Water and pH

Water

سائد

- Water is the predominant chemical component of living organisms.
- Its unique physical properties include:
  - The ability to solvate a wide range of organic and inorganic molecules by its exceptional capacity for forming hydrogen bonds.
  - An excellent nucleophile, water is a reactant or product in many metabolic reactions.
  - Water has a slight propensity to dissociate into hydroxide ions and protons.

ميل OH^-

H^+

physiology

- Normal blood pH ranges from 7.35-7.45
  - Acidosis (blood pH < 7.35) include diabetic ketosis and lactic acidosis.
  - Alkalosis (pH > 7.45) may, for example, follow vomiting of acidic gastric contents.

ممكن مشكلة

1- metabolism
2- respiratory

Water Is an Ideal Biologic Solvent

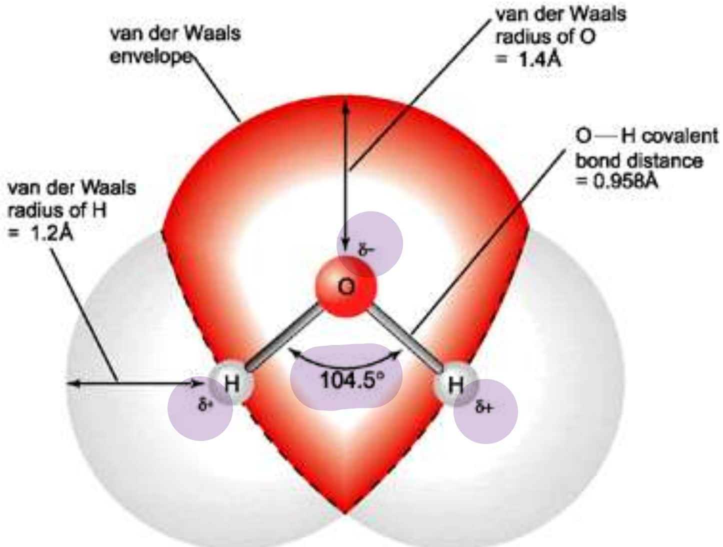
Water Molecules Form Dipoles

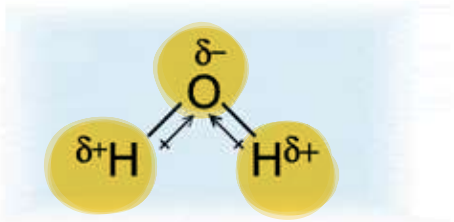
- A water molecule is an irregular, slightly skewed tetrahedron with oxygen at its center.

  ماكل

- Water is a **dipole,** a molecule with electrical charge distributed asymmetrically about its structure.

- The strongly electronegative oxygen atom pulls electrons away from the hydrogen nuclei, leaving them with a partial positive charge, while its two unshared electron pairs constitute a region of local negative charge.





Water Is an Ideal Biologic Solvent

The **dielectric constant** tells us how well a substance reduces electrical attraction between charges.

$\overset{+\delta}{H} \rightarrow \overset{-\delta}{O} \leftarrow \overset{+\delta}{H}$

- Water, a strong dipole, has a $\boxed{\text{high}}$ **dielectric constant**. As described quantitatively by Coulomb's law, the strength of interaction between oppositely charged particles is inversely proportionate to the dielectric constant of the surrounding medium.

$F \propto \frac{1}{\varepsilon\,(\text{dielectric constant})}$

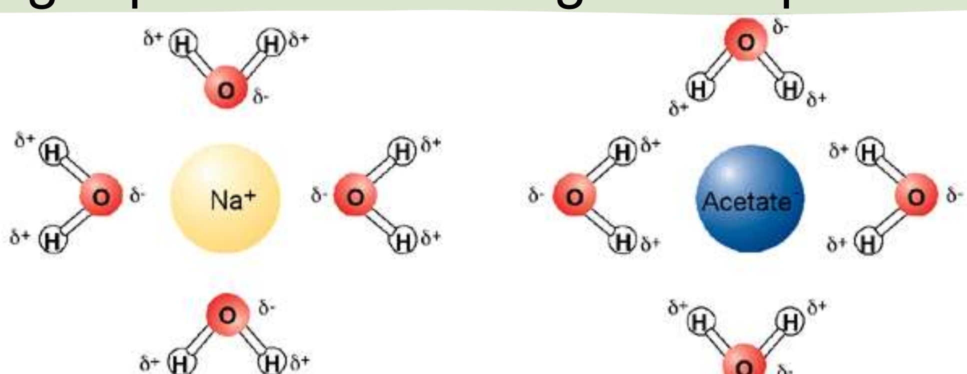
vacuum dielectric constant = 1

water dielectric constant = 78.5

- The dielectric constant for a vacuum is unity; and for water it is 78.5. Water therefore greatly decreases the force of attraction between charged and polar species relative to water-free environments with lower dielectric constants.

- Its ① strong dipole and ② high dielectric constant enable water to dissolve large quantities of charged compounds such as salts

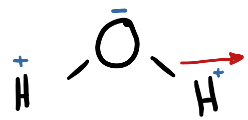
NaCl



easy explanation

https://youtu.be/RSRiywp9v9w?si=Qgjck1AzthWKkf2b

Water Molecules Form Hydrogen Bonds



covalent bond

- A hydrogen nucleus covalently bound to an electron-withdrawing oxygen or nitrogen atom can interact with an unshared electron pair on another oxygen or nitrogen atom to form a **hydrogen bond** .

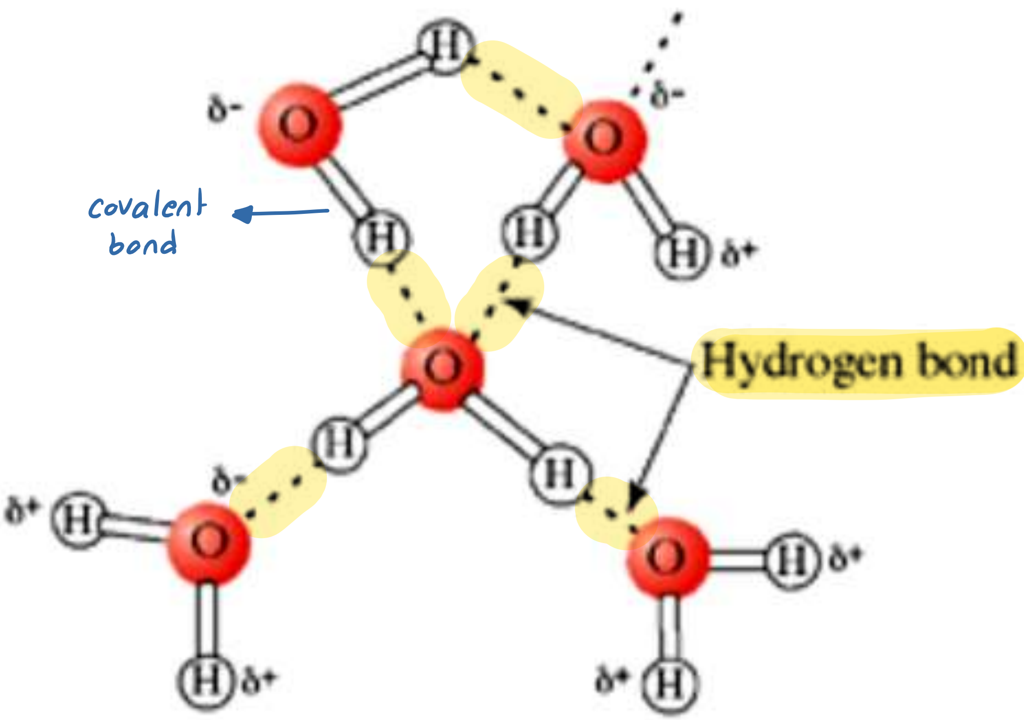
- Hydrogen bonding favors the self-association of water molecules into ordered arrays.

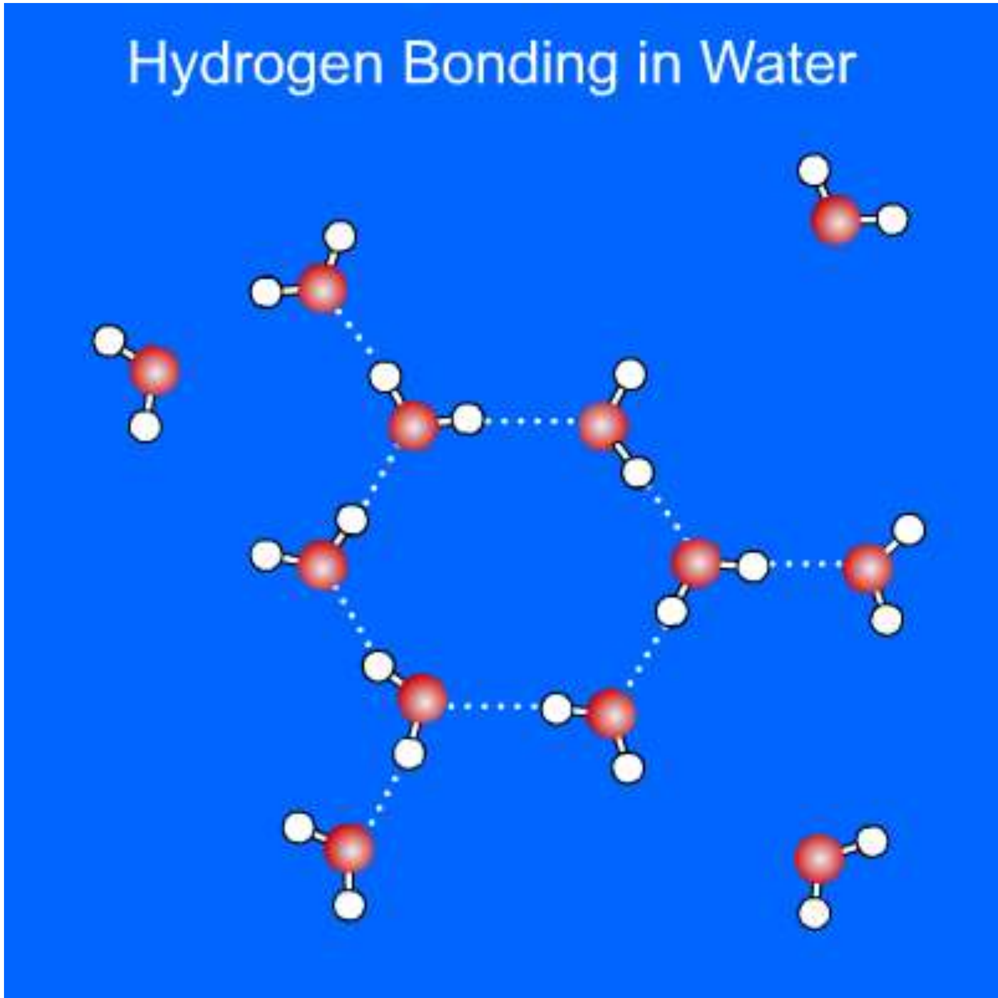
- Hydrogen bonding influences the physical properties of water and accounts for its exceptionally high viscosity, surface tension, and boiling point.

↑ viscosity
surface tension
boiling point

- These bonds are both relatively weak and transient, with a half-life of about one microsecond. Rupture of a hydrogen bond in liquid water requires only about 4.5 kcal/mol, less than 5% of the energy required to rupture a covalent O-H bond.

فصل


covalent bond
Hydrogen bond
O
H
δ-
δ+


Hydrogen Bonding in Water

Describe the role of hydrogen bonding in determining water's physical properties.

A. Hydrogen bonding enhances water's thermal conductivity, density, and viscosity.

B. Hydrogen bonding leads to water's low surface tension and freezing point.

C. Hydrogen bonding causes water's high viscosity, surface tension, and boiling point. ✓

D. Hydrogen bonding reduces water's density, viscosity, and boiling point.

electron rich

Water Is an Excellent Nucleophile

electron dificient

سنوات

- Metabolic reactions often involve the attack by lone pairs of electrons on electron-rich molecules termed **nucleophiles** on electron-poor atoms called **electrophiles** .Nucleophiles and electrophiles do not necessarily possess a formal negative or positive charge.
- Water, whose two lone pairs of electrons bear a partial negative charge, is an excellent nucleophile.

احفظوا الأمثلة مهم

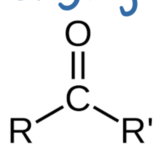
- Other nucleophiles of biologic importance include the oxygen atoms of phosphates, alcohols, and carboxylic acids; the sulfur of thiols; the nitrogen of amines; and the imidazole ring of histidine.

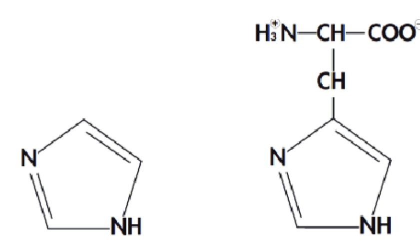
electron pool

سنوات

- Common electrophiles include the carbonyl carbons in amides, esters, aldehydes, and ketones and the phosphorus atoms of phosphoesters.

- carbonyl group in 8 amide
aldehydes
Ketones





Imidazole Histidine

Which of the following atoms commonly acts as an electrophile in biochemical reactions?

A. Nitrogen in amines

B. Carbonyl carbon in aldehydes

C. Oxygen in alcohols

D. Hydrogen in alkanes

Common electrophiles include amine groups and amide nitrogen atoms.

Answer: False.

Explain why water acts as an excellent nucleophile in biochemical reactions.

A. Water's hydrogen atoms can form strong ionic bonds, limiting nucleophilic ability.

B. Water's lone electron pairs bear partial negative charge, enabling nucleophilic attack.

C. Water's high polarity allows it to stabilize charged intermediates during reactions.

D. Water's molecular structure prevents it from acting as a nucleophile in reactions.

B

https://youtu.be/ZMTeqZLXBSo?si=Ai1vgI3nCprEDeNb

- Nucleophilic attack by water generally results in the cleavage of the amide, glycoside, or ester bonds that hold biopolymers together. This process is termed **hydrolysis** .

water break

- Conversely, when monomer units are joined together to form biopolymers such as proteins or glycogen, water is a product

19. Water as a reactant
Page: 69–70 Difficulty: 3 Ans: E
In which reaction below does water *not* participate as a reactant (rather than as a product)?

A) Conversion of an acid anhydride to two acids.
B) Conversion of an ester to an acid and an alcohol.
C) Conversion of ATP to ADP.
D) Photosynthesis
E) Production of gaseous carbon dioxide from bicarbonate.

جاهز ترجع توجيهي؟

Water Molecules Exhibit a Slight But Important Tendency to Dissociate

- The ability of water to ionize, is of central importance for life.
- Water can act both as an acid and as a base, its ionization may be represented as an intermolecular proton transfer that forms a hydronium ion (H_3O^+)and a hydroxide ion (OH^-)

تأين ذاتي للماء

$$H_2O + H_2O \longrightarrow H_3O^+ + OH^-$$

- The transferred proton is actually associated with a cluster of water molecules. Protons exist in solution not only as H_3O^+ but also as multimers such as $H_5O_2^+$ and $H_7O_3^+$
- Since hydronium and hydroxide ions continuously recombine to form water molecules, an *individual* hydrogen or oxygen cannot be stated to be present as an ion or as part of a water molecule. At one instant it is an ion; an instant later it is part of a molecule.

البروتون لا يوجد منفرد في الماء

Water Molecules Exhibit a Slight But Important Tendency to Dissociate

- Hydrogen ions and hydroxide ions contribute significantly to the properties of water.

- For dissociation of water

$$Kw = [H_3O^+]\,[OH^-] \quad = 10^{-14}$$

10^{-7} 10^{-7}

- where brackets indicates the molar conc. of ions, Kw is the dissociation constant of water and = 1×10^{-14} so

$$-\log Kw = -\log [H_3O^+] + -\log [OH^-]$$

$$14 = pH + pOH$$

- **pH Is the Negative Log of the Hydrogen Ion Concentration**

$$\mathbf{pH = -log}\ [H_3O^+]$$

Example: If the concentration of H_3O^+ in solution is 1×10^{-7} calculate pH

$pH = -\log [H_3O^+]$

$= -\log (1 \times 10^{-7}) = 7$

7. Ionization of water, weak acids, and weak bases
Page: 61 Difficulty: 2 Ans: A
The pH of a solution of 1 M HCl is:

A) 0
B) 0.1
C) 1
D) 10
E) –1

Saja Al-najjar All-star contributor

كان في سؤال انه اذا تركيز ال HCl =1M احسب ال ph

pKa

low pKa → stronger acid
high pKa → weaker acid

$= -\log Ka$

- Many biochemicals possess functional groups that are weak acids or bases.

- Carboxyl groups, amino groups, and phosphate esters, whose second dissociation falls within the physiologic range, are present in proteins and nucleic acids, most coenzymes, and most intermediary metabolites.

وسيط

- pKa is important for understanding the influence of intracellular pH on structure and biologic activity.

1 هجرة كهربائية 2 technique

- Charge-based separations such as electrophoresis and ion exchange chromatography also are best understood in terms of the dissociation behavior of functional groups.

- We term the protonated species (eg, HA or R-NH_3^+) the **acid** and the unprotonated species (eg, A^- or R-NH_2) its **conjugate base.**

HA حمض
A^- قاعدة المرافقة

The Henderson-Hasselbalch Equation Describes the Behavior of Weak Acids

- For a weak acid:

$$HA \rightleftharpoons H^+ + A^-$$

$$pH = pKa + \log \frac{[base]}{[acid]}$$

general formula

[conjugate base]

$$\log \frac{\text{Ionized concentration}}{\text{Unionized concentration}} = pH - pK_a$$

[weak acid]

- For a weak base:

[base]

$$\log \frac{\text{Unionized concentration}}{\text{Ionized concentration}} = pH - pK_a$$

[conjugate acid]

$$\log \frac{\text{Unionized concentration}}{\text{Ionized concentration}} = pH - pK_a$$

Pages: 66-67 Difficulty: 2 Ans: E

The Henderson-Hasselbalch equation:

A) allows the graphic determination of the molecular weight of a weak acid from its pH alone.
B) does not explain the behavior of di- or tri-basic weak acids
C) employs the same value for pK_a for all weak acids.
D) is equally useful with solutions of acetic acid and of hydrochloric acid.
E) relates the pH of a solution to the pK_a and the concentrations of acid and conjugate base.

خصائص المتوسط

Values of the pKa depend Properties of the Medium

- The medium may either raise or lower the p*K*a depending on whether the undissociated acid or its conjugate base is the charged species.

The **dielectric constant** tells us **how well a substance reduces electrical attraction between charges.**

- The effect of dielectric constant on p*K*a may be observed by adding ethanol to water.

- The p*K*a of a carboxylic acid *increases*, *w*hereas that of an amine *decreases* because ethanol decreases the ability of water to solvate a charged species.

- The p*K*a values of dissociating groups in the interiors of proteins thus are profoundly affected by their local environment, including the presence or absence of water.

Question

- Calculate the pH of 0.1 M solution of acetic acid, pKa = 4.76, calculate the percentage of ionized and unionized forms.

CH_3COOH

$CH_3COOH \rightleftharpoons CH_3COO^- + H_3O^+$

- Calculate the percetage of ionized and unionized for histidine in hemoglobin at physiological pH knowing that pKa for the side chain of histidine is 6.0. If the pH of blood decreased to 7.1, calculate the percent ionized.

Basic Amino Acid

طبيعي عادي

7.35 - 7.45

Average 7.40

acidosis

all amino acids in human body found in ionized Form Except histadine

مثال من الدكتورة 8

glutamic acid PKa = 4.3

PH blood = 7.4

Aspirin PKa = 3.5

conjugate base glutamate

$7.4 - 4.3 = \log \frac{base}{acid}$

$3.1 = \log \frac{base}{acid}$

ionized

$\frac{[base]}{[acid]} = \frac{1258.93}{1}$ ratio

ionized % = $\frac{[\ \ ]}{total} \times 100\%$

$= \boxed{99.85\%} = \frac{1258.93}{1259.93} \times 100\%$

Q18

PH = ?!

[conjugate base]

$$\log \frac{\text{Ionized concentration}}{\text{Unionized concentration}} = pH - pK_a$$

[weak acid]

PH = - log H_3

PKa = 4.76

$HA \rightleftharpoons A^- + H_3O^+$

$CH_3COOH \rightleftharpoons CH_3COO^- + H_3O^+$

0.1 x x

Acetic acid

$$\log \frac{[A^-]}{[HA]} = -\log X - 4.76$$

$$\log \frac{X}{10^{-1}} = -\log X - 4.76$$

$$\boxed{\begin{array}{l} \log_{10} X - \cancel{\log_{10} 10^{-1}} \\ \log X - -1 \\ \log X + 1 \end{array}}$$

$$\log X + 1 = -\log X - 4.76$$

$$2 \log X = -5.76$$

$$-\log X = 2.88$$

PH = 2.88 #

$$\log \frac{[A^-]}{[HA]} = PH - PKa$$

$$\log \frac{[A^-]}{[HA]} = 2.88 - 4.76 = -1.88$$

$$\frac{[A^-]}{[HA]} = \frac{0.0132}{1}$$

total = 1.0132

$$\text{ionized} = \frac{0.0132}{1.0132} \times 100\% = 1.3\%$$

unionized = 98.7 %

Q3:

$pKa = 6$

histade

طبيعة قاعدية

$pH = 7.40$

$$\log \frac{\text{Unionized concentration}}{\text{Ionized concentration}} = \text{pH} - \text{p}K_a$$

$$\log \frac{[B]}{[BH^+]} = 7.40 - 6$$

$$\log \frac{[B]}{[BH^+]} = 1.40$$

calculater

$$\frac{[B]}{[BH^+]} = \frac{25.12}{1}$$

ratio 25.12 : 1

total = 26.12

$$\text{ionized \%} = \frac{1}{26.12} \times 100\%$$

$= 3.83\%$

$\text{unionized} = 100 - 3.83$

$= 96.17\%$

#

$pH = 7.1$ Acidosis

$pKa = 6$

$$\log \frac{[B]}{[BH^+]} = 7.1 - 6 = 1.1$$

$$\frac{[B]}{[BH^+]} = \frac{12.59}{1}$$

total = 13.59

$$\text{ionized \%} = \frac{1}{13.59} \times 100\%$$

$= 7.36\%$

unionized = 92.64%

سنوات

Q.2 Calculate the %ionized of the acidic drug $\boxed{\text{aspirin}}$ (pKa=3.5) in the intestine where pH=6.8?

$$pH - pKa = \log \frac{\text{ionized}}{\text{unionized}}$$

$$\underset{3.3}{6.8 - 3.5} = \log \frac{\text{ionized}}{\text{unionized}}$$

$$\frac{\text{ionized}}{\text{unionized}} = \text{Anti } \log 3.3 = \frac{1995.3}{1} \qquad \text{total} = 1996.3$$

$$\text{ionized } \% = \frac{1995.3}{1996.3} \times 100\ \% = 99.95\ \%$$

union/ion = 15.6

فكم ال union% بتطلع 6%

$$\frac{\text{ionized}}{\text{unionized}} = \frac{15.6}{1} \qquad \text{total} = 16.6$$

$$\text{unionized} = \frac{1}{16.6} \times 100\,\%$$

$$= 6\,\%$$

سنوات

اذا كانت قيمة ال ph=7.8 وال pka=6

احسب ال unionized%

basic

لما تكون حامظية histadine

base/acid ?

$$pH - pKa = \log \frac{\text{unionized}}{\text{ionized}}$$

$$\frac{7.8 - 6}{1.8} = \log \frac{[B]}{[BH^+]}$$

$$\frac{[B]}{[BH^+]} = \frac{63.1}{1} \qquad \text{total} = 64.1$$

$$\text{unionized} = \frac{63.1}{64.1} \times 100\%$$

$$= \underline{98.44\%}$$

تثقّ انه حلك صح لأنه histadine

نسبته الأكبر unionized

سؤال حسابات على قانون ال hasalbalch equation
أعطت كل القيم وطلبت ال Pk

Draw the titration curve for a weak acid, HA, whose pK_a is 3.2. Label the axes properly. Indicate with an arrow where on the curve the ratio of salt (A^-) to acid (HA) is 3:1. What is the pH at this point?

$$pH = pK_a + \log\frac{[\text{conjugate base}]}{[\text{acid}]} = 3.2 + \log 3 = 3.2 + 0.48 = 3.68$$

30. Buffering against pH changes in biological systems
Pages: 66–67 Difficulty: 2
What is the pH of a solution containing 0.2 M acetic acid ($pK_a = 4.7$) and 0.1 M sodium acetate?

Ans:

$$pH = pK_a + \log \frac{[\text{conjugate base}]}{[\text{acid}]} = 4.7 + \log (0.1/0.2)$$

$$= 4.7 - 0.3 = 4.4$$

31. Buffering against pH changes in biological systems
Pages: 66–67 Difficulty: 2
You have just made a solution by combining 50 mL of a 0.1 M sodium acetate solution with 150 mL of 1 M acetic acid ($pK_a = 4.7$). What is the pH of the resulting solution?

Ans:

$$pH = pK_a + \log \frac{[\text{conjugate base}]}{[\text{acid}]} = 4.7 + \log (5/150)$$

$$= 4.7 - 1.48 = 3.22$$

32. Buffering against pH changes in biological systems
Pages: 66–67 Difficulty: 2
For a weak acid with a pK_a of 6.0, show how you would calculate the ratio of acid to salt at pH 5.

Ans:

$$pH = pK_a + \log \frac{[\text{conjugate base}]}{[\text{acid}]}, \text{ so } pK_a - pH = -\log \frac{[\text{conjugate base}]}{[\text{acid}]}$$
$$= \log \frac{[\text{acid}]}{[\text{conjugate base}]}$$

$$6.0 - 5.0 = \log \frac{[\text{acid}]}{[\text{conjugate base}]}; \quad \frac{[\text{acid}]}{[\text{conjugate base}]} = \text{antilog } 1 = 10$$