Unit title: Atomic and Nuclear Physics for Spectroscopic Applications

Unit code: **Y/601/0417**

Level: **4**

Credit value: **15**

Aim

This unit provides an understanding of the underlying atomic and nuclear physics involved in the processes of spectroscopy and matter analysis.

Unit abstract

Understanding the structure of compounds on an atomic and molecular level is an important part of modern analytical chemistry. This can be carried out directly, by viewing individual atoms with a scanning tunnelling electron microscope, or indirectly through methods such as infrared spectroscopy. This unit aims to develop learners' knowledge and understanding of the structure of the atom gained in the core units and extend it so that learners gain an understanding of the principles of spectroscopy and matter analysis.

Starting with an overview of quantum theory and the particle-wave nature of matter, the unit covers the key processes behind electron transitions. This directly leads to an understanding of electromagnetic wave spectroscopy, specifically optical and ultraviolet. Other wavelengths involve different processes within the atom and infrared, x-ray and gamma ray spectroscopy are explored in turn.

The use of charged particles in matter analysis is examined by exploring the interaction between charge and electromagnetic fields. This leads into an examination of the construction and operation of the electron microscope and the mass spectrometer. The unit concludes with an overview of how the nucleus of the atom is being used increasingly in analytical chemistry, through the use of neutron scattering and nuclear magnetic resonance.

Learning outcomes

On successful completion of this unit a learner will:

1 Understand the behaviour of matter in an atomic scale

2 Understand spectroscopic methods that use electromagnetic waves

3 Understand matter analysis methods that use charged particles

4 Understand spectroscopic methods that use the nucleus of an atom.

Unit content

1 **Understand the behaviour of matter in an atomic scale**

Quantum theory: Planck's model of radiation; the photoelectric effect; Einstein's solution to the photoelectric effect; quanta and photons

Particle-wave duality: de Broglie's hypothesis; particle versus radiation wavelengths e.g. electrons vs light; experimental evidence e.g. Compton scattering, electron diffraction; Heisenberg uncertainty principle

Model of the atom: concept of spin; magnetic moment; Bohr's model of hydrogen; overview of the quantum mechanical model; quantum numbers; electron orbitals

Electron transitions: Pauli exclusion principle; selection rules for transitions; Hund's rules

2 **Understand spectroscopic methods that use electromagnetic waves**

Optical spectroscopy: emission spectra eg Balmer series of hydrogen; absorption spectra; continuous spectra; fine structure; effect of external magnetic fields on spectra; the use of optical spectra in determining sample composition

High energy spectroscopy: transitions involving ultraviolet radiation; ultraviolet fluorescence spectrometers; sources of x-rays; synchrotron radiation; Bragg's law; x-ray diffraction of metals and crystals; sources of gamma rays; Mössbauer absorption spectroscopy

Infrared spectroscopy: simple harmonic motion; resonance; modes of vibration; quantisation of vibration; infrared spectra for common organic compounds e.g. alcohols

3 **Understand matter analysis methods that use charged particles**

Electromagnetic fields and charge: description of electromagnetic fields; effects of electromagnetic fields on charged particles; particle acceleration; energy gained in a field

Electron microscopes: electron sources; thermionic emission; field emission; electron diffraction; transmission electron microscopes; tunnelling electron microscopes; resolution limits

Mass spectrometers: structure of a mass spectrometer; mode of operation of mass spectrometers; use of mass spectra in determining relative atomic mass; use of mass spectra in determining molecular structure

4 **Understand spectroscopic methods that use the nucleus of an atom**

Nuclear structure: nucleons; nuclear shell structure; magic numbers; strong nuclear force; nuclear stability; modes of decay; neutron emission

Neutron spectroscopy: neutron sources; neutron energy levels; neutron detectors; neutron diffraction; health risks associated with using neutrons

Nuclear magnetic resonance: nucleon spin; nuclear magnetic moment; nuclear energy levels; nuclear magnetic resonance condition; Nuclear Magnetic Resonance (NMR) spectroscopy

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 matter in an atomic scale	1.1 explain the relationship of quantum theory to the atomic structure of matter 1.2 evaluate the particle-wave nature of the components of atoms for given energy levels 1.3 justify the use of quantum theory in the model of an atom 1.4 evaluate electron transitions for hydrogen-like atoms
LO2 Understand spectroscopic methods that use electromagnetic waves	2.1 compare the optical spectra of elements to their electronic structure 2.2 evaluate the lattice structure of a specific metal using high energy spectroscopy 2.3 discuss the molecular structure and vibrational modes of an organic compound with reference to infrared spectra
LO3 Understand matter analysis methods that use charged particles	3.1 explain the effects of electromagnetic fields on charged particles 3.2 explain the operation and applications of electron microscopy 3.3 determine the molecular structure of compound using data gathered via mass spectroscopy
LO4 Understand spectroscopic methods that use the nucleus of an atom	4.1 explain the nuclear structure of an atom 4.2 compare the use of neutron spectroscopy in matter analysis against electromagnetic wave forms of spectroscopy 4.3 explain the operation of an imaging device that uses nuclear magnetic resonance

Guidance

Links

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

- *Unit reference number R/601/0352: Organic Chemistry*
- *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 T/601/0411: Environmental Chemical Analysis*
- *Unit reference number D/601/0418: Nuclear Chemistry.*

Essential requirements

Delivery

Where possible, the unit must be delivered using a combination of theory and practical experiments. Access to mass spectrometers, NMR machines etc could be achieved through arranged visits to analytical, research or medical facilities. The content is sufficiently flexible that this can be biased towards the specialist knowledge of the member of staff concerned as long as the basic understanding of the links are made between the chemistry and the theoretical physics. A strongly mathematical approach should be avoided, although the basic formulae such as $E=hf$ and the key physics behind the processes, such as spin and magnetic moments, must be covered. There are opportunities for learners to research and summarise evidence for themselves.

Assessment

Learning outcome 1 involves the fundamental physics behind the principles of spectroscopy and matter analysis. Evidence may be integrated with evidence from learning outcomes 2 and 3. Evidence should contain example calculations involving the key formula involved.

Learning outcomes 2 and 3 involve the application of the knowledge and principles from learning outcome 1 to electromagnetic wave spectroscopy, electron microscopes and mass spectrometers. The evidence should include case studies or experimental studies, where appropriate.

Learning outcome 4 involves the fundamental physics behind the use of neutrons in matter analysis and nuclear magnetic resonance spectroscopy.

Resources

This unit requires that learners can access suitable optical spectrometers and spectral sources (at least hydrogen and sodium lamps). Ideally, electron tubes to demonstrate electromagnetic deflection of charged particles and particle diffraction should be available. A demonstration of quantum theory in practice and a measurement of Planck's constant can be carried out via the use of LEDs.

Employer engagement and vocational contexts

Learners will benefit from visits to industrial and research facilities to observe practical applications of spectrophotometers.

