2017 CHEM 1A03 Test 2 - ANSWERS

1. What **volume (in mL)** of a 2.40 mol L^{-1} magnesium bromide solution would contain 3.40 x 10^{23} **bromide** [Br^-(aq)] ions?

A) 118
B) 12.3
C) 543
D) 58.9
E) 74.6

1.0 L of a 2.40 M solution of $MgBr_2$ will contain 4.80 moles of bromide (Br^-).
Ions of bromide in 1.0 L = 4.80 moles x N_A = 4.80 x (6.022 x 10^{23}) = 2.89 x 10^{24}
Answer = 3.40 x 10^{23} / 2.89 x 10^{24} = 0.1176 L = 118 mL

A

2. The human eye contains a molecule called 11-*cis*-retinal that changes shape when struck with light of sufficient energy, which results in an electrical signal being sent to the brain. The minimum energy required to change the conformation of 11-*cis*-retinal within the eye is 164 kJ/mol. Calculate the **longest wavelength (in nm) visible to the human eye.**

A) 729
B) 752
C) 196
D) 121
E) 247

Energy per molecule = (164,000 J/mol) / N_A = 2.723 x 10^{-19} J

$E = hc/\lambda \rightarrow \lambda = hc/E = (6.625 \times 10^{-34})(2.998 \times 10^{8})/(2.723 \times 10^{-19}) = 7.19 \times 10^{-7}$ m = 729 nm

3. Which species would **fall in the middle** when the following species are ranked from smallest to largest radius ?

Al, Al^{3+}, S^{2-}, P, Cl^-

A) Al
B) Al^{3+}
C) S^{2-}
D) P
E) Cl^-

$Al^{3+} < P < Al < Cl^- < S^{2-}$
- All are 2p elements.
- Cations will be particularly small. Anions particularly large.
- Of the neutral elements, P < Al because of increasing Z_{eff} across a period.

4. Which one of the following statements is **FALSE** ?

A) The magnitude of the electron affinity of C is larger than that of N.
B) The first ionization energy of Li is larger than that of Na.
C) The radius of F^- is larger than that of F.
D) The first ionization energy of Mg is smaller than that of Al.
E) The effective nuclear charge, Z_{eff}, is higher for Mg than for Na.

Mg has a $2s^2$ configuration (a full 2s-shell). By contrast, Al has a $2s^2 2p^1$ configuration and has an increased tendency to lose 1 electron to achieve a $2s^2$ configuration. Therefore, the ionization energy of Al is smaller than that of Mg.

5. What is the **electron pair geometry** for the AsF_4^- anion ?

A) See-saw
B) Square planar
C) Trigonal bipyramidal
D) Octahedaral
E) Square pyramidal

AsF_4^- has a trigonal bipyramidal electron pair geometry, and a see-saw molecular geometry.

6. Which one of the following statements about **BCl_3** is **FALSE** ?

A) The B atom does not obey the octet rule.
B) The B−Cl bonds are polar.
C) The BCl_3 molecule has a permanent dipole moment.
D) The Cl-B-Cl bond angles are 120°.
E) The formal charge on boron is zero.

BCl_3 has a trigonal planar molecular geometry with 6 valence electrons.

7. How many unique, **polar isomers** could exist for AsF_2Cl_3 ?

A) 1
B) 2
C) 3
D) 4
E) 5

AsF_2Cl_3 will have a trigonal bipyramidal molecular geometry, in which the 3 equatorial sites are not the same as the 2 axial sites. The fluorine substituents could both be axial, both equatorial, or one equatorial and one axial. Only the latter 2 isomers are polar.

8. Four chemical species are shown below. Based on the principles of the VSEPR theory, how many of these molecules are **unlikely to exist** (i.e. there are fundamental reasons why these molecules would not be stable) ? In each case **the central atom is singly bonded to each of the halogen atoms**.

NF_5 BeI_2 CF_4 **CCl_2**

A) 0
B) 1
C) 2
D) 3
E) 4

NF_5 would have 10 valence electrons on nitrogen - this is not allowed for an element from the 2nd period.

BeI_2 has 4 valence electrons. This is OK for a group 2 or 3 element, so it is stable.

CF_4 has an octet of electrons. Stable compound.

CCl_2 has only 6 valence electrons - this is allowed for groups 2 and 3, but not group 4.

9. A stable, non-paramagnetic molecule, **EF_5**, has a **square pyramidal** molecular geometry. Which one of the following is a possible **identity for the element E** ?

A) Xe
B) F
C) Te
D) P
E) Cl

If the molecular geometry is square pyramidal, E must have a lone pair of electrons (i.e. the electron pair geometry is octahedral). E must therefore be a halogen, and it must be Cl, not F. This is because E in square pyramidal EF_5 has 12 valence electrons, so it exceeds the octet rule, and it cannot be an element from the 2nd period. Also, FF_5 (i.e. F_6) is not a known allotrope of fluorine.

A quick way to determine the identity of E is to note that if E is using 5 electrons to interact with the 5 fluorine atoms, and it still has 2 electrons for a lone pair, neutral atom E must have 7 valence electrons (i.e. it must be a group 7 element)

10. Which one of the following statements is **FALSE** ?

A) Arsenic (As) has less metallic character than thallium (Tl).
B) The bonds in $SnCl_4$ have more ionic character than those in SCl_2.
C) VSEPR would predict the bond angles in H_2S to be larger than those in a BH_2^- anion.
D) The oxidation state of tin in $SnCl_4$ is 4+.
E) There are two lone pairs in H_2S.

H_2S has an AX_2E_2 structure, so will be bent, based on a tetrahedral electron pair geometry. Therefore, the H-S-H angle is predicted to be a bit less than 109.5°.

BH_2^- has an AX_2E structure, so will be bent, based on a trigonal planar electron pair geometry. Therefore, the H-B-H angle is predicted to be a bit less than 120°.

11. When strontium nitrate and sodium sulfate are mixed, the **net ionic equation** is:

A) $Sr(NO_3)_2\ (aq) + Na_2SO_4\ (aq) \rightarrow 2\ NaNO_3\ (aq) + SrSO_4\ (s)$
B) $Sr^{2+}\ (aq) + SO_4^{2-}\ (aq) \rightarrow SrSO_4\ (s)$
C) $2\ SrNO_3\ (aq) + NaSO_3\ (aq) \rightarrow Sr_2SO_3\ (s)$
D) $2\ Sr^+\ (aq) + SO_4^{2-}\ (aq) \rightarrow Sr_2SO_4\ (s)$
E) $Na^+\ (aq) + NO_3^-\ (aq) \rightarrow NaNO_3\ (s)$

Just show ions involved in formation of a solid product (not spectator ions), and recognize that as a group 2 element, strontium must be Sr^{2+}.

12. A chemical reaction has an equilibrium constant, *K*, with a value of X. If the stoichiometric coefficients of all reactants and products are doubled, what is the **new value of *K*** ?

A) X
B) 2X
C) X^2
D) X/2
E) X^{-1}

If an equation with $K = X$ is multiplied by 2, then the new equilibrium constant will be X^2.

13. Determine the one **FALSE** statement.

A) Pure water is a strong electrolyte.
B) At equal concentrations, $MgCl_2$ is a stronger electrolyte than NaCl.
C) $CaSO_4$ is insoluble in water.
D) The oxidation state of vanadium in VO_4^{3-} is +5.
E) Adding 1.0 M Na_2CO_3 (aq) to a 1.0 M solution of $Ca(ClO_4)_2$ (aq) will precipitate $CaCO_3$ (s).

14. Consider the following gas phase equilibrium.

$A\ (g) + B\ (g) \rightleftharpoons 2\ C\ (g) \qquad K = 36.0$

Initially 2.00 bar of A and 2.00 bar of B were mixed in a sealed vessel, and equilibrium was established. Then 0.50 bar of C was added. After the final equilibrium is established, what is the **partial pressure of C (in bar)** in the reaction vessel ?

A) 4.55
B) 4.50
C) 3.00
D) 3.38
E) 3.50

Ice table:

	A (g)	+	B (g)	⇌	2 C (g)
I	2.00		2.00		0.50
C	-x		-x		+2x
E	2-x		2-x		0.5+2x

$K = 36 = P_C^2 / (P_A \times P_B) = (0.5 + 2x)^2 / (2-x)^2 = (0.25 + 2x + 4x^2) / (4 - 4x + x^2)$

$36x^2 - 144x + 144 = 0.25 + 2x + 4x^2$

$32x^2 - 146x + 143.75 = 0$

Solve quadratic → x = 3.125 or **1.4375** (only the latter makes sense, otherwise 2-x would give a negative partial pressure).

Answer = (0.5 + 2x) = 3.375 = 3.38 bar

15. Considering the chemical equilibrium below, which of the following changes will cause the equilibrium **amount of D to increase** ?

$A\,(g) + B\,(s) \rightleftharpoons 2\,C\,(l) + D\,(g) \qquad \Delta H = -100\ kJ\ mol^{-1}$

i. Increasing the volume of the vessel. *No effect (same number of moles of gas on each side)*
ii. Decreasing the temperature. *Reaction is exothermic (heat as product). Removing heat drives to right hand side.*
iii. Adding B. *Since B is a solid (not in equilibrium expression), this will have no effect.*
iv. Removing C. *Since C is a liquid (not in equilibrium expression), this will have no effect.*
v. Adding A. *By Le Chateliers's principle, adding A will push equilibrium towards products.*

A) ii
B) iii, v
C) ii, v
D) i, v
E) iv

16. From the following information :

$CoO\,(s) + H_2\,(g) \rightleftharpoons Co\,(s) + H_2O\,(g) \qquad K_1 = 66.99$
$CoO\,(s) + CO\,(g) \rightleftharpoons Co\,(s) + CO_2\,(g) \qquad K_2 = 490.2$

determine ***K*** for the reaction shown below.

$2\,CO\,(g) + 2\,H_2O\,(g) \rightleftharpoons 2\,CO_2\,(g) + 2\,H_2\,(g)$

A) 53.55
B) 1.212×10^{-4}
C) 9.385×10^{3}
D) 7.303×10^{-3}
E) 13.56

To obtain the final equation, we need to:

i) reverse equation 1

$Co\,(s) + H_2O\,(g) \rightleftharpoons CoO\,(s) + H_2\,(g) \qquad K_{1'} = 1/66.99 = 0.01493$

ii) multiply both equations by two

$2\,Co\,(s) + 2\,H_2O\,(g) \rightleftharpoons 2\,CoO\,(s) + 2\,H_2\,(g) \qquad (K_{1'})^2 = (0.01493)^2$
$2\,CoO\,(s) + 2\,CO\,(g) \rightleftharpoons 2\,Co\,(s) + 2\,CO_2\,(g) \qquad (K_2)^2 = (490.2)^2$

iii) add the two equations together (chemical species that cancel out are indicated above) to give final equation, so we need to multiply the K values together:

$K = (K_{1'})^2(K_2)^2 = (0.01493)^2(490.2)^2 = 53.55$

17. Recall that K_{ow} relates to the following equilibrium S (aq) $\rightleftharpoons$ S (org) where S is a substance which is partially soluble in both aqueous and organic phases. A certain POP (persistent organic pollutant) was stored as a 1.00 M solution in octanol. S has **log K_{ow} = 3.10**. If a large spill of the POP occurred into a pond (pond and spill each have a volume of 15,500 L), what would be the **total number of POP molecules in the aqueous phase of the pond** ?

A) 7.41×10^{24}
B) 9.31×10^{23}
C) 8.62×10^{22}
D) 1.13×10^{25}
E) 4.08×10^{23}

	S (aq) $\rightleftharpoons$	S (org)
I	0	1.00
C	+x	–x
E	x	1-x

K_{ow} = [S(org)]/[S(aq)] = (1-x)/x

log K_{ow} = 3.10, so $K_{ow} = 10^{3.10} = 1259$

1259x = 1-x → 1260x = 1 → x = 1/1260 = 7.94×10^{-4} M

Moles = 15500 L x 7.94×10^{-4} M = 12.30

Molecules = 12.30 x $N_A = 7.41 \times 10^{24}$

18. In the **forward** reaction below, which species is behaving as a **Bronsted-Lowry acid** ?

K^+ (aq) + **HCO_3^- (aq)** + H_2O (l) $\rightleftharpoons$ H_3O^+ (aq) + K^+ (aq) + CO_3^{2-} (aq)

A) HCO_3^-
B) H_2O
C) H_3O^+
D) CO_3^{2-}
E) K^+

K^+ is just a spectator ion.

HCO_3^- gives up a proton, so is acting as a Bronsted-Lowry acid.

H_2O accepts a proton, so is acting as a Bronsted-Lowry base.

The other species are not on the left hand side of the equation, so are not involved in the forward reaction.

19. The shells of corals and other marine organisms contain calcium carbonate, $CaCO_3$. In the presence of acid, the shell dissolves according to the following balanced equation:

$$CaCO_3\,(s) + H_3O^+\,(aq) \rightleftharpoons Ca^{2+}\,(aq) + HCO_3^-\,(aq) + H_2O\,(l)$$

At greater water depths, the pressure increases, and the dissociation constant of water (K_w) also increases.

Which of the following statements are **TRUE** ?

(i) Shallow water has a greater concentration of H_3O^+ than deep water.
(ii) Deep water has a greater concentration of H_3O^+ than shallow water.
(iii) Sea shells dissolve to a greater extent in shallow water compared to deep water.
(iv) Sea shells dissolve to a greater extent in deep water compared to shallow water.

A) (i) and (iii)
B) (ii) and (iii)
C) (ii) and (iv)
D) (i) and (iv)
E) None of these statements are true.

20. Determine the **pH** at 25 °C of a 0.0162 mol/L solution of **calcium hydroxide**.

A) 1.790
B) 12.210
C) 1.489
D) 12.511
E) 13.489

$Ca(OH)_2$ is a strong base, so we can consider it to dissociate completely.

Therefore, $[OH^-] = 2 \times 0.0162 = 0.0324$

Therefore, $pOH = -\log(0.324) = 1.489$

$pH = 14 - pOH = 12.511$

21. Rank the following polyprotic oxyacids **from most acidic to least acidic** for the first dissociation in water.

H_3AsO_3 H_3PO_4 H_3PO_3

A) H_3PO_4 > H_3PO_3 > H_3AsO_3
B) H_3AsO_3 > H_3PO_3 > H_3PO_4
C) H_3PO_3 > H_3PO_4 > H_3AsO_3
D) H_3AsO_3 > H_3PO_4 > H_3PO_3
E) H_3PO_3 > H_3AsO_3 > H_3PO_4

H_3PO_4 is a stronger acid than H_3PO_3 (more resonance structures to delocalize the negative charge upon dissociation of a proton).

H_3PO_3 is a stronger acid than H_3AsO_3 because P is more electronegative than As, so will help to stabilize the anion formed upon loss of a proton.

Correction! Turns out there is a blip in the trend for H_3PO_3 and H_3PO_4. H_3PO_3 is a stronger acid with a $pKa_1 = 1.1$ while H_3PO_4 has $pKa_1 = 2.15$. Therefore, both A and C were graded as correct. We will try to avoid these anomalies in future.

22. Codeine, a painkiller, is a weak base that can accept only one proton. A 0.0600 mol L^{-1} solution of codeine at 25 °C has a pH of 10.36. What is the K_b **of codeine** ?

A) 2.3×10^{-4}
B) 8.8×10^{-7}
C) 4.3×10^{-11}
D) 1.6×10^{-6}
E) 3.7×10^{-3}

If we know the pH, we can find $[OH^-]$:

pOH = 14–10.36 = 3.64

$[OH^-] = 10^{-3.64} = 2.291 \times 10^{-4}$. This is the value of x in the ICE table below.

K_b is for: $B + H_2O \rightleftarrows HB^+ + OH^-$

I	0.06	0	0
C	-x	x	x
E	(0.06-x)	x	x

$K_b = x^2/(0.06\text{-}x) = (2.291 \times 10^{-4})^2/(0.06 - 2.291 \times 10^{-4}) = 8.78 \times 10^{-7}$

23. Acetylsalicylic acid is the active ingredient of aspirin. It is a weak acid with $K_a = 3.0 \times 10^{-4}$. What **concentration of acetylsalicylic acid (in mol/L)** will result in a solution with pH = 2.00 at 25 °C ?

A) 2.0
B) 3.0×10^{-4}
C) 1.0×10^{-2}
D) 1.6
E) 3.4×10^{-1}

If pH = 2.00, then $[H_3O^+] = 10^{-2} = 0.01$

For K_a, the equation is: $HA + H_2O \rightleftarrows H_3O^+ + A^-$

I	x	0	0
C	-0.01	+0.01	+0.01
E	x-0.01	0.01	0.01

$K_a = 3 \times 10^{-4} = (0.01)^2/(x-0.01) \rightarrow (3 \times 10^{-4}\ x) - 3 \times 10^{-6} = 0.0001$

$x = (0.0001 + 3 \times 10^{-6})/(3 \times 10^{-4}) = 0.343$

24. When placed in distilled water, how **many** of the following salts have a **neutral pH** at 25 °C ?

NH_4Br **NaBr** Na_2CO_3 CaO **$KClO_4$**

A) 1
B) 2
C) 3
D) 4
E) 5

NH_4Br - can consider to be formed from NH_3 (weak) and HBr (strong) → acidic
NaBr - can consider to be formed from NaOH (strong) and HBr (strong) → neutral
Na_2CO_3 - can consider to be formed from NaOH (strong) and H_2CO_3 (weak) → basic
CaO - group 2 oxides are strongly basic
$KClO_4$ - can consider to be formed from KOH (strong) and $HClO_4$ (strong) → neutral

25. From the following list of reactions, **how many** demonstrate **work being done *by* the system *on* the surroundings** ?

$2\ SO_2\,(g) + O_2\,(g) \rightarrow 2\ SO_3\,(g)$

$C_6H_6\,(l) + 15/2\ O_2\,(g) \rightarrow 6\ CO_2\,(g) + 3\ H_2O\,(l)$

$NaOH\,(aq) + HCl\,(aq) \rightarrow NaCl\,(aq) + H_2O\,(l)$

$Zn\,(s) + 2\ HCl\,(aq) \rightarrow ZnCl_2\,(aq) + H_2\,(g)$

$PCl_5\,(g) \rightarrow PCl_3\,(g) + Cl_2\,(g)$

A) 5
B) 4
C) 3
D) 2
E) 1

The question is basically how many of these reactions result in an increase in the number of moles of gas.

26. When a particular gas is compressed with a constant external pressure of 3.50 atm, the volume decreases by 7.95 L. During this transformation the gas also releases 900. J of heat. What is the energy change, ΔU **(in kJ)**, for the gas ?

A) +3.02
B) +1.92
C) −1.92
D) +3.72
E) −2.02

$w = -P_{ext}\Delta V$ (where pressure is in kPa, and $\Delta V = -7.95$L)

$w = -3.50$ atm x 101.3 kPa/atm x -7.95 L = 2819 J

$\Delta U = q + w = -900$ J + 2819 J = 1919 J = 1.92 kJ

27. During experiment 2, Cycles of Copper, a student obtains a percent yield/recovery that is less than 100%. Which of the following observations is **NOT a plausible cause of reduced yield** for this experiment?

A) After adding the Zn, the solution was still faintly blue before the copper product was rinsed and dried.
B) Despite the addition of the H_2SO_4, some black precipitate was present when Zn(s) was added to the reaction beaker.
C) Small amounts of CuO(s) were lost during the decanting step.
D) The final product was slightly damp and smelled of acetone when its mass was recorded. *If the product contained acetone, the yield would appear artificially high, not low.*
E) The actual mass of Cu(s) reacted was 0.2013 g, but the student accidentally used a value of 0.2031 g in their calculations.

Correction! Answer B is also correct and was re-graded as such There is no step in the procedure that would separate out the black precipitate (CuO) so it would still be part of the final yield measurement making it artificially high.

28. A student is titrating NaOH against HCl to determine the unknown concentration of NaOH. The student accidentally uses a 20.00 mL volumetric pipette to transfer the 0.1351 M HCl thinking they used a 10.00 mL volumetric pipette. The student determines the concentration of NaOH to be 0.1071 M. What is the **actual concentration (in M) of NaOH** ?

A) 0.05355
B) 0.2142
C) 0.06755
D) 0.1351
E) 0.1071

Student has twice as much HCl. Therefore, they will have to use twice as much NaOH, making them think that the concentration is half that of the real concentration. To find the real concentration, multiply 0.1071 M by two.