

**UNIVERSITY OF CALGARY**  
**FACULTY OF SCIENCE**  
**FINAL EXAMINATION**  
**CHEMISTRY 351**

December 10<sup>th</sup> 2007

Time: 3 Hours

**READ ALL THE INSTRUCTIONS CAREFULLY**

PLEASE WRITE YOUR NAME, STUDENT I.D. NUMBER ON **BOTH** YOUR EXAM ANSWER BOOKLET AND COMPUTER ANSWER SHEET.

The examination consists of Parts 1 - 9, each of which should be attempted. Note that some Parts provide you with a choice of questions, *i.e.* answer 4 out of 5. These will be graded in numerical order until the required number have been completed, regardless of whether they are right or wrong. Parts 1 - 5 will be computer graded, and Parts 6 - 9 are to be answered in the answer booklet provided. A periodic table with atomic numbers and atomic weights, and spectroscopic tables are appended to this examination paper.

Parts 1 - 5 consist of a series of multiple choice questions numbered 1 - 42, which are to be answered on your computer answer sheet. Indicate your answer by blackening out the appropriate space, A, B, C, D or E on the answer sheet. Use a pencil only and **not ink**. In some cases it is required that you indicate **multiple** items for a complete and/or correct answer by blackening out more than one space. In some other cases more than five options are available and some of these also require more than one space to be blackened out. For an example, an option specified as AB requires that you blacken out **both** space A and space B. Part marks may be awarded in some of the questions. Incorrect answers must be erased **cleanly**.

Molecular models are permitted during the exam; calculators are also permitted, **but NOT programmable calculators**.

**Absolutely no other electronic devices are allowed.**

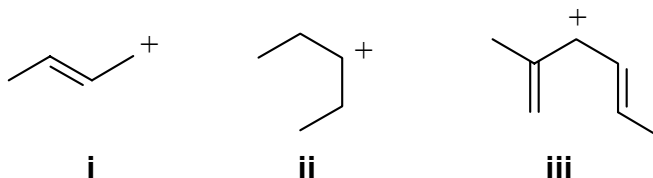
**20% PART 1 RELATIVE PROPERTIES****ANSWER ANY TEN (10) OF QUESTIONS 1 TO 12.**

Arrange the items in questions 1-12 in **DECREASING ORDER** (i.e. greatest, most etc. first) with respect to the indicated property.

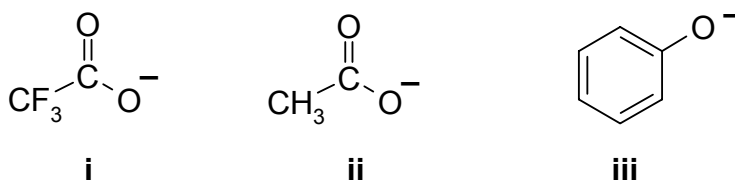
Use the following code to indicate your answers.

- |           |                           |            |                           |
|-----------|---------------------------|------------|---------------------------|
| <b>A.</b> | <b>i &gt; ii &gt; iii</b> | <b>D.</b>  | <b>ii &gt; iii &gt; i</b> |
| <b>B.</b> | <b>i &gt; iii &gt; ii</b> | <b>E.</b>  | <b>iii &gt; i &gt; ii</b> |
| <b>C.</b> | <b>ii &gt; i &gt; iii</b> | <b>AB.</b> | <b>iii &gt; ii &gt; i</b> |

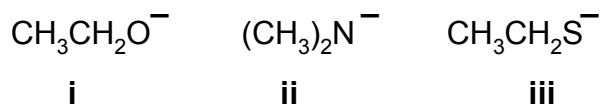
1. The relative stability of the following carbocations:



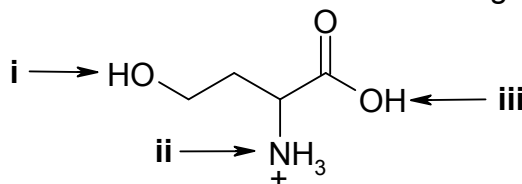
2. The relative nucleophilicity of the following in a polar, protic solvent:



3. The relative basicity of the following:



4. The relative acidity of the **atoms** indicated in the following structure :



Use the following code to indicate your answers.

**A.** i > ii > iii

**B.** i > iii > ii

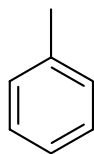
**C.** ii > i > iii

**D.** ii > iii > i

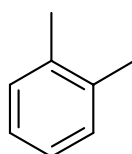
**E.** iii > i > ii

**AB.** iii > ii > i

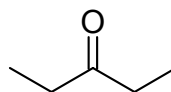
5. The number of peaks seen in the normal broadband decoupled  $^{13}\text{C}$  nmr spectrum for each of the following:



**i**

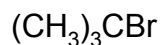


**ii**



**iii**

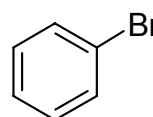
6. The relative rate of reaction of each of the following with NaI / acetone:



**i**

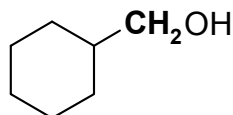


**ii**

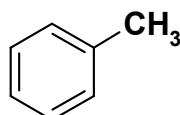


**iii**

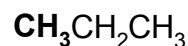
7. The number of peaks in the normal H nmr spectra in the coupling pattern corresponding to the group in **bold** in each of the following:



**i**

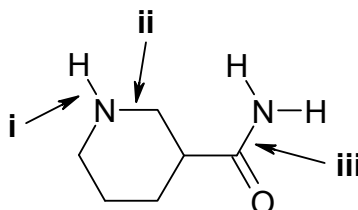


**ii**



**iii**

8. The relative bond length of the indicated bond:

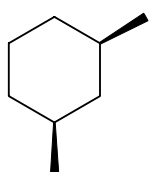


Use the following code to indicate your answers.

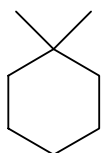
**A.** i > ii > iii  
**B.** i > iii > ii  
**C.** ii > i > iii

**D.** ii > iii > i  
**E.** iii > i > ii  
**AB.** iii > ii > i

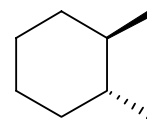
9. The relative energies of the most stable conformation of the following molecules:



**i**

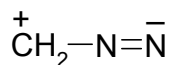


**ii**

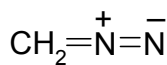


**iii**

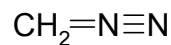
10. The relative importance of the following resonance contributors to  $\text{CH}_2\text{N}_2$  (all required charges are shown):



**i**



**ii**



**iii**

11. The relative yields of the Zaitsev product produced by the reaction of each of the following with 2-bromobutane at  $80^\circ\text{C}$ :



**i**

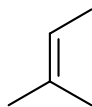


**ii**

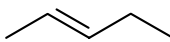


**iii**

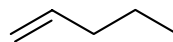
12. The heats of combustion of the following alkenes (most endothermic to most exothermic):



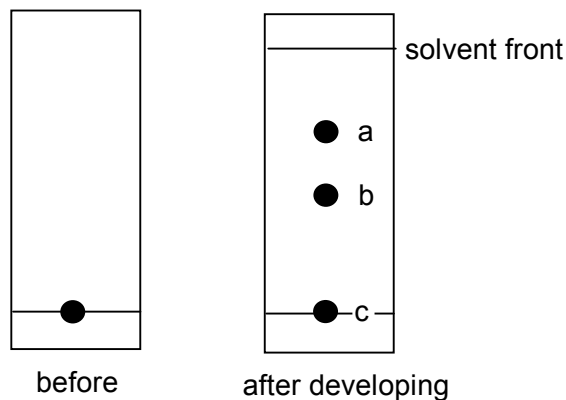
**i**



**ii**



**iii**

**9% PART 2: LABORATORY****ANSWER ALL FIVE (5) OF THE QUESTIONS 13-17.****Questions 13-17 are based on the laboratory component of the course.**

13. What is the R<sub>f</sub> value for the sample spot "a" shown on the normal chromatographic plate after development (see diagram above) ?

- A** 1.5      **B** 0.75      **C** 0.67      **D** 0.5      **E** 0.25

14. Which of the following 3 statements about the normal chromatographic plate shown above are correct ?

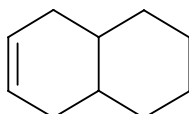
- i** the original sample is probably impure.
- ii** sample "b" is more polar than "c"
- iii** sample "a" eluted more rapidly than sample "b"

- A** only **i** is true      **B** only **ii** is true      **C** only **iii** is true  
**D** only **i** and **ii** are true      **E** only **i** and **iii** are true      **AB** **i**, **ii** and **iii** are true

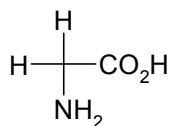
**In questions 15-17 select the ALL statements that are true. In some questions, MORE THAN ONE STATEMENT MAY BE TRUE.**

15. Based on the molecular models exercise, which of the following statements are true ?

- A 1,2,4,5-tetramethylbenzene has an index of hydrogen deficiency = 4
- B 1,3-dimethylbenzene has 4 types of carbon.
- C the following molecule has 4 types of hydrogen.



- D the amino acid glycine (below) is non-superimposable on its mirror image.



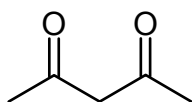
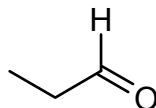
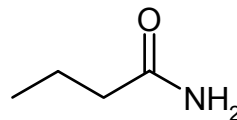
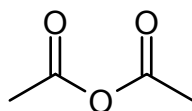
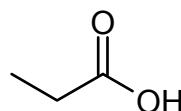
- E trans-1,3-dimethylcyclohexane is non-superimposable on its mirror image.

16. Which of the following statements from the experiment "Reactivity in Substitution Reactions" using aqueous ethanolic silver nitrate are true ?

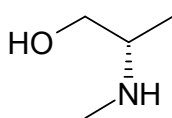
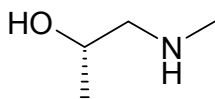
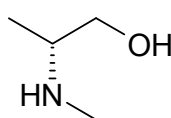
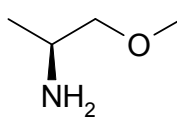
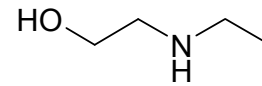
- A ethanol is an example of a polar, protic solvent.
- B the nitrate ion is a good nucleophile.
- C positive reactions were identified by observation of a silver halide precipitate.
- D bromides are less reactive than chlorides.
- E t-butyl bromide reacted more rapidly than n-butyl bromide.

17. Which of the following statements about laboratory techniques are true ?

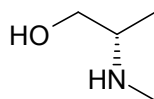
- A the observed boiling point of a liquid in Calgary is higher than at sea level.
- B silica gel is a common mobile phase for TLC.
- C a Buchner funnel is used for vacuum filtrations.
- D charcoal can be used to remove water from organic solutions.
- E a filtering funnel can be used to separate two immiscible liquids.

**10% PART 3: MOLECULAR PROPERTIES****ANSWER ALL TEN (10) of the questions 18-27****Use the following information and structures A-E to answer questions 18 - 20****A****B****C****D****E**

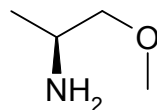
18. Which structure has the most acidic hydrogen atom ?
19. Which structure has the hydrogen with the most shielded chemical shift in its proton NMR spectrum ?
20. Which structure has the carbonyl group that gives the IR absorption with the lowest frequency ?

**Use the following list of structures to answer questions 21 and 22.****A****B****C****D****E**

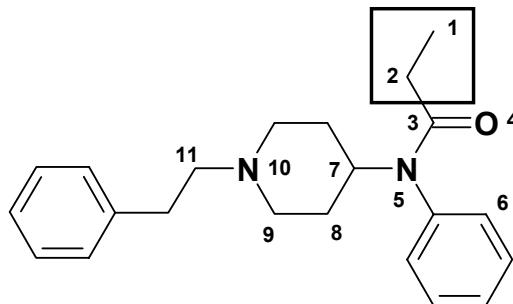
21. Select a configurational isomer of:



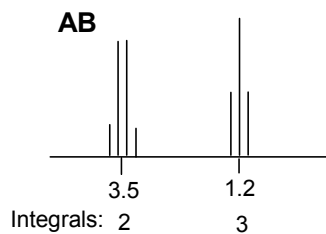
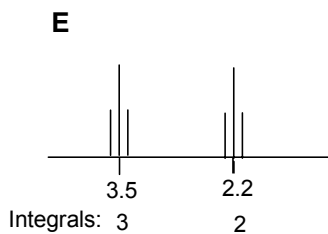
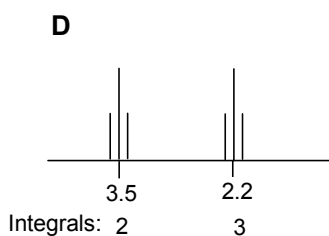
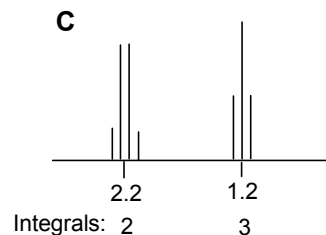
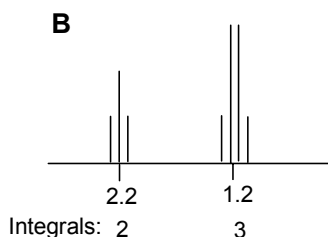
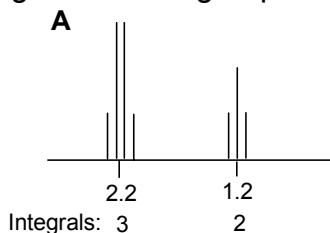
22. Select a conformational isomer of:



For each of the questions about **FENTANYL** (right), select the answer from those provided.



23. How many chiral carbons are there in **FENTANYL** ?
- A. 0      B. 1      C. 2      D. 3      E. 4
24. How many types of carbon are there in **FENTANYL** ?
- A. 12      B. 15      C. 16      D. 18      E. 22
25. In **FENTANYL**, what are the hybridisations of **O4**, **N10**, and **C6** respectively:
- A.  $sp^3$ ,  $sp^3$ ,  $sp^3$       B.  $sp^2$ ,  $sp^3$ ,  $sp^3$       C.  $sp^2$ ,  $sp^2$ ,  $sp^3$   
 D.  $sp^3$ ,  $sp^3$ ,  $sp^2$       E.  $sp^2$ ,  $sp^3$ ,  $sp^2$       AB.  $sp^2$ ,  $sp^2$ ,  $sp^2$
26. In **FENTANYL**, which of the following best describes the orbital the lone pair on **N5** occupies ?
- A. s      B. p      C.  $sp^3$       D.  $sp^2$       E. sp
27. In a  $^1H$ -NMR spectrum of **FENTANYL**, which of the following figures best match the signals for the group in the box ?



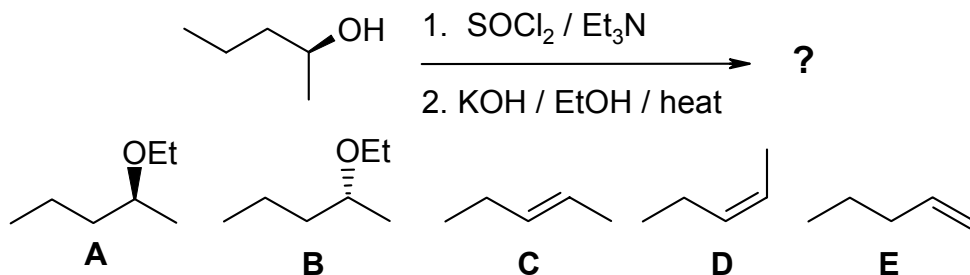
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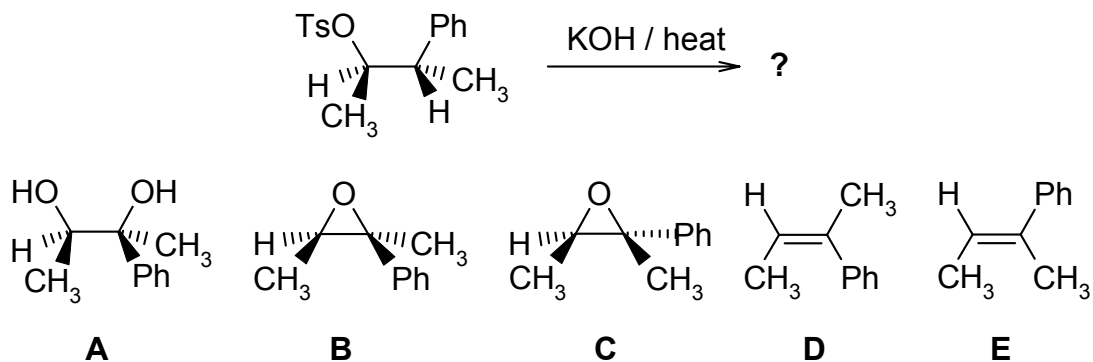
12% **PART 4: REACTIONS****ANSWER ANY EIGHT (8) OF QUESTIONS 28-36.**

For each of questions 28-36 select the **MISSING** component (the best starting material, the major product or the best reagents) required in order to **BEST** complete each of the reaction schemes.

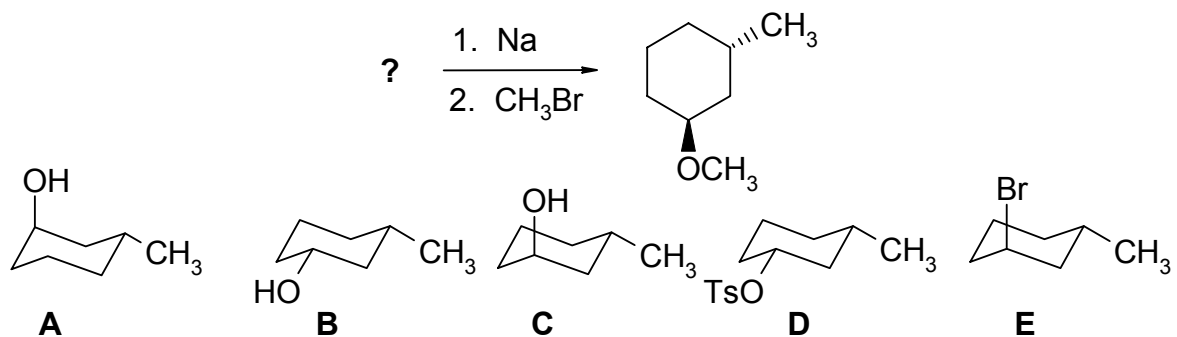
28.



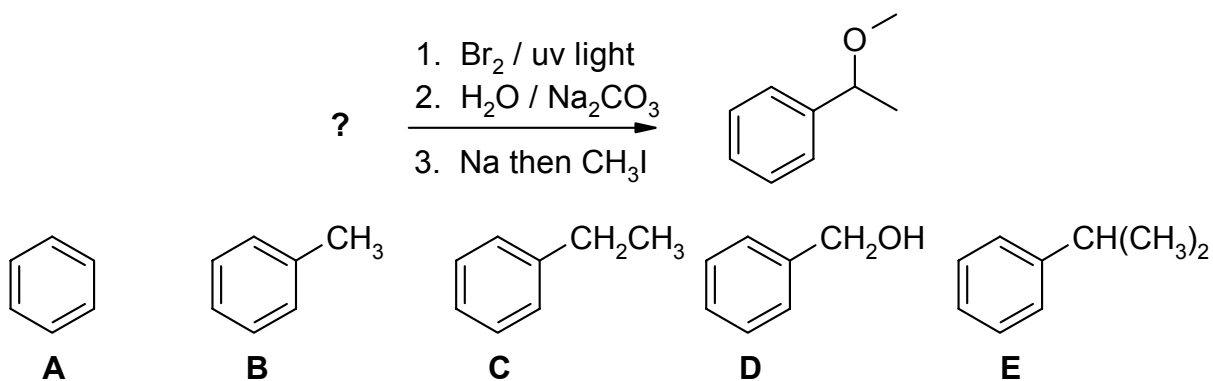
29.



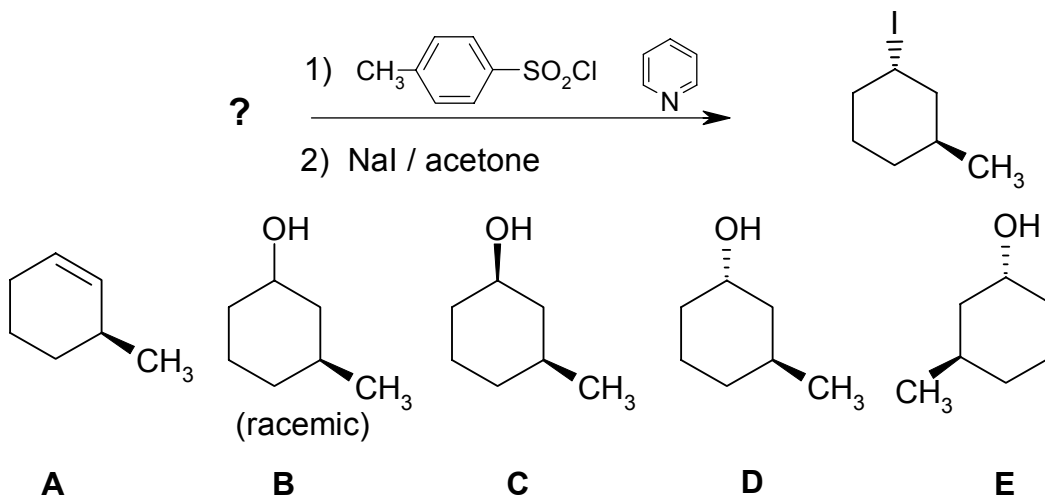
30.



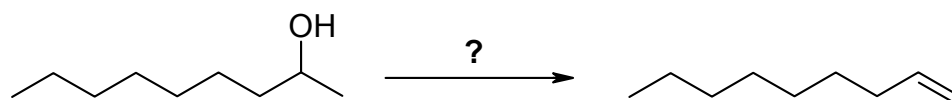
31.



32.



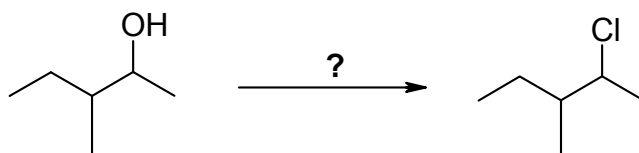
33.



- A** conc.  $\text{H}_2\text{SO}_4$  / heat  
**B**  $\text{KOH}$  /  $\text{EtOH}$  / heat  
**C**  $\text{KOtBu}$  /  $\text{DMSO}$  / heat

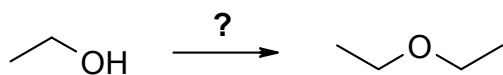
- D** 1. tosyl chloride /  $\text{Et}_3\text{N}$   
 2.  $\text{KOH}$  /  $\text{EtOH}$  / heat  
**E** 1.  $\text{HBr}$   
 2.  $\text{KOtBu}$  /  $\text{DMSO}$  / heat

34.



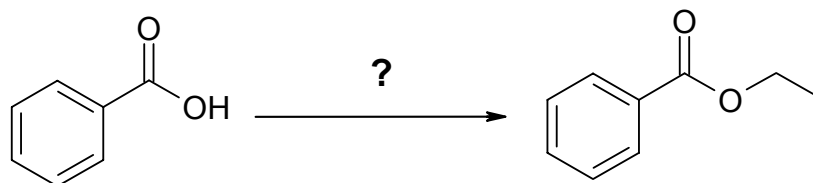
- A** conc. HCl / heat  
**B** Cl<sub>2</sub> / heat  
**C** NaCl / DMSO  
**D** tosyl chloride / Et<sub>3</sub>N  
**E** SOCl<sub>2</sub> / Et<sub>3</sub>N

35.



- A** NaOH  
**B** H<sup>+</sup> / heat  
**C** CH<sub>3</sub>Br  
**D** Br<sub>2</sub>  
**E** 1. Na  
     2. CH<sub>3</sub>Br

36.

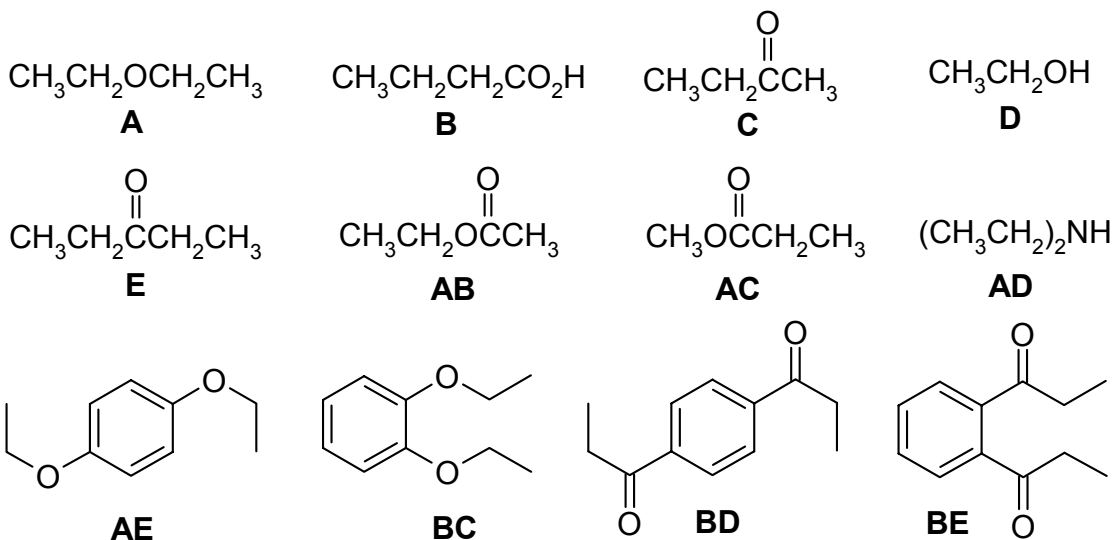


- A** CH<sub>3</sub>I  
**B** NaOCH<sub>2</sub>CH<sub>3</sub> / EtOH  
**C** 1. H<sub>2</sub>SO<sub>4</sub>  
     2. CH<sub>3</sub>CH<sub>2</sub>Br  
**D** 1. Na<sub>2</sub>CO<sub>3</sub> / DMF  
     2. CH<sub>3</sub>CH<sub>2</sub>I  
**E** 1. Na<sub>2</sub>CO<sub>3</sub> / DMF  
     2. CH<sub>3</sub>CH<sub>2</sub>OH

**12% PART 5: SPECTROSCOPY****ANSWER ALL SIX (6) OF QUESTIONS 37 - 42.**

For each of questions 37-41 select the compound from the list provided that corresponds **BEST** with the spectroscopic data provided. The following common abbreviations have been used s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, m = multiplet

37.  $^1\text{H NMR}$  :  $\delta/\text{ppm}$  1.1 (t, 3H), 2.1 (s, 3H), 2.4 (q, 2H)  
 $^{13}\text{C-NMR}$ :  $\delta/\text{ppm}$  7.9, 29.4, 36.9, 209.3  
 IR :  $1718\text{ cm}^{-1}$
38.  $^1\text{H NMR}$  :  $\delta/\text{ppm}$  1.2 (t, 3H), 2.3 (q, 2H), 3.7 (s, 3H)  
 $^{13}\text{C-NMR}$ :  $\delta/\text{ppm}$  9.2, 27.5, 51.5, 174.9  
 IR :  $1741\text{ cm}^{-1}$
39.  $^1\text{H NMR}$  :  $\delta/\text{ppm}$  1.1 (t, 3H), 2.4 (q, 2H)  
 $^{13}\text{C-NMR}$ :  $\delta/\text{ppm}$  7.9, 35.5, 212.1  
 IR :  $1716\text{ cm}^{-1}$
40.  $^1\text{H NMR}$  :  $\delta/\text{ppm}$  1.4 (t, 3H), 4.0 (q, 2H), 6.9 (m, 2H)  
 $^{13}\text{C-NMR}$ :  $\delta/\text{ppm}$  14.9, 64.6, 114.0, 121.1, 149.0
41.  $^1\text{H NMR}$  :  $\delta/\text{ppm}$  1.3 (t, 3H), 2.0 (s, 3H) 4.1 (q, 2H)  
 $^{13}\text{C-NMR}$ :  $\delta/\text{ppm}$  14.3, 21.0, 60.4, 171.0  
 IR :  $1743\text{ cm}^{-1}$
42.  $^1\text{H-NMR}$ :  $\delta/\text{ppm}$  1.0 (t, 3H), 1.7 (sextet, 2H), 2.3 (t, 2H), 11.5 (s, 1H,  $\text{D}_2\text{O}$  exchange)  
 $^{13}\text{C-NMR}$ :  $\delta/\text{ppm}$  13.7, 18.4, 36.2, 180.7  
 IR:  $2700\text{-}3300, 1712\text{ cm}^{-1}$



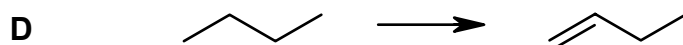
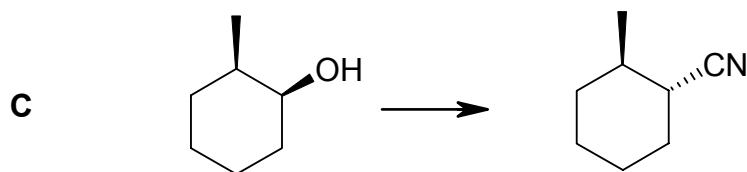
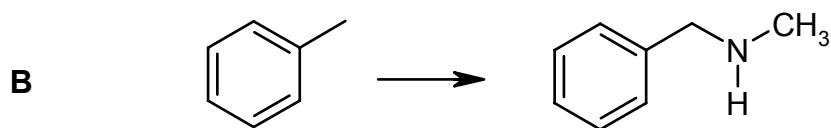
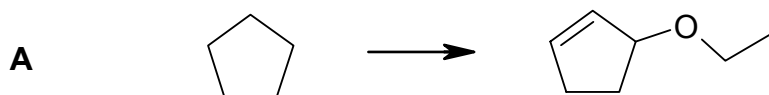
Cont'd --&gt;

**6% PART 6: SYNTHESIS**

DESIGN EFFICIENT SYNTHESSES OF ANY TWO (2) of the following target molecules from the starting material indicated. In addition, you are allowed to use any other hydrocarbon with three or less carbon atoms and any solvent or inorganic reagent that does not become part of the carbon skeleton in the product.

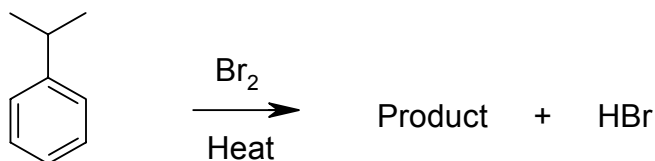
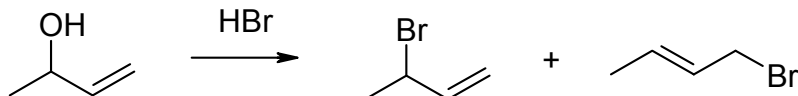
WRITE YOUR ANSWERS IN THE BOOKLET PROVIDED.

DO NOT SHOW MECHANISMS.

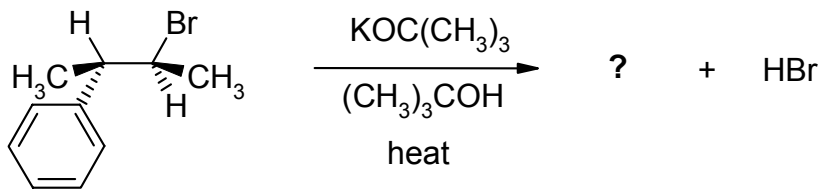


**9% PART 7: MECHANISMS****WRITE YOUR ANSWERS IN THE BOOKLET PROVIDED****ANSWER ANY THREE (3) OF THE QUESTIONS I to IV.**

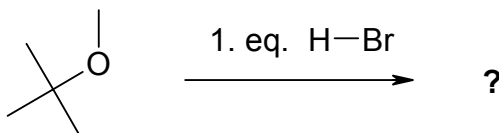
Use **CURLY ARROW MECHANISMS** to explain any **THREE (3)** of the following reactions / observations (curly arrow mechanisms are required in order to get full marks).

**I.****II**

**III.** Predict the major product of this reaction by showing the mechanism of the reaction:



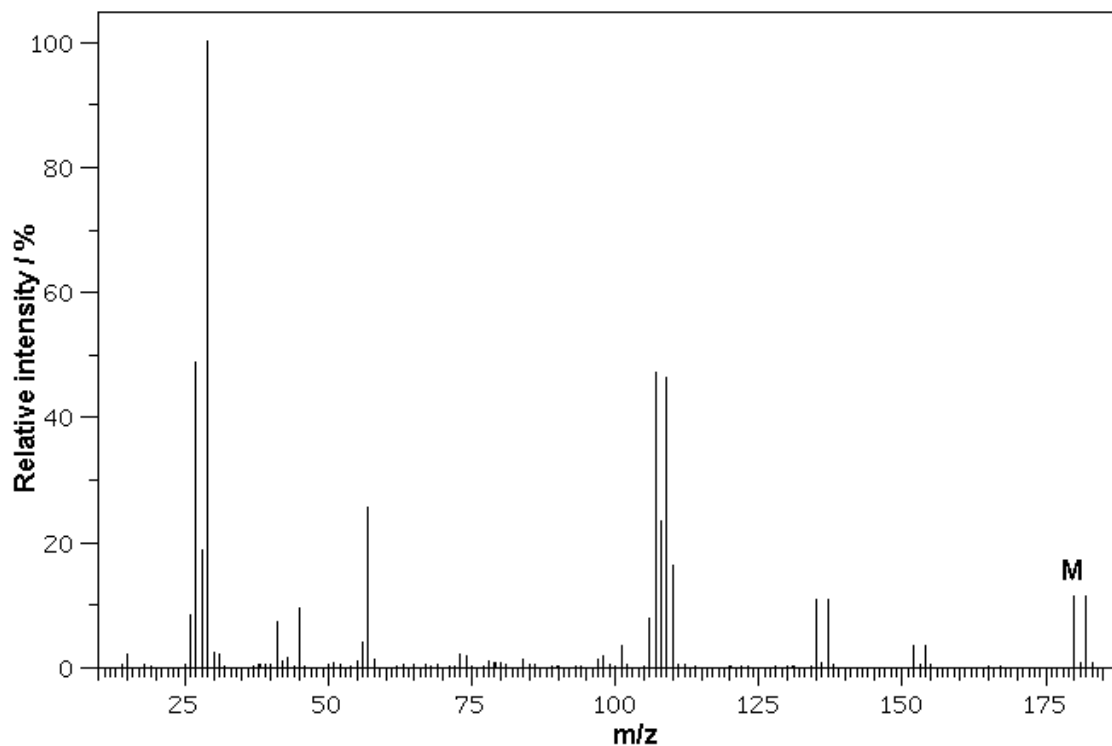
**IV.** Predict the major product of this reaction by showing the mechanism of the reaction:



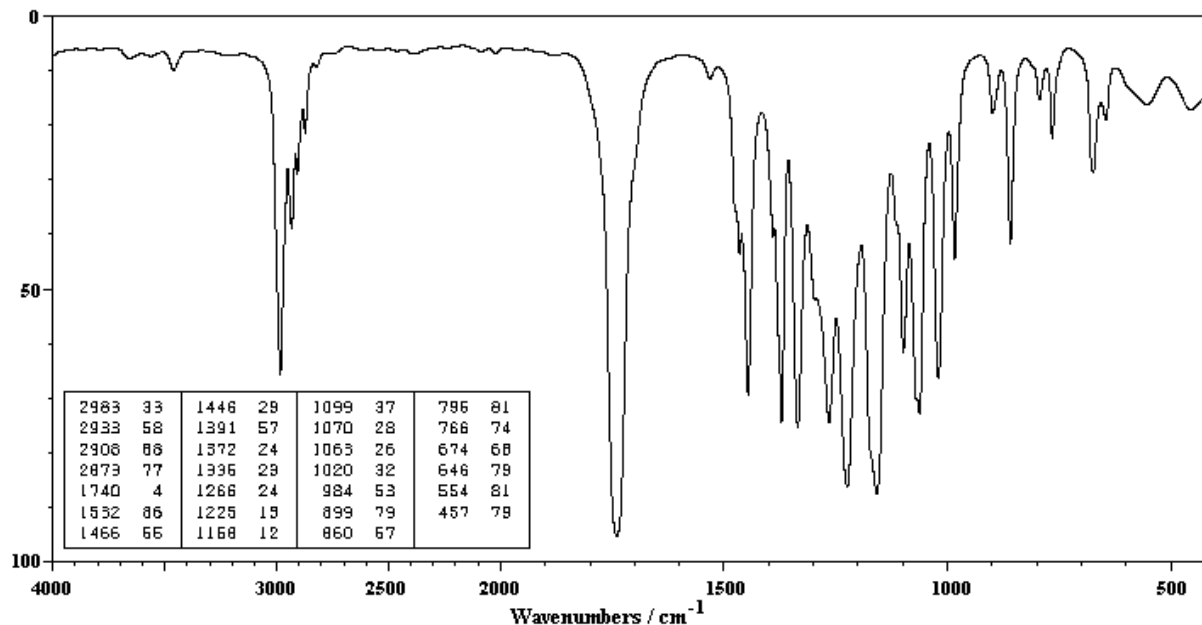
**10% PART 8: SPECTROSCOPY**

**WRITE YOUR ANSWERS IN THE BOOKLET PROVIDED. Show your workings as PARTIAL marks will be given.**

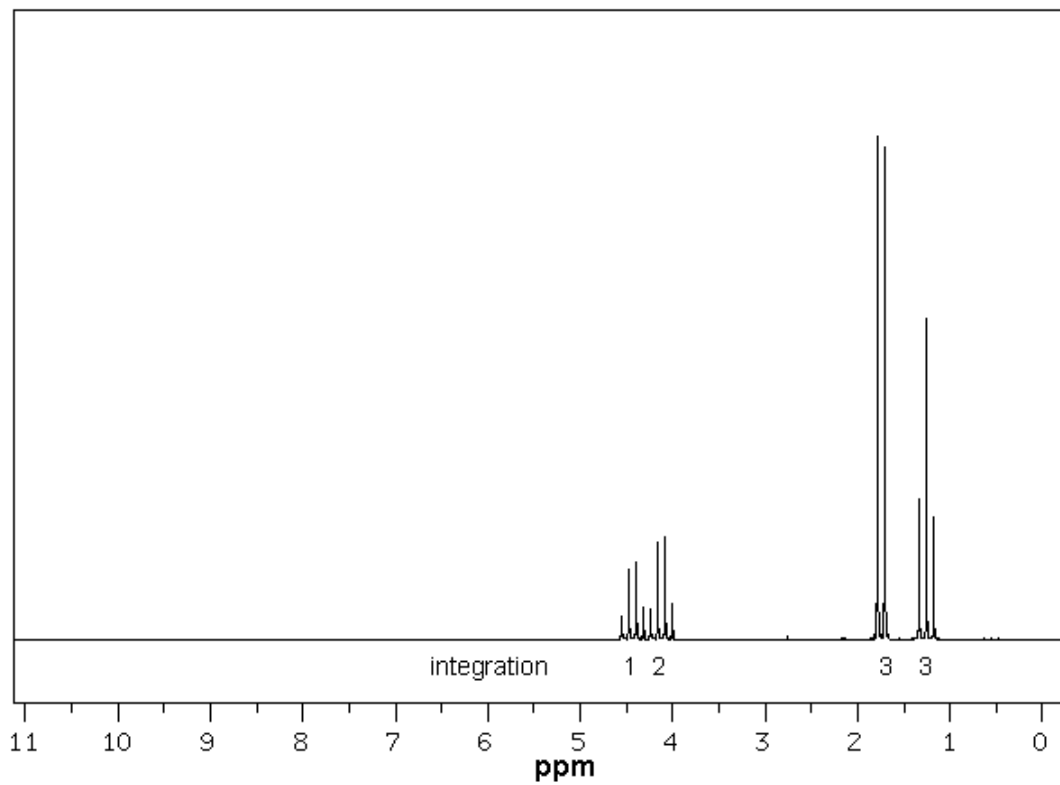
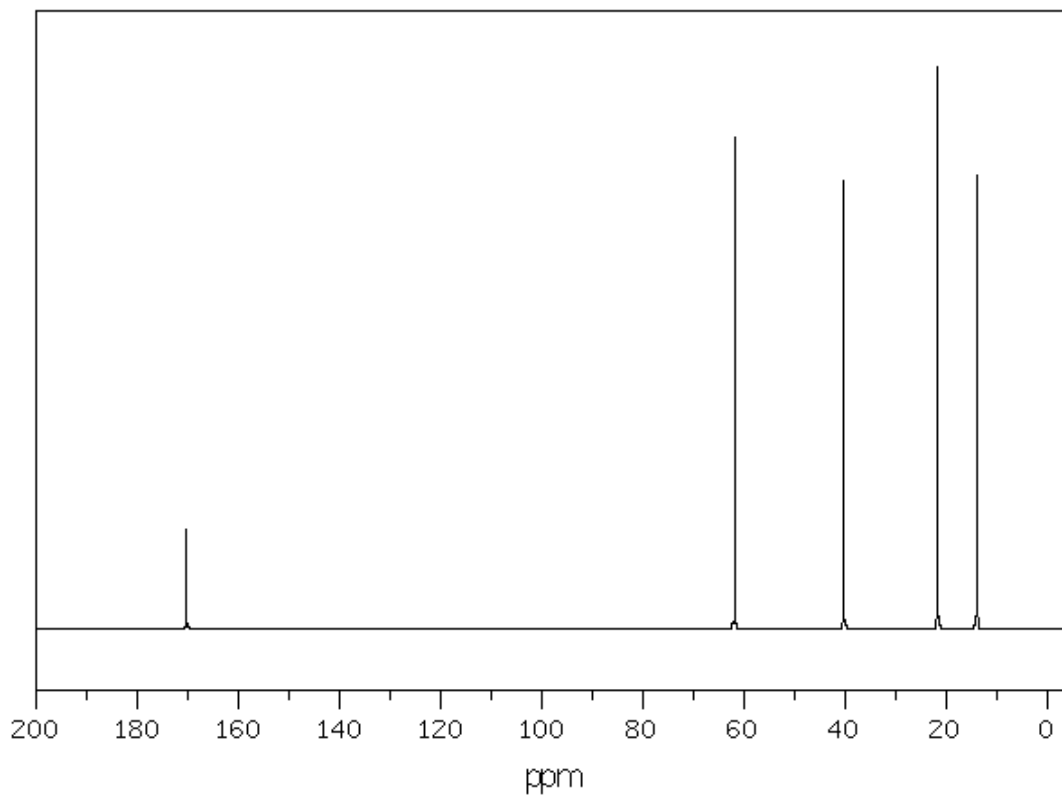
From the spectral data provided below, identify the structure of the "unknown" molecule.



Absorbance / %



Cont'd --&gt;





**12% PART 9: STRUCTURE DETERMINATION****WRITE YOUR ANSWERS IN THE BOOKLET PROVIDED**

Compound **A**,  $C_6H_{12}O$ , (IR :  $3500\text{cm}^{-1}$ , broad) was reacted with  $PBr_3 / Et_3N$  to give **B**  $C_6H_{11}Br$  as the major product. **B** was observed to react quite slowly with aqueous ethanolic silver nitrate but rapidly with sodium iodide in acetone. When **B** was reacted with either hot  $KOH / EtOH$  or  $KOtBu / DMSO$  it gave the same product, **C**,  $C_6H_{10}$  (IR :  $1650\text{cm}^{-1}$ ).

In contrast, when **B** was reacted with cold aq.  $NaOH$  solution the major product was **A**.

When **A** was heated with conc.  $H_2SO_4$ , two constitutional isomer of **C** were obtained, **D** and **E**. Catalytic hydrogenation of either **C** or **D** was found to give methylcyclopentane but **E** gave a different alkane.

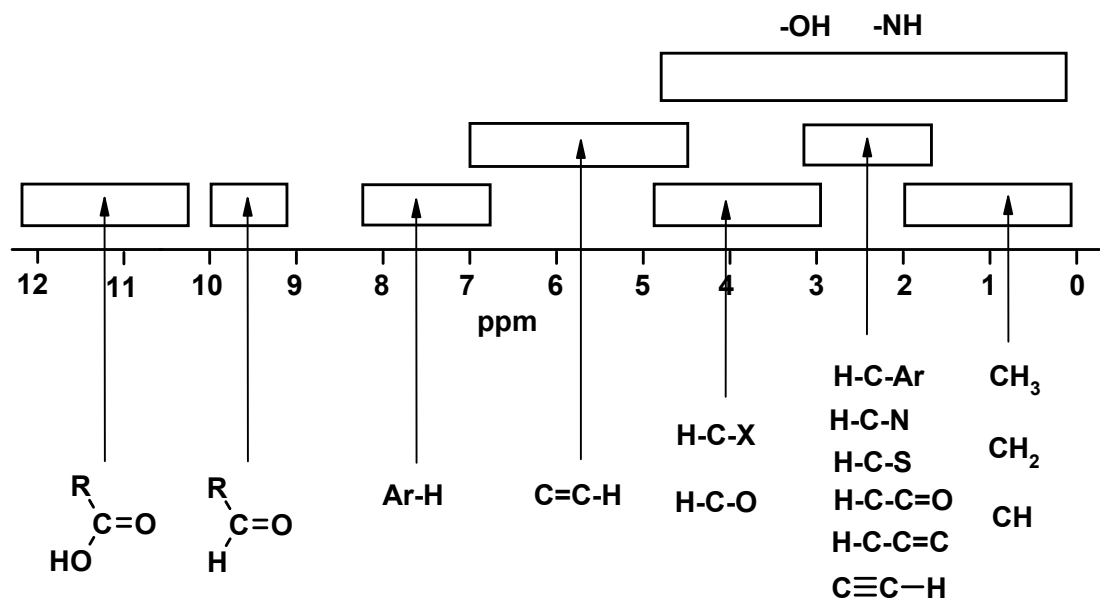
When **A** was treated with  $HBr$  the reaction gave **F** and **G**, constitutional isomers of **B**. **F** was observed to react rapidly with aqueous ethanolic silver nitrate but very slowly (if at all) with sodium iodide in acetone while **G** reacted at a moderate rate with both reagents. **F** could also be obtained on reaction of methylcyclopentane with bromine / uv light.

In a  $^{13}C$  nmr spectroscopic analysis of the isomeric compounds, **C**, **D** and **E** it was found that **E** had only 3 peaks, **C** had 4 peaks and **D** had 6 peaks.

None of the compounds **A - G**, have chirality centers.

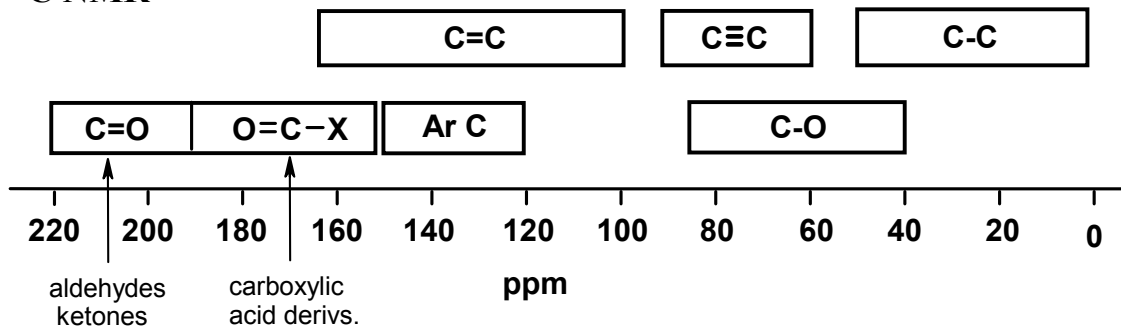
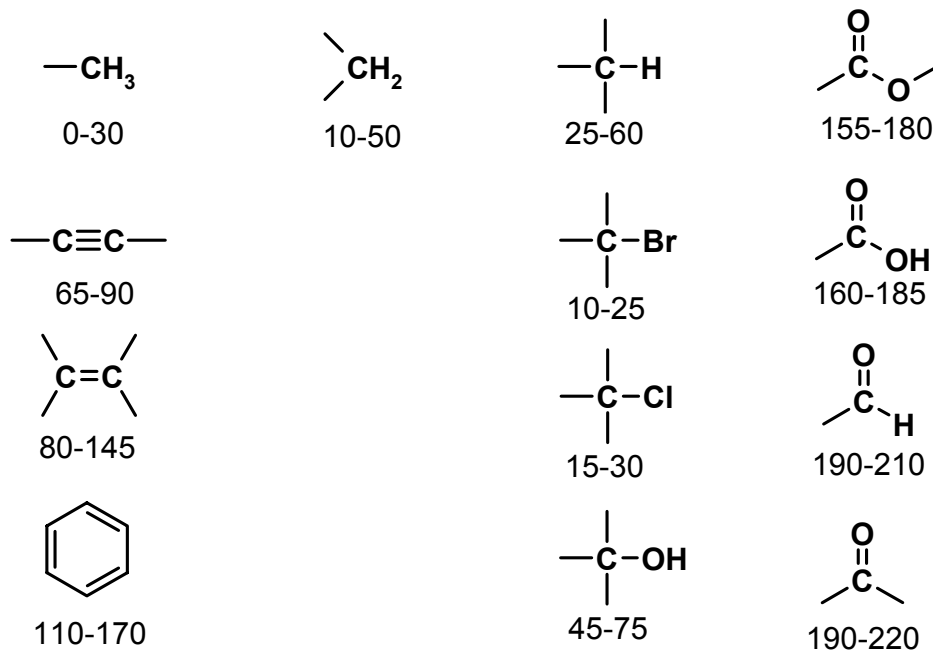
- Identify **A-G** (only structures are needed)
- Give the complete name of compound **F**.

**\*\*\*\* THE END \*\*\*\***

**SPECTROSCOPIC TABLES****<sup>1</sup>H NMR****<sup>1</sup>H NMR CHARACTERISTIC CHEMICAL SHIFTS / ppm**

	methyl CH <sub>3</sub> -	methylene -CH <sub>2</sub> -	methyne CH	other	
$\text{R}-\text{C}-$	0.9	1.4	1.5	-OH	1-5
$\text{R}-\text{C}=\text{C}$	1.6	2.3	2.6	-NH	1-3
$\text{R}-\text{C}(=\text{O})$	2.1	2.4	2.5	$\text{C}\equiv\text{CH}$	2.5
$\text{R}-\text{N}$	2.2	2.5	2.9	$\text{C}=\text{C}-\text{H}$	5.5
R-Ar	2.3	2.7	3.0	Ar-H	7.3
R-Br	2.7	3.3	4.1	$\text{R}-\text{C}(=\text{O})-\text{H}$	10
R-Cl	3.1	3.4	4.1	$\text{R}-\text{C}(=\text{O})-\text{OH}$	9-12
R-O-	3.3	3.4	3.7		

Cont'd --&gt;

**$^{13}\text{C}$  NMR** **$^{13}\text{C}$  NMR CHARACTERISTIC CHEMICAL SHIFTS / ppm**

**INFRA-RED GROUP ABSORPTION FREQUENCIES**

		<u>TYPE OF VIBRATION</u>	<u>FREQUENCY (cm<sup>-1</sup>)</u>	<u>WAVELENGTH (μ)</u>	<u>INTENSITY (1)</u>	
C-H	Alkanes	(stretch)	3000-2850	3.33-3.51	s	
		-CH <sub>3</sub>	(bend)	1450 and 1375	6.90 and 7.27	m
		-CH <sub>2</sub> -	(bend)	1465	6.83	m
	Alkenes	(stretch)	3100-3000	3.23-3.33	m	
		(bend)	1700-1000	5.88-10.0	s	
	Aromatics	(stretch)	3150-3050	3.17-3.28	s	
		(out-of-plane bend)	1000-700	10.0-14.3	s	
	Alkyne	(stretch)	ca. 3300	ca.3.03	s	
	Aldehyde		2900-2800	3.45-3.57	w	
			2800-2700	3.57-3.70	w	
C-C	Alkane	not usually useful				
C=C	Alkene		1680-1600	5.95-6.25	m-w	
	Aromatic		1600-1400	6.25-7.14	m-w	
C≡C	Alkyne		2250-2100	4.44-4.76	m-w	
C=O	Aldehyde		1740-1720	5.75-5.81	s	
	Ketone		1725-1705	5.80-5.87	s	
	Carboxylic acid		1725-1700	5.80-5.88	s	
	Ester		1750-1730	5.71-5.78	s	
	Amide		1700-1640	5.88-6.10	s	
	Anhydride		ca. 1810	ca. 5.52	s	
			ca. 1760	ca. 5.68	s	
C-O	Alcohols, Ethers, Esters,					
	Carboxylic acids		1300-1000	7.69-10.0	s	
O-H	Alcohols, Phenols	Free	3650-3600	2.74-2.78	m	
		H-Bonded	3400-3200	2.94-3.12	m	
		Carboxylic acids (2)	3300-2500	3.03-4.00	m	
N-H	Primary and secondary amines		ca. 3500	ca. 2.86	m	
C≡N	Nitriles	2260-2240	4.42-4.46	m		
N=O	Nitro (R-NO <sub>2</sub> )		1600-1500	6.25-6.67	s	
			1400-1300	7.14-7.69	s	
C-X	Fluoride		1400-1000	7.14-10.0	s	
	Chloride		800-600	12.5-16.7	s	
	Bromide, Iodide		<600	>16.7	s	

(1) s = strong, m = medium and w = weak

(2) note that the -OH absorption of solid carboxylic acids which run as a nujol mull can be difficult to see as they maybe very broad

Cont'd -->

## PERIODIC TABLE

<b>1</b> 1A																	<b>18</b> 8A
<b>1</b> <b>H</b> 1.008	<b>2</b> 2A											<b>13</b> 3A	<b>14</b> 4A	<b>15</b> 5A	<b>16</b> 6A	<b>17</b> 7A	<b>2</b> <b>He</b> 4.003
<b>3</b> <b>Li</b> 6.941	<b>4</b> <b>Be</b> 9.012											<b>5</b> <b>B</b> 10.81	<b>6</b> <b>C</b> 12.01	<b>7</b> <b>N</b> 14.01	<b>8</b> <b>O</b> 16.00	<b>9</b> <b>F</b> 19.00	<b>10</b> <b>Ne</b> 20.18
<b>11</b> <b>Na</b> 22.99	<b>12</b> <b>Mg</b> 24.31	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b> <b>Al</b> 26.98	<b>14</b> <b>Si</b> 28.09	<b>15</b> <b>P</b> 30.97	<b>16</b> <b>S</b> 32.07	<b>17</b> <b>Cl</b> 35.45	<b>18</b> <b>Ar</b> 39.95
<b>19</b> <b>K</b> 39.10	<b>20</b> <b>Ca</b> 40.08	<b>21</b> <b>Sc</b> 44.96	<b>22</b> <b>Ti</b> 47.88	<b>23</b> <b>V</b> 50.94	<b>24</b> <b>Cr</b> 52.00	<b>25</b> <b>Mn</b> 54.94	<b>26</b> <b>Fe</b> 55.85	<b>27</b> <b>Co</b> 58.93	<b>28</b> <b>Ni</b> 58.69	<b>29</b> <b>Cu</b> 63.55	<b>30</b> <b>Zn</b> 65.38	<b>31</b> <b>Ga</b> 69.72	<b>32</b> <b>Ge</b> 72.59	<b>33</b> <b>As</b> 74.92	<b>34</b> <b>Se</b> 78.96	<b>35</b> <b>Br</b> 79.90	<b>36</b> <b>Kr</b> 83.80
<b>37</b> <b>Rb</b> 85.47	<b>38</b> <b>Sr</b> 87.62	<b>39</b> <b>Y</b> 88.91	<b>40</b> <b>Zr</b> 91.22	<b>41</b> <b>Nb</b> 92.91	<b>42</b> <b>Mo</b> 95.94	<b>43</b> <b>Tc</b> (98)	<b>44</b> <b>Ru</b> 101.1	<b>45</b> <b>Rh</b> 102.9	<b>46</b> <b>Pd</b> 106.4	<b>47</b> <b>Ag</b> 107.9	<b>48</b> <b>Cd</b> 112.4	<b>49</b> <b>In</b> 114.8	<b>50</b> <b>Sn</b> 118.7	<b>51</b> <b>Sb</b> 121.8	<b>52</b> <b>Te</b> 127.6	<b>53</b> <b>I</b> 126.9	<b>54</b> <b>Xe</b> 131.3
<b>55</b> <b>Cs</b> 132.9	<b>56</b> <b>Ba</b> 137.3	<b>57*</b> <b>La</b> 138.9	<b>72</b> <b>Hf</b> 178.5	<b>73</b> <b>Ta</b> 180.9	<b>74</b> <b>W</b> 183.9	<b>75</b> <b>Re</b> 186.2	<b>76</b> <b>Os</b> 190.2	<b>77</b> <b>Ir</b> 192.2	<b>78</b> <b>Pt</b> 195.1	<b>79</b> <b>Au</b> 197.0	<b>80</b> <b>Hg</b> 200.6	<b>81</b> <b>Tl</b> 204.4	<b>82</b> <b>Pb</b> 207.2	<b>83</b> <b>Bi</b> 209.0	<b>84</b> <b>Po</b> (209)	<b>85</b> <b>At</b> (210)	<b>86</b> <b>Rn</b> (222)
<b>87</b> <b>Fr</b> (223)	<b>88</b> <b>Ra</b> 226.0	<b>89**</b> <b>Ac</b> (227)	<b>104</b> <b>Rf</b> (261)	<b>105</b> <b>Ha</b> (262)	<b>106</b> <b>Sg</b> (263)	<b>107</b> <b>Ns</b> (262)	<b>108</b> <b>Hs</b> (265)	<b>109</b> <b>Mt</b> (266)	<b>110</b> <b>Uun</b> (269)	<b>111</b> <b>Uuu</b> (272)							

Lanthanides \*

<b>58</b> <b>Ce</b> 140.1	<b>59</b> <b>Pr</b> 140.9	<b>60</b> <b>Nd</b> 144.2	<b>61</b> <b>Pm</b> (145)	<b>62</b> <b>Sm</b> 150.4	<b>63</b> <b>Eu</b> 152.0	<b>64</b> <b>Gd</b> 157.3	<b>65</b> <b>Tb</b> 158.9	<b>66</b> <b>Dy</b> 162.5	<b>67</b> <b>Ho</b> 164.9	<b>68</b> <b>Er</b> 167.3	<b>69</b> <b>Tm</b> 168.9	<b>70</b> <b>Yb</b> 173.0	<b>71</b> <b>Lu</b> 175.0
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Actinides \*\*

<b>90</b> <b>Th</b> 232.0	<b>91</b> <b>Pa</b> 231.0	<b>92</b> <b>U</b> 238.0	<b>93</b> <b>Np</b> 237.0	<b>94</b> <b>Pu</b> (244)	<b>95</b> <b>Am</b> (243)	<b>96</b> <b>Cm</b> (247)	<b>97</b> <b>Bk</b> (247)	<b>98</b> <b>Cf</b> (251)	<b>99</b> <b>Es</b> (252)	<b>100</b> <b>Fm</b> (257)	<b>101</b> <b>Md</b> (258)	<b>102</b> <b>No</b> (259)	<b>103</b> <b>Lr</b> (260)
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