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Nobel Prize in Physics 1981


Nicolaas Bloembergen


Arthur Leonard Schawlow


Kai M. Siegbahn

The Nobel Prize in Physics 1981 was divided, one half jointly to Nicolaas Bloembergen and Arthur Leonard Schawlow *"for their contribution to the development of laser spectroscopy"* and the other half to Kai M. Siegbahn *"for his contribution to the development of high-resolution electron spectroscopy"*.

Information about winners:

Nicolaas Bloembergen,
Harvard University, USA,
Arthur L. Schawlow,
Stanford University, USA,
Kai M. Siegbahn,
Uppsala University, Sweden,

RESEARCH INFORMATION:

Laser spectroscopy

Albert Einstein in 1917 showed that there are three different kinds of radiation processes: absorption, when radiation energy is taken up by the system; spontaneous emission, when a system without external influences emits radiation; and stimulated

emission, when a system by means of external influences is stimulated to emit radiation. The first two processes have been known for a long time and form the basis for the origin of for instance optical spectra. The existence of stimulated emission, however, was something new at the time of Einstein's famous work, but no practical importance of this could be seen at that time.

In the early 1950s, scientists in both the USA and the Soviet Union were at work in trying to make use of the stimulated emission of atomic systems in order to amplify weak microwave signals and to design oscillators based on such systems. This led to the maser (Microwave Amplification by Stimulated Emission of Radiation), first designed by Townes and his co-workers in the USA and which at the same time had been suggested by Basov and Prokhorov in the USSR.

The idea of extending the principle of the maser to the infrared or optical region arose in different quarters in the late 1950s. The wholly decisive contribution in the realization of this idea was made in 1958 by Schawlow and Townes, who then published a work analysing the preconditions necessary for such a design, theoretical as well as practical. Prokhorov around the same time proposed a similar design for the generation of longer waves. Other suggestions based on the same idea were also presented at that time. However, it was primarily the work by Schawlow and Townes which initiated the whole dynamic field which we now associate with the concept of "laser" (Light Amplification by Stimulated Emission of Radiation).

The 1964 Nobel Prize in Physics was awarded to Townes, Prokhorov and Basov for "fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser-principle". Subsequent developments, however - particularly in lasers - have made this field increasingly deserving of additional rewards.

The fundamental principle of laser - as for maser - is that an attempt is made in one way or another to bring about a population inversion, i.e. a system with more atoms in a higher state than a lower, as opposed to what is obtained when the system is left to itself

without external influences. If an atom in the higher state falls down to the lower state by the emission of a photon (light quantum), this photon may stimulate another atom to emit a photon of the same kind, etc. In this way a chain process may be built up, and we obtain what is known as laser light. This light has the particular property of being coherent, and the photons forming part of the light beam oscillate largely in phase with one another - as opposed to ordinary light, as from a light bulb. The laser light may further be made extremely parallel and monochromatic, which is the foundation of many of its areas of application.

The first functioning laser was constructed in 1960, and since then developments have been rapid. It is now possible to produce laser light throughout the entire range of visible wavelengths, as well as in portions of the infrared and ultraviolet ranges. Thus the laser has become a next to ideal instrument of atomic spectroscopy for studying the properties of atoms and molecules, and a number of spectrographic methods have been developed in recent years. Many of these methods are based on non-linear, optical phenomena, caused by the circumstance that laser light is so strong that the usual linear relationships no longer apply.

One such a class of non-linear, spectrographical methods, which have been developed and applied particularly by Schawlow and his co-workers at Stanford university, are founded on the circumstance that "saturation phenomena" may appear in the absorption of the laser light because of the high intensity. This may be utilized in so-called Doppler-free spectroscopy, where the broadening of the spectral lines due to the motion of the atoms (the Doppler effect) has been eliminated. This method has been applied in the study of the simplest of all substances, hydrogen, with extremely high precision. Thereby it has been possible to determine one of the most fundamental of atomic constants, the Rydberg constant, with a significantly higher degree of precision than was previously possible, which is of the greatest importance to our knowledge of the fundamental constants in nature in general.

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Another class of non-linear, optical methods of spectroscopy is based on the mixing of two or more light waves. This type of phenomenon was demonstrated shortly after the laser was introduced, and the theory for it was comprehensively explored around the same time by Nicolaas Bloembergen and his co-workers. Of particular interest is four-wave mixing where three coherent light waves act together in generating a fourth light wave. By this method it is possible to generate laser light far outside the visible range, in both the infrared and the ultraviolet directions. The method has thus drastically extended the range of wavelengths accessible to laser spectroscopy studies. A special form of four-wave mixing is known as "CARS" (Coherent Anti-Stokes Raman Scattering), which has been applied in studies of widely differing kinds - all the way from optimization of combustion processes in motorcar engines to the study of element transport in biological tissues.

Electron spectroscopy

When a substance is irradiated with ultraviolet light of X-rays it may be made to emit electrons. This photo-electric effect, as it is known, was first observed by Heinrich Hertz in the 1880s. The correct explanation was given in 1905 by Albert Einstein using the quantum hypothesis introduced by Max Planck five years earlier. The energy of the emitted electrons is equal to the photon energy of the incident light, minus the energy with which the electron is bound to the sample. By using monochromatic light - for which all photons have the same energy - it is thus possible through studying the emitted electrons to get valuable information on the electron structure of the sample being examined. This method began to be applied already in the 1910s, primarly by H. Robinson in Britain. However, it turned out that the spectra obtained gave little information on the material investigated, chiefly because the electrons are exposed to larger or smaller energy losses through collisions on their way out of the material. The method thus did not become of major importance at that period. Instead an alternative method was developed for studying the interior of atoms, viz. X-ray spectroscopy, where the radiation is studied which is emitted when an electron moves from one inner energy level to another.

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Interest in the serious study of photo-electrons did not revive until the 1950s. The decisive step at that time was taken when Kai Siegbahn together with his co-workers Carl Nordling and Evelyn Sokolowski began to analyse photo-electrons with the aid of a high-resolution, double-focusing spectrometer, which was originally designed for the precision study of electrons emitted in the radioactive decay of some atomic nuclei, the so-called beta decay. The electron spectra contained - in addition to the broad lines observed previously - a number of strong and extremely narrow lines which had not been observed before, These came from electrons which had left the sample without energy loss. Because the energy losses are quantized - i.e. the electrons may on their way out give off energy to the sample only in specific amounts - the probability is considerable that no energy loss occurs. In order to discover these sharp lines, however, the resolution of the instrument must be sufficiently high, which was not the case in earlier experiments. Through this discovery, the way had been prepared for a new form of spectroscopy.

This new form of electron spectroscopy could now compete in earnest nest with the X-ray spectroscopy technique, and Siegbahn, Nordling and Sokolowski during several years in the late 1950s made a systematic study of the electron energies binding of different elements, a study which is still the major source of information.

At a closer study of the electron energies it was found that these for one and the same atom were to a small extent dependent on the molecule or the crystal to which the atom was bound, a chemical shift. Similar shifts had already been observed in X-ray spectra, but these shifts were considerably more difficult to interpret. The chemical shifts are caused by different electron densities in the vicinity of the atoms. In the development of electron spectroscopy, a practically useful analytical method had been obtained with which it was possible to study not only which atoms are included in a sample but also in which chemical environment these atoms exist. At this time the concept of "ESCA" (Electron Spectroscopy for Chemical Analysis) was created for this method.

After the introductory stage the electron spectroscopy has developed rapidly. This development has been greatly influenced by the efforts of Siegbahn and his co-workers.

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Commercial electron spectrometers have already been available for some years, and electron spectroscopy is now applied in various forms at hundreds of laboratories throughout the world. The method has found several important fields of application, for instance in the study of surface-chemistry processes such as catalysis and corrosion.

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