• 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>$^1$C</td>
<td>tetrahedral</td>
<td>$sp^3$</td>
<td>tetrahedral</td>
</tr>
<tr>
<td>$^2$C</td>
<td>trigonal planar</td>
<td>$sp^2$</td>
<td>trigonal planar</td>
</tr>
<tr>
<td>$^3$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.

$$\text{H}_2\text{N}-\text{CH(CH}_2\text{CH(CH}_3\text{)_2})-\text{COOH} \rightleftharpoons \text{H}_3\text{N}^+\text{-CH(CH}_2\text{CH(CH}_3\text{)_2})-\text{CO}_2^-$$

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

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

for which:

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

The equilibrium for protonation of the amine group is:

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

\[ K = \frac{[H_3N^+ - \text{CHR} - \text{COO}^-]}{[H_2N\text{CHR} - \text{COO}^-][H^+]} = \frac{1}{K_{a(NH_3^+)}^1} = \frac{1}{10^{-9.76}} = 10^{9.76} \]

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

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

\[ H_2N-\text{CHR-COOH} \rightleftharpoons H_3N^+-\text{CHR-COO}^- \]

for which:

\[ K' = \frac{[H_3N^+ - \text{CHR} - \text{COO}^-]}{[H_2N\text{CHR} - \text{COOH}]} = \frac{K_a(\text{COOH})}{K_{a(NH_3^+)}^1} = 10^{-2.32} \times 10^+ 9.76 = 10^{7.44} \]

>> 1

As the equilibrium constant >> 1, the equilibrium lies far to the right and so the zwitterionic form dominates.