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| 1                  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    | 18                 |                    |                    |                    |                    |                    |                    |
| 1<br>H<br>1.008    | 2                  |                    |                    |                    |                    |                    |                    |                    |                    |                    | 2<br>He<br>4.003   |                    |                    |                    |                    |                    |                    |
| 3<br>Li<br>6.941   | 4<br>Be<br>9.012   |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    | 5<br>B<br>10.81    | 6<br>C<br>12.01    | 7<br>N<br>14.01    | 8<br>O<br>16.00    | 9<br>F<br>19.00    | 10<br>Ne<br>20.18  |
| 11<br>Na<br>22.99  | 12<br>Mg<br>24.31  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    | 13<br>Al<br>26.98  | 14<br>Si<br>28.09  | 15<br>P<br>30.97   | 16<br>S<br>32.07   | 17<br>Cl<br>35.45  | 18<br>Ar<br>39.95  |
| 19<br>K<br>39.10   | 20<br>Ca<br>40.08  | 21<br>Sc<br>44.96  | 22<br>Ti<br>47.87  | 23<br>V<br>50.94   | 24<br>Cr<br>52.00  | 25<br>Mn<br>54.94  | 26<br>Fe<br>55.85  | 27<br>Co<br>58.93  | 28<br>Ni<br>58.69  | 29<br>Cu<br>63.55  | 30<br>Zn<br>65.38  | 31<br>Ga<br>69.72  | 32<br>Ge<br>72.64  | 33<br>As<br>74.92  | 34<br>Se<br>78.96  | 35<br>Br<br>79.90  | 36<br>Kr<br>83.80  |
| 37<br>Rb<br>85.47  | 38<br>Sr<br>87.62  | 39<br>Y<br>88.91   | 40<br>Zr<br>91.22  | 41<br>Nb<br>92.91  | 42<br>Mo<br>95.94  | 43<br>Tc<br>(98)   | 44<br>Ru<br>101.07 | 45<br>Rh<br>102.91 | 46<br>Pd<br>106.42 | 47<br>Ag<br>107.87 | 48<br>Cd<br>112.41 | 49<br>In<br>114.82 | 50<br>Sn<br>118.71 | 51<br>Sb<br>121.76 | 52<br>Te<br>127.60 | 53<br>I<br>126.90  | 54<br>Xe<br>131.29 |
| 55<br>Cs<br>132.91 | 56<br>Ba<br>137.33 | 57<br>La<br>138.91 | 72<br>Hf<br>178.49 | 73<br>Ta<br>180.95 | 74<br>W<br>183.84  | 75<br>Re<br>186.21 | 76<br>Os<br>190.23 | 77<br>Ir<br>192.22 | 78<br>Pt<br>195.08 | 79<br>Au<br>196.97 | 80<br>Hg<br>200.59 | 81<br>Tl<br>204.38 | 82<br>Pb<br>207.20 | 83<br>Bi<br>208.98 | 84<br>Po<br>(209)  | 85<br>At<br>(210)  | 86<br>Rn<br>(222)  |
| 87<br>Fr<br>(223)  | 88<br>Ra<br>(226)  | 89<br>Ac<br>(227)  | 104<br>Rf<br>(267) | 105<br>Db<br>(268) | 106<br>Sg<br>(269) | 107<br>Bh<br>(270) | 108<br>Hs<br>(270) | 109<br>Mt<br>(278) | 110<br>Ds<br>(281) | 111<br>Rg<br>(282) | 112<br>Cn<br>(285) | 113<br>Nh<br>(286) | 114<br>Fl<br>(289) | 115<br>Mc<br>(290) | 116<br>Lv<br>(293) | 117<br>Ts<br>(294) | 118<br>Og<br>(294) |

|                    |                    |                    |                   |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |
|--------------------|--------------------|--------------------|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| 58<br>Ce<br>140.12 | 59<br>Pr<br>140.91 | 60<br>Nd<br>144.24 | 61<br>Pm<br>(145) | 62<br>Sm<br>150.36 | 63<br>Eu<br>151.96 | 64<br>Gd<br>157.25 | 65<br>Tb<br>158.93 | 66<br>Dy<br>162.50 | 67<br>Ho<br>164.93 | 68<br>Er<br>167.26 | 69<br>Tm<br>168.93 | 70<br>Yb<br>173.04 | 71<br>Lu<br>174.97 |
| 90<br>Th<br>232.04 | 91<br>Pa<br>231.04 | 92<br>U<br>238.03  | 93<br>Np<br>(237) | 94<br>Pu<br>(244)  | 95<br>Am<br>(243)  | 96<br>Cm<br>(247)  | 97<br>Bk<br>(247)  | 98<br>Cf<br>(251)  | 99<br>Es<br>(252)  | 100<br>Fm<br>(257) | 101<br>Md<br>(258) | 102<br>No<br>(259) | 103<br>Lr<br>(266) |

constants

$R = 0.08206 \text{ L atm/mol K}$

$R = 0.08314 \text{ L bar/mol K}$

$R = 62.36 \text{ L Torr/mol K}$

$R = 8.314 \text{ L kPa/mol K}$

$R = 8.314 \text{ J/mol K}$

$N_A = 6.022 \times 10^{23} / \text{mol}$

conversions

$1 \text{ atm} = 760 \text{ torr}$

$1 \text{ atm} = 14.7 \text{ psi}$

$1 \text{ atm} = 101325 \text{ Pa}$

$1 \text{ atm} = 1.01325 \text{ bar}$

$1 \text{ bar} = 10^5 \text{ Pa}$

$^{\circ}\text{F} = ^{\circ}\text{C}(1.8) + 32$

$\text{K} = ^{\circ}\text{C} + 273.15$

conversions

$1 \text{ in} = 2.54 \text{ cm}$

$1 \text{ ft} = 12 \text{ in}$

$1 \text{ yd} = 3 \text{ ft}$

$1 \text{ mi} = 5280 \text{ ft}$

$1 \text{ lb} = 453.6 \text{ g}$

$1 \text{ ton} = 2000 \text{ lbs}$

$1 \text{ tonne} = 1000 \text{ kg}$

$1 \text{ gal} = 3.785 \text{ L}$

$1 \text{ gal} = 231 \text{ in}^3$

$1 \text{ gal} = 128 \text{ fl oz}$

$1 \text{ fl oz} = 29.57 \text{ mL}$

$1 \text{ Troy oz} = 31.104 \text{ g}$

water data

$C_{s,\text{ice}} = 2.09 \text{ J/g } ^{\circ}\text{C}$

$C_{s,\text{water}} = 4.184 \text{ J/g } ^{\circ}\text{C}$

$C_{s,\text{steam}} = 2.03 \text{ J/g } ^{\circ}\text{C}$

$\rho_{\text{water}} = 1.00 \text{ g/mL}$

$\rho_{\text{ice}} = 0.9167 \text{ g/mL}$

$\rho_{\text{seawater}} = 1.024 \text{ g/mL}$

$\Delta H_{\text{fus}} = 334 \text{ J/g}$

$\Delta H_{\text{vap}} = 2260 \text{ J/g}$

$k_f = 1.86 \text{ } ^{\circ}\text{C}/m$

$k_b = 0.512 \text{ } ^{\circ}\text{C}/m$

$K_w = 1.0 \times 10^{-14}$

This exam should have exactly 25 questions. Each question is equally weighted at 4 points each. You will enter your answer choices on the virtual bubbleseet after you have finished. Your score is based on what you submit on the virtual bubblesheet and not what is circled on the exam.

1. What is the conjugate base of trichloroacetic acid ( $\text{Cl}_3\text{CO}_2\text{H}$ )?

- a.  $\text{Cl}_3\text{CO}_2\text{H}_2^+$
- b.  $\text{Cl}_3\text{CO}_2^+$
- c. It is not possible to say.
- d.  $\text{Cl}_3\text{CO}_2^-$
- e.  $\text{Cl}_3\text{CO}_2\text{H}_2^-$

**Explanation:** remove one  $\text{H}^+$  to get  $\text{Cl}_3\text{CO}_2^-$

2. You have a solution where you know that the  $[\text{H}^+]$  is exactly 3.5 times that of  $[\text{OH}^-]$ . What is the pH of the solution?

- a. 6.73
- b. 7.27
- c. 8.65
- d. 2.23
- e. 5.32

**Explanation:**  $[\text{H}^+][\text{OH}^-] = K_w$ ,  $(3.5x)(x) = K_w$ ,  $x = \sqrt{K_w/3.5} = 5.35 \times 10^{-8}$ .  $[\text{H}^+] = 3.5x = 3.5(5.35 \times 10^{-8}) = 1.87 \times 10^{-7}$  M. Take  $-\log$  and get  $\text{pH} = 6.73$ .

3. You go into the lab and mix up 100 mL of a buffer which is 0.15 M in HA and 0.10 M in  $\text{A}^-$ . You then add 150 mL of 0.1 M NaOH. What is the new pH? Assume that  $K_a$  for HA =  $6.4 \times 10^{-5}$ .

- a. 6.91
- b. 8.60
- c. 2.34
- d. 4.19
- e. 11.88
- f. 5.40

**Explanation:** Initial amounts are 15 mmol HA and 10 mmol  $\text{A}^-$ . You add 15 mmol  $\text{OH}^-$ . This completely converts all of the HA to  $\text{A}^-$ . So you now have 25 mmol of  $\text{A}^-$  in 250 mL of solution which means you have 0.10 M  $\text{A}^-$  (it's all weak base).  $K_b = K_w/K_a = 10^{-14}/6.4 \times 10^{-5} = 1.56 \times 10^{-10}$ . Now use  $[\text{OH}^-] = \sqrt{K_b(C_A)} = 3.95 \times 10^{-6}$ .  $\text{pOH} = 5.40$  and  $\text{pH} = 8.60$

4. A solution of RbOH has a pH of 9.87. What is the concentration of RbOH?

- a.  $8.1 \times 10^{-2}$  M
- b.  $7.4 \times 10^{-5}$  M
- c.  $1.4 \times 10^{-10}$  M
- d.  $3.3 \times 10^{-3}$  M
- e.  $6.1 \times 10^{-4}$  M

**Explanation:**  $\text{pOH} = 14 - 9.87 = 4.13$ .  $[\text{OH}^-] = 10^{-4.13} = 7.4 \times 10^{-5}$  M

5. We learned in our study of equilibrium that the value of  $K$  will change with temperature.  $K_w$  is  $1.0 \times 10^{-14}$  at  $25^\circ\text{C}$ . As water gets warmer and warmer the value of  $K_w$  increases. How does this affect what we call neutral pH which is normally 7.0 ?

- a. will cause it to rise a bit,  $\text{pH} > 7$
- b. will cause it to drop a bit,  $\text{pH} < 7$
- c. will not affect it, it remains  $\text{pH} 7$

**Explanation:** Definition of neutral pH is when  $[\text{H}^+] = [\text{OH}^-]$  and means that the concentration of each of those is  $\sqrt{K_w}$ . If  $K_w$  increases (say  $2.5 \times 10^{-14}$  for example), then so does  $\sqrt{K_w}$ , which for this example would be  $1.58 \times 10^{-7}$  M which will be a neutral pH of 6.80 (less than 7).

6. Which of the following is not a strong acid?

- a. hydrobromic acid
- b. nitrous acid
- c. hydroiodic acid
- d. chloric acid
- e. sulfuric acid

**Explanation:** Nitrous acid is NOT on the strong acid list, the others are.

7. (Part 1 of 2) You decide to titrate a solution of  $\text{NaH}_2\text{PO}_4$ . You add just enough  $\text{NaOH}$  to achieve an equal ratio of  $\text{NaH}_2\text{PO}_4$  and  $\text{Na}_2\text{HPO}_4$ . What is the pH of this solution? (for  $\text{H}_3\text{PO}_4$ ,  $\text{p}K_{a1} = 2.12$ ,  $\text{p}K_{a2} = 7.21$ ,  $\text{p}K_{a3} = 12.32$ )

- a. 12.32
- b. 9.77
- c. 2.12
- d. 7.21
- e. 4.67

**Explanation:** Anytime you have equal amounts (a 1-to-1 ratio) of conjugates, your pH will equal pKa. The pKa for this pair is  $\text{p}K_{a2}$  which is 7.21.

8. (Part 2 of 2) You decide to repeat the experiment from the previous question, but this time you add just enough  $\text{NaOH}$  to neutralize all of the  $\text{NaH}_2\text{PO}_4$ , leaving you with only  $\text{Na}_2\text{HPO}_4$ . What is the pH of this solution?

- a. 7.21
- b. 12.32
- c. 4.67
- d. 9.77
- e. 2.12

**Explanation:** When you neutralize all of the diprotic, you have a solution of only monoprotic acid ( $\text{HPO}_4^{2-}$ ). This is in between  $\text{p}K_{a2}$  and  $\text{p}K_{a3}$ , so you average them.  $(7.21+12.32)/2 = 9.77$ .

9. According to the Lewis Theory of acids and bases, an acid is:

- a. A proton acceptor.
- b. An electron donor.
- c. An electron acceptor.
- d. A proton donor.
- e. A substance which when dissolved in water yields hydroxide ions.

**Explanation:** Lewis theory deals with e- pair donating and accepting.

10. What is the pH of 0.0045 M  $\text{HClO}_4$ ?

- a. 2.35
- b. 11.65
- c. 3.73
- d. 1.35
- e. 8.93

**Explanation:** strong acid.  $-\log(0.0045)$  and get  $\text{pH} = 2.35$

11. Consider these four acids for this question. Each are listed by name and their corresponding  $K_a$  values:

benzoic acid  $6.4 \times 10^{-5}$     hydrazoic acid  $2.5 \times 10^{-5}$   
 formic acid  $1.8 \times 10^{-4}$     chlorous acid  $1.2 \times 10^{-2}$

Now you mix up equimolar solutions of each acid. Which acid solution has the highest pH?

- a. benzoic acid
- b. It is not possible to say.
- c. formic acid
- d. chlorous acid
- e. hydrazoic acid

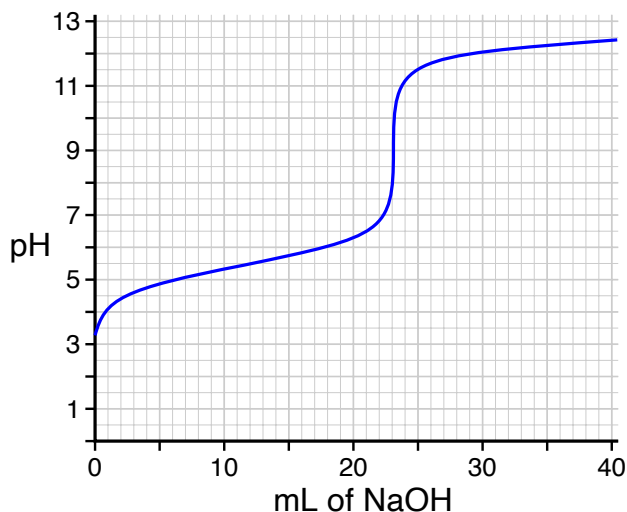
**Explanation:** The highest pH will be from the weakest acid in the group. The weakest acid will be the one with the smallest value of  $K_a$  which is hydrazoic acid.

12. Consider the triprotic acid  $H_3A$ . It possesses  $pK_{a1} = 2.30$ ,  $pK_{a2} = 7.03$ ,  $pK_{a3} = 11.52$ . What is the main species present in a solution with  $pH = 5.6$ ?

- a.  $H_3A$
- b.  $HA^{2-}$
- c.  $A^{3-}$
- d.  $HA^{3-}$
- e.  $H_2A^-$

**Explanation:** For any weak acid, if the pH is below the  $pK_a$  of the acid by more than 1 unit, then the major species is the protonated acid. On the other hand, if you the pH is above the  $pK_a$  by more than 1 pH unit the major species is the deprotonated acid. Thus, at a pH of 5.6, the protons associated with  $pK_a = 7.03$  and  $11.52$  are still present, where as the proton associated with  $pK_a = 2.30$  is deprotonated. Overall, this is  $H_2A^-$ .

13. (Part 1 of 4) 50 mL of an unknown monoprotic acid solution is titrated with 0.026 M NaOH. The titration curve for this is shown below. What is the pH at the equivalence point of this titration?



- a. 10.0
- b. 8.1
- c. 6.5
- d. 11.2
- e. 9.1

**Explanation:** The endpoint volume is easily seen at 23 mL. The center of the vertical rise is at 9.1 (this is the best number of those listed).

14. (Part 2 of 4) Again using the titration curve, what is the  $K_a$  of the unknown weak acid?

- a.  $1.8 \times 10^{-6}$
- b.  $1.1 \times 10^{-5}$
- c.  $8.8 \times 10^{-7}$
- d.  $6.3 \times 10^{-6}$
- e.  $3.2 \times 10^{-6}$

**Explanation:** Go to half titration volume (11.5 mL) and read the pH there of 5.5. Now convert to  $K_a$  via  $10^{-5.5} = 3.2 \times 10^{-6}$ .

15. (Part 3 of 4) Again using the titration curve, determine the concentration of the starting acid solution.

- a. 0.024 M
- b. 0.057 M
- c. 0.012 M
- d. 0.015 M
- e. 0.0082 M

**Explanation:**  $23\text{mL}(0.026\text{M}) = 0.598 \text{ mmol OH}^-$ . acid conc =  $0.598/50 \text{ mL} = 0.012 \text{ M}$

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16. (Part 4 of 4) Finally, referring to the titration curve, which indicator would be best for this titration?

- a. propyl red (red to yellow, pH 4.8-6.6)
- b. bromocresol purple (yellow to purple pH 5.2-6.8)
- c. phenol red (yellow to red, pH 6.6-8.0)
- d. methyl orange (red to yellow, pH 3.2-4.4)
- e. phenolphthalein (colorless to pink, pH 8.2-10.0)
- f. alizarin yellow (yellow to red, pH 10.1-12.0)

**Explanation:** the phenolphthalein is the only one with the 9.1 equivalence point pH in the transition of its color range.

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17. (Part 1 of 2) How much 0.28 M HCl solution is needed to neutralize 1400 mL of 0.035 NaOH?

- a. 125 mL
- b. 300 mL
- c. 225 mL
- d. 1750 mL
- e. 175 mL
- f. 1400 mL

**Explanation:**  $M_A V_A = M_B V_B$  solve for  $V_A$ .  
 $V_A = 0.035(1400)/0.28 = 175 \text{ mL}$

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18. (Part 2 of 2) Referring to the previous question, which best describes the pH at the equivalence point of the titration?

- a. It is not possible to say.
- b. 9.5
- c. 6.3
- d. 8.1
- e. 7.0
- f. 5.4

**Explanation:** The equivalence point of any strong acid with strong base is a water solution of a neutral salt (no acid or base is present) and therefore perfectly neutral at pH of 7.

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19. A 0.025 M solution of a weak base has a measured pH of 11.65. What is the percent ionization of this base?.

- a. 18%
- b. 12%
- c. 15%
- d. 1.2%
- e. 7.5%

**Explanation:** pOH is  $14 - 11.65 = 2.35$  which corresponds to a  $\text{OH}^-$  conc of 0.0045 M.  
 $0.0045/0.025 \times 100\% = 18\%$

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20. You mix up a 0.01 M weak acid solution. Which of the following is a reasonable guess for the pH of the solution?

- a. 7.0
- b. 12.0
- c. 5.4
- d. 2.0
- e. 8.8

**Explanation:** A weak acid will be acidic and therefore a pH less than 7. However, a pH of 2 would mean the acid is strong... therefore, only 5.4 is a logical choice for the pH of this weak acid.

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21. (Part 1 of 2) Hexahydroxybenzene ( $C_6H_6O_6$ ) is a hexaprotic acid whose salts have been considered for use as a battery electrolyte. If we represent the acid in a general way ( $H_6A$ ), what is the conjugate acid of  $H_3A^{3-}$ ?

- a.  $H_2A^{2-}$
- b.  $H_4A^{4-}$
- c.  $H_2A^{4-}$
- d.  $H_4A^{2-}$
- e.  $H_3A^{2-}$

**Explanation:** ADD one  $H^+$  to get  $H_4A^{-2}$

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22. (Part 2 of 2) Referring to the last question, which  $K_a$  relates to the previously mentioned conjugate pair?

- a.  $K_{a5}$
- b.  $K_{a4}$
- c.  $K_{a2}$
- d.  $K_{a3}$
- e.  $K_{a1}$
- f.  $K_{a6}$

**Explanation:** The pairing of  $H_4A^{-2}$  and  $H_3A^{-3}$  corresponds to the removal of the 3rd proton in the sequence and means that  $K_{a3}$  is what relates them.

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23. What is the pH of 0.0033 M  $Ba(OH)_2$ ?

- a. 11.96
- b. 2.48
- c. 11.82
- d. 11.52
- e. 2.18
- f. 8.70

**Explanation:** This is a double base - two  $OH^-$ 's, so first double the concentration to get 0.0066 M  $[OH^-]$ . Now take  $-\log$  to get  $pOH = 2.18$ , subtract from 14 to get  $pH = 11.82$

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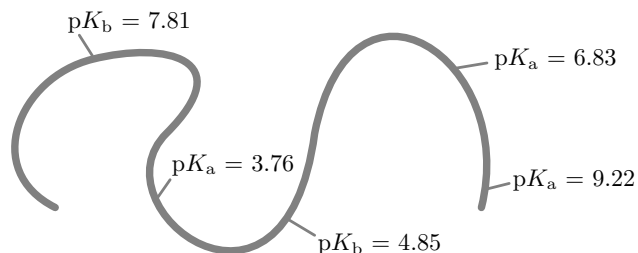
24. Acrylic acid is a feedstock which forms the basis for a number of useful products such as paints, absorbents, and glues. What is the pH of a 0.067 M acrylic acid solution? (For acrylic acid,  $K_a = 5.6 \times 10^{-5}$ )

- a. 3.55
- b. 1.17
- c. 8.42
- d. 2.71
- e. 9.81

**Explanation:** Use the assumption shortcut:  $[H^+] = \sqrt{K_a(\text{conc})} = 1.94 \times 10^{-3}$  M which gives a pH of 2.71.

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25. Consider the following protein chain with five acid/base residues labeled with their corresponding  $pK_a$  or  $pK_b$ .



What is the overall charge on the this protein chain at a physiological pH of 7.4?

- a. 0
- b. +2
- c. -1
- d. -2
- e. +1

**Explanation:** The two acid residues at 3.76 and 6.83 would both be deprotonated and have  $-1$  charges. The acid at 9.22 would still be protonated and be neutral (0). You have to convert the  $pK_b$ 's to  $pK_a$ 's... you get 6.19 for one and it is not protonated and is still neutral at 0. The other is 9.15 and would be protonated at  $+1$ . Summing up you have

$$0 - 1 - 1 + 0 + 1 = -1 \text{ overall}$$

After you are finished and have all your answers circled, go to the front of the room and then use the QR code show below to pull up the virtual answer page for your exam. Enter the appropriate info plus all your answers - click the SUBMIT button. Double check your choices on the next page. Once your are sure, click the submit button on that page to enter your answers. Make sure you get the confirmation screen (different background color!) and show it to the TA or proctor. After that, turn in your exam and scratch paper. You're free to leave after that.



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