The partial Lewis structure of lactic acid, the molecule that forms in muscle during exercise, is shown below. Complete the Lewis structure of lactic acid by drawing the non-bonded electron pairs around the relevant atoms.

![Lactic Acid Lewis Structure](image)

Complete the following table.

<table>
<thead>
<tr>
<th>Atom</th>
<th>Geometric arrangement of the groups around the atom</th>
<th>Hybridisation of atom</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^1\text{C})</td>
<td>tetrahedral</td>
<td>(sp^3)</td>
</tr>
<tr>
<td>(^2\text{O})</td>
<td>bent</td>
<td>(sp^3)</td>
</tr>
<tr>
<td>(^3\text{C})</td>
<td>trigonal planar</td>
<td>(sp^2)</td>
</tr>
</tbody>
</table>

Name three types of intermolecular interactions expected of lactic acid.

- hydrogen bonding (alcohol and acid groups)
- dipole-dipole interactions (alcohol and acid groups)
- dispersion forces (all groups but the only interactions for methyl group)
Some micro-organisms thrive under warm, acidic conditions where sulfuric acid is produced as a metabolic by-product from the reaction between sulfur (S), water and oxygen (O₂). Write a balanced equation for this reaction.

\[2S(s) + 3O_2(g) + 2H_2O(l) \rightarrow 2H_2SO_4(l)\]

Calculate the volume of oxygen that is required to react to completion with 0.0655 g of sulfur at 1.00 atm and 55 °C.

The number of moles of sulfur in 0.0655 g is:

\[
\text{number of moles} = \frac{\text{mass}}{\text{atomic mass}} = \frac{0.0655 \text{ g}}{32.07 \text{ g mol}^{-1}} = 0.00204 \text{ mol}
\]

From the chemical equation, two moles of S react with three moles of O₂. Therefore, \(1.5 \times 0.00204 \text{ mol} = 0.00306 \text{ mol}\) of oxygen is required.

Using the ideal gas law, \(PV = nRT\), the volume of this number of moles of O₂ can be calculated. As the pressure = 1.00 atm, the corresponding value of \(R\) to be used is 0.08206 L atm K\(^{-1}\) mol\(^{-1}\). \(T = 55 \degree C = (55 + 273) K = 328 K\).

\[
V = \frac{nRT}{P} = \frac{(0.00306 \text{ mol})(0.08206 \text{ L atm K}^{-1} \text{ mol}^{-1})(328 \text{ K})}{1.00 \text{ atm}}
\]

\[
= 0.0825 \text{ L or 82.5 mL}
\]

ANSWER: 0.0825 L or 82.5 mL

Calculate the pH of the final solution if the reaction is carried out in 20.0 L of water. Assume that the sulfuric acid fully dissociates.

Two moles of H\(_2\)SO\(_4\) are produced for every two moles of sulfur used. The number of moles of H\(_2\)SO\(_4\) produced is therefore 0.00204 mol.

If the H\(_2\)SO\(_4\) completely dissociates into H\(^+\) and SO\(_4^{2-}\), two moles of H\(^+\) are produced for every one mole of H\(_2\)SO\(_4\). The number of moles of H\(^+\) is therefore 0.00408 mol.

This number of moles is dissolved in 20.0 L of water, the concentration of H\(^+\) is therefore:

\[
\text{concentration} = \frac{\text{number of moles}}{\text{volume}} = \frac{0.00408 \text{ mol}}{20.0 \text{ L}} = 0.000204 \text{ M}
\]

Using the definition of pH,

\[
pH = -\log_{10}[H^+] = -\log_{10}(0.000204) = 3.69
\]

ANSWER: 3.69
Shown here are the classical and the zwitterionic forms of the amino acid leucine.

List the types of intermolecular interactions in which each of the indicated sites (A, B, and C) in leucine could be involved.

- A: ion-ion, ion-dipole, ion-induced dipole
- B: dispersion
- C: hydrogen bonding, dipole-dipole, dipole-induced dipole

Provide the requested information for each of the indicated atoms in leucine.

<table>
<thead>
<tr>
<th>Atom</th>
<th>Geometric arrangement of the electron pairs around the atom</th>
<th>Hybridisation of the atom</th>
<th>Geometry/shape of σ-bonding electron pairs around the atom</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^1\text{C}$</td>
<td>tetrahedral</td>
<td>$sp^3$</td>
<td>tetrahedral</td>
</tr>
<tr>
<td>$^2\text{C}$</td>
<td>trigonal planar</td>
<td>$sp^2$</td>
<td>trigonal planar</td>
</tr>
<tr>
<td>$^3\text{O}$</td>
<td>tetrahedral</td>
<td>$sp^3$</td>
<td>bent</td>
</tr>
</tbody>
</table>

Given that the $pK_a$ of the carboxylic acid group of leucine is 2.32 and the $pK_b$ of the amine group is 4.24, do you expect the classical or the zwitterionic form to predominate when leucine is dissolved in water? In other words, does the following equilibrium lie to the right or left? Show your reasoning.

$$\text{H}_2\text{N}^–\text{CHR}^+\text{COO}^- \rightleftharpoons \text{H}_2\text{N}^-\text{CHR}^–\text{COO}^–$$

The equilibrium for the $K_a$ of the acid group is:

$$\text{H}_2\text{N}^-\text{CHR}^–\text{COO}^– \rightleftharpoons \text{H}_2\text{N}^–\text{CHR}^+\text{COO}^- + \text{H}^+$$

for which:

$$K_{a(COOH)} = \frac{[\text{H}^+][\text{H}_2\text{N}^-\text{CHR}^–\text{COO}^-]}{[\text{H}_2\text{N}^–\text{CHR}^+\text{COO}^-]} = 10^{-2.32}$$

The equilibrium for protonation of the amine group is:

$$\text{H}_2\text{N}^–\text{CHR}^–\text{COO}^- + \text{H}^+ \rightleftharpoons \text{H}_3\text{N}^+\text{CHR}^–\text{COO}^–$$
for which:

\[
K = \frac{[H_3N^+ - \text{CHR} - \text{COO}^-]}{[H_2N\text{CHR} - \text{COO}^-][H^+]} = \frac{1}{K_{a(\text{NH}_3^+)} 10^{-pK_a}} = 10^{+9.76}
\]

in which \(pK_a + pK_b = 14\) has been used.

The equilibrium for formation of the zwitterionic form in the question is:

\[
H_3N-\text{CHR-COOH} \rightleftharpoons H_3N^+-\text{CHR-COO}^-
\]

for which:

\[
K' = \frac{[H_3N^+ - \text{CHR} - \text{COO}^-]}{[H_2N\text{CHR} - \text{COOH}]} = \frac{K_{a(\text{COOH})}}{K_{a(\text{NH}_3^+)} 10^{-2.32 \times 10^+ 9.76}} = 10^{7.44}
\]

\(>> 1\)

As the equilibrium constant \(>> 1\), the equilibrium lies far to the right and so the zwitterionic form dominates.
Consider the following equation.

\[ \text{HBrO}(aq) + \text{NH}_3(aq) \rightleftharpoons \text{BrO}^-(aq) + \text{NH}_4^+(aq) \]

Name all of the species in this equation.

<table>
<thead>
<tr>
<th>Species</th>
<th>HBrO</th>
<th>NH(_3)</th>
<th>BrO(^-)</th>
<th>NH(_4^+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>hypobromous acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hypobromite ion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ammonia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ammonium ion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Complete the following table by giving the correct \(pK_a\) or \(pK_b\) value where it can be calculated. Mark with a cross (\(\times\)) those cells for which insufficient data have been given to calculate a value.

<table>
<thead>
<tr>
<th>Species</th>
<th>HBrO</th>
<th>NH(_3)</th>
<th>BrO(^-)</th>
<th>NH(_4^+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(pK_a) of acid</td>
<td>8.64</td>
<td>(\times)</td>
<td>(\times)</td>
<td>9.24</td>
</tr>
<tr>
<td>(pK_b) of base</td>
<td>(\times)</td>
<td>4.76</td>
<td>5.36</td>
<td>(\times)</td>
</tr>
</tbody>
</table>

Determine on which side (left or right hand side) the equilibrium for the reaction above will lie. Provide a brief rationale for your answer.

The reaction is the sum of the acid-base equilibria for HBrO and NH\(_3\):

\[ \text{HBrO}(aq) \rightarrow \text{H}^+(aq) + \text{BrO}^-(aq) \quad K_a(\text{HBrO}) = 10^{-8.64} \]

\[ \text{H}^+(aq) + \text{NH}_3(aq) \rightarrow \text{NH}_4^+(aq) \quad K_a(\text{NH}_3) = \frac{1}{K_a(\text{NH}_4^+)} = 10^{+9.24} \]

\[ \text{HBrO}(aq) + \text{NH}_3(aq) \rightarrow \text{BrO}^-(aq) \quad K = K_a(\text{HBrO}) \times K_a(\text{NH}_3) \]

Hence, \(K = (10^{-8.64}) \times (10^{+9.24}) = 10^{0.64} = 4.4\). As \(K > 1\), the reaction favours products.
Glycine, $\text{NH}_2\text{CH}_2\text{COOH}$, the simplest of all naturally occurring amino acids, has a melting point of $292\,^\circ\text{C}$. The $pK_a$ of the acid group is 2.35 and the $pK_a$ associated with the amino group is 9.78. Draw a structure that indicates the charges on the molecule at the physiological pH of 7.4.

As pH = 7.4 is higher than the $pK_a$ of the acid group, $-\text{COOH}$, it will exist primarily in its deprotonated, conjugate base form, $-\text{COO}^-$.

As pH = 7.4 is lower than the $pK_a$ of the amino group, $-\text{NH}_2$, it will exist primarily in its protonated form, $-\text{NH}_3^+$.

Glycine will exist in the uncharged, zwitterionic form: $\oplus \text{H}_3\text{N}−\text{CH}_2−\text{COO}^\ominus$

Describe the hybridisation of the two carbon atoms and the nitrogen atom in glycine and the geometry of the atoms surrounding these three atoms.

The structure is:

- N has 4 bonds and no lone pairs: $\text{sp}^3$ with a tetrahedral arrangement.
- C$_a$ has 4 bonds and no lone pairs: $\text{sp}^3$ with a tetrahedral arrangement.
- C$_b$ has 3 bonds and no lone pairs: $\text{sp}^2$ with a trigonal planar arrangement.

Glycine has an unusually high melting point for a small molecule. Suggest a reason for this.

Glycine with a positively and a negatively charged end. There is therefore ionic bonding between the molecules leading to strong intermolecular forces.
• The molecular structure of nicotine, the addictive component of tobacco, is shown below.

The molecular structure of nicotine, the addictive component of tobacco, is shown below.

List the types of intermolecular interactions that each of the following sites on nicotine would be involved in when it is dissolved in water.

A – H bonding and dipole-dipole interactions

B – dispersion forces and dipole-induced dipole

Provide the requested information for each of the indicated atoms in nicotine.

<table>
<thead>
<tr>
<th>Atom</th>
<th>Geometric arrangement of the electron pairs around the atom</th>
<th>Hybridisation of the atom</th>
<th>Geometry around the atom</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-1</td>
<td>trigonal planar</td>
<td>( sp^2 )</td>
<td>bent (~120°)</td>
</tr>
<tr>
<td>N-2</td>
<td>tetrahedral</td>
<td>( sp^3 )</td>
<td>trigonal pyramidal</td>
</tr>
<tr>
<td>C-3</td>
<td>tetrahedral</td>
<td>( sp^3 )</td>
<td>tetrahedral</td>
</tr>
<tr>
<td>C-4</td>
<td>trigonal planar</td>
<td>( sp^2 )</td>
<td>trigonal planar</td>
</tr>
</tbody>
</table>

The \( pK_b \) of N-1 is 10.88 and the \( pK_b \) of N-2 is 5.98. Draw the structure of the predominant form of nicotine that exists in the human body at pH 7.4.

For N-1, the \( pK_a \) of the protonated form (the conjugate acid) is \( (14.00 - 10.88) = 3.12 \). As the pH is higher than the \( pK_a \), the conjugate acid is deprotonated: very little protonation occurs.

For N-2, the \( pK_a \) of the protonated form is \( (14.00 - 5.98) = 8.02 \). As the pH is lower than the \( pK_a \) the conjugate acid form dominates: protonation occurs.
Lithium salts, especially lithium carbonate, are commonly used in the treatment of bipolar disorder. Write the net ionic equation for the reaction which occurs between lithium carbonate and hydrochloric acid in the stomach.

\[ \text{Li}_2\text{CO}_3(s) + 2\text{H}^+(aq) \rightarrow 2\text{Li}^+(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \]

Lithium orotate (as a monohydrate salt, LiC$_5$H$_3$N$_2$O$_4$⋅H$_2$O) is a controversial alternative formulation sold in some health food stores. The orotate ion is the conjugate base of orotic acid, whose structure is shown below.

```
\begin{align*}
\text{O} & \text{O} \\
\text{HN} & \text{NH} \\
\text{O} & \text{OH}
\end{align*}
```

Like the carbonate, lithium orotate is taken orally. Using an equation, comment on any differences between the form in which lithium is bioavailable from these two lithium salts.

When lithium orotate, LiC$_5$H$_3$N$_2$O$_4$, dissolves in water, it forms Li$^+$ ions and orotate ions:

\[ \text{LiC}_5\text{H}_3\text{N}_2\text{O}_4(s) \rightarrow \text{Li}^+(aq) + \text{C}_5\text{H}_3\text{N}_2\text{O}_4^-(aq) \]

Both lithium carbonate and lithium orotate thus give rise to the same form of lithium, Li$^{2+}$(aq), when taken orally.
The molecular structure of adrenaline (epinephrine), a hormone involved in the "fight or flight" response, is shown below.

List the types of intermolecular interactions that each of the following sites on adrenaline would be involved in if dissolved in water.

A  H-bonding, dipole-dipole, dispersion forces

B  dispersion forces

C  H-bonding, dipole-dipole, dispersion forces

Pharmaceuticals with amine groups are frequently supplied as their “hydrochloride salts”. Draw the structure that would result if adrenaline were reacted with one equivalent of HCl. What additional intermolecular forces would be present if this form of adrenaline were dissolved in water?

With this form present, ion-dipole interactions would be introduced.

Provide the requested information for each of the indicated sites on adrenaline.

<table>
<thead>
<tr>
<th>Atom</th>
<th>Geometric arrangement of the electron pairs around the atom</th>
<th>Hybridisation of the atom</th>
<th>Geometry around the atom</th>
<th>Approximate angles around the atom</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1O</td>
<td>tetrahedral</td>
<td>$sp^3$</td>
<td>bent</td>
<td>109°</td>
</tr>
<tr>
<td>#2N</td>
<td>tetrahedral</td>
<td>$sp^3$</td>
<td>trigonal pyramidal</td>
<td>109°</td>
</tr>
<tr>
<td>#3C</td>
<td>trigonal planar</td>
<td>$sp^2$</td>
<td>trigonal planar</td>
<td>120°</td>
</tr>
</tbody>
</table>
Glycine, NH$_2$CH$_2$COOH, is the simplest of all naturally occurring amino acids. The pK$_a$ of the acid group is 2.35 and the pK$_a$ associated with the amino group is 9.78. Draw a structure that indicates the charges on the molecule at the physiological pH of 7.4.

\[ \overset{\ominus}{\text{H}_3\text{N}}\text{CO}_2\overset{\ominus}{\text{O}} \]

**This pH is much greater than the pK$_a$ value of the acid group: it is deprotonated.**

**This pH is much lower than the pK$_a$ value of the amino group: it is protonated.**

Use your structure to illustrate the concept of resonance.

\[ \overset{\ominus}{\text{H}_3\text{N}}\text{CO}_2\overset{\ominus}{\text{O}} \leftrightarrow \overset{\oplus}{\text{H}_3\text{N}}\text{CO}_2\overset{\ominus}{\text{O}} \]

What are the hybridisation states and geometries of the two carbon atoms and the nitrogen atom in glycine?

**The carbon on the acid group is sp$^2$ hybridised and the geometry is trigonal planar.**

**The carbon on the CH$_2$ group is sp$^3$ hybridised and the geometry is tetrahedral.**

**The nitrogen is sp$^3$ hybridised and the geometry is tetrahedral.**

Propionic acid, CH$_3$CH$_2$COOH, has a melting point of –20.7 °C while glycine has a melting point of 292 °C. Suggest a reason why these two molecules have such different melting points.

**Propionic acid has strong hydrogen bonds, giving it a relatively high melting point.**

**However, glycine has very strong ionic bonds between the NH$_3^+$ and CO$_2^-$ groups giving it very high melting point.**
Explain the terms ‘weak’ and ‘strong’ and the terms ‘dilute’ and ‘concentrated’ in the context of acids and bases.

<table>
<thead>
<tr>
<th>A weak acid or base is one which only partially dissociates in water:</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ \text{e.g. } \text{CH}_3\text{COOH(aq)} \rightleftharpoons \text{CH}_3\text{CO}_2^-(aq) + \text{H}^+(aq) ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A strong acid or base is one which completely dissociates in water:</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ \text{e.g. } \text{HCl(aq)} \rightarrow \text{H}^+(aq) + \text{Cl}^-(aq) ]</td>
</tr>
</tbody>
</table>

Concentrated and dilute are terms that can be used in reference to any solute, describing the number of moles of solute relative to the volume of solvent. A concentrated solution has a high solute: solvent ratio, whilst a dilute solution has a low solute: solvent ratio.