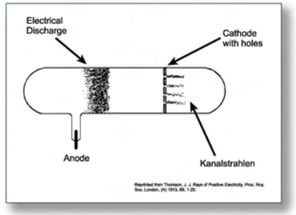
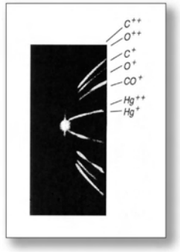
• Building Blocks of the Atom: *ca* 1900 •

Rays of Positive Electricity

Thomson also investigated rays of positive electricity, or "Kanalstrahlen". These differed considerably from beams of electrons. Whereas electron behaved the same regardless of the gas used to create the discharge, Kanalstrahlen behaved differently for different gases. Initially, it was thought that they could not be deflected by electric and magnetic fields, but it was later discovered that much more intense fields were required to deflect Kanalstrahlen than beams of electrons.



Thomson subjected Kanalstrahlen to combined electric and magnetic fields in a device similar to that used for the study of cathode rays and was able to observe several "lines" on a phosphorescent screen. He reasoned that these lines were indicative of the nature of the gas used to create the Kanalstrahlen by electrical discharge. When he changed the gas, he observed lines at different positions. His apparatus for working with Kanalstrahlen is considered to be the first mass spectrograph, although Wilhelm Wien was acknowledged by Thomson as having first demonstrated that Kanalstrahlen could be deflected by magnetic fields.

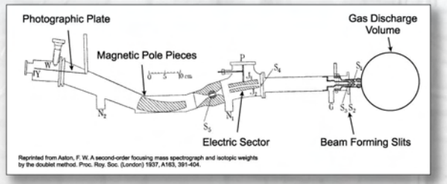


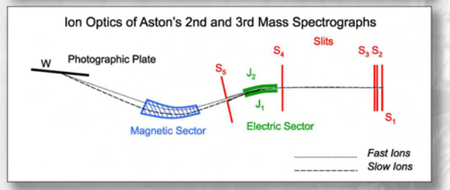
One of Thomson's protégé's, Francis W. Aston, took up the study of Kanalstrahlen with more sophisticated mass spectrographs. During the period from 1919 to 1937, he used three different instruments, each with improved resolving power, to study the elements. The first of these Aston used to demonstrate the existence of the isotopes of neon.

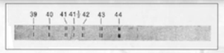
> *The existence of isotopes of the stable elements was a controversial subject as many scientists of the day thought that only radioactive elements could have isotopes. Interestingly, one critic of Aston's work on isotopes of the stable elements was none other than Sir J. J. Thomson himself! In 1921 before the Royal Society, Thomson argued that the two lines observed in the mass spectrum of chlorine could be explained by any number of phenomena other than isotopes. Arrayed against Thomson in favor of the isotopic explanation were Aston, Frederick Soddy, T. R. Merton and F. A. Lindemann. This was not exactly a team of dilettantes. All were members of the Royal Society and both Aston and Soddy would be co-recipients of the Nobel Prize in Chemistry in the following year for their work on isotopes. After the recognition accorded the subject by the Nobel Committee, the controversy came to an abrupt end.*

The second Aston mass spectrograph was used in 1927 to improve the accuracy of mass measurements of various elements and their isotopes as well as to determine the masses of elements and isotopes not previously investigated. This instrument was very similar to his first mass spectrograph, except for the addition of an electric sector to reduce the energy spread in the ion beam.

In 1937 Aston's third mass spectrograph, a replica of which is shown here, was used to further improve the accuracy of the masses of the elements and their isotopes. The resolving power of his third mass spectrograph was 2000, with a mass measurement accuracy of about 2 in 10^5. With this instrument, Aston was able to determine the packing fractions, or binding energy, of many of the elements and their isotopes. By this time, the physics community understood that the small difference in mass between the elements and the mass of their constituent parts was critically important.







Operation of Aston's Third Mass Spectrograph

The operation of Aston's third mass spectrograph depended upon the generation of positive ions by an electric discharge in the gas to be analyzed in the glass bulb on the right. These ions passed through a pair of collimating slits, the width of which could be adjusted externally by means of the white discs. The ions then passed through an electric field E that deflected them through an angle $\theta = eEd/mv2$, where v is the velocity of the ions, and d the path length along the field. A further slit selects ions in a small range of θ, and they then pass between the poles of a magnet which deflects them in the opposite direction through an angle $\theta = eBD/mv$; where B is the strength of the magnetic field, and D the distance over which it acts. The magnet, not shown here, acts over the region of the tube in the left-hand support. The geometry of the apparatus is arranged so that ions with a range of velocities are brought to focus along a plane. A photographic plate placed at the focal plane at the left end of the tube was used to record the spectrum.

The position of a line on the photo plate depends on the value of e/m for the ion, and since the charge e is numerically equal to that of the electron, or an easily identified small multiple of it, the position of the line gives the value of the mass.

Even Nobel winning scientists have experimental difficulties. In Aston's report on the performance of his second mass spectrograph and results from it, he laments the difficulty he had in making the instrument perform up to the limits of its design.

> *When the atomic and molecular lines of hydrogen were tested . . .on the new apparatus a discordance was observed not merely measurable but absurdly large, several parts in 1000. The search for the cause of this was both long and disheartening for it must be remembered that the results of the smallest alterations in the apparatus take at least a day, generally several days to test. After months of disappointing work the conclusions reached were that the disturbing cause must be a charging up due to the impact of the rays, and its most probable location was the electric plates themselves.*

The electric plates referred to by Aston are the brass replicas shown below. This whole apparatus is contained in the region of the replica instrument immediately after the slit assembly. The charging phenomenon that Aston laments was probably due to a thin oxide coating that formed on the brass plates between the time they were polished and installed in the mass spectrograph. Only after the electric sector "plates were . . . heavily gilded" was the performance satisfactory. It is somehow heartening to know that even Nobel Prize winning scientists have bad instrument days, or in Aston's case, months!

MASS SPECTROMETRY

1886 Goldstein reports observation of "Kanalstrahlen"

1897 Thomson determines cathode rays are actually negatively charged particles

1898 Wien deflects Kanalstrahlen with magnet and shows they are positively charged particles

1906 Thomson awarded Nobel Prize in Physics "in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases"

1907 Thomson creates mass spectrograph

1918 Dempster describes 180 degree sector instrument with electron bombardment ionization.

1919 Aston reports first mass spectrograph to employ photographic plates for recording mass spectra

1922 Aston awarded Nobel Prize in Chemistry "for his discovery, by means of his mass spectrograph, of isotopes, in a large number of non-radioactive elements, and for his enunciation of the whole-number rule"

1927 Aston reports first double focusing mass spectrograph

1932 Chadwick discovers neutron

1935 Chadwick awarded Nobel Prize in Physics "for discovery of the neutron"

HISTORY

1856 Giessler develops rotating mercury pump capable of 0.1 torr vacuum

1895 Röntgen discovers "Kanalstrahlen" produce x-rays when they collide with metal

1901 Röntgen awarded Nobel Prize in Physics "in recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him"

1903 DeForest introduces the triode, the prototype of the modern vacuum tube amplifier

1906 San Francisco is devastated by a massive earthquake

1908 Ford Model 'T' introduced

1912 Titanic sinks in the North Atlantic after striking an iceberg

1916 Albert Einstein publishes his general theory of relativity

1920 Mustafa Kemal Ataturk establishes the modern Turkish state

1923 In Munich Germany, the Beer Hall Putsch fails and Adolf Hitler is sentenced to nine months in prison

1926 Hirohito becomes Emperor of Japan