MILESTONE 1

Discovering the power of mass-to-charge

The twenty-first century is an exciting time for mass spectrometrists. But things were quite exhilarating even at the technique's birth, more than a hundred years ago. The discovery of the electron and of the isotopes of neon, and year-to-year leaps in the degree of accuracy and resolution of the data, were just some of the reasons scientists were motivated to push ahead with the nascent technology.

It was perhaps Wilhelm Wien's discovery showing that rays of positively charged particles could be deflected with very powerful magnetic fields that gave mass spectrometry its start. Wien measured the deflection of these positive particles and was able to calculate their mass.

Following up on these discoveries, Joseph John (J.J.) Thomson showed that positive rays traveling along an axis *x* and striking a plane at right angles could be deflected by parallel electric and magnetic forces on axis *y*. This caused the rays to be deflected and strike the plane at a different place depending on their charge-to-mass ratio. The rays hit the plane on a parabolic arc, so to capture this information, Thomson allowed the particles to fall on a photographic plate. He then measured the parabolas on the photograph and calculated the charge-to-mass ratio of the particles using mathematical equations.

J.J. Thomson captured the parabolas of deflected rays on a photographic plate. Reproduced with permission from *Proc. Roy. Soc. A* **89**, 1–20 (1913), J.J. Thomson, 'Bakerian Lecture: rays of positive electricity'.

Thomson, working at the University of Cambridge, made another crucial observation: he found that in the purest preparations of neon gas there were two parabolas, one corresponding to an atomic weight of 20 and another one to 22. Although he could not explain it at the time, this discovery would later be recognized as the first indication that stable elements can have isotopes.

Though regarded as a major advance, Thomson's technique had limitations, as he himself recognized. In particular, some of the rays hit the walls of the tube as they traveled, filling the tubes with 'metallic dust' and requiring frequent cleanings, and the intensities of the parabolas on the photographic plate were sometimes insufficient for accurate measurements.

Francis Aston, also at the University of Cambridge, shortly thereafter took on these challenges with the aim of increasing the intensity of the signal. He did this by designing an instrument that would focus the rays in the form of a line hitting the plate at a specific point on a focal plane. Aston's device incorporated two parallel slits and used two electromagnetically charged plates to focus the rays, mimicking the focusing effect of an optical lens. This first mass spectrograph had not only greater measurement intensity and accuracy but also better resolution than Thomson's instrument. Aston used his spectrograph to resolve the puzzle of neon, demonstrating for the first time that stable elements can be isotopic.

Another important technological development came from Arthur Dempster at the University of Chicago. Dempster's spectrograph, referred to as a magnetic sector analyzer, deflected the rays by 180° by applying a strong magnetic field. This focused the rays of a specific mass-to-charge ratio through a narrow slit. These were then detected in real time using an electrometer, doing away with the cumbersome photographic plates. Dempster also introduced electron bombardment as a method to generate positive ions. Both of these discoveries made ripples in the field, and Dempster's 'mass spectrometer', as it came to be called, became the basis of later commercially developed instruments.

Dempster and Aston also carried out critical work toward determining the isotopic abundance and mass of the elements. Among these was uranium. Others had shown that splitting the uranium atom released a large amount of energy, and on the brink of the Second World War, the idea that the fission of high-purity uranium could be used as a powerful weapon was born. In 1940, Alfred Nier (see **Milestone 2**) provided the missing piece: he was able to make pure preparations of ^{235}U and ^{238}U, which were then used to identify ^{235}U as responsible for slow neutron fission. Efforts to isolate ^{235}U were named the 'Manhattan Project' and occupied leading physicists during the war.

Investments toward a nuclear bomb led to the development of techniques that advanced the field of mass spectrometry in the postwar years. As we now know, and as is described in the following milestones, there would be many more critical developments to follow.

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