**MULTIPLE CHOICE**

1. Consider a solution made from CH3COOH(aq) and CH3COONa(aq) mixed in a 1:1 molar ratio. When a small amount of HCl(aq) is added to the solution, the pH is found to

(A) Not change

(B) Go down slightly because of the reaction,

CH3COO-(aq) + H3O+(aq) 🡺 CH3COOH(aq) + H2O(l)

(C) Go down slightly because of the reaction,

CH3COOH(aq) + OH-(aq) 🡺 CH3COO-(aq) + H2O(l)

(D) Go up slightly because of the reaction,

CH3COO-(aq) + H3O+(aq) 🡺 CH3COOH(aq) + H2O(l)

2. The He+ ion and the H atom have identical electronic configurations. Which of the following best describes the species (and the reason) that would require the largest amount of energy to promote an electron from its ground state to an excited state?

(A) He+ because inert gases have the highest ionization energies in any given period

(B) He+ because it has more protons than H, and therefore a greater Coulombic attraction between the electrons and the nucleus must be overcome

(C) H because has the highest first ionization of all elements since the 1s electron is closest to the nucleus

(D) H because having a single electron in the ground state of 1s1 is the most stable in terms of energy

3. Given the standard reduction potentials below, which of the following could be used to displace elemental bromine from a solution of sodium bromide?

Cl2 + 2e- ⇄ 2Cl- E° = + 1.36 V

Br2 + 2e- ⇄ 2Br- E° = + 1.07 V

I2 + 2e- ⇄ 2I- E° = + 0.53 V

Ca2+ + 2e- ⇄ Ca E° = - 2.87 V

K+ + e- ⇄ K E° = - 2.92 V

(A) Chorine

(B) Iodine

(C) An aqueous solution of calcium chloride

(D) An aqueous solution of potassium chloride

4. Given that the ion CH3+ is electron deficient, what shape would you expect the ion to be, and how many valence electrons would you expect in the Lewis structure of the ion?

**Shape Number of valence electrons**

(A) Tetrahedral 6

(B) Tetrahedral8

(C) Trigonal planar6

(D) Trigonal planar8

5. What is the value of ∆G° for the following *unbalanced* REDOX reaction? Relevant, *balanced* half-reactions with their standard reduction potentials are given.

Cr2O72- + Fe2+ + H+ 🡺 Fe3+ + H2O + Cr3+

Cr2O72- + 14H+ + 6e- ⇄ 7H2O + 2Cr3+ E° = + 1.33 V

Fe3+ + e- ⇄ Fe2+ E° = + 0.770 V

(A) + 324 kJ

(B) - 324 kJ

(C) + 54.0 kJ

(D) - 54.0 kJ

6. Which of the following transitions of an electron in a hydrogen atom would be associated with radiation that has the largest wavelength?

(A) n = 6 to n = 5

(B) n = 5 to n = 4

(C) n = 3 to n = 2

(D) n = 2 to n = 1

7. In which of the following species would you expect there to be sp3 hybridization around the central atom?

(A) NH2-  
(B) HF  
(C) CO2  
(D) BF3

8. In which of the following titrations would you find an equivalence point with a pH lower than 7, and what would be the species responsible for the observed pH at the equivalence point?

(A) HCOOH titrated with NaOH with HCOO- responsible for the pH at the equivalence point

(B) NH3 titrated with HNO3 with NH4+ responsible for the pH at the equivalence point

(C) NH3 titrated with HNO3 with HNO3 responsible for the pH at the equivalence point

(D) NaOH titrated with CH3COOH with CH3COOH responsible for the pH at the equivalence point

9. Which list includes *only* substances whose solids exhibit a giant, covalent network structure?

(A) SiO2, graphite and KCl

(B) SiO2, diamond and K

(C) SiO2, diamond and SiC

(D) Graphite, diamond, and iron

10. Which of the following is an impossible electronic configuration?

(A) 1s2 2s2 2p6 3s2 3p5  
(B) 1s2 2s2 2p6 3s2 3p6  
(C) 1s2 2s2 2p6 2d10 3s2 3p6  
(D) 1s2 2s2 2p6 3s2 3p6 3d10

11. How many of the following molecules exhibit sp3 hybridization around the central atom?

H2O, NH3, SF6, H2S, PF5, BF3

(A) 2

(B) 3

(C) 4

(D) 6

12. The reaction below has a Keq = 8.4 x 10-6.

H2C2O4(aq) ⇄ 2H+(aq) + C2O42-(aq)

If Ka2 = 1.5 x 10-4 , what is the value of Ka1?

(A) 1.3 x 10-9

(B) 1.3 x 10-10

(C) 1.5 x 10-4

(D) 5.6 x 10-2

Questions 13 and 14.

Given sufficient time, the following reaction is observed to create an equilibrium mixture.

2SO2(g) + O2(g) ⇄ 2SO3(g)

13. If the reaction vessel is expanded to increase its volume, *but all the other conditions remain the same*, predict the effect on the moles of SO2(g) present in the equilibrium mixture, and the effect on numerical value of the equilibrium constant for the reaction Kp.

(A) The moles of SO2(g) will increase and Kp will increase

(B) The moles of SO2(g) will decrease and Kp will decrease

(C) The moles of SO2(g) will increase and Kp will remain the same

(D) The moles of SO2(g) will remain the same and Kp will remain the same

14. Sulfur dioxide SO2, is a molecule that has two, S to O covalent bonds that are identical to one another. It is found that the bonds are *not* intermediate in length between double and single bonds. Which phenomena best accounts for these observations?

(A) The expansion of the S atom’s octet

(B) Resonance

(C) The sp hybridization of the S atom

(D) The periodic similarity between the S atom and the O atoms

15. A 0.010 M ethanoic acid CH3COOH has a Ka = 1.8 x 10-5. What is the % ionization of the solution?

(A) 0.010 %

(B) 0.000018 %

(C) 1.0 %

(D) 4.2 %

16. Which statement describes a *difference* between the separate, full photoelectron spectra (PES) plots of elemental argon and elemental sulfur?

(A) The total number of peaks

(B) The position on the x-axis of the peak corresponding to the 1s electrons/orbital

(C) A 3p peak that is at the lowest energy of all of peaks in the spectrum

(D) A 2p peak that is the same height (intensity)

17. In a Beer-Lambert law experiment which of the following experimental errors could account for the point marked as X on the plot?

A graph of absorption and concentration

Description automatically generated

(A) The solution under test was colorless

(B) A 0.01 M solution was incorrectly labeled as 0.02 M

(C) The colorimeter was set to the wrong wavelength

(D) The student handled the cuvette leaving fingerprints on it

Questions 18 - 21

In an attempt to calculate the enthalpy of combustion of a flammable liquid with a molar

mass of 32.00 g/mol, a small burner containing the liquid was placed underneath a

beaker of water. The liquid in the burner was ignited and allowed to heat the water for a

period of time. The following data were collected.

A flame and a flask

Description automatically generated with medium confidence

|  |  |
| --- | --- |
| Mass of burner before the experiment | 232.0 g |
| Mass of burner after the experiment | 228.8 g |
| Initial temperature of water | 25.50 °C |
| Final temperature of water | 64.90 °C |
| Mass of water | 412.0 g |

18. Assuming that all the energy created by burning the liquid is transferred to the water, and that the specific heat capacity of the water is 4.184 J/g °C, calculate the enthalpy of combustion of the liquid in kJ/mol.

(A) - 679.2 kJ/mol

(B) - 684.5 kJ/mol

(C) - 67.92 kJ/mol

(D) - 68.45 kJ/mol

19. The assumption that all the energy is transferred from the combustion reaction to the water is a poor one. Suggest a reason that the assumption is considered to be flawed.

(A) The exact time period that the reaction was carried out for is unknown

(B) The energy from the combustion reaction heats up the air, the glass, and things other than just the water

(C) The water fails to reach its boiling temperature

(D) Not all the flammable liquid is consumed during the reaction

20. A compound related to the flammable liquid used in the experiment is propan-1-ol. An *incomplete* Lewis structure for propan-1-ol is shown below. What is missing from the Lewis diagram, and what is the hybridization around the O atom?

A black background with a black square

Description automatically generated with medium confidence

**Missing from diagram Hybridization around O atom**

(A) Lone pairs of electrons on O atom sp2

(B) Lone pairs of electrons on H atoms sp2

(C) Lone pairs of electrons on O atom sp3

(D) Lone pairs of electrons on H atoms sp3

21. When the experiment is complete an error was found. It was determined that the final mass of the burner should have been recorded as 231.7 g and not as 228.8 g. What effect did this error have on magnitude of the calculated enthalpy of combustion?

(A) No effect

(B) The calculated value had too large a magnitude

(C) The calculated value had too small a magnitude

(D) Without more data it is impossible to know the effect that the error had

22. If an electrochemical cell is constructed from the two-half cells below, where the Cu2+(aq) concentration is 2.0 M and the Al3+(aq) concentration is 2.0 M, what will be the effect on the voltage generated by the cell when compared to the standard voltage, E°?

Cu2+(aq) + 2e- ⇄ Cu(s) E° = + 0.34 V

Al3+(aq) + 3e- ⇄ Al(s) E° = -1.66 V

(A) The generated voltage will be smaller than the standard voltage, E°

(B) The generated voltage will be larger than the standard voltage, E°

(C) The generated voltage will be the same as the standard voltage, E°

(D) The generated voltage will be the same magnitude as the standard voltage, E° but will have a different sign

Questions 23 – 24

A biological reaction can be summarized by the following reaction where “Py” and “La”

represent organic molecules.

2Fe2+ + “Py” + 2H+ 🡺 2Fe3+ + “La”

It is a REDOX reaction that is based upon the following half-reactions.

“Py” + 2H+ + 2e- ⇄ “La” E° = - 0.19 V

Fe3+ + e- ⇄ Fe2+ E° = + 0.77 V

23. Calculate the value of the equilibrium constant K, for the reaction at 298 K.

(A) 5.5 x 1030

(B) 5.8 x 10-17

(C) 3.4 x 10-33

(D) 3.0 x 10-59

24. Which species undergoes oxidation in the overall reaction?

(A) Fe2+

(B) Fe3+

(C) “La”

(D) “Py”

25. Which of the following acids would you expect to have the highest value for its pKa?

(A) HCl

(B) HClO

(C) HClO2

(D) HClO4

26. The decomposition of sodium carbonate is studied by heating a 100.0 g sample of the

solid in a previously evacuated, 1.000 L closed container to a constant temperature of 400.0 K, and by observing the change in pressure inside the container over time.

Na2CO3(s) ⇄ Na2O(s) + CO2(g)

A sketch of the change in pressure over time is shown below.

A line graph with text

Description automatically generated

It is found that the pressure inside the container comes to a constant value of 0.6001 atm. What is the value of Kp for the reaction at this temperature?

(A) 0.6001

(B) 0.1200

(C) (0.06001)(1.000)/(0.08206)(400.0) = 0.001828

(D) (100.0)/(105.991)\*22.4 = 21.13

27. For the chemical reaction that the plot below represents, how does entropy change over the course of the reaction, and when is the reaction thermodynamically favored?

A graph with a line and numbers

Description automatically generated with medium confidence

(A) Entropy increases and the reaction is thermodynamically favored at temperatures above 400 K

(B) Entropy increases and the reaction is thermodynamically favored at temperatures below 400 K

(C) Entropy decreases and the reaction is thermodynamically favored at temperatures above 400 K

(D) Entropy increases and the reaction is only thermodynamically favored at 400 K

28. A solid binary compound at room temperature does not conduct electricity. When it is

heated and melts, it is found to conduct electricity very well. What type of bonding is

most likely to be present in the substance?

(A) Metallic bonding

(B) Ionic bonding

(C) Covalent bonding

(D) Dipole-dipole bonding

29. All diatomic molecules have bond enthalpies that vary according to type of bond that holds one atom to another within the molecule. When considering the diatomic molecules N2, O2, and F2, which molecule would you expect to have the strongest bond between the atoms and why?

(A) O2 since oxygen is a common atom involved in hydrogen bonding

(B) F2 since F is the most electronegative of all the atoms

(C) N2 since the molecule contains a triple covalent bond

(D) The bond between the atoms would have the same strength in each case because they molecules are all covalent diatomics and linear in shape

30. In an atom of gallium Ga, between which two ionization energies would one expect to find the greatest difference?

(A) 1st and 2nd

(B) 2nd and 3rd

(C) 3rd and 4th

(D) All the increases are equal in magnitude

31. The Ka value for butanoic acid CH3CH2CH2COOH is 1.51 x 10-5. What will be the pH of a solution made by combining 25.00 mL of 0.100 M butanoic acid with 12.50 mL of 0.200 M KOH?

(A) pH = 1.51

(B) pH = 4.82

(C) pH = 7

(D) pH > 7

Questions 32 - 33

Consider these molecules their Lewis structures and their VSEPR predicted shapes.

CH4, SO3, NF3 and CO2

32. Which molecule contains the largest bond angle?

` (A) CH4

(B) SO3

(C) NF3

(D) CO2

33. Of the central atoms in each case, which is the only one able to carry a positive formal charge?

(A) C in CH4

(B) S in SO3

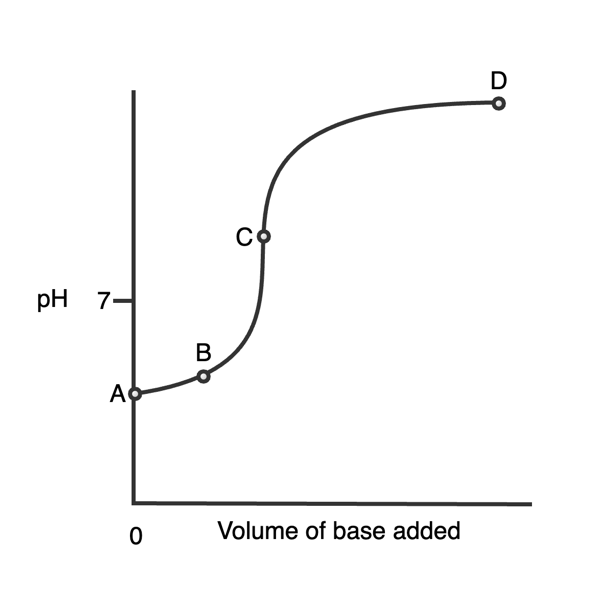
(C) N in NF3

(D) C in CO2

Questions 34 - 37

In a titration between 50.0 mL of 0.01 M CH3COOH(aq) and 0.01 M NaOH(aq) the

following titration curve is generated. The Ka for CH3COOH is known to be 1.79 x 10-5.



34. At point D, which species is most responsible for the pH of the solution in the flask?

(A) H3O+(aq)

(B) CH3COO-(aq)

(C) OH-(aq)

(D) CH3COOH(aq)

35. If a vertical line is drawn from point C to the x-axis, what approx. numerical value on the x-axis will be observed at the intercept between the drawn vertical line and the x-axis?

(A) 0.0

(B) 9.0

(C) 25.0

(D) 50.0

36. At all points on the curve between point B and point C, ignoring water what will be the dominant species in the solution in terms of its concentration?

(A) CH3COOH(aq)

(B) CH3COO- Na+(aq)

(C) OH-(aq)

(D) NaOH(aq)

37. What is the pH of the solution when 70.0 mL of NaOH have been added?

(A) 2.778

(B) 10.301

(C) 11.222

(D) 12.000

38. For the reaction represented by the two, elementary steps below, what is the rate law?

A ⇄ B

B 🡺 C

A graph of a reaction progress

Description automatically generated

(A) Rate = k[B]2

(B) Rate = k[A]2

(C) Rate = k[A]

(D) Rate = k[C]

39. The equilibrium vapor pressures of four liquids at a particular temperature are listed in the table below.

|  |  |
| --- | --- |
|  | **Equilibrium Vapor Pressure in mmHg** |
| W(l) | 174.9 |
| X(l) | 92.0 |
| Y(l) | 43.7 |
| Z(l) | 3.51 |

Which liquid has the *weakest* intermolecular forces between it particles?

(A) W(l)

(B) X(l)

(C) Y(l)

(D) Z(l)

Questions 40 and 41

A sample of liquid butan-1-ol is burned according to the equation below. Some

thermodynamic data for the reaction are provided.

C4H9OH(l) + 6O2(g) 🡺 4CO2(g) + 5H2O(g)

* ∆H° = -2657 kJ mol-1
* ∆S° = +155.9 J K-1 mol-1
* ∆G° for the reaction is determined to have a negative value at 298 K

40. The reaction is observed to *not* occur when a sample of butanol is placed in oxygen at 298 K. Which statement best accounts for this observation?

(A) The reaction would need a positive ∆G° value to be thermodynamically favorable

(B) The reaction has a high activation energy

(C) Because of the nature of the reaction it is simply not possible to observe any chemical reaction occurring

(D) The ∆S° value is measure in J and the ∆H° value in kJ, so the entropy change is too small to allow the reaction to occur

41. Which aspect of the thermodynamics of the reaction make it thermodynamically favorable?

(A) Entropy only

(B) Enthalpy only

(C) Both entropy and enthalpy

(D) It could be enthalpy or entropy, it depends on the temperature

42. Which species contains the *shortest* carbon to oxygen bond?

(A) CO32-

(B) CO

(C) CO2

(D) CH3COOH

43. The heating curve below shows the change in temperature as a solid is heated. Which of the following statements about the plot is true?

A line graph with a white background

Description automatically generated

(A) The solid to liquid phase change requires the greatest input of energy

(B) The liquid to gas phase change requires the greatest input of energy

(C) Heating the solid to its melting point requires the greatest input of energy

(D) Heating the liquid to its boiling point requires the greatest input of energy

44. The Ksp values for silver chloride, copper(I) chloride and mercury(I) chloride are tabulated below.

|  |  |
| --- | --- |
| **Compound** | **Ksp at 298 K** |
| AgCl | 1.8 x 10-10 |
| CuCl | 1.6 x 10-7 |
| PbCl2 | 1.7 x 10-5 |

At 298 K, the saturated solution that contains the *lowest* concentration of chloride ions is

(A) AgCl

(B) CuCl

(C) PbCl2

(D) The three salts cannot be compared to one another since the stoichiometry of

their dissociation is not consistent

45. Which of the following gases is likely to deviate least from ideal behavior?

(A) H2

(B) O2

(C) NO2

(D) CO2

46. Which of the following anions is expected to be the strongest base?

(A) CH3COO- (aq)

(B) CF3COO-(aq)

(C) CCl3COO-(aq)

(D) CBr3COO-(aq)

47. Iodine I2, has a boiling point of 457 K. KI has a boiling point of 1603 K. Which statement best accounts for the difference in boiling points of these substances?

(A) The covalent bond in I2 is weaker than the covalent bond in KI

(B) The dipole-dipole intermolecular forces in KI are stronger than the London dispersion intermolecular forces in I2

(C) The KI molecule is much larger than I2 and molecular size affects the extent of the London dispersion forces present

(D) I2’s boiling point is determined by weak London dispersion forces, whereas KI’s boiling point is determined by relatively strong ionic bonds

Questions 48 - 50

2A + B 🡺 C + D

The rate law for the reaction above is experimentally determined as being, Rate = k[A]2

48. When the experiment is carried out at two different temperatures, one relatively cold and one relatively hot, what can be said of the rate of the reaction and the rate constant k when comparing the two sets of conditions?

(A) At the hotter temperature the rate of reaction will be greater, but k is constant at the two temperatures

(B) At the hotter temperature the rate of reaction will be greater, and k will be greater at the hotter temperature

(C) At the colder temperature the rate of reaction will be smaller, but k is constant at the two temperatures

(D) At the colder temperature the rate of reaction will be the same, and k is constant at the two temperatures

49. How can the value of the rate constant k, be determined from a graph?

(A) By plotting [A] against time and reading the intercept on the x-axis

(B) By plotting ln[A] against time and determining the slope of the line

(C) By plotting 1/[A] against time and determining the slope of the line

(D) By plotting 1/[A] against time and reading the intercept on the y-axis

50. Assuming rate to be measured in units of mol L-1 min-1, what could the units of k be?

(A) mol L-1 min-1

(B) mol-1 L min-1

(C) mol-2 L2 min-1

(D) mol2 L-2 min-1

**ANSWERS**

**1. B**

**2. B**

**3. A**

**4. C**

**5. B**

**6. A**

**7. A**

**8. B**

**9. C**

**10. C**

**11. B**

**12. D**

**13. C**

**14. A**

**15. D**

**16. B**

**17. D**

**18. A**

**19. B**

**20. C**

**21. C**

**22. B**

**23. C**

**24. A**

**25. B**

**26. A**

**27. A**

**28. B**

**29. C**

**30. C**

**31. D**

**32. D**

**33. B**

**34. C**

**35. D**

**36. B**

**37. C**

**38. C**

**39. A**

**40. B**

**41. C**

**42. B**

**43. B**

**44. A**

**45. A**

**46. A**

**47. D**

**48. B**

**49. C**

**50. B**

**FREE RESPONSE**

1. Silver phosphate Ag3PO4, is a sparingly soluble salt with a Ksp = 8.9 x 10-17 at 298 K.

(a) Write an equation to illustrate the dissolution of silver phosphate in water.

**Ag3PO4(s) ⇄ 3Ag+(aq) + PO43-(aq)**

(b) Calculate the molar solubility of silver phosphate at 298 K.

**Ksp = 8.9 x 10-17 = [Ag+]3 [PO43-] = (3s)3 (s) = 27s4**

**s = (8.9 x 10-17/27)0.25 = 4.3 x 10-5 M**

(c) When a few drops of aqueous silver nitrate AgNO3, are added to a saturated solution of silver phosphate, would you expect the solubility of the silver phosphate to increase, decrease or remain the same? Explain your answer.

**Decrease. Addition of Ag+(aq) ions increases the value of Q meaning the reaction needs to shift to the reactant side to restore the value of K. This creates more solid thus decreasing the solubility of the silver phosphate.**

Two Lewis structures for the phosphate ion PO43-, are proposed below. ***In both cases, any***

***charges and any lone pairs have been omitted.***

|  |  |
| --- | --- |
| A diagram of a molecule  Description automatically generated | A diagram of a molecule  Description automatically generated |
| **STRUCTURE 1** | **STRUCTURE 2** |

(d) Add lone pairs of electrons to the Lewis structures as appropriate. ***(There is no need to add any charges)***.

|  |  |
| --- | --- |
| A black and white diagram of a molecule  Description automatically generated | A black and white diagram of a molecule  Description automatically generated |
| **STRUCTURE 1** | **STRUCTURE 2** |

(e) Select the more likely (“better”) of the two structures and give a reason for your choice.

**Structure 1. It has the more favorable (closer to 0 on each atom, and any negative charges on the electronegative atoms) formal charges.**

|  |  |
| --- | --- |
| **Structure 1** | **Structure 2** |
| **Single bonded O = 6 – 6 - 1 = -1** | **Single bonded O = 6 – 6 - 1 = -1** |
| **Double bonded O = 6 – 4 – 2 = 0** | **P = 5 – 0 – 4 = +1** |
| **P = 5 – 0 – 5 = 0** |  |

(f) According to VSEPR theory, what would be the shape of the structure you have identified in (e)?

**Tetrahedral.**

(g) Identify the number of sigma and pi bonds present in the structure you have identified in (e).

**4 sigma, 1 pi.**

2. This question involves some of the elements found in group 1 and group 2 of the

periodic table.

(a) Write the full electron configuration for a Sr2+ ion.

**1s2 2s2 2p6 3s2 3p6 4s2 3d10 4p6**

(b) Explain why the first ionization energy of Sr is lower than the first ionization energy of Ca.

**The electron removed from a strontium atom is found in the 5s orbital.**

**The electron removed from a calcium atom is found in the 4s orbital.**

**The 5s electron is, on average, further from the nucleus than the 4s electron,**

**so it experiences a smaller Coulombic attraction from the nucleus, and**

**therefore it is easier to remove, requiring less energy to overcome the**

**attraction from the nucleus.**

(c) When heated strongly, compounds that contain Sr ions and those that contain Ca ions each emit light in the red region of the visible spectrum.

(i) Calculate the energy in J, of one photon of red light that has a wavelength

of 710. nm.

**c = λ ν = 3.00 x 108 ms-1 = (710 x 10-9m) ν**

**ν = 4.23 x 1014 s-1**

**E = h ν = (6.626 x 10-34 J s)(4.23 x 1014 s-1)**

**E = 2.80 x 10-19 J**

(ii) The first ionization energy of Na is 496 kJ/mol. If a single Na atom were bombarded with a mole of photons, each with the energy you have calculated in (c)(i), and assuming that all the energy is absorbed, would it be sufficient to ionize one mole of Na atoms? Support your answer with calculations.

**Total energy from the photons = (6.022 x 1023)(2.80 x 10-19 J) = 169 kJ**

**This is less than the required energy, so a mole of Na atoms would not be ionized.**

(d) Strontium carbonate will react with acids such as hydrochloric acid HCl, to release carbon dioxide gas. The equation for the reaction is given below.

SrCO3(s) + 2HCl(aq) 🡺 SrCl2(aq) + H2O(l) + CO2(g)

(i) Re-write the equation as a net ionic equation.

**SrCO3(s) + 2H+(aq) 🡺 Sr2+(aq) + H2O(l) + CO2(g)**

(ii) A student suggests that the reaction between the strontium carbonate and the hydrochloric acid can be classified as a REDOX reaction. Do you agree or disagree. Justify your choice.

**Disagree. All elements retain their original oxidation states, so no electrons are lost or gained.**

(iii) The carbonate ion CO32- is found to have three, carbon to oxygen bonds that are identical to one another, being intermediate in length and in strength between a single bond and a double bond. Explain this observation.

**The carbonate ion exhibits resonance, where the one double bond and two single bonds in the classic Lewis structure average out to give three, identical bonds between the C and O atoms.**

3. The decomposition of NO2(g) in the reaction below is monitored at 298 K, and the following data collected, tabulated, and graphed.

2NO2(g) 🡺 2NO(g) + O2(g)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  |  |  | | --- | --- | --- | --- | | **Time in s** | **[NO2]** | **ln[NO2]** | **1/[NO2]** | | 0.0 | 0.0100 | -4.6052 | 100.0 | | 50.0 | 0.0079 | -4.8434 | 126.9 | | 100.0 | 0.0065 | -5.0406 | 154.6 | | 200.0 | 0.0048 | -5.3391 | 208.3 | | 300.0 | 0.0038 | -5.5728 | 263.2 | |

|  |  |  |
| --- | --- | --- |
| A graph with a line  Description automatically generated | **A graph with a line  Description automatically generated** | A graph with a line  Description automatically generated |

(a) Deduce the rate law for the reaction.

**Rate = k[NO2]2**

(b) Determine a value for the rate constant k and state its units.

**1/[NO2] = kt + 1/[NO2]0**

**1/0.0038 = k (300) + (1/0.0100)**

**k = 0.544 M-1 s-1**

(c) Calculate the [NO2] after 500 seconds.

**1/[NO2] = kt + 1/[NO2]0**

**1/[NO2] = (0.544)(500) + (1/0.0100)**

**[NO2] = 0.00269 M**

(d) The experiment is repeated at the same temperature, and keeping all other conditions constant, *but in a smaller vessel*. What can be said of how each of the following change? In each case, explain your answer.

(i) The rate of the reaction.

**Increased, since the reduction in volume would increase the concentration of NO2, leading to a greater number of collisions, and an increase in reaction rate.**

(ii) The value of the rate constant.

**Remains constant. k is constant at constant temperature.**

(e) The following mechanism is proposed for the reaction.

2NO2(g) 🡺 NO3(g) + NO(g) slow

NO3(g) 🡺 NO(g) + O2(g) fast

(i) Identify any intermediates in the mechanism. If there are none, say so.

**NO3**

(ii) Is the mechanism consistent with your answer to (a)? Explain

**Yes, since the reactant in the slow step and its coefficient, both match the rate equation.**

4. Electrochemical cells can be divided into two types; those that are used to generate electricity, commonly known as batteries or galvanic cells, and those that need electricity to work, commonly called electrolysis cells.

(a) In the first type of cell it is observed that the voltage generated by a cell that is made by combining a standard (1.0 M) Fe2+/Fe half-cell and a standard (1.0 M) Sn2+/Sn half-cell, is lower when the 1.0 M solution of Fe2+ ions is replaced by a 2.0 M solution of Fe2+ ions. Explain this observation.

Fe2+(aq) + 2e- ⇄ Fe(s) E° = - 0.44 V

Sn2+(aq) + 2e- ⇄ Sn(s) E° = - 0.14 V

**The reaction that takes place in the cell is**

**Sn2+(aq) + Fe(s) 🡺 Sn(s) + Fe2+(aq)**

**And has a voltage of – 0.14 + 0.44 = 0.30 V**

**Since Q = [Fe2+]/[Sn2+], changing the values from the original, standard 1.0 M values also changes Q from a value of 1 (1/1) to a value of 2 (2/1). Since Q is larger, the cell is closer to reaching its large K value, and the voltage in the cell is closer to zero, i.e., smaller than it is when using 1.0 M solutions.**

(b) In the second type of cell, sodium metal can be obtained at the cathode when electricity is passed through a molten sample of NaCl. The half-reaction to summarize the process is given below.

Na+(l) + e- 🡺 Na(l)

(i) Calculate the time it would take to produce 28.0 g of Na metal, by using a current of 8.00 A.

**Moles of Na = 28.0/22.99 = 1.218 mols**

**The ratio of mols of Na to mols of electrons required is 1:1, so 1.218 mols of electrons are required.**

**(1.218)(96485) = 117519 c total charge required**

**117519 c = (8.00)(t)**

**t = 1.47 x 104 s**

(ii) Identify the reaction that takes place at the anode in the cell.

**Cl-(l) 🡺 ½Cl2(g) + e-**

5. The Haber-Bosch process is an important industrial reaction where ammonia is

produced from the reaction between nitrogen gas and hydrogen gas. The equation for

the reaction and other data are given below.

N2(g) + 3H2(g) ⇄ 2NH3(g) ∆H = -92.0 kJ mol-1

|  |  |
| --- | --- |
| **Substance** | **Standard Molar Absolute Entropy**  **in J K-1 mol-1** |
| N2 | 192 |
| H2 | 131 |
| NH3 | 193 |

(a) Calculate the temperature at which the reaction changes from being a thermodynamically favored process, to one that is no longer thermodynamically favored.

**∆S° = ΣS°(products) – ΣS°(reactants) = (2(193)) – (192 + 3(131) ) = -199 J K-1 mol-1**

**∆G° = ∆H° – T∆S°**

**0 = -92.0 kJ mol-1 – ((T)(-0.199 kJ K-1 mol-1))**

**T = 462 K**

(b) The reaction is catalyzed with iron metal. Using the axes provided below, sketch a carefully labeled diagram showing how the reaction proceeds both with, and without, the catalyst being present. Be sure to indicate each of the following on your sketch (*activation energy with and without a catalyst, the enthalpy change, products, reactants*).

A graph with a line

Description automatically generated

|  |
| --- |
| Diagram of a diagram of a cat product  Description automatically generated |

6. Deviation from ideal behavior can be accounted for by using a modified version of the ideal gas equation called the van der Waals equation. One version of the equation is given below.

A math equation with square and square numbers

Description automatically generated

(a) The “a” value in the equation is unique to each gas, and two such values are given below.

|  |  |
| --- | --- |
|  | **“a” in units of L2bar/mol2** |
| Neon | 0.2135 |
| Hydrogen fluoride | 9.565 |

Carefully explain why,

(i) a factor is added to the pressure component when using the van der Waals equation *regardless of the nature of the gas.*

**The assumption that the particles of an ideal gas do not attract one another is incorrect, and this leads to a situation where the particles collide with the walls of the container with less force than they ought to, so a term needs to be added to the observed pressure to bring it up to its correct value.**

(ii) the “a” value for hydrogen fluoride is so much larger than that of neon.

**HF molecules are attracted to one another with relatively strong hydrogen bonds. Neon atoms are attracted to one another with relatively weak London Dispersion Forces.**

**As such, hydrogen fluoride’s observed pressure is affected downwards to a greater degree than neon’s, so a larger factor needs to be added to adjust the pressure to its correct value.**

(b) Neon is found to have boiling point of 27 K. Radon has a boiling point of 212 K. The group 18 elements have an approx. linear relationship in the increase of their observed boiling points down the group. In terms of the similarities and differences in the intermolecular forces present, explain why this trend is observed.

**London Dispersion Forces are the only IMFs between atoms of the group 18 elements. LDFs increase with surface area, the number of electrons, and the atoms become more polarizable down the group. These increased IMFs mean that more energy is required to separate molecules from one another at the bottom of the group, so boiling points increase.**

7. An experiment is conducted to determine the value of x in the formula MgSO4•xH2O. A sample of the hydrated salt is placed in test tube, the apparatus is weighed. The

tube and its contents are then heated it strongly. After cooling, the student weighs the test tube and contents once more, and then repeats the heating, cooling, and weighing cycle of the sample until a constant mass is achieved.

(a) Suggest how each of the following experimental errors will affect the calculated value of x. In each case state whether the value of x will be calculated as too large, too small, or that the error will have no effect on the calculation and explain your answer carefully.

(i) Unknown to the student, during the experiment some of the hydrated salt spits out of the tube and is lost.

**x will be too big. The mass (water) loss will be recorded as being too large, leading to a value for the number of moles of water being recorded as too large.**

(ii) Having already recorded a constant mass, the student repeats the heating/cooling/weighing cycle twice more, on each occasion recording the same constant mass.

**x will be unaffected. Once a constant mass has been recorded, no further change will take place, and this is confirmed by the mass remaining constant.**

(b) The formula of the hydrated salt is known to have an accepted value of x = 7, i.e., the formula is known to be MgSO4•7H2O. The reaction can be summarized thus.

MgSO4•7H2O(s) 🡺 MgSO4(s) + 7H2O(g)

Given the following data, calculate the value that is missing from the table.

|  |  |
| --- | --- |
| Mass of empty test tube | 15.210 g |
| Mass of test tube and hydrated salt sample | ? |
| Final, constant mass of test tube and anhydrous salt | 16.544 g |

**Mass of anhydrous salt (MgSO4) = 16.544 – 15.210 = 1.334 g**

**Moles of anhydrous salt (MgSO4) = (1.334)/(24.3 + 32 + 64) = 0.0110889 mols**

**Moles of water = (0.0110889)(7) = 0.0776226 mols**

**Mass of water = (0.0776226)(18) = 1.397 g**

**Total mass of test tube + anhydrous salt + water = 16.544 + 1.397 = 17.941 g**