1) Which of the following CANNOT be probed by an NMR spectrometer? See sect 16.1

A) nucleus with odd number of protons & odd number of neutrons
B) nucleus with odd number of protons & even number of neutrons
C) nucleus with even number of protons & odd number of neutrons
D) nucleus with even number of protons & even number of neutrons
E) none of these
Ans: 

2) How many nuclear spin states are possible for the $^1\text{H}$ nucleus?

A) 1
B) 2
C) 4
D) 5
E) none of these
Ans: 

3) Which of the following electromagnetic radiation is used in NMR spectroscopy?

A) UV
B) IR
C) visible
D) $\gamma$-rays
E) radio wave
Ans: 

4) ______ protons experience a net magnetic field strength that is smaller than the applied magnetic field.

A) Deshielded
B) Shielded
C) Paramagnetic
D) Diamagnetic
E) none of these
Ans: 

5) ______ protons experience a net magnetic field strength that is higher than the ______ protons.

A) Deshielded, shielded
B) Shielded, deshielded
C) Paramagnetic, diamagnetic
D) Shielded, diamagnetic
E) none of these
Ans: 

6) Which of the following is true about the relationship between the energy gap (ΔE) between the spin states for a \(^1\)H nucleus and the strength of the external magnetic field?

   A) they are inversely proportional
   B) they are directly proportional
   C) there is no relationship
   D) the magnetic field is slightly less
   E) none of these

   Ans: 

7) Which of the following is true about the number of different signals in a \(^1\)H NMR spectrum? Section: 16.3

   A) it indicates the number of neighboring protons
   B) it indicates the electronic environment of neighboring protons
   C) it indicates the number of different kinds of protons
   D) it indicates the electronic environment of absorbing protons
   E) it indicates the number of protons in the signal

   Ans: 

8) Which of the following is true about the location of signals in a 1H NMR spectrum? Section: 16.3

   A) it indicates the number of neighboring protons
   B) it indicates the electronic environment of neighboring protons
   C) it indicates the number of different protons
   D) it indicates the electronic environment of absorbing protons
   E) it indicates the number of protons in the signal

   Ans: 

9) Which of the following is true about the area under each signal in a \(^1\)H NMR spectrum? Section: 16.3

   A) it indicates the number of neighboring protons
   B) it indicates the electronic environment of neighboring protons
   C) it indicates the number of different protons
   D) it indicates the electronic environment of absorbing protons
   E) it indicates the relative number of protons in the signal

   Ans: 

10) Which of the following is true about the shape (multiplicity) of the signal in a $^1$H NMR spectrum?

Section: 16.3

A) it indicates the number of neighboring protons
B) it indicates the electronic environment of neighboring protons
C) it indicates the number of different protons
D) it indicates the electronic environment of absorbing protons
E) it indicates the number of protons in the signal

Ans: [ ]

11) Which of the following type of protons are chemically non-equivalent? Section: 16.4

A) homotopic
B) enantiotopic
C) diastereotopic
D) A and B
E) B and C

Ans: [ ]

12) Which of the following type of protons are chemically equivalent? Section: 16.4

A) homotopic
B) enantiotopic
C) diastereotopic
D) A and B
E) B and C

Ans: [ ]

13) Which of the following is the maximum multiplicity observed for $H_b$ protons. Assume that $J_{ab}$ and $J_{bc}$ values are different.

A) 9
B) 12
C) 21
D) 24
E) none of these

Ans: [ ]
14) Which of the following is the maximum multiplicity observed for Hc protons. Assume that Jcd and Jcb values are DIFFERENT.

\[ \text{H} \quad \text{N} \quad \text{c} \quad \text{d} \quad \text{a} \quad \text{b} \]

A) 5 
B) 6 
C) 8 
D) 12 
E) none of these

Ans:  

15) Which of the following is the maximum multiplicity observed for Hc protons. Assume that Jcd and Jcb values are the SAME.

\[ \text{H} \quad \text{N} \quad \text{c} \quad \text{d} \quad \text{a} \quad \text{b} \]

A) 5 
B) 6 
C) 8 
D) 12 
E) none of these

Ans:  

16) Hb and Hd should be placed in 2 of the three boxes below. An X should be drawn in the remaining box.
17) Identify the indicated sets of protons as (U)nrelated, (H)omotopic, (E)nantiotopic or (D)iastereotopic

18) How many kinds of *nonequivalent* carbons (C) and protons (H) are present in the following? That is, how many unique \(^1\text{H}\) and \(^{13}\text{C}\) signals will you observed in an NMR spectrum for each.
19) MATCH a term to each description below. Place the letter of the term in the Box.
A) TMS (tetramethylsilane)  B) downfield (or low-field)
C) upfield (or high-field)  D) chemical shift
E) MHz  F) delta (δ)

☐ When looking at an NMR chart the right-hand part of the chart is...

☐ The exact place on the chart at which a nucleus absorbs is called its...

☐ A calibration standard that was commonly used to mark the 0 ppm for ¹H and ¹³C NMR is...

☐ The NMR charts are calibrated using an arbitrary X-axis scale denoting parts-per-million that is divided into ____ units.
20) Identify the chemically non-equivalent and equivalent hydrogens by writing the letters in the boxes, starting with the letter 'A'.

In the following example, protons 'A' and 'H' are equivalent but are not equivalent to 'J', and so on. Note, not every box has to be filled. HERE IS AN EXAMPLE. X in box(es) not used

```
A, H, I, J, K, L, X
```

![Chemical structure diagram]

21) How many different kinds of non-equivalent CARBONS are there in the following?

```
Number Here
```

22) Predict the splitting patterns in the $^1$H NMR or all of the unique protons indicated in the molecules

```
<table>
<thead>
<tr>
<th>Proton</th>
<th>Total # of Adjacent Spin-Coupled Protons</th>
<th>Splitting (# of peaks seen) (n + 1)</th>
<th>Integrates to X # of Equivalent Hydrogens</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
23) The relative proton chemical shifts of the labeled hydrogens are shown in the $^1$H NMR. The integration of the peak areas is shown in the spectrum.

24) Fill in Table below with number of adjacent hydrogens and the splitting patterns you would expect for each proton in the molecules below.

<table>
<thead>
<tr>
<th>Proton</th>
<th>Number of Adjacent Protons that Couple</th>
<th>Splitting (use capital letters above)</th>
<th>Proton</th>
<th>Number of Adjacent Protons that Couple</th>
<th>Splitting (use capital letters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td>G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td>H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td>I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td>J</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td>K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Splitting: S = singlet; D = doublet; T = triplet; Q = quartet; QU = quintet; SX = sextet; SP = septet; DD = doublet of doublet
25) Calculate the degrees of unsaturation for the formula \( \text{C}_5\text{H}_{10}\text{O} \) TABLES ATTACHED, if you need them. Logical labeling/work that supports your answer should appear within spectra.

13C NMR

1H NMR

IR data

26) Structure here.
27) Calculate the degrees of unsaturation for the formula (C₄H₁₀O)₂. TABLES ATTACHED, if you need them. Logical labeling/work that supports your answer should appear within spectra.

13C NMR

1H NMR

IR data

28) Structure here.

Structure MUST BE PLACED Here (show work for credit)
29) Calculate the degrees of unsaturation for the formula (C₄H₉NO)
TABLES ATTACHED, if you need them.
13C NMR

![13C NMR spectrum](image)

1H NMR

![1H NMR spectrum](image)

IR data

![IR spectrum](image)

30) Structure here.

Structure MUST BE PLACED Here
(show work for credit)
31) Which of the following display a signal in the DEPT-90 $^{13}$C NMR spectroscopy?
   A) CH$_3$
   B) CH$_2$
   C) CH
   D) C
   E) none of these
   Ans: 

32) Which of the following displays a negative signal in the DEPT-135 $^{13}$C NMR spectroscopy?
   A) CH$_3$
   B) CH$_2$
   C) CH
   D) C
   E) none of these
   Ans: 

33) Which of the following does NOT display a signal in the DEPT-135 $^{13}$C NMR spectroscopy?
   A) CH$_3$
   B) CH$_2$
   C) CH
   D) C
   E) none of these
   Ans:
Many will feel lost WITHOUT a Table of chemical shift values, but you do not need a table. The following problems are designed to test deductive reasoning.

34) The following compounds show a single line in their $^1$H NMR spectra. Write the letter assigned to each spectrum next to the corresponding compound. (4 pts)

- Compound A
  - NMR spectrum: 
  - Chemical shift: $0.23 \delta$

- Compound B
  - NMR spectrum: 
  - Chemical shift: $3.24 \delta$

- Compound C
  - NMR spectrum: 
  - Chemical shift: $9.60 \delta$

- Compound D
  - NMR spectrum: 
  - Chemical shift: $2.16 \delta$
35) Place the number next to the indicated protons in the boxes in the $^1$H NMR spectrum?

36) Place the number next to the indicated protons in the boxes in the $^1$H NMR spectrum?
NOTE: protons attached to N and O generally don't couple to nearest neighboring protons.
Match the following $^1$H NMR spectra to compounds 1 – 5 below.

I

II

III

IV

V

37) Match the following $^1$H NMR spectra to compounds 1 – 5 below.
38) Which of the following compounds is consistent with the $^{13}$C NMR spectrum?

![Chemical structures and NMR spectrum](image)

39) Which of the following compounds is consistent with the $^{13}$C NMR spectrum?

![Chemical structures and NMR spectrum](image)
40) Which of the following compounds is consistent with the $^{13}$C NMR spectrum?

![化合物图像]

41) The broadband decoupling in $^{13}$C NMR suppresses ______ splitting.
A) $^{12}$C-$^{13}$C
B) $^{12}$C-$^1$H
C) $^{13}$C-$^{13}$C
D) $^{13}$C-$^1$H
E) none of these

Ans:  

42) How many unique signals would you expect to find in the $^{13}$C NMR spectrum of the following compound?

![化合物图像]

A) 6
B) 7
C) 8
D) 9
E) none of these

Ans:  

43) Match the following $^1$H NMR spectra to compounds 1 – 4 below

I

singlet

singlet

overlapping peaks
doublet
doublet of doublet
triplet

singlet

singlet

triplet
doublet

singlet

singlet

singlet
44) How many unique signals would you expect to find in the \(^{13}\text{C}\) NMR spectrum of the following compound?

\[
\text{I} \quad \text{II} \quad \text{III} \quad \text{IV}
\]

A) 2  
B) 3  
C) 4  
D) 5  
E) none of these

Ans: 

45) How many unique signals would you expect to find in the \(^{13}\text{C}\) NMR spectrum of the following compound?

\[
\text{V}
\]

A) 6  
B) 7  
C) 8  
D) 9  
E) none of these

Ans: 

46) How many unique signals would you expect to find in the $^{13}$C NMR spectrum of the following compounds?

A) I-5, II-8  
B) I-3, II-6  
C) I-4, II-8  
D) I-5, II-6  
E) none of these

Ans:  

47) Which of the following C atoms (underlined C) will display the signal MOST downfield in the $^{13}$C NMR?

Hint: think about resonance and electronegativity together.

A) I  
B) II  
C) III  
D) IV  
E) none of these

Ans:  

48) Calculate the degree of unsaturation for the formula \((\text{C}_3\text{H}_8\text{Br}_2)\).

DEPT90

DEPT 135

\(^{13}\text{C NMR}\)

Solvent

75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 ppm

49) Structure here.

Structure MUST BE PLACED Here
(show work for credit)
50) Calculate the degree of unsaturation for the formula \((\text{C}_7\text{H}_7\text{Br})\)

DEPT90

DEPT 135

\(^{13}\text{C} \text{ NMR}\)

Solvent

131 ppm

51) Structure here.

Structure MUST BE PLACED Here
(show work for credit)
52) Calculate the degree of unsaturation for the formula \((\text{C}_4\text{H}_9\text{Br})\) 

53) Structure here. 

Structure MUST BE PLACED Here 
(show work for credit)
54) Calculate the degree of unsaturation for the formula \((\text{C}_{11}\text{H}_{14}\text{O})\)

55) Structure here.

Structure MUST BE PLACED Here
(show work for credit)
56) Calculate the degree of unsaturation for the formula (C\textsubscript{7}H\textsubscript{14}O\textsubscript{2})

57) Structure here.

Structure MUST BE PLACED Here
(show work for credit)
58) Calculate the degree of unsaturation for the formula \( (C_9H_{12}O) \).

59) Structure here.

Structure MUST BE PLACED Here
(show work for credit)
60) Calculate the degree of unsaturation for the formula (C₅H₇NO₂)

Structure MUST BE PLACED Here
(show work for credit)
62) Calculate the degree of unsaturation for the formula \( (\text{C}_3\text{H}_6\text{O}_2) \).
64) Calculate the degree of unsaturation for the formula \((C_6H_{12}O)\).

65) Structure here.

Structure MUST BE PLACED Here
(show work for credit)
66) Calculate the degree of unsaturation for the formula (C_{10}H_{14})

A compound with molecular formula C_{10}H_{14} displays the following IR, 1H NMR, 13C NMR spectra. Propose a structure for this compound.

67) Structure here.

Structure MUST BE PLACED Here
(show work for credit)
68) Calculate the degree of unsaturation for the formula (C₈H₁₁N)

69) Structure here.

Structure MUST BE PLACED Here
(show work for credit)
70) Calculate the degree of unsaturation for the formula (C₈H₁₄O₃)

71) Structure here.
72) Calculate the degree of unsaturation for the formula \((C_7H_{14}O_2)\)

73) Structure here.

Structure MUST BE PLACED Here
(show work for credit)
74) Calculate the degree of unsaturation for the formula \((\text{C}_6\text{H}_{15}\text{N})\).

![IR spectrum](image)

![\(^1\text{H}\) NMR spectrum](image)

![MS spectrum](image)

![\(^{13}\text{C}\) NMR spectrum](image)

75) Structure here.
### Table 16.2 Chemical Shifts for Protons in Different Electronic Environments

<table>
<thead>
<tr>
<th>Type of Proton</th>
<th>Chemical Shift (δ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methyl R−CH₃</td>
<td>~0.9</td>
</tr>
<tr>
<td>Methine</td>
<td>~1.7</td>
</tr>
<tr>
<td>Alkyl halide</td>
<td>2−4</td>
</tr>
<tr>
<td>Alcohol</td>
<td>2−5</td>
</tr>
<tr>
<td>Vinylic</td>
<td>4.5−6.5</td>
</tr>
<tr>
<td>Aryl</td>
<td>6.5−8</td>
</tr>
<tr>
<td>Aldehyde</td>
<td>~10</td>
</tr>
<tr>
<td>Carboxylic acid</td>
<td>~12</td>
</tr>
<tr>
<td>Allylic</td>
<td>~2</td>
</tr>
<tr>
<td>Alkynyl</td>
<td>~2.5</td>
</tr>
<tr>
<td>Aromatic methyl</td>
<td>~2.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Proton</th>
<th>Chemical Shift (δ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allylic</td>
<td>~2</td>
</tr>
<tr>
<td>Alkynyl</td>
<td>~2.5</td>
</tr>
<tr>
<td>Aromatic methyl</td>
<td>~2.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Proton</th>
<th>Chemical Shift (δ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methyl R−CH₃</td>
<td>~0.9</td>
</tr>
<tr>
<td>Methylene</td>
<td>~1.2</td>
</tr>
<tr>
<td>Methine</td>
<td>~1.7</td>
</tr>
</tbody>
</table>

---

Carbon atoms of carbonyl groups. These carbon atoms are highly deshielded.

$sp^2$-hybridized carbon atoms.

$sp^2$-hybridized carbon atoms as well as $sp^1$-hybridized carbon atoms that are deshielded by electronegative atoms.

$sp^1$-hybridized carbon atoms (methyl, methylene, and methine groups).

---

![Chemical Structures and Shifts Diagram](image-url)