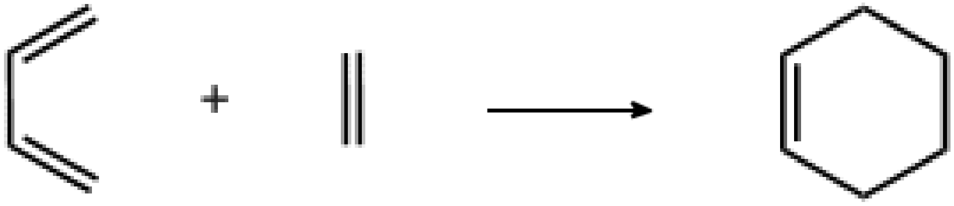
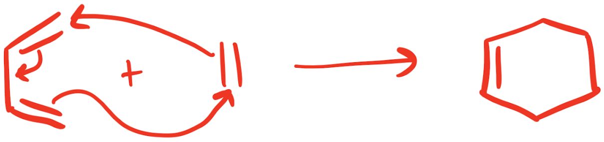
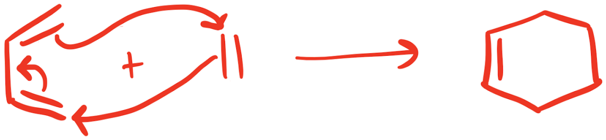
HARD PACKET 1 **ANSWER KEY**

1. The following is a simple representation of an organic synthesis process known as the Diels-Alder reaction. Draw electron pushing arrows on the reactants to make the product.

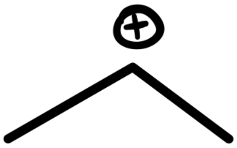




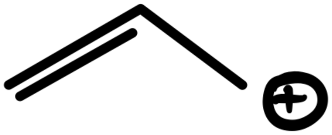
or



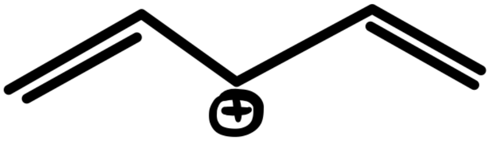
2. Rank the following cations in order from longest (#1) to shortest wavelength (#3). (Hint: energy is inversely proportional to wavelength)



3 (shortest)



2 (middle)



1(longest)

3. Which of the following gas molecules will have the lowest root-mean-square speed at 150˚C: SF_6, CCl_4, or H_2O

Using the equation “v = sqrt(3RTM)” we know the substance with the largest molar mass will have the lowest root-mean-square speed. SF_6 has a molar mass of 146.06 g/mol, CCl_4 has a molar mass of 153.82 g/mol, and H_2O has a molar mass of 18.02 g/mol. Thus, **CCl_4 has the lowest root-mean-square speed at 150˚C.**

HARD PACKET 2 ANSWER KEY

1. A sample of nitrogen gas effuses at a rate four times that of an unknown gas. What is the molecular weight of the unknown gas in g/mol? (Hint: $\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$)

   Graham's law of effusion: r1/r2 = sqrt(M2/M1)
   Rate of effusion of N_2 = 4 = r1, Rate of effusion of unknown gas = 1 = r2
   Molecular mass of N_2 = 28.0134 g/mol = M1, Molecular mass of unknown gas = x = M2
   Molecular mass of unknown gas = x = (r1/r2)^2 * M1 = **448.2144 g/mol**

2. A 14.5 L closed vessel contains 1.49 g H_2O, 4.32 g CO_2, and 3.21 g SO_3. At 40˚C, what is the pressure in the vessel (in atm)? Assume these gases behave ideally.

$$PV = nRT$$

$$P = \frac{nRT}{V}$$

$$1.49\text{g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g}} = 0.083 \text{ mol } H_2O$$

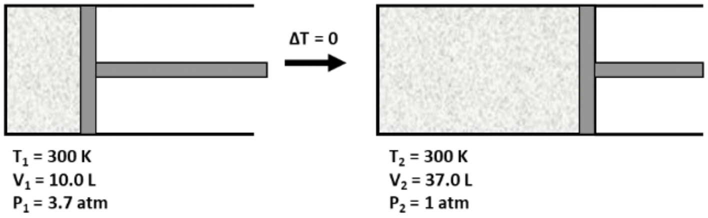
$$4.32\text{g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.01\text{g}} = 0.098 \text{ mol } CO_2$$

$$3.21\text{g } SO_3 \times \frac{1 \text{ mol } SO_3}{80.06\text{g}} = 0.040 \text{ mol } SO_3$$

$$\text{Total mol of gas} = 0.083 + 0.098 + 0.040 = 0.221 \text{ mol}$$

$$P = \frac{nRT}{V} = \frac{(0.221)(0.08206)(313.15)}{14.5} = 0.392 \text{ atm}$$

3. Considering the ideal gas as the system, calculate the heat transferred to/from the surroundings ($q_{surroundings}$) in the process below. This expansion is performed against a constant external pressure of 1 atm.

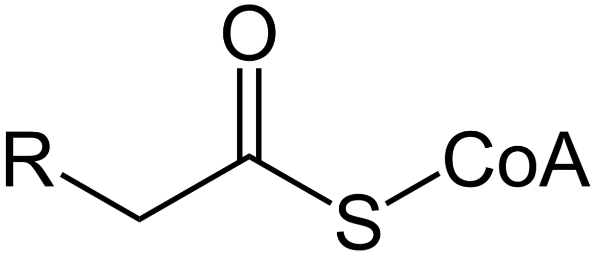


ΔT = 0, ΔU = 0

$w_{sys} = -P_{ext}\,\Delta V$ = -1atm(37L-10L)(101.325J/atmL) = -2736J
$q_{sys} = -w_{sys}$ = 2736J
$q_{surroundings} = -q_{sys}$ = **-2736J**

HARD PACKET 3 ANSWER KEY

1. In the conversion of acetyl CoA (shown below) to carbon dioxide, is carbon oxidized or reduced?



Oxidized

2. Suppose you are conducting an experiment to study two silver salts, AgBr and AgCl. They have solubility product constants of 7.7 * 10^{-13} and 1.6 * 10^{-10}, respectively. You begin with a solution of 0.10M Br^- and 0.10M Cl^- and gradually add in Ag^+. What percent of Br^- remains in solution when AgCl first precipitates?

AgBr will start to precipitate when $[Ag^+][Br^-]$ = 7.7 * 10^{-13}
$[Ag^+]$ = 7.7 * 10^{-13}/ 0.10 = 7.7 * 10^{-12}
AgCl will start to precipitate when $[Ag^+][Cl^-]$ = 1.6 * 10^{-10}
$[Ag^+]$ = 1.6 * 10^{-10} / 0.10 = 1.6 * 10^{-9}

When AgCl begins to precipitate, $[Ag^+]$ = 1.6 * 10^{-9}, $[Ag^+][Br^-]$ = 7.7 * 10^{-12}, [Br-] = 4.8 * 10^{-4} (remaining in solution, not precipitated)

% remaining in solution when AgCl first precipitates = 4.8 * 10^{-4} / 0.10 * 100% = **0.48%**

3. Billy conducts an electron diffraction experiment. There are 2 slit openings lined up top to bottom with the appropriate width for diffraction. Billy will fire trillions of electrons upon the slits. How many detectors should Billy use if they want the diffraction pattern to appear as if there is only a single slit?
1

HARD PACKET 4 **ANSWER KEY**

1. The photoelectric effect describes the emission of electrons from a material, oftentimes a metal, when electromagnetic radiation hits its surface. The equation $KE_{max} = E_p - \phi$ describes the maximum kinetic energy of the ejected electrons in terms of E_p, the energy of the incoming photon, and ϕ, the work function. ϕ for gold is $8.17 \cdot 10^{-19}$J and light with a frequency of $1.00 \cdot 10^{15}$s^{-1} is shined on a gold plate. If there are ejected electrons, what is the speed of the ejected electrons? If there are no ejected electrons, write "no electrons are ejected."

   No electrons ejected

2. Pu-244 undergoes beta-decay at a half-life of 16 hours. If a chemist starts with a sample of 512 g of Pu-244 and allows it to undergo beta-decay, how much of the original sample remains after 4 days?

   8 grams

3. Calculate the pH of a $1.00 \times 10^{-2} M\ H_2SO_4$ solution. (K_{a1} is very large, consider the first dissociation step as totally complete; $K_{a2} = 1.2 \times 10^{-2}$)

First dissociation: $[H^+] = 1.00 \times 10^{-2}$ M
Second dissociation:
Ice Table:

	HSO_4^-	SO_4^{2-}	H^+
I	$1.00 \times 10^{-2} M$	0	$1.00 \times 10^{-2} M$
C	-x	+x	+x
E	$(1.00 \times 10^{-2} - x)$	x	$(1.00 \times 10^{-2}$ + x)

$K_{a2} = 1.2 \times 10^{-2} = \frac{(1.00\times10^{-2} + x)\bullet x}{(1.00\times10^{-2} - x)}$

$x = -0.026524$ or 0.004524

$[H^+] = 1.00 \times 10^{-2} + 0.004524 = 0.014524\ M$

$pH = -\ log\ 0.014524 \simeq$ **1.838**

HARD PACKET 5 ANSWER KEY

1. How many more chlorine atoms are present in a 3-chloropentane molecule compared to a 2-chloropentane molecule?

0

2. An 80 mL aqueous solution contains 0.7 g of hydrofluoric acid (initial amount) dissolved in water. Calculate the pH of the solution (K_a of HF = 6.6×10^{-4} at 25° C; MW HF = 20.01 g/mol).

$0.7 \text{ g HF } \left(\frac{1\ mol}{20.01\ g}\right) = 0.03498 \text{ mol HF}$ $\qquad$ $\frac{0.03498\ mol}{0.08\ L} = 0.437 \text{ M HF}$

$HF\ (aq) + H_2O\ (l) \rightleftharpoons H_3O^+\ (aq) + F^-$

I	0.437 M	—-	0	0
E	0.437 - x	-—	x	x

$K_a = 6.6 \times 10^{-4} = \frac{(x)(x)}{0.437 - x}$

use method of successive approximation → $\approx 6.6 \times 10^{-4} = \frac{(x)(x)}{0.437}$

$x = 0.0167 = [H_3O^+]$

pH = -log(0.0167) = **1.77-1.78**

3. The percent dissociation of a solution with an initial amount of 0.3 M of nitrous acid is 1.3%. A 0.3 M solution of hydrocyanic acid has the same percent dissociation. Calculate the pOH of the solution with hydrocyanic acid.

$\frac{H3O}{0.3} \cdot 100 = 1.3\%$ for HNO_2

$[H_3O^+] = 0.0039$ M for HNO_2 = $[H_3O^+]$ for HCN

pH = -log(0.0039) = 2.41

pOH = 14-2.41 = **11.59**

HARD PACKET 6

ANSWER KEY

1. $2SO_{2\,(g)} + O_{2\,(g)} \rightarrow 2SO_{3\,(g)}$ is one of the essential reactions involved in the industrial production of H_2SO_4. Suppose at the beginning of the reaction, there are 100L of mixed gases: 7% is SO_2, 11% is O_2, 82% is N_2. At the end of the reaction, the total volume of the gas becomes 97.2L. What percentage of SO_2 was converted? (Assume that the total pressure and temperature remain constant throughout the reaction, and the gasses behave ideally) (3 significant figures)

   Since the total pressure and temperature remain constant

   $$\frac{n_i}{V_i} = \frac{n_f}{V_f} \Rightarrow n_f = 0.972\,n_i$$

   $$\Delta n = (1 - 0.972)\,n_i = 0.028\,n_i$$

   $$\Delta n(SO_2) = 2\times\Delta n = 0.056\,n_i$$

   $$\%n(SO_2)_{converted} = \frac{0.056\,n_i}{0.11\,n_i} = 50.9\%$$

2. You are performing a titration to determine the concentration of the weak monoprotic acid HA ($K_a = 2.0 * 10^{-3}$) using a strong monoprotic base B with a concentration of 1M ($K_b = 8.6 * 10^{3}$). You know that the initial concentration of HA is 1.6M and that the equivalence point is reached when you add exactly 50 mL of B. Determine the pH value of the solution at the equivalence point. (Temperature = 25ºC)

   $$V(HA)_i = \frac{1\times0.05}{1.6} = 0.03125\,L$$

   $$V(Solution)_{eq} = 0.03125\,L + 0.05\,L = 0.08125\,L$$

   $$n(A^-)_{eq} = 0.05\,L \times 1M = 0.05\,mol$$

   $$[A^-]_{eq} = \frac{0.05\,mol}{0.08125\,L} = 0.615384615\,M$$

   $$K_b(HA) = 2.0 \times 10^{-3} = \frac{x^2}{0.615384615\,M - x} \rightarrow x = 0.035082321$$

   $$pH = 14 - pOH = 14 - (-\,log(0.035082321)) = 12.54508832 \simeq 12.55$$

3. A Na_2SO_3 solid is exposed to the air for an extended period of time. Some of the Na_2SO_3 is oxidized by the oxygen in the air. To determine the purity of the Na_2SO_3, a 3.5g sample is taken from the solid and reacted with excess H_2SO_4. 560 mL of gas is produced under standard conditions. What is the purity in percent of the Na_2SO_3 solid?

   $$n\,(SO_2) = 0.56L \div 22.4\,L/mol = 0.025\,mol$$

   $$m\,(Na_2SO_3) = 0.025\,mol \times 126.043\,g/mol = 3.151075\,g$$

   $$\%Na_2SO_3 = \frac{3.151075\,g}{3.5\,g} \times 100\% \simeq 90.0\%$$

HARD PACKET 7 ANSWER KEY

1. Calculate the pH once 5 mL of 1M HCl is added to 500 mL of a buffer solution of 0.4M CH_3COOH (a weak acid) and 0.1M CH_3COO^-. (Given: K_b (CH_3COO^-) = 5.56×10^{-10})

Find moles of CH_3COOH and CH_3COO-
CH_3COOH: 0.5*0.4 = 0.2 moles
CH_3COO-: 0.1*0.5 = 0.05 moles

Find moles of HCl
0.005*1 = 0.005 moles

Find pKa
10^-14/5.56*10^-10 = 1.8*10^-5
-log (1.8*10^-5)=5.1

Henderson Hasselbach
5.1 - log (0.2+0.005/0.05-0.005) = **4.438**

2. What happens to the boiling point of water when you dissolve rock climbing chalk (magnesium carbonate) in it?
   The boiling point **increases**

3. A certain amount of SO_2 (a L) and H_2S (b L) are mixed under room temperature and normal atmospheric pressure. They react to form yellow solids (S) and water. If the volume of the gases after reaction is only ¼ of the volume before the reaction, what is the ratio of a:b? (There are two possible ratios, list both of them).
   Answer:

   a. SO_2 is the limiting reactant

   $\frac{b-2a}{a+b} = 1/4 \rightarrow a:b = 1:3$

   b. H_2S is the limiting reactant

   $\frac{a-1/2\times b}{a+b} = 1/4 \rightarrow a:b = 1:1$

HARD PACKET 8 **ANSWER KEY**

1. A mixture contains Na_2S, Na_2SO_3, Na_2SO_4. Knowing that there is 38% of sulfur in this mixture (by mass). What is the percentage of oxygen (by mass)?

$$\%Na = 38\% \times \frac{2 \times 22.990 g/mol}{32.066 g/mol} = 54.49\%$$

$$\%O = 100\%-38\%-54.49\%=\mathbf{7.51\%}$$

2. A/an ______________ is a mixture of two compounds with well-defined boiling points that cannot be separated through fractional distillation.

Azeotrope

3. Write the chemical formula of Cobalt (III) oxalate

($Co_2(C_2O_4)_3$)

HARD PACKET 9 ANSWER KEY

1. Given the following reaction: ½ $N_2(g) + O_2(g) \rightarrow NO_2(g)$ $\Delta H_f = +33.2$ kJ

If you have 2.1 L (at STP) of N_2, which is the limiting reagent, how much heat is needed for the reaction to use up all the N_2. (1 mol = 22.4L at STP)

Answer key:

½ $N_2(g) + O_2(g) \rightarrow NO_2(g)$ $\Delta H_f = +33.2$ kJ

If you have 2.1 L (at STP) of N_2, which is the limiting reagent, how much heat is needed for the reaction to use up all the N_2? (1 mol = 22.4L at STP)

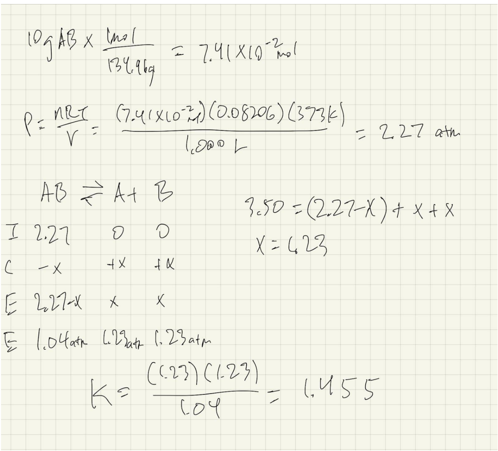
2.1 L N_2 x 1mol N_2 / 22.4L N_2 = 0.093725 mol N_2

0.093725 mol N_2 x 1mol of rxn / ½ mol N_2 x 33.2 kJ / 1 mol rxn = **6.225 kJ**

2. An unknown gas AB decomposes into A and B in the following reaction:

$$AB_{(g)} \rightleftharpoons A_{(g)} + B_{(g)}$$

10g of AB is sealed into an evacuated 1.000L container at 100℃. After equilibrium is reached, the total pressure in the container is 3.50 atm. Given the molar mass of AB is 134.96g/mol, calculate the equilibrium constant K for the decomposition reaction above.



$$10g\,AB \times \frac{1mol}{134.96g} = 7.41 \times 10^{-2} mol$$

$$P = \frac{nRT}{V} = \frac{(7.41 \times 10^{-2} mol)(0.08206)(373K)}{1.000\,L} = 2.27\ atm$$

	AB	$\rightleftharpoons A +$	B
I	2.27	0	0
C	$-x$	$+x$	$+x$
E	$2.27-x$	x	x
E	1.04atm	1.23atm	1.23atm

$$3.50 = (2.27-x) + x + x$$

$$x = 1.23$$

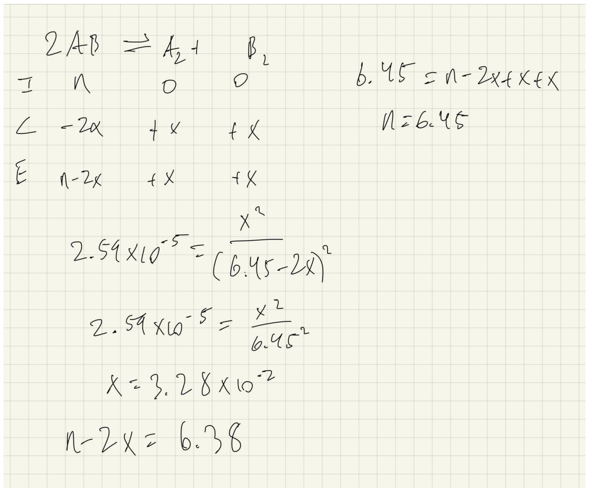
$$K = \frac{(1.23)(1.23)}{1.04} = 1.455$$

Answer: 1.455

3. Consider the following decomposition reaction of an unknown gas AB:

$$2AB_{(g)} \rightleftharpoons A_{2(g)} + B_{2(g)}$$

50g of AB is sealed into a 1.5L evacuated container and heated to 500℃. The equilibrium constant of this reaction at this temperature is 2.59 x 10^{-5}. Find the equilibrium partial pressure of AB to 3 significant figures given the total pressure at equilibrium is 6.45atm.



	$2AB$	$\rightleftharpoons A_2 +$	B_2
I	n	0	0
C	$-2x$	$+x$	$+x$
E	$n-2x$	$+x$	$+x$

$$6.45 = n - 2x + x + x$$

$$n = 6.45$$

$$2.59 \times 10^{-5} = \frac{x^2}{(6.45-2x)^2}$$

$$2.59 \times 10^{-5} = \frac{x^2}{6.45^2}$$

$$x = 3.28 \times 10^{-2}$$

$$n - 2x = 6.38$$

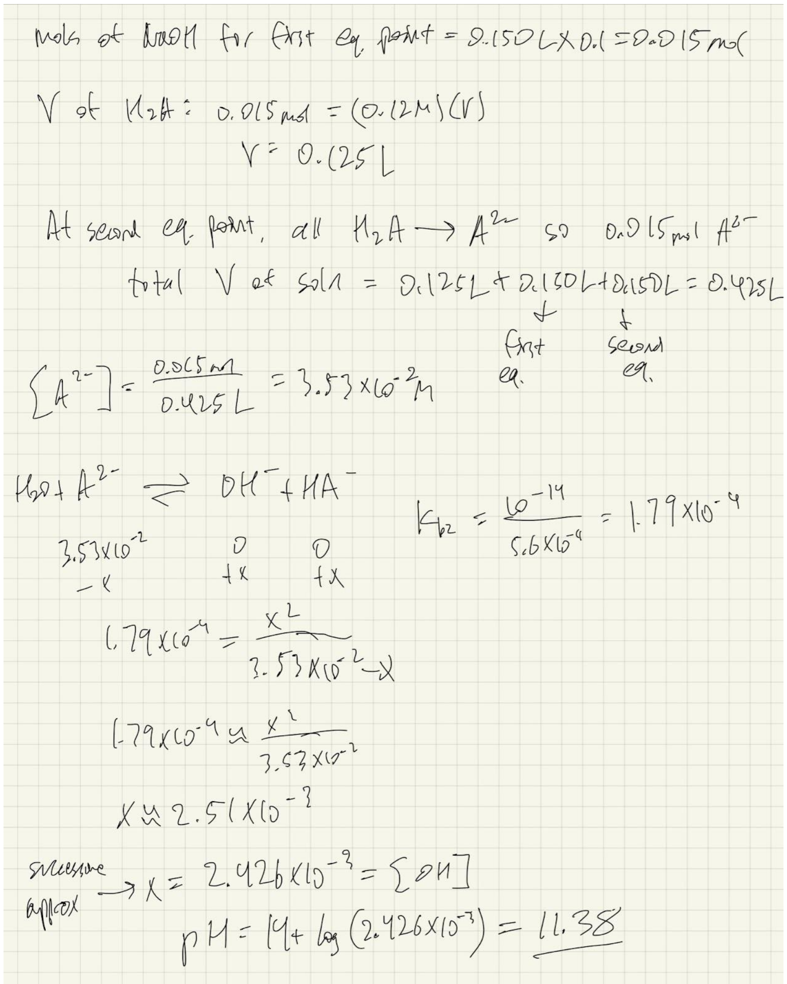
Answer: 6.38

HARD PACKET 10 ANSWER KEY

1. The following is the equations and K_a values of the dissociation of an unknown weak diprotic acid, H_2A:

$$H_2A + H_2O \rightleftharpoons HA^- + H_3O^+ \qquad K_{a1} = 4.3 \times 10^{-7}$$
$$HA- + H_2O \rightleftharpoons A^{2-} + H_3O^+ \qquad K_{a2} = 5.6 \times 10^{-11}$$

A 0.12M solution of H_2A is titrated with 0.1M solution of NaOH. Given that 150mL of the NaOH solution is required to reach the first equivalence point of H_2A, what is the pH of the solution at the second equivalence point?



mols of NaOH for first eq. point $= 0.150L \times 0.1 = 0.015 mol$

V of H_2A: $0.015 mol = (0.12M)(V)$

$V = 0.125 L$

At second eq. point, all $H_2A \longrightarrow A^{2-}$ so $0.015 mol$ A^{2-}

total V of soln $= \underset{\substack{\downarrow \\ \text{first eq.}}}{0.125L} + \underset{\substack{\downarrow \\ \text{second eq.}}}{0.150L} + 0.150L = 0.425L$

$[A^{2-}] = \frac{0.015 m}{0.425 L} = 3.53 \times 10^{-2} M$

$H_2O + A^{2-} \rightleftharpoons OH^- + HA^-$

3.53×10^{-2} $\quad 0 \quad 0$

$-x \quad +x \quad +x$

$K_{b2} = \frac{10^{-14}}{5.6 \times 10^{-4}} = 1.79 \times 10^{-4}$

$1.79 \times 10^{-4} = \frac{x^2}{3.53 \times 10^{-2} - x}$

$1.79 \times 10^{-4} \approx \frac{x^2}{3.53 \times 10^{-2}}$

$x \approx 2.51 \times 10^{-3}$

successive approx $\rightarrow x = 2.426 \times 10^{-3} = [OH]$

$pH = 14 + \log(2.426 \times 10^{-3}) = \underline{11.38}$

2. According to solvent leveling, what is the strongest acid that can exist in water?

H_3O^+

3. According to solvent leveling, what is the strongest base that can exist in water?

OH^-