

# Organic Chemistry –

The chemistry of the compounds of carbon.

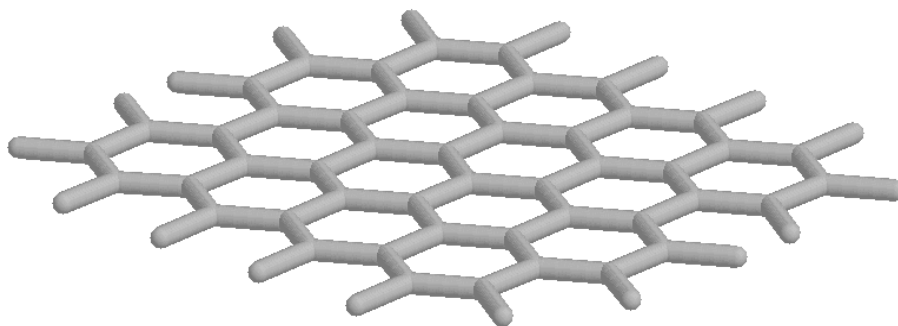
(Allotropic forms of carbon: diamond, graphite, fullerenes.)

Graphite —



Graphite and Clay

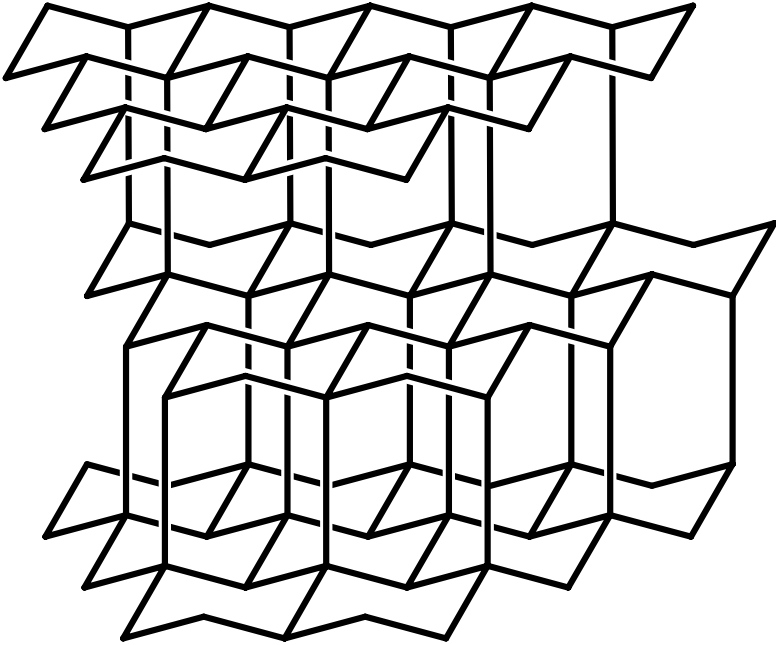
Graphite Structure



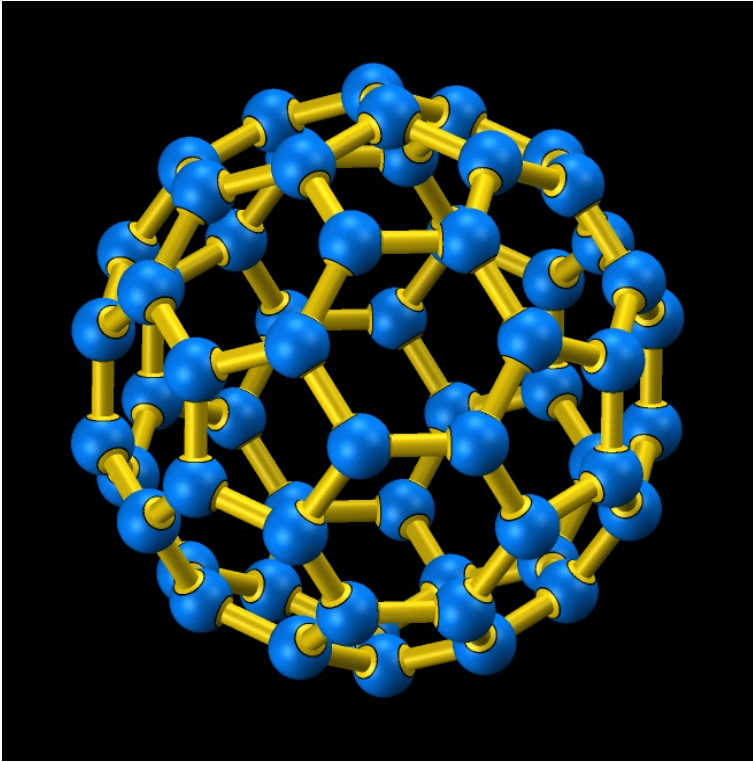
Diamond —



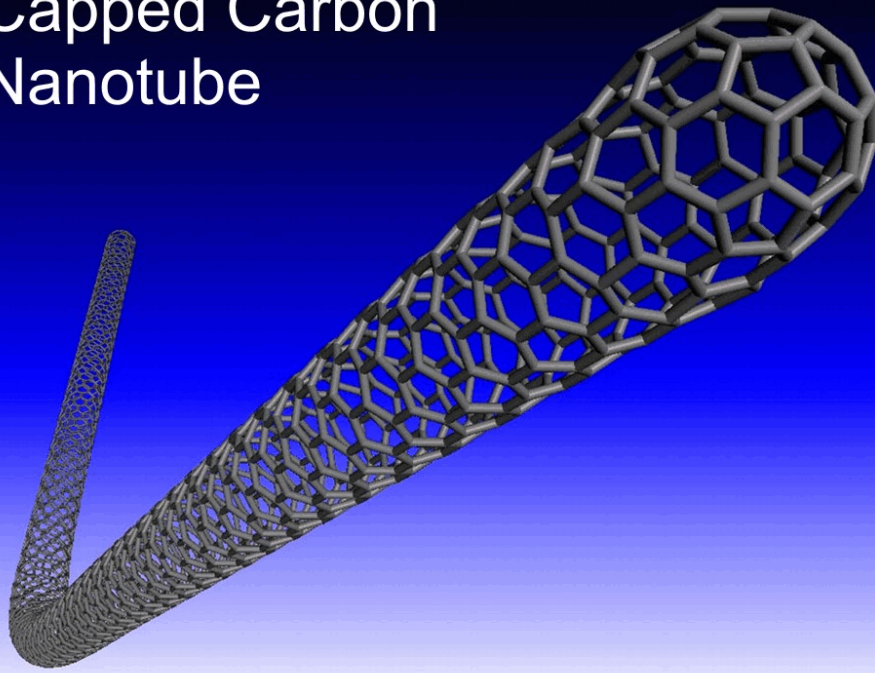
Diamond Structure —



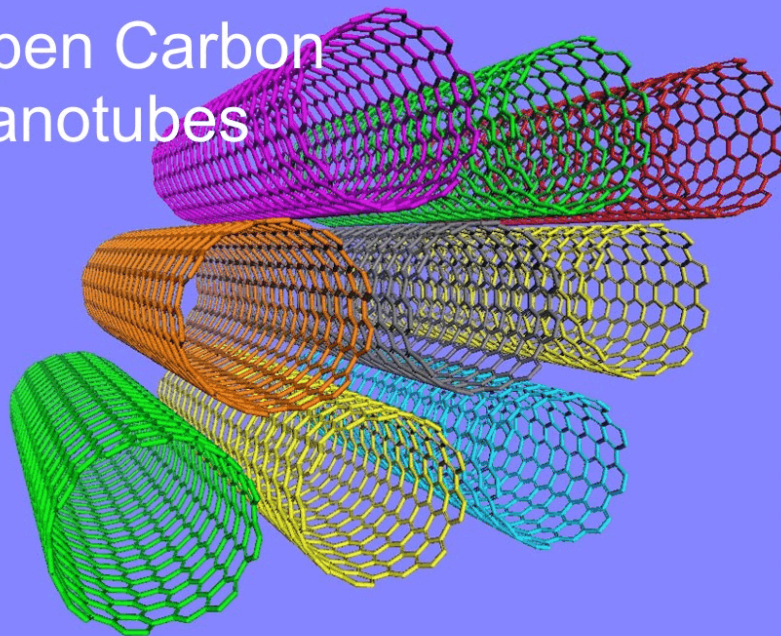
Buckminsterfullerene —



## Capped Carbon Nanotube



## Open Carbon Nanotubes



Inorganic Chemistry:

The chemistry of the other ~100 elements.

Historical reason for division:

The sources of chemicals for early chemical investigations (last quarter of 18th and first quarter of 19th centuries) were: animal, vegetable, mineral.

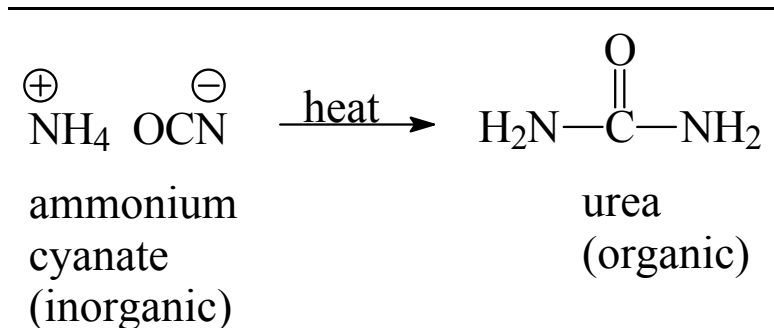
Organic chemicals, those from living organisms (animal, vegetable) were complex and contained C, H, and often N and/or O.

Inorganic chemicals (mineral) were simpler, could contain a variety of elements, but only rarely carbon, except for carbonates.

It seemed that inorganic sources of carbon (carbonate, cyanide, carbon dioxide, etc.) could not be converted into organic compounds. This led to —

Vital Force Theory: only living organisms can convert carbon containing inorganic compounds to organic compounds.

Friedrich Wöhler, 1828 –



Letter from Wöhler to Berzelius: "I must tell you that I can prepare urea without requiring a kidney or an animal ..."

Letter from Wöhler to Berzelius (1835):  
"Organic chemistry just now is enough to drive one mad. It gives me an impression of a primeval tropical forest, full of the most remarkable things, a monstrous and boundless thicket, with no way to escape, into which one may well dread to enter."

By 1850, general agreement that organic chemistry is the study of the compounds of carbon.

Contemporary reason for division:

Convenience of study —

~20 million known compounds; over 90% contain C.

(Fortunately, there are classes of organic compounds, each of which is characterized by a "functional group".)

Why so many organic compounds?

C has the almost unique ability to join to itself, as well as some "hetero" atoms (eg O, N, S) to form long chains. Si, also, can do this, but usually does not, and other atoms (eg O, N, S) apparently cannot.

Consider the *alkanes*, the simplest organic compounds, hydrocarbons with single bonds, only.

<u>Molecular Formula</u>	<u>Name</u>	<u>Structure (2-D, not 3-D)</u>
CH <sub>4</sub>	methane	$\begin{array}{c} \text{H} \\   \\ \text{H}-\text{C}-\text{H} \\   \\ \text{H} \end{array}$
C <sub>2</sub> H <sub>6</sub>	ethane	$\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}-\text{C}-\text{H} \\   \quad   \\ \text{H} \quad \text{H} \end{array}$
C <sub>3</sub> H <sub>8</sub>	propane	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$
C <sub>4</sub> H <sub>10</sub>	<div style="display: flex; align-items: center;"> <span style="font-size: 3em; margin-right: 10px;">{</span> <span>butane</span> </div>	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$
		<div style="display: flex; align-items: center;"> <span style="font-size: 3em; margin-right: 10px;">{</span> <span>isobutane</span> </div> $\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \\ \text{H} \quad \text{C} \quad \text{H} \\   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$

Same molecular formula, but different molecules:

*isomers.*

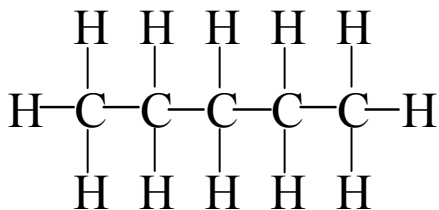
If molecules differ in regard to which atoms are attached to which: *constitutional* or *structural isomers.*

Molecular formula:  $C_5H_{12}$  — the pentanes; 3 constitutional isomers.

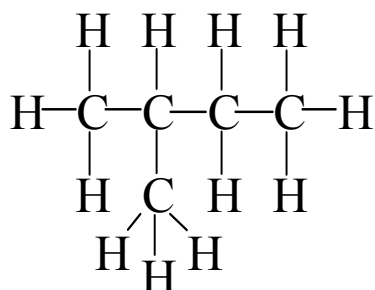
Name

Structure (2-D, not 3-D)

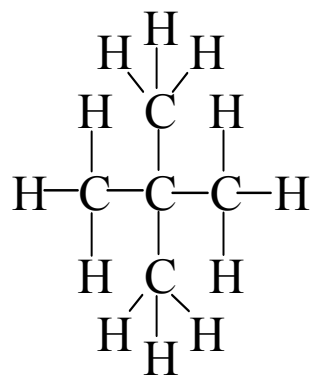
pentane



isopentane



neopentane



$C_6H_{14}$ : the hexanes; 5 constitutional isomers.  
 $C_7H_{16}$ : the heptanes; 9 constitutional isomers.  
 $C_8H_{18}$ : the octanes.  
 $C_9H_{20}$ : the nonanes.  
 $C_{10}H_{22}$ : the decanes; 75 constitutional isomers  
theoretically possible.

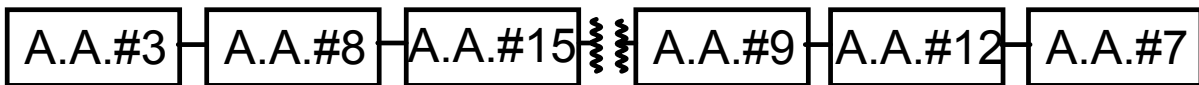
$C_{20}H_{42}$ : the eicosanes; 366,319 constitutional isomers  
theoretically possible (not all could be made; in some the  
atoms would be too close to each other for the molecule to  
be stable [*steric hindrance*]).

Proteins are macromolecules formed from *amino acid residue* units. Twenty different amino acids are found incorporated into proteins.

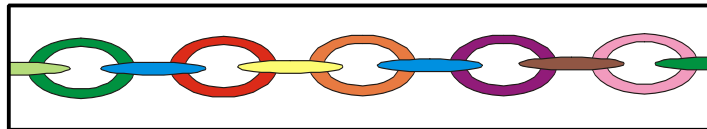
Amino Acids:

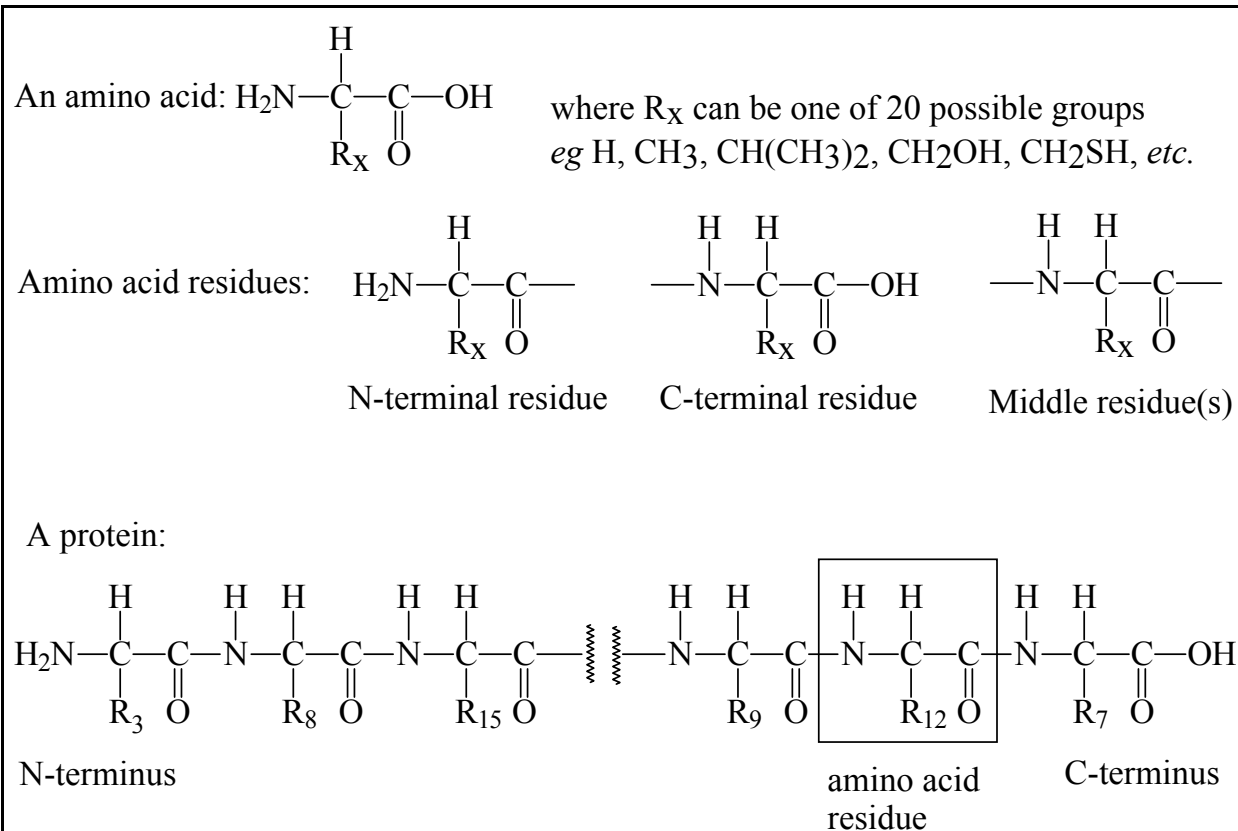


Amino Acid Residues Incorporated into a Protein:



AS AN ANALOGY, WE MIGHT IMAGINE THAT A PROTEIN MOLECULE IS LIKE A CHAIN WHERE THE LINKS ARE AMINO ACID RESIDUES. EACH OF THE LINKS IS ONE OF TWENTY COLORS, CORRESPONDING TO THE TWENTY DIFFERENT AMINO ACIDS.





Interchange of any two nonequivalent residues results in a different (structurally isomeric) protein.

Consider a protein having 120 amino acid residues; 20 different residues, 6 of each.

The total number of different (isomeric) protein molecules which could be formed merely by permutation of the amino acid residues is  $120!/(20!)^6 = 3.23 \times 10^{88}$ .

Assuming an average MW of the residues to be 100 Daltons, the MW of each protein molecule would be 12,000 Daltons, and a sample of 1 molecule of each isomer would have a mass of —

$\sim 6.45 \times 10^{65}$  kg.

Assuming a density of 1.0 gram/cubic centimeter, the sample would fill a cubic box

$\sim 9.13 \times 10^4$  light years on an edge,

which is approximately the diameter of the Milky Way.

Since the mass of the universe is believed to be on the order of  $10^{60}$  kg, an attempt to make all these isomers would consume all the known matter in the universe when fewer than 0.001% of them had been made.