Bringing Atomic and Nuclear Physics Laboratory Data Into the Classroom*

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For many years, atomic and nuclear physics have been part of the undergraduate physics curriculum. More recently, at both the national and state levels, many educational organizations have adopted standards that call for the teaching of atomic and nuclear physics in the high school classroom. These standards include the basic concepts of atomic structure, nuclear structure, and radioactivity. While many textbooks cover these topics, in a high school or undergraduate laboratory setting it is often difficult to perform experiments to illustrate these ideas. In order to address this issue, we have developed three websites where students can analyze atomic and nuclear physics data from modern laboratories. By working through the procedures described on these sites, students can gain familiarity with the concepts of characteristic x-ray spectra, half-life, and the techniques of x-ray fluorescence, and neutron activation analysis.

In order to fluoresce the elements, we used an ^{241}Am source, which emits a 59.5 keV gamma ray. Using this gamma ray source we were able to fluoresce the K x-rays of the elements ranging from Ca (atomic number, Z=20), whose K electron has a binding energy of 4.038 keV, to Tm (Z = 69), whose K electron has a binding energy of 59.390 keV. For elements with Z ranging from 70 (ytterbium) to 83 (bismuth) and for thorium (Z=90) and uranium (Z=92), we were able to fluoresce only the L x-rays. To measure the x-rays emitted from each target, we used a planar germanium detector 1.3 cm thick and 3.6 cm in diameter positioned at a 90^{O} angle from the ^{241}Am source. We acquired the x-ray spectra in 512 channels using an ORTEC PC based data acquisition system. We produced a total of 63 energy spectra of individual elements plus 12 spectra of "unknown" samples that students can analyze in order to determine their elemental compositions. These spectra have been placed on the web at http://ie.lbl.gov/xray.

The isotopes we chose for this project β^- decay into more stable isotopes. This beta minus decay often leaves the new isotope in an excited energy level, which in turn causes this new isotope to gamma decay down to its ground state (lowest energy state). These gamma rays (photons with energies usually higher than those of x-rays) are characteristic for each isotope. An example of this type of decay sequence is: $^{198}\mathrm{Au} \rightarrow {}^{198}\mathrm{Hg}^* \rightarrow {}^{198}\mathrm{Hg}_{gs} + \gamma$, where the gamma ray energy is 412 keV.

To measure the gamma rays emitted from each isotope, we used a coaxial germanium detector 5 cm thick and 5 cm in diameter sitting directly in front of the isotope sample. We acquired the gamma ray spectra in 4096 channels using an ORTEC, PC based data acquisition system. Data were accumulated in sequential energy spectra whose durations were chosen on the basis of the half-life of each isotope. Students can analyze these spectra on-line to determine the peak areas as a function of time. Instructions are provided that describe the steps needed to extract the half-lives of the isotopes. All of the gamma ray spectra that we acquired for this project can be found at http://ie.lbl.gov/gamma.

Neutron activation analysis is usually performed with neutrons from a nuclear reactor. In our case, we used neutrons produced by a mixed source of ^{241}Am and ^{9}Be. Inside this source the following reaction takes place: $^{9}\mathrm{Be} + {}^{4}\mathrm{He} \rightarrow {}^{12}\mathrm{C} + {}^{1}\mathrm{n}$, where ^{1}n is the neutron that is released in the reaction. The most common type of neutron-induced reaction is the neutron-capture reaction. The product nucleus is often radioactive and, as discussed in the previous section of this paper, will beta decay to an excited state of another nucleus resulting in the emission of one or more characteristic gamma rays. The samples of materials used for this project were placed on top of the neutron source in a shielded container for about 48 hours. To measure the gamma rays emitted from each isotope, we used a coaxial germanium detector 5 cm thick and 5 cm in diameter sitting directly in front of the sample. We acquired the gamma ray spectra in 4096 channels using an ORTEC, PC based data acquisition system. We used lead bricks to shield the detector from outside sources. All of the data that we collected and the procedures needed to analyze them can be found at http://ie.lbl.gov/naa.

By going through the analyses of the data available on the three websites described here, a number of basic concepts of atomic and nuclear structure and radioactive decay should become less abstract and easier to comprehend. We hope that these websites will be useful tools for students and instructors alike to become more familiar with atomic and nuclear processes.

REFERENCES

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