1. Calculate the number of vibrational degrees of freedom of these molecules.
   a) $\text{HN}_3$  b) $\text{NO}_2^+$  c) $\text{CONH}_2$  d) $\text{FNO}_2$

2. Classify these vibrations as IR active, IR inactive or forbidden.
   a) [Diagram of a molecule with double bonds]
   b) [Diagram of a molecule with single bonds]
   c) [Diagram of a molecule with double bonds]
   d) [Diagram of a molecule with double bonds and additional bromine atoms]
   e) [Diagram of a molecule with double bonds]

3. How can these compounds be distinguished by inspecting the C-H, C-Cl and C=C stretching regions of their IR spectra?
   a) [Diagram of a molecule with double bonds]
   b) [Diagram of a molecule with double bonds]
   c) [Diagram of a molecule with single bonds]

4. Deduce the structure of these compounds from their IR and NMR spectra.
   a) $\text{C}_4\text{H}_8\text{O}$ (IR) 2941, 1709; (NMR) 1.0, 3H t; 2.1, 3H s; 2.4, 2H q
b \( \text{C}_5\text{H}_{10}\text{O}_2 \): (IR) 3400–2800, 1710; (NMR) 1.3, 9H s; 11.3, 1H s

\( \text{C}_9\text{H}_{10}\text{O}_2 \): (IR) 1725; (NMR) 1.2, 6H d; 2.5, 1H sep; 3.7, 3H s

d \( \text{C}_5\text{H}_{10}\text{O}_2 \): (IR) 1725; (NMR) 1.2, 6H d; 2.0, 3H s; 5.0, 1H sep

e \( \text{C}_5\text{H}_{10}\text{O}_2 \): (IR) 2750, 1740; (NMR) 1.2, 6H s; 3.5, 3H s; 9.7, 1H s

f \( \text{C}_{10}\text{H}_{14}\text{O} \): (IR): 3448, 2985, 1613; (NMR): 1.2, 6H s; 1.6, 1H s; 3.7, 2H s; 7.2, 5H s

g \( \text{C}_9\text{H}_{12}\text{O} \): (IR) 3077, 2985, 1613; (NMR): 1.2, 6H d; 2.9, 1H sep; 7.1, 5H s

h \( \text{C}_9\text{H}_{10}\text{O} \): (IR) 3010, 1720, 1600, 1500; (NMR): 2.1, 3H s; 3.8, 2H s; 7.2, 5H s

i \( \text{C}_8\text{H}_9\text{NO}_2 \): (IR) 3226, 3206, 1666; (NMR): 3.9, 3H s; 7.2, 2H broad; 7.4, 4H AB quartet

j \( \text{C}_8\text{H}_6 \): (IR): 3310, 2210; (NMR): 3.1, 1H s; 7.4, 5H s

5 Match the compound with its IR spectrum

\[ \text{HO-} \text{Ph} \quad \text{CH} \quad \text{CO-} \text{Ph} \quad \text{CO-} \text{Ph} \quad \text{Ph} \]

\[ \text{Wavenumber (cm}^{-1}\text{)} \]

\[ \text{a} \]

\[ \text{b} \]
Match the following IR spectra with the appropriate category of compound: alcohol, primary amide, primary amine, secondary amide, secondary amine, carboxylic acid, ketone.
Answers

1a six 1b four 1c 39 1d three 2a Forbidden 2b Inactive 2c Active 2d Inactive 2e Active 3a Two C-Cl, one C=C and two C-H stretches 3b One C-Cl, no C=C and one C-H stretches 3c Two C-Cl, no C=C and two C-H stretches

4a \( \text{CH}_3\text{CO} \) 4b \( \text{HO}\text{CH}_2\text{CO} \) 4c \( \text{MeO}\text{CH}_3\text{CO} \) 4d \( \text{MeO} \text{CO} \) 4e \( \text{H} \text{CH} \text{C} \text{H} \) 4f \( \text{HO} \text{CH} \text{Ph} \) 4g \( \text{Ph} \text{CH} \text{Ph} \) 4h \( \text{Ph} \text{CO} \) 4i \( \text{Ph} \text{CH} \text{NH}_2 \) 4j \( \text{Ph} \text{CH} \text{CH}_2 \text{CO} \) 5a \( \text{CH} \text{CO} \text{CH}_2\text{CH}_3 \) 5b \( \text{Ph} \text{CO} \text{Ph} \) 5c \( \text{HO} \text{Ph} \text{CH} \text{Ph} \) 5d \( \text{CO} \text{Ph} \) 6a primary amide 6b carboxylic acid 6c secondary amine 6d ketone