20-2 The most fragmentation and hence the most complex spectra come from electron impact ionization. Field ionization will produce the simplest spectra. Chemical ionization and electron impact ionization are more sensitive.

20-5 (a) CH$_4^+$ has an m/z = 16, which is the beginning of the proposed scan range. Using the equation for a magnetic sector experiment, we can determine the relationship between m/z and the field strength B.

$$16 = \frac{m}{z} = \frac{B^2 r^2 e}{2V} = k B^2 = k(0.126 \text{ T})^2$$

Because the other variables are fixed in this part of the problem, we can also write, where B is the upper field strength to be determined.

$$250 = k B^2$$

If we divide the two equations, we can solve for the unknown field strength.

$$\frac{250}{16} = \frac{(0.126 \text{ T})^2}{k} \Rightarrow B = \sqrt{\frac{250}{16}}(0.126 \text{ T})^2 = \sqrt{0.248} = 0.498 \text{ T}$$

Scan the field strength from 0.126 T to 0.498 T will sample m/z from 16 to 250.

(b) We do the same thing except that V is the variable in this case.

$$16 = \frac{m}{z} = \frac{B^2 r^2 e}{2V} = k' \left( \frac{1}{V} \right) = k' \left( \frac{1}{3000 \text{ V}} \right) \Rightarrow 250 = k' \left( \frac{1}{V_{250}} \right)$$

Divide the two equations and solve for the accelerating voltage.

$$\frac{16}{250} = \frac{k'}{k' V_{250} = \frac{V_{250}}{3000 \text{ V}}} \Rightarrow V_{250} = 3000 \left( \frac{16}{250} \right) = 192 \text{ V}$$

A scan from V = 3000 V to 192 V will scan the m/z range from 16 to 250.

20-7 We assume that the ion originally has 0 velocity. Its acceleration to its final kinetic energy value can determine its final kinetic energy by the relation (convert mass from amu into kg).

$$E_k = z e V = \frac{1}{2} m v^2 \quad \therefore v = \sqrt{\frac{2 z e V}{m}} = \sqrt{\frac{2(1)(1.602 \times 10^{-19})(5.00)}{78.0 \text{ amu} \times 1.66 \times 10^{-27} \text{ kg/amu}}} = 3517 \frac{m}{s}$$

Since x = v t, we can find the time to traverse 15 cm at this velocity.
\[ t = \frac{x}{v} = \frac{0.150 \text{ m}}{3517 \text{ m/s}} = 42.6 \mu\text{s} \]

20-10. The expression for mass resolution is just \( m/\Delta m \). Take \( m \) to be the central average of the two peaks under consideration. Watch out for (d); the Th ion is doubly charged and recall we are measuring \( m/z \).

(a) \[ R = \frac{\left( \frac{m}{z} \right)}{\left( \Delta \frac{m}{z} \right)} = \frac{\left( \frac{28.0187 + 28.0061}{2} \right)}{\left( 28.0187 - 28.0061 \right)} = \frac{28.0124}{0.0126} = 2223 \]

(b) \[ R = \frac{\left( \frac{m}{z} \right)}{\left( \Delta \frac{m}{z} \right)} = \frac{\left( \frac{28.0313 + 27.9949}{2} \right)}{\left( 28.0313 - 27.9949 \right)} = \frac{28.0131}{0.0364} = 769.6 \]

(c) \[ R = \frac{\left( \frac{m}{z} \right)}{\left( \Delta \frac{m}{z} \right)} = \frac{\left( \frac{85.0641 + 85.0653}{2} \right)}{\left( 85.0653 - 85.0641 \right)} = \frac{85.0647}{0.0012} = 70887 \]

(d) \[ R = \frac{\left( \frac{m}{z} \right)}{\left( \Delta \frac{m}{z} \right)} = \frac{\left( \frac{115.90129 + \left( \frac{232.03800}{2} \right) \right)}{\left( \left( \frac{232.03800}{2} \right) - 115.90129 \right)} = \frac{115.960595}{0.11681} = 992.7 \]

20-12 (a) You could do this with a single op amp, with the appropriate gain. The voltage across the load resistor is amplified in a voltage amplifier.

20-12 (b) Here you could do it with two op amps, where a voltage amplifier is preceded by a current-to-voltage converter.
20-13 (a) Since all variables are held constant except \(V\), we can rewrite the magnetic sector equation, replacing all other terms with a constant \(k\), as

\[
\frac{m}{z} = \frac{B^2 r^2 e}{2 V} = k \left( \frac{1}{V} \right)
\]

Hence, for the two peaks, the standard and the unknown, we can write

\[
\left( \frac{m}{z} \right)_s = k \left( \frac{1}{V_s} \right), \quad \left( \frac{m}{z} \right)_u = k \left( \frac{1}{V_u} \right)
\]

For the ratio between the two measured \(m/z\) values, we obtain

\[
\frac{\left( \frac{m}{z} \right)_s}{\left( \frac{m}{z} \right)_u} = \frac{k \left( \frac{1}{V_s} \right)}{k \left( \frac{1}{V_u} \right)} = \frac{V_u}{V_s}
\]

(b) Given that we have the voltage ratio and the mass of the standard as 69.00, we can find \(m/z\) for the unknown to be

\[
\left( \frac{m}{z} \right)_u = \left( \frac{m}{z} \right)_s \left[ \frac{V_s}{V_u} \right] = 69.00 \left[ \frac{1}{0.965035} \right] = 71.50
\]

(c) Since the \(m/z\) is half-integral, it suggests that the ion is a doubly charged ion. Since the known molecular mass is 143, then this is consistent and our unknown peak is the parent ion, doubly charged. Since it is an organic compound, then the fact that it has an odd mass value suggests that it likely contains an odd number of nitrogen atoms, who bring an odd bonding valency (compared to carbon or oxygen) to a molecule.

20-15. Note first of all that the two clusters have the same general shape. They are offset from each other by a mass spacing of 14 amu. This is the mass of a CH\(_2\) unit. The two groups differ, then by this molecular fragment. Given the known identity of the original compound, the first group of peaks arise from a loss of 1 Cl and the second group comes from the additional loss of a
CH₂. Since the two groups are related by the loss of the CH₂, the first Cl missing must have come from the lone Cl atom in the molecule. The six peaks are:

\[
\left( \frac{m}{z} = 117 \right) \text{ is due to } 35\text{Cl}_3C^+ \quad \left( \frac{m}{z} = 119 \right) \text{ is due to } 37\text{Cl}35\text{Cl}_2C^+
\]

\[
\left( \frac{m}{z} = 121 \right) \text{ is due to } 37\text{Cl}_235\text{ClC}^+ \quad \left( \frac{m}{z} = 131 \right) \text{ is due to } 35\text{Cl}_3\text{CCH}_2^+
\]

\[
\left( \frac{m}{z} = 133 \right) \text{ is due to } 37\text{Cl}35\text{Cl}_2\text{CCH}_2^+ \quad \left( \frac{m}{z} = 135 \right) \text{ is due to } 37\text{Cl}_235\text{ClCCH}_2^+
\]

Note that we are not seeing a mass 123 or a mass 137, because the isotopic abundance of the ions with three 37-amu Cl atoms is too low to be seen here.