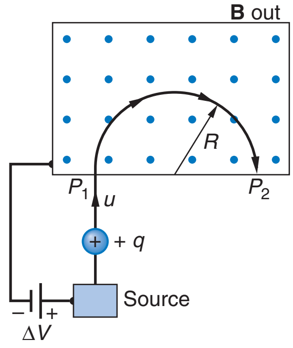
Mass Spectrometer

One of several devices currently used to measure the charge-to-mass ratio q/m of charged atoms and molecules is the mass spectrometer. The mass spectrometer is used to find the charge-to-mass ratio of ions of known charge by measuring the radius of their circular orbits in a uniform magnetic field. Equation 3-2 gives the radius of R for the circular orbit of a particle of mass m and charge q moving with speed u in a magnetic field B that is perpendicular to the velocity of the particle. Figure MS-1 shows a simple schematic drawing of a mass spectrometer. Ions from an ion source are accelerated by an electric field and enter a uniform magnetic field produced by an electromagnet. If the ions start from rest and move through a potential ΔV, their kinetic energy when they enter the magnetic field equals their loss in potential energy, $q\Delta V$:

$$\frac{1}{2}mu^2 = q\Delta V \qquad \textbf{MS-1}$$

The ions move in a semicircle of radius R given by Equation 3-2 and exit through a narrow aperture into an ion detector (or, in earlier times, a photographic plate) at point P_2, a distance $2R$ from the point where they enter the magnet. The speed u can be eliminated from Equations 3-2 and MS-1 to find q/m in terms of ΔV, B, and R. The result is

$$\frac{q}{m} = \frac{2\Delta V}{B^2R^2} \qquad \textbf{MS-2}$$



MS-1 Schematic drawing of a mass spectrometer. Ions from an ion source, positively charged ions in this diagram, are accelerated through a potential difference ΔV and enter a uniform magnetic field at P_1. The magnetic field **B** is directed out of the plane of the page as indicated by the dots. The ions are bent into circular arcs and strike a photographic plate or exit through an aperture to an ion detector at P_2. The radius of the circle is proportional to the mass of the ion.

In the original mass spectrometer, invented by F. W. Aston (a student of Thomson's) in 1919, mass differences could be measured to a precision of about 1 part in 10,000. The precision has been improved by introducing a velocity selector between the ion source and the magnet, which makes it possible to limit the range of velocities of the incoming ions and to determine the velocities of the ions more accurately. Today, values of atomic and molecular masses are typically measured with mass spectrometers to precisions of better than 1 part in 10^9. The method normally used is to measure the differences in R between standard masses and the ions of interest, as illustrated in the following example.

EXAMPLE MS-1 Mass Spectrometer Measurements A ^{58}Ni ion of charge $+e$ and mass 9.62×10^{-26} kg is accelerated through a potential difference of 3 kV and deflected in a magnetic field of 0.12 T. (*a*) Find the radius of curvature of the orbit of the ion. (*b*) Find the difference in the radii for curvature of ^{58}Ni ions and ^{60}Ni ions. (Assume that the mass ratio is 58/60.)

SOLUTION

1. For question (*a*), the radius of the ion's orbit is given by rearranging Equation MS-2:

$$R^2 = \frac{2m\Delta V}{qB^2}$$

2. Noting that in this case $q = +e$ and substituting the values yields

$$R^2 = \frac{(2)(9.62 \times 10^{-26}\ \text{kg})(3000\ \text{V})}{(1.60 \times 10^{-19}\ \text{C})(0.12\ \text{T})^2}$$
$$= 0.251\ \text{m}^2$$
$$R = \sqrt{0.251\ \text{m}^2} = 0.501\ \text{m}$$

3. For question (*b*), note that according to Equation MS-2, an ion's orbit radius is proportional to the square root of its mass. For identical values of q, V, and B, if R_1 is the radius for the ^{58}Ni ion and R_2 is the radius for the ^{60}Ni ion, their ratio is

$$\frac{R_2}{R_1} = \sqrt{\frac{M_2}{M_1}} = \sqrt{\frac{60}{58}} = 1.017$$

4. Substituting the value for the ^{58}Ni radius computed above gives

$$R_2 = 1.017R_1 = (1.017)(0.501\ \text{m})$$
$$= 0.510\ \text{m}$$

5. The difference ΔR in the radii is then

$$\Delta R = R_2 - R_1 = 0.510\ \text{m} - 0.501\ \text{m}$$
$$= 0.009\ \text{m} = 9\ \text{mm}$$