the ground state of the Hydrogen atom.

To the right is an excited state of hydrogen.

Notice that at the center, where the nucleus is, the picture is dark, indicating that the electron is unlikely to be there. The two light regions, where the electron is most likely to be found, are really just one region. Remember, you have to mentally rotate this around a vertical axis, so that in three dimensions the light region is really doughnut shaped.
The text and images in this section were adapted from Dave Slaven's page on The Atom (see References below).



Probable locations of the electron in an excited state of hydrogen.

Reference URLs:

The Atom

http://webs.morningside.edu/slaven/Physics/atom/

Spectra
http://www.colorado.edu/physics/PhysicsInitiative/Physics2000/quantumzone/

The Periodic Table
http://www.webelements.com/

Activity: Calculate the Energy!

Days Needed: less than 1
Grade level: 9 – 12

Objective

Students will review what has been learned so far about the basic structure of an atom. Students will then calculate the energy differences in different energy states of the Bohr atom of Hydrogen. They will then compare these energy levels with observed Hydrogen lines in a laboratory spectrum.

Science and Math Standards

NCTM

- Content Standard 2
  - Mathematics as Communications
- Content Standard 4
  - Mathematics as Connections

NSES

- Content Standard A
  - Evidence, models, and explanation
- Content Standard C
  - Structure of atoms

Prerequisites

- **Math Students** should be familiar with basic algebra.
- **Science Students** should understand the structure of atoms and the relationship between energy and light, and how atoms emit light.
- Students should have read the background sections on the Properties of Light and Atoms and Light Energy.

Introduction

We can use tools like the periodic table of elements to figure out exactly how many protons, neutrons, and electrons at atom has. Understanding the structure and function of an atom is very important in understanding spectroscopy. Spectroscopy is one of the most useful tools for unlocking the mysteries of supernovae and their remnants.

Engagement

Edible Subatomic Particles

Materials needed:

- large plastic easter eggs, enough for one per student, or one per group
- gumballs or m&ms of two different colors

- tic tacs
- ping pong balls (same amount as easter eggs)

A large plastic egg (atom) is given, one per person – each egg contains a split ping-pong ball (nucleus) with a set number of either gumballs or M&M-type candies (neutrons and protons) inside. Be sure to use different colors for protons and neutrons. Put smaller hard candy (like tic tacs, for instance) in the egg, but so they can move freely around the ping-pong ball. They will be the electrons. Make sure there are the same number of protons and electrons (unless you want an ionized atom). You may want to give each student an "atom" of a different "element" by varying the number of sub-atomic particles in each students egg.

Without opening the egg, and using the scientific method, have the students determine the components within: number, size, movement, weight/mass, sound.

Have the students open the eggs – now report on the contents specifically as to number and size only. Can the student deduce what element they have an atom of? Make sure to point out that the electrons are not in perfect orbits around the nucleus. Like real electrons, they form a sort of electron cloud. Now is a good time to bring in information about the quantum mechanical nature of the atom. For example, originally, each electron orbital was pictured as having a specific radius, much like a planetary orbit in the solar system. However, the modern view is not so simple. Though each orbital does have a precise energy, the electron is now envisioned as being smeared out in an "electron cloud" surrounding the nucleus.

Adapted from a lesson plan by Miriam Meade, http://www.iit.edu/~smile/ch9211.html

Exploration

In the background section on "Atoms and Light Energy", the students should have learned that there are many energy states within an atom. The class is now going to calculate the energies differences between some of the different levels the atom. This will tie directly in to the concept of a spectrum.

Print out the "Student Worksheet: Calculate the Energy!" for the class. Have students eat remains of atom while completing on the worksheet.

Evaluation

Students should show calculations of energy levels. These calculations and answers to the questions on the Student Handout, as well as the closure exercise, provide material for assessing the students' understanding of the concept that energy transitions lead to emission of observed light at particular wavelengths.

Closure

Students should write a three-minute paper describing how this exercise explains line emission from atoms such as hydrogen.

Adaptations

Any number of materials could be substituted to create the “atoms”: corn kernels for protons, navy beans for neutrons, alfalfa seeds poppy seeds or cake decorating sprinkles or small beads for electrons, etc. If plastic eggs are out of season, a clear plastic ball that come in two halves (available at craft or fabric stores) can be used.

Students can also weigh the individual constituents before the atom is assembled. They should see that most of the mass of the atom is made up of the protons and neutrons.

Student Worksheet:
Calculate the Energy!

Neils Bohr numbered the energy levels (n) of hydrogen, with level 1 (n=1) being the ground state, level 2 being the first excited state, and so on. Remember that there is a maximum energy that each electron can have and still be part of its atom. Beyond that energy, the electron is no longer bound to the nucleus of the atom and it is ionized. In that case n approaches infinity.

The equation for determining the energy of any state (the nth) is as follows:

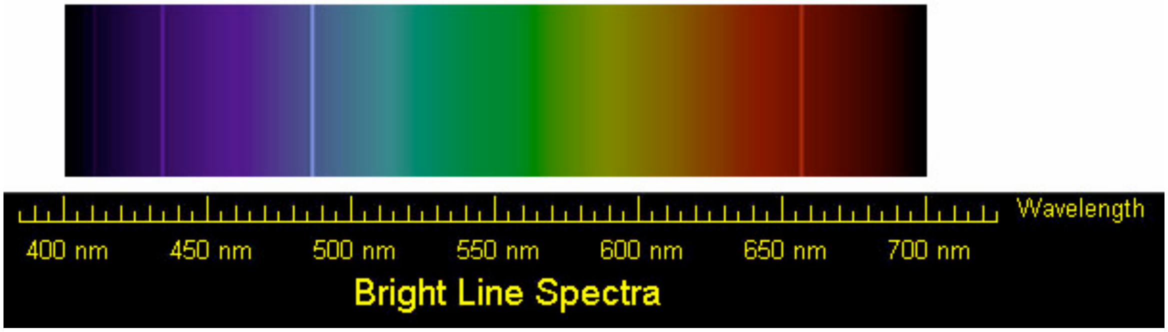
$$E = -13.6/n^2 \text{ eV}$$

Because the energy is so small, the energy is measured in electron-volts, designated as "eV".

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J.}$$

Answer the following questions:

1. Using the above expression, calculate the energy of the first excited state. Your answer will be negative. This signifies that the electron is bound to the atom (as opposed to being a free electron).
2. Use the above expression to find the energy of the photon released when an electron around a hydrogen atom moves from the 4th to the 2nd level.
3. Now use the above expression to find the energy of the photon released when a free electron is captured to the 2nd level.
4. **4.** Use the relationship between a photon's energy and its wavelength to calculate the wavelength of the photon emitted in question 2.
5. **5.** Compare the wavelength for this transition with the lab spectrum of hydrogen below.



Solution: Student Worksheet: Calculate the Energy!

Neils Bohr numbered the energy levels (n) of hydrogen, with level 1 (n=1) being the ground state, level 2 being the first excited state, and so on. Remember that there is a maximum energy that each electron can have and still be part of its atom. Beyond that energy, the electron is no longer bound to the nucleus of the atom and it is ionized. In that case n approaches infinity.

The equation for determining the energy of any state (the nth) is as follows:

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Because the energy is so small, the energy is measured in electron-volts, designated as "eV".

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J.}$$

Answer the following questions:

1. **Using the above expression, calculate the energy of the first excited state. Your answer will be negative. This signifies that the electron is bound to the atom (as opposed to being a free electron).**

   For the first excited state, n=2. Using this in the above equation gives E = -3.40 eV

2. **Use the above expression to find the energy of the photon released when an electron around a hydrogen atom moves from the 4th to the 2nd level.**

   The energy of the photon is found by computing the difference in the energies of the fourth (n=4) and second (n=2) levels

   $$E = -13.6/4^2 - (-13.6/2^2)$$
   $$E = -0.85 + 3.40$$
   $$E = 2.55 \text{ eV}$$

3. **Now use the above expression to find the energy of the photon released when a free electron is captured to the 2nd level.**

   We represent a free electron by assigning it an infinite n. Hence, its energy is zero.

   The energy of the photon emitted by a free electron captured to the n=2 level is thus

   $$E = 0 - (-13.6/22) = 3.4 \text{ eV}$$

4. **Use the relationship between a photon's energy and its wavelength to calculate the wavelength of the photon emitted in question 2.**

   From the Calculation Investigation, we learned that energy and wavelength are related through E = h c / l.

   We can solve this for the wavelength, l = h c / E. where h = 6.626 × 10^{-34}J-s, and c = 3 × 10^{8} m/s

   We convert our energy E= 2.55 eV into Joules using 1 eV = 1.6×10^{-19} J. This gives an energy of E = 4.08 × 10^{-19} J

   We then find a wavelength of
   l = ((6.626 × 10^{-34}) x (3 × 10^{8})) / (4.08 × 10^{-19})
   l = 4.87 × 10^{-7} m

   Or, using 1 nm = 1 × 10^{-9} m,
   l = 487 nm.

5. **Compare the wavelength for this transition with the lab spectrum of hydrogen below.**

   The transition is the bright blue line, just to the left of the center.