

Applying Inquiry Skills

29. Hypothesis

- (a) One might logically hypothesize that double bonds should be longer and stronger than single bonds, and triple bonds longer and stronger yet, because more electron orbital density is between the nuclei. More electron density might make the bonds longer with more space required for more electrons but make the bond stronger because there is more electrostatic attraction of electrons and nuclei.

Analysis

- (b) According to the evidence provided, the order of bond length, from shortest to longest is triple, double, and then single bonds. The order of bond strength, from weakest to strongest is single, double, and then triple bonds. Single bonds are the longest but the weakest, and triple bonds are the shortest but the strongest.

Evaluation

- (c) The hypothesis is verified for bond strength, but not for bond length. The reasoning based on electron density appears acceptable for bond strength but does not appear correct for bond lengths. (Note that the reasoning did not take into account the shapes and directions of the *p* orbitals forming the pi bonds.)

Making Connections

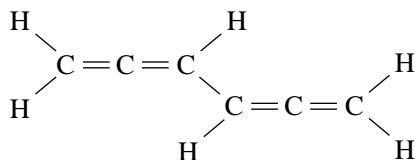
30. (Student reports should contain the following information.)

- (a) Infrared spectroscopy is based on the frequencies absorbed by the internal vibrations of molecules—that is, the vibration of atoms on either side of a bond.
- (b) Each type of bond has a specific vibrational frequency which varies slightly depending on the other atoms in the molecule. Therefore, a unique compound has a unique set of frequencies that it will absorb which allow it to be uniquely identified.
- (c) This technique is used in analysis in medical, pharmaceutical, sports, and industrial chemical laboratories, to name a few.

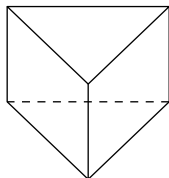
CASE STUDY: THE STRANGE CASE OF BENZENE

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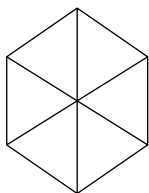
- (d) Benzene is found in coal tar and also in the combustion products of natural materials. Technologically, benzene is produced by the catalytic re-forming of petroleum and is also made from toluene ($\text{C}_6\text{H}_5\text{CH}_3$, or methylbenzene).
- (e) More than half of all benzene is used to produce styrene (phenylethene or vinyl benzene) which is the monomer for the plastic polystyrene. Benzene is also used to make detergents, pharmaceuticals, pesticides, and explosives.
- (f) Couper and Loschmidt proposed the following non-cyclic structure but could not provide any empirical support.



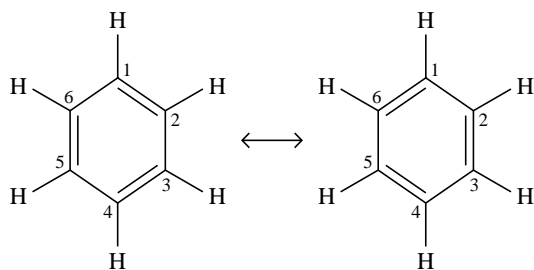
- Ladenburg tried to explain the chemical reactivity of benzene by proposing a prism-type structure.



- Clause also tried to explain the properties of benzene using a hexagon of carbon atoms with diagonal bonds between opposite carbon atoms.



- Kekulé initially proposed that a benzene molecule is a ring of six carbon atoms with alternating single and double covalent bonds. However, he later realized that the chemical reactivity of benzene could be better explained as two possible structures with their double bonds in different locations. Kekulé suggested that these two structures are in a very rapid equilibrium so that there is no fixed location for a particular double bond.



- (g) According to modern theory, each carbon atom in benzene is bonded to two adjacent carbons (in the ring) and one hydrogen using the three sp^2 hybrid orbitals to form sigma bonds. Each of the six carbon atoms has a half-filled p orbital (perpendicular to the plane of the ring) which overlaps with adjacent p orbitals. The six p orbitals overlap above and below the plane of the carbon atoms. In modern terms, the p electrons are delocalized around the ring. This is a particularly stable arrangement. (This description actually describes only one of three molecular orbitals for benzene, each containing two paired electrons.)

4.3 VSEPR THEORY

Try This Activity: Electrostatic Repulsion Model

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- Two balloons are at about 180° to each other (a linear arrangement).
- Three balloons are at about 120° to each other and all in one plane (a trigonal planar arrangement).
- Four balloons are at about 109° to each other with each one pointing to one corner of a tetrahedron (a tetrahedral arrangement).
- Balloons let you visualize electron orbitals and how they might be arranged. The electrostatic repulsion is modelled by the balloons pushing equally against each other. A disadvantage of the balloon model is that electron orbitals are not physical objects of a fixed size. A balloon only contacts or “repels” where it touches another balloon. Electrostatic repulsion occurs to varying extents between all electrons in the two nearby orbitals. In other words, the repulsion is much more complicated than implied by the two touching balloons.

PRACTICE

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Understanding Concepts

- VSEPR is an acronym for valence shell electron pair repulsion — a theory that predicts molecular shape by assuming that repulsion between all pairs of electrons in the valence shell of an atom controls the direction of those pairs formed by bonding, and thus determines the shapes of molecules.
- $\text{I} - \text{Be} - \text{I}$ linear
 - pyramidal
 - V-shape