Advanced Light Source

The brightest source in America for light from ultraviolet through soft x rays is not a laser, a medical x-ray machine, or even the sun. It is a beam of electrons, accelerated nearly to the speed of light by a large particle accelerator called a synchrotron—the **Advanced Light Source.**

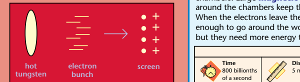
Read on to find out how the electrons start out, speed up, gain energy, and produce exceptionally bright light. This light, often focused into beams thinner than a human hair, fuels scientific experiments from physics to forensics.

Scientists from around the world can do experiments at the ALS, a research facility funded by the Department of Energy and located at Lawrence Berkeley National Laboratory, University of California.

Electron Gun: Where do the electrons come from?

Bunches of electrons blast out of an electron gun.

The electron source is a button-sized piece of treated tungsten (the same material as in light bulb filaments) that releases **electrons** (key 1) when it is heated to about 1000°C. A screen near the electron source is given a strong, short-lived positive charge 125 million times each second, and this positive charge pulls negatively charged electrons away from the electron source (**opposites attract** key 2) in bunches of billions of electrons each.



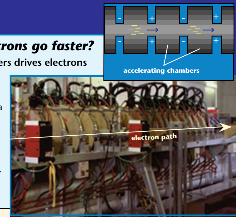
AT THE END OF ELECTRON GUN			
Time 400 billionths of a second	Distance 1 meter	Speed 59.5% of speed of light (178,484,000 meters per second)	Energy 120,000 electron volts

Linac: How do you make the electrons go faster?

A long series of accelerating chambers drives electrons nearly to the speed of light.

When an electron bunch enters an accelerating chamber, it speeds toward a positive charge on the far wall (**opposites attract** key 2). While the electrons race through a hole into the next chamber, the charges are reversed, so the now-negative charge repels the electrons and the now-positive charge ahead attracts them.

The linear accelerator (linac) has 120 small accelerating chambers. Large **magnetic focusing** (key 2) coils around the chambers keep the electrons in tight bunches. When the electrons leave the linac, they are traveling fast enough to go around the world 7 1/2 times in one second, but they need more energy to generate x rays.

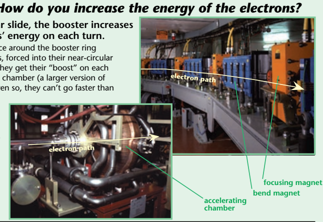


AT THE END OF LINAC			
Time 800 billionths of a second	Distance 5 meters	Speed 99.9948% of speed of light (299,777,000 meters per second)	Energy 50 million electron volts

Booster Ring: How do you increase the energy of the electrons?

Like a circular slide, the booster increases the electrons' energy on each turn.

The electrons race around the booster ring more than 1 million times, forced into their near-circular path by bend magnets. They get their "boost" on each turn from an accelerating chamber (a larger version of those in the linac), but even so, they can't go faster than the speed of light. Pushing closer to light speed makes the electrons gain mass, though, and this increases their energy. So the booster's "accelerating chamber," which boosts the electrons' energy by 30 times, does it mostly by increasing their mass, not their speed.

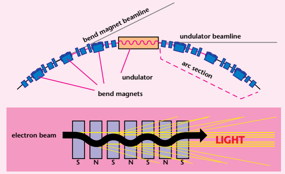


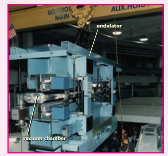
AT THE END OF BOOSTER CYCLE			
Time 0.33 seconds	Distance 98,000 kilometers	Speed 99.99994% of speed of light (299,792,000 meters per second)	Energy 1.5 billion electron volts

Storage Ring: How do electrons generate light?

Electrons zip around the storage ring 1.5 million times per second, producing bright light at every turn.

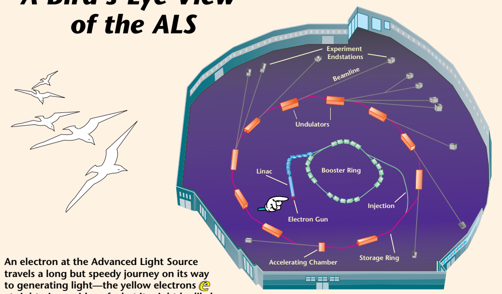
Once the electrons reach their target energy, an injection system transfers them from the booster to the storage ring, where they circulate for hours. At every curve in their path, the electrons emit light (**photons** key 4) forward like a car headlight. Electrons curving through the **bend magnets** (key 2) in the ring's 12 arc sections emit fanlike beams of photons, like cars rounding a bend at night. Between these curves are straight sections where multi-magnet devices called undulators wiggle the electrons back and forth, so the light from each wiggle overlaps and forms a narrow beam 100 million times brighter than conventional **x-ray** (key 6) sources. The electrons travel in a vacuum chamber with fewer atoms per unit volume than outer space, so there are almost no collisions to slow them down. However, each photon they emit carries off a bit of the electrons' **energy** (key 5), which is replenished in two accelerating chambers (like the one in the booster).





AFTER FOUR HOURS IN STORAGE RING			
Time 4 hours	Distance 4.32 billion kilometers	Speed 99.999994% of speed of light (299,792,000 meters per second)	Energy 1.5 billion electron volts

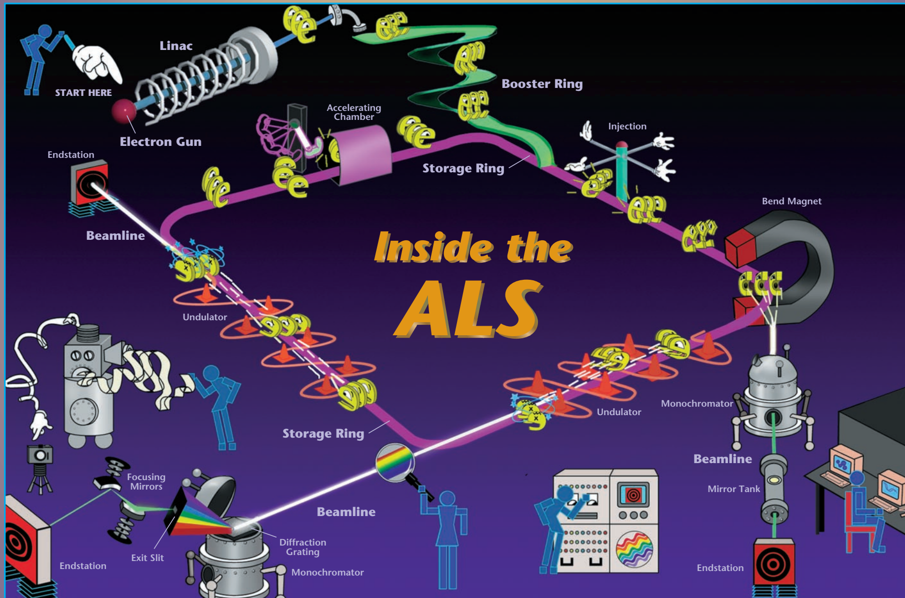
A Bird's-Eye View of the ALS



An electron at the Advanced Light Source travels a long but speedy journey on its way to generating light—the yellow electrons (e) at right give an idea of what it might be like!

The text and pictures around the edge of the poster will help you follow the action inside the ALS, beginning with the electron gun. Whenever you see the key symbol, you can find more explanation in the Key Concepts section below.

Inside the ALS

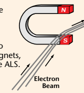


Key Concepts

1. What is an electron?
An electron is a negatively charged particle that orbits outside the positively charged center (nucleus) of an atom. Electrons can be pulled away from atoms to flow as an electric current. In power lines and lamp cords, for example, electrons flow through wires, but in the ALS they circulate inside a vacuum chamber.

2. How do you make an electron in the ALS do things?
If you want the electron to speed up, put positive and/or negative charges nearby. The positive charges will attract the negatively charged electron (opposites attract), and the negative charges will repel it.

If you want a moving electron to change direction, use a magnet; for instance, if you place a magnet with its north pole above and its south pole below the electron's path, the electron will curve to the right. This effect is used in bend magnets, undulators, and focusing magnets at the ALS.

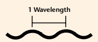


3. How does the ALS generate light from electrons?
It makes the electrons accelerate (change their speed or direction of travel). Whenever an electron (or any other charged particle) accelerates, it produces light. Light produced this way is called synchrotron light.

4. What is a photon?
A photon is a "particle" of light. All light can behave either as particles or as waves depending on what you do with it—that's why scientists speak of light sometimes as photons and sometimes as waves.

5. What is light?
The light our eyes see is only a small part of the vast spectrum of light, also called electromagnetic radiation. All light travels at the same speed (299,792,458 meters per second in vacuum) and can be described using a few simple quantities:

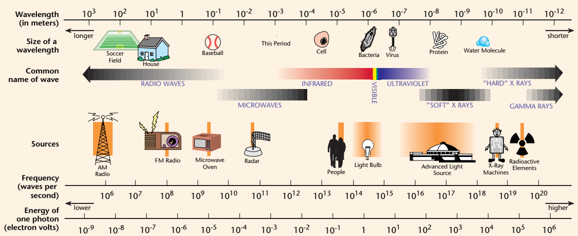
- Wavelength is the distance from one peak to the next in a light wave.



- Frequency is the number of waves that pass one place each second.
- Energy refers to the amount of energy carried by one photon. An electron volt (eV) is a very small unit of energy, useful for measuring the tiny amounts of energy that individual photons carry. High-energy, high-frequency photons have the shortest wavelengths.

6. What is an x ray?
X rays are light with photon energies of about 100 electron volts or more. They are commonly divided into "soft" and "hard"; hard x rays, with higher energies, penetrate farther through most materials. The ALS mostly produces ultraviolet light and soft x rays, which have just the right energies to explore many of the atomic-level properties of matter.

THE ELECTROMAGNETIC SPECTRUM

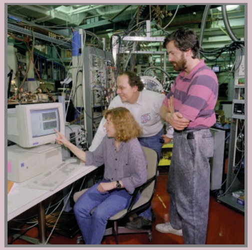


Target on Science

The bright beams of the ALS illuminate the mysteries of our world, enhancing our ability to see as well as to draw conclusions about what we can't see.

The special features of ALS light make it a very useful tool for science. Just a few of the research possibilities include discerning the structural details of human protein molecules, so drugs can be designed to block the sites where disease organisms attach themselves; developing techniques for fabricating smaller-than-ever integrated circuits that will let semiconductor manufacturers pack more circuitry onto a chip; and exploring the processes by which ozone is formed and destroyed in the earth's protective ozone layer.

The most prized characteristic of ALS light is high brightness, meaning the rays of light are very intense and are focused to a small spot. The ALS delivers America's brightest light in the ultraviolet and soft x-ray regions of the electromagnetic spectrum (key 5), making possible a host of different experiments that were once only dreamed of.

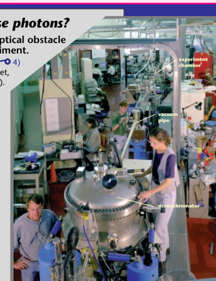


Beamlines: What happens to all those photons?

Beamlines deliver the photons down an optical obstacle course from the storage ring to the experiment.

Beamline mirrors steer and focus a thin beam of **photons** (key 4) down meters of vacuum pipe from the storage ring to the target, a sample of interest inside an experiment chamber (endstation). Some experiments use all the available photons, but the storage ring produces so many photons that scientists can afford to be choosy about which photons they use. Scientists who want to select only photons with certain **wavelengths** (key 5) use beamlines with monochromators ("one-colorers") which act like prisms, spreading the thin photon beam into a spectrum of different wavelengths so only the desired ones go through an exit slit.

Researchers make observations by using the photons to produce small changes in their samples, and a variety of instruments record the results. Computers help convert the instruments' readings into images, graphs, or even 3-D models, making new information available for advancing science and technology.



Concept and Content: Jane Cross, Deborah J. Dixon, Annette Greiner, Elizabeth Moxon, Jeff Sensabaugh • Art Direction: Crystal Stevenson • Illustrations: the TEID staff •
For more information, contact Elizabeth Saucier, Lawrence Berkeley National Laboratory, MS 80-101, Berkeley, CA 94720; email: alsuser@lbl.gov • ALS Web page: http://www-als.lbl.gov/

Can You Find These Inside the ALS? Aluminum foil • Red and green water hoses • The words *light bulb* (2 places) • The words *car headlight* • A skeleton • North and south poles • A camera • A U.S. flag • A traffic cone • A definition of *monochromator* • A really big hook • A yellow ribbon • A microwave oven • A hard hat • A parking lot

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098.