CHEM3111/3911

Organic Structure and Reactivity
(updated March 2015)

6 credit points. Session: Semester 1. Classes: Two 1hr lectures & 4 hrs prac.

Lecturers: Professor Kate Jolliffe and A/Professor Matthew Todd
Timetable: Mondays and Tuesdays at 10am

The structure and shape of organic molecules determines their physical properties, their reaction chemistry as well as their biological/medicinal activity. The determination of this structure and understanding its chemical consequences is of fundamental importance in chemistry, biochemistry, medicinal and materials chemistry. This course examines the methods and techniques used to establish the structure of organic molecules as well as the underlying principles that dictate molecular shape and reactivity. The first part of the course examines the use of modern spectroscopic methods (nuclear magnetic resonance spectroscopy, infrared spectroscopy and mass spectrometry), which are used routinely to identify organic compounds. The second part of the course examines the chemical consequences of molecular shape in more depth and looks at the inter-relationship between molecular shape and the processes by which bonds are made and broken (the reaction mechanism). An understanding of these processes allows the outcome of reactions to be predicted, which is an essential tool enabling the construction of complex molecules from simple starting materials.

Recommended Textbook:
- Organic Structures from Spectra, L D Field, S Sternhell and J R Kalman, 5th edn (John Wiley and Sons, 2013)

Reference:
Lecture Summary

Lectures 1-2

• General principles of absorption spectroscopy
  ▪ relationships between spectroscopic transitions, energy levels, wavelengths and frequency
  ▪ key concepts of chromophore, structural element, connectivity and sensitivity
• Mass Spectrometry
  ▪ different methods of ionisation (EI, CI, electrospray, laser desorption)
  ▪ low and high resolution mass spectra
  ▪ molecular ion and fragment peaks
  ▪ common fragmentation pathways
• Ultraviolet (UV) and Infrared (IR) spectroscopy
  ▪ practical considerations – basic structure of IR and UV spectrometers, sample size, sample preparation
  ▪ quantitative aspects of UV spectroscopy - “important chromophores” in UV and IR

Lecture 3-4

• Nuclear Magnetic Resonance (NMR) spectroscopy.
  ▪ the physics of NMR (descriptive) nuclear spin and nuclear spin quantum numbers.
  ▪ basic structure of an NMR spectrometer and NMR spectra
  ▪ the Chemical shift - the dimensionless chemical shift scale
  ▪ low- and high-field chemical shifts
  ▪ solvent effects
  ▪ integration and the analysis of mixtures
  ▪ \(^1\text{H}\) chemical shifts and correlation with molecular structure
  ▪ shielding zones around Ar, CO, C=C, C≡C groups (qualitative)
Lectures 5-6

• $^1$H-$^1$H Spin-spin coupling
  ▪ physical causes of hyperfine structure in NMR spectra
  ▪ chemical and magnetic equivalence
• Splitting diagrams and spectral analysis
• Strongly and weakly coupled systems
  ▪ conventions for naming spin-systems, rules for spectral analysis
  ▪ extended first-order analysis of spin-systems
  ▪ correlation of $^1$H-$^1$H spin-spin coupling constants with structure
  ▪ homonuclear decoupling as an aid to solving spectra

Lecture 7

• $^{13}$C NMR
  ▪ characteristic chemical shifts
  ▪ coupled, broad-band decoupled and off-resonance decoupled spectra
  ▪ the DEPT spectrum (descriptive)

Lecture 8

• Dynamic NMR – Chemical exchange
• Nuclear Overhauser Effect (NOE)
  ▪ establishing the 3D geometry (stereochemistry) of molecules with NOE
  ▪ $r^{-6}$ dependence
• Two-dimensional NMR spectroscopy
  ▪ COSY, NOESY and C-H correlation

Lectures 9-13

• Determining the structures of compounds from spectra
  ▪ a series of five problem-solving workshops will be held in weeks 5-9, one per week, alternating with the first five lectures described below.

Lectures 14-16

• Stereoisomerism
  ▪ revision of stereoisomerism from Chemistry 1
• Conformational analysis
  ▪ acyclic alkanes, cyclic alkanes: torsional, steric and ring strains
  ▪ chair and boat conformations of 6-membered rings
  ▪ equatorial and axial substituents
  ▪ conformations of mono-, di-, tri-substituted cyclohexanes
  ▪ conformations of decalin and steroids
• $^1$H NMR and the Karplus equation
  ▪ heterotopicity and determination of conformation
  ▪ determination of relative stereochemistry
Lecture 17

- Frontier molecular orbitals and organic chemical reactions
  - the inter-relationship of stereochemistry and reactivity
  - stereochemistry of reactive intermediates – carbocations, organometallics, radicals

Lectures 18-20

- Nucleophilic substitution at sp³ carbon
  - retention, inversion and racemisation
  - neighbouring group effects, meso and C₂-symmetric intermediates
  - opening epoxides, trans-diaxial ring opening

Lectures 21-23

- Addition reactions to alkynes and alkenes
  - regiochemistry and stereochemistry in cyclic and acyclic systems
  - bromonium ions: stereochemistry of bromination and bromohydrin formation
  - hydrogenation, hydroxylation, hydrohalogenation, hydroboration
  - acetoxymercuration: regio- and stereochemical comparisons

Lecture 24

- Elimination reactions
  - stereochemical and conformational effects in E1, E2 reactions

Lectures 25-26

- Pericyclic reactions
  - electrocyclic reactions
  - cycloaddition reactions
  - sigmatropic rearrangements