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Chemistry, 2018 EC, entrance exam, version 2

Grade 12 · Chemistry · 2018 E.C.

MARKING KEY — CONFIDENTIAL

Time allowed: 120 minutes | **Questions:** 69 | **Total marks:** 69

1. Which one is a step-growth polymer? (1)

A. ✓ **Polyester**
B. PTFE
C. Polystyrene
D. PVC

Answer: A
A step-growth polymer builds up when two functional groups react and join, usually letting a small molecule such as water leave. A polyester forms when a diacid and a diol condense, so any two pieces that meet can link and the chain grows step by step. PTFE, polystyrene and PVC all come from monomers with a C=C bond that opens and adds onto a growing active end, which is chain growth. PTFE tempts because it is a famous plastic, but tetrafluoroethene polymerises through its double bond, not by condensation.

2. All of the following are thermoplastic polymers; except: (1)

A. Polyethylene
B. Nylon
C. ✓ **Bakelite**
D. Dacron

Answer: C
A thermoplastic softens every time it is heated, because its chains are separate and held together only by weak forces between them. Bakelite is made from phenol and formaldehyde into a rigid three dimensional network of covalent cross links, so heating cannot slide the chains past each other. It sets once and then chars instead of melting, which makes it a thermoset. Nylon looks like a candidate because it is also a condensation polymer, but its chains are linear, so it melts and can be reshaped.

3. All of the following are addition polymer; except: (1)

A. ✓ **Dacron**
B. PVC
C. Polypropylene
D. PMMA

Answer: A
An addition polymer keeps every atom of its monomer, because the monomer carries a C=C bond that opens and adds on. PVC, polypropylene and PMMA all come from vinyl monomers in that way. Dacron is poly(ethylene terephthalate), made when a diacid and a diol join and a water molecule leaves at each link, so it is a condensation polymer. PMMA can look out of place because of its ester side group, but that ester is already present in the monomer and the chain still grows across the C=C bond.

4. Which polymer is sold under the trade name Lucite or Plexiglas? (1)

A. PTFE
B. PET
C. ✓ **PMMA**
D. Nylon-66

Answer: C
Poly(methyl methacrylate) is the hard, glass clear plastic sold as Lucite or Plexiglas, used for aircraft windows, safety screens and signs. It is transparent, tough and lighter than glass. PET is also clear, which is why option B tempts, but PET is the bottle and fibre polyester known as Dacron, not the rigid glass substitute.

5. Which one is the use of Teflon? (1)

A. It is used as airplane windows.

B. It is used for making pipes and raincoats.

C. It is used for making parachutes and ropes.

D. ✓ **It is used for coating cooking utensils.**

> **Answer:** D
> Teflon is PTFE, a carbon chain wearing fluorine on every side. The C-F bonds are strong and the fluorine surface attracts other substances very weakly, so food and water do not stick and the coating survives cooking temperatures. That is why it lines frying pans and other cookware. Option A, aircraft windows, belongs to PMMA, the transparent plastic, while PTFE is waxy and opaque.

6. The widely used PVC is a polymerized product of _____ (1)

A. $CH_2 = CH_2$

B. $CH_2 = CCl_2$

C. $CH_2Cl – CH_2Cl$

D. ✓ **$CH_2 = CHCl$**

> **Answer:** D
> PVC stands for poly(vinyl chloride), so its monomer must be vinyl chloride, $CH_2{=}CHCl$. The double bond opens and the units join into a long chain carrying one chlorine on every second carbon. Option C, $CH_2Cl - CH_2Cl$, has the same atoms but no double bond, so there is nothing for the chain to add across. It is a saturated dichloroethane and cannot polymerise this way.

7. The compound $CH_3CH_2CH_2CH_2CH_2OH$ and $CH_3 – CH_2 – CH_2 – CH_2COOH$ react in the presence of an acid catalyst to form _____ (1)

A. carboxylic acid

B. alcohol

C. ✓ **ester**

D. aldehyde

> **Answer:** C
> A carboxylic acid heated with an alcohol and an acid catalyst undergoes Fischer esterification. The OH of the acid leaves together with the H of the alcohol as water, and the two fragments join through a C-O-C(=O) link. Here pentan-1-ol and pentanoic acid give an ester plus water. Option A tempts because a carboxylic acid is sitting there in the question, but that is a starting material, not the product.

8. Which one of the following classes of hydrocarbon is less reactive? (1)

A. ✓ **Alkane**

B. Alkene

C. Alkyne

D. Aromatic hydrocarbon

> **Answer:** A
> Alkanes hold only single C-C and C-H sigma bonds. Those bonding electrons sit tightly between the two nuclei, and there is no loose pi cloud on the outside of the molecule for an attacking reagent to reach. So alkanes react only under harsh conditions such as burning or free radical halogenation in strong light. Aromatic hydrocarbons tempt because the benzene ring is famously stable, but benzene still undergoes substitution with electrophiles at ordinary temperatures, which alkanes will not do.

9. Alcohol that yield aldehyde on oxidation are classified as (1)

A. secondary alcohol

B. ✓ **primary alcohol**

C. dihydric alcohol

D. trihydric alcohol

> **Answer:** B
> In a primary alcohol the OH sits on a carbon that still carries two hydrogen atoms. Oxidation removes one of those hydrogens along with the hydrogen of the OH group, giving $RCH_2OH \rightarrow RCHO$, an aldehyde, which can then be oxidised further to a carboxylic acid. A secondary alcohol has only one hydrogen on that carbon, so oxidation stops at the ketone. That is why option A is wrong.

10. During concentrating the ore; which method is chemical method? (1)

A. ✓ **Leaching**
B. Froth floatation
C. Amalgamation
D. Gravity separation

Answer: A
Concentration removes the worthless gangue from an ore. Froth flotation, gravity separation and amalgamation all sort particles by a physical property: how well a surface wets, how dense the grains are, or whether the metal dissolves in mercury. Leaching is different, because a reagent reacts with the wanted mineral and carries it into solution, as when bauxite dissolves in hot sodium hydroxide. A chemical change happens, so leaching is the chemical method. Amalgamation tempts because mercury seems to act on the gold, but forming an amalgam is dissolving, not converting the ore.

11. Roasting is generally done in case of the: (1)

A. oxide ores
B. silicate ores
C. ✓ **sulphide ores**
D. carbonate ores

Answer: C
Roasting heats the concentrated ore strongly in a good supply of air. Sulphide ores need that oxygen, because the sulphur burns away as $\mathrm{SO_2}$ and the metal is left behind as its oxide, for example $2\mathrm{ZnS} + 3\mathrm{O_2} \rightarrow 2\mathrm{ZnO} + 2\mathrm{SO_2}$. Carbonate ores are instead heated with little or no air, which is calcination, so option D is the usual trap. Oxide ores need no such step, because they are already oxides.

12. Extraction of gold and silver involves leaching with CN^- ion. Silver is later recovered by: (1)

A. distillation
B. zone refining
C. liquation
D. ✓ **displacement with Zn**

Answer: D
In the MacArthur-Forrest process the crushed ore is treated with dilute sodium cyanide and air, and the silver dissolves as the complex ion $[\mathrm{Ag(CN)_2}]^-$. Zinc dust is then stirred in. Zinc is more reactive than silver, so it hands over electrons and pushes silver out of solution as the free metal. Zone refining tempts because it is also a recovery method, but it purifies a solid such as silicon or germanium and cannot take a metal out of a solution.

13. What type of catalyst is used in the contact process? (1)

A. ✓ **V_2O_5**
B. Fe
C. Ni
D. Pt

Answer: A
The contact process makes sulphuric acid, and its key step is the oxidation $2\mathrm{SO_2} + \mathrm{O_2} \rightleftharpoons 2\mathrm{SO_3}$. Vanadium(V) oxide catalyses that step at about 450 degrees Celsius. Platinum catalyses the same reaction, which is why option D tempts, but platinum is expensive and is poisoned by traces of arsenic in the gas stream, so industry uses $\mathrm{V_2O_5}$.

14. In the tanning process, the purpose of putting the skin into slaked lime solution is to: (1)

A. Facilitate the removal of unwanted flesh
B. ✓ **Facilitate the removal of hair**
C. Dehydrate the skin
D. Soften the skin

Answer: B
Slaked lime is calcium hydroxide, a base. In liming, the soaked hide is steeped in it and the alkali attacks the protein holding each hair in its follicle, so the hair loosens and can be scraped off. The treatment also swells the skin and opens up the fibre structure ready for tanning. Option A tempts because unwanted flesh is indeed removed nearby in the process, but that is fleshing, done mechanically with a knife or machine.

15. Nylon-66 is obtained by condensation polymerization of (1)

A. ✓ **Adipic acid and hexamethylene diamine**
B. Terephthalic acid and ethylene glycol
C. Phenol and formaldehyde
D. Acrylic acid and ethane diol

> **Answer:** A
> Nylon-66 takes its name from two monomers of six carbon atoms each. Adipic acid supplies two $-\mathrm{COOH}$ groups and hexamethylene diamine supplies two $-\mathrm{NH_2}$ groups. Every time an acid group meets an amine group they form an amide link and release a molecule of water, so the chain grows by condensation. Option B is also a condensation pair, but an acid with an alcohol gives an ester, so terephthalic acid with ethylene glycol makes the polyester PET rather than a nylon.

16. What is the purpose of adding cryolite during the extraction of aluminum from bauxite in the Hall process? (1)

A. To get pure aluminum oxide
B. To dissolve impurities like iron oxides
C. ✓ **To lower the melting point of crude bauxite**
D. To decrease the conductivity of bauxite

> **Answer:** C
> Pure alumina melts at about 2050 degrees Celsius, which is far too hot to electrolyse at reasonable cost. Dissolving it in molten cryolite, $\mathrm{Na_3AlF_6}$, gives a bath that works near 950 degrees Celsius and still carries current well. Option D says the opposite of what happens: the cryolite melt conducts electricity better than molten alumina, so conductivity goes up, not down.

17. Salts that absorb water from the atmosphere and become solution are: (1)

A. ✓ **deliquescent**
B. efflorescent
C. hygroscopic
D. Florescent

> **Answer:** A
> A deliquescent salt takes in so much water vapour from the air that it ends up dissolving in the water it has absorbed, leaving a solution. Calcium chloride and sodium hydroxide pellets behave this way. A hygroscopic substance also absorbs moisture but stays a solid, so option C is the near miss. Efflorescent works the other way round: the crystal loses its water of crystallisation to the air and crumbles to a powder.

18. If a salt releases a reddish – brown gas upon heating with a disagreeable smell that turns moist blue litmus into red, which anion is most likely present in the salt? (1)

A. Bromide
B. ✓ **Nitrate**
C. Sulphate
D. Carbonate

> **Answer:** B
> Heating the nitrate of a heavy metal breaks it down into the oxide, oxygen and nitrogen dioxide, for example $2\mathrm{Pb(NO_3)_2} \rightarrow 2\mathrm{PbO} + 4\mathrm{NO_2} + \mathrm{O_2}$. Nitrogen dioxide is the reddish brown gas with a sharp, unpleasant smell, and because it dissolves in water to give acids, it turns moist blue litmus red. Carbonates tempt because they also decompose on heating, but the gas they release is $\mathrm{CO_2}$, which is colourless and has no smell.

19. What is the molar mass of a polyethylene sample [-CH_2 – CH_2-]$_n$, when n = 4600? (H = 1, C = 12) (1)

A. 1.288 × 10^3 g/mol
B. 1.196 × 10^4 g/mol
C. 1.196 × 10^3 g/mol
D. ✓ **1.288 × 10^5 g/mol**

> **Answer:** D
> The repeating unit is $-\mathrm{CH_2} - \mathrm{CH_2}-$: two carbons and four hydrogens, so $2(12) + 4(1) = 28$ g/mol. There are 4600 of them, so the molar mass is $28 \times 4600 = 128800$ g/mol. Written in standard form that is 1.288×10^5 g/mol. Option A carries the right digits but the wrong power of ten, so count the places carefully before choosing.

20. Which of the following quantum number is not permitted in sub-level notation? (1)

A. n = 2, ℓ = 0

B. ✓ **n = 3, ℓ = 3**

C. n = 4, ℓ = 3

D. n = 1, ℓ = 0

Answer: B

Within a shell, the value of ℓ can only run from 0 up to $n-1$. With $n=3$ the allowed values are 0, 1 and 2, which are the 3s, 3p and 3d sublevels, so $\ell=3$ does not exist in the third shell. Option C, $n=4$ with $\ell=3$, passes the same test because $3 \leq 4-1$, and it is the real 4f sublevel.

21. Which salt yields a basic solution on dissolution in water? (1)

A. Salts of strong acid & strong base

B. ✓ **Salts of weak acid & strong base**

C. Salts of weak base & strong acid

D. Salts of NaOH and HCl

Answer: B

When this salt dissolves, the cation comes from a strong base and stays as a spectator ion. The anion is the conjugate base of a weak acid, so it is strong enough to pull a proton off water: $\mathrm{A^- + H_2O \rightleftharpoons HA + OH^-}$. The hydroxide released makes the solution basic, as happens with sodium acetate. Option D is built from NaOH and HCl, a strong base with a strong acid, and that combination gives a neutral solution.

22. Which pair of compounds forms a buffer solution? (1)

A. KCl/HCl

B. CH_3COONa/H_2SO_4

C. $NaNO_3/HNO_3$

D. ✓ **NH_4Cl/NH_3**

Answer: D

A buffer needs a weak acid together with its conjugate base, both present in useful amounts. Ammonia is a weak base and the ammonium ion supplied by $\mathrm{NH_4Cl}$ is its conjugate acid, so the pair can absorb added acid or added base and hold the pH steady. Option B tempts because acetate is the anion of a weak acid, but sulphuric acid is a strong acid: it would react with the acetate rather than pair with it.

23. Which one of the following undergoes cation hydrolysis? (1)

A. BaI_2

B. $NaNO_3$

C. ✓ **$MgSO_4$**

D. CH_3COONa

Answer: C

Cation hydrolysis happens when the positive ion comes from a weak base and is small enough and highly charged enough to pull on the water molecules around it and release $\mathrm{H^+}$. $\mathrm{Mg^{2+}}$ comes from the weak base $\mathrm{Mg(OH)_2}$, while sulphate is the anion of the strong acid $\mathrm{H_2SO_4}$ and does nothing, so the solution turns slightly acidic. Sodium acetate tempts, but there it is the acetate anion that reacts with water, which is anion hydrolysis.

24. Which of the following devices is designed to produce electromagnetic radiation with the longest wavelength in order to operate? (1)

A. Light bulb

B. Microwave oven

C. X-ray microscope

D. ✓ **FM radio transmitter**

Answer: D

Radio waves sit at the long wavelength end of the electromagnetic spectrum. An FM broadcast near 100 MHz has a wavelength of about 3 m, while a microwave oven works at roughly 12 cm, visible light from a bulb is under a micrometre, and X-rays are shorter still. Microwaves tempt because a microwave oven sounds powerful, but the prefix micro tells you the wavelength is far shorter than a radio wave.

25. Which group of elements have variable valence and make colored compound? (1)

A. ✓ **Transition elements**
B. Representative elements
C. Rare earth metals
D. P – block elements

> **Answer:** A
> Transition elements have d orbitals that are only partly filled, and the energy needed to remove a d electron is close to that of the outer s electrons, so several oxidation states are within reach. That same partly filled d level lets electrons jump between d orbitals of slightly different energy by absorbing part of visible light, and the light that is left looks coloured. Representative elements tempt, but their outer s and p electrons are used all at once, so they show one main valence and their simple compounds are usually white.

26. When $Cr_2(SO_4)_3$ changed to CrO_3; the oxidation number of Chromium: (1)

A. Decrease as it undergo reduction
B. Increase as it undergo reduction
C. ✓ **Increase as it undergo oxidation**
D. Decrease as it undergo oxidation

> **Answer:** C
> In $\mathrm{Cr_2(SO_4)_3}$ each sulphate carries $2-$, so three of them need $6+$ shared between two chromium atoms, putting chromium at $+3$. In $\mathrm{CrO_3}$ three oxygens at -2 need $+6$ from a single chromium. The oxidation number rises from $+3$ to $+6$, and losing electrons is oxidation. Option B pairs a rise with reduction, which contradicts the definition of reduction as a gain of electrons.

27. What is the maximum number of electrons in n = 5, mℓ = -1? (1)

A. 6e
B. 12 e
C. ✓ **8 e**
D. 32e

> **Answer:** C
> In the shell $n = 5$, the possible values of ℓ are 0, 1, 2, 3 and 4. The value $m_\ell = -1$ only exists once ℓ is at least 1, so it appears one time each in $\ell = 1, 2, 3$ and 4. That is four orbitals, and each orbital holds two electrons, giving $4 \times 2 = 8$. Option D, 32, is the electron capacity of the whole $n = 5$ shell, not of one value of m_ℓ.

28. What is the oxidation number of "Cr" in the ionic compound ammonium dichromate, $(NH_4)_2Cr_2O_7$? (1)

A. +3
B. +7
C. ✓ **+6**
D. +5

> **Answer:** C
> The ammonium ion is $\mathrm{NH_4^+}$, so the two of them bring $+2$. Seven oxygen atoms at -2 each bring -14. For a neutral compound, $2(+1) + 2x + 7(-2) = 0$, which gives $2x = 12$ and $x = +6$. Option B, $+7$, is what you get if you forget that the charge has to be shared between two chromium atoms.

29. A metal corrodes if; (1)

A. It serve as cathode in the corrosion process
B. It does not react with oxygen
C. ✓ **It serve as anode in the corrosion process**
D. It is plated with corrosion resistant metal

> **Answer:** C
> Corrosion is the metal losing electrons and turning into ions, which is oxidation. Oxidation always takes place at the anode, so the region of metal acting as the anode is the region that eats away, while the cathode region is protected. Option D describes galvanising or plating, which is a way of preventing corrosion, not a condition for it.

30. What is E° for the following balanced reaction? Use the information given below. $4H^+(aq) + Fe(s) + NO_3^-(aq) \rightarrow Fe^{3+}(aq) + NO(aq) + 2H_2O(l)$ I. $NO_3^- + 4H^+ + 3e^- \rightarrow NO + 2H_2O$ E°red = +0.960 V II. $Fe^{3+} + 3e^- \rightarrow Fe$ E°red = -0.771 V (1)

A. +0.189 V
B. −0.189 V
C. −1.731 V
D. ✓ **+1.731 V**

> **Answer:** D
> In this reaction iron is oxidised and nitrate is reduced, so half reaction II runs backwards. Using reduction potentials throughout, $E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode} = 0.960 - (-0.771) = +1.731$ V. The positive value fits a reaction that goes on its own. Option A comes from treating -0.771 as if the minus sign could be dropped before subtracting.

31. The pH of an aqueous sodium fluoride (NaF) solution is _____ because _____ (1)

A. 7; Sodium fluoride is a neutral salt.
B. Above 7; Fluoride ion is a strong base.
C. Below 7; fluoride reacts with water to make hydrofluoric acid
D. ✓ **Above 7; fluoride ion is a weak base**

> **Answer:** D
> NaF is the salt of the strong base NaOH and the weak acid HF. Sodium is a spectator ion, but fluoride is the conjugate base of a weak acid, so some of it takes protons from water: $F^- + H_2O \rightleftharpoons HF + OH^-$. The extra hydroxide lifts the pH above 7. Option B gives the right pH with the wrong reason: the conjugate base of a weak acid is a weak base, and a strong base would not sit in equilibrium like this.

32. The substance formed at the anode during the electrolysis of dilute sodium chloride is: (1)

A. Hydrogen
B. Chlorine
C. Sodium
D. ✓ **Oxygen**

> **Answer:** D
> At the anode two things could lose electrons: chloride ions, giving chlorine, or water, giving oxygen. In a dilute solution there are few chloride ions reaching the electrode, so water is oxidised instead: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$. Chlorine tempts because that is what concentrated brine produces, and concentration is exactly the factor that decides between the two.

33. The percentage dissociation of a 0.20 M formic acid is 3.2%. What is its dissociation constant? (1)

A. 2.1×10^{-2}
B. 9.6×10^{-8}
C. ✓ **2.1×10^{-4}**
D. 1.1×10^{-6}

> **Answer:** C
> A dissociation of 3.2 per cent means $\alpha = 0.032$, so the acid that ionised is $0.20 \times 0.032 = 6.4 \times 10^{-3}$ M, and that is also the concentration of H^+ and of $HCOO^-$. The un-ionised acid left is $0.20 - 0.0064 = 0.194$ M. Then $K_a = \frac{(6.4 \times 10^{-3})^2}{0.194} = 2.1 \times 10^{-4}$. Option A is close to what you get if you divide without squaring the ion concentration first, so square before you divide.

34. The following reaction occurs in basic solution. Identify the oxidizing agent. Note the reaction equation is not balanced. $H_2O(l) + Zn(s) + NO_3^-(aq) + OH^-(aq) \rightarrow Zn(OH)_4^{2-}(aq) + NH_3(aq)$ (1)

A. Zn(s)

B. ✓ **NO_3^-(aq) (the nitrogen)**

C. $H_2O(l)$ (the oxygen)

D. $NH_3(aq)$ (the nitrogen)

E. $OH^-(aq)$

> **Answer:** B
> The oxidising agent is the species that gets reduced, so look for the atom whose oxidation number falls. Nitrogen is $+5$ in NO_3^- and -3 in NH_3, a drop of eight, so nitrate takes electrons and is the oxidising agent. Zinc goes from 0 to $+2$, losing electrons, so it is the reducing agent. Option A tempts because zinc is the reactive metal in the equation, but a reactive metal is reactive at giving electrons away.

35. In the electrochemical reaction: $2Fe^{3+} + Zn \rightarrow Zn^{2+} + 2Fe^{2+}$, on increasing the concentration of Fe^{2+} (1)

A. increases cell emf

B. ✓ **decreases the cell emf**

C. increases the current flow

D. alters the pH of the solution

> **Answer:** B
> Fe^{2+} is a product of this cell reaction. The Nernst equation, $E = E^\circ - \frac{0.059}{n} \log Q$, shows that raising a product concentration raises Q, so a larger number is subtracted from E° and the emf drops. In Le Chatelier terms, adding product pushes the reaction back toward the reactants, which weakens its drive. Option C tempts because more ions sound like more current, but the question asks about the voltage the cell can deliver.

36. One of the differences between a voltaic cell and an electrolytic cell is that in an electrolytic cell ___ (1)

A. Electron's flow toward the anode

B. ✓ **A non-spontaneous reaction is forced to occur**

C. An electric current is produced by a chemical reaction

D. O_2 gas is produced at the cathode

E. Oxidation occurs at the cathode

> **Answer:** B
> In a voltaic cell a reaction that wants to happen pushes electrons round the circuit and produces electricity. An electrolytic cell is the reverse: an outside power supply forces electrons through and drives a reaction that would never go on its own, as when molten NaCl is split into sodium and chlorine. Option C describes the voltaic cell, which is the very thing the question is contrasting it with. Oxidation still happens at the anode in both cells, so option E is wrong too.

37. The highest electrical conductivity of the following aqueous solutions is of (1)

A. 0.1 M Sugar

B. 0.1 M $MgCl_2$

C. 0.1 M $AlCl_3$

D. ✓ **0.1 M Ca_3N_2**

> **Answer:** D
> Conductivity depends on how many ions the solute releases and how much charge each ion carries. One formula unit of Ca_3N_2 supplies $3Ca^{2+}$ and $2N^{3-}$, five heavily charged ions, against four ions from $AlCl_3$ and three from $MgCl_2$. Sugar dissolves without splitting into ions at all, so it barely conducts. $AlCl_3$ tempts because Al^{3+} carries a high charge, but it puts fewer ions into the solution in total.

38. In a solution of $CuSO_4$ how much time will be required to precipitate 2 g copper by 0.5 ampere current? (1)

A. ✓ **12157.48 sec**

B. 102 sec

C. 510 sec

D. 642 sec

> **Answer:** A
> Copper is deposited by $\mathrm{Cu}^{2+} + 2\mathrm{e}^- \rightarrow \mathrm{Cu}$, so every mole of copper needs two moles of electrons. Moles of copper $= 2/63.5 = 0.0315$, so moles of electrons $= 0.0630$ and the charge needed is $0.0630 \times 96500 \approx 6079$ C. Then $t = Q/I = 6079/0.5 \approx 1.2 \times 10^4$ s. The other options are only a few hundred seconds, which is roughly what you would get by forgetting that the current is half an ampere and that copper takes two electrons per atom.

39. Based on the periodic table and general patterns of activity, which of the following would react with metallic calcium? (KBr, NaI, $FeCl_2$, $NiBr_2$) (1)

A. KBr and NaI only

B. ✓ **Both $FeCl_2$ and $NiBr_2$**

C. $FeCl_2$ only

D. $NiBr_2$ only

> **Answer:** B
> A metal can displace another metal from its salt only if it stands higher in the activity series. Calcium sits above iron and nickel, so it pushes Fe^{2+} and Ni^{2+} out of their salts and takes their place. Potassium and sodium stand above calcium, so calcium cannot displace them from KBr or NaI. Option A reverses the order, which is the usual trap.

40. Ammonia is manufactured in industry according to the following reaction: $N_2 + 3H_2 \rightarrow 2NH_3$. Which one of the following is TRUE about currently used sources of the reactants? (1)

A. Both nitrogen and hydrogen are obtained directly from air.

B. Both nitrogen and hydrogen are obtained as petroleum products.

C. Nitrogen is obtained from thermal decomposition of nitrates while hydrogen is from methane from natural gas.

D. ✓ **Nitrogen is obtained from fractional distillation of liquid air while hydrogen is from the electrolytic decomposition of water.**

> **Answer:** D
> Nitrogen for making ammonia is taken from the air, and the industrial way to separate it from oxygen in bulk is to cool air until it liquefies and then distil it, because nitrogen boils off first. Only option D names that source correctly, and electrolysis of water is a genuine, if smaller, route to hydrogen. Option C tempts because methane from natural gas really is the main hydrogen feedstock, but its nitrogen half is wrong: no ammonia plant decomposes nitrates to get nitrogen when the air is free.

41. The radius of the second orbit of hydrogen is 2.12Å. The radius of the first orbit would be: (1)

A. ✓ **0.53Å**

B. 0.26Å

C. 1.06Å

D. 0.12Å

> **Answer:** A
> In the Bohr model the radius of an orbit grows with the square of the shell number: $r_n = n^2 r_1$. So $r_2 = 2^2 r_1 = 4r_1$, which gives $r_1 = 2.12/4 = 0.53$ angstrom, the familiar Bohr radius of hydrogen. Option C, 1.06 angstrom, comes from dividing by 2 instead of by 2^2.

42. What is the quantum energy associated with the sodium-D line having a wavelength of 589 nm? (1)

A. ✓ **3.38×10^{-19} J**

B. 5.4×10^{-19} J

C. 2.7×10^{-19} J

D. 4.56×10^{-19} J

> **Answer:** A
> Use $E = \frac{hc}{\lambda}$ with $h = 6.626 \times 10^{-34}$ J s, $c = 3.0 \times 10^8$ m/s and the wavelength converted to metres, $\lambda = 589 \times 10^{-9} = 5.89 \times 10^{-7}$ m. The numerator is $6.626 \times 10^{-34} \times 3.0 \times 10^8 = 1.99 \times 10^{-25}$ J m. Dividing gives $E = 3.38 \times 10^{-19}$ J. The common mistake is leaving the wavelength in nanometres, which throws the answer out by a factor of 10^9, so convert first.

43. Which sets of quantum number (n, ℓ, mℓ, ms) is not permitted by the rules of quantum Mechanics respectively? (1)

A. 1, 0, 0, +½
B. 3, 2, -1, -½
C. 4, 3, 2, -½
D. ✓ **2, 2, 1, +½**

> **Answer:** D
> The rule is that ℓ may only take values from 0 up to $n-1$. With $n=2$ the allowed values are 0 and 1, so $\ell=2$ cannot exist in the second shell and that set is forbidden. Option C, $4, 3, 2, -\frac{1}{2}$, looks suspicious because the numbers are large, but $\ell=3$ is allowed when $n=4$, and $m_\ell=2$ lies inside the range -3 to $+3$, so it is a legal 4f electron.

44. Maximum number of electrons in a subshell of an atom is determined by: (1)

A. ✓ **4ℓ + 2**
B. 2n²
C. n²
D. 2ℓ + 1

> **Answer:** A
> A subshell with quantum number ℓ contains $2\ell+1$ orbitals, because m_ℓ runs from $-\ell$ through 0 to $+\ell$. Each orbital holds two electrons of opposite spin, so the subshell holds $2(2\ell+1)=4\ell+2$. Check it on the p subshell: $\ell=1$ gives $4(1)+2=6$ electrons. Option B, $2n^2$, is the capacity of a whole shell, not of one subshell.

45. In which orbital diagram both Pauli's exclusion principle and Hund's rule are violated? (1)

A. Diagram A
B. Diagram B
C. ✓ **Diagram C**
D. Diagram D

> **Answer:** C
> Two rules are being tested at once. Pauli's exclusion principle says two electrons sharing an orbital must have opposite spins, so a box holding two arrows pointing the same way breaks it. Hund's rule says electrons spread out singly across orbitals of equal energy before any orbital takes a second electron, so a p box left empty while another already holds two electrons breaks that. Diagram C does both at the same time. A diagram that only pairs electrons early, with the spins opposite, breaks Hund's rule alone and is the usual trap.

46. What is the bond order and magnetic property respectively of F_2^+? (1)

A. ✓ **1.5, paramagnetic**
B. 2.5, diamagnetic
C. 2.0, diamagnetic
D. 0.5, paramagnetic

> **Answer:** A
> Counting molecular orbitals for F_2 gives 8 bonding and 6 antibonding electrons, so the bond order is $(8-6)/2=1$. Removing one electron to make F_2^+ takes it out of a filled antibonding π^* orbital, so the bond order rises to $(8-5)/2=1.5$. That leaves one unpaired electron in the π^* level, and an unpaired electron makes the species paramagnetic. Option C tempts if you assume removing an electron cannot change the magnetic behaviour, but a single unpaired electron is exactly what paramagnetism needs.

47. The chemistry of lithium is very similar to that of magnesium even though they are placed in different groups. Its reason is: (1)

A. Both are found together in nature
B. Both have nearly the same size
C. Both have similar electronic configuration
D. ✓ **The ratio of their charge and size (i.e. charge density) is nearly the same**

> **Answer:** D
> Lithium and magnesium are neighbours along a diagonal of the periodic table. Moving down group 1 makes the ion bigger, and moving across to group 2 raises the charge, and the two changes cancel so that Li^+ and Mg^{2+} end with a similar charge to size ratio. Equal polarising power is why both burn in nitrogen to give nitrides and why both have carbonates that decompose on heating. Option B is half right, since their radii are close, but size on its own would not explain the resemblance without the matching charge.

48. Which pair of elements belongs to same group? (1)

A. Elements with atomic no. 17 and 38
B. Elements with atomic no. 20 and 40
C. ✓ **Elements with atomic no. 17 and 53**
D. Elements with atomic no. 11 and 33

> **Answer:** C
> Element 17 is chlorine. Counting on through the periodic table, 35 is bromine and 53 is iodine, and all of them sit in group 17 with seven electrons in the outer shell. Option A pairs chlorine with element 38, strontium, which is a group 2 metal. It tempts if you assume that equal steps in atomic number mean the same group, but the periods have different lengths, so the gap between members of a group keeps changing.

49. The wavelength of which series lie towards the ultraviolet? (1)

A. ✓ **Lyman**
B. Balmer
C. Paschen
D. Bracket

> **Answer:** A
> The Lyman series is made of every jump that ends on $n = 1$, the lowest level in hydrogen. Falling all the way to the ground level releases more energy than any other series, and high energy means short wavelength, which puts the Lyman lines in the ultraviolet. Balmer tempts because it is the series students meet first, but it ends on $n = 2$ and most of its lines are visible.

50. How many sigma & pi bond are there in CH_3-CN molecule respectively? (1)

A. 4σ & 2π
B. 3σ & 2π
C. 4σ & 3π
D. ✓ **5σ & 2π**

> **Answer:** D
> Draw the molecule as $\mathrm{CH_3 - C{\equiv}N}$ and count. The sigma bonds are three C-H, one C-C and one inside the triple bond, giving five. A triple bond is always one sigma plus two pi, so there are two pi bonds. Option A, four sigma bonds, comes from forgetting that the triple bond contains a sigma bond of its own as well as the two pi bonds.

51. Which of the following four molecules is/are polar: PH_3, OF_2, HF, SO_3? (1)

A. Only HF and SO_3
B. Only HF
C. Only HF and OF_2
D. ✓ **PH_3, OF_2 and HF**

> **Answer:** D
> A molecule is polar when it has polar bonds and a shape that leaves them unbalanced. HF is a single polar bond, so it is polar. $\mathrm{PH_3}$ is pyramidal and $\mathrm{OF_2}$ is bent, both because of lone pairs on the central atom, so their bond dipoles do not cancel. $\mathrm{SO_3}$ has three identical S-O bonds spread at 120 degrees in a flat triangle, so the pulls cancel and the molecule is non-polar. Option A includes $\mathrm{SO_3}$, which is the trap: polar bonds do not always add up to a polar molecule.

52. What is the hybridization of the central atom in the BCl_3 molecule? (1)

A. sp
B. ✓ **sp^2**
C. sp^3
D. sp^3d^1

> **Answer:** B
> Boron in $\mathrm{BCl_3}$ makes three bonds and holds no lone pair, so it has three regions of electron density around it. Three regions spread out into a flat triangle at 120 degrees, and the set of hybrid orbitals that gives three equivalent directions in one plane is sp^2. Option C, sp^3, is what you would choose by assuming boron must reach an octet, but boron is stable here with only six electrons.

53. What are the bond angles in NO_3^-? (1)

A. 90°
B. 109.5°
C. ✓ **120°**
D. 90° and 120°

> **Answer:** C
> The nitrogen in $\mathrm{NO_3^-}$ is surrounded by three oxygen atoms and carries no lone pair, so there are three regions of electron density. They repel each other into the widest flat arrangement, a trigonal planar shape, and a full turn shared between three directions gives $360/3 = 120$ degrees. Option B, 109.5 degrees, is the tetrahedral angle, which would need four regions around the nitrogen.

54. What is the hybridization of the carbon atoms in ethyne, C_2H_2? (1)

A. sp^2
B. sp^3d
C. sp^3
D. ✓ **sp**

> **Answer:** D
> In $\mathrm{HC{\equiv}CH}$ each carbon is bonded to one hydrogen and to the other carbon, so it has two regions of electron density. A multiple bond counts as one region, so the two extra pi bonds do not add to the count. Two regions push to opposite sides, which needs two hybrid orbitals in a straight line, so each carbon is sp hybridised and the molecule is linear. Option A, sp^2, is right for ethene, where each carbon has three regions.

55. The hybridization associated with the central atom of a molecule in which all the bond angles are 120° is: (1)

A. sp
B. ✓ **sp^2**
C. sp^3
D. sp^3d

> **Answer:** B
> Three hybrid orbitals spread as far apart as possible within one plane point at the corners of an equilateral triangle, which puts them 120 degrees apart. Making three equivalent orbitals takes one s orbital mixed with two p orbitals, so the hybridisation is sp^2. Option D, sp^3d, gives a trigonal bipyramid, which does have 120 degrees between its three equatorial bonds but 90 degrees to the axial ones, so not all of its angles are 120 degrees.

56. The central atom in a molecule has three regions of high electron density. What type of hybrid orbitals are formed by the central atom? (1)

A. ✓ **sp^2**
B. sp^3d
C. sp^3
D. sp^3d^2

> **Answer:** A
> Count regions of high electron density, treating every lone pair and every bond as one region, whether the bond is single, double or triple. Three regions call for three hybrid orbitals, and one s orbital mixed with two p orbitals gives exactly three. So the central atom is sp^2 hybridised, with its orbitals 120 degrees apart in a plane. Option C, sp^3, would be the answer for four regions, as in methane or ammonia.

57. Which of the following species has a linear shape? (1)

A. ✓ **I_3^-**
B. SO_2
C. O_3
D. ClO_2

> **Answer:** A
> In $\mathrm{I_3^-}$ the central iodine has two bonding pairs and three lone pairs, five regions in all, so the electron arrangement is trigonal bipyramidal. Lone pairs need more room, so all three take the equatorial positions, leaving the two bonded iodines at the axial positions directly opposite each other. The ion is therefore linear. $\mathrm{SO_2}$ tempts because it has only two bonds, but its sulphur also carries a lone pair, which bends the molecule to about 119 degrees.

58. Silicon dioxide (SiO_2) and diamonds are best described as (1)

A. molecular substances with coordinate covalent bonding

B. molecular substances with ionic bonding

C. ✓ **network solids with covalent bonding**

D. network solids with ionic bonding

> **Answer:** C
> In both solids every atom is joined to its neighbours by covalent bonds that run right through the crystal, so there are no separate small molecules to point at. Breaking the solid means breaking covalent bonds, which is why diamond and quartz are both very hard and melt only at very high temperatures. Option A tempts because the bonding really is covalent, but calling them molecular would predict a soft solid with a low melting point, which is the opposite of what diamond does.

59. Which molecular structure will have the bond angle of 120° around the central atom? (1)

A. ✓ **Triangular planar**

B. Seesaw

C. Triangular bipyramid

D. Octahedral

> **Answer:** A
> Three bonding regions around a central atom spread out within one plane, and sharing a full turn between them gives $360/3 = 120$ degrees. $\mathrm{BF_3}$ and $\mathrm{NO_3^-}$ are the standard examples of this shape. Option C, the trigonal bipyramid, tempts because its three equatorial bonds are also 120 degrees apart, but its axial bonds sit at 90 degrees to them, so the molecule does not have a single bond angle.

60. A molecule with five bonding pair and one lone pair electron has (1)

A. octahedral shape

B. trigonal bipyramid shape

C. ✓ **square pyramid shape**

D. tetrahedral shape

> **Answer:** C
> Five bonding pairs plus one lone pair make six regions of electron density, and six regions arrange themselves octahedrally. The lone pair takes one of those six positions, and shape names describe only where the atoms are, so the five remaining atoms form a square base with one atom at the top. That is a square pyramid, as in $\mathrm{BrF_5}$. Option A names the electron arrangement rather than the molecular shape, which is the usual slip.

61. The bond angle in H_2O is (1)

A. = $BeCl_2$

B. ✓ **< NH_4^+**

C. > CO_2

D. > BF_3

> **Answer:** B
> Water has two bonding pairs and two lone pairs on its oxygen. Lone pairs sit closer to the central atom and push harder than bonding pairs, so they squeeze the H-O-H angle down to about 104.5 degrees from the ideal 109.5 degrees. The ammonium ion has four bonding pairs and no lone pair, so it keeps the full 109.5 degrees, which is larger. Option C tempts, but $\mathrm{CO_2}$ is linear at 180 degrees, so water's angle is smaller than that, not greater.

62. Which of the following is true regarding the concentration of products, for a chemical reaction that is already at equilibrium, assuming no disruptions to the equilibrium? (1)

A. The concentrations of products will not change because there are no more reactants.

B. The concentrations of products will not change because the limiting reagent is gone.

C. ✓ **The [ ] of products will not change because the forward and reverse rates are equal.**

D. The concentrations of products will change continually because of reversibility.

> **Answer:** C
> At equilibrium the reaction has not stopped. Reactants keep turning into products and products keep turning back into reactants, but the two rates are equal, so the amount of each substance stays steady. That balance is what holds the concentrations constant. Option A is the common misunderstanding: reactants are still present at equilibrium, and it is the matching rates, not an empty flask, that keeps the numbers fixed.

63. For the chemical equilibrium A + 2B ⇌ 2C, the value of the equilibrium constant, KC, is 16. What is the value of the equilibrium constant for the following reaction? ½A + B ⇌ C, KC = ? (1)

A. ✓ **4.0**

B. 0.20

C. 40

D. 400

> **Answer:** A
> When an equation is multiplied by a factor n, its equilibrium constant is raised to the power n. The second equation is the first one halved, so $n = \frac{1}{2}$ and $K' = K^{1/2} = \sqrt{16} = 4.0$. Option B, 0.20, is roughly $\frac{1}{4}$, which is what you get by taking the square root and then inverting it. Inverting belongs to a reversed equation, and this equation has not been reversed.

64. For the reaction $N_2O_4 \rightleftharpoons 2NO_2$; ΔH = +14 kJ. The extent of the reaction can be increased by: (1)

A. Increasing the pressure

B. Using a catalyst

C. ✓ **Increasing the temperature**

D. Introduce inert gas at constant volume

> **Answer:** C
> ΔH is positive, so the forward reaction absorbs heat. By Le Chatelier's principle, supplying more heat pushes the equilibrium in the direction that uses heat up, so more $\mathrm{N_2O_4}$ breaks apart into $\mathrm{NO_2}$ and the extent of reaction rises. Option A moves it the other way: raising the pressure favours the side with fewer gas molecules, and that is the single $\mathrm{N_2O_4}$, so less product would form.

65. In which of the following cases the reaction goes farthest to completion? (1)

A. Kc = 10^{-2}

B. ✓ **Kc = 10^3**

C. Kc = 10^2

D. Kc = 10^{-3}

> **Answer:** B
> The equilibrium constant compares products with reactants at equilibrium. A large K_c means the products term on top of the fraction is much bigger, so the reaction has travelled a long way toward completion. Of the four values given, 10^3 is the largest. Option C, 10^2, is also greater than 1 and tempting, but it is ten times smaller, so it leaves more reactant unconverted.

66. Which of the following statements is true about an ideal gas? It is a hypothetical gas that obeys the gas laws (1)

A. at low temperature and low pressure

B. at low temperature and high pressure

C. ✓ **closely at high temperatures and low pressures**

D. closely at high temperatures and high pressures

> **Answer:** C
> An ideal gas is imagined as particles with no volume of their own and no attraction between them. A real gas comes close to that when its molecules are far apart, which happens at low pressure, and when they move fast enough that brief attractions cannot hold them, which happens at high temperature. Option D keeps the high temperature but adds high pressure, and squeezing the molecules together makes their own volume matter, which pushes the gas away from ideal behaviour.

67. If an unknown gas diffuses 1.75 times faster than sulfur dioxide gas, what is the molar mass of the unknown gas? (molar mass of "SO_2" is 64) (1)

A. ✓ **21.16**

B. 36.57

C. 48

D. 96

> **Answer:** A
> Graham's law says the rate of diffusion is inversely proportional to the square root of the molar mass: $\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$. Here $1.75 = \sqrt{\frac{64}{M}}$. Squaring both sides gives $3.0625 = \frac{64}{M}$, so $M = \frac{64}{3.0625} \approx 21$ g/mol. Option B, 36.57, is $64/1.75$, which is what you get by dividing by the ratio without squaring it first.

68. During a phase change, the temperature of a substance (1)

A. increases.

B. ✓ **stays the same.**

C. decreases.

D. Unknown

> **Answer:** B
> While a substance is melting or boiling, the heat going in is used to break the forces holding the particles in place, not to make them move faster. A thermometer reads the average kinetic energy of the particles, so the reading holds steady until the change of state is complete. The energy taken in this way is the latent heat of the change. Option A tempts because heat is still being supplied and heating usually raises temperature, but during a phase change that energy goes into potential energy instead.

69. Which one of the following items does not characterize an oxidizing agent? (1)

A. An oxidizing agent gains electrons.

B. An oxidizing agent causes another species to be oxidized.

C. The oxidation number of an oxidizing agent decreases.

D. A good oxidizing agent is a metal in a high oxidation state, such as Mn^{7+}.

E. ✓ **An example of a good oxidizing agent is an alkali metal, such as Na.**

> **Answer:** E
> An oxidising agent takes electrons from something else, so it is itself reduced and its own oxidation number falls. Sodium is an alkali metal with one loosely held outer electron that it gives away readily, which makes it a strong reducing agent, the opposite of what the question describes. Option D looks odd because Mn^{7+} is an unusual species, but a metal already stripped to a high oxidation state has plenty of room to accept electrons, so it really is a good oxidising agent.

— END OF MARKING KEY —