Physics Methods and Techniques in Art and Archaeology

Fall 2008

Course Information

Content: The course will be taught on an advanced undergraduate level and is primarily designed for art and history majors although a broader audience of science students might also be interested. The goal of the course is to give an overview of the various physics based analysis and dating techniques used in art, archaeology, and anthropology. Prerequisites will be honor level high school mathematics and physics. The physics principles of the methods and techniques will be taught in a more descriptive manner but the use of mathematical formulas will be necessary to underline the physics principles of the method and to characterize observable signatures. The course covers applications of material science, atomic physics, and nuclear physics based techniques. This necessitates a basic introduction in the principles of modern physics as well as an introduction to detector techniques and data processing. The usefulness and the applicability of each technique will be demonstrated by presenting one or two examples for applications in art analysis, archaeology, or anthropology. The subject of the course represents a rather broad and rapidly evolving field; the course will focus on the presentation and discussion of only a subset of all the presently available techniques.

Laboratory: The course outlines the underlying physical and theoretical principles of the experimental techniques; this theoretical concept will be complemented by a laboratory section to demonstrate a number of analytical techniques. This includes techniques such as X-Ray Fluorescence (XRF), Particle Induced X-ray Emission (PIXE), Neutron Activation Analysis (NAA), and Thermo-Luminescence (TL).

Course requirements: Mathematics is the language of the sciences, while this course aims at topics of science applications it will be given on a more descriptive level. Nevertheless, knowledge of pre-calculus and the very basic of calculus will be required. The mathematical discussion focuses on the application of only two equations,

$$E_x = (Z-\sigma)^2 \cdot 13.6\,[eV] \cdot \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

$$N(t) = N_0 \cdot e^{-\lambda \cdot t}$$

which are the equation for calculating x-ray energies and the equation for radioactive decay processes.

Exams: One mid-term and a final exam are scheduled as shown on the semester schedule for the course. *Exams are open book. During exams you may have your class material, calculators, pens, and pencils on your desk.* Honesty is expected and under the honor system the primary responsibility for regulation lies with the students. Any student who will be unavoidably absent from an exam must obtain permission in advance to make up the exam at a later date. Travel plans are not a legitimate excuse for missing an exam.

Homework problems: After the completion of each section, homework problems will be handed out. You are supposed to return them within one week. Working them will greatly enhance your understanding of the material, your ability to use it in later courses, and your performance in this course. The graders will deduct points for solutions that are illegible or difficult to follow. Unexcused late problem sets will normally not be accepted. While you are encouraged to discuss the problems with your classmates, you are expected to write up and turn in the solutions by yourself. Solutions will be posted after the due date, and you are *strongly encouraged* to check your solutions against those posted.

Study groups and presentations: Study groups of four students will be formed. The goal is that these groups will prepare a report on one of the subjects or topics covered by the lecture by the end of the semester and in addition give a special 10 minute topical presentation on this topic. The reports and presentations should be prepared jointly by the group; special study material will be made available. A written out-line of the presentation and the final report should be submitted to me before mid-term break.

Semester Grade: The numerical grade is calculated at the end of the semester using the following approximate weighting: attendance & participation 10%, homework 20%, report 15%, presentation 15%, mid-term exam 20%, final exam 20%. The letter grade scale will be based on the performance of the class as a whole.

Course Material

No textbook is available! There is a broad spectrum of literature available addressing the various aspects and topics of the course. Unfortunately, most of the available textbooks are on the graduate student level and not suitable for this class from the pedagogical as well as the financial point of view. The presented material is rather complex and has therefore been collected from a wide variety of different sources. The class material will be made available at the web. To come to grasp with the class material additional study of recommended books will be necessary. A literature list is given below; the books have been ordered for the library and will be on hold for general use at the Physics/Chemistry Library in Nieuwland Science Hall:

M.J. Aitken; Science-based Dating in Archaeology, Longman, London 1990
Hesburgh Library General Collection: CC 78 .A39 1990

S. Bowman; Radiocarbon Dating; Univ. of California Press, Berkeley & Los Angeles 1990
Hesburgh Library General Collection: CC 78 .B68 1990

E. Ciliberto & G. Spoto; Modern Analytical Methods in Art and Archeology; Wiley, New York 2000
Hesburgh Library General Collection: N 8558 .M63 2000

D.C. Creagh & D.A. Bradley; Radiation in Art and Archaeometry; Elsevier, Amsterdam 2000
Chem/Physics (231 Nieuwland) General Collection: N 8558.2 .R33 R33 2000

S. Fleming; Dating in Archaeology; St. Martin's Press, New York, 1977
Hesburgh Library General Collection: CC 78 .F54 1977

H. E. Gove; From Hiroshima to the Iceman; Institute of Physics, Bristol & Philadelphia 1999
Chem/Physics (231 Nieuwland) General Collection: QC 454 .A25 G68 1999

N. Herz & E. Garrison; Geological Methods for Archaeology; Oxford Univ. Press, Oxford 1999
Hesburgh Library General Collection: CC 77.5 .H47 1998

S. Johansson, J. Campbell & K. Malmquist; Particle-Induced X-Ray Emission Spectrometry (PIXE); John Wiley & Sons, New York 1995
Chem/Physics (231 Nieuwland) General Collection: QD 96 .X2 P37 1995

J. Lang & A. Middleton; Radiography of Cultural Material; Butterworth Heinemann, Oxford 1997
Hesburgh Library General Collection: N 8558 .R33 1997

J. Lilley; Nuclear Physics – Principles and Applications; Wiley & Sons, New York 2001
Chem/Physics (231 Nieuwland) General Collection: QC 776 .L45 2001

A. M. Sackler Colloquia; Scientific Examination of Art; National Academics of Science Press, Washington, DC 2002
http://www.nap.edu/catalog.php?record_id=11413

W. S. Taft, J. W. Mayer; The Science of Paintings; Springer Verlag, New York 2000
Chem/Physics (231 Nieuwland) General Collection: ND 1143 T34 2000

C. Tuniz, J. R. Bird, D. Fink, G. F. Herzog; Accelerator Mass Spectrometry; CRC Boca Raton 1998
Chem/Physics (231 Nieuwland) General Collection: QC 454 A25 A25 1998

M. Uda, G. Demortier, I, Nakai; X-Rays for Archaeology; Springer Verlag, Dordrecht 2005

F. Watt & G.W. Grime; Principles and Applications of High-Energy Ion Microbeams; Adam Hilger, Bristol 1987
Chem/Physics (231 Nieuwland) General Collection: QC 702.7 .B65 P75 1987

Course Content

1. Physics Background and Techniques

1.1. Goals and Purpose of Archaeometry

1.2. Principles of Atomic Spectroscopy

1.3. Principles of Nuclear Decay and Reaction Processes

1.4. Natural Radioactivity – Dangers and Opportunities

1.5. Tools and Techniques

2. Analytical Methods in Art and Archaeology

2.1. Principles of X-Ray Sources and Absorption Techniques

2.2. Radiography with X-rays
Examples: analysis of paintings and sculpture

2.3. Principles of X-Ray Fluorescence (XRF)
Examples: analysis of violin varnish; analysis of paintings, analysis of ink and medieval book illustrations;

2.4. Principles of Proton induced X-ray Emission (PIXE)
Examples: pottery and ancient burning techniques; metal and solder techniques; letter and paper forgeries

2.5. Principles of Infrared, Raman and Visible Spectroscopy Methods
Examples: pigment analysis in paintings

2.6. Principles of Neutron induced Activation Analysis
Examples: Origin of ceramic or coinage material (trade); Provenance of Qumran scrolls; Quality comparison with X-Ray Radiography

2.7. Isotope Analysis and Isotope Separation
Examples: Antique mining industry, Provenance of ancient metal

3. Isotope Analysis and Dating Methods

3.1. Basic Principles of Radiocarbon Dating

3.2. Examples for Radiocarbon Dating: The spread of African iron industry; Age of Stonehenge; Caucasian mummies in Central Asia; Noah's flood

3.3. Basic Principles of Anthropological Dating techniques (Ar-K/U-Th-dating)
Examples: the cradle of mankind; the spread of mankind

3.4. Accelerator Mass Spectroscopy
Example: the Iceman; the Turin Shroud

3.5. Carbon Contamination and Fractionation Problems
Examples: North American eating habits; the Norsemen as vegetarians; problems with the dating of the Shroud

3.6. Luminescence Dating
Examples: Stone-Age tools and Weapons; the Fate of the Neanderthals; Modern forgeries

4. Bioanalytic Techniques

4.1. DNA analysis

4.2. Examples of DNA techniques (Brother Neanderthal?)