ehp

LESSON:

X-Rays Get in Synch

Summary: Students review the X-ray region of the electromagnetic spectrum, then explain how X-rays are used to obtain chemical and microbiological information via X-ray spectromicroscopy. Then they identify an environmental health issue and generate ideas about how X-ray spectromicroscopy could be used to advance understanding of that issue.

***EHP* Article:** "X-Rays Get in Synch"
EHP Student Edition, April 2006, p. A26
http://ehp.niehs.nih.gov/docs/2006/114-1/forum.html#xray

Objectives: By the end of this lesson, students should be able to

1. define energy;
2. define X-rays;
3. list the energy range of X-rays and identify the "soft" X-ray energy range;
4. compare the energy range of X-rays to other regions of the electromagnetic spectrum;
5. convert between SI (International System) units of electronvolts (e.g., mega- to femto-);
6. summarize how X-ray spectroscopy works;
7. differentiate between spectroscopy, microscopy, and spectromicroscopy; and
8. provide an example of how X-ray spectromicroscopy could be used to advance environmental health research.

Class Time: 1–1.5 hours, depending on the extent of review needed

Grade Level: 11–12

Subjects Addressed: Chemistry, Physics/Physical Science, Environmental Health, Biology, Microbiology

Prepping the Lesson (15 minutes)

INSTRUCTIONS:

1. Download the entire April 2006 *EHP Student Edition* at http://www.ehponline.org/science-ed/, or download just the article "X-Rays Get in Synch" at http://ehp.niehs.nih.gov/docs/2006/114-1/forum.html#xray.
2. Review the article, Background Information, and Student Instructions.
3. You may need to provide additional information on the electromagnetic spectrum, depending on the students' current background knowledge. However, students could successfully do the lesson without extensive background knowledge.
4. Make copies of the Student Instructions (including tables 1 and 2 on pages 9 and 10) and the article.

MATERIALS (per student):

- 1 copy of *EHP Student Edition*, April 2006
- 1 copy of the Student Instructions, including Table 1 and Table 2

VOCABULARY:

- electromagnetic spectrum
- electronvolts
- electrons
- energy
- femto-
- kilo-
- mega-
- micro-
- microscopy
- milli-

- nano-
- orbitals
- pico-
- “soft” X-rays
- spectromicroscopy
- spectroscopy
- spectrum
- synchrotron radiation
- synchrotrons

BACKGROUND INFORMATION:

Synchrotron radiation is a form of electromagnetic radiation that spans the entire range of electromagnetic energies. Synchrotron radiation is often referred to as “light,” but this is simply a reference to the electromagnetic spectrum, which includes visible light and the nonvisible forms of light such as X-rays.

Synchrotron radiation is generated by synchrotrons, or huge particle accelerators, where electrons or positrons are accelerated to nearly the speed of light and then forced to change direction by a magnetic field. Synchrotron radiation produces a continuous spectrum (i.e., no bumps and wiggles from energy levels) and is easily controlled in the laboratory. This makes it very useful for many of the new chemistry and microbiology research tools such as X-ray spectromicroscopy.

Although X-ray spectromicroscopy depends on the use of synchrotron radiation in the X-ray energy range, this lesson does not explicitly discuss synchrotron radiation. Instead, the lesson refers to the more familiar electromagnetic radiation and encourages students to think about all of these processes in terms of energy. Thus, spectroscopy is simply bombarding a sample with energy, which is absorbed in a way that is unique to that sample (absorption spectrum), and then released in a way that is unique to that sample (emission spectrum). The spectrum is the intensity as a function of energy. Every element and chemical compound has its own unique signature, which allows us to identify its presence in the sample.

Spectromicroscopy is the combination of spectroscopy (the generation of a spectrum) and microscopy (making an image of something that is too small to see with the naked eye). A spectromicroscopy image is generated by color-coding regions that produce similar or different spectra. You can think of it as a chemical contour map.

RESOURCES:

Environmental Health Perspectives, Environews by Topic page, http://ehp.niehs.nih.gov. Choose Radiation/Radioactivity

Australian Synchrotron, Synchrotron science: what is synchrotron light? http://www.synchrotron.vic.gov.au/content.asp?Document_ID=96

Brookhaven National Laboratory, Scientists describe new way to peer inside bacteria: X-rays yield pictures and chemical clues that may help trace contaminants, thwart terrorists, http://www.bnl.gov/bnlweb/pubaf/pr/PR_display.asp?prID=05-77

Dictionary.com, “-scopy” and “microscopy” definitions, http://dictionary.reference.com

How Stuff Works, How the flu works, http://health.howstuffworks.com/flu4.htm

Koprinarov I, Hitchcock AP. X-ray spectromicroscopy of polymers: an introduction for the non-specialist, http://unicorn.mcmaster.ca/stxm-intro/polySTXMintro-all.html

Nova: Science in the News, Synchrotrons: making the light fantastic http://www.science.org.au/nova/068/068key.htm

Wikipedia, Electromagnetic spectrum, http://en.wikipedia.org/wiki/Electromagnetic_spectrum

Implementing the Lesson

INSTRUCTIONS:

1. Hand out the Student Instructions and the accompanying tables.
2. Have the students complete Step 1 individually, in groups, or as a class. How you approach Step 1 may depend on how much the students already know about X-rays, the electromagnetic spectrum, and converting SI units (e.g., mega- to femto-).
3. Hand out the article “X-Rays Get in Synch” and instruct the students to complete Steps 2–5.
4. Have students share their ideas in Step 5 with the class.

NOTES & HELPFUL HINTS:

- Although synchrotron radiation is mentioned in the article and lesson, students do not need to fully understand what it is to complete the lesson. It is more important that students understand the X-ray energy range and how energy interacts with matter to generate the spectra and images produced by X-ray spectromicroscopy.
- This lesson would complement a unit on imaging, spectra, or the electromagnetic spectrum.

- Step 5 asks students to select an article from the April 2006 *EHP Student Edition*, summarize the environmental health issue in the article, and share an idea about how synchrotron X-ray technology could advance understanding of that issue. Instead of handing out the whole April 2006 *EHP Student Edition*, you could choose a single article and have everyone work with the same environmental health issue.

Aligning with Standards

SKILLS USED OR DEVELOPED:
- Classification
- Communication (written—including summarization)
- Comprehension (listening, reading)
- Computation
- Critical thinking and response
- Graph reading
- Tables and figures (creating, reading)
- Technological design
- Unit conversion

SPECIFIC CONTENT ADDRESSED:
- Atoms
- Electromagnetic spectrum
- Electrons
- Energy
- Spectrum
- Spectroscopy
- Microscopy
- Spectromicroscopy
- X-ray
- Imaging
- Technology
- Environmental health

NATIONAL SCIENCE EDUCATION STANDARDS MET:

Science Content Standards

Unifying Concepts and Processes Standard
- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement

Science As Inquiry Standard
- Understanding about scientific inquiry

Physical Science Standard
- Structure of atoms
- Structure and properties of matter
- Interactions of energy and matter

Life Science Standard
- The cell
- Matter, energy, and organization in living systems

Science and Technology Standard
- Abilities of technical design
- Understanding about science and technology

Science in Personal and Social Perspectives Standard
- Science and technology in local, national, and global challenges

Assessing the Lesson

Step 1: Table key below.

Name of Electromagnetic Energy Band	1. Energy Range (MeV–feV)	2. Energy Range (converted to eV)	3. Higher- or Lower-Energy Compared to X-Rays
gamma	1.24 MeV–124 keV	1,240,000–124,000 eV	Higher
"hard" X-rays	124–12.4 keV	124,000–12,400 eV	—
"soft" X-rays	12.4 keV–124 eV	12,400 eV–124 eV	—
visible light	3.1–1.65 eV	3.1–1.65 eV	Lower
infrared light	1.65 eV–1.24 meV	1.65–0.00124 eV	Lower
radio	1.24 meV–124 feV	0.00124–0.000000000000124 eV	Lower

Step 2: a) In general are X-rays high-energy or low-energy? High-energy.

b) Define energy. The ability to do work.

c) The article says that, at 800 eV, soft X-rays are a "relatively small amount of energy." Explain why "relatively" is an important word in this statement. Be sure to discuss the energies in other bands of the electromagnetic spectrum.

X-rays are the second highest range of energies in the electromagnetic spectrum, just under gamma rays. Soft X-rays span an energy range of 12.4 keV (12,400 eV) to 124 eV, which, compared to the rest of the electromagnetic spectrum, is still a very high energy. Relative to the range of X-ray energies, 800 eV is low, thus the word "relatively" is used.

Step 3: Rewrite the following paragraph about X-ray spectromicroscopy in terms of energy. Replace the following terms as described:

replace synchrotrons *with* electromagnetic energies

replace soft X-rays *with* 124 to 12,400 electronvolt energy range

replace electromagnetic spectrum *with* energy spectrum

replace radiation *with* energy

replace orbital(s) *with* energy level(s)

replace measured spectrum *with* graph of intensity as a function of energy

Synchrotrons in the **soft X-ray** range of the **electromagnetic spectrum** hit the sample, which then absorbs the **radiation** and causes the electrons to jump into higher **orbitals**. Every element and bonded molecule in the sample responds to the **radiation** differently depending on the **orbital** and bonding location of the electron. The response can be seen as specific "signatures," or bumps and dips in the **measured spectrum**.

Electromagnetic energies in the **124 to 12,400 electronvolt energy range** of the **energy spectrum** hits the sample, which then absorbs the energy and causes the electrons to jump up into higher **energy levels**. Every element and bonded molecule in the sample responds to the **energy** differently depending on the energy level and bonding of the electrons. This response can be seen as specific "signatures," or bumps and dips in the **graph of intensity as a function of energy**.

Step 4: a) Based on what you know about energy, spectroscopy, and microscopy, why do you think the spore looks different from the rest of the bacteria?

The different parts of the bacterium absorb the energy differently and produce a unique spectrum. Thus, the spectrum of the spore looks different from spectra of the other areas of the bacterium.

b) How do you think the image in Figure 2 was made (rather than having just spectra)?

The differences in the spectra are color-coded and used to make a magnified image of the bacterium.

Step 5: Select another article in the April 2006 *EHP Student Edition* that describes a specific environmental health issue and write a brief summary of the issue. If you had access to synchrotron X-ray techniques, describe one way the techniques could be used to advance scientific understanding of the environmental health issue you selected.

Answers will vary based on the article the student selects. Students need to provide a clear, brief summary of the environmental health issue of interest. The description of how they would use the synchrotron X-ray technology to advance understanding does not need to contain a lot of details; it just needs to be reasonable with respect to the specific issue they selected and the abilities of the technique. Students should describe why or how they think their synchrotron X-ray research would advance the issue they selected. The description should be similar in detail to the bioremediation example.

Authors and Reviewers

Author: Stefani D. Hines, University of New Mexico, College of Pharmacy, Community Environmental Health Program

Reviewers: Susan Booker, Erin Dooley, Liam O'Fallon, Dean C. Hines, Lisa Pitman, Wendy Stephan, Kimberly Thigpen Tart, Heather Valli

Contributing Reviewer: Jeff Gillow, Brookhaven National Laboratory

ehp

STUDENT INSTRUCTIONS: X-Rays Get in Synch

Step 1: Most of us know about X-rays because of their use in medical imaging. We get an "X-ray" to see if a bone is broken or if there is a cavity in our teeth. Bones absorb X-rays differently than skin and teeth, which is why we can differentiate between them in an "X-ray" image. X-rays make up one specific range of energies in the electromagnetic spectrum.

Using the Table 1 and Table 2, answer the questions below.

a) Refer to Table 1 on page 9. You see there are different classes of radiation such as gamma, X-ray, light, and radio. The different classes are categorized by their energy level either in terms of frequency (hertz), wavelength (meters), or energy (electronvolts; eV). Referring to the energy units in Table 1, fill out column 1 below. Be sure to write down the correct unit (e.g., MeV) after each number.

b) Using Table 2 on page 10, convert the units to eV. For example, MeV stands for mega-electronvolts, and 1 MeV = 1,000,000 eV. Write your answers in column 2.

c) In column 3 indicate whether the energy band is higher- or lower-energy compared to X-rays.

Name of Electromagnetic Energy Band	1. Energy Range (MeV–feV)	2. Energy Range (converted to eV)	3. Higher- or Lower-Energy Compared to X-Rays
gamma			
"hard" X-rays			—
"soft" X-rays			—
visible light			
infrared light			
radio			

Step 2: Read the article "X-Rays Get in Synch." Then answer the following questions. Refer to the information you collected in Step 1 to help you.

a) In general are X-rays high-energy or low-energy?

b) Define energy.

c) The article says that, at 800 eV, soft X-rays are a "relatively small amount of energy." Explain why "relatively" is an important word in this statement. Be sure to discuss the energies in other bands of the electromagnetic spectrum.

Step 3: Electromagnetic spectrum, radiation, spectroscopy, synchrotrons, absorption spectrum, electron orbitals, bonds… If all of these fancy words sound confusing to you there is one simple word to describe them all—ENERGY! All of these concepts relate to energy.

Rewrite the following paragraph about X-ray spectromicroscopy in terms of energy. Replace the following terms as described:

replace synchrotrons *with* electromagnetic energies

replace soft X-rays *with* 124 to 12,400 electronvolt energy range *replace* electromagnetic spectrum *with* energy spectrum

replace radiation *with* energy

replace orbital(s) *with* energy level(s)

replace measured spectrum *with* graph of intensity as a function of energy

Synchrotrons in the soft X-ray range of the electromagnetic spectrum hit the sample, which then absorbs the radiation and causes the electrons to jump into higher orbitals. Every element and bonded molecule in the sample responds to the radiation differently depending on the orbital and bonding location of the electron. The response can be seen as specific "signatures," or bumps and dips in the measured spectrum.

Step 4: X-ray spectromicroscopy is made up of two parts, spectroscopy and microscopy. "-Scopy" simply means viewing, seeing, or observation. So, spectroscopy is viewing the spectrum (a graph of intensity as a function of energy), and microscopy is viewing images of magnified objects.

Figure 1 shows the X-ray absorption spectrum of the *Clostridium* bacteria. Figure 1 shows how the spectra of different types of molecules look different from each other. Figure 2 is a color-coded X-ray spectromicroscopy image of a bacterium forming a spore (as described in the article).

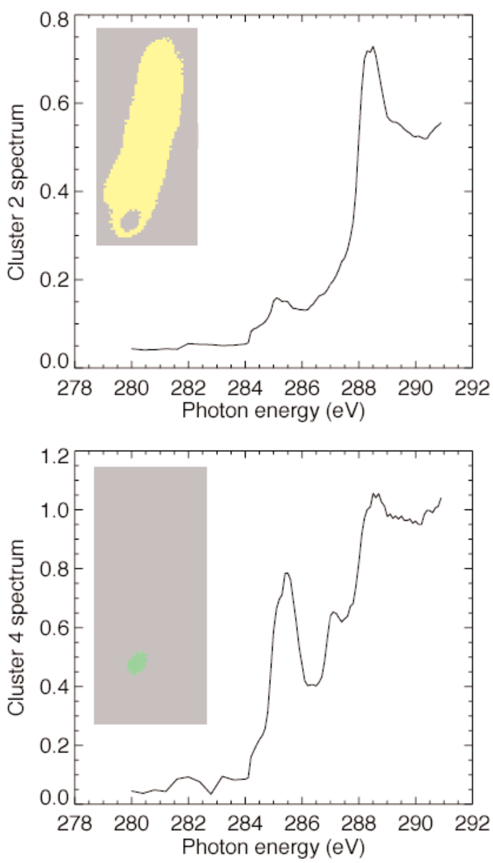

Figure 1: X-ray absorption spectra of a *Clostridium* bacterium forming a spore

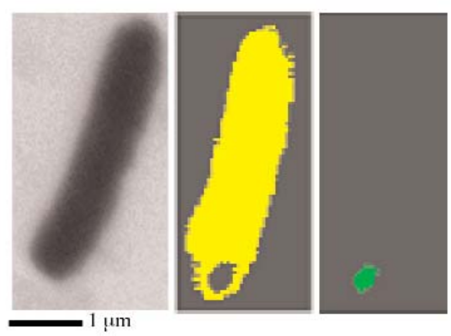

Figure 2: X-ray spectromicroscopy image of a *Clostridium* bacterium forming a spore

Source: X-Ray spectromicroscopy images courtesy of Brookhaven National Laboratory.

a) Based on what you know about energy, spectroscopy, and microscopy, why do you think the spore looks different from the rest of the bacteria?

b) How do you think the image in Figure 2 was made (rather than having just spectra)?

Step 5: Techniques that use synchrotron X-rays, such X-ray spectromicroscopy, are very valuable in helping scientists understand biochemical processes. Below are three descriptions of how synchrotron X-ray techniques have been used in medical science, biology, and environmental science.

Analyzing viral proteins

The anti-flu drugs Relenza and Tamiflu were developed after analyzing the surface of an influenza virus enzyme (a type of protein) called neuraminidase. The virus uses this enzyme to help them infect nearby healthy cells (viruses need to reproduce inside of host cells).

Investigating cell structure

Images are being made of the internal features of cells. Scientists can observe cells features up to a thousand times smaller than previously possible and create high-precision 3-D cell maps. Scientists can also monitor cellular processes during biochemical reactions.

Bioremediation

The article "X-Rays Get in Synch" describe the use of X-ray spectromicroscopy to investigate how bacteria used in bioremediation (i.e., using a living agent to clean up pollution) modify the chemistry of metals and radioactive elements in order to remove those pollutants from soils and water. Select another article in the April 2006 *EHP Student Edition* that describes a specific environmental health issue and write a brief summary of the issue. If you had access to synchrotron X-ray techniques, describe one way the techniques could be used to advance scientific understanding of the environmental health issue you selected.

TABLE 1: Energy, Frequency and Wavelength of the Electromagnetic Spectrum

Class of Radiation	Frequency (hertz, Hz)	Wavelength (meters, m)	Energy (electronvolts, eV)
Gamma	300–30 Ehz	1–10 pm	1.24 MeV–124 keV
Hard X-rays	30–3 Ehz	10–100 pm	124–12.4 keV
“Soft” X-rays	3 Ehz–30 PHz	100 pm–10 nm	12.4 keV–124 eV
Ultraviolet light	30–0.7 PHz	10–400 nm	124–3.1 eV
Visible light	0.7 PHz–300 THz	400–750 nm	3.1–1.65 eV
Infrared light	300 THz–300 GHz	750 nm–1 mm	1.65 eV–1.24 meV
Extremely high frequency radio (microwaves)	300–30 GHz	1 mm–1 cm	1.24 meV–124 meV
Super high frequency radio (microwaves)	30–3 GHz	1 cm–1 dm	124–12.4 meV
Ultrahigh frequency radio	3 GHz–300 MHz	1 dm–1 m	12.4–1.24 meV
Very high frequency radio	300–30 MHz	1 m–1 dam	1.24 meV–124 neV
High frequency radio	30–3 MHz	1 dam–1 hm	124–12. 4 neV
Medium frequency radio	3 MHz–300 kHz	1 hm–1 km	12.4–1.24 neV
Low frequency radio	300–30 kHz	1–10 km	1.24 neV–124 peV
Very low frequency radio	30–3 kHz	10–100 km	124–12.4 peV
Voice frequency	3 kHz–300 Hz	100 km–1 Mm	12.4–1.24 peV
Extremely low frequency radio	300–30 Hz	1–10 Mm	1.24 peV–124 feV

TABLE 2: International System (SI) Units

Prefix	Symbol	Numeric Meaning	Exponential Notation
exa-	E	1,000,000,000,000,000,000	10^{18}
peta-	P	1,000,000,000,000,000	10^{15}
tera-	T	1,000,000,000,000	10^{12}
giga-	G	1,000,000,000	10^{9}
mega-	M	1,000,000	10^{6}
kilo-	k	1,000	10^{3}
hecto-	h	100	10^{2}
deka-	da	10	10^{1}
—	—	1	10^{0}
deci-	d	0.1	10^{-1}
centi-	c	0.01	10^{-2}
milli-	m	0.001	10^{-3}
micro-	µ	0.000001	10^{-6}
nano-	n	0.000000001	10^{-9}
pico-	p	0.000000000001	10^{-12}
femto-	f	0.000000000000001	10^{-15}
atto-	a	0.000000000000000001	10^{-18}