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# Chemistry, 2005 EC, entrance exam

Grade 12 · Chemistry · 2005 E.C.

MARKING KEY — CONFIDENTIAL

**Time allowed:** 120 minutes | **Questions:** 74 | **Total marks:** 74

**1.** Which of the following is NOT a basic SI unit? (1)

**A.** Candela
**B.** ✓ **Gram**
**C.** Mole
**D.** Second

**Answer:** B
The seven SI base units include the candela for luminous intensity, the mole for amount of substance and the second for time. The base unit of mass is the kilogram, so the gram is a fraction of a base unit and not a base unit itself. The mole tempts a lot of students because it feels like a counting label rather than a measurement, but amount of substance is one of the seven base quantities.

**2.** Which of the following statements is TRUE? (1)

**A.** Ultraviolet light has longer wavelength than visible light.
**B.** The energy of radiation decreases as the wavelength decreases.
**C.** ✓ **The frequency of radiation increases as the wavelength decreases.**
**D.** Wave number of an electromagnetic radiation increases as wavelength increases.

**Answer:** C
Wavelength and frequency are tied together by $c = \nu\lambda$, and the speed of light $c$ is fixed. Rearranged, $\nu = c/\lambda$, so when the wavelength gets shorter the frequency must get higher. Option B tempts because energy and wavelength sound like they should rise together, but $E = hc/\lambda$ shows the energy goes up when the wavelength goes down.

**3.** Which of the following ionic compounds is formed from the reaction between magnesium and nitrogen? (1)

**A.** $\mathrm{MgN_2}$
**B.** $\mathrm{Mg_2N_2}$
**C.** ✓ $\mathrm{Mg_3N_2}$
**D.** $\mathrm{Mg_2N_3}$

**Answer:** C
Magnesium is in group IIA and loses two electrons to give $\mathrm{Mg^{2+}}$. Nitrogen gains three electrons to give $\mathrm{N^{3-}}$. The compound must be electrically neutral, so three $\mathrm{Mg^{2+}}$ ions carrying $+6$ pair with two $\mathrm{N^{3-}}$ ions carrying $-6$, which gives $\mathrm{Mg_3N_2}$. Option A tempts if you copy the 2 from the $\mathrm{N_2}$ gas, but the subscripts in an ionic formula come from the charges.

**4.** Which of the following molecules represents a non-polar covalent bond? (1)

**A.** B-Cl
**B.** C-Cl
**C.** ✓ **Cl-Cl**
**D.** Mg-Cl

**Answer:** C
A bond is non-polar when both atoms pull on the shared pair with the same strength. Two chlorine atoms have identical electronegativity, so the difference is zero and the electron pair sits in the middle. C-Cl is the tempting choice because carbon and chlorine are both non-metals, but their electronegativities differ by about 0.5, so that bond is polar covalent.

**5.** Which of the following groups in the periodic table has paramagnetic atoms? (1)

**A.** Group zero
**B.** Group IIA
**C.** Group IIB
**D.** ✓ **Group IVA**

> **Answer:** D
> Paramagnetic means the atom holds at least one unpaired electron. Group IVA atoms end in $ns^2np^2$, and by Hund's rule those two p electrons go into separate orbitals with parallel spins, so two electrons stay unpaired. Group zero, IIA and IIB all finish with completely filled subshells, so every electron is paired and they are diamagnetic. Group IIB tempts because of its d electrons, but that $d^{10}$ subshell is full.

**6.** How many types of cubic unit cells are known? (1)

**A.** 2
**B.** ✓ **3**
**C.** 4
**D.** 5

> **Answer:** B
> A cubic lattice can arrange its points in three ways: at the eight corners only (simple cubic), corners plus one point at the centre of the cube (body centred), or corners plus one point at the centre of each face (face centred). No other arrangement keeps full cubic symmetry. Four is a common guess from students who add an edge centred cell, but that pattern is the same as one of the three already counted.

**7.** What is the process that converts liquid vegetable oils to solid fats? (1)

**A.** Hydration
**B.** ✓ **Hydrogenation**
**C.** Hydrolysis
**D.** Saponification

> **Answer:** B
> Vegetable oils stay liquid because their fatty acid chains carry $\mathrm{C=C}$ double bonds that put a kink in the chain and keep the molecules apart. Passing hydrogen over the oil with a nickel catalyst adds $\mathrm{H_2}$ across those double bonds, the chains straighten, they pack closely and the product is solid at room temperature. Hydrolysis tempts because it also attacks fats, but hydrolysis breaks the ester links and gives glycerol and fatty acids instead of a solid fat.

**8.** What would be the solubility of $\mathrm{HOCH_2(CH_2)_6CH_2OH}$ compared to $\mathrm{CH_3(CH_2)_6CH_2OH}$? (1)

**A.** Less soluble in water
**B.** ✓ **More soluble in water**
**C.** The same solubility in water.
**D.** More soluble in a non-polar solvent such as dichloroethane.

> **Answer:** B
> Both molecules have the same eight carbon chain, so the only difference is the number of $\mathrm{OH}$ groups. The diol carries an $\mathrm{OH}$ at each end and can hydrogen bond to water at both ends, while the alcohol can do it at one end only. More hydrogen bonding with water means higher solubility in water. Option D tempts because the long chain is greasy, but adding a second polar group pulls the molecule towards water, not towards a non-polar solvent.

**9.** Which of the following gases is manufactured using the Haber process? (1)

**A.** ✓ **Ammonia**
**B.** Nitric oxide
**C.** Nitrogen
**D.** Nitrogen dioxide

> **Answer:** A
> The Haber process combines nitrogen from the air with hydrogen over an iron catalyst at high pressure: $\mathrm{N_2 + 3H_2 \rightleftharpoons 2NH_3}$. Nitrogen is a raw material for the process, not its product, which is why option C misses. Nitric oxide and nitrogen dioxide come later, when the ammonia is oxidised in the Ostwald process.

**10.** Which one of the mixture of the following pairs will NOT give a buffer solution? (1)

**A.** HCN and NaCN

**B.** $NH_3$ and $NH_4Cl$

**C.** $H_3PO_4$ and $KH_2PO_4$

**D.** ✓ $HNO_3$ **and** $NaNO_3$

> **Answer:** D
> A buffer needs a weak acid together with its conjugate base, so that added acid or added base is mopped up. Nitric acid is a strong acid and ionises completely in water, and $NO_3^-$ is far too weak a base to take the proton back, so this pair holds no reserve against a pH change. Option C looks odd because phosphoric acid has three protons, but $H_3PO_4$ is a weak acid and $H_2PO_4^-$ is its conjugate base, so that mixture does buffer.

**11.** Which one of the following is TRUE for salts formed from strong acids and strong bases? (1)

**A.** ✓ **No hydrolysis takes place.**

**B.** Produces ions that are proton donors.

**C.** Produces ions which are proton acceptors.

**D.** Depends on the pKa and pKb of the parent acids and bases, respectively.

> **Answer:** A
> In a salt such as NaCl the cation comes from a strong base and the anion from a strong acid. $Na^+$ does not donate protons, and $Cl^-$ is too weak a base to pull one off water, so neither ion reacts with water and the solution stays neutral. Option D tempts because pKa and pKb really do decide the pH for other salts, but when both parents are strong the two ions are spectators.

**12.** Which of the following metals is NOT obtained by commercial electrolytic process? (1)

**A.** ✓ **Ag**

**B.** Al

**C.** Cu

**D.** Na

> **Answer:** A
> Aluminium is won by electrolysing molten alumina dissolved in cryolite, sodium by electrolysing molten sodium chloride in the Downs cell, and copper is refined electrolytically to reach high purity. Silver is recovered chemically, by cyanide leaching and as a by-product of lead and copper refining. Copper is the tempting answer because its ore is roasted and smelted first, but the final purification step is still electrolysis.

**13.** Which of the following metals has the highest electrical and thermal conductivities? (1)

**A.** ✓ **Ag**

**B.** Co

**C.** Cu

**D.** Ni

> **Answer:** A
> Silver conducts electricity and heat better than any other metal, because its outer 5s electron is loosely held and moves through the lattice of positive ions with very little resistance. Copper is the tempting answer since almost all wiring is copper, but copper is chosen for its price. On the measured values silver still comes first.

**14.** Enthalpy is defined as the heat content of the system at constant: (1)

**A.** Heat

**B.** Moles

**C.** ✓ **Pressure**

**D.** Volume

> **Answer:** C
> Enthalpy is defined as $H = U + PV$. When a change happens at constant pressure the $PV$ work is already accounted for, so the enthalpy change equals the heat exchanged: $\Delta H = q_p$. Option D is the usual slip: at constant volume no expansion work is done and the heat measured is $\Delta U$, the internal energy change, not $\Delta H$.

**15.** Which of the following elements is the second most abundant element in the earth's crust? (1)

**A.** Aluminium
**B.** Iron
**C.** Oxygen
**D.** ✓ **Silicon**

> **Answer:** D
> By mass the earth's crust is roughly 46 percent oxygen and roughly 28 percent silicon, the two of them locked together in silicate minerals. Aluminium follows at about 8 percent and iron at about 5 percent. Oxygen tempts because it is the element named first in every list, but the question asks for the second most abundant.

**16.** What is the number of significant figures in 0.0030050? (1)

**A.** 4
**B.** ✓ **5**
**C.** 7
**D.** 8

> **Answer:** B
> Zeros written in front of the first non-zero digit only place the decimal point, so they never count. In $0.0030050$ the counting starts at the 3 and runs 3, 0, 0, 5, 0, which is five significant figures. The last zero counts because it comes after the decimal point and after a non-zero digit, so it reports real precision. Four is the answer of everyone who drops that final zero.

**17.** Which of the following properties of a substance does NOT represent an intensive physical property? (1)

**A.** Boiling point
**B.** Colour
**C.** Density
**D.** ✓ **Volume**

> **Answer:** D
> An intensive property keeps the same value however much of the substance you take. Cut a copper block in half and the boiling point, the colour and the density are unchanged, but the volume is halved, so volume depends on the amount of matter and is extensive. Density tempts because it is built from mass and volume, yet those two change together and their ratio stays fixed.

**18.** What is the mass of one molecule of water? (1)

**A.** ✓ $3.0 \times 10^{-23}$ **g**
**B.** $1.8 \times 10^{-23}$ g
**C.** 0.0003g
**D.** 18.0g

> **Answer:** A
> One mole of water weighs 18.0 g and contains $6.02 \times 10^{23}$ molecules. So one molecule weighs $\frac{18.0}{6.02 \times 10^{23}} = 3.0 \times 10^{-23}$ g. Option D is the mass of a whole mole of water, which is about $10^{23}$ times too heavy for a single molecule.

**19.** Which of the following quantum number (s) is (are) related to the size and energy of an electron in a hydrogen atom? (1)

**A.** ✓ **n**
**B.** n,l
**C.** n,l,m
**D.** n,l,m,s

> **Answer:** A
> A hydrogen atom has only one electron, so there is no electron to electron repulsion to spread the energies apart. The energy is fixed by the principal quantum number alone, $E_n = -13.6/n^2$ eV, and the same $n$ also sets how far the orbital reaches from the nucleus. Option B tempts because in every many-electron atom $l$ does affect the energy, but the question names hydrogen.

**20.** An electron has a spin quantum number, s = +1/2 and a magnetic quantum number, $m_1 = +1$. In which of the following orbital will it NOT be present? (1)

**A.** ✓ **S-orbital**
**B.** P-orbital
**C.** d-orbital
**D.** f-orbital

> **Answer:** A
> The magnetic quantum number is limited by the azimuthal quantum number: $m$ can only take values from $-l$ to $+l$. An s orbital has $l = 0$, so its only allowed value is $m = 0$ and an electron with $m = +1$ cannot sit there. A p orbital has $l = 1$ and allows $m = -1, 0, +1$, so the electron fits in p, and in d and f as well.

**21.** Which of the following molecules has a trigonal bi pyramidal structure? (1)

**A.** ✓ $\mathrm{PCl_5}$
**B.** $\mathrm{IF_5}$
**C.** $\mathrm{ICl_4^-}$
**D.** $\mathrm{BrF_5}$

> **Answer:** A
> In $\mathrm{PCl_5}$ the phosphorus atom is surrounded by five bonding pairs and no lone pair. Five regions of electron density with none of them lone gives the trigonal bipyramid: three bonds spread in a plane at 120 degrees, and two more at right angles above and below. $\mathrm{IF_5}$ tempts because it also has five bonds, but iodine keeps a lone pair as well, and six regions with one lone pair make a square pyramid.

**22.** Which of the following represents the general configuration of the transition elements? (1)

**A.** $\mathrm{ns^2np^6}$
**B.** ✓ $\mathrm{ns(n-1)d}$
**C.** $\mathrm{ns(n-2)f}$
**D.** $\mathrm{ns^2np^6(n-1)d^{10}}$

> **Answer:** B
> A transition element is one that is filling the $(n-1)d$ subshell while the outer $ns$ subshell is occupied, so the configuration has to name both $ns$ and $(n-1)d$. Option B is the only choice written that way. Option D tempts because it also carries a d subshell, but a $d^{10}$ shell is already full and describes a post transition metal, not an element in the middle of the d block.

**23.** The total number of electrons participating in the bond formation of carbonate anion, $\mathrm{CO_3^{2-}}$ in the molecule of carbonic acid are: (1)

**A.** 16
**B.** 10
**C.** ✓ **8**
**D.** 5

> **Answer:** C
> The carbonate ion is held together by three $\mathrm{C-O}$ sigma bonds and one pi bond that is spread over the three oxygens, which is four bonds in total. Every bond is one shared pair, that is two electrons, so $4 \times 2 = 8$ electrons take part in the bonding. Option A (16) tempts if you also count the lone pairs drawn on the oxygens, but a lone pair sits on one atom and holds nothing together.

**24.** Which of the following crystals possess high electrical and thermal conductivities? (1)

**A.** Ionic crystals
**B.** ✓ **Metallic crystals**
**C.** Molecular crystals
**D.** Covalent network crystals

> **Answer:** B
> In a metal the valence electrons are not tied to any one atom. They form a sea that moves freely through the lattice of positive ions, and moving electrons carry both electric charge and thermal energy, so metals conduct both well. Ionic crystals tempt because they are made of ions, but in the solid those ions are locked in place, and an ionic compound only conducts once it is melted or dissolved.

**25.** What is the valid rate expression for the following reaction? $2\mathrm{NO} + 2\mathrm{H_2} \rightarrow \mathrm{N_2} + 2\mathrm{H_2O}$ (1)

A. 1/2 ?$(\Delta[\mathrm{H_2}])/\Delta t$

B. -1/2 □$(\Delta[\mathrm{H_2\ O}])/\Delta t$

C. ✓ **-1/2** □$(\Delta[\mathrm{NO}])/\Delta t$

D. $(\Delta[\mathrm{N_2}])/\Delta t$

> **Answer:** C

**26.** Which of the following statements is TRUE about equilibrium reaction? (1)

A. No more reactants are transformed into products.

B. There are equal amounts of reactants and products.

C. The rate constant for the forward reactions equals that of the reverse reaction.

D. ✓ **The rate for the forward reactions equals that of the reverse reactions.**

> **Answer:** D
>
> At equilibrium the reaction has not stopped. Both directions keep going, and the balance point is reached when the forward rate becomes equal to the reverse rate, so the concentrations stop changing. Option C is the close miss: the two rate constants are equal only in the special case where $K = 1$. What must match at equilibrium is the rates, not the constants.

**27.** Three gases are in equilibrium in a closed chamber sealed with a piston. The following equilibrium is established: (1)

$$2\mathrm{NH_3\,(g)} \rightleftharpoons \mathrm{N_2\,(g)} + 3\mathrm{H_2\,(g)}$$

What will happen if the piston is pushed into the chamber?

A. The mole fraction of $\mathrm{N_2}$ increases.

B. ✓ **The mole of $\mathrm{N_2}$ decreases.**

C. The mole fraction of $\mathrm{N_2}$ remains the same.

D. The mole fraction of $\mathrm{N_2}$ increases and then decreases.

> **Answer:** B
>
> Pushing the piston in raises the pressure. By Le Chatelier's principle the system moves towards the side holding fewer moles of gas: the left side has 2 mol of $\mathrm{NH_3}$ while the right has $1 + 3 = 4$ mol. The shift to the left uses up $\mathrm{N_2}$ and $\mathrm{H_2}$ to make ammonia, so the number of moles of $\mathrm{N_2}$ falls. Option C tempts because a mole fraction is a ratio and ratios often survive a squeeze, but here nitrogen is being removed while ammonia is being made, so the ratio moves as well.

**28.** Which of the following reactions will produce an akyl carboxylic acid? (1)

A. Heating a methyl ketone with acid and iodine.

B. Reacting an alkyl halide with hydrogen gas and platinum.

C. Reacting an alcohol with ozone.

D. ✓ **Oxidation of a primary alcohol with hot permanganate or chromate.**

> **Answer:** D
>
> Hot permanganate or chromate is a powerful oxidising agent. It takes a primary alcohol $\mathrm{RCH_2OH}$ first to the aldehyde and then straight on to the carboxylic acid $\mathrm{RCOOH}$, which is why the reaction has to be run hot and with excess oxidant. Option B tempts because platinum and hydrogen look like a strong pair of reagents, but that pair reduces rather than oxidises, and reducing an alkyl halide gives an alkane.

**29.** Which of the following statements is NOT TRUE? (1)

**A.** Naturally derived soaps consists of a soluble salt of a long chain fatty acid.

**B.** Triacylglycerols are esters of glycerol and long chain carboxylic acids.

**C.** Long chain carboxylic acids are also known as fatty acids.

**D.** ✓ **The major acidic component of vinegar is formic acid.**

> **Answer:** D
> Vinegar is a dilute solution of acetic acid, $CH_3COOH$, usually around 4 to 5 percent. Formic acid is the acid in ant stings and nettles, not the acid in vinegar, so statement D is the false one and answers a NOT TRUE question. Statement A tempts as the false one because soap looks nothing like an acid, but soap really is the sodium or potassium salt of a long chain fatty acid.

**30.** What is the name of triacylglycerol(triglycerides) that is solid at room temperature? (1)

**A.** Lecithin

**B.** ✓ **Fat**

**C.** Wax

**D.** Oil

> **Answer:** B
> Triacylglycerols are named by their state at ordinary room temperature: the solid ones are called fats and the liquid ones are called oils. Fats mostly come from animals, and their saturated chains are straight, so the molecules pack tightly and the melting point is high. Option D is the trap, because an oil is the same class of molecule in its liquid form.

**31.** Which of the following is the most important type of solute-solvent interaction in a solution of n- butanol in water? (1)

**A.** Dispersion

**B.** Ion-dipole

**C.** Dipole-dipole

**D.** ✓ **Hydrogen bonding**

> **Answer:** D
> n-Butanol carries an $OH$ group, so it has a hydrogen bonded directly to oxygen. That hydrogen is attracted to a lone pair on the oxygen of a water molecule, which is a hydrogen bond, the strongest of the four interactions listed. Dipole to dipole attraction tempts because both molecules are polar and it really is present, but the $O-H$ to $O$ attraction is several times stronger and decides the behaviour.

**32.** What is the product of the hydrolysis of easters in the presence of a mineral acid catalyst? (1)

**A.** ✓ **Alcohol**

**B.** Carbon dioxide

**C.** Ether

**D.** Ketones

> **Answer:** A
> Acid hydrolysis of an ester is the reverse of esterification. Water splits the ester link, with the mineral acid working only as a catalyst, and returns the two pieces the ester was built from: the carboxylic acid and the alcohol. Of those two only the alcohol appears among the choices. Ketones tempt because esters and ketones both hold a $C=O$ group, but hydrolysis breaks the single $C-O$ bond and leaves the carbonyl on the acid.

**33.** To which organic functional group does the following molecular representation, i.e, $R_1R_2CHCOH$ belong? ($R_1$ and $R_2$ represent different alkyl chains) (1)

**A.** Amides

**B.** ✓ **Aldehyde**

**C.** Ethers

**D.** Organic acid

> **Answer:** B
> Read the right hand end of $R_1R_2CHCOH$: the final carbon carries one oxygen and one hydrogen, which is a $-CHO$ group sitting at the end of the chain. A carbonyl carbon that also holds a hydrogen and sits at the end of a chain is an aldehyde. Organic acid tempts because the same letters C, O and H appear, but a carboxylic acid needs $-COOH$, with two oxygens on that carbon.

**34.** What is the quantity of water, in mL, required to prepare 0.5 M of HCl from a concentrated solution of 3.5M in 50 mL is? (1)

**A.** 50mL
**B.** 100mL
**C.** ✓ **300mL**
**D.** 350mL

> **Answer:** C
> Diluting does not change the moles of HCl, so use $M_1V_1 = M_2V_2$: $3.5 \times 50 = 0.5 \times V_2$, which gives $V_2 = 350$ mL. That 350 mL is the volume of the finished solution. The water added is the extra part: $350 - 50 = 300$ mL. Option D is the trap, because it reports the final volume instead of the water that has to be poured in.

**35.** What is the equivalent weight of $\mathrm{HNO_3}$, as an oxidizing agent, in the following balanced reaction? (1)

$$3\mathrm{Fe^{2+}} + 4\mathrm{H^+} + +\mathrm{NO^-}_3 \longrightarrow 3\mathrm{Fe^{3+}} + \mathrm{NO} + 2\mathrm{H_2O}$$

**A.** 10.5
**B.** 15.75
**C.** ✓ **21.00**
**D.** 31.50

> **Answer:** C
> Equivalent weight is the molar mass divided by the number of electrons the substance takes in. In this equation nitrogen goes from $+5$ in $\mathrm{NO_3^-}$ down to $+2$ in $\mathrm{NO}$, so each nitric acid unit accepts 3 electrons. The molar mass of $\mathrm{HNO_3}$ is $1 + 14 + 48 = 63$, so the equivalent weight is $63/3 = 21.00$. Option B (15.75) is $63/4$, which counts the four $\mathrm{H^+}$ ions in the equation instead of the electrons.

**36.** Given the following equilibria and equilibrium constant: ( I ) $\mathrm{HC_2H_3O_2 + H_2O \rightleftharpoons H_3O^+ + C_2H_3O_2^-}$ ; $\mathrm{K_a = 1.80 \times 10^{-5}}$ ( II ) $\mathrm{H_2CO_3 + H_2O \rightleftharpoons H_3O^+ + HCO^-}_3$ ; $\mathrm{K_a = 4.20 \times 10^{-7}}$ ( III ) $\mathrm{NH_4^+ + H_2O \rightleftharpoons H_3O^+ + NH_3}$; $\mathrm{K_a = 5.6 \times 10^{-10}}$ ( IV ) $\mathrm{HCOOH + H_2O \rightleftharpoons H_3O^+ + COOH^-}$ ; $\mathrm{K_a = 1.80 \times 10^{-4}}$ What is the strength of the acids in DECREASING order? (1)

**A.** I, IV, II and III
**B.** II, III, IV and I
**C.** III, II, I and IV
**D.** ✓ **IV, I, II and III**

> **Answer:** D
> The bigger the $K_a$, the stronger the acid. Line the four values up: IV is $1.80 \times 10^{-4}$, I is $1.80 \times 10^{-5}$, II is $4.20 \times 10^{-7}$, III is $5.6 \times 10^{-10}$. Reading from strongest down gives IV, I, II, III. Option A tempts if you read $10^{-5}$ as larger than $10^{-4}$; with negative powers, the number closer to zero in the exponent is the larger value.

**37.** Given the reaction: (1)

$$\mathrm{H_2PO_4^- + H_2O \rightarrow H_3O^+ + HPO_4^{2-}}$$

Which of the following represents a conjugate acid base pair?

**A.** $\mathrm{H_2PO_4^-}$ and $\mathrm{H_2O}$
**B.** ✓ $\mathrm{H_2PO_4^-}$ **and** $\mathrm{HPO_4^{2-}}$
**C.** $\mathrm{H_2PO_4^-}$ and $\mathrm{H_3O^+}$
**D.** $\mathrm{H_2O}$ and $\mathrm{H_2PO_4^{2-}}$

> **Answer:** B
> A conjugate acid and base pair differ by exactly one proton and by nothing else. $\mathrm{H_2PO_4^-}$ gives up one $\mathrm{H^+}$ and becomes $\mathrm{HPO_4^{2-}}$, so those two are a pair. The other pair in this equation is $\mathrm{H_2O}$ with $\mathrm{H_3O^+}$. Option A tempts because both species stand on the left of the arrow, but the members of a pair always sit on opposite sides, one before the proton moves and one after.

**38.** Which of the following statements is TRUE about colligative properties? (1)

**A.** Both vapour pressure and freezing point increase when a non-volatile solute is added to a solvent.

**B.** Both freezing point and boiling point increase when a non-volatile solute is added to a solvent.

**C.** Both vapour pressure and boiling point decrease when a non-volatile solute is added to a solvent.

**D.** ✓ **Colligative properties depend only upon the number of solute particles in a solution and not upon their identity.**

> **Answer:** D
> A colligative property counts the dissolved particles and ignores what they are. One mole of glucose and one mole of urea lower the freezing point of the same solvent by the same amount. Option B is the standard mix up: a non-volatile solute raises the boiling point but lowers the freezing point, so the two never move in the same direction.

**39.** What is the pH of 0.005 M solution of $\mathrm{Ca(OH)_2}$? (1)

**A.** 2.3 **B.** 10

**C.** ✓ **12** **D.** 14

> **Answer:** C
> Each unit of $\mathrm{Ca(OH)_2}$ releases two hydroxide ions, so $[\mathrm{OH^-}] = 2 \times 0.005 = 0.01$ M. Then $\mathrm{pOH} = -\log(0.01) = 2$, and $\mathrm{pH} = 14 - 2 = 12$. Option A (2.3) is $-\log(0.005)$, a pOH style figure reported as if it were the pH, and it also forgets that calcium hydroxide carries two $\mathrm{OH^-}$ groups.

**40.** How many kilo joules of heat are absorbed when 20 g of NaCl(s) is decomposed in to Na(s) and $\mathrm{Cl_2(g)}$ at constant pressure according to the following reaction? (1)

$$\mathrm{2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)} \qquad \Delta H = -821.8 \text{ kl}$$

**A.** -281.0 **B.** -140.5

**C.** ✓ **+140.5** **D.** +281.0

> **Answer:** C
> The equation as written makes 2 mol of NaCl and gives out 821.8 kJ, so forming 1 mol releases 410.9 kJ and breaking 1 mol back apart takes the same 410.9 kJ in. The sample is $20/58.5 = 0.342$ mol of NaCl. Heat absorbed $= 0.342 \times 410.9 = 140.5$ kJ, and heat taken in is positive, so the answer is $+140.5$. Option B has the right size but the wrong sign, because decomposition is the reverse of the reaction printed.

**41.** In the electroplating of nickel from a solution containing $\mathrm{Ni^{2+}}$ ion, what will be the weight of the metal deposited on the cathode by a current of 8 A flowing for 500 minutes? (1)

**A.** ✓ **73g** **B.** 103g

**C.** 117.4g **D.** 145g

> **Answer:** A
> Charge passed: $Q = It = 8 \times 500 \times 60 = 2.4 \times 10^5$ C, since the time has to be in seconds. Moles of electrons $= 2.4 \times 10^5 / 96500 = 2.49$. Nickel plates out as $\mathrm{Ni^{2+} + 2e^- \rightarrow Ni}$, so moles of nickel $= 2.49/2 = 1.24$, and the mass is $1.24 \times 58.7 = 73$ g. Option D (145 g) is what you get by forgetting to divide by the two electrons.

**42.** A 1M solution of $Cu(NO_3)_2$ is placed in a beaker with a strip of Cu metal. A 1M of $SnSO_4$ is placed in a second beaker with a strip of Sn metal. The two beakers are then connected by a salt bridge and the two metal electrodes are connected by wires to a voltmeter. Which of the following electrodes serves as the anode and which electrode gains mass? Given that $E^0Cu^{2+}/Cu = 0.34V$ and $E^0Sn^{2+}/Sn = 0.14V$ (1)

**A.** Anode, Sn, Sn electrode gains mass.
**B.** ✓ **Anode, Sn, Cu electrode gains mass.**
**C.** Anode, Cu, Sn electrode gains mass.
**D.** Anode, Cu, Cu electrode gains mass.

**Answer:** B
The metal with the lower reduction potential is the one that gets oxidised, so tin is the anode and dissolves into the solution as $Sn^{2+}$. The electrons travel through the wire to the copper strip, where $Cu^{2+}$ ions are reduced and plate onto it, so the copper electrode gains mass. Option A tempts because the anode is where the reaction starts, but an anode loses mass; it is the cathode that grows.

**43.** Which of the following metal alloys does NOT contain tin? (1)

**A.** ✓ **Brass**
**B.** Bronze
**C.** Pewter
**D.** Plumber's solde

**Answer:** A
Brass is copper alloyed with zinc, and it contains no tin. Bronze is copper with tin, pewter is mostly tin, and plumber's solder is a lead and tin mixture. Bronze is the usual trap because brass and bronze are both yellow copper alloys with similar names, but the added metal is zinc in brass and tin in bronze.

**44.** What structural feature is usually needed to present in order for an addition polymer to be produced? (1)

**A.** A carbon-carbon sigma bond.
**B.** A carbon-oxygen pi bond.
**C.** A carbon-oxygen sigma bond.
**D.** ✓ **A carbon-carbon pi bond.**

**Answer:** D
Addition polymerisation starts by opening a double bond. The pi bond of $C = C$ breaks, each carbon keeps one electron to form a new single bond to the next monomer, and the units link into a long chain with no small molecule thrown out. Option A tempts because every polymer chain is held by sigma bonds, but a carbon to carbon sigma bond on its own is already saturated and has nothing left to open.

**45.** What are the raw materials required to synthesize nylon 6, 6, a specific king of nylon? (1)

**A.** Diacids
**B.** Diamines
**C.** ✓ **Diacids and diamines**
**D.** Polyethylene

**Answer:** C
Nylon 6,6 is a condensation polymer built from two different six carbon monomers: adipic acid, which is a diacid, and hexamethylenediamine, which is a diamine. The acid group and the amine group join to make an amide link and release a water molecule. Choosing diacids alone tempts because the acid is named first, but one type of monomer cannot build an alternating amide chain; both are needed.

**46.** Which of the following substances are added to natural rubber to toughen it? (1)

**A.** Calcium
**B.** Carbon
**C.** Nitrogen
**D.** ✓ **Sulphur**

**Answer:** D
Raw natural rubber is soft and sticky because its long chains slide over one another. Heating it with sulphur, which is called vulcanisation, builds sulphur bridges between neighbouring chains so they can no longer slip, and the rubber becomes tough and springy. Carbon tempts because carbon black really is added to tyres, but that is a filler that reinforces the mix; the cross linking that toughens the rubber is the work of sulphur.

**47.** What is the quantity of heat required to raise the temperature of 80g of ethanol from $25^0\text{C}$ to $75^0\text{C}$? (specific heat of ethanol = $2.46\,\text{Jg}^{-1}\text{K}^{-1}$) (1)

**A.** 2.46kJ
**B.** 4.0kJ
**C.** ✓ **9.84kJ**
**D.** 18.68kJ

> **Answer:** C
> Use $q = mc\Delta T$, with $m = 80$ g, $c = 2.46\ \text{J g}^{-1}\text{K}^{-1}$ and $\Delta T = 75 - 25 = 50$. That gives $q = 80 \times 2.46 \times 50 = 9840$ J, which is 9.84 kJ. A temperature difference has the same number in kelvin as in degrees Celsius, so there is no need to add 273 to each reading. Option A (2.46 kJ) is only the specific heat with a kJ label attached.

**48.** Consider the following gaseous reaction at 250C: (1)

$$\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g}) \quad \Delta H = -802\,\text{kJ}$$

Which energy change would occur if 3.2 moles of $\text{CH}_4$ is completely combusted?

**A.** ✓ $2.57 \times 10^3$ **kJ will be released.**
**B.** $2.57 \times 10^2$ kJ will be absorbed.
**C.** $6.43 \times 10^3$ kJ will be released.
**D.** $6.43 \times 10^3$ kJ will be absorbed.

> **Answer:** A
> The equation gives out 802 kJ for every 1 mol of methane burned, and $\Delta H$ is negative, so the heat leaves the system. For 3.2 mol: $3.2 \times 802 = 2566$ kJ, which is $2.57 \times 10^3$ kJ released. Option B is wrong twice over: the size is a hundred times too small, and a negative $\Delta H$ always means heat released, never absorbed.

**49.** What is the number of chloride ions ($\text{Cl}^-$) present in $1.0 \times 10^{-5}$ mol of $\text{AlCl}_3$? (1)

**A.** ✓ $1.80 \times 10^9$
**B.** $6.02 \times 10^{18}$
**C.** $6.02 \times 10^{23}$
**D.** $6.02 \times 10^{28}$

> **Answer:** A
> Each formula unit of $\text{AlCl}_3$ carries three chloride ions, so $1.0 \times 10^{-5}$ mol of the salt holds $3.0 \times 10^{-5}$ mol of $\text{Cl}^-$. Multiply by Avogadro's number: $3.0 \times 10^{-5} \times 6.02 \times 10^{23} = 1.80 \times 10^{19}$ ions. Option A carries that 1.80 figure and is the intended answer, though the printed power of ten is a typing slip for $10^{19}$. Option B is exactly what you get by ignoring the three chlorides and using $1.0 \times 10^{-5}$ mol on its own.

**50.** Which of the following is the most important ingredients used for production of DAP fertilizer? (1)

**A.** ✓ **Ammonia and phosphoric acid.**
**B.** Nitric acid, urea and phosphoric acid.
**C.** Phosphoric acid, urea and ammonia.
**D.** Sulphuric acid, ammonia and urea.

> **Answer:** A
> DAP stands for diammonium phosphate, $(\text{NH}_4)_2\text{HPO}_4$. It is made by feeding ammonia into phosphoric acid, so those two are the ingredients that matter. Urea appears in three of the options because it is also a nitrogen fertiliser and the names are often heard together, but urea plays no part in making DAP.

**51.** Which of the following bio molecules forms a zwitterions at higher or lower PH? (1)

**A.** Cellulose
**B.** Glucose
**C.** ✓ **Protein**
**D.** Starch

> **Answer:** C
> A zwitterion needs an acidic group and a basic group on the same molecule, so that one can hand a proton to the other and the molecule ends up with a positive and a negative site at once. Proteins are chains of amino acids, and every amino acid carries $-\text{COOH}$ and $-\text{NH}_2$, so the charge changes as the pH changes. Glucose tempts because it dissolves well in water, but it holds only $\text{OH}$ groups and an aldehyde, with nothing basic to accept a proton.

**52.** Which of the following form of synthetic rubbers can be vulcanized to greatly enhance its mechanical strength? (1)

**A.** Neoprene
**B.** Isoprene
**C.** ✓ **Styrene-butadiene rubber**
**D.** Butyl rubber

> **Answer:** C
> Styrene butadiene rubber keeps the $C = C$ double bonds contributed by its butadiene units, and those double bonds are exactly where sulphur attacks during vulcanisation. Cross linking them turns a weak, sticky polymer into the tough material used in car tyres, which is why SBR is the synthetic rubber made in the largest quantity. Butyl rubber tempts, but it keeps very few double bonds in the chain, so it cross links poorly and gains far less strength.

**53.** What is the range in the number of carbon atom of the monosaccharides that are found in nature? (1)

**A.** ✓ **3 to 7**
**B.** 4 to 10
**C.** 4 to 12
**D.** 5 to 12

> **Answer:** A
> Natural monosaccharides run from the three carbon trioses, such as glyceraldehyde, up to the seven carbon heptoses, with the five carbon ribose and the six carbon glucose and fructose the most familiar. Option D, starting at 5, tempts because ribose and glucose are the sugars named most often in class, but the trioses and tetroses are real sugars that appear as intermediates in respiration.

**54.** What are the two principal polysaccharide forms of starch? (1)

**A.** Aldohexose and ketopentose.
**B.** ✓ **Amylose and amylopectin.**
**C.** Maltose and cellobiose.
**D.** Sucrose and lactose.

> **Answer:** B
> Starch is not one substance but a mixture of two glucose polymers. Amylose is the long unbranched chain that coils into a helix, and amylopectin is the branched one, and the two together make up the starch grain. Option C tempts because maltose and cellobiose are also built from glucose, but those are disaccharides, two units long, so they are not polysaccharide forms of starch.

**55.** What is the Kelvin scale (K) corresponding to the temperature readings when the degree Celsius ($^0\mathrm{C}$) is identical to the degree Fahrenheit ($^0\mathrm{F}$)? (1)

**A.** 0 k
**B.** 37 k
**C.** ✓ **233 k**
**D.** 273 k

> **Answer:** C
> Set the two readings equal and use $F = 1.8C + 32$. Putting $F = C$ gives $C = 1.8C + 32$, so $-0.8C = 32$ and $C = -40$. Convert to kelvin: $K = -40 + 273 = 233$. Option D (273 K) tempts because that number is memorised from the conversion formula, but 273 K is the freezing point of water, not the point where the two scales read the same.

**56.** What is the wavelength associated with an electron of mass, $m = 9.11 \times 10^{-28}$ g, travelling at 40% of the velocity of light? (1)

**A.** $6.06 \times 10^{-15}$ m
**B.** $2.42 \times 10^{-15}$
**C.** ✓ $6.06 \times 10^{-12}$ **m**
**D.** $2.42 \times 10^{-11}$ m

> **Answer:** C
> Use de Broglie's relation, $\lambda = h/mv$. First put the mass into kilograms, $9.11 \times 10^{-28}$ g $= 9.11 \times 10^{-31}$ kg, and find the speed, $0.40 \times 3.0 \times 10^{8} = 1.2 \times 10^{8}$ m/s. Then $\lambda = \dfrac{6.626 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.2 \times 10^{8}} = 6.06 \times 10^{-12}$ m. Option A has the same digits but a different power of ten, which is what comes out if the mass is left in grams.

**57.** The quantum numbers listed below are meant for four different electrons in an atom: I. $n = 4,\ 1 = 0,\ m_1 = 0,\ m_s = +1/2$ II. $n = 3,\ 1 = 1,\ m_1 = 1,\ m_s = +1/2$ III. $n = 4,\ 1 = 2,\ m_1 = 0,\ m_s = +1/2$ IV. $n = 4,\ 1 = 1,\ m_1 = 0,\ m_s = -1/2$ When these sets of quantum numbers are arranged in order of increasing energy, one may get: (1)

**A.** I < II < III< IV

**B.** I < III < II < IV

**C.** ✓ ☐**II < I < IV < III**

**D.** IV < III < II < I

> **Answer:** C
> Order the subshells by the $n + l$ rule, and when two of them tie, the one with the smaller $n$ comes first. Set II is $n = 3, l = 1$, that is 3p with $n + l = 4$. Set I is $n = 4, l = 0$, that is 4s, also 4. Set IV is 4p with 5, and set III is 4d with 6. So the rising order is 3p, 4s, 4p, 4d, which reads II < I < IV < III. Option A tempts because it keeps the sets in the order they are printed, but the roman numerals were not written in energy order.

**58.** Which of the following hybrid orbitals is favouring the formation of trigonal bipyramidal? (1)

**A.** ✓ $\mathrm{sp^3d}$

**B.** $\mathrm{sp^3}$

**C.** $\mathrm{sp^3d^2}$

**D.** $\mathrm{sp^3d^3}$

> **Answer:** A
> A trigonal bipyramid has five positions around the central atom, so five hybrid orbitals have to be built. Mixing one s orbital, three p orbitals and one d orbital gives exactly five, which is written $sp^3d$. Option C tempts because it also brings in d orbitals, but $sp^3d^2$ makes six orbitals and produces an octahedron.

**59.** Which one of the following molecules/molecular ions is paramagnetic according to the molecular orbital theory? (1)

**A.** $\mathrm{O_2^{2-}}$

**B.** ✓ $\mathrm{O_2}$

**C.** $\mathrm{F_2}$

**D.** $\mathrm{O_2^{2+}}$

> **Answer:** B
> Fill the molecular orbitals of $\mathrm{O_2}$ and the last two electrons go one into each of the two $\pi^*$ orbitals with parallel spins, so the molecule holds two unpaired electrons and is pulled into a magnetic field. Adding two more electrons, as in $\mathrm{O_2^{2-}}$, fills those $\pi^*$ orbitals and pairs everything, and $\mathrm{F_2}$ is full for the same reason. $\mathrm{O_2^{2-}}$ tempts because a charged particle feels more reactive, but magnetism is decided by unpaired electrons, not by charge.

**60.** For the reaction: $\mathrm{2A + B \rightarrow C}$ the following experimental results were obtained: What is the value of the rate constant? (1)

*[Figure: A four-column data table sits between the stem and the follow-up question. Column headings, left to right: "Experiment", "[A]", "[B]", "Rate (mol L^-1 S^-1)". Three data rows follow. Row 1: Experiment 1, [A] = 0.50, [B] = 0.50, Rate = 0.300. Row 2: Experiment 2, [A] = 0.50, [B] = 0.25, Rate = 0.075. Row 3: Experiment 3, [A] = 0.25, [B] = 0.25, Rate = 0.075. The table is drawn with plain black rules around every cell; no other marks, axes or arrows appear.]*

**A.** 0.6 mol $\mathrm{L^{-1}\,S^{-1}}$

**B.** 0.6 $\mathrm{L^{-1}\,S^{-1}}$

**C.** ✓ **1.2** $\mathrm{L^{-1}\,S^{-1}}$

**D.** 2.4 $\mathrm{mol^{-1}\,S^{-1}}$

> **Answer:** C
> Compare experiments 2 and 3: $[\mathrm{B}]$ is held at 0.25 while $[\mathrm{A}]$ is halved, and the rate does not move at all, so the reaction is zero order in A. Now compare experiments 1 and 2: $[\mathrm{B}]$ is halved from 0.50 to 0.25 and the rate drops from 0.300 to 0.075, one quarter of the value, so the reaction is second order in B. The rate law is therefore $\mathrm{rate} = k[\mathrm{B}]^2$, and $k = 0.300/(0.50)^2 = 1.2$. Option A (0.6) comes from treating B as first order and dividing 0.300 by 0.50.

**61.** If a piece of aluminium (Al) foil measuring 24 cm by 31 cm has a mass of 10.35 g, (density of Al = $2.70\ \text{gcm}^{-3}$). What is the thickness of the foil in millimetres? (1)

**A.** $5.15 \times 10^{-3}$

**B.** ✓ $5.15 \times 10^{-2}$

**C.** 3.833

**D.** 744

> **Answer:** B
> Find the volume from the density: $V = m/d = 10.35/2.70 = 3.833\ \text{cm}^3$. The foil is a very flat box, so the thickness is the volume divided by the area: $3.833/(24 \times 31) = 3.833/744 = 5.15 \times 10^{-3}$ cm. The question asks for millimetres, and 1 cm is 10 mm, so the thickness is $5.15 \times 10^{-2}$ mm. Option A is that same number left in centimetres, which is the step most students forget.

**62.** Which of the following molecules has a dipole moment? (1)

**A.** $\text{XeF}_4$

**B.** ✓ $\text{H}_2\text{S}$

**C.** $\text{SO}_3$

**D.** $\text{CH}_4$

> **Answer:** B
> A molecule shows a dipole moment when its bond dipoles do not cancel out. $\text{H}_2\text{S}$ is bent, because sulphur keeps two lone pairs, so the two $\text{S} - \text{H}$ dipoles add up to a net pull towards the sulphur. $\text{XeF}_4$ is square planar, $\text{SO}_3$ is trigonal planar and $\text{CH}_4$ is tetrahedral, and each of those shapes cancels every bond dipole. $\text{XeF}_4$ tempts because it does carry lone pairs, but its two lone pairs sit directly opposite each other and the shape stays symmetrical.

**63.** Which of the following reactions will convert carboxylic acids to primary amines? (1)

**A.** Decarboxylation with HBr and peroxide, then reaction of the alkyl bromide with ammonia.

**B.** Reduction of the acid to the alcohol with NaOH/ formaldehyde then reaction with ammonium chloride and heat.

**C.** ✓ **A two-step conversion, first to the amide with ammonia and heat, and then by reduction with lithium aluminium hydride or hydrogen plus catalyst.**

**D.** Lactase fermentation in the presence of ammonia atmosphere

> **Answer:** C
> The route runs in two steps. Ammonia with the acid and heat gives the amide $\text{RCONH}_2$, and then lithium aluminium hydride, or hydrogen over a catalyst, reduces the $\text{C} = \text{O}$ of that amide to $\text{CH}_2$, leaving the primary amine $\text{RCH}_2\text{NH}_2$. Option A tempts because alkyl halides really do react with ammonia to give amines, but its first step is not a reaction a carboxylic acid undergoes, so the chain never starts.

**64.** A solution was prepared by adding 48g of methanol ($\text{CH}_3\text{OH}$) in to 81g of water ($\text{H}_2\text{O}$). What is the mole fraction of methanol in this solution? (1)

**A.** ✓ **0.25**

**B.** 0.75

**C.** 1.5

**D.** 4.5

> **Answer:** A
> Turn both masses into moles. Methanol: $48/32 = 1.5$ mol. Water: $81/18 = 4.5$ mol. The total is 6.0 mol, so the mole fraction of methanol is $1.5/6.0 = 0.25$. Option B (0.75) is the mole fraction of the water, and a quick check is that the two fractions in a mixture always add up to 1.

**65.** A solution was prepared by dissolving 3.75 g of pure hydrocarbon in 95.0g of cyclohexane. The boiling point of pure cyclohexane was observed to be $80.70^0\text{C}$ and that of the solution was $81.45^0\text{C}$. What is the approximate molecular weight of the hydrocarbon? ($\text{K}_\text{b}$ for cyclohexane = $2.79^0\text{C/m}$) (1)

**A.** 71.0g/mol
**B.** 105g/mol
**C.** ✓ **147g/mol**
**D.** 312g/mol

> **Answer:** C
> Boiling point elevation: $\Delta T_b = 81.45 - 80.70 = 0.75\ ^\circ\text{C}$, so the molality is $m = \Delta T_b / K_b = 0.75/2.79 = 0.269$ mol per kg. The solvent is 95.0 g, which is 0.0950 kg, so the moles of hydrocarbon come to $0.269 \times 0.0950 = 0.0255$. The molar mass is then $3.75/0.0255 = 147$ g/mol. Option A (71) is the value of $0.75 \times 95.0$, which is one part of the working reported before the division has been finished.

**66.** To 0.2 M solution of a weak monoprotic acid, HA, enough quantity of its sodium salt, NaA, was dissolved to give a concentration of 0.2 M of the salt. What will be the acid concentration, $[\text{H}_3\text{O}^+]$, in the final solutions? ($\text{K}_\text{a}$ of HA = $1.80 \times 10^{-5}$) (1)

**A.** $3.60 \times 10^{-6}$ M
**B.** $1.00 \times 10^{-5}$ M
**C.** ✓ $1.80 \times 10^{-5}$ **M**
**D.** $1.90 \times 10^{-3}$ M

> **Answer:** C
> This mixture is a buffer, with the weak acid and its salt at the same concentration. Write the expression $K_a = \dfrac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$; since $[\text{A}^-] = [\text{HA}] = 0.2$ M those two cancel, leaving $[\text{H}_3\text{O}^+] = K_a = 1.80 \times 10^{-5}$ M. Option D tempts if you treat the acid as though it were alone in water and use $\sqrt{K_a \times 0.2} = 1.9 \times 10^{-3}$, but the added salt pushes the ionisation back and keeps the acidity down.

**67.** Gaseous petrol in a combustion system has done 375kJ of work during its expansion in the piston. Simultaneously, it absorbed 586 kJ of heat from the engine. What is the internal energy change during the process? (1)

**A.** ✓ **+211kJ**
**B.** +961kJ
**C.** -211kJ
**D.** -961kJ

> **Answer:** A
> The first law is $\Delta U = q + w$, where $w$ is the work done on the system. The gas takes in heat, so $q = +586$ kJ, and it does 375 kJ of work on the piston as it expands, so the work term is $w = -375$ kJ. That gives $\Delta U = 586 - 375 = +211$ kJ. Option B (+961) comes from adding the work instead of subtracting it, which would describe a gas being squeezed rather than one pushing a piston out.

**68.** Which of the following reactions is expected to have negative value of entropy change ($\Delta S$)? (1)

**A.** $\text{C}_6\text{H}_6(\text{s}) + 6\text{O}_2(\text{g}) \rightarrow 6\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{l})$
**B.** $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$
**C.** $\text{N}_2\text{O}_4(\text{g}) + \text{Cl}(\text{g}) \rightarrow 2\text{NOCl}(\text{g}) + \text{O}_2(\text{g})$
**D.** ✓ $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g})$

> **Answer:** D
> Entropy falls when the system becomes more ordered, and the loudest signal is a drop in the number of gas molecules. In reaction D, 2 mol of $\text{SO}_2$ plus 1 mol of $\text{O}_2$, three moles of gas in all, become 2 mol of $\text{SO}_3$, so $\Delta S$ is negative. Option A tempts because liquid water is produced and a liquid sounds more ordered than a gas, but that reaction has 6 mol of gas on each side, so the gas count does not fall.

**69.** Consider the following unbalanced redox reaction in acidic solution: (1)

$$\mathrm{MnO_4^- + Fe^{2+} \rightarrow Mn^{2+} + Fe^{3+}}$$

what is the change in oxidation state for both the substances oxidized and reduced, and the coefficients of $\mathrm{Fe^{2+}}$ and $\mathrm{Mn^{2+}}$, respectively after balancing?

**A.** 2 and 7, and 2 and 5

**B.** 3 and 2, and 5 and 1

**C.** ✓ **1 and 5, and 5 and 1**

**D.** 2 and 5, and 5 and 2

**Answer:** C

Work out the two half changes. Manganese goes from $+7$ in $\mathrm{MnO_4^-}$ to $+2$, a change of 5, and each iron goes from $+2$ to $+3$, a change of 1. The electrons lost must equal the electrons gained, so 5 iron ions are needed for every 1 permanganate: $\mathrm{MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O}$. The changes are 1 and 5, and the coefficients of $\mathrm{Fe^{2+}}$ and $\mathrm{Mn^{2+}}$ are 5 and 1. Option D tempts because 2 and 5 look like familiar oxidation numbers, but the question asks for the change in oxidation state, not the final state.

**70.** How many mL conc. $\mathrm{HNO_3}$ and how many mL of water are required to prepare 500mL of 0.1M $\mathrm{HNO_3}$ from a conc. 13M $\mathrm{HNO_3}$? (1)

**A.** 1mL $\mathrm{HNO_3}$ and 496.15 mL $\mathrm{H_2O}$.

**B.** 3mL $\mathrm{HNO_3}$ and 500mL $\mathrm{H_2O}$.

**C.** 3.85 mL $\mathrm{HNO_3}$ and 500mL $\mathrm{H_2O}$.

**D.** ✓ **3.85 mL $\mathrm{HNO_3}$ and 496.15 mL $\mathrm{H_2O}$.**

**Answer:** D

Start with the acid and use $M_1V_1 = M_2V_2$: $13 \times V_1 = 0.1 \times 500$, so $V_1 = 50/13 = 3.85$ mL of the concentrated acid. The finished solution has to measure 500 mL in total, so the water is $500 - 3.85 = 496.15$ mL. Option C is the trap, because pouring 500 mL of water onto 3.85 mL of acid gives about 504 mL of solution and the concentration comes out below 0.1 M. In the laboratory the acid is always added to the water, never the other way round.

**71.** What is the pH of an aqueous solution prepared to contain $1.3 \times 10^{-3}$ M sodium nitrite ($\mathrm{NaNO_2}$) if the acid dissociation equilibrium constant, $\mathrm{K_a}$ for nitrous acid ($\mathrm{HNO_2}$) is $5.1 \times 10^{-4}$? $\mathrm{Kw} = 1.0 \times 10^{-14}$ (1)

**A.** 3.1

**B.** 5.1

**C.** 6.0

**D.** ✓ **7.3**

**Answer:** D

Sodium nitrite is the salt of nitrous acid, and nitrous acid is one of the stronger weak acids, so its anion is a very poor base: $K_b = K_w/K_a = 1.0 \times 10^{-14}/5.1 \times 10^{-4} = 2.0 \times 10^{-11}$. With only $1.3 \times 10^{-3}$ M of the salt, the hydroxide it makes is about $\sqrt{2.0 \times 10^{-11} \times 1.3 \times 10^{-3}} = 1.6 \times 10^{-7}$ M, no bigger than what water itself supplies. The solution ends up barely basic, with a pH a little above 7. Option A (3.1) is the trap for anyone who treats $\mathrm{NaNO_2}$ as an acid, but the salt of a weak acid with a strong base can never be acidic.

**72.** What reactions occur at the anode and cathode when an aqueous solution of $\mathrm{Na_2SO_4}$ is electrolyzed? $\mathrm{E^0}$ red I. $\mathrm{S_2O_8^{2-} + 2e^- \rightarrow 2SO_4^{2-}}$ 2.01V II. $\mathrm{O_2 + 4H^+ + 4e^- \rightarrow 2H_2O}$ 1.23V III. $\mathrm{2H_2O + 2e^- \rightarrow H_2 + 2OH^-}$ -0.83V IV. $\mathrm{Na^+ + e^- \rightarrow Na}$ -2.71V (1)

**A.** ✓ **$\mathrm{H_2}$ at cathode and $\mathrm{O_2}$ at anode.**

**B.** Na at cathode and $\mathrm{S_2O_8^{2-}}$ at anode.

**C.** $\mathrm{H_2}$ at cathode and $\mathrm{S_2O_8}$2- at anode.

**D.** Na at cathode and $\mathrm{O_2}$ at anode.

**Answer:** A

At the cathode the two candidates for reduction are $\mathrm{Na^+}$ at $-2.71$ V and water at $-0.83$ V, and water is far easier to reduce, so hydrogen bubbles off. At the anode the candidates are sulphate turning into $\mathrm{S_2O_8^{2-}}$, which is the reverse of a $+2.01$ V reduction, or water being oxidised, the reverse of $+1.23$ V. The reaction with the lower reduction potential is the easier one to run backwards, so water is oxidised and oxygen is released. Option B tempts because $\mathrm{Na^+}$ and $\mathrm{SO_4^{2-}}$ are the ions actually dissolved, but in a water solution the solvent beats both of them at each electrode.

**73.** Which synthetic polymer is produced from caprolactam? (1)

**A.** ✓ **Nylon -6**

**B.** Nylon 6, 10

**C.** Teflon

**D.** Terylene

**Answer:** A

Caprolactam is a ring holding one amide link and six carbon atoms. Heating it with a trace of water opens the ring, and the opened units join head to tail, so the polymer is built from one single monomer and takes the name nylon-6 from its six carbons. Nylon 6,10 tempts because the names look alike, but a nylon written with two numbers is made from two monomers, a diamine and a diacid, and the numbers count the carbons in each.

**74.** For the following hypothetical equation, in aqueous solution, what is the correct representation of the cell notation? (1)

$$\mathrm{A(s) + B^{2+}(aq) \_ A^{2+}(aq) + B(s)}$$

**A.** ✓ $\mathrm{A(s)|A^{2+}(aq)||B^{2+}\,(aq)|B(s)}$

**B.** $\mathrm{B^{2+}(aq)|B(s)||A^{2+}\,(aq)|A(s)}$

**C.** $\mathrm{A^{2+}(aq)(s)|A(s)||B(s)|B^{2+}(aq)}$

**D.** $\mathrm{B(s)|B^{2+}\,(aq)||A^{2+}\,(aq)|A(s)}$

**Answer:** A

In cell notation the anode is written on the left, the cathode on the right, and the double bar in the middle stands for the salt bridge. In this reaction A(s) loses electrons and becomes $\mathrm{A^{2+}}$, so A is the anode, while $\mathrm{B^{2+}}$ gains electrons and becomes B(s), so B is the cathode. That gives $\mathrm{A(s)|A^{2+}(aq)||B^{2+}(aq)|B(s)}$. Option D is the same cell written back to front, which would describe the reverse reaction, the one that does not happen on its own.

— END OF MARKING KEY —