

# Advanced Cell Biology. Lecture 3

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# Outline

## Questions and answers

## Chemistry of life

Chemical elements and atoms

## Organic molecules

Basics of organic chemistry



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## Previous final question: the answer

Which organelle is present in most prokaryotic cells and absent in all eukaryotic?



## Previous final question: the answer

Which organelle is present in most prokaryotic cells and absent in all eukaryotic?

- ▶ Flagella<sub>1</sub>
- ▶ Thylakoid
- ▶ Nucleoid



# Chemistry of life

## Chemical elements and atoms



# Periodic table and atomic features

**IUPAC Periodic Table of the Elements**

Key: atomic number  
Symbol  
name  
standard atomic weight

|   |                                       |                                      |                                       |                                      |   |                                       |                                       |                                     |                                       |                                    |                                     |   |                                       |                                      |   |                                     |                                     |   |  |  |  |   |                                      |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
|---|---------------------------------------|--------------------------------------|---------------------------------------|--------------------------------------|---|---------------------------------------|---------------------------------------|-------------------------------------|---------------------------------------|------------------------------------|-------------------------------------|---|---------------------------------------|--------------------------------------|---|-------------------------------------|-------------------------------------|---|--|--|--|---|--------------------------------------|--------------------------------------|--|-------------------------------------|--|-------------------------------------|------------------------------------|-------------------------------------|---------------------------------------|--------------------------------------|--|--|--|
| 1<br><b>H</b><br>hydrogen<br>[1.007; 1.008] |                                       |                                      |                                       |                                      |   |                                       |                                       |                                     |                                       |                                    |                                     |   |                                       |                                      |   |                                     | 2<br><b>He</b><br>helium<br>4.003   |   |  |  |  |   |                                      |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
| 3<br><b>Li</b><br>lithium<br>[6.938; 6.997] | 4<br><b>Be</b><br>beryllium<br>9.012  |                                      |                                       |                                      |   |                                       |                                       |                                     |                                       |                                    |                                     |   |                                       |                                      |   |                                     |                                     | 13<br><b>B</b><br>boron<br>[10.80; 10.83] | 14<br><b>C</b><br>carbon<br>[12.00; 12.02]   | 15<br><b>N</b><br>nitrogen<br>[14.00; 14.01] | 16<br><b>O</b><br>oxygen<br>[15.99; 16.00] | 17<br><b>F</b><br>fluorine<br>18.99           | 18<br><b>Ne</b><br>neon<br>20.18     |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
| 11<br><b>Na</b><br>sodium<br>22.99          | 12<br><b>Mg</b><br>magnesium<br>24.31 |                                      |                                       |                                      |   |                                       |                                       |                                     |                                       |                                    |                                     |   |                                       |                                      |   |                                     |                                     | 13<br><b>Al</b><br>aluminium<br>26.98     | 14<br><b>Si</b><br>silicon<br>[28.08; 28.09] | 15<br><b>P</b><br>phosphorus<br>30.97        | 16<br><b>S</b><br>sulfur<br>[32.05; 32.06] | 17<br><b>Cl</b><br>chlorine<br>[35.44; 35.46] | 18<br><b>Ar</b><br>argon<br>39.95    |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
| 19<br><b>K</b><br>potassium<br>39.10        | 20<br><b>Ca</b><br>calcium<br>40.08   | 21<br><b>Sc</b><br>scandium<br>44.96 | 22<br><b>Ti</b><br>titanium<br>47.87  | 23<br><b>V</b><br>vanadium<br>50.94  | 24<br><b>Cr</b><br>chromium<br>52.00      | 25<br><b>Mn</b><br>manganese<br>54.94 | 26<br><b>Fe</b><br>iron<br>55.85      | 27<br><b>Co</b><br>cobalt<br>58.93  | 28<br><b>Ni</b><br>nickel<br>58.69    | 29<br><b>Cu</b><br>copper<br>63.55 | 30<br><b>Zn</b><br>zinc<br>65.38(2) | 31<br><b>Ga</b><br>gallium<br>69.72           | 32<br><b>Ge</b><br>germanium<br>72.63 | 33<br><b>As</b><br>arsenic<br>74.92  | 34<br><b>Se</b><br>selenium<br>78.96(3) | 35<br><b>Br</b><br>bromine<br>79.90 | 36<br><b>Kr</b><br>krypton<br>83.80 |   |  |  |  |   |                                      |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
| 37<br><b>Rb</b><br>rubidium<br>85.47        | 38<br><b>Sr</b><br>strontium<br>87.62 | 39<br><b>Y</b><br>yttrium<br>88.91   | 40<br><b>Zr</b><br>zirconium<br>91.22 | 41<br><b>Nb</b><br>niobium<br>92.91  | 42<br><b>Mo</b><br>molybdenum<br>95.96(2) | 43<br><b>Tc</b><br>technetium         | 44<br><b>Ru</b><br>ruthenium<br>101.1 | 45<br><b>Rh</b><br>rhodium<br>102.9 | 46<br><b>Pd</b><br>palladium<br>106.4 | 47<br><b>Ag</b><br>silver<br>107.9 | 48<br><b>Cd</b><br>cadmium<br>112.4 | 49<br><b>In</b><br>indium<br>114.8            | 50<br><b>Sn</b><br>tin<br>118.7       | 51<br><b>Sb</b><br>antimony<br>121.8 | 52<br><b>Te</b><br>tellurium<br>127.6   | 53<br><b>I</b><br>iodine<br>126.9   | 54<br><b>Xe</b><br>xenon<br>131.3   |   |  |  |  |   |                                      |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
| 55<br><b>Cs</b><br>caesium<br>132.9         | 56<br><b>Ba</b><br>barium<br>137.3    | 57-71<br>lanthanoids                 | 72<br><b>Hf</b><br>hafnium<br>178.5   | 73<br><b>Ta</b><br>tantalum<br>180.9 | 74<br><b>W</b><br>tungsten<br>183.8       | 75<br><b>Re</b><br>rhenium<br>186.2   | 76<br><b>Os</b><br>osmium<br>190.2    | 77<br><b>Ir</b><br>iridium<br>192.2 | 78<br><b>Pt</b><br>platinum<br>195.1  | 79<br><b>Au</b><br>gold<br>197.0   | 80<br><b>Hg</b><br>mercury<br>200.6 | 81<br><b>Tl</b><br>thallium<br>[204.3; 204.4] | 82<br><b>Pb</b><br>lead<br>207.2      | 83<br><b>Bi</b><br>bismuth<br>209.0  | 84<br><b>Po</b><br>polonium             | 85<br><b>At</b><br>astatine         | 86<br><b>Rn</b><br>radon            |   |  |  |  |   |                                      |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
| 87<br><b>Fr</b><br>francium                 | 88<br><b>Ra</b><br>radium             | 89-103<br>actinoids                  | 104<br><b>Rf</b><br>rutherfordium     | 105<br><b>Db</b><br>dubnium          | 106<br><b>Sg</b><br>seaborgium            | 107<br><b>Bh</b><br>bohrium           | 108<br><b>Hs</b><br>hassium           | 109<br><b>Mt</b><br>meitnerium      | 110<br><b>Ds</b><br>darmstadtium      | 111<br><b>Rg</b><br>roentgenium    | 112<br><b>Cn</b><br>copernicium     | 114<br><b>Fl</b><br>flerovium                 |                                       | 116<br><b>Lv</b><br>livermorium      |   |                                     |                                     |   |  |  |  |   |                                      |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
|   |                                       |                                      |                                       |                                      |   |                                       |                                       |                                     |                                       |                                    |                                     |   |                                       |                                      |   |                                     |                                     | 57<br><b>La</b><br>lanthanum<br>138.9     | 58<br><b>Ce</b><br>cerium<br>140.1           | 59<br><b>Pr</b><br>praseodymium<br>140.9     | 60<br><b>Nd</b><br>neodymium<br>144.2      | 61<br><b>Pm</b><br>promethium                 | 62<br><b>Sm</b><br>samarium<br>150.4 | 63<br><b>Eu</b><br>europium<br>152.0 | 64<br><b>Gd</b><br>gadolinium<br>157.3 | 65<br><b>Tb</b><br>terbium<br>158.9 | 66<br><b>Dy</b><br>dysprosium<br>162.5 | 67<br><b>Ho</b><br>holmium<br>164.9 | 68<br><b>Er</b><br>erbium<br>167.3 | 69<br><b>Tm</b><br>thulium<br>168.9 | 70<br><b>Yb</b><br>ytterbium<br>173.1 | 71<br><b>Lu</b><br>lutetium<br>175.0 |  |  |  |
|   |                                       |                                      |                                       |                                      |   |                                       |                                       |                                     |                                       |                                    |                                     |   |                                       |                                      |   |                                     |                                     | 88<br><b>Ac</b><br>actinium               | 89<br><b>Th</b><br>thorium<br>232.0          | 90<br><b>Pa</b><br>protactinium<br>231.0     | 91<br><b>U</b><br>uranium<br>238.0         | 92<br><b>Np</b><br>neptunium                  | 93<br><b>Pu</b><br>plutonium         | 94<br><b>Am</b><br>americium         | 95<br><b>Cm</b><br>curium              | 96<br><b>Bk</b><br>berkelium        | 97<br><b>Cf</b><br>californium         | 98<br><b>Es</b><br>einsteinium      | 99<br><b>Fm</b><br>fermium         | 100<br><b>Md</b><br>mendelevium     | 101<br><b>No</b><br>nobelium          | 102<br><b>Lr</b><br>lawrencium       |  |  |  |





# Periodic table and atomic features

**IUPAC Periodic Table of the Elements**

Key: atomic number  
**Symbol**  
name  
standard atomic weight

|   |                                       |                                      |                                       |                                      |   |                                       |                                       |                                     |                                       |                                    |                                     |   |                                       |                                      |   |  |   |   |   |  |                                       |                               |                                      |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
|---|---------------------------------------|--------------------------------------|---------------------------------------|--------------------------------------|---|---------------------------------------|---------------------------------------|-------------------------------------|---------------------------------------|------------------------------------|-------------------------------------|---|---------------------------------------|--------------------------------------|---|--|---|---|---|--|---------------------------------------|-------------------------------|--------------------------------------|--------------------------------------|--|-------------------------------------|--|-------------------------------------|------------------------------------|-------------------------------------|---------------------------------------|--------------------------------------|--|--|--|
| 1<br><b>H</b><br>hydrogen<br>1.007; 1.008 |                                       |                                      |                                       |                                      |   |                                       |                                       |                                     |                                       |                                    |                                     |   |                                       |                                      |   |  | 2<br><b>He</b><br>helium<br>4.003       |   |   |  |                                       |                               |                                      |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
| 3<br><b>Li</b><br>lithium<br>6.938; 6.997 | 4<br><b>Be</b><br>beryllium<br>9.012  |                                      |                                       |                                      |   |                                       |                                       |                                     |                                       |                                    |                                     |   |                                       |                                      |   | 5<br><b>B</b><br>boron<br>10.80; 10.83 | 6<br><b>C</b><br>carbon<br>12.00; 12.02 | 7<br><b>N</b><br>nitrogen<br>14.00; 14.01 | 8<br><b>O</b><br>oxygen<br>15.99; 16.00 | 9<br><b>F</b><br>fluorine<br>18.99       | 10<br><b>Ne</b><br>neon<br>20.18      |                               |                                      |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
| 11<br><b>Na</b><br>sodium                 | 12<br><b>Mg</b><br>magnesium          |                                      |                                       |                                      |   |                                       |                                       |                                     |                                       |                                    |                                     |   |                                       |                                      |   | 13<br><b>Al</b><br>aluminium           | 14<br><b>Si</b><br>silicon              | 15<br><b>P</b><br>phosphorus              | 16<br><b>S</b><br>sulfur                | 17<br><b>Cl</b><br>chlorine              | 18<br><b>Ar</b><br>argon              |                               |                                      |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
| 19<br><b>K</b><br>potassium<br>39.10      | 20<br><b>Ca</b><br>calcium<br>40.08   | 21<br><b>Sc</b><br>scandium<br>44.96 | 22<br><b>Ti</b><br>titanium<br>47.87  | 23<br><b>V</b><br>vanadium<br>50.94  | 24<br><b>Cr</b><br>chromium<br>52.00      | 25<br><b>Mn</b><br>manganese<br>54.94 | 26<br><b>Fe</b><br>iron<br>55.85      | 27<br><b>Co</b><br>cobalt<br>58.93  | 28<br><b>Ni</b><br>nickel<br>58.69    | 29<br><b>Cu</b><br>copper<br>63.55 | 30<br><b>Zn</b><br>zinc<br>65.38(2) | 31<br><b>Ga</b><br>gallium<br>69.72         | 32<br><b>Ge</b><br>germanium<br>72.63 | 33<br><b>As</b><br>arsenic<br>74.92  | 34<br><b>Se</b><br>selenium<br>78.96(3) | 35<br><b>Br</b><br>bromine<br>79.90    | 36<br><b>Kr</b><br>krypton<br>83.80     |   |   |  |                                       |                               |                                      |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
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| 87<br><b>Fr</b><br>francium               | 88<br><b>Ra</b><br>radium             | 89-103<br>actinoids                  | 104<br><b>Rf</b><br>rutherfordium     | 105<br><b>Db</b><br>dubnium          | 106<br><b>Sg</b><br>seaborgium            | 107<br><b>Bh</b><br>bohrium           | 108<br><b>Hs</b><br>hassium           | 109<br><b>Mt</b><br>meitnerium      | 110<br><b>Ds</b><br>darmstadtium      | 111<br><b>Rg</b><br>roentgenium    | 112<br><b>Cn</b><br>copernicium     | 114<br><b>Fl</b><br>flerovium               |                                       | 116<br><b>Lv</b><br>livermorium      |   |  |   |   |   |  |                                       |                               |                                      |                                      |  |                                     |  |                                     |                                    |                                     |                                       |                                      |  |  |  |
|   |                                       |                                      |                                       |                                      |   |                                       |                                       |                                     |                                       |                                    |                                     |   |                                       |                                      |   |  |   | 57<br><b>La</b><br>lanthanum<br>138.9     | 58<br><b>Ce</b><br>cerium<br>140.1      | 59<br><b>Pr</b><br>praseodymium<br>140.9 | 60<br><b>Nd</b><br>neodymium<br>144.2 | 61<br><b>Pm</b><br>promethium | 62<br><b>Sm</b><br>samarium<br>150.4 | 63<br><b>Eu</b><br>europium<br>152.0 | 64<br><b>Gd</b><br>gadolinium<br>157.3 | 65<br><b>Tb</b><br>terbium<br>158.9 | 66<br><b>Dy</b><br>dysprosium<br>162.5 | 67<br><b>Ho</b><br>holmium<br>164.9 | 68<br><b>Er</b><br>erbium<br>167.3 | 69<br><b>Tm</b><br>thulium<br>168.9 | 70<br><b>Yb</b><br>ytterbium<br>173.1 | 71<br><b>Lu</b><br>lutetium<br>175.0 |  |  |  |
|   |                                       |                                      |                                       |                                      |   |                                       |                                       |                                     |                                       |                                    |                                     |   |                                       |                                      |   |  |   | 89<br><b>Ac</b><br>actinium               | 90<br><b>Th</b><br>thorium<br>232.0     | 91<br><b>Pa</b><br>protactinium<br>231.0 | 92<br><b>U</b><br>uranium<br>238.0    | 93<br><b>Np</b><br>neptunium  | 94<br><b>Pu</b><br>plutonium         | 95<br><b>Am</b><br>americium         | 96<br><b>Cm</b><br>curium              | 97<br><b>Bk</b><br>berkelium        | 98<br><b>Cf</b><br>californium         | 99<br><b>Es</b><br>einsteinium      | 100<br><b>Fm</b><br>fermium        | 101<br><b>Md</b><br>mendelevium     | 102<br><b>No</b><br>nobelium          | 103<br><b>Lr</b><br>lawrencium       |  |  |  |



# Terms of atomic chemistry and physics

- ▶ Number of protons, neutrons, electrons and periodic table
- ▶ Isotopes, radioactivity
- ▶ Atomic weight, molecular weight
- ▶ Mole, molar solution, Avogadro's number



# Primary elements

- ▶ Main three biogenic elements: carbon (C), hydrogen (H), oxygen (O)
- ▶ Slightly less important are nitrogen (N) and phosphorus (P)
- ▶ Potassium (K), sodium (Na), calcium (Ca), magnesium (Mg): as cations, e.g.  $K^+$  or  $Ca^{2+}$
- ▶ Chlorine (Cl) and sulfur (S): used as anions, e.g.  $Cl^-$



# Microelements

- ▶ Play a lesser roles and used in lesser amounts (< 0.9%)
- ▶ These are: iron (Fe), silicon (Si), iodine (I), fluorine (F), selenium (Se), vanadium (V), manganese (Mn), boron (B), molybdenum (Mo), copper (Cu), nickel (Ni), zinc (Zn) and chromium (Cr)



# All biogenic elements

|                              |                              |    |    |                             |                              |                              |                              |                              |                              |                              |                              |                            |                              |                             |                              |                              |    |
|------------------------------|------------------------------|----|----|-----------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|----------------------------|------------------------------|-----------------------------|------------------------------|------------------------------|----|
| <b>1</b><br><b>H</b><br>1    |                              |    |    |                             |                              |                              |                              |                              |                              |                              |                              |                            |                              |                             |                              |                              | He |
| Li                           | Be                           |    |    |                             |                              |                              |                              |                              |                              |                              |                              | <b>5</b><br><b>B</b><br>11 | <b>6</b><br><b>C</b><br>12   | <b>7</b><br><b>N</b><br>14  | <b>8</b><br><b>O</b><br>16   | <b>9</b><br><b>F</b><br>19   | Ne |
| <b>11</b><br><b>Na</b><br>23 | <b>12</b><br><b>Mg</b><br>24 |    |    |                             |                              |                              |                              |                              |                              |                              |                              | Al                         | <b>14</b><br><b>Si</b><br>28 | <b>15</b><br><b>P</b><br>31 | <b>16</b><br><b>S</b><br>32  | <b>17</b><br><b>Cl</b><br>35 | Ar |
| <b>19</b><br><b>K</b><br>39  | <b>20</b><br><b>Ca</b><br>40 | Sc | Ti | <b>23</b><br><b>V</b><br>51 | <b>24</b><br><b>Cr</b><br>52 | <b>25</b><br><b>Mn</b><br>55 | <b>26</b><br><b>Fe</b><br>56 | <b>27</b><br><b>Co</b><br>59 | <b>28</b><br><b>Ni</b><br>59 | <b>29</b><br><b>Cu</b><br>64 | <b>30</b><br><b>Zn</b><br>65 | Ga                         | Ge                           | As                          | <b>34</b><br><b>Se</b><br>79 | Br                           | Kr |
| Rb                           | Sr                           | Y  | Zr | Nb                          | <b>42</b><br><b>Mo</b><br>96 | Tc                           | Ru                           | Rh                           | Pd                           | Ag                           | Cd                           | In                         | Sn                           | Sb                          | Te                           | <b>53</b><br><b>I</b><br>127 | Xe |
| Cs                           | Ba                           | La | Hf | Ta                          | W                            | Re                           | Os                           | Ir                           | Pt                           | Au                           | Hg                           | Tl                         | Pb                           | Bi                          | Po                           | At                           | Rn |
| Fr                           | Ra                           | Ac | Rf | Ha                          |                              |                              |                              |                              |                              |                              |                              |                            |                              |                             |                              |                              |    |



# Ionic bonds

- ▶ Based on electrostatic attraction
- ▶ Requires electron transfer from one to another atom
- ▶ Molecules with ionic bonds are normally well dissolved in water



# Covalent bonds

- ▶ Based on electron sharing
- ▶ Depending on strength, may be polar or non-polar



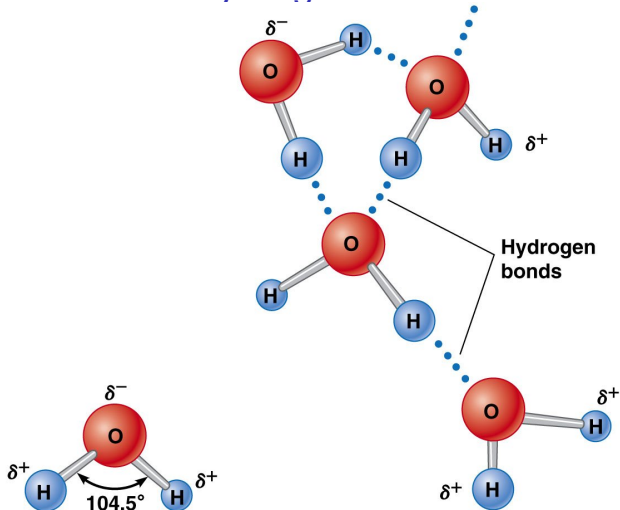
# Hydrogen bonds

- ▶ Molecule-to-molecule bonds
- ▶ Normally occurs between molecules with polar covalent bonds and appropriate size





# Water molecule and hydrogen bonds



**(a) Polarity of water molecule**

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**(b) Hydrogen bonding between water molecules**



# Water and its importance

- ▶ Universal solvent
- ▶ Water molecules are cohesive (water attracts water) and has high surface tension (pond-skaters may skate on water)
- ▶ Water molecules are adhesive (water attracts other materials)
- ▶ Water has high heat capacity (keeps warmth)
- ▶ Water is more dense than ice (water bodies are not completely frozen)



# Pond-skater



# Acids, bases and pH

- ▶ Molecules dissociates with hydrogen ion (or, in other model, hydronium ion) are acids
- ▶ Molecules dissociates with hydroxyl ion are bases
- ▶ Weak acids/bases have high frequency of reverse reaction
- ▶ pH represents the concentration of hydrogen ions, high pH ( $> 7$ ) corresponds with bases, low pH (1–5) corresponds with acids



# Hydrophobic “bonds”

- ▶ Inside water solutions, hydrophobic (non-solvable) molecules often united in groups
- ▶ This process is often called “hydrophobic” bonds



# Organic molecules

## Basics of organic chemistry



# Carbon and carbon skeleton

- ▶ Carbon atom has a small size and 4 electrons in the outer layer
- ▶ Consequently, it can form 4 bonds per atom, double and triple bonds, and may even form long chains of same element
- ▶ Other elements with similar features: silicon (same Group IV!), nitrogen, sulfur



# Bonds in organic molecules



Carbon  
(valence: 4)



Oxygen  
(valence: 2)



Hydrogen  
(valence: 1)



Nitrogen  
(valence: 3)

**(a)** Some biologically important atoms and their valences



Methane  
(CH<sub>4</sub>)



Ethanol  
(CH<sub>3</sub>—CH<sub>2</sub>OH)



Methylamine  
(CH<sub>3</sub>—NH<sub>2</sub>)

**(b)** Some simple organic molecules with single bonds



Ethylene  
(CH<sub>2</sub>=CH<sub>2</sub>)



Carbon dioxide  
(CO<sub>2</sub>)

**(c)** Some simple molecules with double bonds



Molecular nitrogen  
(N<sub>2</sub>)



Hydrogen cyanide  
(HCN)



Acetylene  
(CH≡CH)

**(d)** Some simple molecules with triple bonds





# Basic classes of organic molecules

- ▶ Hydrocarbons with single, double and triple bonds:  $C_nH_m$
- ▶ Aromatic hydrocarbons (arenes): benzene etc.
- ▶ Alcohols and phenols:  $R-OH$
- ▶ Ethers:  $R-O-R$
- ▶ Aldehydes:  $R-CHO$ ,  $R-C \begin{array}{l} \diagup H \\ \diagdown O \end{array}$
- ▶ Ketones:  $R-CO-R$ ,  $R-C \begin{array}{l} \diagdown O \\ \diagup R \end{array}$
- ▶ Carboxylic acids:  $R-COOH$ ,  $R-C \begin{array}{l} \diagup O \\ \diagdown OH \end{array}$
- ▶ Amines:  $R-NH_2$



# Basic groups of biochemical compounds

- ▶ Mono-, disaccharides (sugars) and polysaccharides: alcohols + ketons / aldehydes
- ▶ Fatty acids and lipids: hydrocarbons + carboxylic acids
- ▶ Amino acids and proteins: amines + carboxylic acids
- ▶ Nucleotides and nucleic acids: sugars + amines + phosphorous acid



# Final question (1 point)



## Final question (1 point)

Name one chemical element which is NOT biogenic



# Summary

- ▶ There are five main biogenic elements: carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and phosphorus (P)
- ▶ Ionic and covalent bonds are inter-atomic, hydrogen and hydrophilic bonds are inter-molecular
- ▶ Organic chemistry is a chemistry of carbon



# For Further Reading



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