CRYEBIS AND ECR

The fast ion beams produced by the Tandem and LINAC can be stripped to high charge states by passing them through thin foils, thus reaching a state of ionization/excitation comparable to an atom in a gas heated to roughly 10 million degrees. An alternative way to produce such highly stripped ions is to hold the ion still and subject it to an intense beam of electrons.

The Cryogenic Electron Beam Ion Source (Figure 4) and the Electron Cyclotron Resonance ion source follow this route, producing slow-moving beams of highly charged ions. The CRYEBIS does this by immersing atoms in an extremely intense (1000 A/cm^2) electron beam. The ECR source does it by developing a plasma with a circulating high-energy electron flux.

The CRYEBIS can produce ions up to fully stripped argon and 45 times ionized xenon. The ECR source produces more intense beams of less highly charged ions. Both sources are operated as stand-alone low-energy accelerators for delivering beams to target stations.

A Electron gun
B Superconducting solenoid
C Analyzing magnet
D Beamlines

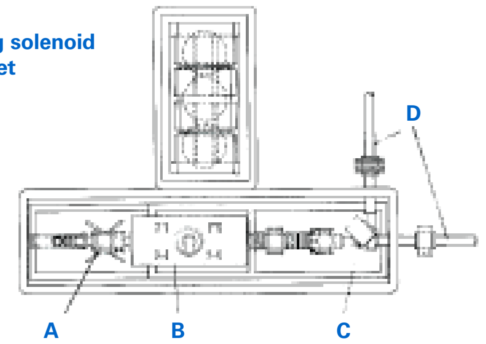

Figure 4
CRYEBIS

LUMOS

Researchers in the LUMOS laboratory (Figure 5) are working to create stable optical frequency combs by sending ultrafast laser pulses through specialty optical fibers. This generates a rainbow of optical frequencies, or a supercontinuum. The properties of the rainbow spectrum that emerges from the fiber can be measured and used to stabilize the ultrafast laser. The stable pulse train, when amplified, can be used for atomic physics experiments.

In addition, the broad spectrum is actually a comb of optical frequencies that spans the visible or near-infrared end of the spectrum. When stabilized, this comb forms a frequency "ruler" that can be used to measure unknown optical frequencies to very high precision.

The LUMOS optical frequency comb will be used to make precise measurements of optical frequencies in molecular gases important for frequency standards in the telecommunications industry. By confining these gases in novel photonic bandgap fibers, precise saturation spectroscopy can be performed toward improving the convenience and accuracy of these standards.

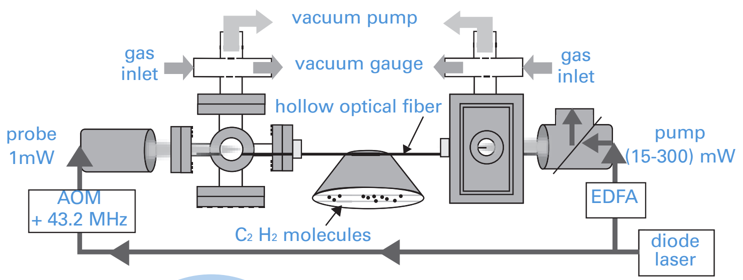

Figure 5
LUMOS

MOTRIMS

If the electrical power from a wall outlet is used in just the right way, it can be used to cool things down (as in a refrigerator) rather than heat things up. Similarly, if the power from lasers is used in just the right way, it can be used to cool atoms down, rather than heat them up.

In the MOT room (Figure 6), researchers use lasers to cool atoms down to a temperature far lower than anything found in nature, more than a million times colder than room temperature. When a group of atoms are cooled, their average speed is reduced. Furthermore, their spread in speed is reduced. That is, if all of the cooled atoms move at nearly the same speed, and that speed is very low (inches per second, rather than a thousand feet per second at room temperature).

These very slow atoms are then used as targets, with ions used as the "bullets." Because the target atoms are moving so uniformly and slowly before their collisions with the ions, their motion after a collision yields much more information about their interaction with the ion during the collision.

Other lasers can be used to excite these slow atoms before their collisions, allowing researchers to learn in detail how ions interact with excited atoms. These same measurements also yield details about how efficiently the cloud of atoms can be excited with the additional lasers. These measurements could help researchers develop the tools necessary to implement "quantum computers," devices that use the subtle—and often surprising—laws of quantum mechanics to perform complex calculations much more efficiently than possible with conventional computers.

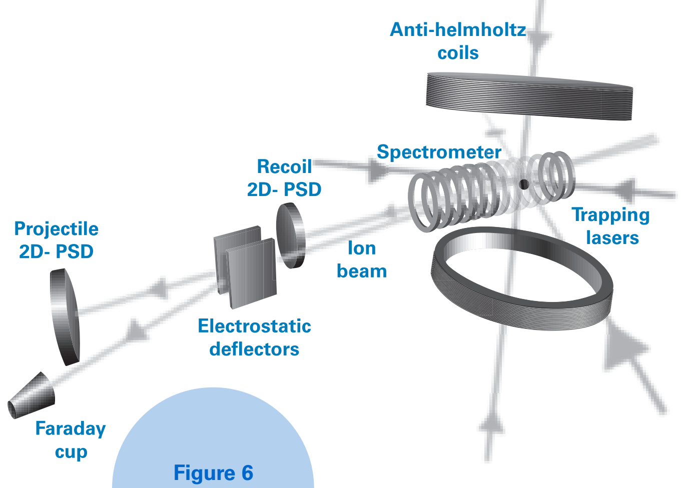

Figure 6
MOTRIMS

THEORETICAL AMO PHYSICS

The theoretical AMO group strives to provide fundamental understanding of experiments carried out in the Macdonald Laboratory and elsewhere based on the principles of classical and quantum mechanics. A broad range of problems are being investigated.

For interactions of short pulse lasers with matter, we are looking into the new frontier of physics at the attosecond (10^{-18} s) level where electron dynamics can be probed in the time domain. We are also investigating the interaction of molecules in an intense laser field. By understanding how a molecule breaks, a "molecular clock" can be made where time can be read with a precision of less than a femtosecond such that distances can be determined with an accuracy of a fraction of an Angstrom (10^{-8} cm).

Theoretical models are also being developed to study the interactions of laser-light and particles with clusters (C_{60}), thin films, atomically flat, and nano-structured surfaces. Our calculations of basic electron transfer and resonance formation processes during the interaction of a slow projectile atom or ion with a surface are of both fundamental interest and of practical importance for various areas of science and engineering, such as the development of ion sources, the improvement of surface analytical methods, the control of ion-wall interactions in fusion plasma, reactive ion etching, nano-technology, semiconductor miniaturization via thin-film deposition, and surface chemistry, including catalysis and corrosion prevention. Furthermore, we investigate interactions of ions with atoms and molecules.

With regard to "basic" physics issues, we are working on collisions of anti-protons and positrons with simple atoms, on the structure and stability of few-particle atomic and molecular systems, and on guiding the Bose-Einstein condensate in a chip.

2983-36772-5/05-1M

K-State PHYSICS

Visitor's Guide

James R. Macdonald Laboratory
Department of Physics
Kansas State University

The James R. Macdonald Laboratory is an atomic, molecular, and optical physics research facility funded by the U.S. Department of Energy. The lab is located in the sub-basement of Cardwell Hall on the Kansas State University campus. This 16,000-square-foot facility (Figure 1) houses ion sources, particle accelerators, lasers, experimental areas, cryogenics equipment, and computer support facilities.

The laboratory is dedicated to Professor James R. Macdonald (1936–1979), who made significant contributions in atomic collisions physics in the 1960s and 1970s and whose dynamic personality and research productivity were the major impetus for the establishment of a full-scale accelerator-based atomic physics program at Kansas State University.

Additional information may be found on the web at *http://www.phys.ksu.edu/area/jrm.*

FOR MORE INFORMATION

J.R. Macdonald Laboratory
Department of Physics
Kansas State University
106 Cardwell Hall
Manhattan, KS 66505-2604

J.R. Macdonald Laboratory

- A Accelerator room
- B Tandem accelerator
- C Equipment room
- D Computer room
- E Experiment
- F Control room
- G LINAC
- H Clean room
- I CRYEBIS
- J MOT
- K ECR
- L Cryogenics area
- M KLS laser labs
- N Lumas

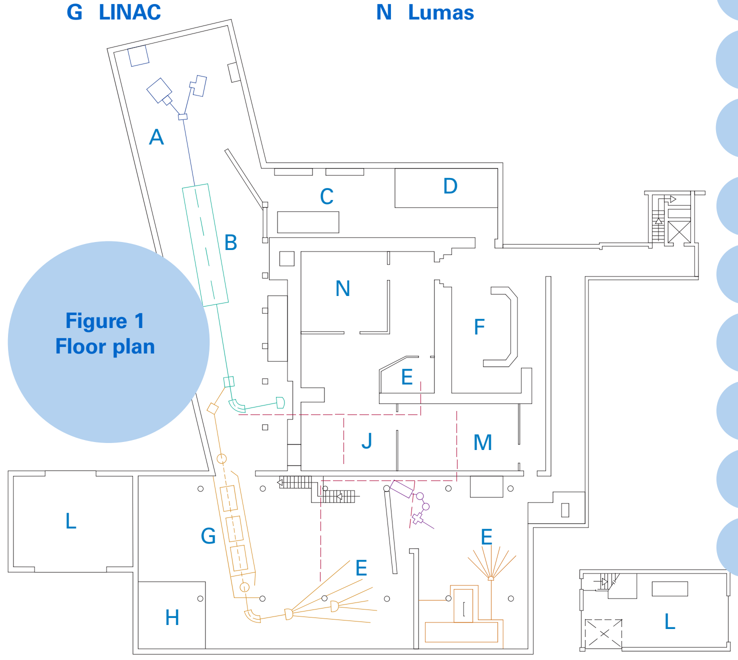

Figure 1
Floor plan

ABOUT THE LAB

The laboratory employs about 50 people to handle the activities in this large-scale research facility. The equipment found there provides high-intensity, short pulse laser beams and energetic beams of heavy ions for use in fundamental experiments in atomic physics.

The basic atomic physics experiments conducted in the Macdonald Laboratory provide a deeper understanding of the dynamics of matter when atoms are subjected to ultra-strong electromagnetic fields and/or stripped of many electrons. The results of these experiments and the associated work by our theory group find applications in astrophysics, fusion technology, quantum computing, ultrafast "cameras," telecommunications frequency standards, and surface science. A central mission of the laboratory is to train young scientists in preparation for careers in physics.

The initial cost of the Tandem Van de Graaff accelerator facility in 1967 was $2.5 million. Of this, $1.5 million was from the U.S. Atomic Energy Commission, forerunner to the U.S. Department of Energy, and $1 million from the state of Kansas. In 1986 a laboratory extension to house the LINAC and CRYEBIS was provided by the state at a cost of $1.09 million, and a $5.1 million grant (1985-1989) from the Department of Energy provided funds for constructing and installing these additional facilities. In 2001 the Kansas Light Source was installed at a cost of approximately $1 million, with funds from the Department of Energy, the National Science Foundation, and K-State. The operation of the lab is funded by a continuing grant from the Department of Energy at a level of approximately $2–3 million per year.

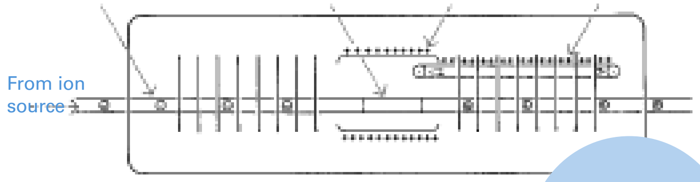

Figure 2
Tandem
accelerator

KANSAS LIGHT SOURCE

The Kansas Light Source (pictured on cover) is an ultrafast high intensity laser facility for studying the fastest dynamics in atoms, molecules, and other matter under the influence of strong electric fields. The facility was installed in 2001 and is being continuously upgraded.

It can provide extremely short pulses of light, as short as 8 femtoseconds (1 fs=10^{-15} seconds). This time is comparable to the period of the fastest molecular oscillations. The focused laser intensity can reach 10^{16} watts/cm^2, where the electric field of the light is equivalent to the Coulomb field experienced by the electron in a hydrogen atom. The laser produces 8 fs to 30 ps pulses at a central wavelength of 790 nm with a pulse energy up to 5 mJ and repetition rate of 2 kHz.

The laser system uses the principle of chirped pulse amplification. To avoid damaging the laser amplification medium, 10 fs seed pulses with nanojoule (10^{-9} Joule) energy are stretched to 100 ps by a pair of gratings, amplified at an intensity below the damage threshold of the gain material (Ti:Sapphire in this case), and subsequently recompressed to 25 fs by another set of gratings.

The uniqueness of the Kansas Light Source is that the 5 mJ, 30 ps pulses are obtained from a single stage amplifier, while other lasers use at least two amplifiers. This novel design makes the Kansas Light Source easy to operate and maintain.

The 8 fs pulses are generated by compressing 25 fs pulses using nonlinear optics. The 25 fs pulses are coupled to a hollow-core fiber filled with argon gas. The laser intensity in the fiber is so high that the refractive index of argon is changed by the electric field of the laser. The time-dependent refractive index modifies the pulses in such a way that the frequency bandwidth is increased by at least a factor of three, allowing the pulses to then be compressed to as short as 8 fs in the time domain.

Several experiments can be done simultaneously using the Kansas Light Source by splitting the laser beams. It runs seven days a week, up to 24 hours a day. It serves several different target stations, including those where it interacts with the ion beams produced by the accelerator. The capability to couple the laser and ion-beam facilities to produce ultra-short bursts of energetic ions is under development.

TANDEM VAN DE GRAAFF ACCELERATOR AND LINAC

Negatively charged ion beams ranging from hydrogen (Z = 1) to uranium (Z = 92) are injected into the Tandem van de Graaff accelerator from one of two ion sources where they are attracted to the positively charged terminal located at the center of the accelerator (Figure 2). Upon arriving at this terminal, the ions pass through a tenuous gas that strips them of several electrons, thus rendering them positively charged.

They are then accelerated further by repulsion from this terminal as they continue their journey out the other end of the machine. This pull-push acceleration is the reason for the name "tandem." The accelerator has a maximum accelerating voltage of 7.5 x 10^6 (7.5 milion) volts and produces ions with velocities up to six percent of the speed of light with typical beam currents of 1 x 10^{-6} (one millionth) amperes.

If the experiment requires a higher beam energy, the ions can be accelerated further by passage through the LINAC, which consists of 14 superconducting resonators arranged as shown in Figure 3. Each resonator is approximately one-third of a meter long and has an equivalent accelerating potential of approximately 1 million volts.

Electromagnetic power is fed into the resonators at a frequency of 97 MHz (97 million cycles per second), which causes the electric fields within the resonators to oscillate back and forth along the ion path. The ion beam must be pulsed and bunched so that the ions pass through the resonators during the time when the electric field is directed along the direction of travel and are thus accelerated. These bunches are typically 100 picoseconds (100 trillionths of a second) wide and have a spacing of approximately 80 nanoseconds (80 billionths of a second) between bunches.

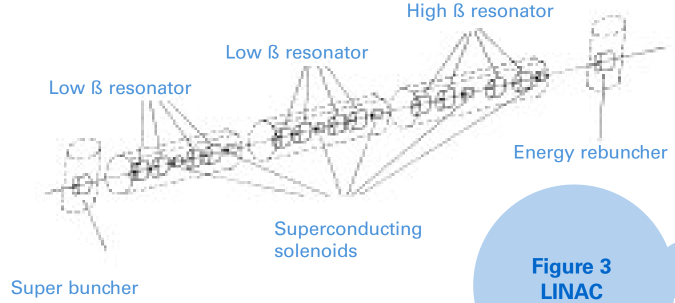

Figure 3
LINAC