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Nobel Prize in Physics 1986

Ernst Ruska

Gerd Binnig

Heinrich Rohrer

The Nobel Prize in Physics 1986 was divided, one half awarded to Ernst Ruska *"for his fundamental work in electron optics, and for the design of the first electron microscope"*, the other half jointly to Gerd Binnig and Heinrich Rohrer *"for their design of the scanning tunneling microscope"*.

Information about winners:

Ernst Ruska,

Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Federal Republic of Germany,

Dr **Gerd Binnig** and Dr **Heinrich Rohrer**,

IBM Research Laboratory, Zurich, Switzerland,

RESEARCH INFORMATION:

One half of this year's Nobel Prize in Physics has been awarded to **Ernst Ruska** for "his fundamental work in electron optics and for the design of the first electron microscope". The significance of the electron microscope in different fields of science such as biology and medicine is now fully established: it is one of the most important inventions of this century.

Its development began with work carried out by Ruska as a young student at the Berlin Technical University at the end of the 1920's. He found that a magnetic coil could act as a lens for electrons, and that such an electron lens could be used to obtain an image of an object irradiated with electrons. By coupling two electron lensed he produced a primitive microscope. He very quickly improved various details and in 1933 was able to build the first electron microscope with a performance clearly superior to that of the conventional light microscope. Ruska subsequently contributed actively to the development of commercial mass-produced electron microscopes that rapidly found applications within many areas of science.

Electron microscopy has since been developed through technical improvements and through the advent of entirely new designs, among them the scanning tunnelling electron microscope. A number of researchers have taken part in both this and the earlier development, but Ruska's pioneering work is clearly the outstanding achievement.

The other half of this year's prize has been awarded to **Gerd Binnig** and **Heinrich Rohrer** for "their design of the scanning tunneling microscope". This instrument is not a true microscope (i.e. an instrument that gives a direct image of an object) since it is based on the principle that the structure of a surface can be studied using a stylus that scans the surface at a fixed distance from it. Vertical adjustment of the stylus is controlled by means of what is termed the tunnel effect - hence the name of the instrument. An electrical potential between the tip of the stylus and the surface causes an electric current to flow between them despite the fact that they are not in contact. The strength of the current is strongly dependent on the distance, and this makes it possible to maintain the distance constant at approximately 10^{-7} cm (i.e. about two atom diameters). The stylus is also extremely sharp, the tip being formed of one single atom. This enables it to follow even the smallest details of the surface it is scanning. Recording the vertical movement of the stylus makes it possible to study the structure of the surface atom by atom.

The scanning tunneling microscope is completely new, and we have so far seen only the beginning of its development. It is, however, clear that entirely new fields are opening

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up for the study of the structure of matter. Binnig's and Rohrer's great achievement is that, starting from earlier work and ideas. they have succeeded in mastering the enormous experimental difficulties involved in building an instrument of the precision and stability required.

Background information

The invention of the conventional microscope represented a great step forward for science, particularly in biology and medicine. As better and better microscopes were built, it was discovered that there exists a limit that cannot be exceeded. This is connected with the wave characteristics of light. Using light waves, it is impossible to distinguish details smaller than the wavelength of the light. The term "resolution" refers to the distance between two details of an image that can just be distinguished. For a conventional microscope using visible light, the resolution is some 4 000 Å (1 Å, ångstrom = $l0^{-8}$cm).

The great breakthrough in microscopy came when it was found possible to produce an image of an object using an electron beam. The starting point was the discovery that a magnetic coil can function like an optical lens. A divergent bundle of electrons passing through the coil is focused to a point. A suitable electric field can also act as an electron-optical lens. Using a lens of this type, an enlarged image can be obtained of an object irradiated with electrons. the image is recorded on a fluorescent screen or a photographic plate. It also proved possible to combine two or more lenses to increase the magnification. The work was carried out at the Technical University of Berlin at the end of the 1920's.

The scientist who has made the greatest contribution to this development is Ernst Ruska. As a young student together with his supervisor Max Knoll, he began studying simple magnetic coils, He found that the use of suitably-designed iron encapsulation improved their electron-optical properties. Above all, it now became possible to build a lens of short focal length. This is essential if high magnification is desired. Using two coils in series, Ruska achieved a magnification of fifteen times. Even though this was a modest result, it nevertheless represents the first prototype of an electron micrcscope. Ruska subsequently worked purposefully to improve the details, and in 1933 he built what can be described as the first electron microscope in the modern sense - an instrument with considerably better performance than a conventional light microscope 's. He was then appointed by Siemens and took part in the development of the first commercially-available, mass-produced electron microscope, which entered the market in 1939. This event may be considered the real breakthrough for electron microscopy.

Since then, development of the electron microscope has been very extensive. Its resolving power could be considered theoretically unlimited, since the electron is a pointlike particle, However, according to quantum mechanics, every particle has wave characteristics which introduce an uncertainty into the determination of its position. This sets a theoretical limit to resolution for the acceleration potentials normally used of the order of 0.5 - 1 Å. In practice, resolutions down to about 1 Å have been achieved.

The type of elect on microscope developed by Ruska is called the transmission microscope. The object to be examined is in the form of a thin section. The electron beam goes right through this in the same way that light pierces the object in a light microscope. There are, however, several other types of electron microscope, the most important apart from the transmission microscope being perhaps the scanning electron microscope. In this extremely sharply focused electron beam strikes the object The secondary electrons emitted are collected by a detector and the current is recorded. Magnetic coils cause the electron beam to scan the object in the same way as the beam of a TV tube. The variations in the emission of secondary electrons carn be used to build up an image. The advantage is the large depth of focus which gives a three-dimensional image as opposed to the sectional image obtained with a transmission microscope. However, the resolution is poorer. These two types of microscope thus complement each other.

Electron microscopy has developed extremely over the last few decades, with technical improvements and entirely new designs. Its importance can scarcely be exaggerated and, against this background, the importance of the earliest, fundamental work becomes increasingly evident. While many researchers were involved Ruska's

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contributions clearly predominate. His electron-optical investigations and the building of the first true electron microscope were crucial for future development.

The latest contribution to the development of microscopy is what is termed the scanning tunneling microscope. Its principle differs completely from that of other microscopes. A mechanical device is used to sense the structure of a surface. To this extent, the principle is the same as that of braille-reading. In braille, it is the reader's fingers that detect the impressed characters but a much more detailed picture of the topography of a surface can be obtained if the surface is traversed by a fine stylus, the vertical movement of which is recorded. What determines the amount of detail in the image - the resolution - is the sharpness of stylus and how well it can follow the structure of the surface. Obviously if the tip of the stylus is too sharp, it rapidly becomes destroyed. At the same time, small structural details of the surface can be damaged by mechanical contact, One solution to this problem would be to maintain the stylus at a small, constant distance from the surface The first to succeed in doing this was the American physicist Russel Young at the National Bureau of Standards in the USA. He used the phenomenon known as field emission. If a sufficiently high potential is applied between stylus and surface, a current flows with a strength depending on the stylus-surface distance. If regulated by a servo mecanism controlled by the current, this distance can be kept constant without mechanical contact. Young succeeded in building an instrument that worked on this principle. The distance between the stylus tip and the surface was approximately 200 Å. Its resolution was thus considerably poorer than that of an electron microscope

However, Young realised, that it should be possible to achieve better resolution by using the so-called tunnel effect This is a quantummechanical effect that allows an electron (and also other particles to cross an area where, according to classical physics it cannot exist since it lacks sufficiently high energy. It makes its way so to speak, through a potential mountain by quantum-mechanical tunneling; hence the name tunneling microscope. This means here that if the tip of the stylus is near enough to the surface (10 Å, i.e. 1-2 atom diameters) a current flows even at low voltages. In the same way as field emission, it

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should be possible to control the stylus without mechanical contact. However, Young was unable to convert this idea into practice owing to the exceptionally large experimental difficulties involve

The first researchers to succeed in building a scanning tunneling microscope were Gerd Binnig and Heinrich Rohrer at the IBM Research Laboratories in Zürich, Switzerland. The reason for their success was the exceptional precision of the mechanical design One example of this is that disturbing vibrations from the environment were eliminated by building the microscope upon a heavy permanent magnet floating freely in a dish of superconducting lead. Less bulky but equally effective devices for stable, disturbance-free suspension of the microscope have now been developed. Piezoelectrical elements are used to control the horizontal movement of the stylus in two perpend icular directions so that it scans the surface a long parallel lines - hence the name scanning microscope The vertical movement of the stylus is controlled and measured using another piozoelement. Using a special technique it has been possible to produce styluses with tips consisting of a single atom. Consequently, the precision of the image is particularly great. Horizontal resolution is approximately 2 Å and vertical resolution. approximately 0.1 Å. This makes it possible to depict individual atoms, that is, to study in the greatest possible detail the atomic structure of the surface being examined.

It is evident that this technique is one of exceptional promise, and that we have so far seen only the beginning or its development. Many research groups in different areas of science are now in using the scanning tunneling microscope. The study of surfaces is an important part of physics, with particular applications in semiconductor physics and microelectronics In chemistry, also, surface reactions play an important part, for example in connection with catalysis. It is also possible to fixate organic molecules on a surface and study their structures. Among other applications, this technique has been used in the study of DNA molecules.

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