Inside the **ALS**

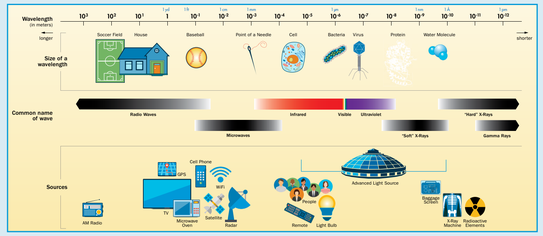
BERKELEY LAB

ALS ADVANCED LIGHT SOURCE

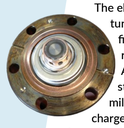
America's brightest source of light ranging from the ultraviolet through lower-energy ("soft") x-rays is not a laser, a medical x-ray machine, or even the sun. It is a beam of electrons, accelerated to almost the speed of light by a particle accelerator, called a synchrotron, at the Advanced Light Source (ALS). *Inside the ALS* tells how the electrons start out, speed up, gain energy, and produce exceptionally bright light. This light fuels scientific experiments from physics to forensics.

ELECTROMAGNETIC SPECTRUM

The electromagnetic (EM) spectrum covers a wide range of wavelengths and photon energies. EM waves used to "see" an object must have a wavelength about the same size as or smaller than the object. Longer-wavelength radio waves can only resolve large structures. Visible light allows us to see whole cells or bacteria. But to look at smaller structures, like viruses or molecules, we need shorter wavelengths. The ALS is an extremely bright source of shorter-wavelength energy — primarily x-rays — that is used for many different types of research.



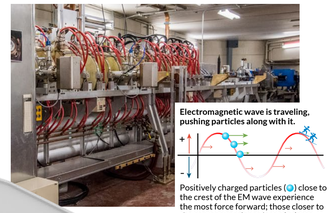
1 Electron Source



The electron source is a button-sized piece of tungsten (the same material that is in the filament of an incandescent light bulb) that releases electrons when heated to 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 the negatively charged electrons away from the electron source in bunches of billions of electrons each.

2 Linear Accelerator

The electrons travel though a linear accelerator, a copper structure shaped such that radio-frequency (rf) waves travel through it at the same speed as the electrons. This way, the electrons are accelerated by the rf waves as they travel through the structure, like a surfer riding a wave.



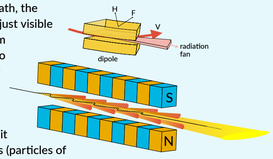
Positively charged particles (●) close to the crest of the EM wave experience the most force forward; those closer to the center experience less of a force. The result is that the particles tend to bunch closer together.

3 Booster Ring

The electrons race around a booster ring more than 1 million times, forced into a near-circular path by magnets. They get a boost in energy on each turn from an accelerating rf cavity, but even so, they can't go faster than the speed of light. So while the booster ring increases the energy of the electrons by almost 40 times, it mostly goes into increasing their mass, not their speed. Once the electrons reach their target energy, they are transferred to the main storage ring, where they circulate for hours.

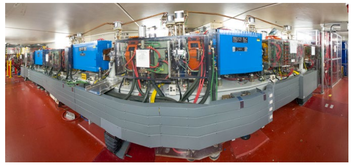
Synchrotron Radiation

At every curve in their path, the electrons emit light (not just visible light, but everything from radio-frequency waves to x-rays) forward like a car headlight. Electrons curving through the storage ring's dozens of dipole bend magnets emit fanlike beams of photons (particles of light). Between these curves are straight sections where multi-magnet arrays, called insertion devices, wiggle the electrons back and forth. The light from each wiggle overlaps and forms a narrow beam 100 million times brighter than conventional x-ray sources.



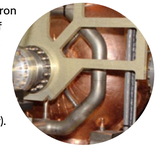
4 Storage Ring

Electrons zip around the main storage ring 1.5 million times a second, producing light every time a magnet changes their direction. The electrons travel in a vacuum chamber, where the number of molecules per unit volume is comparable to the surface of the moon, so there are almost no collisions. In regular air, the electrons would on average make it about 1 meter before hitting a molecule and being lost.



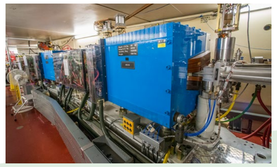
5 Rf Cavities

Every photon that an electron emits carries away some of the energy of the electron. This energy is replenished each time the electrons travel through the two rf cavities in the storage ring (like the one in the booster).



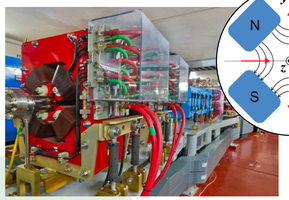
6 Dipole Bend Magnets

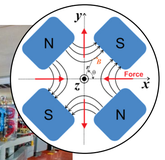
To keep the electrons on their curved path, dipole bend magnets are used. They are essentially large, horseshoe-shaped magnets. The vertical magnetic field they produce deflects the electron beam horizontally. The main storage ring at the ALS has 36 dipoles, each bending the beam by 10 degrees, resulting in a 10-degree fan of light.



7 Quadrupole Magnets

Quadrupole magnets focus the electron beam, similar to the way lenses focus light beams. We actually calculate the size of the electron beam using the same mathematical formalism used for light optics.





8 Insertion Devices

Insertion devices, placed in the straight sections between the bend magnets, use a series of very short permanent magnets to wiggle the electrons from side to side. This results in a much smaller but brighter fan of light.

9 Beamlines and Endstations

Beamline mirrors steer and focus a thin beam of photons down meters of vacuum pipe from the storage ring to the target: a sample of interest in an experimental chamber (endstation). Some experiments use all the available photons, but the storage ring produces so many photons, scientists can afford to be choosy about which photons they use. Often they select only photons with a certain wavelength ("color").

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

Science at the ALS

APPLIED SCIENCES

Solar cells printed on plastic film using a photovoltaic "ink" are a potential source of inexpensive renewable energy, but some efficiency is lost in the transition from lab to factory. To understand why, researchers put a factory-type solar-cell printer inside an ALS beamline, allowing them to study changes in the ink's molecular structure and chemistry as it dries.

BIOLOGICAL SCIENCES

Amgen Inc. identified a promising anticancer drug that targets tumors caused by mutations in a type of protein that signals cells to divide and proliferate. Crucial atomic-level information about how the prospective drug molecule interacts with the cell-signaling protein was revealed using light from the ALS.

CHEMICAL SCIENCES

Magnesium/sulfur batteries hold promise as a safer, more compact alternative to lithium batteries, but they have suffered from extremely limited recharging capabilities. To learn more about why, researchers used the ALS to investigate the batteries' chemistry as they're charged and discharged, identifying the limiting steps and pointing the way to a solution.

EARTH AND ENVIRONMENTAL SCIENCES

Researchers used the ALS to study comet dust particles, which are "forensic" material samples preserved from the birth of the solar system. Their analysis of the particles' structure and composition, at unprecedented spatial scales and sensitivity, identified certain complex mineral grains as likely to be the original "bricks and mortar" of the solar system.

ENERGY SCIENCES

Despite conventional wisdom that reactions involving oxygen will reduce a battery's rechargeability and safety, experiments performed at the ALS showed that some oxygen reactions are both beneficial and reversible. The results open up new ways to explore how to pack more energy into batteries with electrodes made out of low-cost, common materials.

MATERIALS SCIENCES

To store more information in less space while conserving power, scientists are studying materials that contain tiny, swirling magnetic and electric structures that could be used to encode binary data. At the ALS, researchers confirmed the binary nature of such swirls in a material that, crucially, allows for them to be controlled using an external electric field.

PHYSICAL SCIENCES

Researchers at the ALS showed that computers can learn to predict noisy fluctuations in the size of beams generated by synchrotron light sources and correct them before they occur. This "machine learning" approach solves a decades-old noise problem and will allow researchers to fully exploit the smaller beams made possible by recent advances in light source technology.

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