Core topics

Essential idea: Medicines and drugs have a variety of different effects on the functioning of the body.

D.1 Pharmaceutical products and drug action

Nature of science:

Risks and benefits—medicines and drugs go through a variety of tests to determine their effectiveness and safety before they are made commercially available. Pharmaceutical products are classified for their use and abuse potential. (4.8)

Understandings:

- In animal studies, the therapeutic index is the lethal dose of a drug for 50% of the population (*LD50*) divided by the minimum effective dose for 50% of the population (*ED50*).
- In humans, the therapeutic index is the toxic dose of a drug for 50% of the population (*TD50*) divided by the minimum effective dose for 50% of the population (*ED50*).
- The therapeutic window is the range of dosages between the minimum amounts of the drug that produce the desired effect and a medically unacceptable adverse effect.
- Dosage, tolerance, addiction and side effects are considerations of drug administration.
- Bioavailability is the fraction of the administered dosage that reaches the target part of the human body.
- The main steps in the development of synthetic drugs include identifying the need and structure, synthesis, yield and extraction.
- Drug–receptor interactions are based on the structure of the drug and the site of activity.

International-mindedness:

- In some countries certain drugs are only available with prescription while in other countries these same drugs are available over the counter.

Theory of knowledge:

- The same drug can be identified by different names. Are names simply labels or do they influence our other ways of knowing?
- Drugs trials use double blind tests. When is it ethically acceptable to deceive people?
- All drugs carry risks as well as benefits. Who should ultimately be responsible for assessing these? Public bodies can protect the individual but also limit their freedom. How do we know what is best for society and the individual?

Aims:

- **Aim 9**: There have been advances in the development of pharmaceuticals, but there are many limitations to their impact and reach.
- **Aim 10**: The development of new medicines is often done in collaboration with biologists and physicists.

D.1 Pharmaceutical products and drug action	
Applications and skills: • Discussion of experimental foundations for therapeutic index and therapeutic window through both animal and human studies. • Discussion of drug administration methods. • Comparison of how functional groups, polarity and medicinal administration can affect bioavailability. **Guidance:** • For ethical and economic reasons, animal and human tests of drugs (for LD_{50}/ED_{50} and TD_{50}/ED_{50} respectively) should be kept to a minimum.	

Essential idea: Natural products with useful medicinal properties can be chemically altered to produce more potent or safer medicines.

D.2 Aspirin and penicillin

Nature of science:

Serendipity and scientific discovery—the discovery of penicillin by Sir Alexander Fleming. (1.4)

Making observations and replication of data—many drugs need to be isolated, identified and modified from natural sources. For example, salicylic acid from bark of willow tree for relief of pain and fever. (1.8)

Understandings:

Aspirin:

- Mild analgesics function by intercepting the pain stimulus at the source, often by interfering with the production of substances that cause pain, swelling or fever.
- Aspirin is prepared from salicylic acid.
- Aspirin can be used as an anticoagulant, in prevention of the recurrence of heart attacks and strokes and as a prophylactic.

Penicillin:

- Penicillins are antibiotics produced by fungi.
- A beta-lactam ring is a part of the core structure of penicillins.
- Some antibiotics work by preventing cross-linking of the bacterial cell walls.
- Modifying the side-chain results in penicillins that are more resistant to the penicillinase enzyme.

International-mindedness:

- Aspirin is used in many different ways across the globe.
- The first antibacterial changed the way that disease was treated across the globe.

Theory of knowledge:

- Different painkillers act in different ways. How do we perceive pain, and how are our perceptions influenced by the other ways of knowing?
- “Chance favours only the prepared mind.” (Louis Pasteur). Fleming’s discovery of penicillin is often described as serendipitous but the significance of his observations would have been missed by non-experts. What influence does an open-minded attitude have on our perceptions?

Utilization:

Syllabus and cross-curricular links:
Topic 1.3—yield of reaction
Topic 10.2—functional groups
Biology topic 6.3—defence against infectious disease

D.2 Aspirin and penicillin	
Applications and skills: *Aspirin* • Description of the use of salicylic acid and its derivatives as mild analgesics. • Explanation of the synthesis of aspirin from salicylic acid, including yield, purity by recrystallization and characterization using IR and melting point. • Discussion of the synergistic effects of aspirin with alcohol. • Discussion of how the aspirin can be chemically modified into a salt to increase its aqueous solubility and how this facilitates its bioavailability. *Penicillin* • Discussion of the effects of chemically modifying the side-chain of penicillins. • Discussion of the importance of patient compliance and the effects of the over-prescription of penicillin. • Explanation of the importance of the beta-lactam ring on the action of penicillin. **Guidance:** • Students should be aware of the ability of acidic (carboxylic) and basic (amino) groups to form ionic salts, for example soluble aspirin. • Structures of aspirin and penicillin are available in the data booklet in section 37.	**Aims:** • **Aim 6**: Experiments could include the synthesis of aspirin. • **Aim 8**: Discuss the use/overuse of antibiotics for animals.

Essential idea: Potent medical drugs prepared by chemical modification of natural products can be addictive and become substances of abuse.

D.3 Opiates

Nature of science:

Data and its subsequent relationships—opium and its many derivatives have been used as a painkiller in a variety of forms for thousands of years. One of these derivatives is diamorphine. (3.1)

Understandings:

- The ability of a drug to cross the blood–brain barrier depends on its chemical structure and solubility in water and lipids.
- Opiates are natural narcotic analgesics that are derived from the opium poppy.
- Morphine and codeine are used as strong analgesics. Strong analgesics work by temporarily bonding to receptor sites in the brain, preventing the transmission of pain impulses without depressing the central nervous system.
- Medical use and addictive properties of opiate compounds are related to the presence of opioid receptors in the brain.

Applications and skills:

- Explanation of the synthesis of codeine and diamorphine from morphine.
- Description and explanation of the use of strong analgesics.
- Comparison of the structures of morphine, codeine and diamorphine (heroin).
- Discussion of the advantages and disadvantages of using morphine and its derivatives as strong analgesics.
- Discussion of side effects and addiction to opiate compounds.
- Explanation of the increased potency of diamorphine compared to morphine based on their chemical structure and solubility.

Guidance:

- Structures of morphine, codeine and diamorphine can be found in the data booklet in section 37.

International-mindedness:

- Many illegal drugs are cultivated or produced in a small number of countries and then sold and distributed globally. Cultural and economic viewpoints differ on the production and sale of opiates around the world.

Theory of knowledge:

- Cultures often clash over different perspectives and ideas. Is there any knowledge which is independent of culture?

Utilization:

Syllabus and cross-curricular links:
Topic 10.2—functional groups

Aims:

- **Aim 7**: Use computer animations for the investigation of 3-D visualizations of drugs and receptor sites.

Essential idea: Excess stomach acid is a common problem that can be alleviated by compounds that increase the stomach pH by neutralizing or reducing its secretion.

D.4 pH regulation of the stomach

Nature of science:

Collecting data through sampling and trialling—one of the symptoms of dyspepsia is the overproduction of stomach acid. Medical treatment of this condition often includes the prescription of antacids to instantly neutralize the acid, or H_2-receptor antagonists or proton pump inhibitors which prevent the production of stomach acid. (2.8)

Understandings:

- Non-specific reactions, such as the use of antacids, are those that work to reduce the excess stomach acid.
- Active metabolites are the active forms of a drug after it has been processed by the body.

Applications and skills:

- Explanation of how excess acidity in the stomach can be reduced by the use of different bases.
- Construction and balancing of equations for neutralization reactions and the stoichiometric application of these equations.
- Solving buffer problems using the Henderson–Hasselbalch equation.
- Explanation of how compounds such as ranitidine (Zantac) can be used to inhibit stomach acid production.
- Explanation of how compounds like omeprazole (Prilosec) and esomeprazole (Nexium) can be used to suppress acid secretion in the stomach.

Guidance:

- Antacid compounds should include calcium hydroxide, magnesium hydroxide, aluminium hydroxide, sodium carbonate and sodium bicarbonate.
- Structures for ranitidine and esomeprazole can be found in the data booklet in section 37.

International-mindedness:

- Different cultures (ie diet, lifestyle, etc) and genetics can affect the need for pH regulation of the stomach.

Theory of knowledge:

- Sometimes we utilize different approaches to solve the same problem. How do we decide between competing evidence and approaches?

Utilization:

Syllabus and cross-curricular links:
Topic 1.3—calculations involving solutions
Topics 8.2 and 8.4—neutralization
Topic 10.2—functional groups
Topic 20.3—enantiomers
Option B.7—amino acid buffers
Biology option D.1—digestion

Aims:

- **Aim 6**: Experiments could include titrations to test the effectiveness of various antacids.

Essential idea: Antiviral medications have recently been developed for some viral infections while others are still being researched.

D.5 Antiviral medications

Nature of science:

Scientific collaboration—recent research in the scientific community has improved our understanding of how viruses invade our systems. (4.1)

Understandings:

- Viruses lack a cell structure and so are more difficult to target with drugs than bacteria.
- Antiviral drugs may work by altering the cell's genetic material so that the virus cannot use it to multiply. Alternatively, they may prevent the viruses from multiplying by blocking enzyme activity within the host cell.

Applications and skills:

- Explanation of the different ways in which antiviral medications work.
- Description of how viruses differ from bacteria.
- Explanation of how oseltamivir (Tamiflu) and zanamivir (Relenza) work as a preventative agent against flu viruses.
- Comparison of the structures of oseltamivir and zanamivir.
- Discussion of the difficulties associated with solving the AIDS problem.

Guidance:

- Structures for oseltamivir and zanamivir can be found in the data booklet in section 37.

International-mindedness:

- How has the AIDS epidemic changed since its discovery in the early 1980s? What is needed to stop the spread of the disease? What is the global impact of this disease?

Utilization:

Syllabus and cross-curricular links:
Options B.2 and B.7—proteins and enzymes
Biology topic 11.1—vaccination

Aims:

- **Aim 8**: The control and treatment of HIV is exacerbated by the high price of anti-retroviral agents and sociocultural issues.

Essential idea: The synthesis, isolation, and administration of medications can have an effect on the environment.

D.6 Environmental impact of some medications

Nature of science:

Ethical implications and risks and problems—the scientific community must consider both the side effects of medications on the patient and the side effects of the development, production and use of medications on the environment (ie disposal of nuclear waste, solvents and antibiotic waste). (4.8)

Understandings:

- High-level waste (HLW) is waste that gives off large amounts of ionizing radiation for a long time.
- Low-level waste (LLW) is waste that gives off small amounts of ionizing radiation for a short time.
- Antibiotic resistance occurs when micro-organisms become resistant to antibacterials.

Applications and skills:

- Describe the environmental impact of medical nuclear waste disposal.
- Discussion of environmental issues related to left-over solvents.
- Explanation of the dangers of antibiotic waste, from improper drug disposal and animal waste, and the development of antibiotic resistance.
- Discussion of the basics of green chemistry (sustainable chemistry) processes.
- Explanation of how green chemistry was used to develop the precursor for Tamiflu (oseltamivir).

Guidance:

- The structure of oseltamivir is provided in the data booklet in section 37.

International-mindedness:

- Consider how pharmaceutical companies determine how to spend research funds to develop new medications.
- Do pharmaceutical companies have a responsibility to do research on rare diseases that will not provide them with significant financial profit?
- Production of a drug typically involves a number of different organic reactions. What are the ethics governing the design (synthesis) of drugs? Do standards and practices vary by country and region?

Theory of knowledge:

- How do we balance ethical concerns that appear to be at odds with each other when trying to formulate a solution to the problem?

Aims:

- **Aim 8**: How do we safely dispose of medicinal nuclear waste?
- **Aim 8**: The Pacific yew tree which is the source of the chemotherapy drug Taxol is facing extinction.
- **Aim 8**: Solvent disposal is a growing environmental problem.