NUCL 420
Radiation Interaction with Materials and Applications
Fall 2024

Course Time: Monday, Wednesday, and Friday, 9:30 - 10:20 a.m.
Course Location: GRIS 118
Instructor: Prof. Ahmed Hassanein
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Office: POTR 376C
Office hours: Anytime and/or with prior appointment
Prerequisites NUCL 320
Co-requisites N/A

Catalogue Description

NUCL 420: *Radiation Interaction with Materials and Applications* The course covers the fundamentals of ion and neutron interaction with materials and applications. The course introduces students to the types of radiation and radiation sources, physical mechanisms of ion and neutron interaction with solids, radiation damage, ion beam mixing, applications in nuclear fission and fusion reactors and materials modification and synthesis by ion beams.

Textbook

Michael Nastasi, et al, *Ion-Solid Interactions: Fundamentals and Applications*, Cambridge University Press, 1996, ISBN 0-521-61606-9.

Reference Books

Gary S. Was, *Fundamentals of Radiation Materials Science: Metals and Alloys*, Springer, 2007, ISBN 978-3-540-49471-3.

Donald R. Olander, *Fundamental Aspects of Nuclear Reactor Fuel Elements*, ERDA Technical Information Center, 1976.

Additional Reading Material

Instructor may provide the students with additional materials to further help their understanding.

Course Objectives

In this course students will

- Learn the types and sources of ion and neutron radiation
- Understand the physical mechanisms of ion and neutron interaction with materials and model ion interactions quantitatively using simulation and other methods
- Understand and model the phenomenon of radiation damage to bulk, surfaces and interfaces using simulation and other methods
- Relate the concepts of radiation damage to neutron interaction with solids in both fission and fusion reactors
- Understand the technological applications of ion interactions with materials

Grading

Grades: ~~A- through A+: 85% - 100%; B- though B+: 75% - 84%; C- through C+: 65% - 74%; D- through D+: 50% - 64%; F <49%~~ Curve grading will be applied

Weighting:

20% Homework
20% Project
30% Mid Exam 1
30% Final Exam 2

Homework Policy

Several homework assignments will be given during the semester. Homework solutions and other assignments should be returned at the beginning of the hour on the date they are due. Solutions will be graded and handed back to students. The assignments are intended to show the application of lecture material and help students prepare for other tests. As such, individual work is essential. The solution steps and the approach followed must be made clear to the grader. Students are allowed to collaborate on solving homework problems but that should be limited to discussing the approach only. Unless indicated otherwise, each student is expected to work on the homework assignments independently. Copying solutions of others is considered plagiarism.

The following header should be printed on the top of each solution page:

> Last name, First name
> NUCL 420 Homework Assignment #

A cover page with the same information should also be used with each assignment.

Project

As a part of class work, students will be assigned research projects. A list of topics will be provided by the instructor during the second week of classes (following the introductory section of the course). Project grading policy and roles of undergraduate and graduate students will be explained then. The project topics include, but are not limited to, radiation damage and defect production in materials, defect diffusion, sputtering processes, and surface and bulk induced effects of radiation.

The project presentation is due date will be announced in advance. The students presentations will be given prior to the scheduled class final exam.

Attendance Policy

Regular attendance is mandatory. Students who have an excused absence are responsible for all material covered during class and for assignments and exams. Excused absences include documented illness, deaths in the family and other documented crises, call to active military duty or jury duty, religious holidays, and official University activities. These absences will be accommodated in a way that does not arbitrarily penalize students who have a valid excuse. Consideration will also be given to students whose dependent children experience serious illness.

Academic Honor Policy

Students are expected to conduct all class related work with the highest level of honesty and integrity. Cheating, plagiarism, and other forms of academic dishonesty will be prosecuted according to the Purdue University policy.

Course Contents

1. Course Introduction
   – Sources and types of radiation
   – Mechanisms of radiation interaction with materials
   – Relevance to nuclear science and engineering
   – Non-nuclear applications (materials and devices)
   – Basic concepts
   – Scope of the course

2. Interatomic Potentials
   – Interatomic forces, short and long-interaction forces
   – Model interatomic potentials
   – Bonding and properties of solids
   – The role of electrons in interactions in solids

3. Binary Elastic Collisions
   – Kinematics of elastic collisions
   – Two-particle scattering theory; energy and momentum conservation
   – Angular orbital momentum and the impact parameter
   – Classical scattering integral

4. Cross Section
   – Angular differential scattering cross section
   – Energy transfer cross section

5. Stopping and Range of Ions in Solids
   – The energy loss process
   – Nuclear stopping
   – ZBL nuclear stopping cross section; ZBL universal screening function
   – Electronic stopping
   – Ion range in solids and related statistical aspects

6. Radiation Damage
   – Concept of radiation damage
   – Atomic displacements and displacement energy
   – Damage produced by energetic ions
   – Damage production rates
   – Polyatomic materials
   – Spikes and replacement collision sequences
   – Morphological aspects of damage
   – Irradiation enhanced diffusion

7. Simulation Techniques
   – Monte Carlo method

– Molecular dynamics method
– Computer simulation codes

8. Ion Implantation and Ion Beam Mixing
   – Implanted ion depth distribution and phase formation
   – Atomic intermixing and alloying at material interfaces
   – Recoil and cascade mixing
   – Thermodynamic effects in ion mixing
   – Thermally assisted ion mixing regime

9. Physical Sputtering
   – Theory of sputtering
   – Models and empirical formulas
   – Sputtering from thermal spikes
   – Sputtering of alloys
   – Computer simulation

10. Neutron Damage and Radiation Effects in Reactor Materials
   – Damage cross sections
   – Damage rates for neutron and connection with neutron fluxes
   – Consequences of radiation damage in reactor materials (material property changes)

EMERGENCY PREPAREDNESS LECTURE

As we begin this semester, I want to take a few minutes and discuss emergency preparedness. Purdue University is a very safe campus and there is a low probability that a serious incident will occur here at Purdue. However, just as we receive a "safety briefing" each time we get on an aircraft, we want to emphasize our emergency procedures for evacuation and shelter in place incidents. Our preparedness will be critical if an unexpected event occurs.

Emergency preparedness is your personal responsibility. Purdue University is actively preparing for natural disasters or human-caused incidents with the ultimate goal of maintaining a safe and secure campus. Let's review the following procedures:

• For any emergency call **911**.

• There are nearly 300 Emergency Telephone Systems throughout campus that connect directly to the Purdue Police Department (PUPD). If you feel threatened or need help, push the button and you will be connected to the PUPD.

• If we hear a fire alarm we will immediately evacuate the building and proceed to **the Emergency Assembly Area at the East end of the Main Aisle of Stewart Center on the First Floor (Near the doors that go outside to the Memorial Union).**

- **Do not use the elevator.**
- Go over evacuation route…see specific Building Emergency Plan.

• If we are notified of a Shelter in Place requirement for a tornado warning we will shelter in the lowest level of this building away from windows and doors. Our preferred location is **Basement Hallway**.

• If we are notified of a Shelter in Place requirement for a hazardous materials release we will shelter in our classroom shutting any open doors and windows.

• If we are notified of a Shelter in Place requirement for a civil disturbance such as a shooting we will shelter in a room that is securable preferably without windows.

(NOTE: Each building will have different evacuation & shelter locations. The specific Building Emergency Plan will provide specific locations and procedures)
Attached to the syllabus is an "Emergency Preparedness for Classrooms" sheet that provides additional preparedness information. Please review the sheet and the Emergency Preparedness website for additional emergency preparedness information.

EMERGENCY PREPAREDNESS SYLLABUS ATTACHMENT

Emergency Notification Procedures are based on a simple concept: if you hear a fire alarm inside, proceed outside. If you hear a siren outside, proceed inside.

• **Indoor Fire Alarms** mean to stop class or research and immediately **evacuate** the building or proceed to your Emergency Assembly Area away from building doors. **Remain outside** until police, fire, or other emergency response personnel provide additional guidance or tell you it is safe to leave.

• **All Hazards Outdoor Emergency Warning Sirens** mean to immediately seek shelter (**Shelter in Place**) in a safe location within the closest building. "Shelter in place" means seeking immediate shelter inside a building or University residence. This course of action may need to be taken during a tornado, a civil disturbance including a shooting or release of hazardous materials in the outside air. Once safely inside, find out more details about the emergency*. **Remain in place** until police, fire, or other emergency response personnel provide additional guidance or tell you it is safe to leave.

**In both cases, you should seek additional clarifying information by all means possible…Purdue Home page, email alert, TV, radio, etc…review the Purdue Emergency Warning Notification System multi-communication layers at:*
http://www.purdue.edu/ehps/emergency_preparedness/warning-system.html

EMERGENCY RESPONSE PROCEDURES:

• Review the **Emergency Procedures Guidelines**
https://www.purdue.edu/emergency_preparedness/flipchart/index.html

• Review the **Building Emergency Plan** (available from the building deputy) for:
- evacuation routes, exit points, and emergency assembly area
- when and how to evacuate the building
- shelter in place procedures and locations
- additional building specific procedures and requirements.

EMERGENCY PREPAREDNESS AWARENESS VIDEOS

"Shots Fired on Campus: When Lightning Strikes," is a 20-minute active shooter awareness video that illustrates what to look for and how to prepare and react to this type of incident. See: http://www.purdue.edu/securePurdue/news/2010/emergency-preparedness-shots-fired-on-campus-video.cfm (Link is also located on the EP website)

MORE INFORMATION

Reference the Emergency Preparedness web site for additional information:
http://www.purdue.edu/emergency_preparedness