32 MEDICINE, AGRICULTURE AND INDUSTRY

Student Learning Outcomes

[C-12-E-50 to C-12-E-65]

Part I MEDICINE

- Recognize the concept of therapeutic index and therapeutic window in relation to drug administration.
- Describe the pH regulation of stomach and its relation to the concept of non- specific reactions and active metabolites.
- Explain the mechanism of action and uses of aspirin and penicillin and explain the chemical structure of the same.
- Describe the mechanism of action of opiates and the concept of opioid receptors in the brain.
- Recognize the challenges in treating viral infections with drugs and the concept of antiviral medications.

Part II AGRICULTURE

- Explain the chemical composition and function of different types of fertilizers, including their role in providing essential nutrients to crops and the impact of their application on soil health.
- Identify the different tunes of pesticides used in agriculture and describe their mode of action, including the potential benefits and risks associated with their use.
- Identify the chemical reactions that occur when acid rain falls on crops and soil and explain the effects it has on crop growth, including nutrient uptake and crop yield.
- Explain how changes in temperature, precipitation, and extreme weather events can affect crop growth and yield, including the potential for crop failures and food shortages, as well as the potential to develop new crop varieties that are more resilient to changing climate conditions.
- Explain the basics of genetic engineering and how it is used in agriculture, including the development of genetically modified crops and the potential benefits and risks associated with their use.

Part III INDUSTRY

- Justify the importance and significance of industrial chemistry in various industries such as manufacturing, energy, healthcare, and environmental protection.
- Identify the raw materials and resources used in industrial chemistry, including those readily available in the context of Pakistan.
- Discuss the importance of chemical industries in the economy of Pakistan, and describe the raw materials that are available in the country for various chemical industries.
- Describe the chemical processes involved in industrial production, including addition and condensation polymerization, and the properties and materials.
- Explain the applications of industrial chemistry in industries such as petrochemical, cosmetics, cement, food production and more.
- Elaborate on the safety measures and precautions necessary in industrial chemical processes and facilities.

Medicines prepared in the pharmaceutical industry are of vital significance as regards human health. Chemistry unlocks the secrets behind how drugs truly work inside the body. A drug's safety limits and optimal dose range are two very crucial aspects of medicine. The knowledge of safety and the action of a drug ensures the safe absorption and action of a drug on the target disease. In this chapter, these aspects will be discussed.

32.1 THERAPEUTIC INDEX AND THERAPEUTIC WINDOW

Pharmacology is the science which deals with, what a drug does and the safety margins within which it operates. Every drug may be a potential poison; the difference lies in the dose of each drug. The therapeutic index and therapeutic window are central concepts for understanding how safe and effective a medicine is. They help doctors to determine the right amount of a drug to give to a patient.

32.1.1 Therapeutic Window

Therapeutic window is the range of drug concentrations in the plasma that are effective without causing harmful side effects. It is the "sweet spot" of medicine i.e. not too less to be ineffective and also not too high to be dangerous.

Minimum effective concentration (MEC) is the lowest dose of the drug below which it fails to produce a clinical effect. Minimum toxic concentration (MTC) is the lowest dose at which drug begins to cause adverse effects or "poisoning". Duration of action is the time duration in which the drug concentration remains within its therapeutic window.

A wide therapeutic window indicates the safety limits of a drug, as there is a large gap between the dose that works and the dose that's harmful. This allows more flexibility in dosing. A narrow therapeutic window means the drug is less safe because the effective dose is very close to the toxic dose. Doctors must be extremely careful when prescribing these drugs and often need to check the patient's blood to ensure the drug level stays within the correct narrow range.

The simultaneous use of multiple medicines, genetic factors, obesity, age, or overall health may also affect the therapeutic window of the drug. All these factors govern the metabolism and efficacy of a drug.

32.1.2 Therapeutic Index

The therapeutic index (TI) is a quantitative measurement of a drug's safety. It compares the dose that causes a toxic effect to the dose that produces a desired therapeutic effect. A higher TI means the drug is safer because there's a larger difference between the effective dose and the toxic dose. A low TI means the drug is more dangerous and requires careful monitoring to avoid toxicity.

Td_{50} (Toxic Dose 50) is the dose that causes a

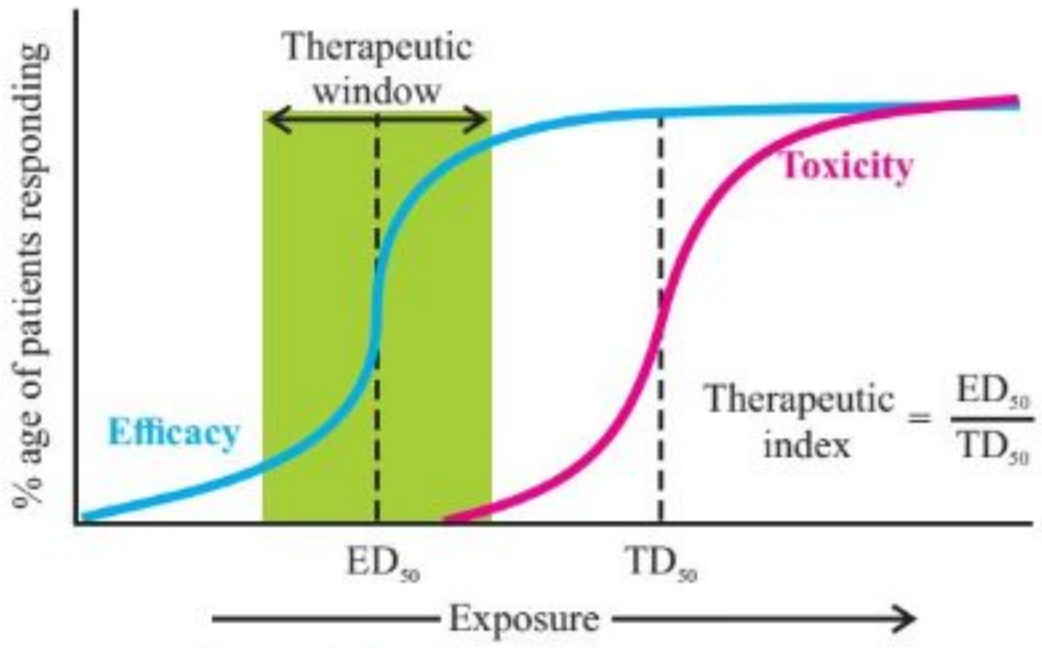

Figure 32.1 Therapeutic window and therapeutic index illustration

toxic effect in 50% of the people who take it. For example, a drug with a TI of 10 is much safer than one with a TI of 2. ED_{50} (Effective Dose 50) is defined as the dose that works for 50% of the people who take it.

Drugs like Penicillin or Paracetamol have high TI. It means if patients accidently double their dose, this will not put a potential threat to their lives. On the other hand, drugs like Warfarin (a blood thinner) or Digoxin (heart medicine) have to be taken very carefully only in proper dosage. Otherwise, they may risk the life of the patient. Patients using low TI drugs must carry regular blood tests for therapeutic drug monitoring (TDM).

Did You Know?

Before modern blood-level monitoring, Digoxin was a frequent cause of accidental hospital deaths. Because, its TI is so low, even minor interactions with common foods or other drugs would push patients into a lethal "toxic zone." Its toxicity causes ventricular fibrillation (a fatal heart rhythm) and "yellow-tinted" vision (xanthopsia).

32.2 IMPORTANCE OF pH IN STOMACH

The stomach has a highly acidic environment with a low pH (1.5–3.5). This acidity is regulated by parietal cells, which actively pump hydrogen ions (H^+) into the stomach. This process is important for digesting food and killing bacteria. Although the stomach has very low pH but it protects itself via a thick layer of mucus and bicarbonate ions, which neutralize acid at the cell surface. The low pH of stomach can cause non-specific reactions, meaning it can chemically change some drugs. For example, some drugs may break down in the acidic environment before they can be absorbed into the bloodstream. This is why some medications are given in a protective coating that only dissolves in the less acidic small intestine.

32.3 MECHANISM OF DRUG ACTION

The mechanism of action is how a drug works at a cellular level to produce medical effects. Here we shall discuss two famous medicines i.e., aspirin and penicillin along with their mechanism of drug action. The action of aspirine in blocking COX enzyme has already been discussed in Chemistry XI (chapter 3). Here we will discuss mechanism of action of penicillin.

32.3.1 Penicillin

It is a powerful antibiotic used to treat many types of bacterial infections, such as respiratory infections like, strep throat, pneumonia, scarlet fever and sinusitis. It also helps to treat skin and soft tissue infections like cellulitis, erysipelas.

The structure of Penicillin contains two core rings; a four-membered beta-lactam ring and a five membered thiazolidine ring. Both the rings have certain side chains attached to them. The beta-lactam ring is crucial for the antibiotic's activity, as it is

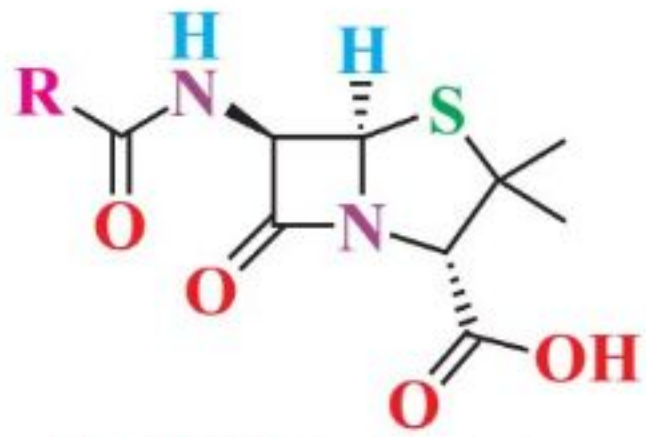

Figure 32.2 Chemical structure of Penicillin

the site where bacterial enzymes called beta-lactamases can attack and deactivate penicillin.

The structure of penicillin looks identical to the amino acid sequence of the enzyme which strengthens the cell wall. The enzyme mistakenly takes up penicillin molecule, where the beta-lactam ring opens and bind permanently to get inactivated. Bacteria continue to grow, but without the functional cell wall, and eventually burst to die. Since human cells don't have cell walls, penicillin does not harm our cells.

Did You Know?

In 1928, Alexander Fleming accidentally discovered penicillin when he noticed that mold growing on a contaminated petri dish had killed surrounding bacteria. The mold, later identified as Penicillium, released a substance that inhibited bacterial growth. This chance observation led to the development of the first antibiotic, revolutionized modern medicine.

32.3.2 OPIATES AND OPIOID RECEPTORS

Opiates are a class of drugs that come from the opium poppy plant. They are powerful pain relievers but also cause addiction. The legal drugs include the morphine, codeine, oxycodone, hydrocodone etc. The illegal category contains drugs like heroin, fentanyl etc.

Concept of Opioid Receptors

The human brain produces our own painkillers called endorphins. These bind with opioid receptors in our Central Nervous System (CNS). Opiates "hijack" this natural system, and become effective for pain relief but also highly addictive.

There are three types of opioid receptors. Mu(μ) receptors are located in the brain and spinal cord. These are primary target for most of the opioids like morphine. They are responsible for analgesic activity of opiates, but activation of these receptors can also cause respiratory depression and intense euphoria. Kappa (κ) receptors are involved in spinal analgesia and sedation; but they are less associated with euphoria. Delta (δ) receptors play a vital role in emotional response and mood regulation.

Mechanism of Action

Opiates work by binding to special proteins in the brain and spinal cord called opioid receptors. It works like a key (opiate) and lock (receptor) model. When the opiate binds to the receptor, it blocks pain signals from reaching the brain, making the person feel less pain. In actual, when an opiate binds the receptor, it closes the calcium channels and opens the potassium channel. This hyperpolarizes the neuron, making it much harder for the cell to send the pain signal. It has been experimentally found that opiates trigger a neurochemical reaction in the reward center of brain, leading to excessive release of dopamine, which give a sense of relief and well-being.

Opioids are used to relief acute pain like sudden and short-term pain. They are also used to manage the severe pain associated to cancer. Opioids like codeine is used in cough syrups as they suppress the cough reflex. They bind to the receptors in gastrointestinal tract, slows down digestion and can alleviate diarrhea.

Did You Know?

Before it became a street drug, Heroin (diacetylmorphine) was a trademarked medicine sold by Bayer as a "non-addictive" alternative to morphine and a cough suppressant for children. Because its potency is roughly five times that of morphine, it crossed the blood-brain barrier faster, creating a "rush" that led to a global addiction epidemic.

32.4 CHALLENGES IN TREATING VIRAL INFECTIONS

Treating viral infections is fundamentally different from bacterial treatment. Bacteria are independent organisms, while viruses are parasites. Unlike bacteria, which are living organisms on their own, viruses are not truly alive. Viruses live inside our cells and use our own DNA/RNA machinery to replicate. This makes it hard to develop a drug that kills the virus without harming our healthy human cells.

Viruses can change their genetic material very quickly. This is called mutation. A drug that works against a virus one year might not work the next because the virus has changed. This is why flu vaccines need to be updated every year.

Viruses also integrate into our genome and stay asleep for years. Drugs at recent times can kill only active viruses and not those which have been sleeping for years.

Antiviral medications work by targeting specific stages of the viral life cycle. For example, some antivirals prevent the virus from entering our cells, while others stop the virus from making copies of its genetic material. One of the most common mechanisms of action of antiviral drugs is enzyme inhibition. For example, protease inhibitor, does not allow the virus to produce their protein in one long strand. These inhibitors also help in the treatment of HIV and hepatitis C infections. Some antiviral drugs enhance the immune response to viral infections. Interferons are proteins that can boost immune system to fight against viruses.

Quick Check 32.1

a) Drug A has a TI of 3, and Drug B has a TI of 50. Which drug is considered safer, and why?
b) How do antacids (e.g., magnesium hydroxide, $Mg(OH)_2$) chemically regulate stomach pH? Write a simple neutralization equation to illustrate this.
c) Identify the core, strained heterocyclic ring system in penicillin that is essential for its antibacterial activity.
d) Compare the chemical structures of morphine and codeine (methylmorphine). How does this small structural difference relate to codeine's action as a prodrug?
e) Why do many antiviral drugs cause significant side effects for the host patient?

AGRICULTURE

In this section, we shall explore the role of chemistry in modern agriculture. Here we shall discuss the importance and role of fertilizers, pesticides, genetic engineering to increase the supply for growing demand of food due to increase in world population. The section will also describe the chemical reactions of acid rain on crops and soil and explains how climate change affects crop growth.

32.5 FERTILIZERS

Fertilizers are the mineral rich superfood given to the soil which improves its fertility. They replenish the depleted soil and boost healthy growth, increase crop yields, and ensure better food production. Fertilizers are chemicals that provide essential nutrients to plants to promote growth and increase crop yields. Synthetic fertilizers are man-made through chemical processes like the Haber-Bosch process for ammonia (NH_3). Organic fertilizers come from natural sources like compost or animal manure.

Plants require seventeen essential elements, as micronutrients and macronutrients. The micronutrients include boron, iron, copper, chlorine, manganese, molybdenum and zinc. Whereas the macronutrients are carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, calcium and magnesium. Out of these nine macronutrients nitrogen, phosphorus, and potassium are needed in such large quantities that they are termed primary macronutrients. Commercial fertilizers are labeled with an N-P-K ratio, which represent the concentration of these three elements.

Role of Fertilizers in Plant Growth

1. **Nitrogen:** Nitrogen is often the most limiting factor in crop production. It is a fundamental component of amino acids, which build proteins, and chlorophyll, the pigment responsible for photosynthesis.
2. **Phosphorus:** It is typically supplied as superphosphates or ammonium phosphates. Phosphorus is a structural component of ATP (adenosine triphosphate) which stores and releases energy.
3. **Potassium:** Unlike nitrogen and phosphorus, potassium does not become part of the plant's physical structure. Instead, it acts as an osmoregulator. It also activates over sixty different enzymes that facilitate plant metabolism.

When applied, these chemicals are taken up by plant roots. However, if too much is used, the excess can wash away into rivers and lakes, causing an overgrowth of algae, which is harmful to aquatic life. Long-term use of some synthetic fertilizers can also change the soil's pH and kill beneficial microorganisms, hurting soil health.

Did You Know?

Why farmers rotate crops? Growing the same crop every year depletes the same nutrients. Crop rotation restores soil nutrients and reduces the need for synthetic fertilizers.

32.6 PESTICIDES

Pesticides are chemicals used to kill or control pests like insects, weeds, or fungi. Pesticides protect crops from damage, preventing food loss and ensuring a stable food supply. They are classified by their target pest into insecticides, herbicides and fungicides.

Insecticides are the chemicals which control the insects by targeting their nervous system. Many modern insecticides like organophosphates or neonicotinoids act as neurotoxins, which damage the nervous system of insects leading to paralysis and death.

Neonicotinoids have been reported to be linked to "Colony Collapse Disorder" in honeybees, threatening global pollination.

Herbicides are the chemicals which control unwanted, competitive plants called weeds. Some herbicides cause enzyme inhibition, and do not allow synthesis of essential amino acids. Whereas, some of them, disrupt electron transport and prevent weeds from performing photosynthesis.

Fungicides kill the fungus by targeting their cellular integrity. They target ergosterol synthesis in fungal cell membranes, and without a stable membrane, the fungal cell leaks and dies. The most common examples are triazoles, strobilurins, zinc phosphide etc.

Pesticides are playing a pivotal role in modern food development programs. They help to protect plants from pests and diseases and enhance the yield of crops. They reduce the risk of epidemics and improve human health as well. They also contribute in food security and stability worldwide.

Pesticides can cause adverse health effects being carcinogenic and neurotoxic. Beneficial insects, birds and aquatic organism can also be affected by pesticides. Runoff water from fields can contaminate water sources and harm aquatic organisms. Pesticides can harm non-target species like pollinators (e.g., bees) which play a key role in pollination of many crops. Overtime, pests can develop immunity against certain pesticides, making them less effective. This forces us to use more toxic pesticides, which may pose further adverse environmental and health issues.

32.7 ACID RAIN

Acid rain is an atmospheric mixture of nitric acid and sulphuric acid produced by industrial pollution. Normal rain water has pH up to or above 5.6, due to carbonic acid. If it has a pH lower than 5.6, it potentially becomes the acid rain.

Acid rain is caused due to sulphur oxides (SO_x) and nitrogen oxides (NO_x) in the atmosphere. These gases, often from industrial pollution, react with water to form sulphuric acid (H_2SO_4) and nitric acid (HNO_3).

$$2SO_2 + O_2 + 2H_2O \longrightarrow 2H_2SO_4 \text{ (Sulphuric acid formation)}$$

$$4NO_2 + O_2 + 2H_2O \longrightarrow 4HNO_3 \text{ (Nitric acid formation)}$$

When acid rain falls on soil, it causes a chemical reaction that leaches out essential nutrients like calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+) from the soil, making them unavailable for plants.

$$K^+\text{—Soil} + H^+ \longrightarrow H^+\text{—Soil} + K^+ \text{ (Potassium leaching)}$$

$$Ca^{2+}\text{—Soil} + 2H^+ \longrightarrow H_2^+\text{—Soil} + Ca^{2+} \text{ (Calcium leaching)}$$

Simultaneously, it can increase the solubility of toxic metals, like aluminium (Al^{3+}), which can then be absorbed by the plants' roots and damage them. This reduces the plants' ability to take up nutrients, leading to slower growth and lower crop yields.

$$Al^{3+}\text{—Soil} + 3H^+ \longrightarrow H_3^+\text{—Soil} + Al^{3+} \text{ (Aluminium leaching)}$$

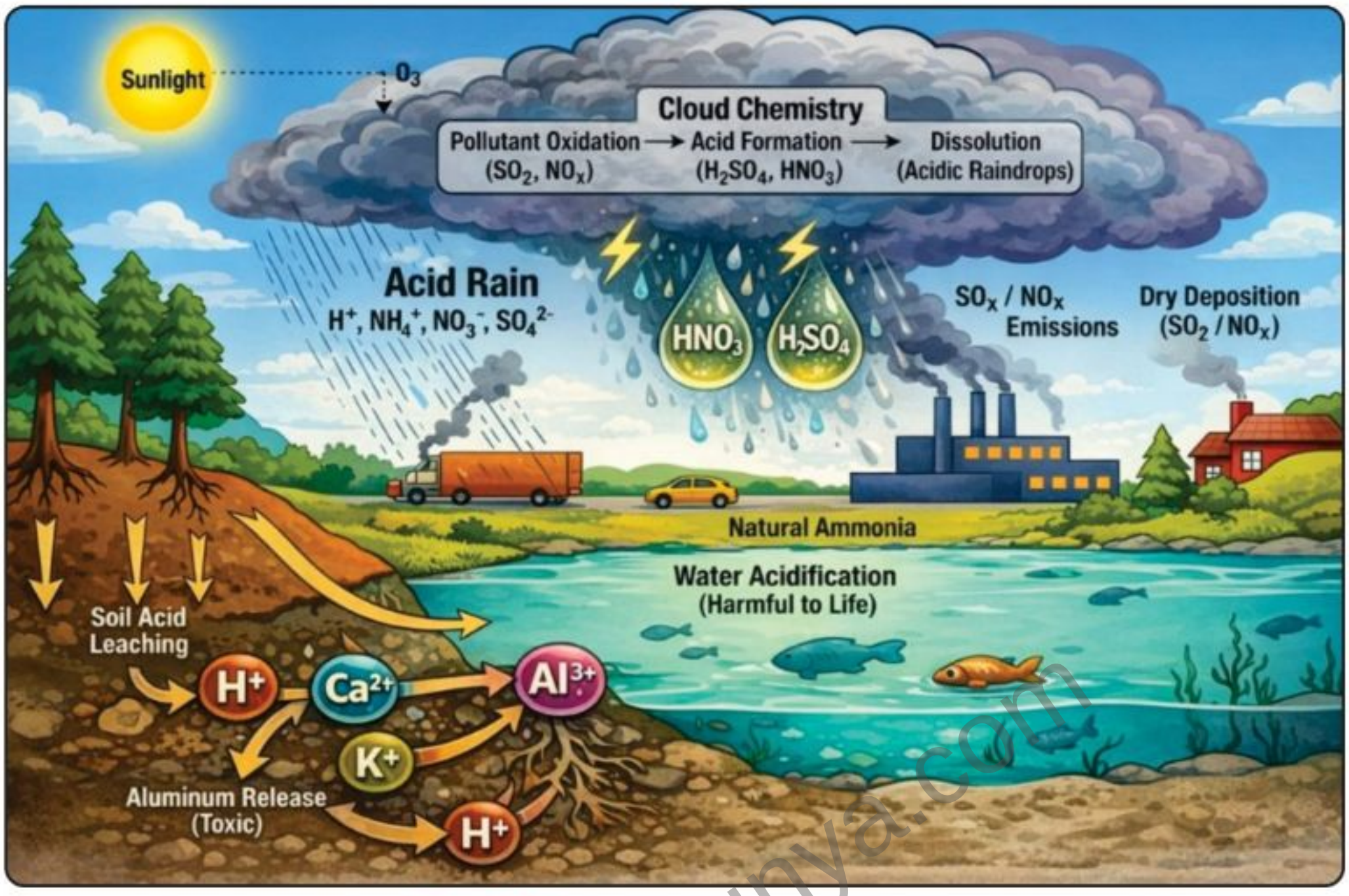

Figure 32.3 Effects of acid rain on agriculture

Direct acid rain can damage the leaves, dehydrate them and makes the plant vulnerable to disease and environmental effects. Acid rain can reduce the soyabean and wheat yields by reducing nitrogen fixation and nutrition intake. Acid rain can adversely affect the soil microbial communities, and disrupt the natural nutrient cycles and decomposition of organic matter.

Did You Know?

Why fish die in acidic lakes? Acid rain releases Al^{3+} from soil, which clogs fish gills and reduces oxygen absorption → fish suffocate.

32.8 EFFECT OF CLIMATE CHANGE ON CROPS

Agriculture is the industry that is most vulnerable to shifting climates. Changes in temperature, precipitation, and extreme weather events due to climate change directly impact agriculture. Heat stress causes dehydration, which ultimately results in poor photosynthesis and respiration. Higher temperatures can speed up a plant's metabolism, but if they get too hot, plants suffer from heat stress, reducing their growth and yield. Similarly, cold climate also damages certain crops. it is fatal to young plants resulting in complete yield loss.

Normal rain helps plants by providing adequate amount of water and nutrients required for their healthy growth. However, changes in rainfall patterns can lead to drought in some areas and floods in others, both of which can cause crop failure. Unpredictable rains, cloud bursts can cause soil erosion, takes the nutrient-rich top soil away.

Events like hurricanes, heatwaves, and hailstorms can destroy crops and agricultural infrastructure, leading to food shortages. Storms can cause uprooting and branch damage. Strong winds cause water loss and can cause drought. Hails damage the leaves, fruit, stems, causing tissue damage, which result in poor photosynthesis. Severe hailing can cause total loss of yield by crop destruction. Higher UV-index and heat waves can put crops under severe heat stress, which speed up the water loss, may also result in leaf burning.

To adapt these changes, scientists are developing new crop varieties that are more resilient to different climates, for example, by creating drought-resistant corn or heat-tolerant wheat. Some drought tolerant and flood-proof traits have also been developed. For example, "Sub1 rice" which can survive being submerge underwater for two weeks.

32.9 GENETIC ENGINEERING

Genetic engineering in agriculture involves changing an organism's DNA by adding, removing, or modifying specific genes. This is used to create genetically modified (GM) crops with desired traits.

Scientists identify a useful gene (e.g., for pest resistance from a bacterium) with a desired trait, such as drought tolerance etc.

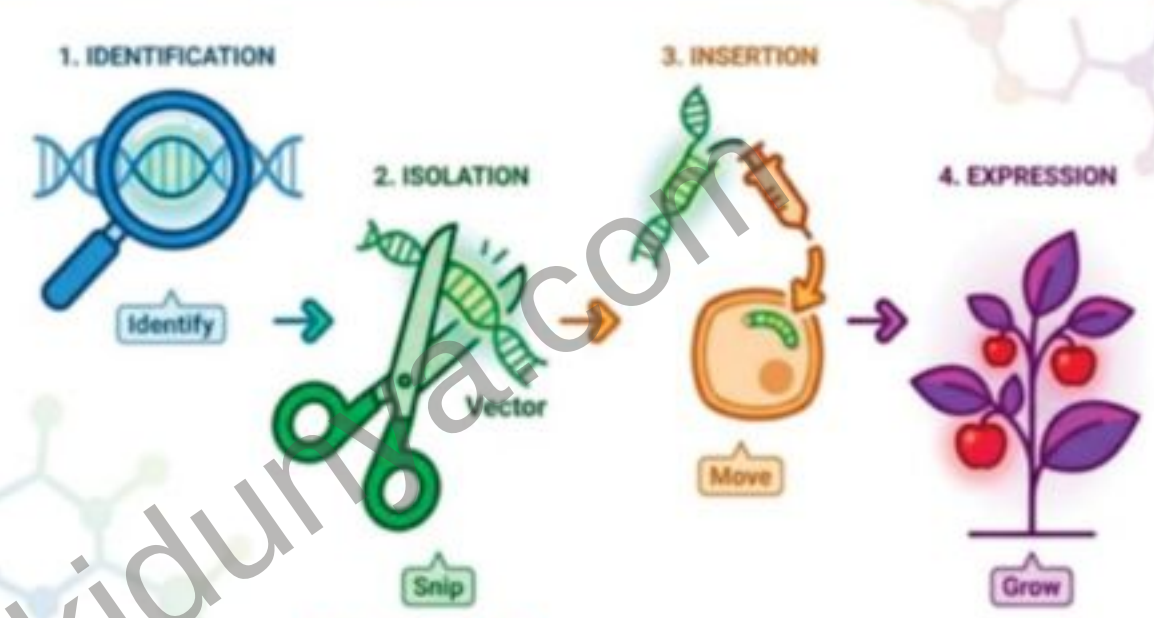

Figure 32.4 Genetic engineering

The gene responsible for a specific trait is isolated from the organism. The isolated gene is inserted into the target plant's genome by using a gene gun or a carrier bacterium to sew that gene into the plant 's DNA. This new gene is then expressed by the plant's cells, giving it the new trait. The modified plant now produces new protein that it could not produce before.

GM crops can have improved resistance to pests and diseases, tolerance to herbicides, and enhanced nutritional value. This can increase crop yields and reduce the need for certain pesticides. For example, BT-Cotton produces its own pesticide, reducing the need for chemical sprays. Golden Rice is engineered with beta-carotene to prevent blindness in developing nations. Concerns include the potential for GM genes to spread to wild plants (outcrossing), the development of "superweeds" where herbicide-resistant genes jump from GM crops to wild weeds via cross-pollination, making them impossible to kill. It also produces resistant insects, and the long-term effects on human health and biodiversity.

Quick Check 32.2

a) State two major agricultural benefits of using fungicides, linking to crop health or yield.

b) Write the balanced chemical equation for reaction that occurs when powdered limestone ($CaCO_3$) is added to a lake or field to neutralize sulphuric acid (H_2SO_4) from acid rain.

c) Identify two specific traits (e.g., heat tolerance, salt tolerance) that scientists aim to develop in new crop varieties to make them more resilient to climate change.

INDUSTRY

Industrial chemistry is crucial for the economy and daily life. This part of the chapter justifies its importance in sectors like manufacturing and energy and identifies key raw materials, especially those available in Pakistan. It describes essential industrial processes such as polymerization and their applications in industries like petrochemicals, cosmetics, and cement. The section concludes by emphasizing the vital safety measures required in chemical processes and facilities.

32.10 RAW MATERIALS IN PAKISTAN

Pakistan has several raw materials that are important for its chemical industries. The feedstock of an industry determines its location and economic viability.

Air provides nitrogen for fertilizers and oxygen for steel manufacturing. Water is used as a solvent, a cooling agent, and a source of hydrogen. Fossil fuels like coal, oil, and natural gas provide the hydrocarbons required for 90% of organic chemicals.

Pakistan possesses a unique geological profile that supports several chemical sub-sectors like:

1. **Natural Gas**: It is a major source of methane (CH_4), used to produce fertilizers (urea) and petrochemicals. It serves as both a fuel and a source of hydrogen.
2. **Rock Salt (Khewra Mines):** Khewra mines are one of the world's largest rock salt deposits. It is the source of sodium chloride (NaCl) for a raw material for Soda ash (Na_2CO_3), caustic soda (NaOH), and chlorine.
3. **Limestone**: Limestone is highly abundant in salt range and Sindh. It is a source of calcium carbonate ($CaCO_3$) for the cement industry.
4. **Gypsum**: It is used in the cement industry and for making plaster. It is also used as a source of calcium and sulphur and employed as a soil conditioner.
5. **Chromite**: It is found in Muslim Bagh, and is used in stainless steel and pigment production.
6. **Crude Oil:** It is refined to produce a wide range of fuels and petrochemicals.
7. **Sulphur**: Sulphur is used to make sulphuric acid (H_2SO_4), a key industrial chemical.

Did You Know?

Pakistan has abundant natural gas, the main raw material for making urea (NH_2CONH_2). Because raw material is locally available, production costs are lower making fertilizers more affordable for farmers.

32.11 CHEMICAL INDUSTRIES AND PAKISTAN'S ECONOMY

The chemical industry is vital to Pakistan's economy, contributing significantly to its Gross Domestic Product (GDP) and providing jobs. It supports other major sectors like agriculture (through fertilizers), construction (through cement), and textiles (through dyes and synthetic fibres). The chemical industries use the country's locally available raw materials, such as natural gas, rock salt, limestone, and crude oil, to produce key products, which reduces reliance on imports.

As an agrarian economy, Pakistan's food security depends on the chemical industry. Local

companies utilize natural gas to produce urea. This reduces the national import bill by billions of dollars. Textiles account for over 50% of Pakistan's exports. This industry is a massive consumer of caustic soda for mercerizing cotton, synthetic dyes to provide colour and fastness and hydrogen peroxide for bleaching fabrics. Due to infrastructure projects and urbanization, the cement industry has become a leading exporter to neighboring regions.

32.12 INDUSTRIAL CHEMICAL PROCESSES

Chemical manufacturing relies on two main pillars, reaction engineering and separation technology. Industrial production uses several key chemical processes. Some of them are:

1. **Polymerisation:** This is a process where small molecules called monomers link up to form large chains called polymers. Addition polymerisation in which monomers add to one another without losing any atoms (e.g., ethylene monomers forming polyethene).
   Condensation polymerisation in which monomers join together and release a small molecule, usually water (e.g., monomers forming polyesters). Engro Polymer and Chemicals is the sole producer of Polyvinyl Chloride (PVC) in Pakistan.
2. **Refining and Reforming:** In refining process, fractional distillation separates crude oil into different products based on their boiling points. The most important fractions include gasoline, diesel, kerosene etc. Reforming is the conversion of straight chain hydrocarbons to branched hydrocarbons to enhance the quality of fuel. During catalytic reforming, hydrocarbons are heated with catalyst to obtain a high-octane number gasoline. While often categorized as "Oil and Gas" the chemical cracking and reforming processes at refineries like PARCO and Attock Refinery provide essential petrochemical feedstocks for wider chemical industry.
3. **Haber-Bosch Process**: In Haber process ammonia (NH_3) gas is synthesized from nitrogen (N_2) and hydrogen (H_2) gases. Iron metal crystals are used as catalyst in this process. This process contributes the 13% of the nitrogen fixation being done on the earth, as 70% of ammonia is utilized directly into fertilizer manufacture. Large-scale plants like Engro Fertilizers and FFC use natural gas as a feedstock and produce ammonia, which is then converted into urea.
4. **Contact Process**: In this process, sulphur dioxide (SO_2) gas is converted into sulphur trioxide (SO_3) gas using V_2O_5 or Pt as catalyst. Then it is transformed into oleum, and in the last is converted into sulphuric acid. This process produces highly pure and concentrated form of H_2SO_4. Sulphuric acid is the most utilized chemical in the world, so it is often called the "King of Chemicals". In Pakistan several plants run contact process e.g. Nimir Indutrial Chemicals.
5. **Solvay Process**: The Solvay process produces sodium carbonate (Na_2CO_3) from brine and limestone. Ammonia is added to brine, and carbon dioxide is passed through it to form sodium bicarbonate ($NaHCO_3$) precipitate. Heating converts it into sodium carbonate. Ammonia is regenerated using lime from calcium carbonate decomposition. The by-product formed is calcium chloride ($CaCl_2$). Lucky Core Industries (formerly ICI) produce soda ash for the glass, detergent and paper industries.
6. **Chlor-Alkali Process**: The chlor-alkali process is an industrial electrolysis method that breaks down sodium chloride brine (NaCl) to produce three key chemical products like chlorine (Cl_2), sodium hydroxide (NaOH) or caustic soda), and hydrogen (H_2). It is crucial for manufacturing plastics, detergents, and water treatment products, commonly using modern

membrane cell technology for high efficiency and purity. In this regard, Sitara Chemical Industries and Ittehad Chemicals are primary players, supporting the textile and water treatment sectors.

32.13 APPLICATIONS OF INDUSTRIAL CHEMISTRY

Petrochemical Industry produces plastics, synthetic rubber, and fibres from crude oil. Crude oil is cracked (broken down) into smaller molecules. These become the building blocks for lubricants, waxes, and synthetic rubbers.

Cosmetics industry creates ingredients for makeup, soaps, and perfumes. This industry uses surfactants (for soaps), emulsifiers (to keep creams smooth), and preservatives (to prevent bacterial growth). Chemistry ensures that these products are pH-balanced for human skin.

Cement industry uses limestone and clay to make a key building material. Cement manufacturing process involves heating an intimate mixture of limestone and clay to 1500°C in a rotary kiln. The resulting product is ground with gypsum to make cement.

Food industry creates food additives, preservatives, and food processing chemicals. Sodium benzoate is mostly used as food preservatives. Hydrogenation is done to turn edible oils into solid fats like margarine. Leavening agents like sodium bicarbonate (baking soda) is used in baking. Fortification is done by adding iodine to salts or Vitamin A to oil.

Did You Know?

Why cement gets hot when you add water? Cement reacts with water in an exothermic hydration reaction, releasing heat. This is why freshly mixed cement becomes warm.

32.14 SAFETY MEASURES AND PRECAUTIONS

Industrial chemical facilities require strict safety measures to prevent accidents and protect workers and the environment. These include:

1. Workers should use personal protective equipment (PPE) such as gloves, goggles, helmets, lab coats, and protective shoes to avoid injuries from chemicals, heat, or harmful fumes.
2. Chemicals must be properly labeled, handled, and stored according to their properties. Flammable, toxic, or corrosive substances should be kept in suitable containers and separate storage areas to prevent leaks, spills, contamination, or dangerous reactions.
3. Industries should have clear emergency plans to handle fires, chemical spills, gas leaks, or explosions. Emergency exits, fire extinguishers, first-aid kits, and spill control materials should be available, and workers should know how to respond during emergencies.
4. Good ventilation systems are necessary to remove toxic gases, fumes, and dust from the workplace. Proper airflow reduces the risk of breathing harmful substances and helps maintain a safe and healthy working environment.
5. Workers must receive proper safety training on handling hazardous materials and operating equipment. Regular inspection and maintenance of machines, pipelines, and storage tanks help detect faults early and reduce the risk of industrial accidents.

Quick Check 32.3

a) Identify two major sectors of Pakistan's economy (other than agriculture) that are heavily reliant on the chemical industry, and name one chemical product essential for each.

b) Explain the physical principle of the process used to separate crude oil (in terms of intermolecular forces and boiling points) on which this separation depends.

c) Many cosmetics and perfumes use esters. Name the two types of reactants needed to synthesize an ester and name the catalyst typically used.

d) Explain the chemical reason why highly oxidizing chemicals (like concentrated HNO_3) must be stored separately from flammable organic chemicals (like ethanol).

Exercise

Q1. MULTIPLE CHOICE QUESTIONS

I) What does the TD_{50} value in the TI formula represent?

a) Dose effective for 100 % of people.
b) Lowest dose that causes harm MTC.
c) Lowest dose that works MEC
d) Dose causing a toxic effect in 50 % of people.

II) What is the key structural feature for penicillin's antibiotic activity?

a) A carboxylic acid group
b) A benzene ring
c) A thiazolidine ring
d) A four-membered beta-lactam ring

III) How do opiates like morphine reduce pain?

a) They destroy pain signals.
b) They bind to opioid receptors, blocking pain signals.
c) They come from the opium poppy.
d) They build new cell walls in the brain.

IV) Which N-P-K nutrient promotes protein synthesis and chlorophyll?

a) Nitrogen
b) Phosphorus
c) Potassium
d) Sulphur

V) How does acid rain primarily damage soil?

a) It increases soil pH.
b) It leaches essential nutrients and releases toxic Al^{3+}.
c) It adds excess nitrogen.
d) It directly destroys plant roots.

VI) What is a primary effect of climate change on agriculture?

a) Reduced atmospheric CO_2
b) Increased crop yields globally

c) Reduced yields due to heat stress and erratic rainfall
d) Fewer extreme weather events

VII) In Pakistan, rock salt (halite) is a key raw material for producing:

a) Fertilizers
b) Caustic soda and chlorine
c) Cement
d) Petrochemicals

VIII) Ammonia gas in industry is prepared by:

a) Contact process
b) Haber-Bosch process
c) Solvay process
d) Refining process

XI) Plastics, synthetic fibres, and synthetic rubber are primary products of the:

a) Cement industry
b) Petrochemical industry
c) Cosmetics industry
d) Food production industry

X) What is the primary purpose of ventilation systems in a chemical facility?

a) To control storage temperature
b) To provide clear emergency exits
c) To assist in labeling chemicals
d) To remove toxic fumes

Q2. SHORT ANSWER QUESTIONS

a) Write significance of Therapeutic Window and how it differs from Therapeutic Index.

b) How structure of penicillin allows it to inhibit the transpeptidase enzyme?

c) What is the primary mechanism of action for opiate drugs, such as morphine, in providing analgesia (pain relief)?

d) Why is it significantly more challenging to develop safe and effective antiviral drugs compared to antibacterial drugs (antibiotics)?

e) What is the concept of pesticide resistance in a target pest population, linking it to the principles of natural selection and repeated application?

f) Define soil salinization. How it can be caused by irrigation practices in regions experiencing higher temperatures and reduced precipitation.

g) How does the chemical industry contribute to both energy production from fossil fuels and the development of renewable energy technologies?

h) Name the industrial process used to produce caustic soda (NaOH) and chlorine (Cl_2) from the rock salt (NaCl).

i) State two different types of products (other than fuels) that are derived from the petrochemical industry, linking them to their use in daily life.

j) Distinguish between a corrosive hazard and a toxic hazard, giving one example of a chemical for each.

Q3. CONSTRUCTED RESPONSE QUESTIONS

a) Drug A has an ED_{50} of 20 mg and a TD_{50} of 80 mg. Drug B has a Minimum Effective Concentration (MEC) of 5 mg/L and a Minimum Toxic Concentration (MTC) of 50 mg/dm^3. Drug C has a therapeutic window where the effective dose is 10 mg and the toxic dose is 15 mg.

(i) Define Therapeutic Index (TI) and calculate the TI for Drug A.
(ii) Define Therapeutic Window (TW) and identify which drug (B or C) has the wider therapeutic window. Justify your answer.
(iii) Compare the relative safety of Drug A and Drug C.

b) **(i)** Contrast synthetic and organic fertilizers based on their origin.
(ii) Identify the three primary macronutrients (N, P, K) and describe the specific biological function of each in a plant.

c) Describe the chemical pathway from Natural Gas (CH_4) to urea fertilizer. Your answer must identify the crucial intermediate compound that is synthesized from CH_4 and air.

DESCRIPTIVE QUESTIONS

Q4. Describe the structure and mechanism of action of penicillin.

Q5. What is Genetic Engineering? Give its main benefits and risks.

Q6. Explain the role of industrial chemistry in economy of Pakistan. Also account the main raw materials available in Pakistan for these industries.

Q7. Write a note on various industrial chemical processes. Also account for the applications of these chemical industries in Pakistan.

Q8. What are important safety measures which must be followed while working in different chemical industries? Make a checklist to verify their adoption.