X-ray Spectroscopy and the Chemistry of Supernova Remnants

Student Worksheets

- *Calculation Investigation* – Students learn about unit analysis by converting energies to wavelengths to frequencies.
- *Calculate the Energy!* – Students will calculate the energy differences in different energy states of the Bohr atom of Hydrogen.
- *Graphing Spectra, Part 1 and 2* – Practice drawing graphs of spectra, and understanding the different ways spectra can be represented, as well as what each representation can tell us.
- *Flame Test* – A chemistry experiment that shows how heated elements emit different colors of light.
- *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!
- *Identifying Light Energy by Temperature Changes* – Learn first hand how a microcalorimeter really works
- *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.
- *Satellite Venn Diagram* – Students will organize the information about X-ray observatories into a Venn diagram.

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:

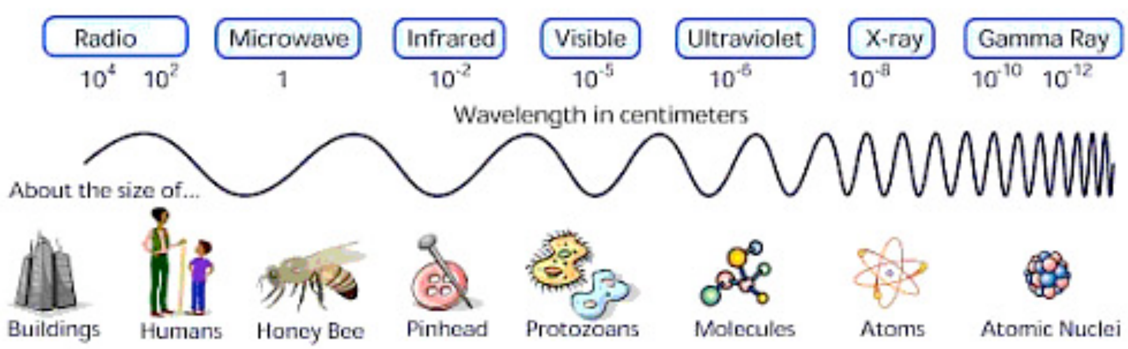
$$c = \lambda\nu$$
speed = wavelength × frequency
$$E = h\nu$$
energy = Planck's constant × frequency

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

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.

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:

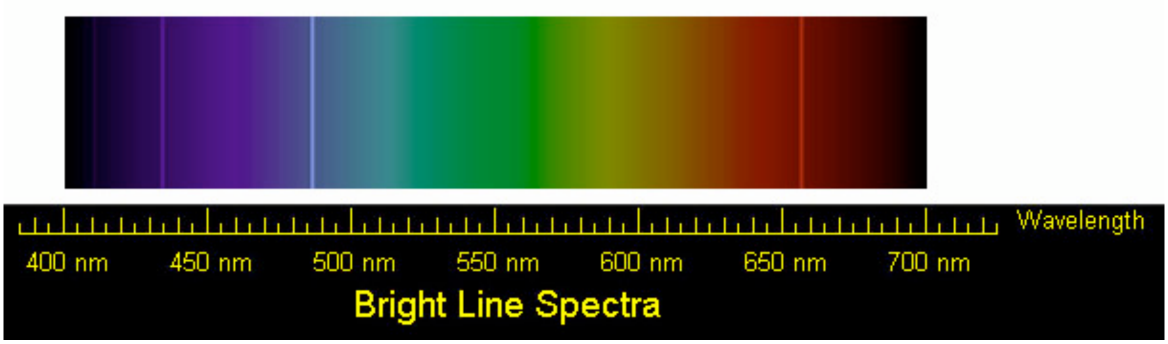
$$E = -13.6/n^2 \text{ eV}$$

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. Use the relationship between a photon's energy and its wavelength to calculate the wavelength of the photon emitted in question 2.
5. Compare the wavelength for this transition with the lab spectrum of hydrogen below.

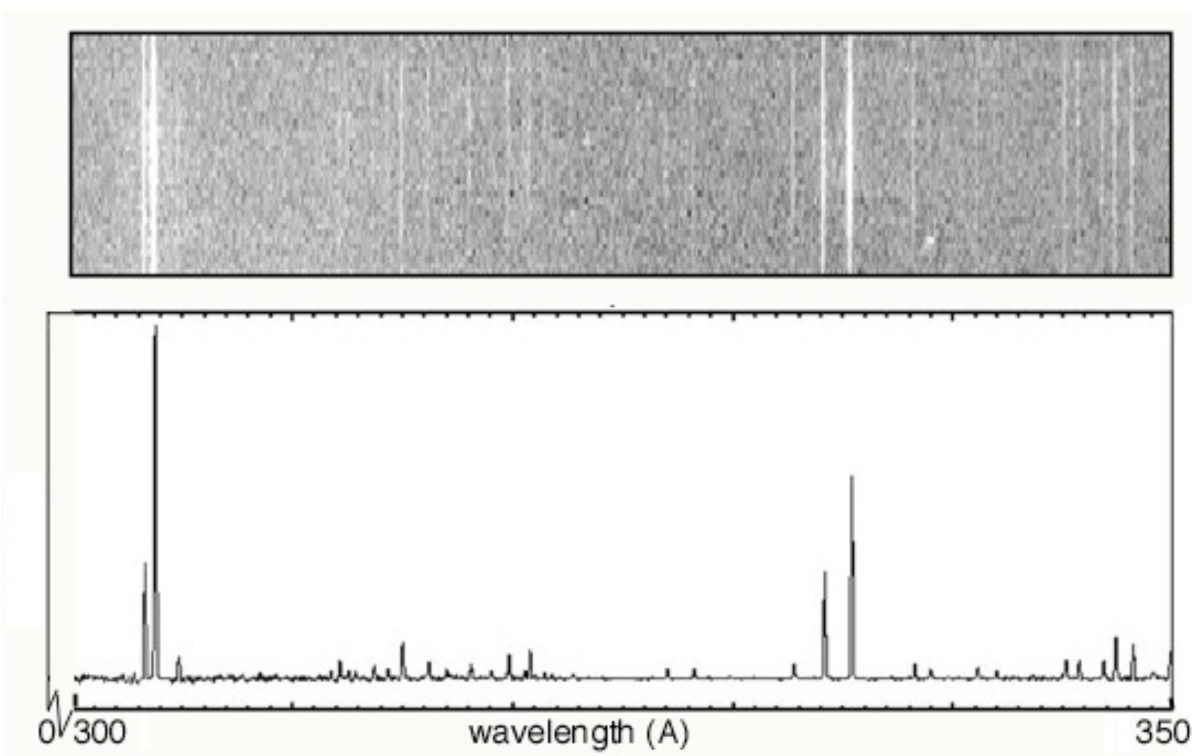


Student Worksheet: Graphing Spectra Part 1

Below are two examples of the same emission spectrum. The first example is without any "quantitative" data, while the second shows light energy as a function of wavelength. The x-axis has the same units (wavelength, in this case, although frequency or energy could also be used) in both cases, and it runs from 300 to 350 Ångstroms. In your group, discuss the following questions, then write individual answers on paper.

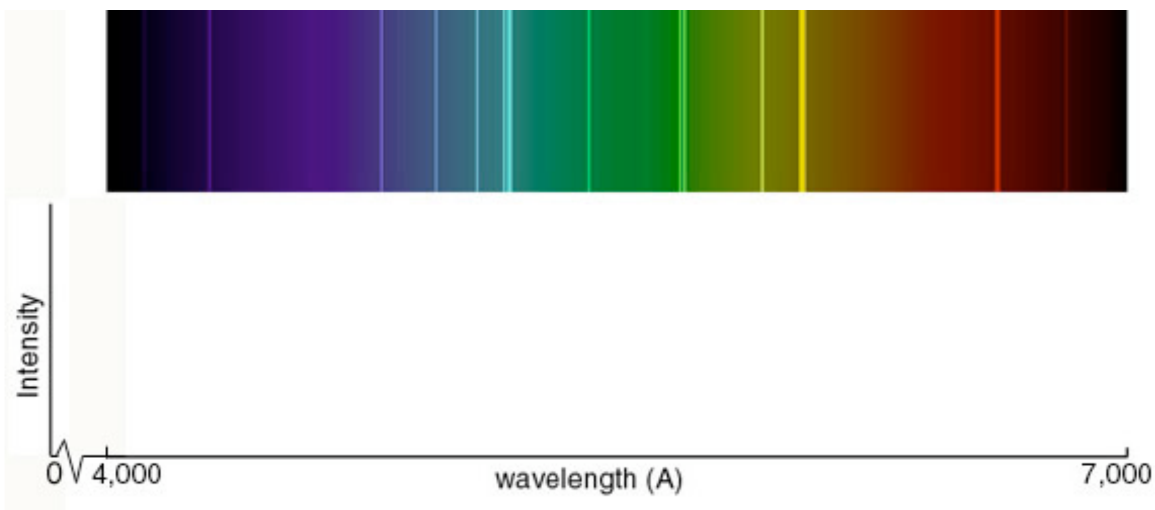
1. As you move along the wavelength axis from 300 Ångstroms to 350 Ångstroms, what will happen to the amount of energy emitted by the source? Explain why.
2. In the second spectrum, explain why the emission lines are at different heights.
3. In order for bottom plot to include more "quantitative" data, what variable should go along the y-axis?
4. How is this variable illustrated in both graphs?
5. Describe how the second spectrum would look if it were a function of energy (instead of wavelength).
6. What types of information are gathered from both spectra?

Solar UV Spectra

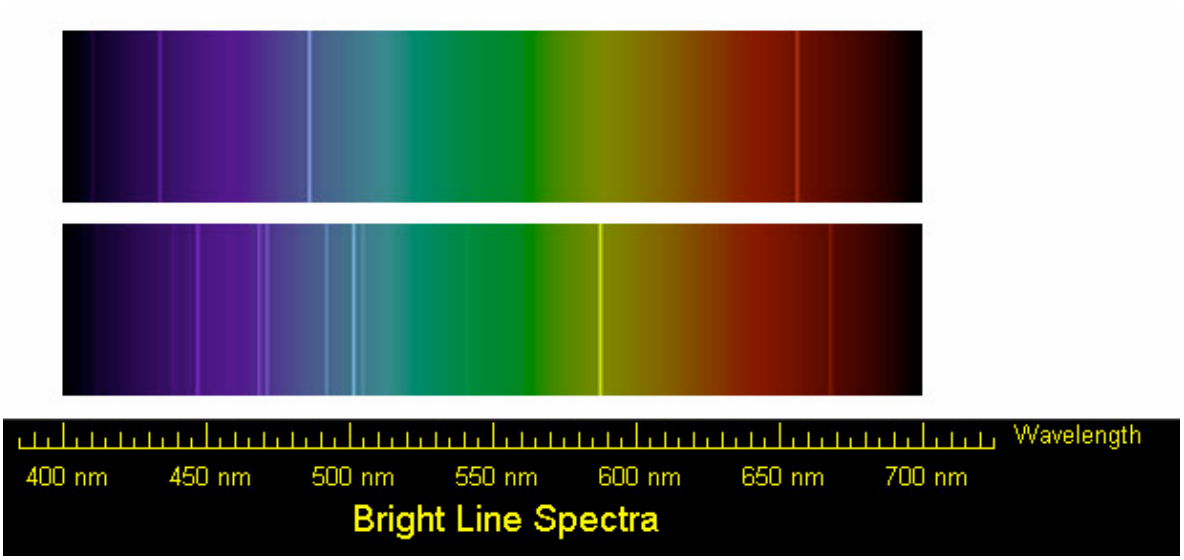


Student Worksheet:
Graphing Spectra Part 2

The following spectrum represents the energy state of the element, carbon. Carbon's emission lines in the visible range are a function of wavelength from 4,000 to 7,000 Ångstroms. You are going to create a graphical representation of carbon's spectrum from the photographic representation. Refer to the example above to help. At the particular wavelengths, illustrate the varying brightness of carbon's emission lines. Notice that in the photographic representation of the spectrum there is an underlying continuum of emission, in addition to the bright spectral lines. This continuum is due to contamination of the spectrum by ambient light, such as small amounts of white light that are picked up by the spectrometer. Your graphical representation should include this low level of emission at all wavelengths as well as carbon's spectral line features.



Below you are given spectra for both hydrogen and helium. For each element, select two of the brightest emission lines at the particular wavelengths and measure the wavelengths. The ruler below indicates the scale of the spectrum. Solve for the frequency and energy of these lines, using the relationships between wavelength and frequency and between frequency and energy. (Hint: You will have to manipulate an equation.) After the flame test, you will complete the same calculations for the following elements: sodium and calcium.



Student Worksheet:
Flame Test

Part I

Procedure

1. Put on lab apron and safety goggles.
2. Add 15 drops of each 0.5M solution to a different clean test tube.
3. To clean the wire, dip it into the test tube of 1M of HCl and heat the wire in the hottest part of the flame until no color shows.
4. When the platinum wire is clean, dip the wire in the test tube containing a 0.5M solution and hold it in the hottest part of the flame. Record your observation of the color of the flame on the data table.
5. Repeat the process of cleaning the platinum wire. Now get ready to test another solution.
6. Test all of the solutions and make sure that you record the color of the flame for each element on the Data Table.
7. Check your flame colors to known results.
8. Fill one clean test tube with 15 drops of one of the 0.5M solutions. The teacher keeps track of what element solution is in this "mystery tube." Repeat the flame test, without telling the students what solution it is. Students must use the information gained from the first part of the experiment to identify the mystery solution.
9. Use the diffraction grating to observe the color of the flame for the following elements: Sodium, Barium, Copper, and Lithium. The students should be able to see the individual lines making up the light from the flame. This can be tricky! In order for it to work, the room will have to be completely dark (in order to block out other light sources) and the students will have to be close to the flame, holding the diffraction grating up to their eyes. It may be necessary to rotate the diffraction grating in order to see the emission lines. Be patient!
10. Record the colors of the elements' emission lines in column three of the Data Table.
11. Before leaving the laboratory, wash your hands thoroughly with soap and water.

Stations	Observed Flame Color	Color of Emission Lines	l (m)	n (Hz)	E (J)
Calcium (0.5M CaCl)					
Sodium (0.5M NaCl)					
Barium (0.5M BaCl)					
Lithium (0.5M LiCl)					
Copper (0.5M CuCl)					
Cesium (0.5MCsCl)					

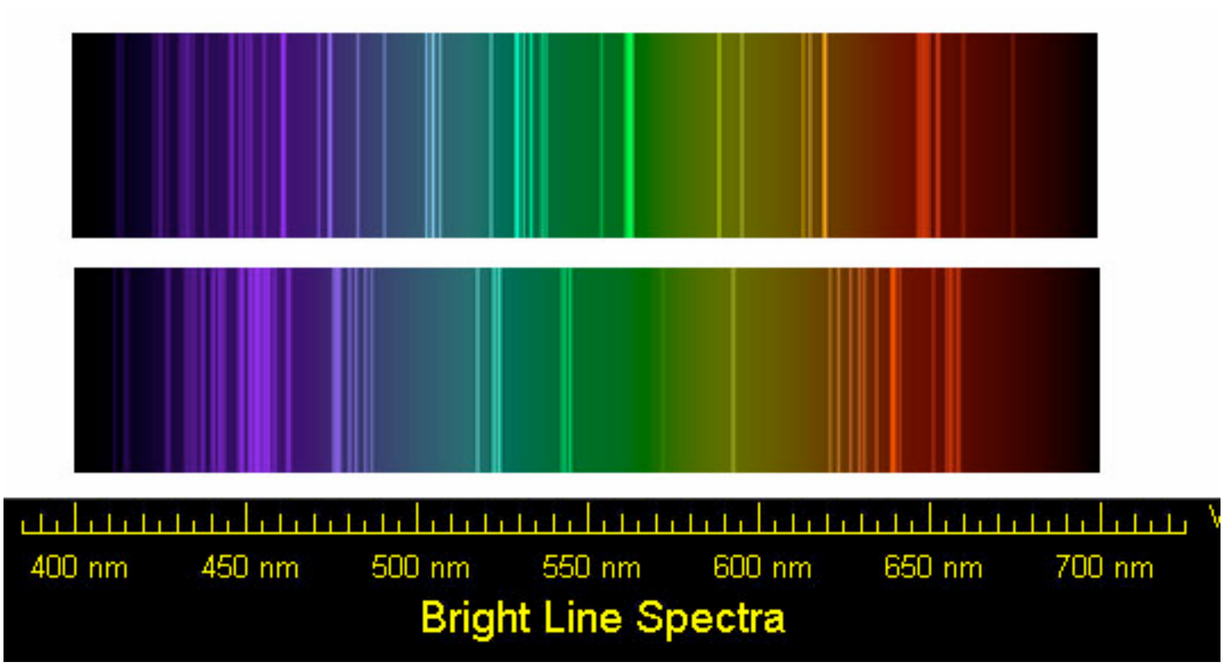
Think About

Discuss the following questions in lab groups. Remember you are trying to determine what is taking place during the Flame Test whereby various colors of light are being emitted. One person in your group will have the responsibility of writing the group answers down. After discussing these questions in the group, another person will be responsible for sharing your thoughts with the whole class. You may refer to background material.

- What particles are found in the chemicals that may be responsible for the production of colored light?
- Why do different chemicals emit different colors of light?
- Why do you think the chemicals have to be heated in the flame first before the colored light is emitted?
- Colorful light emissions are applicable to everyday life. Where else have you observed colorful light emissions. Are these light emission applications related? Explain.
- What is the characteristic flame color for Sodium, Lithium, Barium, Copper, Cesium, and Calcium? Explain why.
- When the diffraction grating was used to view the flame, explain why different colorful emission lines were observed for the elements.

Part II

Use the image below to view the spectra of calcium (top) and sodium (bottom). Solve for frequency and energy of the two brightest emission lines for each element. Use the brightest lines. Show your work and record your answers on the Data Table.



Student Worksheet:

Design an Atom Poster Advertisement

Assignment

Now that you have determined several ways to identify elements, you will be assigned an element to make an advertisement poster on its everyday use. You want to make this poster as appealing as possible for your immediate classmates and school community, so that people will take the time to read and learn about the everyday use of several elements found on the Periodic Table.

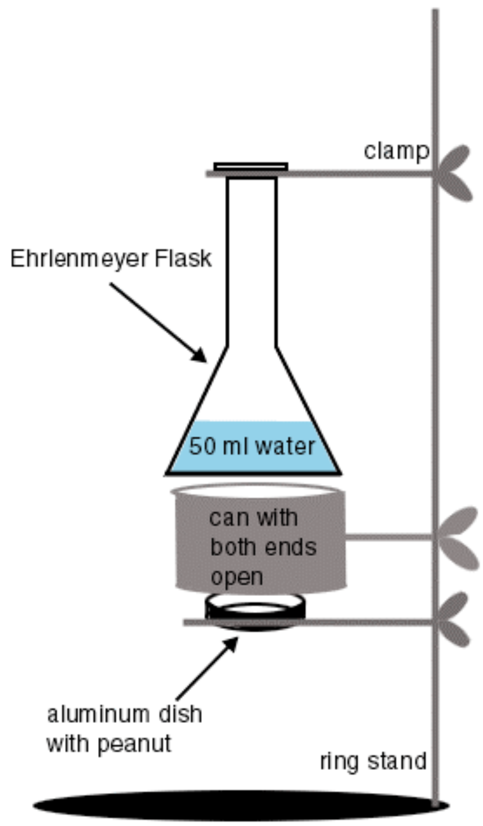
Your poster needs to include the following:

1. a Catchy Title and Atomic Model
2. the Electronic Configuration
3. a Listing of physical and chemical properties of your assigned element (at least two each)
4. a picture of where this element is found and how is it used; in other words, its everyday application; (This picture should either be drawn, taken from the internet, a magazine, or copied from a book).
5. a one-paragraph typed caption for the above picture telling where the element is found and how it is used. Give the element's atomic symbol. This information must be factual and written in your own words. If you choose to do so, your one-paragraph caption can be written as a poem or jingle.

Student Worksheet
Identifying Light Energy by Temperature Changes

Procedure

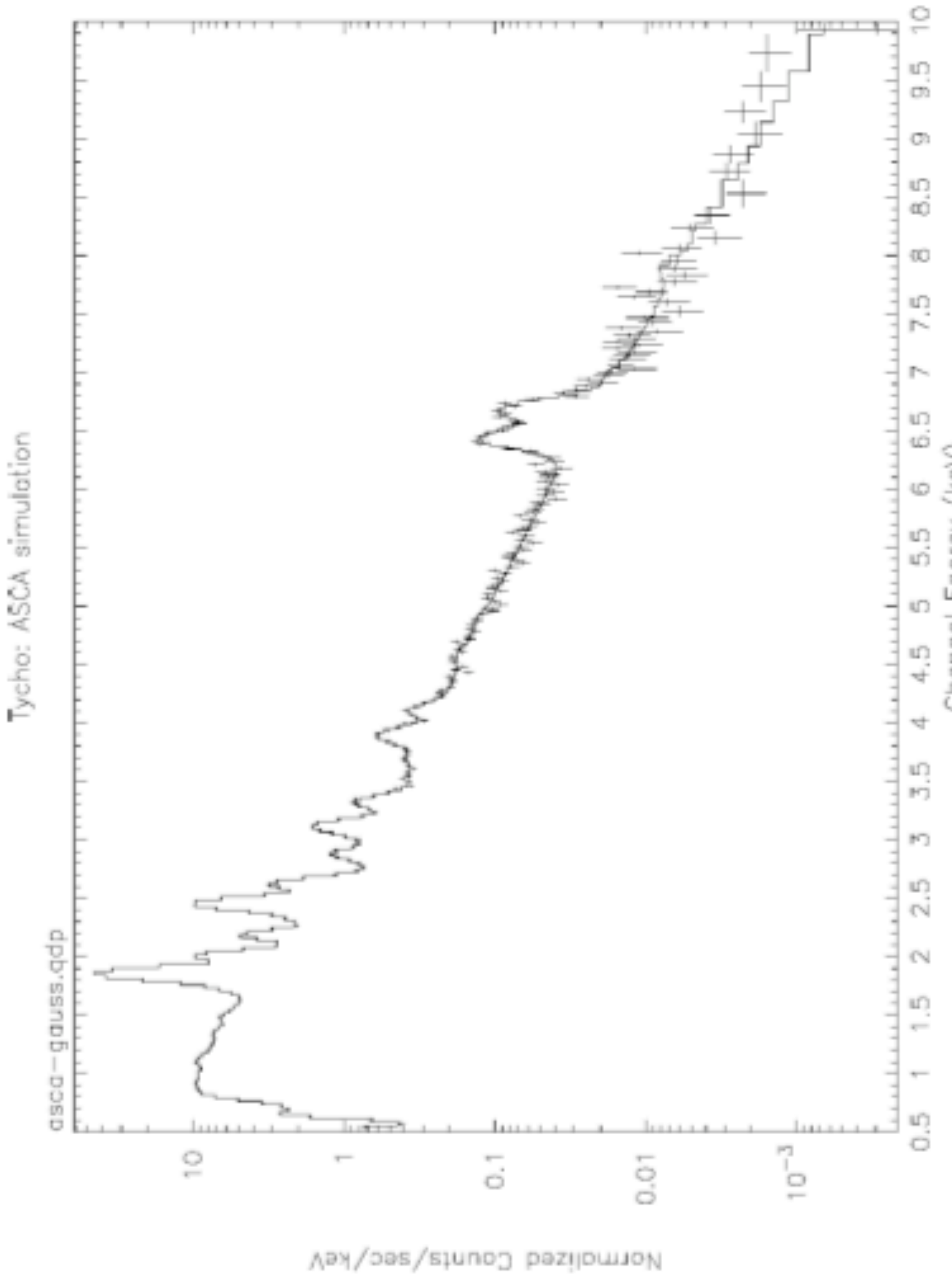
1. As illustrated in the diagram set up your apparatus. Straighten out the paper clip and carefully thread the peanut onto the paper clip. You want to avoid as much as possible cracking the peanut.
2. Measure out 50 ml of water and pour the water into the flask. Determine the mass of 50 ml of water. Record the initial temperature of the water.
3. Place the small aluminum pan with peanut underneath the flask with the water in it. Using a match, light the peanut and allow it to burn. Make sure the apparatus is closely set up so that a large amount of heat is not lost into the air.
4. Record the final temperature of water after the peanut has stopped burning.
5. Answer the Think About questions on paper.



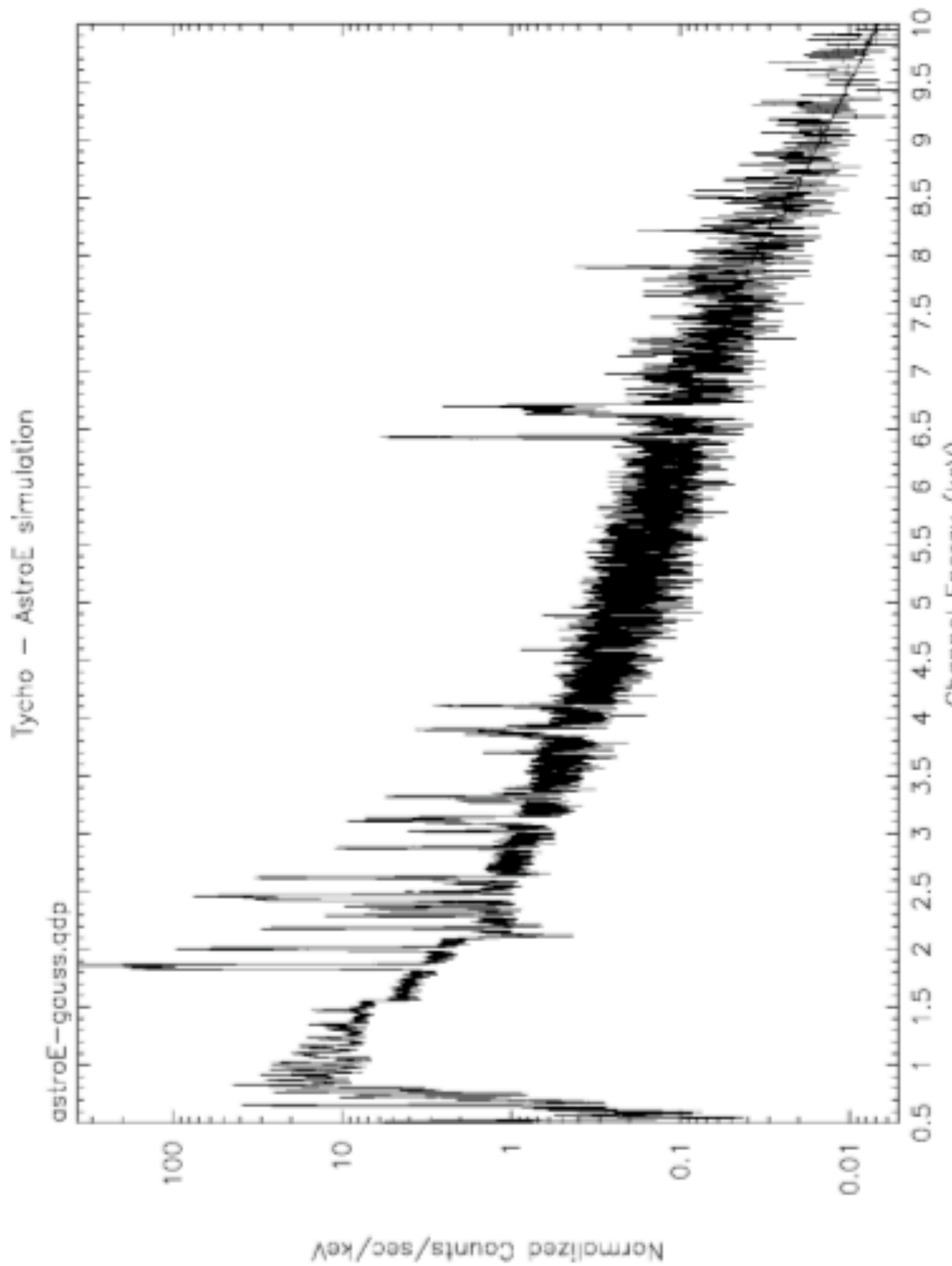
Think About

1. Describe what happened to the final temperature of water and explain why.
2. The energy emitted from the peanut is mostly infrared light (heat). Review the electromagnetic spectrum diagram. What would happen to the temperature of the water if the peanut were to emit the same number of photons but as ultraviolet light? Hint: Compare the energy of infrared and ultraviolet light.
3. Explain how you could use the temperature change of the water to create a spectrum of the light energy released by the burning peanut.
4. Relate this experiment to how a microcalorimeter works.

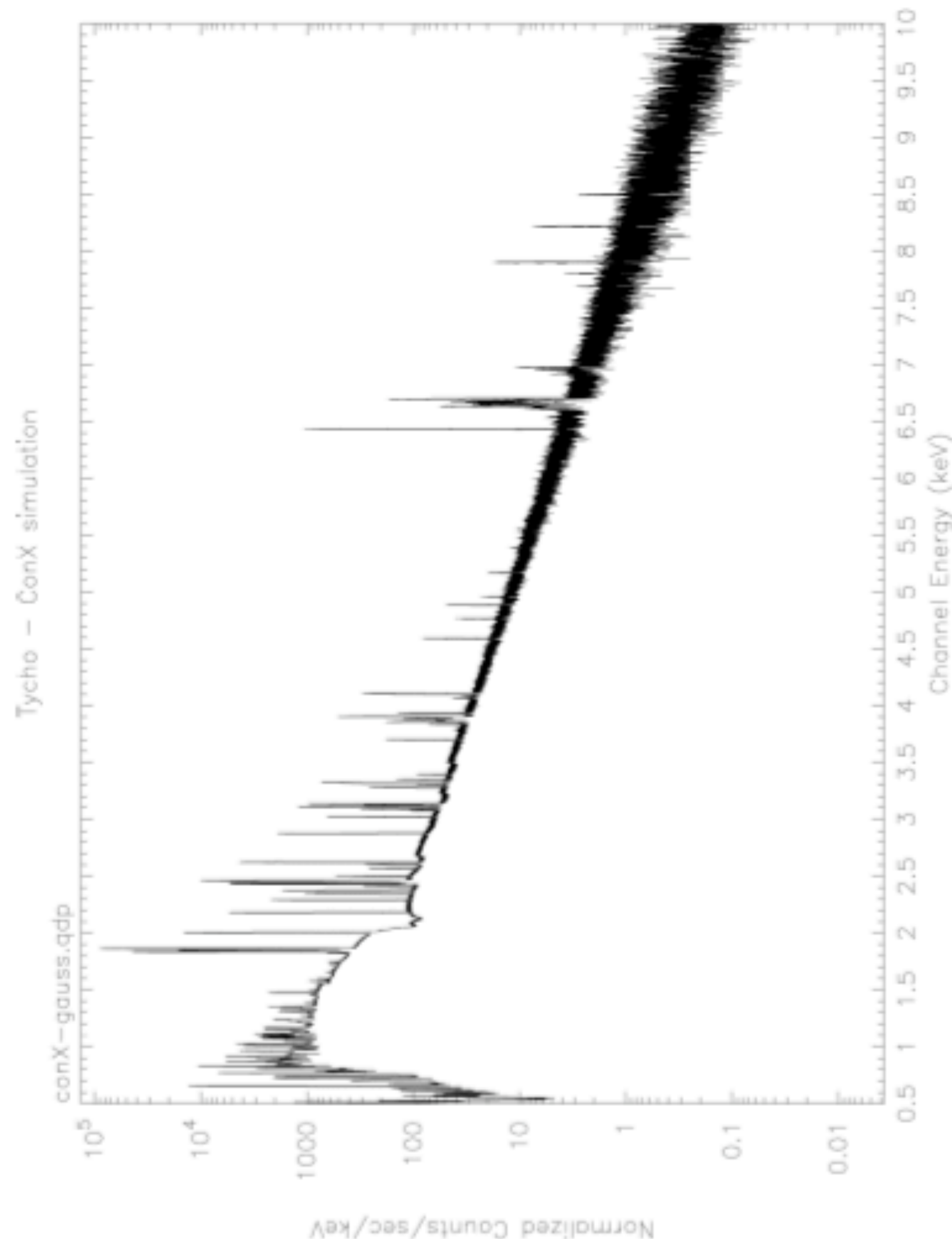
Student Handout:
Identifying Elements in Supernova Remnants
ASCA Simulated Spectrum



Student Handout:
Identifying Elements in Supernova Remnants
Astro-E Simulated Spectrum



Student Handout:
Identifying Elements in Supernova Remnants
Constellation-X Simulated Spectrum



Student Worksheet
Identifying Elements in Supernova Remnants

Procedure

1. Take out the three simulated spectra of the Tycho supernova remnant:
   - Simulated ASCA Spectrum
   - Simulated Astro-E Spectrum
   - Simulated Constellation-X Spectrum
2. Use the X-ray line chart below to identify the elements that correspond to the various peaks of emission seen in the spectra. (You can write directly on the printed spectra).
3. Answer the Think About questions.

Energies of Elemental Spectral Line Features

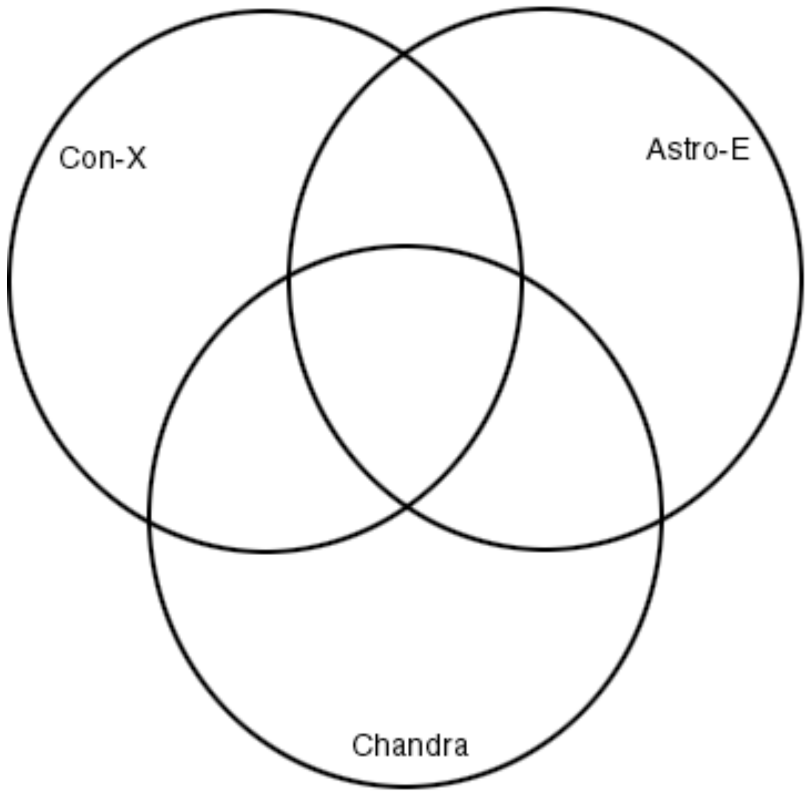
Element	Energy (keV)
O	0.547
O	0.654
Ne	0.922
Ne	1.022
Mg	1.352
Mg	1.471
Si	1.865
Si	2.006
S	2.461
S	2.632
Ar	3.140
Ar	3.323
Ca	3.903
Ca	4.108
Fe	6.701
Fe	6.973

Think About

- Using spectra, how does an astronomer determine the composition of a star or supernova remnant?
- List some differences and similarities in the spectra from the three X-ray observatories (ASCA, Astro-E, and Constellation X).
- Were you able to determine with better accuracy what elements were present in the Astro-E spectra and Con-X spectra as compared to the ASCA spectra? If so, why?

Student Worksheet
Satellite Venn Diagram

Listed below are characteristics of satellites, or descriptions of astronomical sources. After reading the background information on Chandra, Astro-E and the microcalorimeter, and Constellation-X, each listed characteristic should be placed in the appropriate place on a three-ring Venn diagram by their association with the satellites Chandra, Astro-E and/or Constellation-X. Properties of the microcalorimeter may be included as properties of Astro-E. An example of a three ring Venn diagram is shown below. Be sure to label appropriately the Venn diagram.



3-ring Venn Diagram

1. launched in 1999
2. will require several rocket missions to launch the entire observatory
3. consists of four individual satellites
4. perform detailed studies of black holes, supernovas, dark matter, origin, evolution, and destiny of the universe
5. launched in 2000
6. more quantitative data on abundance, velocity, temperature of gas

7. superior ability to discriminate amongst different x-rays wavelengths
8. flies more than 1/3 of the way to the moon
9. an array of 32 individual microcalorimeters
10. exquisitely shaped for pairs of mirrors
11. incorporates a three stage cooling system capable of operating the array at 60 mK for about two years
12. will be placed 1.5 million miles from Earth
13. images are 25-times sharper than previous x-ray telescopes
14. designed to study the universe in x-rays
15. detects broadest range of X-ray wavelengths
16. focusing power equivalent to the ability to read a newspaper a half a mile away
17. focus on smaller areas which will exclude picking up signals from external medium of hot gas
18. X-ray telescopes are one way to observe extremely hot matter with temperature of millions of degrees
19. data collected in hours instead days
20. observatory must be placed high above Earth's surface because Earth's atmosphere absorbs X-rays
21. deployment of observatory commanded by woman
22. 10-times higher spectral resolution for detecting emission from Iron
23. collecting areas 3 square meters which will detect x-ray sources 100-times fainter
24. a high resolution X-ray spectrometer based on a microcalorimeter array, four CCD X-ray cameras, and a hard X-ray telescope
25. detects and images X-ray sources billions of light years away

Thought Questions

In five minutes, write a summary of the capabilities of the three observatories, based on the Venn diagram. Do the observatories compliment each other? Where are they redundant?