General information

- 1 mol of gas molecules occupies 24.0 dm$^3$ at room temperature and pressure, RTP.
- Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol$^{-1}$.
- Ionic product of water, $K_w = 1.00 \times 10^{-14}$ mol$^2$ dm$^{-6}$.
**$^1$H NMR chemical shifts relative to TMS**

Chemical shifts are typical values and can vary slightly depending on the solvent, concentration and substituents.

<table>
<thead>
<tr>
<th>type of proton</th>
<th>chemical shift, $\delta$ / ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{R-CH}_3$</td>
<td>0.7–1.6</td>
</tr>
<tr>
<td>$\text{N-H}$</td>
<td>$\text{R-OH}$</td>
</tr>
<tr>
<td>$\text{R-CH}_2$-$\text{R}$</td>
<td>1.2–1.4</td>
</tr>
<tr>
<td>$\text{R}_3$,$\text{CH}$</td>
<td>1.6–2.0</td>
</tr>
</tbody>
</table>

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>$\text{H}_3$</td>
<td>$\text{C-C}$</td>
<td>$\text{RCH}_2$</td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>$\text{CH}_3$</td>
<td>$\text{CH}_2$</td>
<td>$\text{R}$</td>
</tr>
<tr>
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</tr>
<tr>
<td>$\text{N-CH}_3$</td>
<td>$\text{N-CH}_2$</td>
<td>$\text{N-CHR}_2$</td>
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<tr>
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<tr>
<td>$\text{O-CH}_3$</td>
<td>$\text{O-CH}_2$</td>
<td>$\text{O-CHR}_2$</td>
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<tr>
<td></td>
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</tr>
<tr>
<td>$\text{Br or Cl-CH}_3$</td>
<td>$\text{Br or Cl-CH}_2$</td>
<td>$\text{Br or Cl-CHR}_2$</td>
</tr>
<tr>
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<tr>
<td>$\text{OH}$</td>
<td>$\text{CH}=\text{CH}$</td>
<td>4.5–6.0</td>
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<tr>
<td>$\text{NH}_2$</td>
<td>$\text{HN}$</td>
<td>5.0–12.0*</td>
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<tr>
<td></td>
<td>$\text{H}$</td>
<td>6.5–8.0</td>
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<td>$\text{H}$</td>
<td>9.0–10</td>
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<tr>
<td></td>
<td>$\text{H}$</td>
<td>11.0–12.0*</td>
</tr>
</tbody>
</table>

* OH and NH chemical shifts are very variable (sometimes outside these limits) and are often broad. Signals are not usually seen as split peaks.
$^{13}$C NMR chemical shifts relative to TMS
Chemical shifts are typical values and can vary slightly depending on the solvent, concentration and substituents.

<table>
<thead>
<tr>
<th>type of carbon</th>
<th>chemical shift, $\delta$/ ppm</th>
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</thead>
<tbody>
<tr>
<td>C–C (alkanes)</td>
<td>10–35</td>
</tr>
<tr>
<td>( \text{C} = \text{O} )</td>
<td>20–30</td>
</tr>
<tr>
<td>C–Cl or C–Br</td>
<td>30–70</td>
</tr>
<tr>
<td>C–N (amines)</td>
<td>35–60</td>
</tr>
<tr>
<td>C–OH</td>
<td>50–65</td>
</tr>
<tr>
<td>C=C (alkenes)</td>
<td>115–140</td>
</tr>
<tr>
<td>aromatic</td>
<td>125–150</td>
</tr>
<tr>
<td>C=O (ester, carboxylic acid, amide)</td>
<td>160–185</td>
</tr>
<tr>
<td>C=O (aldehyde, ketone)</td>
<td>190–220</td>
</tr>
</tbody>
</table>

Characteristic infrared absorptions in organic molecules

<table>
<thead>
<tr>
<th>bond</th>
<th>location</th>
<th>wavenumber/cm$^{-1}$</th>
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<tbody>
<tr>
<td>C–O</td>
<td>alcohols, esters, carboxylic acids</td>
<td>1000–1300</td>
</tr>
<tr>
<td>C=O</td>
<td>aldehydes, ketones, carboxylic acids, esters, amides</td>
<td>1640–1750</td>
</tr>
<tr>
<td>C–H</td>
<td>organic compound with a C–H bond</td>
<td>2850–3100</td>
</tr>
<tr>
<td>O–H</td>
<td>carboxylic acids</td>
<td>2500–3300 (very broad)</td>
</tr>
<tr>
<td>N–H</td>
<td>amines, amides</td>
<td>3200–3500</td>
</tr>
<tr>
<td>O–H</td>
<td>alcohols, phenols</td>
<td>3200–3550 (broad)</td>
</tr>
</tbody>
</table>

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**The Periodic Table of the Elements**

| 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  | 21  | 22  | 23  | 24  |
|----|----|----|----|----|----|----|----|----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| H  | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

**Key**

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**Relative Atomic Mass**

| 23.0 | 24.3 | 10.8 | 12.0 | 14.0 | 16.0 | 19.0 | 20.0 | 27.0 | 28.1 | 31.0 | 32.1 | 35.5 | 39.9 |

**Atomic Symbol**

| 6.9 | 9.0 | 23.0 | 24.3 | 39.1 | 40.1 | 55.8 | 63.5 | 69.7 | 72.6 | 74.9 | 79.9 | 79.9 | 83.8 |

**Atomic Number**

| 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |

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Elements with atomic numbers 112–116 have been reported but not fully authenticated.

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**Table Continued**

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<td>B boron</td>
<td>5</td>
<td>C carbon</td>
<td>6</td>
<td>N nitrogen</td>
<td>7</td>
<td>O oxygen</td>
<td>8</td>
<td>F fluorine</td>
<td>9</td>
<td>Ne neon</td>
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<td>Na sodium</td>
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<td>Mg magnesium</td>
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<td>P phosphorus</td>
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<td>Th thorium</td>
<td>108</td>
<td>Ho holmium</td>
<td>109</td>
<td>Er erbium</td>
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<td>Tm thulium</td>
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<td>Yb ytterbium</td>
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<td>Lu lutetium</td>
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<td>Am actinium</td>
<td>106</td>
<td>Cm curium</td>
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<td>Bk berkelium</td>
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<td>Cf californium</td>
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<td>Es einsteinium</td>
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<th>168.9</th>
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</thead>
<tbody>
<tr>
<td>Pr promethium</td>
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<td>Nd neodymium</td>
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<td>Pm promethium</td>
<td>61</td>
<td>Sm samarium</td>
<td>62</td>
<td>Eu europium</td>
<td>63</td>
<td>Gd gadolinium</td>
<td>64</td>
<td>Tb terbium</td>
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**Table Continued**

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<tbody>
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<td>Pa protactinium</td>
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