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Answers

Practice exam questions

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Check your answers to the questions in this issue.

Towards greener agriculture (pp. 2–5)

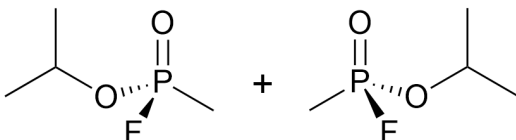
- 1 To allow the system to reach dynamic equilibrium and maximise the yield of ammonia. Otherwise, gases would escape, and the reaction would not reach equilibrium.
- 2 The forward reaction of the Haber–Bosch process is exothermic, so according to Le Chatelier’s principle, a lower temperature favours a higher yield of ammonia. However, at very low temperatures, the reaction rate becomes extremely slow, making the process impractical for industrial production. A temperature of around 450°C provides a compromise: the reaction is fast enough to produce ammonia at a reasonable rate, while still giving an acceptable yield.
- 3 While industrial ammonia production enhances agricultural productivity, it alters the natural nitrogen cycle by increasing the availability of reactive nitrogen, affecting microbial activity, and causing environmental impacts such as water pollution and greenhouse gas emissions.
- 4 One major advantage of using electrochemical ammonia production over the traditional Haber–Bosch process is its potential to be more environmentally sustainable. Unlike the Haber–Bosch process, which relies on high temperatures and pressures and often uses hydrogen derived from fossil fuels, electrochemical methods can operate at lower temperatures and pressures and use renewable electricity to drive the reaction. This allows the process to potentially integrate with green hydrogen production from water electrolysis, reducing carbon emissions. Additionally, the lower operating conditions can make the process more energy efficient.

Acetylcholine (pp. 6–9)

- 1 Approximately 60°. This angle positions the functional groups correctly so that acetylcholine can fit and interact effectively with the muscarinic receptor binding site.
- 2 The hydroxyl group in the active site of acetylcholinesterase (AChE–OH) acts as a nucleophile. It can attack the electrophilic carbonyl carbon in the ester of acetylcholine, leading to the transfer of the acyl group. This gives the acylated enzyme, AChE–O–COCH₃, and choline. The acylated enzyme is then hydrolysed to regenerate the hydroxyl group (AChE–OH).
- 3 Organophosphorus nerve agents like sarin react with the nucleophilic hydroxyl group in the active site of acetylcholinesterase (AChE–OH), forming a stable phosphonate group, such as

AChE–O–P(O)Me(OCHMe₂), where Me represents methyl (–CH₃). The phosphonate group blocks the active site and prevents the enzyme from reacting with acetylcholine.

4



- 5 Pralidoxime has a positively charged nitrogen that mimics that in acetylcholine, so binding in the active site is similar (i.e. an electrostatic interaction is possible between the positively charged nitrogen in pralidoxime and a negatively charged site within the receptor).

Pralidoxime has a nucleophilic oxygen that can attack the electrophilic phosphorus atom in the phosphorylated acetylcholinesterase.

Sunscreen under the microscope (pp. 12–14)

- 1 Sunscreens protect against ultraviolet (UV) radiation, specifically UVA and UVB. They work by absorbing, reflecting or scattering UV radiation. Organic UV filters like oxybenzone absorb UV light and dissipate the energy as heat.
- 2 The conjugated π system in oxybenzone allows electrons to become delocalised over multiple bonds. This lowers the energy gap between molecular orbitals, enabling the molecule to absorb UV photons, which have enough energy to excite electrons to a higher energy level.
- 3 Studies have shown that oxybenzone can accumulate in marine environments and potentially cause coral bleaching, DNA damage in marine organisms, and endocrine disruption. It has prompted bans in some regions, such as Hawaii and Palau.
- 4 'Reef-safe' sunscreens typically exclude certain organic UV filters like oxybenzone and use inorganic filters such as zinc oxide or titanium dioxide. However, their safety is not fully established because fewer studies have been done on their long-term effects on marine life.
- 5 Many studies only measured the concentration of oxybenzone inside organisms, not in the surrounding water, making bioavailability unclear. Also, most studies focused on a limited number of species and regions, reducing the global relevance of the findings.

Chemistry sudoku (p. 15)

Methanol X1	Citric acid X7	TNT X9	Ethene H4	Formic acid H2	Tol H8	Acetone C3	Glucose C6	Gln C5
Arg X6	Ribose X5	EtOAc X2	MeBr H3	PrCONH ₂ H7	Glu H9	Caffeine C8	Butyric acid C4	Methanal C1
CTC X4	Glycerol X3	PFP X8	Ethanol H6	PhNO ₂ H5	Chloroform H1	BzCl C7	Ethyne C2	Aspirin C9
Caffeine C8	Methanal C1	BzCl C7	EtOAc X2	Arg X6	Ribose X5	Ethene H4	Glu H9	MeBr H3
Ethyne C2	Butyric acid C4	Acetone C3	Methanol X1	TNT X9	Citric acid X7	PhNO ₂ H5	Tol H8	Ethanol H6
Gln C5	Aspirin C9	Glucose C6	PFP X8	CTC X4	Glycerol X3	Formic acid H2	Chloroform H1	Citric acid X7
Glu H9	Formic acid H2	PhNO ₂ H5	BzCl C7	Methanal C1	Butyric acid C4	Arg X6	Glycerol X3	PFP X8
PrCONH ₂ H7	Tol H8	Ethene H4	Aspirin C9	Acetone C3	Glucose C6	Methanol X1	Ribose X5	EtOAc X2
MeBr H3	Ethanol H6	Chloroform H1	Gln C5	Caffeine C8	Ethyne C2	TNT X9	Citric acid X7	CTC X4

Ivermectin (pp. 18–20)

- 1 Avermectin B_{1a} contains three trisubstituted alkenes (three of the four substituents attached to the C=C carbons are carbon atoms).
- 2 Avermectin B_{1a} contains 20 chiral centres. The stereochemistry at these centres is important because it determines the three-dimensional shape of the molecule, which affects how the molecule interacts with its biological targets.

- 3 Wilkinson's catalyst contains bulky PPh_3 ligands, which shield certain $\text{C}=\text{C}$ double bonds, while a vacant co-ordination site allows the less hindered $\text{C}=\text{C}$ bond to bind and be selectively hydrogenated.
- 4 Avermectins are structurally complex natural products and building them from scratch would require many synthetic steps. Semisynthesis from naturally produced avermectins is more practical, efficient (giving a higher yield) and cost-effective.

Advertising chemistry (pp. 21–23)

- 1 Surfactants have a hydrophilic (water-attracting) head and a hydrophobic (water-repelling) tail. In water, once the concentration reaches a certain level (called the critical micelle concentration) the molecules arrange into spherical structures called micelles. The hydrophobic tails orient themselves toward the interior, away from water, and the hydrophilic heads are directed outward. Oily or greasy substances are drawn into the centre of these micelles, where they are surrounded and trapped by the hydrophobic tails. Rinsing with water then removes the micelles, taking the trapped dirt and oil with them.
- 2 Hyaluronic acid contains hydroxyl ($-\text{OH}$) and carboxyl ($-\text{COOH}$) groups that can form hydrogen bonds with water molecules, allowing it to hold large amounts of water and retain moisture in the skin.
- 3 The effectiveness of killing bacteria depends on several factors, including the concentration of the biologically active chemical, temperature, contact time, pH, and the surface area being cleaned. These factors influence the rate of reaction and how efficiently the disinfectant works.

Periodicity (pp. 24–27)

- 1 In each of the elements, the outermost (highest energy) electron occupies an orbital in a p-shell.
- 2 $\text{Al}^{2+}_{(\text{g})} \rightarrow \text{Al}^{3+}_{(\text{g})} + \text{e}^-$
- 3 Nitrogen has the electron configuration $1\text{s}^2 2\text{s}^2 2\text{p}^3$ which, according to Hund's rule, has one unpaired electron in each orbital in the 2p subshell. Oxygen has the electron configuration $1\text{s}^2 2\text{s}^2 2\text{p}^4$, which means it must pair two electrons in one of the 2p orbitals. This causes electron-electron repulsion, making the electrons higher energy and easier to remove, and decreasing ionisation energy compared with nitrogen.
- 4 Across Period 3, the atomic number increases, adding more protons to the nucleus and more electrons to the same principal energy level. The increased nuclear charge pulls the electrons closer without much increase in shielding, causing the atomic radius to decrease.
- 5 Sodium is a giant metallic lattice where positive ions are surrounded by a sea of delocalised electrons. These free-moving electrons allow sodium to conduct electricity in the solid state.
- 6 Group 4 elements like silicon have giant covalent structures with strong covalent bonds that require a lot of energy to break, resulting in high melting points. Group 5 elements like

phosphorus exist as simple molecular structures held together by weak van der Waals forces, which require much less energy to overcome, leading to much lower melting points.

Sour science (pp. 28–30)

- 1 After the first proton is lost, the negative charge is stabilised by resonance or delocalisation. Losing a second or third proton adds more negative charges, which repel each other, making subsequent protons harder to remove.
- 2 Citric acid (weak acid) can donate protons to neutralise added bases, and the citrate ion (conjugate base) can accept protons to neutralise added acids. This resists large changes in pH, keeping the juice acidic and preventing microbial growth.
- 3 Carboxylic acids can donate a proton from the $\text{-CO}_2\text{H}$ group, forming a carboxylate ion (R-CO_2^-). The negative charge on the carboxylate ion is delocalised by resonance across the two oxygen atoms, stabilising the ion. In alcohols, the negative charge on the alkoxide ion (RO^-) is localised on a single oxygen, so it is less stable, and the proton is less easily lost.