CHEM 1E03 Term Test 2: Solutions

1. It takes 492 kJ of energy to remove one mole of electrons from the atoms on the surface of solid gold. What is the maximum wavelength (in nm) capable of doing this?

A)   123
B)   243
C)   404
D)   743
E)   817

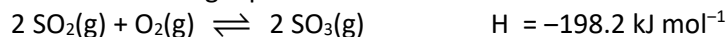2. Which one of the atoms listed below is described by all of the following statements?

(i) The atom contains p electrons in its valence shell.
(ii) The ground state of the atom contains at least one unpaired electron.
(iii) The atom has a smaller atomic radius than magnesium.
(iv) The atom has a larger ionization energy than phosphorus.

A)   Si
B)   Be
C)   Na
D)   Cl
E)   Rb

3. Consider the following equilibrium:
        2 SO$_2$(g) + O$_2$(g) $\rightleftharpoons$ 2 SO$_3$(g)   H = −198.2 kJ mol^{-1}
Which of the following changes does **not** cause the partial pressure of SO$_2$(g) to increase?

A) The temperature is increased.
B) An inert gas is added to increase the total pressure – the volume does not change.
C) The volume is increased.
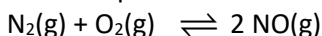D) O$_2$ is removed.
E) SO$_3$ is added.

4. A reaction vessel, at 500 K, contains 1.000 bar $PCl_5(g)$, 0.705 bar $PCl_3(g)$ and 0.705 bar $Cl_2(g)$ – all in equilibrium. Determine the equilibrium constant K_P for the reaction,
$PCl_5(g) \rightleftarrows PCl_3(g) + Cl_2(g)$

A) 0.497
B) 0.558
C) 9.71
D) 0.865
E) –1.41

A)
Already a balanced chemical equation. $K_p = P_{Cl2} * P_{PCl3}/P_{PCl5} =$ (0.705 bar)*(0.705 bar)/ 1.00 bar
= 0.497 (bar) bar units left out of equilibrium constant

5. The equilibrium constant for the reaction
$N_2(g) + O_2(g) \rightleftharpoons 2 NO(g)$
is $K_p = 1.7 \times 10^{-1}$ at an elevated temperature. A reaction vessel at this temperature contains these gases with the following partial pressures:

Gas, Partial Pressure
$N_2(g)$ 0.25 bar
$O_2(g)$ 0.25 bar
$NO(g)$ 4.2×10^{-1} bar

Which of the following statements is true?

A)   Q > K, and the reaction proceeds to the reactants side.
B)   Q > K, and the reaction proceeds to the products side.
C)   The system is at equilibrium.
D)   Q < K, and the reaction proceeds to the products side.
E)   Q < K, and the reaction proceeds to the reactants side.

A)
$Q = P^2_{NO}/P_{N2} P_{O2} = (0.42)^2 / (0.25)(0.25) = 2.82$
Since $Q > K$, the equilibrium will shift to reverse direction to produce more reactants.

6. Consider a 100 mL aqueous solution of lead(II) with an unknown concentration – this is the sample solution. A test solution, 1.00×10^{-1} mol/L aqueous solution of sodium chloride, is dripped

into the sample solution. A precipitate first forms after 13.7 mL of test solution is added to the sample solution. What is the unknown **lead(II) concentration** in mol/L? $K_{sp}[PbCl_2]$ = 1.7×10^{-5}.

A)   0.170
B)   0.00312
C)   0.120
D)   0.0721
E)   0.0532

C)
Unknown conc. of Pb (II) exists in solution → it will be quantified via precipitation with addition of chloride (volumetric titration) to form insoluble $PbCl_2$ (s) → if 13.7 mL of 0.1 mol/L of NaCl is added to solution (100 mL) to form precipitate completely, then dilution factor for NaCl (effective concentration is):
Total volume of solution = 113.7 mL → 0.1 mol/L * (13.7 mL/113.7 mL) = 0.01205 mol/L
Since, $PbCl_2(s) \rightleftharpoons Pb^{2+}$ (aq) + $2Cl^-$ (aq), K_{sp} = 1.7×10^{-1}
Then, K_{sp} = $[Pb^{2+}][Cl^-]^2$ → $[Pb^{2+}]$ = K_{sp} / $[Cl^-]^2$ = 1.75×10^{-1} / $(0.01205)^2$ = 0.120 mol/L

7. Which of the following is **not** a product of one of the reactions in the cycles of copper laboratory?

A) $Cu(NO_3)_2$(aq), blue/green solution
B) $CuSO_4$(s), blue/green precipitate
C)   CuO(s), black precipitate
D) $Cu(OH)_2$(s), blue precipitate
E) NO_2(g), brown gas

B)
$CuSO_4$ is a soluble ionic salt → does not form an insoluble salt in aqueous solution.

8. How much **heat, in kJ**, is required to warm 63.0 g of liquid ethylene glycol (specific heat capacity = $2.20 \: J \: g^{-1} \: K^{-1}$) from 20.0°C to 40.0°C?

A)   1.64
B)   6.11
C)   3.91
D)   5.14
E)   2.77

E)
Heat absorbed by ethylene glycol, q = $m \: s \: \Delta T$ = 63 g * ($2.20 \: J g^{-1} \: K^{-1}$) * (20 K) = 2772 J or 2.77 kJ, where s is the specific heat capacity of ethylene glycol.

9. In an insulated bomb calorimeter, 0.568 g of solid citric acid (C6H8O7, molar mass 192.12 g/mol) was completely combusted, at 25.00 °C. The calorimeter contained 1032 g of water, initially at 25.00 °C. The temperature of the water was observed to rise to 26.36 °C. Assume all the heat of the reaction went into heating the water, and that the heat capacity of water is 4.18 J g^{-1} K^{-1}. Calculate the **molar energy change** (in kJ mol^{-1}) for *combustion of citric acid*.

A)   −487
B)   −1851
C)   1980
D)   487
E)   −1980

E)
$\Delta H = q_p = m_{H2O}\ C_{H2O}\ \Delta T$ = 1032 g * 4.18 J g^{-1} K^{-1} * (1.36 K) = 5867 J
Molar enthalpy change (kJ mol^{-1}) for combustion of citric acid:
= 0.568 g/192.12 g mol^{-1} = 2.96×10⁻³ moles
Molar enthalpy change: 5867 J/2.96 E-3 moles = 1984 kJ
q_{rxt} = - q_{calor} = **-1980 kJ** *(exothermic reaction; 3 significant figures determined by mass weighed)*

10. For which of the following reactions is **heat released** by the system (q < 0), and **work is done** by the system *(w < 0)*?
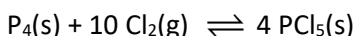
A) $Cl_2(g) \rightarrow 2\ Cl(g)$
B) $H_2O(g) \rightarrow H_2O(l)$
C) $2\ Na(s) + 2\ H_2O(l) \rightarrow 2\ NaOH(aq) + H_2(g)$
D) $Pb(s) \rightarrow Pb(l)$
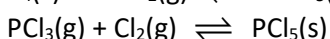E) $Br_2(l) \rightarrow Br_2(g)$

C)
Reaction must be exothermic and involve a gas expansion (increase in moles of gas product) →
Only option is C) since a gas is produced increasing volume and involves a redox reaction that is exothermic. Other reactions are endothermic and do not involve change in volume uon product formation (phase changes or dissociation of diatomic gas)

11. What is the *standard enthalpy of formation* of **PCl₃(g)** (in kJ mol^{-1})? (Note that P₄(s) is the standard state of phosphorus.)

Data:
$P_4(s) + 10\ Cl_2(g) \rightleftharpoons 4\ PCl_5(s)$ $H = -1774.0$ kJ mol^{-1}
$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(s)$ $H = -156.5$ kJ mol^{-1}

A)   −1623
B)   +1623
C)   +287
D)   −287
E)   −491
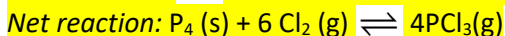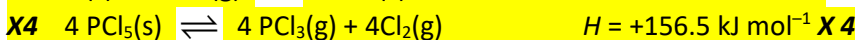
12. The standard enthalpy of formation for acetylene (gas), H-CC-H, is +226.7 kJ mol⁻¹. The average bond enthalpy for a carbon-carbon triple bond (CC) is 837 kJ mol⁻¹ and the average bond enthalpy of a C-H bond is 414 kJ mol⁻¹. The bond enthalpy for H₂ is 436 kJ mol⁻¹. Estimate the **enthalpy of sublimation of graphite**, in kJ mol⁻¹; i.e., H for C(s) → C(g).
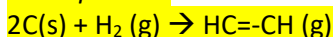
A)   728
B)   1411
C)   1096
D)   571
E)   401

13. Use the following data to calculate the **second electron affinity** (in kJ mol–1) of oxygen, i.e., the enthalpy change for the reaction, O^- (g) + e⁻ → O_2^- (g).

Lattice energy of Na₂O = −2481 kJ mol⁻¹
Formation enthalpy of Na₂O(s) = −279.3 kJ mol⁻¹

Sublimation enthalpy of Na = +107.76 kJ mol^{-1}
First ionization energy of Na = +500.0 kJ mol^{-1}
Formation enthalpy of O(g) = +249.2 kJ mol^{-1}
Electron affinity of O(g) = −141 kJ mol^{-1}

A)   −1297
B)   911
C)   1392
D)   878
E)   −201

D)
Born-Haber Cycle:
Enthalpy of formation: 2 Na (s) + O_2 (g) → Na_2O (s) $\Delta H^o{}_f$ = -279.3 kJ mol^{-1}

1st Electron affinity: O (g) + e⁻ → O⁻ (g) $\Delta H^o{}_{EA1}$ = -141 kJ mol^{-1}
2nd Electron affinity: O⁻ (g) + e⁻ → O^{2-} (g) $\Delta H^o{}_{EA2}$ = ?
Lattice enthalpy: 2 Na⁺ (g) + O⁻ (g) → Na_2O (s) $\Delta H^o{}_f$ = -2481 kJ mol^{-1}
Sublimation: 2 Na (s) → 2 Na (g) $\Delta H^o{}_{sub}$ = +2 x 107.76 kJ mol^{-1}
1st Ionization energy: 2 Na (g) → 2 Na⁺ (g) + 2 e⁻ $\Delta H^o{}_{IE}$ = +2 x 500.0 kJ mol^{-1}
Formation enthalpy: ½ O_2 (g) → O (g) $\Delta H^o{}_f$ = +249.2 kJ mol^{-1}

-279.3 = −141 + x −2481 + 215.58 + 1000.0 +249.2
x = $\Delta H^o{}_{EA2}$ = 878 kJ mol^{-1}

14.   How many charge-minimized resonance structures are required to describe the bonding in the $HPO_4{}^{2-}$ anion? (P is the central atom, and is bonded only to O).
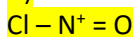
A) 1
B) 2
C) 3
D) 4
E) 6

C)
Three resonance stabilized Lewis structures possible for $HPO_4{}^{2-}$
There are three equivalent terminal O's (the other O is not terminal – it is also bonded to H).

15.   For the molecule $ClNO_2$ nitrogen is the central atom, and all other atoms are bonded to N. In its charge-minimized Lewis structure, the central N atom has:

A) 4 bonding pairs of electrons.
B) 5 bonding pairs of electrons.
C) 1 lone pair and 3 bonding pairs of electrons.
D) 1 lone pair and 4 bonding pairs of electrons.
E) 2 lone pairs and 3 bonding pairs of electrons.

16.   Considering the charge-minimized resonance structures, what is the average formal charge on an oxygen atom in phosphate, PO_4^{3-}?

A) - 0.5
B) - 0.75
C) - 1
D) - 1.5
E) - 2

B)
Charge-minimized structure of phosphate anions has three negative charges at terminal oxygens with four terminal atoms overall, thus -3/4

17.   How many *non-bonding electrons in total* are there in the charge-minimized Lewis structure for nitric oxide, NO_2 ?

A) 14
B) 9
C) 6
D) 11
E) 18

D)
NO_2 has 11 non-bonding electrons. There are $5 + 2\times6 = 17$ valence electrons in total. 6 electrons form three bonds – one single NO bond, and one double NO bond. The N has a +1 formal charge, while one of the O's has a –1 formal charge. A second double bond between N and O cannot be formed, as it would leave N with 9 valence electrons. N cannot go above 8 valence electrons because it is in the second row. It adopts a bent shape with one unpaired non-bonding electron on N atom, 2 non-bonding electron pairs (4 electrons) on the doubly bonded O atom, 3 non-bonding electron pairs (6 electrons) on the singly bonded O atom.

18.   What is the **shape** of PCl_3?

A) trigonal pyramidal
B) trigonal planar
C) T-shaped
D) tetrahedral
E) seesaw

A)
PCl_3 adopts a trigonal pyramidal structure (similar to NH_3) with a lone pair existing on P along with 3 single P-Cl bonds.

19.   Which of the following rankings of the molecules AsF₅, AsF₃ and AsH₃, in order of *increasing* molecular dipole moment, is **CORRECT**?
(Electronegativity values: F = 4.0; As = 2.0; H = 2.1)

A) $AsF_5 < AsF_3 < AsH_3$
B) $AsH_3 < AsF_5 < AsF_3$
C) $AsF_5 < AsH_3 < AsF_3$
D) $AsF_3 < AsF_5 < AsH_3$
E) $AsH_3 < AsF_3 < AsF_5$

C)
AsF_5 is a symmetric trigonal bipyramidal shape and non-polar → lowest dipole moment
AsH_3 adopts a trigonal pyramidal shape and is non-symmetric with lone pair on As → the small electronegativity difference between As and H produces a polar molecule with low dipole moment
AsF_3 in contrast also adopts asymmetric trigonal planar shape with lone pair on As → the high electronegativity difference between As and F results in the largest dipole moment of the series

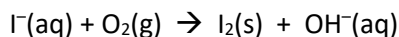20. Which one of the following reactions is an oxidation-reduction reaction?

A) $NaOCl(aq) + CO(g) → NaCl(aq) + CO_2(g)$
B) $SiCl_4(l) + 2 H_2O(l) → 4 HCl(aq) + SiO_2(s)$
C) $SrCO_3(s) → SrO(s) + CO_2(g)$
D) $KCl(aq) + AgNO_3(aq) → AgCl(s) + KNO_3(aq)$
E) $NaNH_2(s) + 2 HBr(aq) → NaBr(aq) + NH_4Br(aq)$

A)
1st reaction is a redox reaction due to oxidation of CO (+2) → CO₂ (+4) and reduction of OCl- (+1) into Cl- (-1). All other reactions are precipitation, ion displacement or acid-base equilibria.
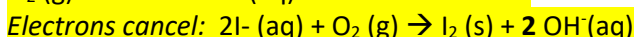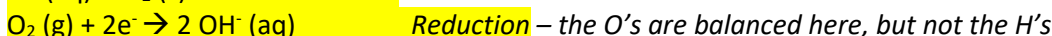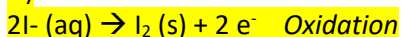
21. Complete and balance the following reaction with the smallest integer coefficients in aqueous media. Determine the *stoichiometric coefficient of **hydroxide*** (OH⁻).
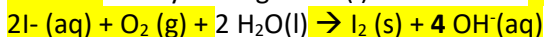
$$I^-(aq) + O_2(g) → I_2(s) + OH^-(aq)$$

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

$2I- (aq) \rightarrow I_2 (s) + 2 e^-$ *Oxidation*
$O_2 (g) + 2e^- \rightarrow 2 OH^- (aq)$ *Reduction – the O's are balanced here, but not the H's*
Electrons cancel: $2I- (aq) + O_2 (g) \rightarrow I_2 (s) + \textbf{2} OH^-(aq)$
Balance H's by adding 2 $H_2O(l)$ to left and 2 $OH^-(aq)$ to right:
$2I- (aq) + O_2 (g) + 2 H_2O(l) \rightarrow I_2 (s) + \textbf{4} OH^-(aq)$

22. In the following ***disproportionation reaction*** phosphorus produces phosphine ($PH_3(g)$) and hypophosphite ($H_2PO_2^-(aq)$). When the reaction is balanced in *basic solution* and the stoichiometric coefficients have been reduced to the lowest integer values, what is the coefficient of $OH^-(aq)$? (In a disproportionation reaction one species is simultaneously oxidized and reduced).
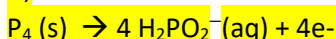
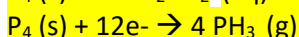$$P_4(s) \rightarrow PH_3(g) + H_2PO_2^-(aq)$$

A) 2
B) 3
C) 4
D) 6
E) 12
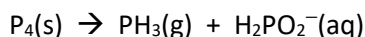
B)
$P_4 (s) \rightarrow 4 H_2PO_2^-(aq) + 4e-$ *Oxidation* X3 to cancel electrons
$P_4 (s) + 12e- \rightarrow 4 PH_3 (g)$ *Reduction*

Net reaction (before balancing H's and O's)
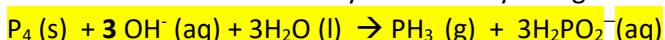$4 P_4 (s) \rightarrow 4 PH_3 (g) + 12 H_2PO_2^-(aq)$
Balance in base (note: you are asked for coefficient of $OH^-(aq)$):
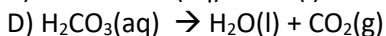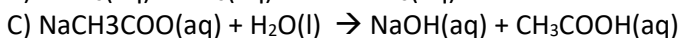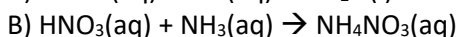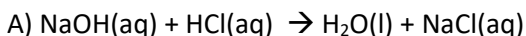Add 24 $OH^-(aq)$ to left to balance O's, then add 12 $H_2O(l)$ to left and 12 $OH^-(aq)$ to right to balance H's. 12 $OH^-(aq)$ cancel from both sides:
$4 P_4 (s) + 12 OH^- (aq) + 12 H_2O (l) \rightarrow 4 PH_3 (g) + 12 H_2PO_2^-(aq)$
All coefficients are divisble by 4. Divide by 4 to get
$P_4 (s) + \textbf{3} OH^- (aq) + 3H_2O (l) \rightarrow PH_3 (g) + 3H_2PO_2^-(aq)$
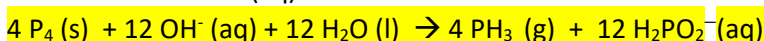
23. Which one of the following reactions is **NOT** an *acid-base* reaction?

A) $NaOH(aq) + HCl(aq) \rightarrow H_2O(l) + NaCl(aq)$
B) $HNO_3(aq) + NH_3(aq) \rightarrow NH_4NO_3(aq)$
C) $NaCH3COO(aq) + H_2O(l) \rightarrow NaOH(aq) + CH_3COOH(aq)$
D) $H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g)$
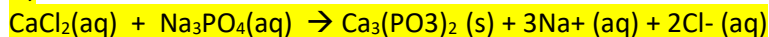E) $HCl(g) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$
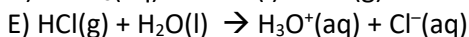
D)
Decomposition reaction for carbonic acid → not an acid base reaction. All other reactions are acid-base processes

24. Which of the following reactant pairs is most likely to undergo a precipitation reaction?

A) Cu(s) + HBr(aq)   ?
B) Cl_2(aq) + KBr(aq)   ?
C) $HClO_3$(aq) + NH_3(aq)   ?
D) $CaCl_2$(aq) + Na_3PO_4(aq)   ?
E) KOH(aq) + $Li(NO_3)_2$(aq)   ?

D)
$CaCl_2$(aq) + Na_3PO_4(aq) → $Ca_3(PO3)_2$ (s) + 3Na+ (aq) + 2Cl- (aq)
$Ca_3(PO3)_2$ is an insoluble phosphate salt, K_{sp} << 1.

25. In the third experiment for Chem 1A03, the K value for the following reaction was determined. Which of the factors below would not cause a potential discrepancy in the experimentally determined value of K?

$$Fe^{3+} (aq) + SCN^- (aq) → FeSCN^{2+} (aq)$$
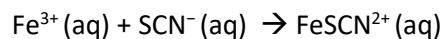
A) Using initial (known) concentrations of Fe^{3+} and SCN^- different from the lab protocol values.
B) Temperature
C) The precision of the spectrometer.
D) Not calibrating the spectrometer before each trial.
E) Unknowingly using the wrong concentration of Fe3+.

A) Varying the initial concentrations of Fe^{3+} and SCN^- (as long as they are known) does not affect the measured equilibrium constant.