CONCEPTUAL CHEMISTRY DIAGNOSTIC INSTRUMENT

Instructions to Students

Answer all questions on the separate answer sheet provided

This paper consists of 21 items that evaluate your understanding of several chemistry concepts.

Each question has two parts: a multiple-choice response followed by a multiple-choice reason.

For each item, you are asked to make one choice from the multiple-choice response section and record your answer in the box provided.

Then choose one of the reasons from the multiple-choice reason section that best matches your answer to the first part and record your answer in the other box.

Remember it is important to select a reason

Do not forget to record your name and other details on your Answer Sheet

Note to the teacher

Please collate your students' answer sheets and mail them to the address below. We will return all answer scripts after they have been graded.

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CONCEPTUAL CHEMISTRY DIAGNOSTIC INSTRUMENT

ANSWER SHEET

Name: ____

Name of College: ______________________________________

Class: ____________ **Age:** _______ **years** **Date:** _____________

1.	Answer	☐	Reason	☐		
2.		☐		☐		
3.		☐		☐		
4.		☐		☐		
5.		☐		☐		
6.		☐		☐		
7.		☐		☐		
8.		☐		☐		
9.		☐		☐		
10.		☐		☐		
11.		☐		☐		
12.	Answer	☐	Reason	☐		
13.		☐		☐		
14.		☐		☐		
15.		☐		☐		
16.		☐		☐		
17.		☐		☐		
18.		☐		☐		
19.		☐		☐		
20.		☐		☐		
21.		☐		☐		

Science and Mathematics Education Centre
Curtin University of Technology
Perth, WA

CONCEPTUAL CHEMISTRY DIAGNOSTIC INSTRUMENT

Concept-cluster 1: Density

Item 1

Under ordinary laboratory conditions, gaseous carbon dioxide has a density near 2 grams per litre.

Liquid carbon dioxide is likely to have a density of about

A	2.5 grams per litre	B	2000 grams per litre
C	0.002 grams per litre	D	0.20 grams per litre

Reason:

1 In the gaseous state the molecules of carbon dioxide weigh less than those in the liquid state.
2 One gram of liquid carbon dioxide is about one thousand times heavier than a gram of gaseous carbon dioxide.
3 The much smaller volume of 2 grams of liquid carbon dioxide leads to a smaller density for the liquid.
4 In the gaseous state the molecules of carbon dioxide are much further apart than those in the liquid state.

Item 2

A rigid box containing only air at 20^{O} C is firmly sealed. The temperature is raised to 100^{O} C.

Which of the following properties of the air would experience an increase?

A viscosity and density
B average intermolecular distance
C cohesive forces and compressibility
D average molecular velocity

Reason:

1 Increased molecular motion is indicated by increased temperature of the air.
2 The increased pressure increases the density and thus the cohesive forces of the molecules.
3 The molecules of air expand on heating, increasing the intermolecular forces and the compressibility.
4 Intermolecular distances increase with increasing energy of the molecules.

Concept-cluster 2: Mixtures/Compounds

Item 3

The following data were reported by an accomplished chemist, Jules, after analysis of the contents of containers X and Y, both known to contain only the elements A and B either as a mixture or a compound.

analysis	**1**	**2**	**3**	**4**	**5**
% A in X	35.96	38.41	41.05	33.72	40.26
% B in X	64.04	61.59	58.95	66.28	59.74
% A in Y	36.40	36.38	36.41	36.36	36.39
% B in Y	63.60	63.52	63.59	63.64	63.61

Another person, Hector, claimed that Jules' data proved that the substance in Y was a compound of A and B.

Which of the following statements best represents your opinion of Hector's claim?

A Hector's claim is correct.
B Jules' data are good evidence for a compound in Y, but do not prove it to be so.
C The data could be proof of a pure compound if more precisely measured.

Reason:

1 The Principle of Constant Composition is the only criterion which must be met to prove the presence of a compound.
2 The presence of a compound is only indicated when the substance has properties different from those of the constituent elements. There is no evidence of this here.
3 The proportions of the sample by weight must reflect a simple ratio of atoms of the elements in a compound.
4 The virtually constant composition in Y may simply reflect a very uniform mixture.

Concept-cluster 3: Structure/Bonding

Item 4

Sodium chloride has a melting point of $801^{O}C$. The compound boron carbide, B_4C, has a melting point of $2350^{O}C$. B_4C is an electrical insulator above and below $2400^{O}C$.

In the solid state B_4C is likely to be a

A metallic lattice
B covalent molecular substance
C continuous covalent lattice
D continuous ionic lattice

Reason:

1 The high melting point and low conductivity indicates very strong bonding forces between the molecules of B_4C.
2 The non-conductivity of B_4C is evidence that the molecules are strongly bonded to each other.
3 Non-conducting properties in the molten state prove that the bonding must be covalent in a continuous lattice of atoms.
4 Since boron is present as B^{3+}, the ions present are unable to dissociate during melting.

Item 5

Which of the following diagrams best represents the position of the shared electron-pair in the HF molecule?

A 

B 

Reason:

1 Non-bonding electrons influence the position of the bonding (shared) electron-pair.
2 Since hydrogen and chlorine form a covalent bond, the electron-pair must be centrally located.
3 Fluorine has a stronger attraction for the electron-pair.
4 Fluorine is the larger of the two atoms and hence exerts greater control over the shared electron-pair.

Item 6
The commercially available substance 'Vaseline' has a thick, smooth, cream-like texture. On the basis of this information, 'Vaseline' would be classified as having

A a covalent molecular structure.
B a continuous covalent structure.

Reason:

1 The substance has a continuous linear lattice structure.
2 The high viscosity of the substance results from the continuous covalent structure.
3 The molecules of the substance experience weak cohesive forces and can move easily to accommodate changes in shape.
4 The bonds within the molecules of the substance break easily to accommodate changes in shape.

Item 7
A student wrote a series of statements about the elements of Groups I (one) to VII (seven) of the Periodic Table.

(a) In any Period the atomic radius increases with Atomic Number.
(b) In any Group the non-metallic character of the elements increases with Atomic Number.
(c) The bonding between any Group I (one) element and any Group VII (seven) element is most likely to be ionic.
(d) In any Group the atom's attraction for electrons (electronegativity) increases with increasing core charge.

Which of the following statements are correct?

A (a) and (b)
B (c)
C (b) and (d)
D (d)

Reason:

1 Non-metallic character is shown by an atom's tendency to gain electrons; this tendency is controlled by the nuclear charge of the atom.
2 The relatively high electronegativity of Group VII (seven) elements can cause the transference of electrons from atoms of Group I (one) elements to those of Group VII (seven).
3 An element's Atomic Number determines its electronic configuration and hence its atomic radius and chemical properties.
4 The Coulomb effect of core charge decreases with increasing separation of charges.
5 Ionic bonding occurs when atoms of high electronegativity transfer electrons to atoms of low electronegativity.

Concept-cluster 4: Bases/salts

Item 8
Barium salts in solution are poisonous to human beings if swallowed.
A suspension of $BaSO_4$ is swallowed by patients about to undergo X-ray examination of their stomach/intestines. ($BaSO_4$ is opaque to X-rays). There are no ill-effects; $BaSO_4$ is insoluble in stomach acids.

If $BaSO_4$ were in short supply, could $BaCO_3$ be safely used in its place?

A Yes
B No
C More information needed

Reason:

1 Like $BaSO_4$, $BaCO_3$ passes through the digestive system unchanged and is excreted.
2 Unlike $BaSO_4$, $BaCO_3$ neutralises digestive acids to produce soluble barium salts.
3 $BaCO_3$ is poisonous whether in solution or in solid form.
4 $BaCl_2$ formed from $BaCO_3$ in the digestive tract is insoluble in water solution and is harmless to human beings.
5 The solubility of $BaCO_3$ in acid needs to be known.

Concept-cluster 5: Redox

Item 9

In the reaction represented as

$$Fe(s) + CuSO_4(aq) \rightarrow FeSO_4(aq) + Cu(s)$$

the copper species is

A oxidised.
B reduced.
C neither oxidised nor reduced.
D a reducing agent.

Reason:

1 Electrons are transferred from the iron atoms to the copper ions.
2 Iron atoms act as an oxidising agent.
3 Copper sulfate loses oxygen atoms.
4 Electron-transfer cannot occur.
5 The oxidation number of copper increases.

Item 10

In the reaction

$$Cu(s) + 2NO_3^-(aq) + 4H^+(aq) \rightarrow Cu^{2+}(aq) + 2NO_2(g) + 4H_2O(l)$$

the reducing agent is

A nitrate ions
B copper atoms
C hydrogen ions

Reason:

1 Nitrate ions have lost electrons.
2 Nitrate ions have lost oxygen.
3 The oxidation number of nitrogen has decreased algebraically.
4 Hydrogen ions have gained electrons.
5 Hydrogen ions have gained oxygen.

Item 11

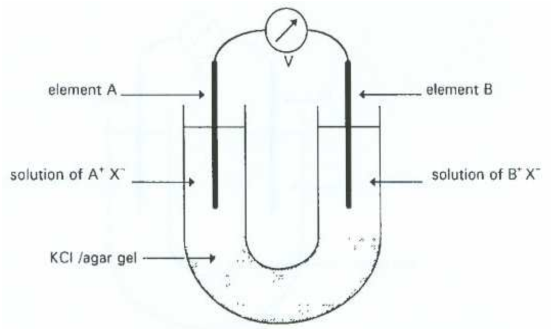


Figure 1

In Figure 1 the chemical change producing the current can be summarised as

A $B + A^+ \rightarrow A + B^+$

B $B^+ + A \rightarrow A^+ + B$

C $A + B \rightarrow A^+ + B^+ + 2e^-$

D $A^+ + B^+ + 2e^- \rightarrow A + B$

Reason:

The direction of the needle of the voltmeter shows that

1 positive charges are lost by B^+.

2 electrons are moving in the external circuit from A to B.

3 X^- ions are moving through the KCl/agar from the B^+X^- arm to the A^+X^- arm.

4 A^+ is being reduced by electrons released by B atoms.

Item 12

In the reaction

$$CO_3^{2-}(s)\ \ 2H^+(aq) \rightarrow CO_2(g) + H_2O(l)$$

the element carbon is

A reduced

B oxidised

C neither oxidised nor reduced

Reason:

1 carbonate ion loses oxygen

2 carbonate ion loses electrons

3 the oxidation number of carbon does not change

4 the oxidation number of carbon increases algebraically

5 the oxidation number of carbon decreases algebraically

Item 13

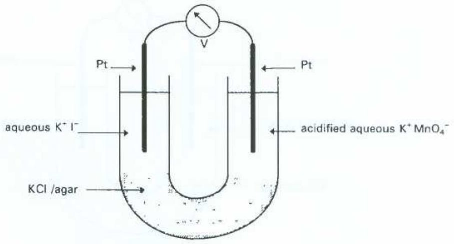


Figure 2

For the working cell (Figure 2), a student wrote four possible half-reactions:

(a) $2I^-(aq) + 2e^- \rightarrow I_2(s)$

(b) $2I^-(aq) \rightarrow I_2(s) + 2e^-$

(c) $MnO_4^-(aq) + 8H^+(aq) \rightarrow Mn^{2+}(aq) + 4H_2O(l) + 5e^-$

(d) $MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$

The correct pair of half-reactions is

A (a) and (c)

B (b) and (c)

C (a) and (d)

D (b) and (d)

Reason:
In the external circuit
1 positive charge is flowing from left to right.
2 electrons are flowing from right to left.
3 electrons are flowing from left to right.
4 positive charge is flowing from right to left.

Concept-cluster 6: Mole

Item 14
In the unit 'Introducing Chemistry' Joanna measured the temperature rise (ΔT^{O} C) in a series of 100 mL mixtures of solutions of 1.0M Cu^{2+} and 2.0M OH^-. She called this Experiment 1. Here are her results.

mL Cu^{2+} (1.0M)	0	10	20	30	40	50	60	70	80	90	100
ml OH^- (2.0M)	100	90	80	70	60	50	40	30	20	10	0
ΔT (C^{O})	0	1.2	2.4	3.6	4.8	6.0	4.8	3.6	2.4	1.2	0

These results confirmed the formula $Cu(OH)_2$ for copper hydroxide and the reaction equation to be $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$.

Joanna plans to make a similar series of mixtures as Experiment 2, using 1.0 M Cu^{2+} and 4.0M OH^- solutions. (She wants to find the maximum value of ΔT and the number of mLs (V) of 4.0M OH^- in the mixture when this maximum occurs).

Which of the following sets of results should she expect in Experiment 2?

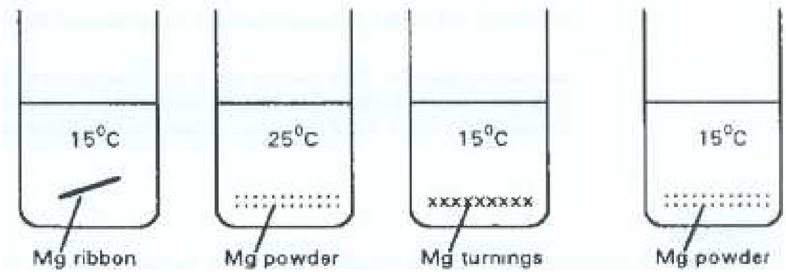
	ΔT (C^{O})	V (mL)
A	3.0	50
B	12.0	50
C	6.0	25
D	12.0	25

Reason:
In Experiment 2:

1 At V = 50 the number of moles of $Cu(OH)_2$ formed is twice as many as at V = 50 in Experiment 1.
2 At V = 50 the number of moles of $Cu(OH)_2$ formed is the same as at V = 50 in Experiment 1.
3 The number of moles of $Cu(OH)_2$ formed is limited only by the number of moles of OH^-.
4 At V = 25 the number of moles of $Cu(OH)_2$ formed is twice as many as at V = 50 in Experiment 1.
5 At V = 25 the number of moles of $Cu(OH)_2$ formed is the same as at V = 50 in Experiment 1.

Concept-cluster 7: Reaction Rate

Item 15
Masses of 1 gram of magnesium metal were reacted with hydrochloric acid (1.0 mol/L) under the conditions shown in the diagrams.



A B C D

In which one of the beakers will the initial reaction be slowest?

Reason:

1 Reactant collision frequencies are increased by a rise in temperature and decreased by greater surface area of solids.
2 Increased surface areas of solid decrease the chance of collision between reactants.
3 Lower temperatures reduce inter-molecular distances thus increasing the number of reactant collisions.
4 Collision frequencies are increased by both increased surface area of solids and a increase in temperature of the reactants.

Item 16

A chemist studied the effects of two catalysts, P and Q, upon the initial rate of the reaction

$$X + Y \rightarrow Z.$$

The rate was measured in five experiments under conditions starting as shown in the table.

Experiment number	[X] (mol/L)	[Y] (mol/L)	[P] (mol/L)	[Q] (mol/L)	Rate (mol/L/hr)
1	1.0	1.0	1.0	1.0	1.0
2	2.0	1.0	1.0	1.0	2.0
3	2.0	2.0	1.0	1.0	4.0
4	1.0	2.0	2.0	1.0	4.0
5	1.0	1.0	1.0	2.0	4.0

The catalyst with the largest influence upon the rate was

A P
B Q
C P and Q equally
D not able to be deduced

Reason:

1 The different concentrations of X and Y in experiments 1, 2, 3, 4 prevent valid conclusions from being made.
2 Doubling [X] or [Y] has the same effect as doubling [P] or [Q].
3 Doubling [Q] results in quadrupling (four times) the rate in experiment 1.
4 Doubling either [P] or [Q] results in quadrupling (four times) the rate in experiment 1.
5 Doubling [P] results in quadrupling (four times) the rate in experiment 1.

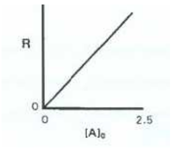
Acknowledgement: This item is based on Question 18, Application section of Beard, Fogliani, Owens & Wilson (1995). Multiple Choice Chemistry Questions. Senior Years 11 & 12 Vol 1. Australian National Chemistry Week.

Item 17

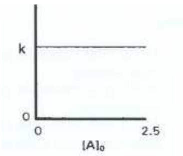
A chemist studied the decomposition of substance A in five experiments. The chemist was interested in the relationship between the initial rate (R), the rate coefficient (k) and the initial concentration $[A]_O$. The following results were obtained, all other variables being kept constant.

Experiment number	1	2	3	4	5
$[A]_O$ (mmol/L)	0.5	1.0	1.5	2.0	2.5
R (mmol/h)	0.48	1.92	4.30	7.60	12.0

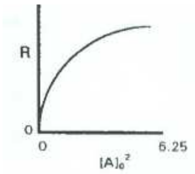
Which of the following plots (a), (b), (c), (d), (e) seem to be true statement(s) for the experiments?



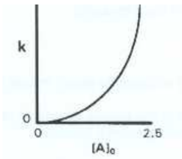
plot a



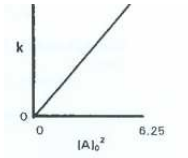
plot b



plot c



plot d



plot e

A (a) and (d)
B (c) and (e)
C (a)
D (d)
E (b)

Reason:

1 k is independent of $[A]_O$.
2 The reaction is first order in $[A]_O$.
3 The reaction is not second order in $[A]_O$.
4 k is proportional to the square of $[A]_O$.
5 R is independent of the order in $[A]_O$.

Item 18

For the system $H_2(g) + I_2(g) \rightarrow 2HI(g)$

- Figure 1 shows two possible orientations of the reactant molecules.
- Figure 2 shows plots representing the fractions of the total number of molecules which have particular energies at two temperatures.

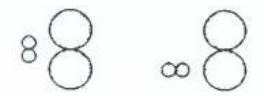

(a) (b)

Figure 1: Orientations of H_2 and I_2

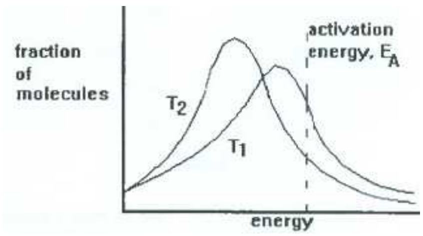


Figure 2: Energies of molecules at temperatures T_1 and T_2

Which combination of conditions is most likely to produce a reaction?

A T_2 plus (a)
B T_1 plus (b)
C T_2 plus (b)
D T_1 plus (a)

Reason:

1 At T_2, more molecular collisions exceed E_A; orientation (b) is more favourable bond-breaking.
2 At T_1, more molecular collisions exceed E_A; orientation (b) is more favourable for bond-making.
3 At T_2, more molecular collisions exceed E_A; orientation (a) is more favourable for bond-making and bond-breaking.
4 At T_1, more molecular collisions exceed E_A; orientation (a) is more favourable for bond-making and bond-breaking.

Concept-cluster 8: Metals

Item 19
Consider the following statements about metals and the Periodic Table.

(a) In any Group the atom's attraction for electrons (electronegativity) decreases with increasing Atomic Number.
(b) The bonding between any Group II (two) element and a halogen is likely to be covalent.
(c) In any Period the metallic character decreases with increasing Atomic Number.
(d) The most powerful oxidisers are to be found nearer the bottom of Groups I (one)and II (two).
(e) Sodium, potassium and mercury are exceptional metals in that they are good electrical conductors.

Which of the following statements (or pairs of statements) is true?
A (d) and (e)
B (c)
C (a) and (c)
D (b)
E (a)

Reason:

1 An atom's attraction for electrons is partly controlled by the size of the atom – Coulomb's Law indicates that the larger the atom the smaller will be its attraction for outer shell electrons.
2 Across a Period the atoms' attraction for electrons decreases according to Coulomb's Law.
3 In Periods and Groups electronegativity increases with increasing Atomic Number.
4 Halogens atoms can achieve a stable octet by sharing electrons with metals to form covalent bonds.
5 The most powerful oxidisers are the largest atoms because they can lose their electrons most readily.

Concept-cluster 9: Halogens

Item 20
Chlorine gas can be used to sterilise water. When chlorine is passed through the water it forms a mixture of hypochlorous acid and hydrochloric acid.

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-$$

The polar covalent compound iodine chloride (ICl, m. pt. $27^{O}C$) is well known. If it were used to sterilise water would the most likely reaction be
A $ICl + H_2O \rightarrow HOCl + H^+ + I^-$ or
B $ICl + H_2O \rightarrow HOI + H^+ + Cl^-$?

Reason:

1 The bonds in both ICl and H_2O are both polar. The δ+ charge on the iodine atom is attracted to the δ- charge on the oxygen atom leading to the formation of an I – O bond and the breaking of O – H and I –Cl bonds.

2 Iodine is lower in Group VII (seven) than chlorine and the I^- ion is therefore more stable than the Cl^- ion. Accordingly I^- forms together with HOCl and H^+.

3 HOCl is a more stable molecule than the HOI molecule because the O – Cl bond is more polar than the O – I bond.

4 Reaction B involves oxidation of the iodine species.

Concept-cluster 10: Hydrocarbons

Item 21

A test-tube contains 100 mmol of a hydrocarbon X whose formula is $C_4H_{6.}$

X does not react with ammoniacal cuprous chloride. When the tube of X is added to 100mmol of bromine (Br_2) as 'bromine water', the bromine is decolourised and a new substance Y is formed. Y, however, decolourises bromine water also. After addition of Y to another 100 mmol of bromine water, the mixture is no longer able to decolourise it. A new substance, Z, is present.

The more likely skeletonic structure of Z is

A
```
     Br     Br     Br     Br
     |      |      |      |
 —   C  —   C  —   C  —   C  —
     |      |      |      |
```

B
```
     Br     Br     Br     Br
     |      |      |      |
 —   C  =   C  —   C  =   C  —
```

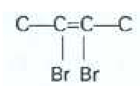
C
```
     Br                   Br
     |                    |
 —   C  —   C  ≡   C  —   C  —
     |                    |
```

D
```
            Br     Br
     |      |      |      |
 —   C  —   C  —   C  —   C  —
     |      |      |      |
            Br     Br
```

Reasons: (reasoning sequence)

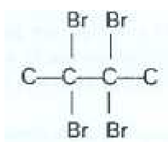
1

- The formula C_4H_6 is consistent with the family formula $C_nH_{(2n-2)}$ of the alkynes, which have one triple covalent bond per molecule. A possible carbon skeleton of this molecule is C – C ≡ C – C.
- Substance Y can form by adding one molecule of Br_2 across the triple bond to form



(skeletonic)

- Mixing with another 100 mmol of bromine adds Br_2 across the double bond to give

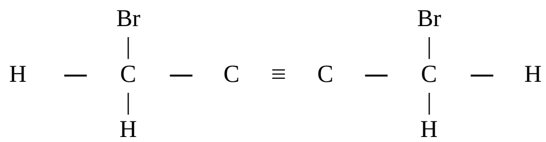


(skeletonic)

which is a likely structure of Z.

2

- In the first reaction, $C_4H_6 + Br_2 \rightarrow C_4H_5Br + HBr$, Y forms by substitution.
- The second reaction, $C_4H_5Br + Br_2 \rightarrow C_4H_4Br_2 + HBr$, is also a substitution reaction where $C_4H_4Br_2$ is Z, which has the structure



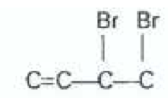
consistent with C – C ≡ C – C (skeletonic) for X.

3

- Bromine is a good oxidising agent, having a strong attraction for the electron-rich double bonds in a possible C = C – C = C structure of X.
- Accordingly it forms four C – Br bonds by substituting one Br atom for an H atom on each atom of carbon, thus forming Z.

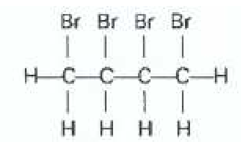
4

- The failure of X to react with ammoniacal cuprous chloride indicates that no triple bond is present. Perhaps there are two double bonds in each molecule of X. A possible carbon skeleton of X is C = C – C = C.
- Addition to 100 mmol of bromine permits bromination of only one of the double bonds to form



(skeletonic)

- Addition to a second portion of Br_2 brominates the other double bond forming



(Developed at SMEC by Glen Chittleborough (1998))