NOBEL LECTURES

PHYSICS

1942-1962

NOBEL LECTURES

INCLUDING PRESENTATION SPEECHES
AND LAUREATES' BIOGRAPHIES

PHYSICS

1942-1962

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Foreword

The Nobel Foundation has, by agreement, granted the Elsevier Publishing Company of Amsterdam the right to publish in English language the Nobel Lectures for 1901–1962. The lectures in the five Nobel Prize domains: Physics, Chemistry, Physiology or Medicine, Literature, and Peace will appear separately, according to the subject. The scientific lectures will each cover three volumes and those in literature and peace one volume each. Short biographical notes and the presentation speeches will also be included.

The Nobel Foundation has since 1901 each year published *Les Prix Nobel* which contains all Nobel Lectures of that year, always in the language in which they were given, as well as short biographies of the laureates. In addition an account is given of the prize-award ceremonies in Stockholm and in Oslo, including presentation addresses and after-dinner speeches, etc., thus covering the whole field of Nobel Prize events of one particular year.

In the Elsevier series the Nobel Lectures, presentation addresses, and biographies will now be more readily accessible to those who wish to follow the development in only certain of the Nobel subjects, as reflected in the prize awards during the years passed. For practical reasons English has been chosen as common language for this series.

It is the hope of the Nobel Foundation that the volumes to be published by Elsevier Publishing Company will supplement *Les Prix Nobel* and that together they will serve to spread knowledge of those landmarks on the road of human progress that have been honoured by Nobel Prizes.

Arne Tiselius – President, Nobel Foundation

Publisher's Note

During the realization of this work we have been confronted by many problems. In solving the great majority of them we have relied heavily upon assistance, both invited and spontaneously offered, from many quarters.

To some problems there was no solution to be found; in particular, it proved impossible to obtain, for some of the lectures, the original photographs or blocks used for the illustrations. As an inevitable consequence of this it was found necessary to reproduce these illustrations from a printed original; this naturally renders them less perfect than we would have wished. We thank those who were able to lend us original material.

The translations of those lectures which were delivered in a language other than English were prepared by the Babylon Translation Service, London. We are indebted to Mr. D. F. Styles, Mr. M. Fedorski (both of Manchester), and Dr. G. Lapage of Cambridge, for research on, and preparation of, most of the biographies. Completion of these, and the addition of much detail, was achieved with the cooperation of many of the laureates themselves, their colleagues and assistants, and other individuals whose help was requested. To all of them we would like to offer our sincerest thanks in appreciation of their efforts.

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Physics 1943 and 1944

The following account of Stern's and Rabi's works is by Professor E. Hulthén, Stockholm (Broadcast lecture, 10th December, 1944)

There is a certain relation between electric and magnetic phenomena in that the magnetic field can generally be ascribed to the presence of electric currents. It was in this way that the famous Ampère sought to trace magnetism back to rotary currents of electricity in the particles of matter, the atoms and molecules. This hypothesis has in fact been confirmed, *inter alia* by spectroscopical investigations into light sources placed in very strong magnetic fields. However, certain difficulties arose when it came to accounting in detail for the influence of the magnetic field on the movement of electrons, which here represents the electric currents in the interior of the atom. For the electrons proved disinclined to obey the electrodynamic laws which have otherwise so brilliantly demonstrated their validity in, for instance, the field of electrotechnics. *Inter alia*, it seemed as if the small, freely moving atomic magnet in the source of light was only capable of assuming certain discrete local positions in relation to the direction of the applied field. I shall start, then, with a reference to an experiment which for the first time revealed this remarkable so-called directional or space-quantization effect.

The experiment was carried out in Frankfurt in 1920 by Otto Stern and Walter Gerlach, and was arranged as follows: In a small electrically heated furnace, was bored a tiny hole, through which the vapour flowed into a high vacuum so as to form thereby an extremely thin beam of vapour. The molecules in this so-called atomic or molecular beam all fly forwards in the same direction without any appreciable collisions with one another, and they were registered by means of a detector, the design of which there is unfortunately no time to describe here. On its way between the furnace and the detector the beam is affected by a non-homogeneous magnetic field, so that the atoms – if they really *are* magnetic – become unlinked in one direction or another, according to the position which their magnetic axles may assume in relation to the field. The classical conception was that the thin and clear-cut beam would consequently expand into a diffuse beam, but in actual fact the opposite proved to be the case. The two experimenters found that the beam divided up into a number of relatively still sharply defined beams, each corresponding to one of the just mentioned discrete positional directions of the atoms in relation to the field. This confirmed the space-quantization hypothesis. Moreover, the experiment rendered it possible to estimate the magnetic factors of the electron, which proved to be in close accord with the universal magnetic unit, the so-called « Bohr's magneton ».

When Stern had, so to speak, become his own master, having been appointed Head of the Physical Laboratory at Hamburg in 1923, he was able to devote all his energies to perfecting the molecular beam method. Among many other problems investigated there was a particular one which excited considerable interest.

It had already been realized when studying the fine structure of the spectral lines that the actual nucleus of the atom, like the electron, possesses a rotation of its own, a so-called « spin ». Owing to the minute size of the nuclear magnet, estimated to be a couple of thousand times smaller than that of the electron, the spectroscopists could only determine its size by devious ways – and that too only very approximately. The immense interest attaching in this connection to a determination of the magnetic factors of the hydrogen nucleus, the so-called proton, was due to the fact that the proton, together with the recently discovered neutron, forms the basic constituent of all the elements of matter; and if these two kinds of particles were to be regarded, like the electron, as true elementary particles, indivisible and uncompounded, then as far as the proton is concerned, its magnetic factor would be as many times smaller than the electron's as its mass is greater than the electron's, implying that the magnetic factor of the proton must be, in round figures, 1,850 times smaller than the electron's. Naturally then, it aroused great interest when, in 1933, Stern and his colleagues made this determination according to the molecular beam method, it being found that the proton factor was about $2\frac{1}{2}$ times greater than had theoretically been anticipated.

Let us now for a moment touch upon Rabi's achievements in this field. Returning to the essential point of the problem, let us put the question: How does the atom react to the magnetic field? According to a theorem stated by the English mathematician Larmor, this influence may be ascribed to a relatively slow precession movement on the part of the electron and the atomic nucleus around the field direction – a gyromagnetic effect most closely recalling the gyroscopic movement performed by a top when it spins around the vertical line. If the strength of the magnetic field is known, the magnetic factor of the electron and of the atomic nucleus can also be estimated by this means, provided that we can observe and measure these precessional frequencies. Rabi solved the problem in a manner as simple as it was brilliant. Within the magnetic field was inserted a loop of wire, attached to an oscillating circuit the frequency of which could be varied in the same manner as we tune in our radio receiving set to a given-wavelength. Now, when the atomic beam passes through the magnetic field, the atoms are only influenced on condition that they precess in time with the electric current in the oscillating circuit. This influence might perhaps be described graphically: the nucleus performs a vault (salto) – the technical term for which is a « quantum jump » – thereby landing in another positional direction to the field. But this means that the atom has lost all chance of reaching the detector and of being registered by it. The effect of these quantum jumps is observable by the fact that the detector registers a marked resonance minimum, the frequency position of the registration being determined with the extraordinary precision achievable with the radio frequency gauge. By this method Rabi has literally established radio relations with the most subtile particles of matter, with the world of the electron and of the atomic nucleus.

OTTO STERN

The method of molecular rays

Nobel Lecture, December 12, 1946

In the following lecture I shall try to analyze the method of molecular rays. My aim is to bring out its distinctive features, the points where it is different from other methods used in physics, for what kind of problems it is especially suited and why. Let me state from the beginning that I consider the directness and simplicity as the distinguishing properties of the molecular ray method. For this reason it is particularly well suited for shedding light on fundamental problems. I hope to make this clear by discussing the actual experiments.

Let us first consider the group of experiments which prove directly the fundamental assumptions of the kinetic theory. The existence of molecular rays in itself, the possibility of producing molecular rays, is a direct proof of one fundamental assumption of that theory. This assumption is that in gases the molecules move in straight lines until they collide with other molecules or the walls of the containing vessel. The usual arrangement for producing molecular rays is as follows (Fig. 1): We have a vessel filled with gas or vapor, the oven. This vessel is closed except for a narrow slit, the oven slit. Through this slit the molecules escape into the surrounding larger vessel which is continually evacuated so that the escaping molecules do not suffer any collisions. Now we have another narrow slit, the collimating slit, opposite and parallel to the oven slit. If the molecules really move in straight lines then the collimating slit should cut out a narrow beam whose cross section by simple geometry can be calculated from the dimensions of the slits and their distance. That it is actually the case was proven first by Dunoyer in 1911. He used sodium vapor and condensed the beam molecules hitting the wall by cooling it with liquid air. The sodium deposit formed on the wall had exactly the shape calculated under the assumption that the molecules move in straight lines like rays of light. Therefore we call such a beam a «molecular ray» or «molecular beam».

The next step was the direct measurement of the velocity of the molecules. The kinetic theory gives quite definite numerical values for this velocity, depending on the temperature and the molecular weight. For example, for silver atoms of 1,000° the average velocity is about 600 m/sec (silver mole-

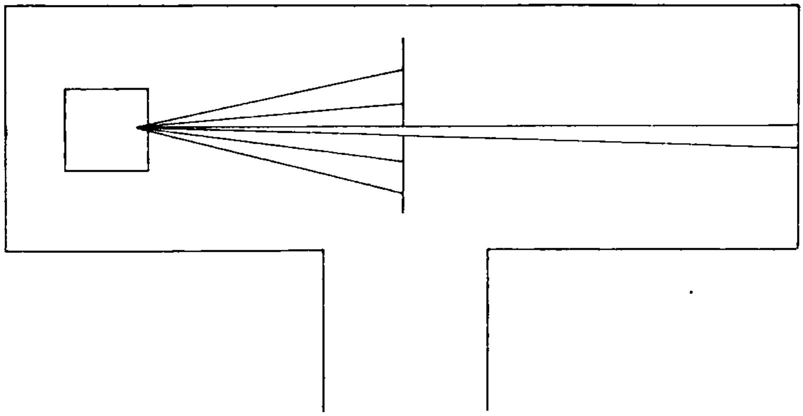

Fig. 1. Arrangement for producing molecular rays.

cules are monoatomic). We measured the velocity in different ways. One way – historically not the first one – was sending the molecular ray through a system of rotating tooth wheels, the method used by Fizeau to measure the velocity of light. We had two tooth wheels sitting on the same axis at a distance of several cm. When the wheels were at rest the molecular beam went through two corresponding gaps of the first and the second wheel. When the wheels rotated a molecule going through a gap in the first wheel could not go through the corresponding gap in the second wheel. The gap had moved during the time in which the molecule travelled from the first wheel to the second. However, under a certain condition the molecule could go through the next gap of the second wheel, the condition being that the travelling time for the molecule is just the time for the wheel to turn the distance between two neighboring gaps. By determining this time, that means the number of rotations per second for which the beam goes through both tooth wheels, we measure the velocity of the molecules. We found agreement with the theory with regard to the numerical values and to the velocity distribution according to Maxwell's law.

This method has the advantage of producing a beam of molecules with nearly uniform velocity. However, it is not very accurate.

As the last one in this group of experiments I want to report on experiments carried out in Pittsburgh by Drs. Estermann, Simpson, and myself before the War, which are now being published. In these experiments we used the free fall of molecules to measure their velocities.

In vacuo all bodies, large and small, fall equal distances in equal times, $s =$