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ABSTRACT

This booklet, one of a series of 17 developed at Prince George's Community College, Largo, Maryland, provides an individualized, self-paced undergraduate organic chemistry instruction module designed to augment any course in organic chemistry but particularly those taught using the text "Organic Chemistry" by Morrison and Boyd. The entire series of modules covers the first 13 chapters of the Morrison-Boyd text in great detail. Each module has been provided with from one to three audiotapes, available from Prince George's Community College, to provide students additional explanations of particular concepts. Each module includes a self-evaluation exercise, a reference guide, worksheets to be completed with the audiotapes, answer sheets for the worksheets, a progress evaluation, an answer sheet for the progress evaluation, an answer sheet for the self-evaluation exercise, an introduction to the topic covered by the module, and student performance objectives for the module. The topic of this module is alkanes: homologous series and isomerism. (SL)

ORGANIC CHEMISTRY

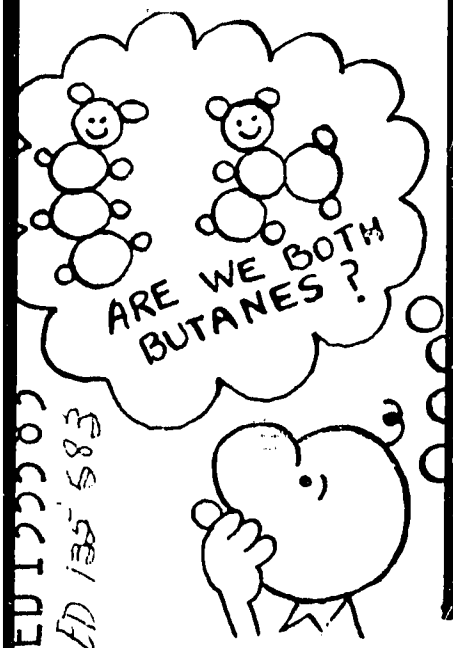
V. Zdravkovich

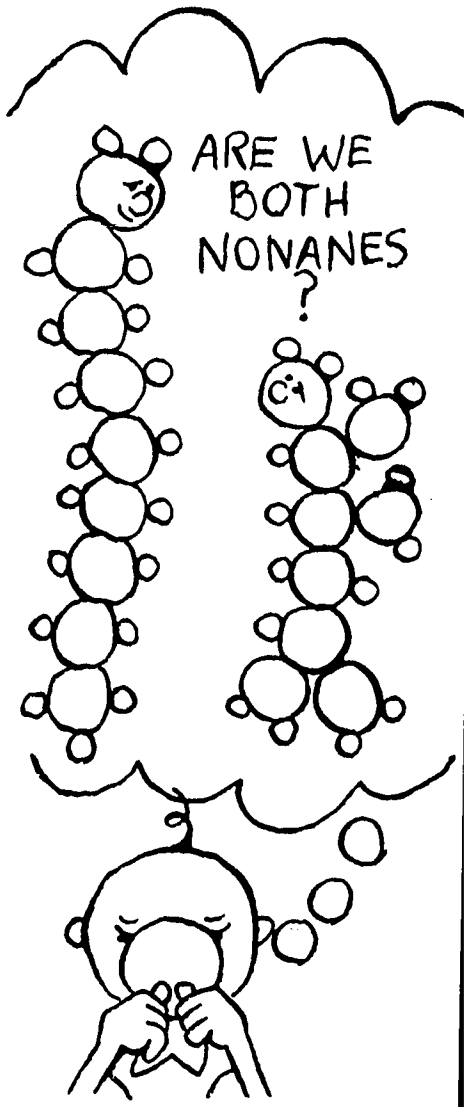
3

Self

Instructional

Package





ALKANES-HOMOLOGOUS SERIES AND ISOMERISM

Self Instructional Sequence in

ORGANIC CHEMISTRY

ALKANES

HOMOLOGOUS SERIES AND ISOMERISM

For centuries, the accepted concept was that the composition of a substance uniquely defined the structure of that substance. It was inconceivable to the chemists of that era that two substances might have the same molecular formula and yet possess different physical and sometimes, different chemical, properties.

In 1830, only three years after Wöhler sired the field of organic chemistry by synthesizing urea in the laboratory, he discovered and identified fulminic acid as the product of the decomposition of urea. At the same time, Justus Liebig identified cyanic acid.

Liebig and Wöhler -two scientists quite different in temperament- were drawn together by their interest in these two acids. Both acids possessed the same molecular formula, and yet they showed striking differences in their physical and chemical behavior. The only reasonable explanation for this, was that the arrangement of their atoms was perhaps different, or that their structure was different. That marked the birth of the structural theory of organic chemistry and the concept of isomerism.

Although many chemists, including Berzelius -who was one of the greatest- were unwilling to acknowledge this for several years, it's significance in explaining the properties of organic compounds could not be ignored.

The object of this S.I.P. is to introduce you to the field of isomerism which was discovered nearly 140 years ago.

Self Instructional Package No. 3
Form A - List of Objectives

ALKANES - HOMOLOGOUS SERIES AND ISOMERISM

DEFINITIONS -

The student will be able to define and to illustrate with an example the following terms: STRUCTURAL ISOMERS, CONFORMATIONAL ISOMERS, PRIMARY, SECONDARY, TERTIARY AND QUATERNARY CARBON ATOMS, HOMOLOGOUS SERIES AND HOMOLOGS, STAGGERED AND ECLIPSED CONFORMATIONS.

ISOMERISM -

The student will be able to identify the structural isomers from the given set of structures.

The student will be able to draw all the structural isomers for a given alkane.

The student will be able to distinguish between the structural and the conformational isomers.

The student will be able to draw a potential energy diagram for the conformational isomers of an alkane.

The student will be able to correlate the conformational isomers of an alkane with the given potential energy diagram.

The student will be able to predict the relative stabilities of the conformational isomers of an alkane.

Self Instructional Package No. 3
Form B - Self Evaluation Exercise

ALKANES - HOMOLOGUE SERIES AND ISOMERISM

1. The molecular formula which corresponds to an alkane is:

   a) C_4H_8

   b) C_5H_{12}

   c) C_3H_4

   d) $C_{12}H_{24}$

2. You are given four compounds - their molecular formula and the name. Identify the set containing an error.

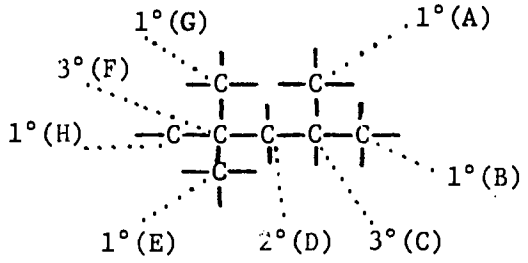
   a) C_4H_{10} - BUTANE

   b) C_5H_{12} - PROPANE

   c) $C_{10}H_{22}$ - DECANE

   d) C_7H_{16} - HEPTANE

3. In a compound given below all the carbons were identified as PRIMARY, SECONDARY, TERTIARY AND QUATERNARY. The one which is mislabeled is:



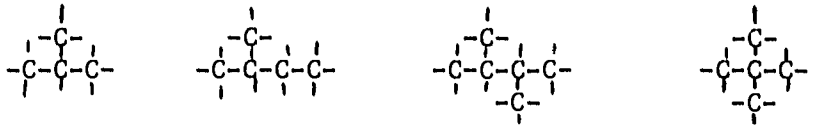
   a) A

   b) C

   c) D

   d) F

4. Identify a pair of structural isomers from the series of alkanes listed below.



I II III IV

a) I and III

b) II and IV

c) I and II

d) III and IV

5. The two species which have the same molecular formula but different physical properties and similar chemical properties are considered:

a) conformational isomers

b) homologs

c) structural isomers

d) identical

6. Identify the correct statements about structural and conformational isomers.

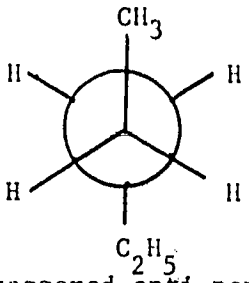
a) structural isomers are non-superimpossible species

b) conformational isomers are non-superimpossible

c) conformational isomers have the same physical properties

d) conformers can be interconverted into each other

7. The Newman projection below represents:



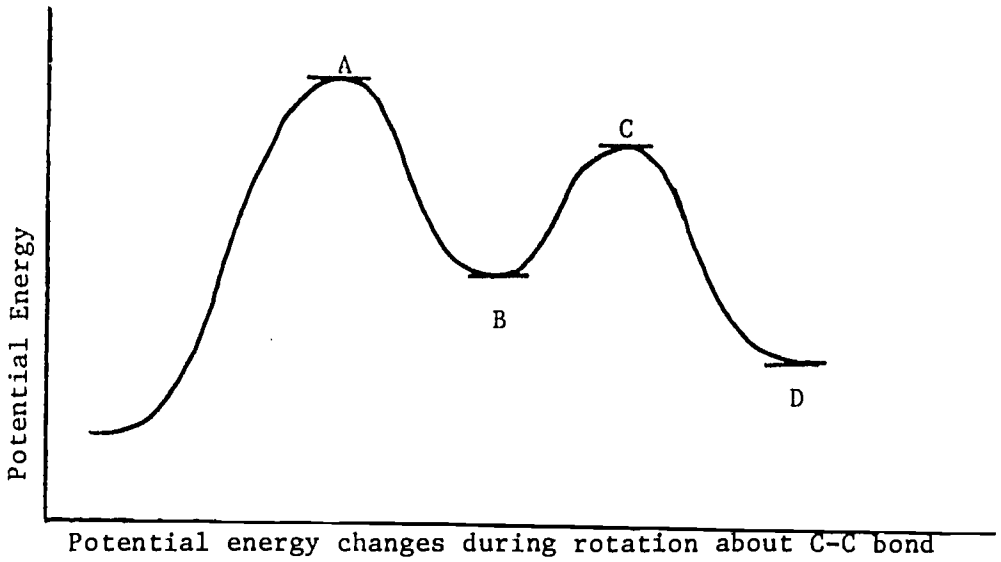
a) staggered anti pentane

b) eclipsed anti pentane

c) staggered anti butane

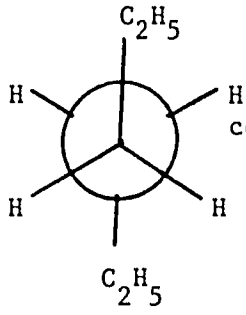
d) eclipsed gauche butane

8. To arrive at the correct answer for questions 8 and 9, use diagram given below:



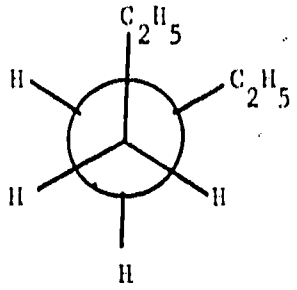
The conformational isomer:
to potential energy level:

a) A b) B c) C d) D



corresponds

SIP #3
Form B - Self Evaluation Exercise

9. The conformational isomer 

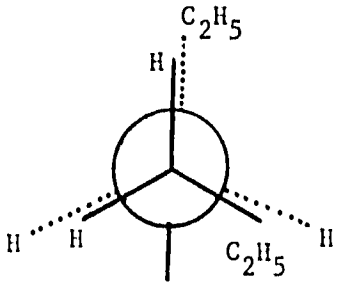
corresponds to potential energy level:

a) A

b) B

c) C

d) D

10. The conformational isomer 

corresponds to potential energy level:

a) A

b) B

c) C

d) D

Self Instructional Package No. 3
Form C - Reference Guide

ALKANES - HOMOLOGUE SERIES AND ISOMERISM

The reference guide should be used in conjunction with Form B or the Self Evaluation Exercise. The references provide the correlation between the questions in Form B and the available material in the textbook and in the form of tapes.

Questions 1, 2, 4	Chapter 3, Section 4	MORRISON & BOYD - Organic Chemistry
Question 3	Chapter 3, Section 11	
Questions 5, 6	Chapter 3, Sections 3, 4, 5	
Questions 7, 8, 9, 10	Chapter 3, Sections 4, 5	

Tape I with the accompanying worksheet and answer sheet titled, "Alkanes and Structural Isomerism".

Tape II with the accompanying worksheet and answer sheet titled, "Alkanes-Conformational Isomerism".

Self Instructional Package No. 3
Tape 1 - Work Sheet

Go, wondrous creature! mount where
Science guides;
Go, measure earth, weigh air, and state
the tides;
Instruct the planets in what orbs to run,
Correct old Time, and regulate the sun...
Go, teach Eternal Wisdom how to rule -
Then drop into thyself, and be a fool!
Alexander Pope

ALKANES

Homologue Series and Structural Isomerism

Example No. 1

methane	CH_4	
ethane	C_2H_6	$\}$ CH_2
propane	C_3H_8	$\}$ CH_2
butane	C_4H_{10}	$\}$ CH_2
pentane	C_5H_{12}	

homologue series - definition:

Assignment No. 1

Draw structures of the following compounds:

a) octane C_8H_{18}

b) hexane C_6H_{14}

c) decane $C_{10}H_{22}$

SIP No. 3
Tape 1 - Work Sheet

Assignment No. 2

The general formula for any ALKANE is:

Assignment No. 3

Write the molecular formula for the following alkanes:

dodecane (12C)

heptane (7C)

pentadecane (?C)

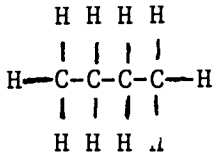
Assignment No. 4

In the list of compounds given below, identify a) the hydrocarbons and b) the alkanes. For each alkane supply its correct name.

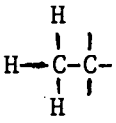
	Hydrocarbon	Alkane
CH_3Br		
C_7H_{16}		
C_8H_{18}		
C_9H_{16}		
$C_5H_{10}OH$		
C_3H_7F		
C_6H_{14}		
C_3H_8		

SIP No. 3
Tape 1 - Work Sheet

Example No. 2

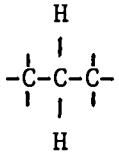


1°2°2°1°



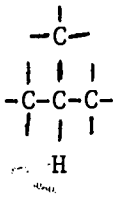
1°

primary carbon atom



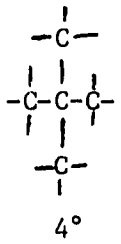
2°

secondary carbon atom



3°

tertiary carbon atom

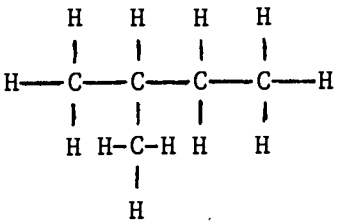


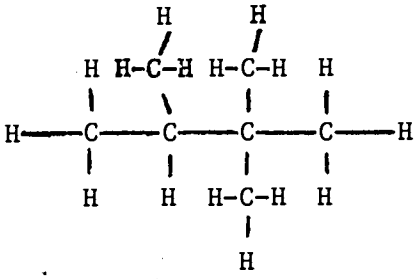
4°

quaternary carbon atom

Assignment No. 5

In the two alkanes below identify the PRIMARY, SECONDARY, TERTIARY and QUATERNARY carbon atoms. Write their molecular formula and assign their names.

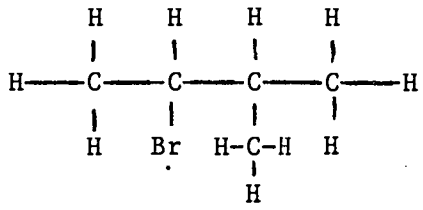


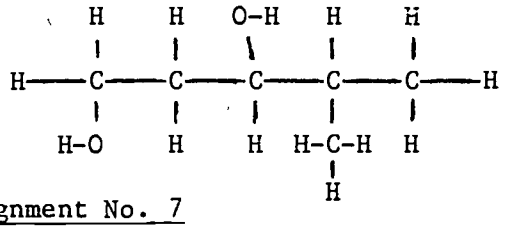


SIP No. 3
Tape 1 - Work Sheet

Assignment No. 6

In the structural formulas of the two organic compounds given below, identify each carbon atom as: PRIMARY, SECONDARY, TERTIARY, OR QUATERNARY.





Assignment No. 7

Draw the structures of the following two alkanes:

A - has five primary carbon atoms, one tertiary carbon atom and one quaternary carbon atom.

B - has four primary carbon atoms, one secondary carbon atom and two tertiary carbon atoms.

Structural formulas of the two butanes from Slide No. 4:

STRUCTURAL ISOMERS are compounds which have the same molecular formula but different structure.

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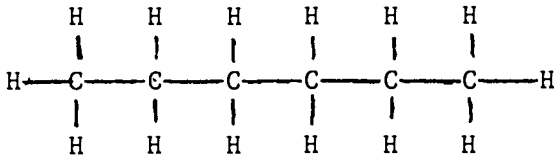
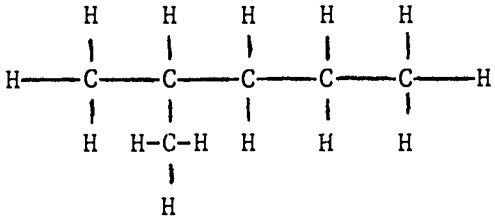
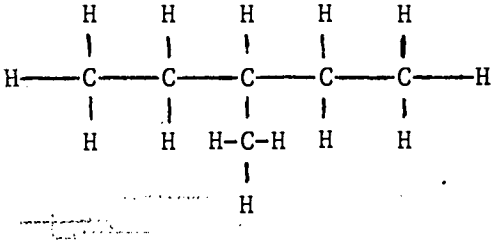
SIP No. 3
Tape 1 - Work Sheet

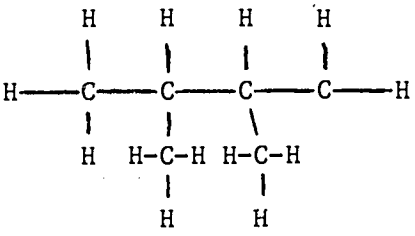
Assignment No. 7 (continued)

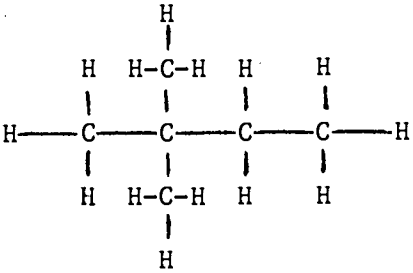
Example No. 3







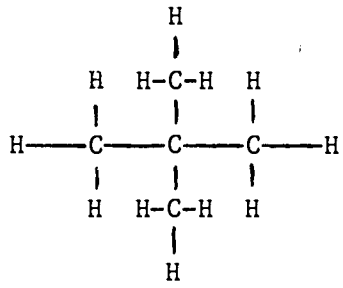


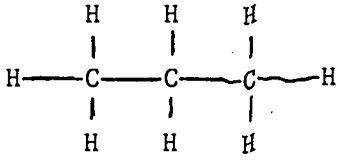


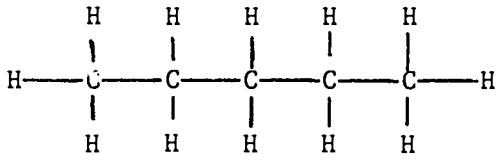
SIP No. 3
Tape 1 - Work Sheet

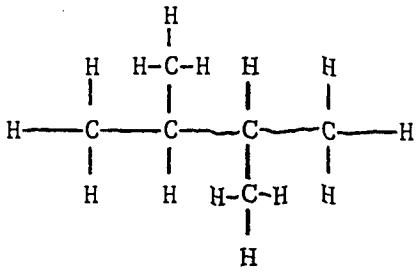
Assignment No. 8

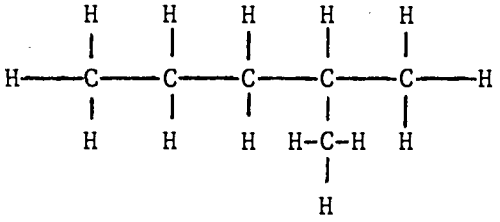
Identify the structural isomers among the structural formulas of the alkanes below.

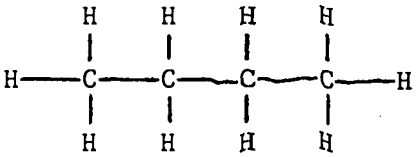
a) 

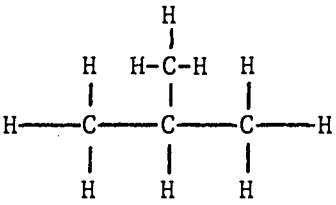
b) 

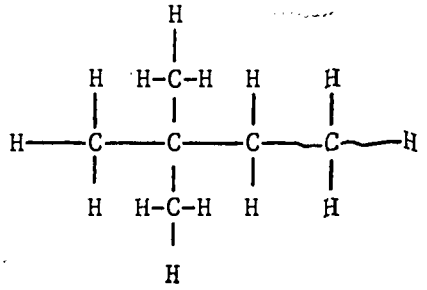
c) 

d) 

e) 

f) 

g) 

h) 

Assignment No. 9

Draw all the possible structural isomers of: a) pentane, b) hexane, and c) octane.

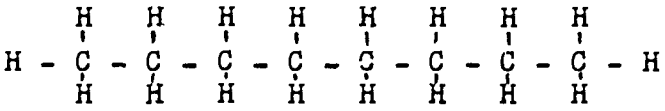
Self Instructional Package 3
Tape 1 - Answer Sheet

ALKANES

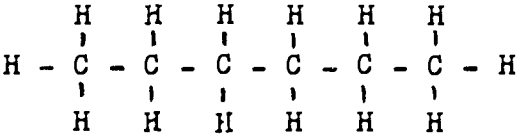
Example 1. Homologue series - definition: A series of compounds in which each member differs from the next member by a constant amount.

ASSIGNMENT 1. Draw structures of the following compounds:

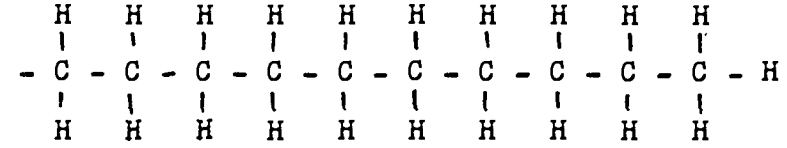
a) Octane C_8H_{18}



b) Hexane C_6H_{14}



c) Decane $C_{10}H_{22}$



ASSIGNMENT 2. The general formula for an ALKANE is:

C_nH_{2n+2}

ASSIGNMENT 3. Write the molecular formula for the following alkanes:

Dodecane (12 C) $C_{12}H_{26}$

Heptane (7 C) C_7H_{16}

Pentadecane (? C) $C_{\quad}H_{32}$

ASSIGNMENT 4. In the list of compounds given below, identify a) the hydrocarbons and b) the alkanes. For each alkane, supply its correct name.

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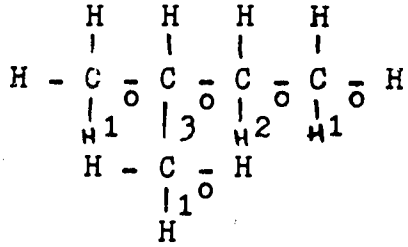
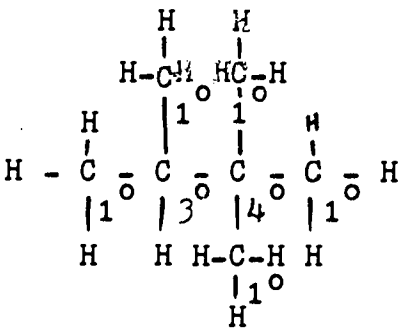
ASSIGNMENT 4. continued

	Hydrocarbon	Alkane	Name
CH_3Br			
C_7H_{16}	✓		Heptane
C_8H_{18}	✓	✓	Octane
C_9H_{16}	✓		
$C_5H_{10}OH$			
C_3H_7F			
C_6H_{14}	✓	✓	Hexane
C_3H_8	✓	✓	Propane

ASSIGNMENT 5. In the two alkanes below, identify the PRIMARY, SECONDARY, TERTIARY and QUATERNARY carbon atoms. Write their molecular formula and assign their names.

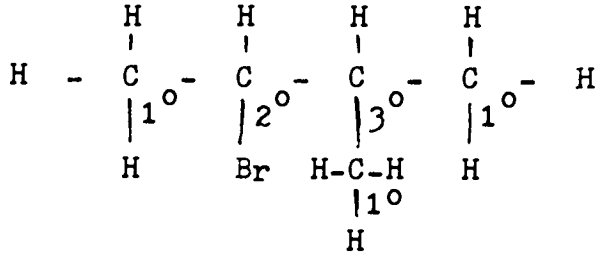


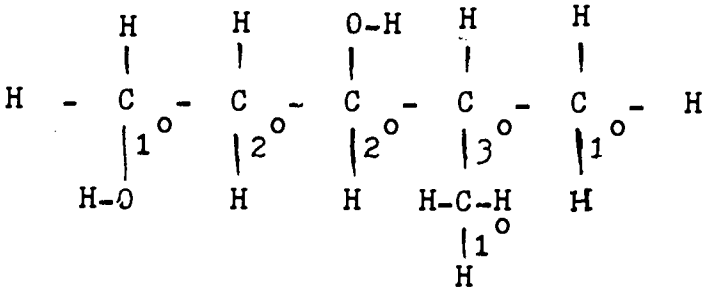
C_5H_{12} - Pentane



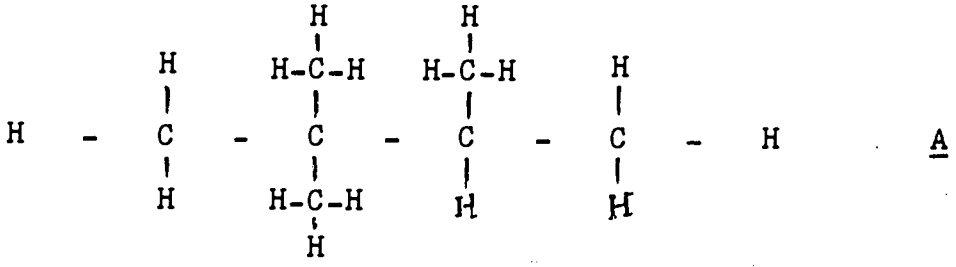
C_7H_{16} - Heptane

ASSIGNMENT 6. In the structural formulas of the two organic compounds given below, identify each carbon as: PRIMARY, SECONDARY, TERTIARY, or QUATENARY.



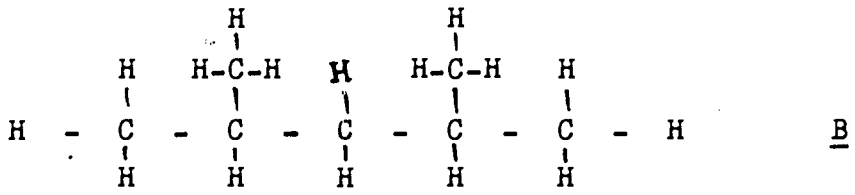


ASSIGNMENT 7. Draw the structures of the following two alkanes:
A - has five primary carbon atoms, one tertiary carbon atom and one quaternary carbon atom.
B - Has four primary carbon atoms, one secondary carbon atom and two tertiary carbon atoms.



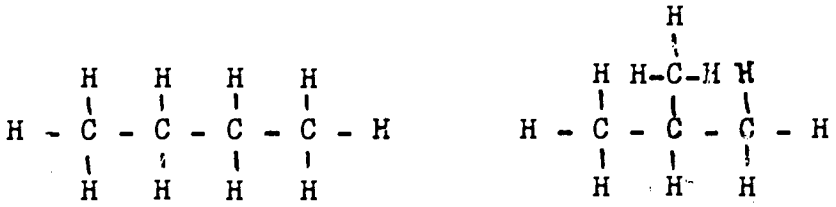
A

ASSIGNMENT 7. continued



B

Structural formulas of the two butanes from slide no. 4:



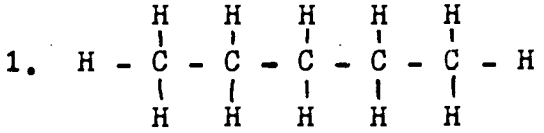
ASSIGNMENT 8. Identify the structural isomers among the structural formulas of the alkanes below:

a and c
e and h and d
g and f

ASSIGNMENT 9. Draw all the possible structural isomers of a) pentane, b) hexane c) octane.

Pentane

1.



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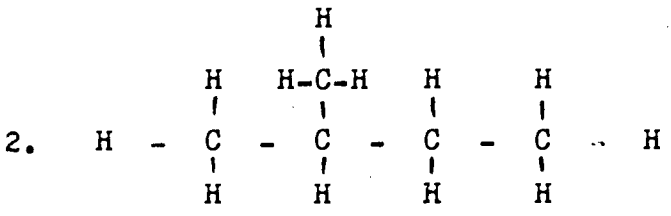
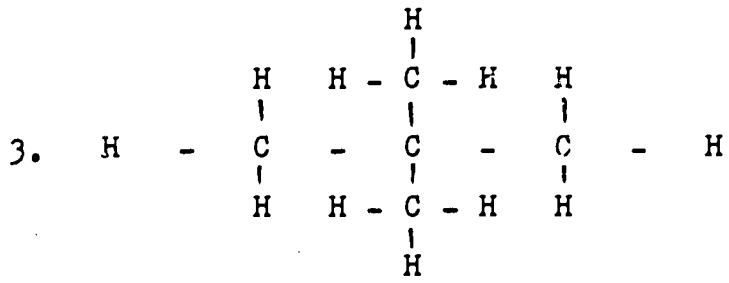


20

ASSIGNMENT 9. continued

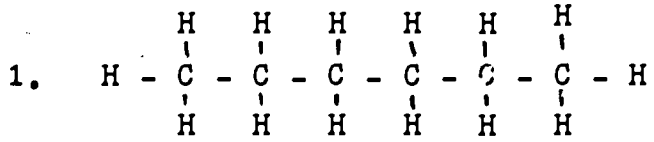
Pentane cont.

3.

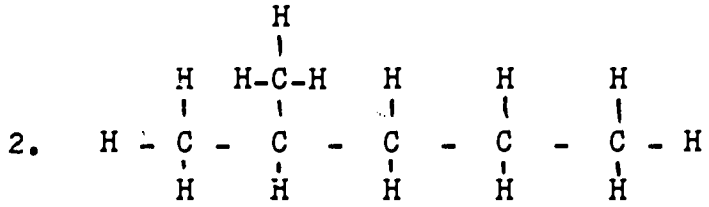


Hexane

1.



2.



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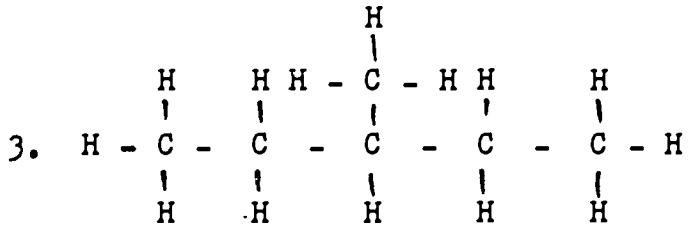

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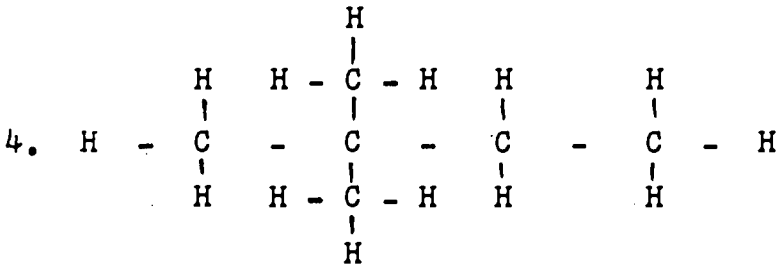
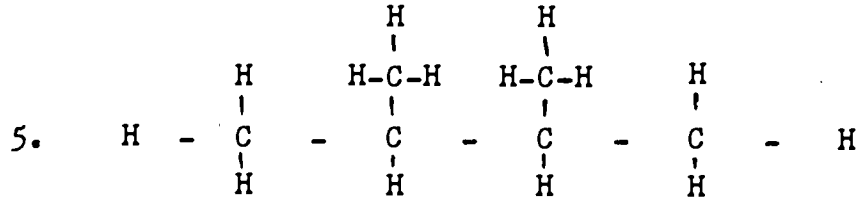


ASSIGNMENT 9. continued

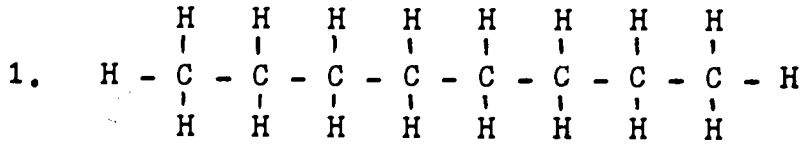
Hexane cont.

5.



Octane

1.



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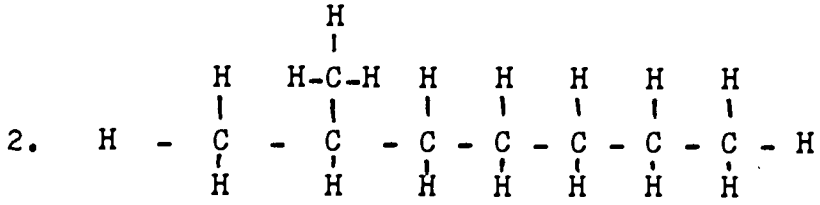

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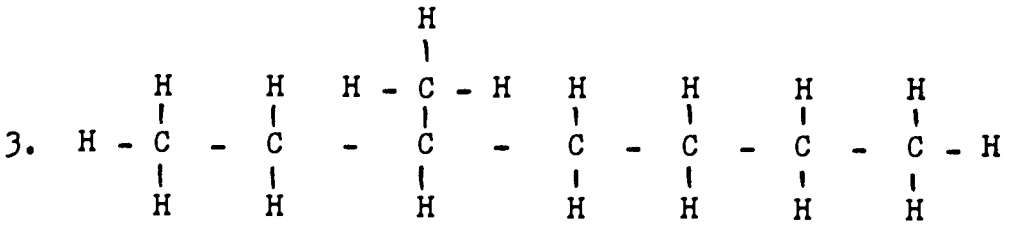

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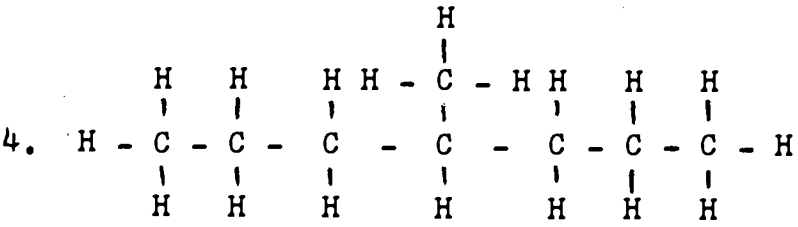
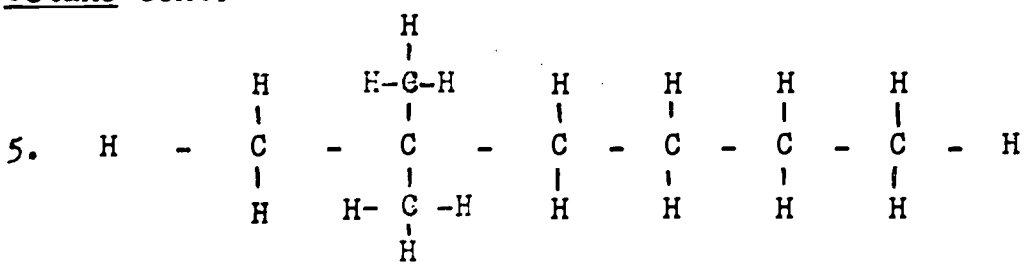


ASSIGNMENT 9. continued

Octane cont.

5.



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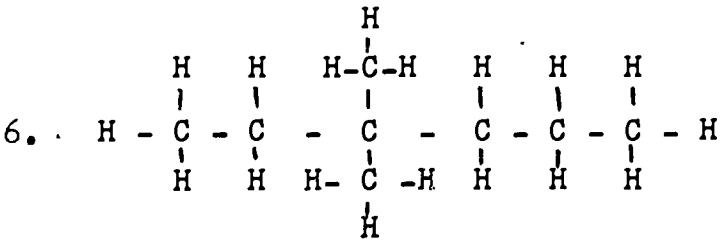

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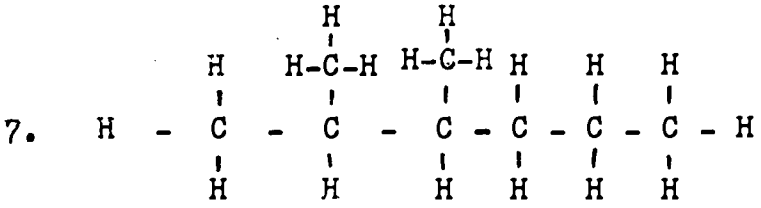

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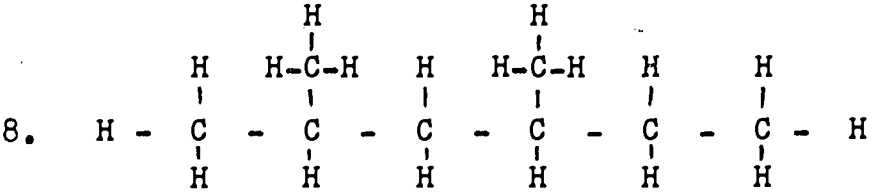

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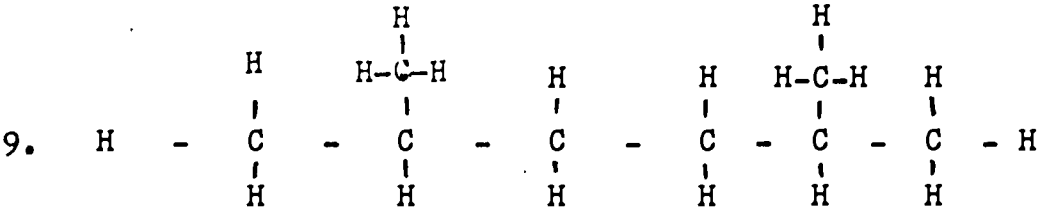
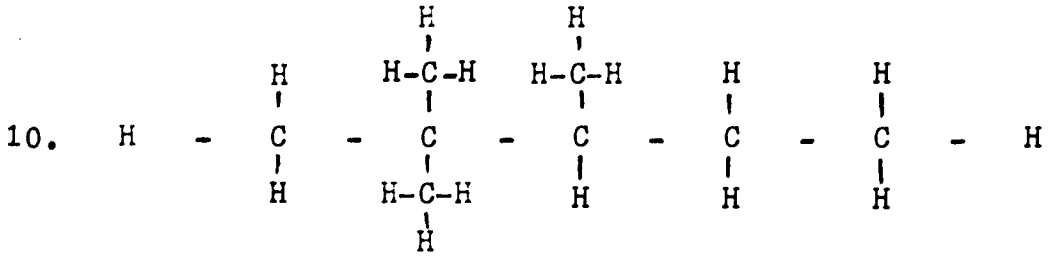


ASSIGNMENT 9. continued

Octane cont.

10.



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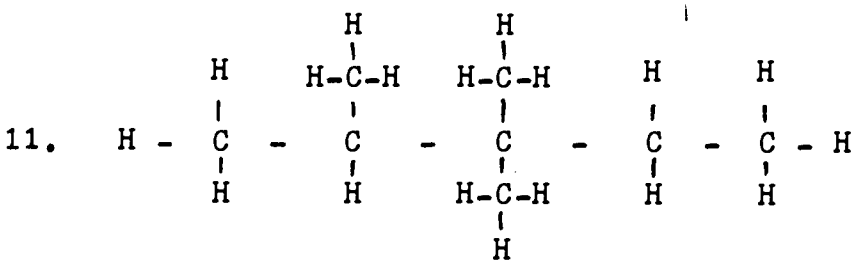

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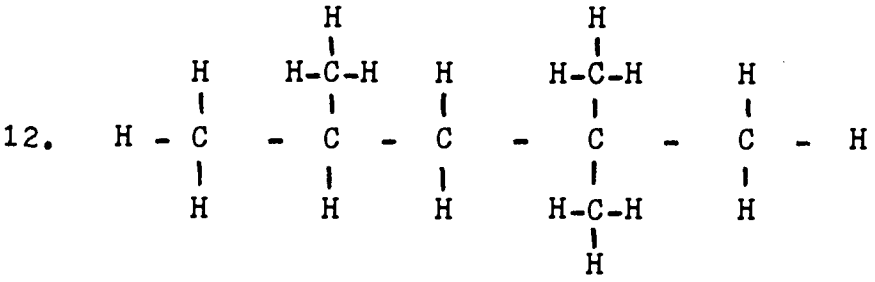

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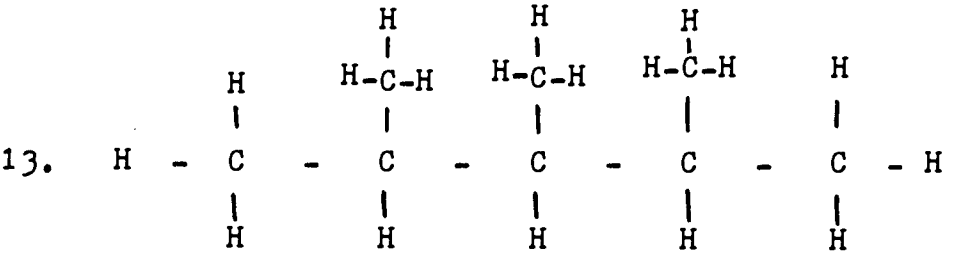
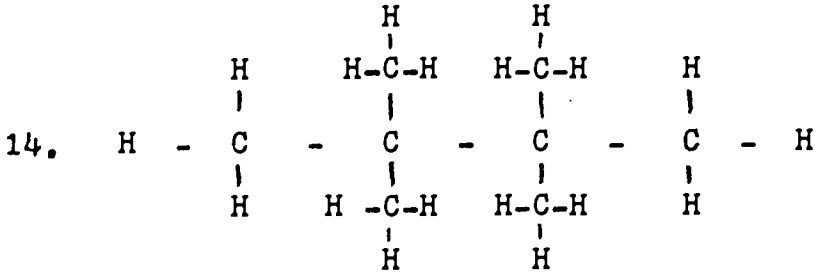


ASSIGNMENT 9. continued

Octane cont.

14.

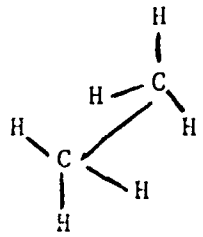


Nothing can be loved or hated unless it is first known. Leonardo da Vinci (c 1500)

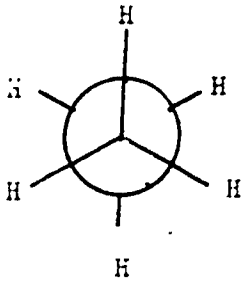
ALKANES

Conformational Isomerism

Example No. 1



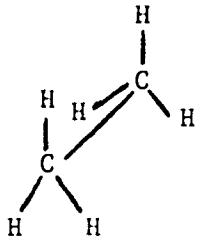
or



staggered ethane

"sawhorse formula"

"Newman projection"



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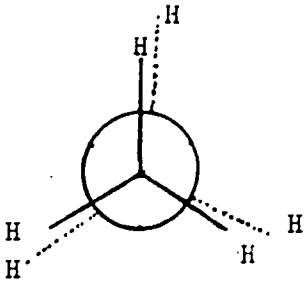


eclipsed ethane

Newman projections of the propane molecule:

staggered propane

eclipsed propane

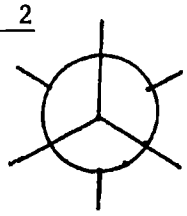
The difference between staggere and eclipsed propane as compared to staggered and eclipsed ethane i

SIP No. 3
Tape 2 - Work Sheet

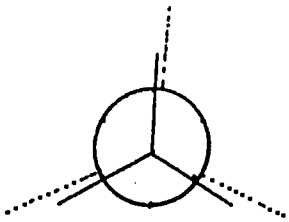
Assignment No. 1

Draw the conformational isomers of n-butane resulting from the free rotation around the bond between carbon atom No. 1 and carbon atom No. 2.

Example No. 2

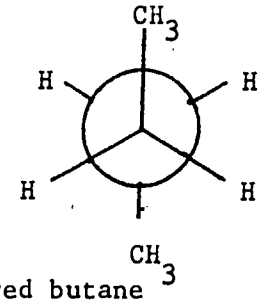


staggered conformation

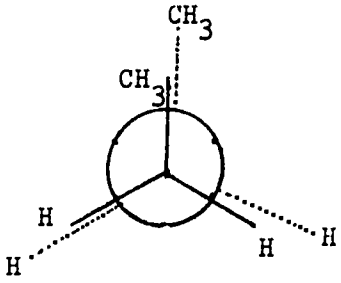


eclipsed conformation

Example No. 3

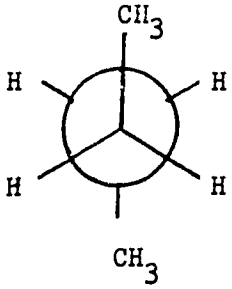


staggered butane

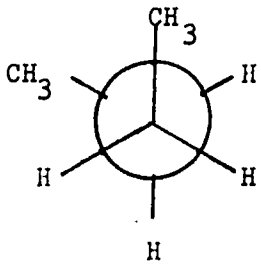


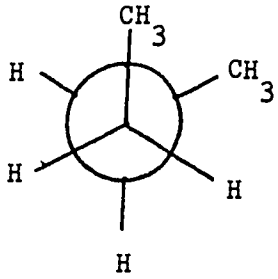
eclipsed butane

Example No. 4



staggered "anti" butane





staggered "gauche" butanes

SIP No. 3
Tape 2 - Work Sheet

Assignment No. 2

Draw Newman projections and name all the possible conformational isomers of the eclipsed butane resulting from the rotation about the bond between carbon atom no. 2 and carbon atom no. 3.

Assignment No. 3

Draw all the possible conformational isomers of the n-pentane which result from the free rotation around the bond between carbon atom no. 2 and carbon atom no. 3.

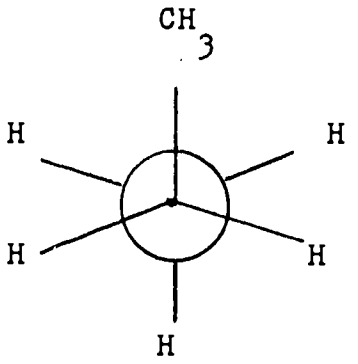
Assignment No. 4

Assign the relative stabilities (i.e. identify the isomers with maximum and minimum stabilities and the ones with the same stability) to all the conformational isomers in Assignment No. 3.

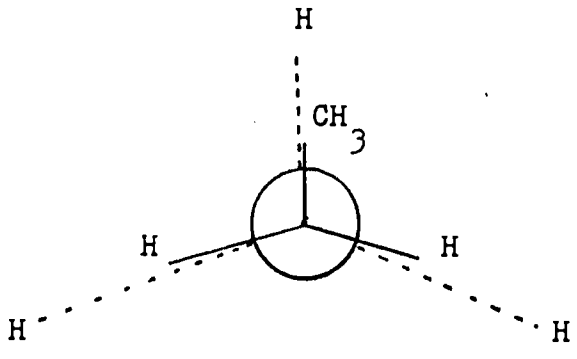
Self Instructional Package 3
Tape 2 - Answer Sheet

ALKANES - CONFORMATIONAL ISOMERISM

Example 1. Newman projections of the propane molecule:



Staggered propane

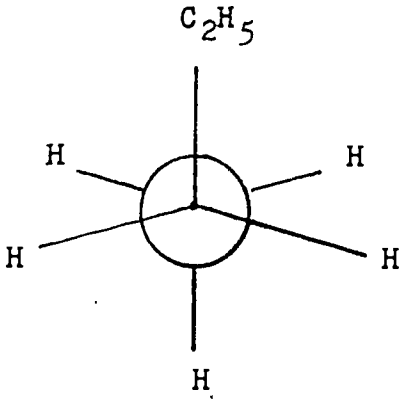


Eclipsed propane

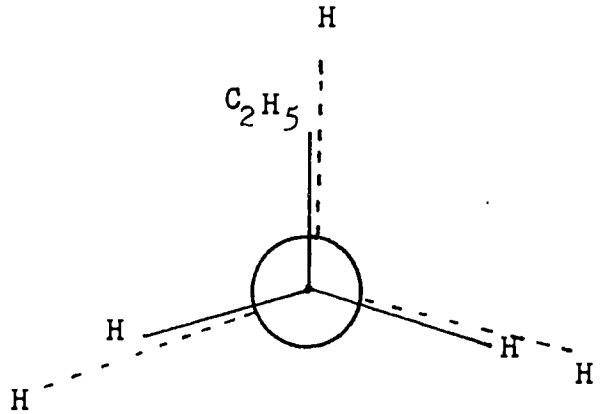
The difference between staggered and eclipsed propane as compared to staggered and eclipsed ethane is:

all bonds in ethane are saturated with H atoms. Five of the bonds in propane are saturated with H atoms and one ends with a methyl - CH_3 - group.

ASSIGNMENT 1. Draw the conformational isomers of n-butane resulting from the free rotation around the bond between carbon atom no. 1 and carbon atom no. 2.

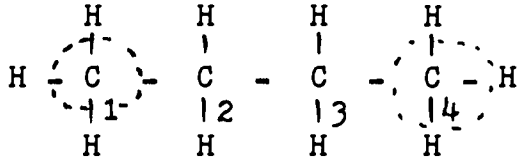


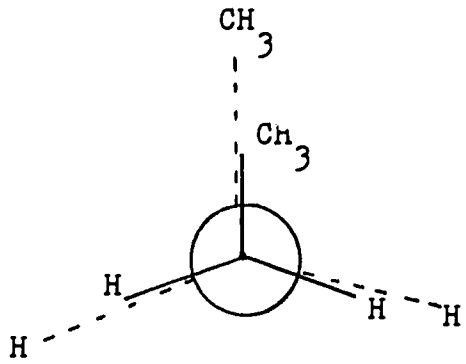
Staggered conformation



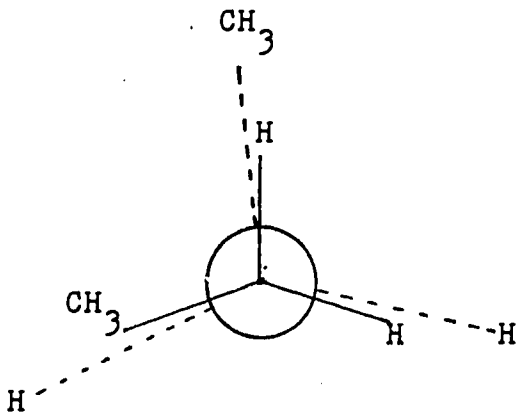
Eclipsed conformation

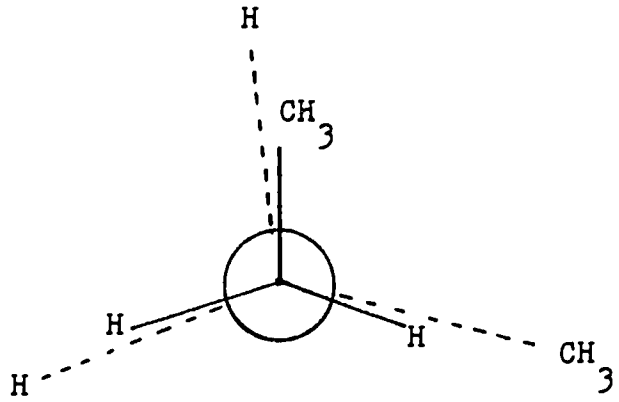
ASSIGNMENT 2. Draw Newman projections and name all the possible conformational isomers of the eclipsed butane resulting from the rotation about the bond between carbon atom no. 2 and carbon atom no. 3.





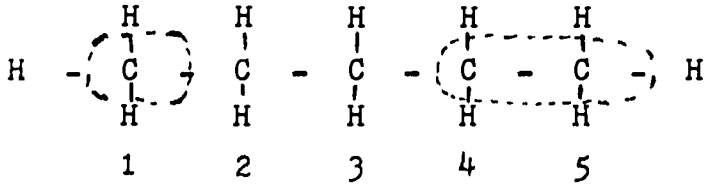
Less stable

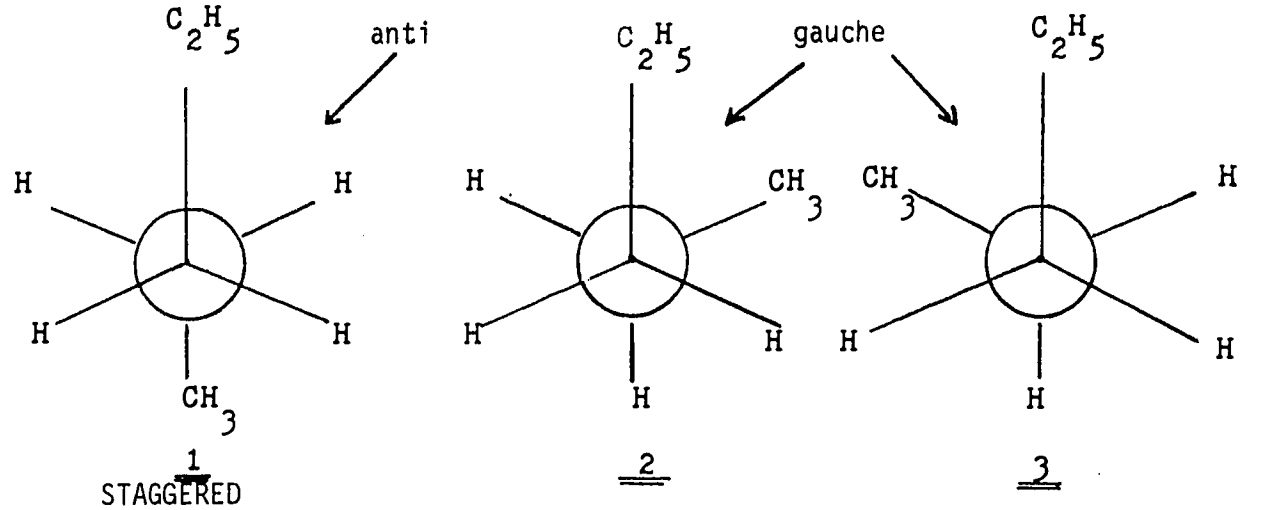




More stable

ASSIGNMENT 3. Draw all the possible conformational isomers of the n-pentane which result from the free rotation around the bond between carbon atom no. 2. and carbon atom no. 3.

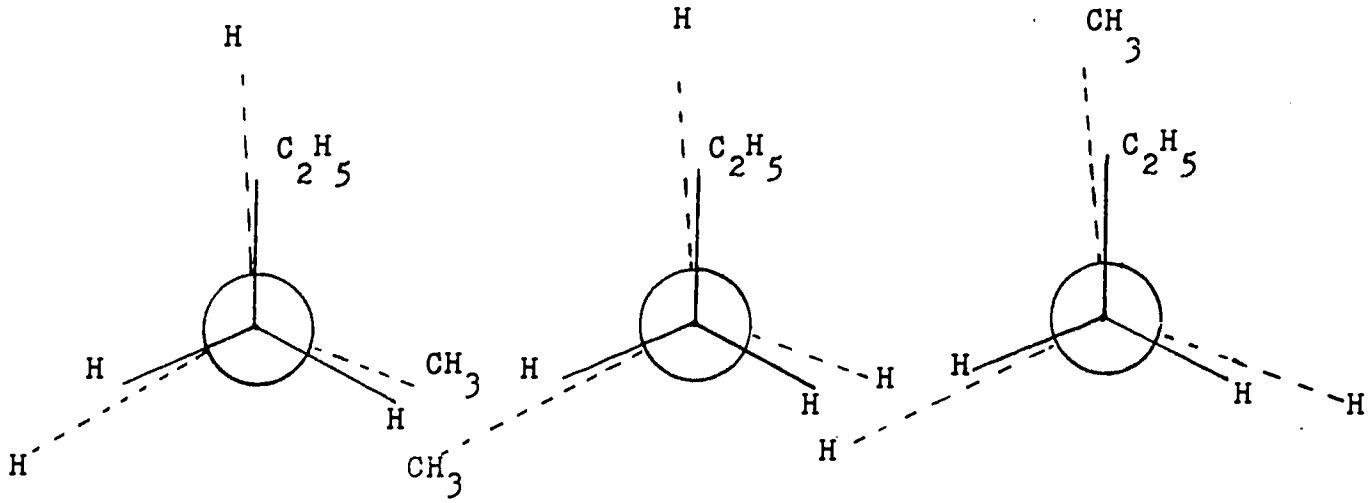




1
STAGGERED

2

3



4

5

6

ECLIPSED

ASSIGNMENT 4. Assign the relative stabilities (i.e. identify the isomers with maximum and minimum stabilities and the ones with the same stability) to all the conformational isomers in assignment 3.

Conformational isomers 2 and 3 have the same stability.
Conformational isomers 4 and 5 have the same stability.

Stability sequence:

$$1 > 2 = 3 > 4 = 5 > 6$$

↑ Maximum stability

↑ Minimum stability

Self Instructional Package No. 3
Form D - Progress Check Evaluation

ALKANES - HOMOLOGOUS SERIES AND ISOMERISM

1. The molecular formula which corresponds to an alkane is:

   a) C_7H_{14}

   b) C_5H_8

   c) $C_{12}H_{26}$

   d) C_6H_{12}

2. Diethyl ether and butanol have the same molecular formula and the same molecular weight. They have different melting point, boiling point, density. Relative to each other they are:

   a) structural isomers

   b) conformational isomers

   c) members of the same family

   d) homologs

3. Staggered and eclipsed butane are:

   a) structural isomers relative to each other

   b) conformational isomers relative to each other

   c) are species that can be interconverted into each other

   d) species that have different physical properties

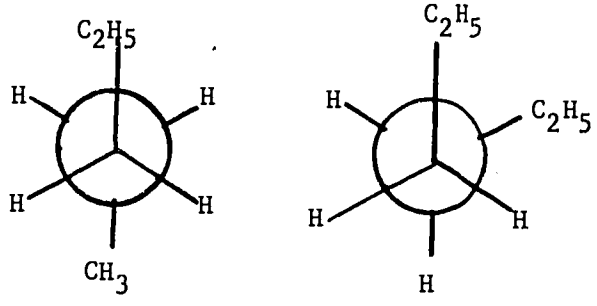
4. Relative to each other the two species represented by their Newman projections are:

   a) conformational isomers

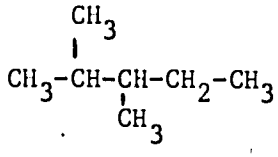
   b) structural isomers

   c) anti staggered isomers

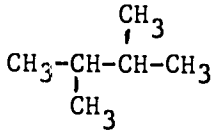
   d) gauche isomers



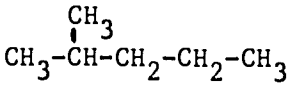
5. From the structural formulas given below identify the structural isomers.



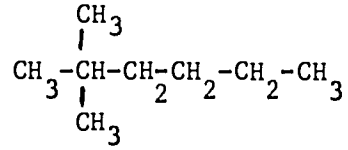
I



II



III



IV

a) I and II

b) II and III

c) III and IV

d) I and IV

6. Identify the erroneous statement below:

C_4H_{10} corresponds to butane

C_7H_{14} corresponds to heptane

C_9H_{20} corresponds to nonane

C_3H_8 corresponds to propane

7. Carbon atom A in the compound below is:

a) Primary
b) Secondary
c) Tertiary
d) Quaternary

8. The following statements about the conformers of butane are correct.

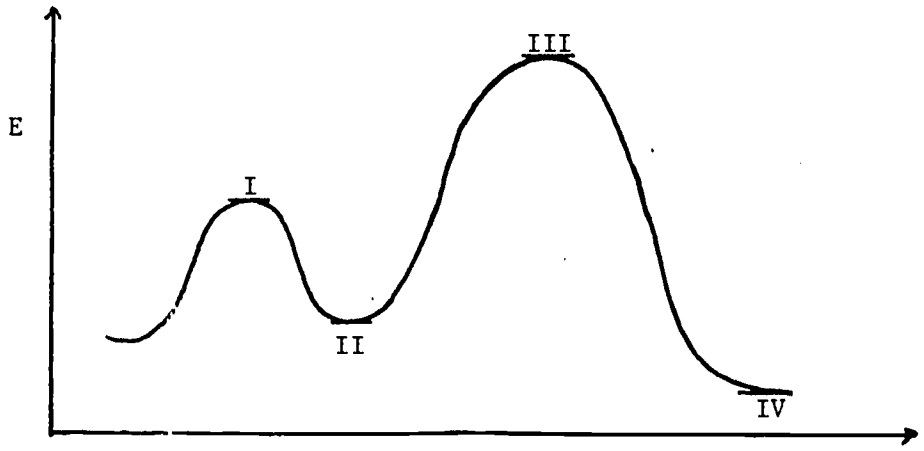
   a) staggered butane is more stable than eclipsed butane.

   b) anti-staggered conformation possesses more energy than the gauche staggered conformation.

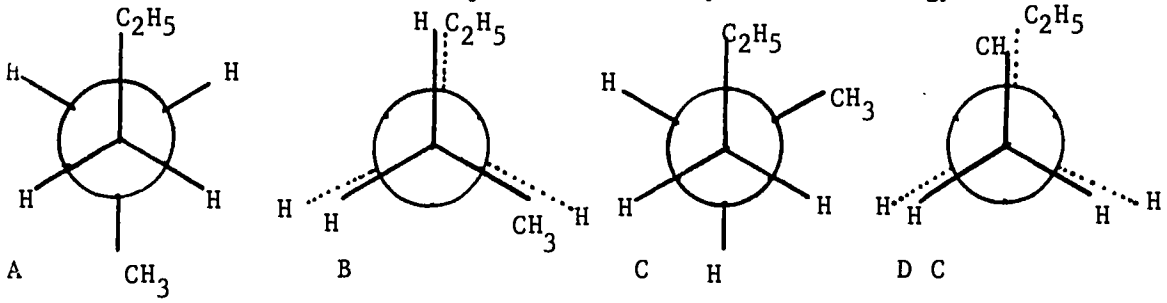
   c) anti-staggered conformation is more stable than the gauche staggered conformation.

   d) eclipsed conformation possesses less energy than the staggered gauche conformation.

9. For this and the next questions use the energy diagram below.



The four conformations of pentane represented by their Newman projections are given below. Choose the answer which gives the correct correlation between the compounds and the potential energy values.



	I	II	III	IV
a)	B	A	D	C
b)	D	C	B	A
c)	A	D	C	B
d)	B	C	D	A

10. The correct statements relative to the compounds and the diagram presented in question 9 are:

a) conformational isomer A is the most stable.

b) conformational isomer D possesses the least amount of energy.

c) B and D are eclipsed conformations.

d) C is the anti-conformation.

Self Instructional Package No. 3
Form B^1 - Answer Sheet

ALKANES - HOMOLOGUE SERIES AND ISOMERISM

1. b
2. b
3. d
4. b
5. c
6. a, c, d
7. a
8. d
9. b
10. c

Self Instructional Package No. 3

Form D[1] - Answer Sheet

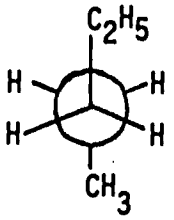
ALKANES - HOMOLOGOUS SERIES AND ISOMERISM

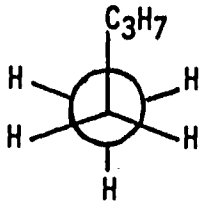
1. c
2. a
3. b, c
4. b
5. b
6. b
7. c
8. a, c
9. d
10. a, c

S.I.P. #3 - ERRATA

CORRECT STATEMENTS AND ANSWERS

FORM D - Question 4





Question 6

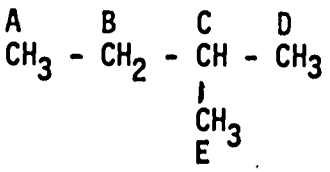
a) C_4H_{10} corresponds to butane

b) C_7H_{14} corresponds to heptane

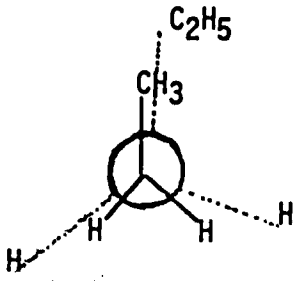
c) C_9H_{20} corresponds to nonane

d) C_3H_8 corresponds to propane

Question 7



Question 9 conformation D



TAPE 1 - Answer Sheet Assignment 4.

	Hydrocarbon	Alkane	Name
C_7H_{16}	✓	✓	Heptane