Exam

Name_____

**SHORT ANSWER. Write the word or phrase that best completes each statement or answers the question.**

1) Calculate the magnetic field that corresponds to the proton resonance frequency of 300.00 MHz. The gyromagnetic ratio of the $^{1}H$ nucleus is 26,753 $s^{-1}$ $gauss^{-1}$. 1) _____

**MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.**

2) A nucleus with an _____ atomic number or an _____ mass number has a nuclear spin that can be observed by the NMR spectrometer. 2) _____
A) even, odd B) odd, even C) even, even D) odd, odd

**SHORT ANSWER. Write the word or phrase that best completes each statement or answers the question.**

3) What three-word term is abbreviated NMR? 3) _____

**MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.**

4) How many nuclear spin states are allowed for the $^{1}H$ nucleus? 4) _____
A) 1 B) 4 C) 2 D) 3 E) 10

5) The energy difference between the allowed spin states for an $^{1}H$ nucleus is _____ the strength of the external magnetic field in which it is placed. 5) _____
A) exponentially related to
B) directly proportional to
C) inversely proportional to
D) logarithmically related to
E) independent of

6) $^{1}H$ nuclei located near electronegative atoms tend to be _____ relative to $^{1}H$ nuclei which are not. 6) _____
A) split
B) deshielded
C) resonanced
D) shielded
E) none of the above

7) Electromagnetic radiation in the _____ region is used in $^{1}H$ NMR spectroscopy. 7) _____
A) X-ray
B) ultraviolet
C) microwave
D) infrared
E) radio wave

**SHORT ANSWER. Write the word or phrase that best completes each statement or answers the question.**

8) _____ is commonly used as an internal reference in NMR spectroscopy; its signal is assigned d = 0 in $^{1}H$ and $^{13}C$ NMR spectroscopy. 8) _____

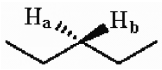
9) On a 90 MHz spectrometer, calculate the frequency at which a proton absorbs if it appears at 4.20 ppm. 9) _____

**MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.**

10) Using a 60–MHz spectrometer, the protons in dichloromethane appear at 5.30 ppm. When the same sample is placed in a 100–MHz instrument, where does the signal appear? 10) _____

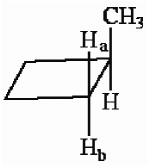
A) 3.18
B) 8.33
C) 5.30
D) cannot be determined from information given

11) The protons marked $H_a$ and $H_b$ in the molecule below are _____. 11) _____



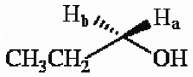

A) diastereotopic
B) chemically equivalent
C) enantiotopic
D) endotopic
E) none of the above

12) The protons marked $H_a$ and $H_b$ in the molecule below are _____. 12) _____




A) enantiotopic
B) diastereotopic
C) chemically equivalent
D) endotopic
E) none of the above

13) The protons marked $H_a$ and $H_b$ in the molecule below are _____. 13) _____




A) endotopic
B) chemically equivalent
C) enantiotopic
D) diastereotopic
E) none of the above

**ESSAY. Write your answer in the space provided or on a separate sheet of paper.**

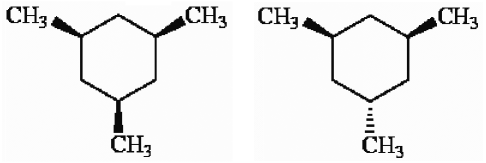
14) The chair form of cyclohexane has protons in two distinct environments, axial and equatorial. When the proton NMR of cyclohexane is run on a 100–MHz instrument at 23°C, only one signal for the compound is observed. Explain this apparent contradiction.

15) How might the proton spectrum of ultrapure dimethylamine, $(CH_3)_2NH$, differ from the spectrum of this compound to which $D_2O$ has been added?

16) Give one reason why $^{13}C$ NMR is less sensitive than $^{1}H$ NMR.

17) Why is Fourier transform NMR spectroscopy preferred over continuous wave as a technique for $^{13}C$ NMR?

18) How might the two trimethylcyclohexane isomers shown below be most readily distinguished using NMR?




**MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.**

19) What multiplicities are observed for the signals in the off–resonance decoupled $^{13}C$ spectrum of 2–chloropropene? 19) _____

A) 2 singlets and a doublet
B) a singlet and 2 doublets
C) 3 singlets
D) a singlet, a doublet and a triplet
E) a singlet, a triplet, and a quartet

**SHORT ANSWER. Write the word or phrase that best completes each statement or answers the question.**

20) What multiplicities are observed in the off–resonance decoupled $^{13}C$ spectrum of 2,3–dimethyl–but–2–ene? 20) _____

**ESSAY. Write your answer in the space provided or on a separate sheet of paper.**

21) Predict the number of signals expected (disregarding splitting) in the $^{1}H$ spectrum of *m*–xylene (1,3–dimethylbenzene).

22) Predict the number of signals expected (disregarding splitting) in the $^{1}H$ spectrum of *o*–chlorophenol (2–chlorophenol).

23) Predict the number of signals expected (disregarding splitting) in the $^{1}H$ spectrum of dibutyl ether.

24) Predict the number of signals expected (disregarding splitting) in the $^{1}H$ spectrum of 1,1–dimethylcyclobutane.

25) Predict the number of signals expected in the proton spin decoupled $^{13}C$ spectrum of *cis*–1,3–dimethylcyclopentane.

26) Predict the number of signals expected in the proton spin decoupled $^{13}C$ spectrum of 3–hexanone, $CH_3CH_2COCH_2CH_2CH_3$.

27) Predict the number of signals expected in the proton spin decoupled $^{13}C$ spectrum of 3–pentanone, $CH_3CH_2COCH_2CH_3$.

28) Predict the number of signals expected in the proton spin decoupled $^{13}C$ spectrum of *m*–dichlorobenzene (1,3–dichlorobenzene).

29) Predict the number of signals expected in the proton spin decoupled $^{13}C$ spectrum of *p*–dibromobenzene (1,4–dibromobenzene).

30) Predict the number of signals expected in the proton spin decoupled $^{13}C$ spectrum of cyclopentane.

31) Predict the number of signals expected, their splitting, and their relative area in the $^{1}H$ NMR spectrum of $CH_3CH_2OCH_3$.

32) Predict the number of signals expected, their splitting, and their relative area in the $^{1}H$ NMR spectrum of $(CH_3)_3CCHO$.

33) Predict the number of signals expected, their splitting, and their relative area in the $^{1}H$ NMR spectrum of 2–methylpropane (isobutane).

34) Predict the number of signals expected, their splitting, and their relative area in the $^{1}H$ NMR spectrum of 1,2–dichloroethane ($ClCH_2CH_2Cl$).

35) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_8H_{10}O$: δ 3.4 (3H, singlet), 4.5 (2H, singlet), 7.2 (5H, singlet) (ppm)

36) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_9H_{10}O_2$: δ 2.2 (3H, singlet), 5.0 (2H, singlet), 7.2 (5H, singlet) (ppm)

37) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_3H_3Cl_5$: δ 4.5 (1H, triplet), 6.1 (2H, doublet) (ppm)

38) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_4H_7BrO$: δ 2.2 (3H, singlet), 3.5 (2H, triplet), 4.5 (2H, triplet) (ppm)

39) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_3H_6Br_2$: δ 2.4 (2H, quintet), 3.5 (4H, triplet) (ppm)

40) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_5H_{10}O$: δ 1.1 (6H, doublet), 2.2 (3H, singlet), 2.5 (1H, septet) (ppm)

41) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_6H_8O_4$: δ 3.9 (6H, singlet), 6.1 (2H, singlet) (ppm)

42) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_7H_{12}O_4$: δ 1.3 (6H, triplet), 3.4 (2H, singlet), 4.2 (4H, quartet) (ppm)

43) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_5H_{12}O$: δ 1.0 (3H, triplet), 1.2–1.8 (6H, multiplet), 3.0 (1H, broad singlet), 3.8 (2H, triplet) (ppm)

44) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_7H_7NO_3$: δ 3.9 (3H, singlet), 6.9 (2H, doublet), 8.1 (2H, doublet) (ppm)

45) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_8H_{18}O$: δ 0.89 (6H, doublet), 1.87 (1H, multiplet), 3.17 (2H, doublet)(ppm)

46) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_6H_{10}O_2$: δ 2.19 (3H, singlet), 2.70 (2H, singlet) (ppm)

47) Deduce the identity of the following compound from the NMR data given.

$C_4H_6O_2$: $^{1}H$ NMR, δ 2.28 (2H, multiplet), 2.50 (2H, triplet), 4.35 (2H, triplet);
$^{13}C$ NMR, δ 177.81 (singlet), 68.58 (triplet), 27.70 (triplet), 22.17 (triplet) (ppm)

48) Deduce the identity of the following compound from the spectral data given.

$C_7H_{10}O_2$: $^{1}H$ NMR, δ 1.16 (3H, singlet), 2.21 (2H, singlet); $^{13}C$ NMR, δ 216.25 (singlet), 52.57 (singlet), 34.51 (triplet), 20.22 (quartet) (ppm)

49) Deduce the identity of the following compound from the $^{13}C$ NMR data given.

$C_9H_{12}$: δ 21.3 (quartet), 127.2 (doublet), 138.0 (singlet) (ppm)

50) Deduce the identity of the following compound from the $^{13}C$ NMR data given.

$C_4H_7Br$: δ 18.0 (quartet), 33.0 (triplet), 128.0 (doublet), 131.0 (doublet) (ppm)

51) Deduce the identity of the following compound from the $^{13}C$ NMR data given.

$C_4H_{10}O$: δ 10.0 (quartet), 22.9 (quartet), 32.0 (triplet), 69.6 (doublet) (ppm)

52) Deduce the identity of the following compound from the $^{13}C$ NMR data given.

$C_8H_8O$: δ 26.4 (quartet), 128.0 (doublet), 128.3 (doublet), 133.0 (doublet), 137.0 (singlet), 198.0 (singlet) (ppm)

53) Deduce the identity of the following compound from the spectral data given.

$C_3H_4BrN$: $^{1}H$ NMR, δ 2.98 (2H, triplet), 3.53 (2H, triplet); $^{13}C$ NMR, δ 21.05 (triplet), 23.87 (triplet), 118.08 (singlet) (ppm); IR, 2963, 2254 $cm^{-1}$

54) Deduce the identity of the following compound from the $^{1}H$ NMR data given.

$C_4H_{11}N$: δ 0.90 (3H, triplet), 1.07 (3H, doublet), 1.14 (2H, broad singlet), 1.34 (2H, multiplet), 2.79 (1H, multiplet) (ppm)

55) Deduce the identity of the following compound from the $^{13}C$ NMR data given.

$C_6H_{12}O$: δ 29.80 (quartet), 30.82 (singlet), 56.53 (triplet), 203.36 (doublet) (ppm)

56) Deduce the identity of the following compound from the $^{13}C$ NMR data given.

$C_4H_8O$: δ 11.97 (triplet), 33.54 (triplet), 67.03 (doublet) (ppm)

57) Deduce the identity of the following compound from the spectral data given.

$C_9H_{10}O_2$: $^{13}C$ NMR, δ 18.06 (quartet), 45.40 (doublet), 127.32 (doublet), 127.55 (doublet), 128.61 (doublet), 139.70 (singlet) (ppm), 180.98 (singlet); IR, broad 3500–2800, 1708 $cm^{-1}$

58) Deduce the identity of the following compound from the spectral data given.

$C_5H_{10}O$: $^{1}H$ NMR, δ 1.2 (6H, doublet), 2.1 (3H, singlet), 2.8 (1H, septet) (ppm); IR, 2980, 1710 $cm^{-1}$; MS, *m*/*z* 71, 43

59) Deduce the identity of the following compound from the spectral data given.

$C_8H_{10}$: $^{1}H$ NMR, δ 1.20 (3H, triplet), 2.60 (2H, quartet), 7.12 (5H, singlet) (ppm); IR, 3050, 2970, 1600 $cm^{-1}$; MS, *m*/*z* 91

60) Deduce the identity of the following compound from the spectral data given.

$C_4H_8O_2$: $^{1}H$ NMR, δ 1.23 (3H, triplet), 2.00 (3H, singlet), 4.02 (2H, quartet) (ppm); IR, 2980, 1740 $cm^{-1}$

**MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.**

61) What is the approximate chemical shift of an alkynyl carbon in $^{13}C$ NMR spectroscopy? 61) _____
A) 200 ppm B) 30 ppm C) 10 ppm D) 120 ppm E) 70 ppm

**ESSAY. Write your answer in the space provided or on a separate sheet of paper.**

62) The $^{1}H$ NMR spectrum of ethanol is acquired and the hydroxyl signal appears as a singlet instead of a triplet. Offer an explanation.

63) You have a sample and its $^{1}H$ NMR spectrum. You know your sample contains O atoms but not N atoms, and you suspect that your sample may be an alcohol. What common spectroscopic technique might you use to confirm your suspicion?

**MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.**

64) If a molecule contains 4 elements of unsaturation and signals in the $^{1}H$ NMR spectrum between δ 7.0 and 8.0 ppm, what structural group is likely to be present? 64) _____

A) a carbon–carbon triple bond
B) an aromatic ring
C) a carbonyl group
D) a hydroxyl group
E) a cyclohexyl ring

**ESSAY. Write your answer in the space provided or on a separate sheet of paper.**

65) Why is carbon–carbon splitting typically not seen in $^{13}C$ NMR spectra?

66) Deduce the identity of the compound whose molecular formula is $C_8H_{14}$ from the spectral data provided: IR ($cm^{-1}$): 2950, 2180; $^{1}H$ NMR (δ): 0.9 (3H, t), 1.0 (9H, s), 2.3 (2H, q) (ppm).

67) Deduce the identity of the compound whose molecular formula is $C_4H_8O_3$ from the spectral data provided: IR ($cm^{-1}$): 2800–3300 (broad), 2950, 1750; $^{13}C$ NMR (δ): 17.7 (q), 65.4 (q), 72.3 (d), 210.8 (s) (ppm)

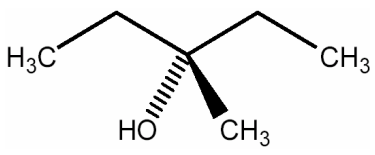
68) Why is carbon–hydrogen splitting not a major part of $^{1}H$ NMR spectra?

69) Predict the number of signals expected in the proton spin decoupled $^{13}C$ NMR spectrum of *o*–diethylbenzene (1,2–diethylbenzene).

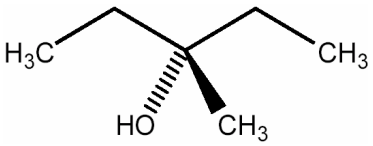
70) Predict the number of signals expected in the proton spin decoupled $^{13}C$ NMR spectrum of *p*–diethylbenzene (1,4–diethylbenzene).

**SHORT ANSWER. Write the word or phrase that best completes each statement or answers the question.**

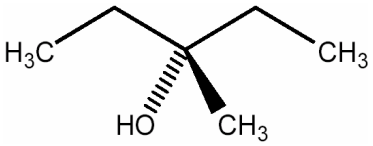
71) Predict the number of signals expected (disregarding splitting) in the $^{1}H$ NMR spectrum of the compound shown below. 71) _____



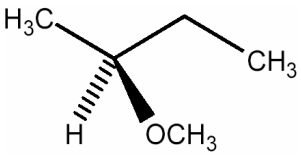
72) Predict the number of signals expected in the proton spin decoupled $^{13}C$ NMR spectrum of the compound shown below. 72) _____



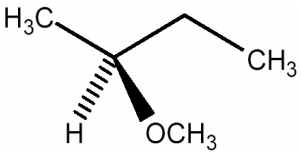

73) Predict the number of distinct quartets expected in the off-resonance decoupled $^{13}C$ NMR spectrum of the compound shown below. 73) _____



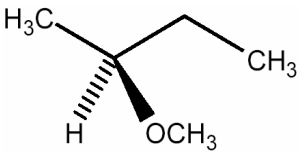

74) Predict the number of signals expected (disregarding splitting) in the $^{1}H$ NMR spectrum of the compound shown below. 74) _____



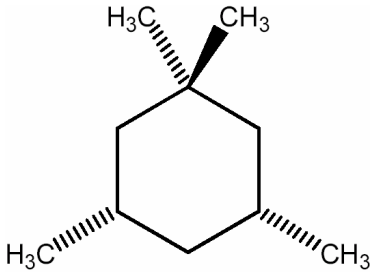

75) Predict the number of signals expected in the proton spin decoupled $^{13}C$ NMR spectrum of the compound shown below. 75) _____



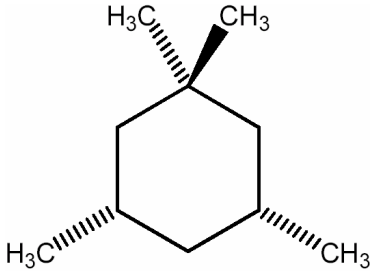

76) Predict the number of distinct quartets expected in the off-resonance decoupled $^{13}C$ NMR spectrum of the compound shown below. 76) _____



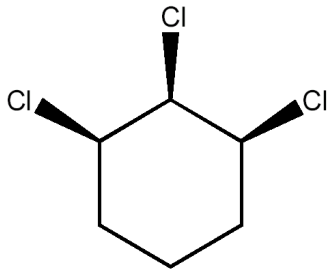
77) Predict the number of signals expected in the proton spin decoupled $^{13}C$ NMR spectrum of the compound shown below. 77) _____



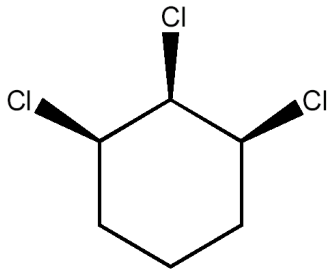

78) Predict the number of distinct quartets expected in the off-resonance decoupled $^{13}C$ NMR spectrum of the compound shown below. 78) _____




79) Predict the number of signals expected in the proton spin decoupled $^{13}C$ NMR spectrum of the compound shown below. 79) _____




80) Predict the number of distinct quartets expected in the off-resonance decoupled $^{13}C$ NMR spectrum of the compound shown below. 80) _____



81) Provide a structure that is consistent with the data below. 81) _____

$C_6H_{10}$
IR ($cm^{-1}$): 2950, 2230
$^1H$ NMR ( d): 2.0 (1H, septet), 1.8 (3H, s), 0.9 (6H, d)
$^{13}C$ NMR (d ): 78 (s), 72 (s), 45 (d), 18 (q), 15 (q)

82) Provide a structure that is consistent with the data below. 82) _____

$C_5H_8Cl_2$
IR ($cm^{-1}$): 2950
$^1H$ NMR ( d): 1.4 (4H, t), 1.2 (4H, t)
$^{13}C$ NMR (d ): 62 (s), 26 (t), 23 (t)

83) Provide a structure that is consistent with the data below. 83) _____

$C_7H_{14}O_2$
IR ($cm^{-1}$): 2950, 1740
$^1H$ NMR ( d): 2.3 (2H, q), 1.0 (3H, t), 0.9 (9H, s)
$^{13}C$ NMR (d ): 185 (s), 78 (s), 29 (t), 14 (q), 12 (q)

84) Provide a structure that is consistent with the data below. 84) _____

$C_5H_{10}O$
IR ($cm^{-1}$): 2950, 1720
$^1H$ NMR ( d): 2.6 (1H, septet), 2.1 (3H, s), 1.0 (6H, d)
$^{13}C$ NMR (d ): 195 (s), 42 (d), 18 (q), 11 (q)

85) Provide a structure that is consistent with the data below. 85) _____

$C_9H_7Cl$
IR ($cm^{-1}$): 3050, 2950, 2220, 1620
$^1H$ NMR ( d): 7.8 (2H, d), 7.2 (2H, d), 2.1 (3H, s)
$^{13}C$ NMR (d ): 140 (s), 132, (s), 125 (d), 122 (d), 88 (s), 83 (s), 18 (q)

86) Provide a structure that is consistent with the data below. 86) _____

$C_7H_{16}O$
IR ($cm^{-1}$): 3200–3600 (broad), 2950
$^1H$ NMR ( d): 2.9 (1H, broad s), 1.2 (6H, q), 0.9 (9H, t)
$^{13}C$ NMR (d ): 70 (s), 25 (t), 12 (q)

87) Provide a structure that is consistent with the data below. 87) _____

$C_5H_{10}O$

IR ($cm^{-1}$): 2950

$^1H$ NMR ( d): 3.5 (4H, s), 0.9 (6H, s)

$^{13}C$ NMR (d ): 64 (t), 41 (s), 12 (q)

88) Provide a structure that is consistent with the data below. 88) _____

$C_7H_{16}O$

IR ($cm^{-1}$): 3200–3600 (broad), 2950

$^1H$ NMR ( d): 2.8 (1H, broad s), 1.0 (6H, s), 0.9 (9H, s)

$^{13}C$ NMR (d ): 68 (s), 39 (s), 16 (q), 13 (q)

89) Provide a structure that is consistent with the data below. 89) _____

$C_9H_9N$

IR ($cm^{-1}$): 3050, 2950, 2240, 1630

$^1H$ NMR ( d): 7.5 (2H, d), 7.1 (2H, d), 2.3 (2H, q), 0.9 (3H, t)

$^{13}C$ NMR (d ): 137 (s), 130, (s), 126 (d), 122 (d), 95 (s), 25 (t), 15 (q)

90) Provide a structure that is consistent with the data below. 90) _____

$C_4H_8O$

IR ($cm^{-1}$): 2950

$^1H$ NMR ( d): 3.2 (4H, t), 1.2 (4H, t)

$^{13}C$ NMR (d ): 68 (t), 27 (t)

**MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.**

91) In the $^1H$ NMR spectrum of bromoethane the methylene group is split into a quartet by the $\alpha$ and $\beta$ nuclear spins of the protons on the neighboring methyl group. If the external magnetic field, $B_\circ$, directs upward, which sequence of nuclear spins contributes to the second farthest peak down field within the spin–spin splitting pattern? 91) _____

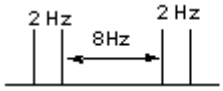
A) ↓↓↓ B) ↑↓↑ C) ↑↓↓ D) ↑↑↑ E) ↑↑↓↓

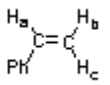
92) What is the relative area of each peak in a quartet spin–spin splitting pattern? 92) _____

A) 1:4:4:1 B) 1:2:2:1 C) 1:2:1 D) 1:3:3:1 E) 1:1:1:1

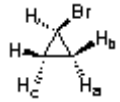
**SHORT ANSWER. Write the word or phrase that best completes each statement or answers the question.**

93) The following splitting pattern represents one of the vinyl protons of styrene. Identify which proton is represented and list all the coupling constants (J values) for the splitting pattern. 93) _____



94) Use the structure below to state the relationship between the indicated protons as equivalent, enantiotopic, diastereotopic, or unrelated. 94) _____




$H_a$ & $H_b$:

$H_a$ & $H_c$:

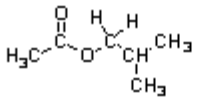
$H_b$ & $H_c$:

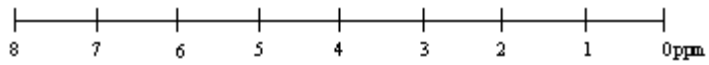
**MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.**

95) Any process faster than _____ will be recorded as an average by NMR spectroscopy. 95) _____
A) 0.0005 seconds
B) 0.1 seconds
C) 0.001 seconds
D) 1 minute
E) 0.01 seconds

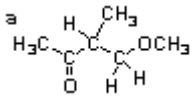
**SHORT ANSWER. Write the word or phrase that best completes each statement or answers the question.**

96) Using the scale below, draw the $^1$H NMR spectrum for isobutyl acetate, shown below. Present the peaks with correct splitting patterns and at the approximate chemical shift (+/– 0.5 ppm). Just above each peak, indicate the relative integration value of each type of hydrogen. 96) _____



97) Label the different $^1H$ environments in the structure below a, b, c.... Then complete the table for each different type of proton. The first one is done for you as an example. (Note: there may be fewer than 7 different proton environments) 97) _____




| **environments** | **a** | **b** | **c** | **d** | **e** | **f** | **g** |
|---|---|---|---|---|---|---|---|
| **chemical shift** (+/– 0.5 ppm) | 1.9 | | | | | | |
| **spin–spin splitting** | s | | | | | | |

**MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.**

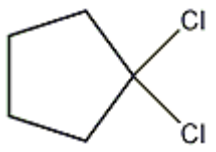
98) An NMR spectrometer that operates at a frequency of 60 MHz for $^{13}C$ NMR spectra, operates at what frequency for $^1H$ NMR spectra? 98) _____
A) 60 MHz B) 240 MHz C) 15 MHz D) 30 MHz E) 120 MHz

**SHORT ANSWER. Write the word or phrase that best completes each statement or answers the question.**

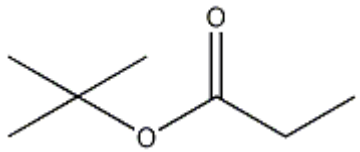
99) Compound **I** has a molecular formula of $C_7H_{16}$. In $^{13}C$ NMR , compound **I** gave 3 peaks and in $^1H$ NMR it also gave 3 peaks, a doublet, a triplet and a multiplet. Provide a structure for compound **I**. 99) _____

1) 70,458 gauss
2) D
3) nuclear magnetic resonance
4) C
5) B
6) B
7) E
8) Tetramethylsilane, $(CH_3)_4Si$
9) 378 Hz
10) C
11) B
12) B
13) C
14) Axial and equatorial positions are being rapidly interchanged by chair–chair conformational interconversions. This rapid exchange results in an average signal for these two positions. At very low temperatures, two distinct signals are observed as the conformational interconversion process is slowed.
15) N–H signal will broaden or disappear upon addition of $D_2O$ as rapid hydrogen exchange occurs.
16) Natural isotopic abundance of $^{13}C$ is about 100 times less than that of $^{1}H$ or gyromagnetic ratio of $^{13}C$ is much smaller.
17) $^{13}C$ nuclei have a low sensitivity which requires multiple acquisitions of the spectrum before data become useful. The time/acquisition is much lower using FT techniques so that $^{13}C$ spectra can be acquired in reasonable times using this method.
18) Number of signals in $^{13}C$ NMR, 3 signals versus 6.
19) E
20) a singlet and a quartet
21) 4
22) 5
23) 4
24) 3
25) 4
26) 6
27) 3
28) 4
29) 2
30) 1
31) 3 signals: (3H, triplet); (2H, quartet); (3H, singlet)
32) 2 signals: (9H, singlet); (1H, singlet)
33) 2 signals: (9H, doublet); (1H, 10 line pattern)
34) 1 signal: singlet
35) $PhCH_2OCH_3$
36) $PhCH_2O_2CCH_3$
37) $Cl_2CHCHClCHCl_2$
38) $CH_3COCH_2CH_2Br$
39) $BrCH_2CH_2CH_2Br$
40) $CH_3COCH(CH_3)_2$
41) $CH_3O_2CCH{=}CHCO_2CH_3$
42) $CH_2(CO_2CH_2CH_3)_2$
43) $CH_3(CH_2)_4OH$

44) p–nitroanisole (*p*–$O_2NC_6H_4OCH_3$)
45) $[(CH_3)_2CHCH_2]_2O$
46) $CH_3COCH_2CH_2COCH_3$
47) γ–butyrolactone
48) 2,2–dimethylcyclopentane–1,3–dione
49) 1,3,5–trimethylbenzene
50) $CH_3CH{=}CHCH_2Br$
51) butan–2–ol
52) acetophenone ($PhCOCH_3$)
53) $BrCH_2CH_2CN$
54) *sec*–butylamine
55) $(CH_3)_3CCH_2CHO$
56) cyclobutanol
57) $PhCH(CH_3)CO_2H$
58) $(CH_3)_2CHCOCH_3$
59) $PhCH_2CH_3$
60) $CH_3CO_2CH_2CH_3$
61) E
62) A fast exchange of the hydroxyl H from one ethanol molecule to another is occurring. This rapidly exchanging H produces a single, unsplit absorption at an average field.
63) Take an IR spectrum and look for the O–H stretch or add some $D_2O$ to the sample and reacquire the $^1H$ NMR to see if a peak broadens or disappears.
64) B
65) Only 1% of the carbon atoms are $^{13}C$ so the probability of two $^{13}C$ nuclei being adjacent is very small.
66) 2,2–dimethylhex–3–yne
67) $CH_3OCH(CH_3)CO_2H$
68) Most of the carbons are $^{12}C$ which does not exhibit coupling to $^1H$.
69) 5
70) 4
71) 4
72) 4
73) 2
74) 5
75) 5
76) 3
77) 7
78) 3
79) 4
80) 0
81) $(CH_3)_2CHC{\equiv}CCH_3$
82)

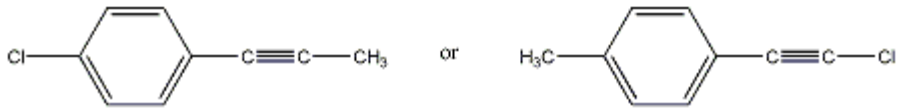


83)



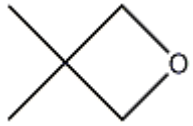
84) $(CH_3)_2CHCOCH_3$

85)



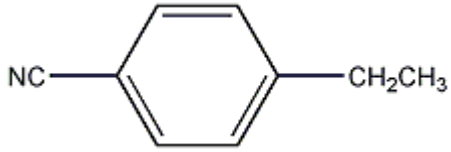
86) $(CH_3CH_2)_3COH$

87)



88) $(CH_3)_3CC(CH_3)_2OH$

89)



90)

91) B

92) D

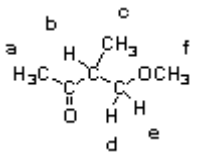
93) Hb, Jab = 10 Hz (cis), Jbc = 2 Hz (geminal)

94) $H_a$ & $H_b$: Diastereotopic
$H_a$ & $H_c$: Enantiotopic
$H_b$ & $H_c$: Diastereotopic

95) E

96) δ 3.9 ppm (d, 2H), 2.1 ppm (s, 3H), 1.9 ppm (m, 1H), 0.9 ppm (d, 6H).

97)




| **environments** | **a** | **b** | **c** | **d** | **e** | **f** | **g** |
|---|---|---|---|---|---|---|---|
| **chemical shift** (+/– 0.5 ppm) | 1.9 | 2.5 | 1 | 3.3 | 3.3 | 3.1 | |
| **spin–spin splitting** | s | ddq | d | dd | dd | s | |

98) B

99)