Cells are mostly made of the most abundant chemical elements: H, C, O, N, Ca, Mg, Na, K, P, etc.

The strongest bond between atoms in the covalent bond. The C-C bond is about 90 kcal/mol \( \approx 3.9 \) eV

\[ 1 \text{ kcal/mol} \approx 0.04336 \text{ eV} \]

\[ 1 \text{ mol} = 6.022 \times 10^{23} \text{ molecules} \]

\[ = 4.0026 \text{ g of He, for example.} \]

The H₂ molecule is held together by a single covalent bond

\[ H = \text{H} \text{.} + \text{V} \]

\[ \text{H}_2 = \frac{\text{p}^2}{2m} + \frac{\text{p}^2}{2m} - \frac{\text{e}^2}{1\text{r} - \text{R} \cdot 1} - \frac{\text{e}^2}{1\text{r} - \text{R} \cdot 1} \]

\[ \text{V} = \frac{\text{e}^2}{1\text{r}^2 - \text{R}^2} + \frac{\text{e}^2}{1\text{r}^2 + \text{r} - \text{R} \cdot 1} - \frac{\text{e}^2}{1\text{r} \cdot \text{r} - \text{R} \cdot 1} - \frac{\text{e}^2}{1\text{r} - \text{R} \cdot 1} \]
H is invariant under the interchange of \( v_1 \) with \( v_2 \). So its e-states may be chosen to be e-states of the operator \( T \), that exchange the electrons.

Since electrons are fermions, their e-states must be antisymmetric under exchange of two electrons.

\[
H \text{ does not involve spin to this order. So we may choose the spin state to be symmetric or antisymmetric:} \\
S = 1 \quad S = 0.
\]

The space state then would be antisymmetric or symmetric, respectively.

Which?

In fact the space state is symmetric and the spin is zero. The two electrons clump together and so attract the two protons. The binding energy \( V(r) \) is a function of the separation \( r = |R_2 - R_1| \).

At \( r = 0.74\,\text{Å} \), \( V(r) \approx -4.75\,\text{eV} \)

\( \approx -110 \,\text{kal/mol} \).
A useful parametrization of \( V(r) \) is:

\[
V(r) = a e^{-br} - \frac{d}{r^6 + e r^6}.
\]

The fit is very good.

Some atoms have more than one covalent bond:

- **O**
- **N**
- **C**
- **H** (104.5°)
- **O** (109.5°) water
- **ethane**
- **ethene, planar**
Single bonds allow notations.

Double, triple bonds do not.

Some bonds are in between single and double bonds, e.g., the peptide bond C-N is a 1.5 bond, and it resists notation.

Water, H$_2$O, is the most abundant molecule in cells.

Water has a large permanent electric dipole moment.
Non-covalent bonds:

1) Ionic bonds, e.g., \( \text{NaCl} = \text{Na}^+ \text{Cl}^- \). Is this a covalent bond in which the electrons clump on the Cl atom?

2) Hydrogen bonds

3) van der Waals: How very light electrons respond to the array of charges near them. At a few Å,

\[
V(r) \propto \frac{-d}{r^6}
\]

At longer distances,

\[
V(r) \propto \frac{-e}{r^{11}}
\]

4) Hydrophobic force: polar water molecules
are attracted to each other and to other polar molecules.

<table>
<thead>
<tr>
<th>bond</th>
<th>Length (Å)</th>
<th>E (vac)</th>
<th>E (H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>covalent</td>
<td>1.5</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>ionic</td>
<td>2.5</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>vdw</td>
<td>3.5</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

\text{kJ mol}^{-1}

Water stays away - is repelled by vacuum and by non-polar media.
Examples of H bonds

N - M  0
O - M  O-
O - H  N
N⁺ - H  0
N - M  N

Bacterial cell has

<table>
<thead>
<tr>
<th>Components</th>
<th>%</th>
<th># kinds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>70%</td>
<td>1</td>
</tr>
<tr>
<td>Organic ions</td>
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<td>20</td>
</tr>
<tr>
<td>Sugars</td>
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<td>250</td>
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<tr>
<td>Amino acids</td>
<td>.4</td>
<td>100</td>
</tr>
<tr>
<td>Nucleotides</td>
<td>.4</td>
<td>100</td>
</tr>
<tr>
<td>Fatty acids</td>
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<td>50</td>
</tr>
<tr>
<td>Small molecules</td>
<td>.2</td>
<td>300</td>
</tr>
<tr>
<td>Big</td>
<td>26</td>
<td>3000</td>
</tr>
</tbody>
</table>
Resonance

methanol

methyl group

saturated hydrocarbon
- C-O groups

alcohol

aldehyde

ketone

carboxylic acid

- COO⁻ + H⁺ ⇌ - COOH

in water

esters

acid + alcohol → ester + H₂O
C-N groups

amines

\[ \text{amine} + \text{acid} \rightarrow \text{amide} \]

amides

\[ \text{amide} \] (unchanged in H₂O)

cytosine a pyrimidine
phosphates

\[ \text{HO} - \text{P} - \text{O}^- \]

\[ \text{HO} - \text{P} - \text{O}^- \]

\[ \text{H}_2\text{O} + \text{HO} - \text{P} - \text{O}^- \xrightarrow{\text{c-OH}} \text{HO} - \text{P} - \text{O}^- + \text{H}_2\text{O} \]

phosphate octen