Unit title: Nuclear Chemistry

Unit code: **D/601/0418**

Level: **5**

Credit value: **15**

Aim

This unit provides learners with an understanding of stability and radioactive decay in isotopes. Applications of radioactive isotopes in chemistry and medicine, nuclear power and the impact of radioactivity on society and the environment are also explored.

Unit abstract

This unit is designed to provide comprehensive coverage of nuclear chemistry with many of the principles building on those gained in level 4 core units. The unit covers four broad areas with the intention of appealing to learners who wish to work in a nuclear-related industry or those who already work in the sector and wish to further develop their understanding of aspects of nuclear chemistry.

The unit commences with a study of aspects of nuclear structure and the criteria for nuclear stability. The use of a range of isotopes in spectroscopy, analysis and investigation of chemical reaction pathways is explored together with applications of radiotracers in medicine.

Aspects of nuclear power production relating to nuclear fuels, types of nuclear reactor and their operation and control are considered. Mining and enrichment of uranium ore, reprocessing used fuel and classification and management of waste are reviewed.

The unit concludes by considering the dangers of radiation exposure, nuclear power accidents and public perception of the use of nuclear power.

Learning outcomes

On successful completion of this unit a learner will:

1 Understand the behaviour of the nucleus

2 Understand the use of isotopes in chemistry and medicine

3 Understand the chemistry of the nuclear power industry

4 Be able to report on the impact of radioactivity on society and the environment.

Unit content

1 **Understand the behaviour of the nucleus**

Nuclear structure: nuclear size compared to radii of atom; proton and neutron properties, mass, charge; nuclear size, relationship of number of nucleons to the cube of the radius; density of nuclear matter; forces between nucleons including calculations of electrostatic and gravitational forces; graphical representations of attraction/repulsion against distance between centres; mass defect and binding energy including calculation of nuclear binding energy and average binding energy per nucleon

Nuclear stability and radioactive decay: nuclear stability in terms of number of neutrons to protons; interpretation of proton numbers vs neutron number plots

Spontaneous radioactive decay: calculations associated with the kinetics of decay; half-life; nuclear equations; decay series

Properties of alpha, beta and gamma radiation: penetrating power and behaviour in an electric field

Health and safety regulations: awareness of important regulations e.g. Ionising Radiations Regulations (1999), Radioactive Substances Act (1993), The Ionising Radiation (Medical Exposure) Regulations (2000)

2 **Understand the use of isotopes in chemistry and medicine**

Use of isotopes in spectroscopy: infrared spectroscopy, application of deuterium exchange reactions; multinuclear nuclear magnetic resonance spectroscopy e.g. ^{31}P nmr, ^{11}B nmr, ^{19}F nmr; nuclear spin quantum number; spin relaxation time; quadrupole moment; chemical shift ranges; spin-spin coupling; Mössbauer spectroscopy limited to basic principles and applications to inorganic chemistry

Use of isotopes in chemistry and analysis: kinetic isotope effects; application to mechanistic studies of chemical reactions; radiocarbon dating including calculations; use of radioisotopes in analytical applications e.g. solubilities of sparingly soluble salts, vapour pressures of involatile substances

Use of isotopes in medicine: radiotracers e.g. ^{131}I in thyroid gland analysis; cobalt as a source of gamma radiation for cancer treatment; technetium-99 in diagnostic radiopharmaceuticals; biochemical analysis e.g. radioimmunoassays; recent advances in radioisotope use; positron emission tomography (PET) with 18F tracer

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3 **Understand the chemistry of the nuclear power industry**

Nuclear fuels: fissile nuclei; uranium-233; uranium-235; plutonium-239; use of moderators (water/graphite); nuclear fission; chain reactions; uranium-238 as non-fissile but fertile in formation of fissile plutonium-239; nuclear fuels including enriched UO_2, natural UO_2, natural uranium/enriched UO_2, PuO_2 and UO_2

Nuclear power stations: diagrammatic structure of typical reactors found around the world (pressurised water reactors (PWR), boiling water reactor (BWR), pressurised heavy water reactor (CANDU), gas-cooled reactor (Magnox and AGR), light water graphite reactor and fast neutron reactor (FBR)); function mechanisms of different reactor types (fuel, moderator, control rods, coolant, pressure vessel, steam generator, containment)

Nuclear fuel cycle: mining and milling of uranium ore; enrichment including formation of uranium hexafluoride from uranium oxide; diffusion process; centrifuge enrichment; fuel element fabrication; nuclear wastes; classification and management of waste

Reprocessing used fuel: magnox and thermal oxide reprocessing from AGR/light water reactors; use of nitric acid; chemical separation; formation of mox; formation of uranium fuel pellets; vitrification of wastes

4 **Be able to report on the impact of radioactivity on society and the environment**

Radiation units: rem; millirem; rads; curie; becquerel; gray; sievet

Radiation exposure: background radiation; radiation dosage; environmental radiation exposure; acute radiation exposure; biological effects of radiation e.g. radiation sickness; European dosage limits

Nuclear power accidents: causes and consequences of nuclear accidents; examples and case studies of nuclear power station accidents e.g. Chernobyl, Three Mile Island, Windscale UK, Chalk River Island, Canada; environmental monitoring

Nuclear power and society: public perceptions and media reporting; nuclear power station safety; nuclear power as a future energy source; potential of nuclear fusion

Learning outcomes and assessment criteria

Learning outcomes **On successful completion of this unit a learner will:**	**Assessment criteria for pass** **The learner can:**
LO1 Understand the behaviour of the nucleus	1.1 explain nuclear structure using specified calculations 1.2 discuss factors affecting nuclear stability 1.3 explain radioactive decay using specified equations 1.4 discuss the properties of alpha, beta and gamma radiation 1.5 review health and safety regulations governing working with radioactive materials
LO2 Understand the use of isotopes in chemistry and medicine	2.1 explain the application of isotopes in spectroscopy 2.2 explain the application of isotopes in chemical reactions and analysis 2.3 discuss the applications of radioisotopes to medicine
LO3 Understand the chemistry of the nuclear power industry	3.1 explain how nuclear fuels function 3.2 explain the function of different types of nuclear power station 3.3 explain the nuclear fuel cycle 3.4 discuss methods used in the reprocessing of spent fuels
LO4 Be able to report on the impact of radioactivity on society and the environment	4.1 define the units used in measuring radiation 4.2 report on biological effects of radiation exposure 4.3 draw conclusions from investigations into nuclear power station accidents 4.4 review public perceptions of nuclear power

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Guidance

Links

This unit has particular links with the following units within this qualification:

- *Unit reference number R/601/0349: Inorganic Chemistry*
- *Unit reference number Y/601/0353: Physical Chemistry*
- *Unit reference number M/601/0410: Analytical Chemistry*
- *Unit reference number R/601/0416: Medicinal Chemistry*
- *Unit reference number F/601/0413: Industrial Chemistry*

Essential requirements

Delivery

Where appropriate, the unit content must be exemplified by case studies, problems and practical exercises. For some topics the delivery of material can be emphasised by viewing relevant DVD programmes or online research. Illustrative material must be selected to emphasise the relevance of the learning outcomes to everyday life or industrial application.

Assessment

For learning outcome 1, assessment must confirm learners' understanding of the behaviour of the nucleus in terms of factors that affect nuclear stability and determine radioactive decay. An appreciation of the characteristic properties of alpha, beta and gamma radiation must be clearly demonstrated.

Learning outcome 2 must assess the use of isotopes in chemistry and medicine. Examples should be selected that demonstrate learners' abilities to explain the application of isotopes in studying reaction mechanisms as well as their use as a tool in analytical chemistry. Spectroscopic applications including multinuclear magnetic resonance spectroscopy should also be assessed in terms of analytical applications. Learners must demonstrate ability to research and discuss specific examples of the usefulness of radioisotopes in diagnostic medicine.

For learning outcome 3, assessment must confirm learners' understanding of the facets of nuclear power with particular emphasis on nuclear fuels, power generation in a variety of nuclear reactors and the enrichment and reprocessing of nuclear fuel.

For learning outcome 4, assessment must confirm learners' abilities to review the impact of radioactive materials and processes, on society and the environment.

Resources

Learners will need access to library and information technology resources, tutorial and technical support.

Employer engagement and vocational contexts

Visits to local industry, for example nuclear power stations, hospital medical physics departments, universities operating nuclear magnetic resonance equipment or radioisotope environmental monitoring units will enhance the delivery of this unit.