SCHOOL OF PHARMACY AND HEALTH SCIENCES

COURSE: CHE 2308: Nuclear Chemistry
LECTURER: Prof. Edith Amuhaya
CREDIT: 3.0 units
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COURSE DESCRIPTION

Nuclear chemistry is the branch of chemistry that deals with the structure, stability, and transformations of atomic nuclei. It focuses on radioactive decay processes such as alpha, beta, and gamma emission, as well as nuclear reactions including fission and fusion. The course introduces concepts of nuclear stability, binding energy, and decay kinetics, including half-life calculations. It also explores the production, detection, and behavior of radionuclides. Applications in medicine, energy production, environmental tracing, and radiometric dating are highlighted. Safety considerations in handling and exposure to radiation are also an important component of the course. This course aligns with SDG 3: Good Health and Well-being**,** through the use of radioisotopes in nuclear medicine for diagnosis, imaging, and cancer treatment (e.g., radiotherapy and PET scanning) as well as SDG 9: Industry, Innovation and Infrastructure**,** through applications in nuclear technology, materials analysis, and scientific innovation in radiochemistry and instrumentation.

Link to University Mission and Program Learning Outcomes:

- **High order thinking:** The ability to collect, analyze and evaluate information and formulate conclusions. Students develop and demonstrate the ability to think critically, analytically and creatively.
- **Literacy:** Competence in oral, written, quantitative, and technological skills. Students develop and demonstrate competency in oral and written communication as well as demonstrate scientific, quantitative and technological literacy.
- **Global understanding and multicultural perspective:** Awareness, knowledge and appreciation of both the diversity and commodity of cultures. Students acquire these perspectives through formal study of languages, history, literature and the arts and through working, studying and living cooperatively in a radically, ethnically, and

culturally diverse environment. Further, students acquire an understanding of economic, historical, political, geographic and environmental relationships on a global basis.

- **Preparedness for career:** Mastery of a field of knowledge and its multi-cultural and multinational application. Such mastery is accomplished through both formal study and various experienced forms of learning such as internships and field experiences.
- **Community service and development***:* A sense of being part of a community and a desire to be of service to it. Students are given opportunities to participate in community service, citizenship, or social action projects or activities.
- **Leadership and ethics***:* As part of their growth and development, students formulate and articulate the ethical standards which will guide their professional and personal lives.

Program Learning Outcomes
By the end of their training the graduates should be able to:

1. Produce pharmaceutical products utilizing appropriate procedures and standards;
2. Manage a supply chain for pharmaceutical materials and products;
3. Apply regulatory and ethical instruments that govern the practice of pharmacy;
4. Design therapeutic management regimens for patients;
5. Disseminate knowledge on health related issues;
6. Participate in health research

Expected Course Learning Outcomes
At the end of this course, a student should be able to:

1. Explain the discovery of radioactive elements
2. Identify and describe the types of radioactive decay
3. Carry out calculations based on decay kinetics of radioactive element.
4. Balance nuclear equations
5. Calculate binding energy of a radioactive element
6. Explain the concept of dating based on radioactive decay
7. Explain the processes of nuclear transformations and transmutations
8. Describe how a nuclear detector works
9. Describe fission and fusion
10. Explain the functions of nuclear reactors
11. Describe radiolabeling techniques in pharmaceuticals
12. Explain the effects of radiation
13. Describe the safety and protection of radiation
14. Identify applications of radiochemistry

COURSE CONTENT
WEEK 1
Course Learning Outcomes: 1
Overview of course outline
Introduction to Nuclear Chemistry

- History of radioactive elements
- Nature of Nuclear Reactions

Learning Outcomes

By the end of this week, students should be able to:

1. Define nuclear chemistry and explain its scope and relevance in science, medicine, energy, and industry.
2. Describe the fundamental nature of the atomic nucleus, including protons, neutrons, isotopes, and nuclear stability.
3. Explain the discovery of radioactivity and outline the historical development of radioactive elements.
4. Identify and discuss the key contributions of pioneering scientists such as Becquerel, Marie Curie, Pierre Curie, and Rutherford in the development of nuclear chemistry.
5. Relate historical milestones in radioactivity to the advancement of modern nuclear science and its applications.

Transformative Activities

1. Students construct a concept map linking terms such as protons, neutrons, isotopes, stability, and binding energy
2. Groups create a chronological timeline of key discoveries in radioactivity and nuclear chemistry (e.g., Becquerel, Curie, Rutherford).

WEEK 2
Course Learning Outcomes: 2,5
Nuclear stability and radioactive decay
Nuclear Binding Energy
Types of Radioactive Decay

- α- particle production
- Spontaneous fission

Learning Activities

By the end of this topic, students should be able to:

1. Explain the concept of nuclear stability and describe the factors that influence the stability of atomic nuclei, including neutron-to-proton ratio and binding energy.
2. Define nuclear binding energy and relate it to nuclear mass defect and the energy required to disassemble a nucleus.
3. Interpret the relationship between nuclear stability and radioactive decay processes.
4. Describe the mechanisms of alpha-particle emission and explain how it affects atomic and mass numbers of a nucleus.
5. Explain spontaneous fission as a mode of radioactive decay and identify conditions under which heavy nuclei undergo fission.

Transformative Activities

1. Nuclear Stability and Decay Prediction - Group Problem-Solving Activity
2. Binding Energy Visualization and Interpretation Exercise

WEEK 3

Course Learning Outcomes: 2

- Types of Radioactive Decay
    - β-particle production
    - positron production
    - Electron capture

Learning Outcomes

By the end of this topic, students should be able to:

1. Describe the general principles of radioactive decay and explain how unstable nuclei achieve stability through particle emission or capture.
2. Explain the mechanism of β^- (beta-minus) decay, including the conversion of a neutron into a proton and the emission of an electron and an antineutrino.
3. Describe positron emission (β^+ decay) and explain how the conversion of a proton into a neutron leads to the emission of a positron and a neutrino.
4. Explain the process of electron capture and describe how an inner orbital electron is absorbed by the nucleus, resulting in nuclear transformation.
5. Write and balance nuclear equations representing β^- decay, positron emission, and electron capture using conservation of mass number and atomic number.

Transformative Activities

1. Problem Based learning - Decay Detection challenge

WEEK 4

Course Learning Outcomes: 4

Balancing Nuclear Equations

Natural radioactivity

Learning Outcomes

By the end of this topic, students should be able to:

1. Explain the principles governing nuclear reactions, including the conservation of mass number and atomic number.
2. Balance nuclear equations for different types of radioactive decay, ensuring correct representation of emitted particles and resulting nuclei.
3. Identify and describe common forms of natural radioactivity, including alpha, beta, and gamma emissions from naturally occurring radionuclides.
4. Explain the origin of natural radioactivity in terms of unstable isotopes found in rocks, minerals, and the environment.
5. Relate natural radioactive processes to real-world applications such as radiometric dating, environmental tracing, and background radiation exposure.

Transformative Activities

1. Nuclear Equation Build-and-Balance Challenge
2. Natural Radioactivity Case Investigation

WEEK 5

Course Learning Outcomes: 3,6

Kinetics of Radioactive Decay

- Half- life

Dating Based on Radioactive Decay

- Radiocarbon dating

Learning Outcomes

By the end of this topic, students should be able to:

1. Explain the concept of radioactive decay as a first-order kinetic process and describe how the rate of decay is independent of external conditions.
2. Define half-life and apply it to quantify the rate of radioactive decay and predict the remaining amount of a radionuclide over time.
3. Solve numerical problems involving radioactive decay, including calculations of remaining nuclei, activity, and elapsed time.
4. Explain the principle of radiocarbon dating and describe how carbon-14 is used to determine the age of once-living materials.
5. Interpret radiocarbon dating data to estimate the age of archaeological or geological samples and discuss its limitations and assumptions.

Transformative Activities

1. Half-Life Simulation Activity
2. Radiocarbon Dating Case Study Challenge

WEEK 6
Course Learning Outcomes: 8
Instruments for Radiation Detection and Measurement

Learning Outcomes

By the end of this topic, students should be able to:

1. Explain the principles behind radiation detection and measurement, including the interaction of ionizing radiation with matter.
2. Describe the structure, working principles, and applications of key radiation detection instruments such as the Geiger–Müller counter, scintillation counter, and ionization chamber.
3. Distinguish between different types of radiation detectors based on their sensitivity, operating range, and suitability for alpha, beta, and gamma radiation.
4. Interpret basic readings from radiation detection instruments and relate them to radiation intensity and activity levels.
5. Evaluate the applications of radiation detection instruments in fields such as nuclear medicine, environmental monitoring, industrial safety, and research laboratories.

Transformative Activities
Problem-Based Learning - Radiation Detection Scenario Challenge

WEEK 7
Mid-Semester Exam

WEEK 8
Course Learning Outcomes: 7
Nuclear Transformations
- Particle accelerators
- Linear accelerators

Nuclear Transmutation
- Transuranium elements

Learning Outcomes

By the end of this topic, students should be able to:

1. Explain the concept of nuclear transformations and distinguish them from natural radioactive decay processes.
2. Describe the principles and functions of particle accelerators, including linear accelerators, in inducing nuclear reactions.

3. Explain how high-energy particles are used to initiate nuclear transmutation in target nuclei.
4. Describe the formation and significance of transuranium elements and outline their general methods of synthesis.
5. Discuss the applications of artificial nuclear transformations in research, medicine, energy production, and the synthesis of new elements.

Transformative Activities

1. Transmutation Simulation Exercises

WEEK 9
Course Learning Outcomes: 9,10
Nuclear Fission

- Nuclear chain reaction

Nuclear Fusion

Learning Outcomes

By the end of this topic, students should be able to:

1. Explain the process of nuclear fission and describe how heavy nuclei split into lighter nuclei with the release of energy.
2. Describe the concept of a nuclear chain reaction and distinguish between controlled and uncontrolled chain reactions.
3. Identify the conditions required to sustain a controlled nuclear chain reaction in nuclear reactors.
4. Explain the process of nuclear fusion and describe how light nuclei combine to form heavier nuclei with energy release.
5. Compare nuclear fission and nuclear fusion in terms of energy production, conditions required, and their applications in energy generation and natural phenomena.

Transformative Activities

1. Controlled vs Uncontrolled Fission

WEEK 10
Course Learning Outcomes: 10
Cyclotron produced radionuclides
Radionuclide generators

Learning Outcomes

By the end of this topic, students should be able to:

1. Explain the principle of cyclotron operation and describe how it is used to produce radionuclides through particle bombardment.
2. Identify common cyclotron-produced radionuclides and describe their applications in medicine, industry, and research.
3. Explain the concept and working principle of radionuclide generators, including parent–daughter decay relationships.
4. Describe commonly used generator systems (e.g., Mo-99/Tc-99m) and their importance in nuclear medicine.
5. Compare cyclotron production and generator systems in terms of production method, availability, and practical applications.

Transformative Activities

1. Radionuclide Generator Simulation
2. Students construct a process flow diagram tracing the production and use of cyclotron-produced radionuclides from initial target bombardment to final application in medicine or industry.

WEEK 11

Course Learning Outcomes: 11,14

Radiolabeling of compounds to prepare radiotracers and radiopharmaceuticals

- Radiolabeling methods
- Design of radiopharmaceuticals

Learning Outcomes

By the end of this topic, students should be able to:

1. Explain the concept of radiolabeling and its role in the preparation of radiotracers and radiopharmaceuticals.
2. Describe common radiolabeling methods used to incorporate radionuclides into chemical compounds without altering their biological behavior.
3. Identify key requirements for selecting suitable radionuclides for medical and diagnostic applications (e.g., half-life, type of radiation, stability).
4. Explain the principles guiding the design of radiopharmaceuticals, including targeting specificity, biodistribution, and safety considerations.
5. Relate the structure and properties of radiolabeled compounds to their applications in imaging and therapy, particularly in nuclear medicine.

Transformative Activities

1. Students construct a step-by-step visual pathway showing how a radiopharmaceutical is prepared, labeled, and used clinically.

WEEK 12
Course Learning Outcomes: 12,13,14
Effects of radiation

- Somatic damage
- Genetic damage

Factors that determine biologic effects
Safety and radiation protection
Applications of radiochemistry

Learning Outcomes

By the end of this topic, students should be able to:

1. Explain the biological effects of ionizing radiation, distinguishing between somatic damage and genetic (hereditary) damage.
2. Describe the mechanisms by which radiation interacts with biological tissues to cause cellular and molecular damage.
3. Identify and explain the key factors that influence the biological effects of radiation, including dose, dose rate, radiation type, and exposure duration.
4. Apply fundamental principles of radiation protection and safety, including time, distance, and shielding, in minimizing exposure risks.
5. Discuss the applications of radiochemistry in medicine, industry, and environmental science, highlighting both benefits and safety considerations.

Transformative Activities

1. Radiation Exposure Risk Analysis - Students are presented with real-life exposure scenarios involving radiation (e.g., hospital radiology staff, uranium mining workers, or accidental exposure in laboratories).

WEEK 13
Final Exam

WEEK 14
Final Exam

TEACHING METHODS

1. Lectures will be conducted using PowerPoint presentations, white board and marker, and class discussions.
2. Lectures will be given in class to explain to students various topics in nuclear chemistry.
3. Lectures will take a participatory approach where the instructor will involve students by frequently asking them questions that are meant to keep them alert and trigger class discussions
4. Assignment criteria: Students will be given several individual or group research assignments on topics relevant to the course. These could include lectures,

discovery learning, problem-based learning, experimental learning, group-based learning, independent studies and e-learning.
5. The instructor will answer questions from students in the course of the lectures and available during office hours for consultations.

CORE READING MATERIALS

CORE TEXT
Modern Nuclear Chemistry, 2017, by Walter D. Loveland, David . Morrissey and Glenn T Seaborg

RECOMMENDED TEXT
General Chemistry by Darell Ebbing and Steven Gammon, 9th or 10th Edition.

COURSE EVALUATION

Attendance and participation	10%
Group/Individual Assignments	15%
Continuous Assessment Test/Quiz	20%
Mid-Semester Exam	25%
Final Exam	30%
Total	1 00%

KEY INSTITUTIONAL ACADEMIC POLICIES

Students should note the following are key policies as outlined in the University Catalogue and Students Handbook.

1. Academic dishonesty

a. Any intentional giving or use of external assistance during an examination without the express permission of the faculty member giving the examination.
b. **Fabrication:** any falsification or invention of data, citation or other authority in an academic exercise;
c. **Plagiarism:** any passing off of another's ideas, words, or work as one's own;
d. **Previously Submitted Work:** presenting work prepared for and submitted to another course

2. More than seven absences from class will result in an automatic grade F

3. For the course to be considered complete student should:
   - Sit in for at least two Quizzes,
   - Hand in all assignments (individual and group) **on the due dates indicated in the course outline**.
   - Undertake all examinations (Mid semester and End semester examinations)

4. Please note that:
    a. No make ups are given for tests, assignments and exams except in cases outlined in the university examination policy.
    b. All references used to do assignments should be cited correctly
5. No student will be allowed to sit for examinations if they show up **20 minutes after the examination has been administered** (See the university policy)
6. A student who fails to take the mid semester exam due to reasons allowed by the university policy will be given an opportunity to sit for a special exam in week 10 of the same semester, provided they produce valid supporting documentation. It is the responsibility of the student to reach out to the faculty and provide the evidence for missing the exam before week 10.
7. A student who fails to sit for the end semester exam due to reasons allowed by the university will be given an opportunity to sit for a special exam on the third Friday of the subsequent semester, provided the student provides valid supporting documentation. It is the responsibility of the student to reach out to the faculty before the end of the semester, to give the reasons for missing the exam, provide the necessary evidence and request for the special exam.

ACCESSIBILITY & INCLUSION STATEMENT

USIU-Africa is committed to ensuring that all students, including those with disabilities, have equitable access to learning opportunities. If you anticipate or experience any barriers to learning, please contact the Disability Inclusion Department at inclusion@usiu.ac.ke. You are also encouraged to speak with me so we can work together to ensure you have the support you need to succeed in this course.

GRADING

A	90 -100
A-	87 - 89
B+	84 - 86
B	80 - 83
B-	77 - 79
C+	74 - 76
C	70 - 73
C-	67 - 69
D+	64 - 66
D	62 - 63
D-	60- 61
F	0 - 59