



מכון ויצמן למדע

WEIZMANN INSTITUTE OF SCIENCE

# Out to the Universe Into the Atom

*Illustration of a collision and particle scattering event in the ATLAS experiment that would provide evidence for the existence of the "God particle," superimposed on an image from the Hubble telescope*



### From the President: Constant Innovation

The large, accomplished physics faculty in today's Weizmann Institute owes its existence to the vision of a few people who made – in circumstances that are now inconceivable to us – far-reaching, momentous decisions. In the first two years of statehood, Israel faced nearly insurmountable difficulties – mass absorption of new immigrants, feeding its people, creating a health care system and a national infrastructure to deal with the rapidly expanding population. Yet the leaders of the day, first among them Prime Minister David Ben-Gurion, reached a decision to send five young students abroad to study physics at the country's expense.

When they returned, Ben-Gurion had retired to Sde Boker in the desert, the plans for a new scientific research institute had been shelved, and the physicists' future looked hazy. It was time for another courageous decision. The heads of the five scientific departments of the Weizmann Institute at that time – Profs. Chaim Pekeris, Israel Dostrovsky, Isaac Berenblum, Ephraim Katzir and Aharon Katzir – together with the president, Meyer Weisgal, invited those young returning physicists to establish a nuclear physics department at the Weizmann Institute. They came, adding their expertise to the existing physics research in infrared radiation and nuclear

magnetic resonance.

Time and again, generations of Institute leaders have made decisions in the field of physics that cause us to wonder, in hindsight, at their boldness and vision. New fields of research, for instance, have received support despite the sometimes considerable risks attached. This is why the Weizmann Institute is always at the forefront, and often in the lead, in many fields of global scientific research.

This book presents 100 milestones in physics research at the Weizmann Institute of Science. As a story, it is full of twists and surprises. Looking back, it is hard to believe that in such a short time, Weizmann scientists have managed to accomplish so much: to lay such strong foundations for their field, to leave such a lasting imprint on the history of physics worldwide, to have such a wide influence on Israel's economy and on its society, and to build such a solid reputation for constant innovation. This achievement continues today and will carry on into the future.

Daniel Zajfman



### From the Dean: The Big Adventure

Research in physics arises out of the desire to understand nature's rules, the ways in which these rules dictate the behavior of large and small systems alike, and the possibilities of applying them for the benefit of humanity. The variety of phenomena physicists investigate is tremendous: They can be as large as the entire Universe or as small as the tiny particles that make up a proton, as energetic as a gamma ray burst or as cold as the cosmic background radiation. In short, physics is an amazing adventure that leads us deep into unknown territory.

More than any other field, scientific advance in physics relies on a dialogue between theory and experiment. Sometimes an experiment will disprove the prevailing understanding and will challenge the theorists to come up with new ways of thinking. Sometimes it is the theory that comes first, predicting an undiscovered phenomenon; experimentalists are then led to work out ways of testing the theory in the lab. This cross-fertilization between experiment and theory has been a hallmark of the Weizmann Institute Physics Faculty for all of its existence.

The Physics Faculty is, on the one hand, a collection of individual scientists: each,

together with his or her research group, investigating the questions that interest them with the means – theoretical or experimental – that they prefer. On the other hand, this Faculty is a community that directs its own future by choosing young scientists who will come aboard. It is a collective that takes pride and joy in the accomplishments of each and every one of its members and that acts as one – scientists, students and research staff together – in the pursuit of excellence.

In this volume are presented 100 brief descriptions of physics research at the Weizmann Institute of Science. I hope that beyond the outlines that have been sketched here of the history and development of the Faculty, beyond the richness and variety of topics, the reader will also get a feel for the intellectual adventure, and maybe even the "joy of physics" that beats in the breast of everyone who engages in this special branch of science.

Yossi Nir





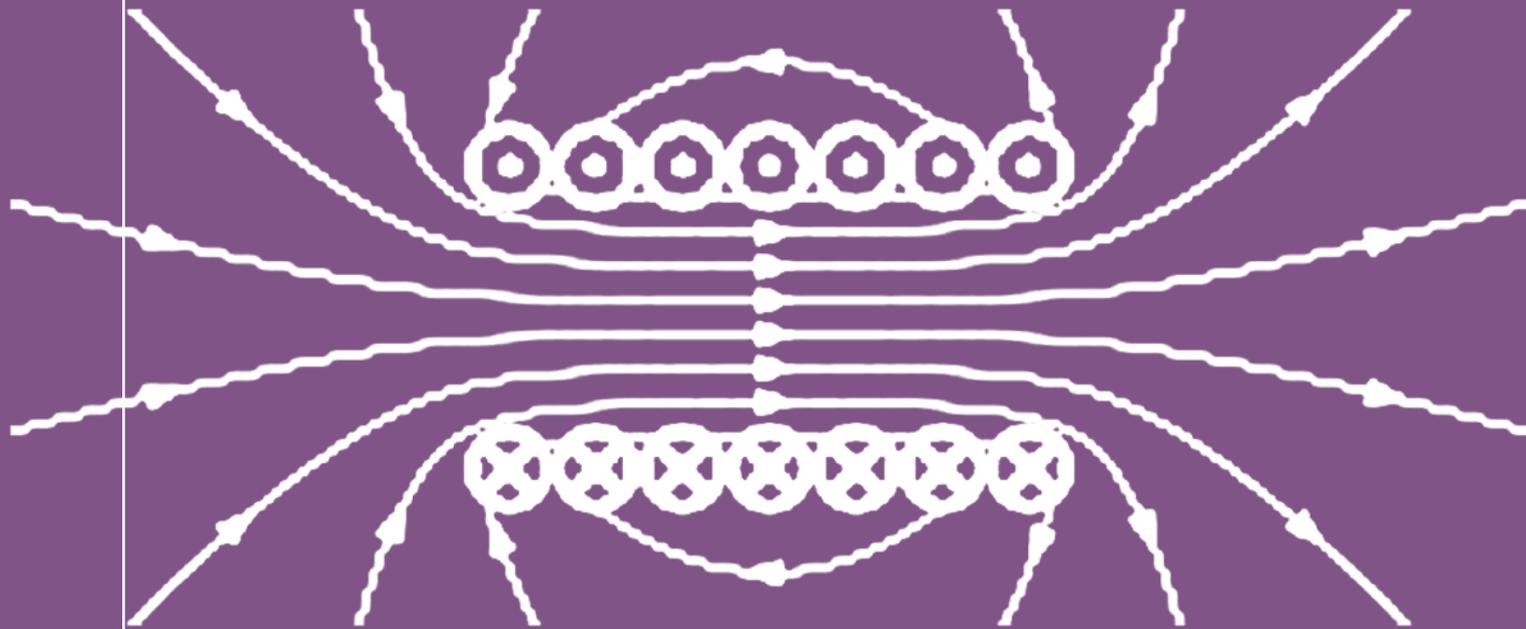
## Israel's Oxygen 1949

The Weizmann Institute was a world leader in isotope research. It boasted unique apparatus for separating isotopes – elements that are heavier or lighter than the regular versions, due to a non-standard number of neutrons in the atomic nucleus. The Weizmann facility produced heavy oxygen –  $^{17}\text{O}$  (found at natural concentrations of 0.037%) and  $^{18}\text{O}$  (0.204% in nature). Heavy oxygen is used in a wide variety of research fields – in chemistry, physics, biology and medicine, as well as in the PET scan technology employed to assess nutritional status in pregnant women and children, for instance, or to image such neurological problems as Alzheimer's or Parkinson's.

For many years, the Institute supplied most of the world's demand for this isotope, leading to the establishment of Yeda Research and Development Ltd., the first technology transfer company in Israel and one of the first in the world.

## 1954 Nuclear Magnetic Resonance

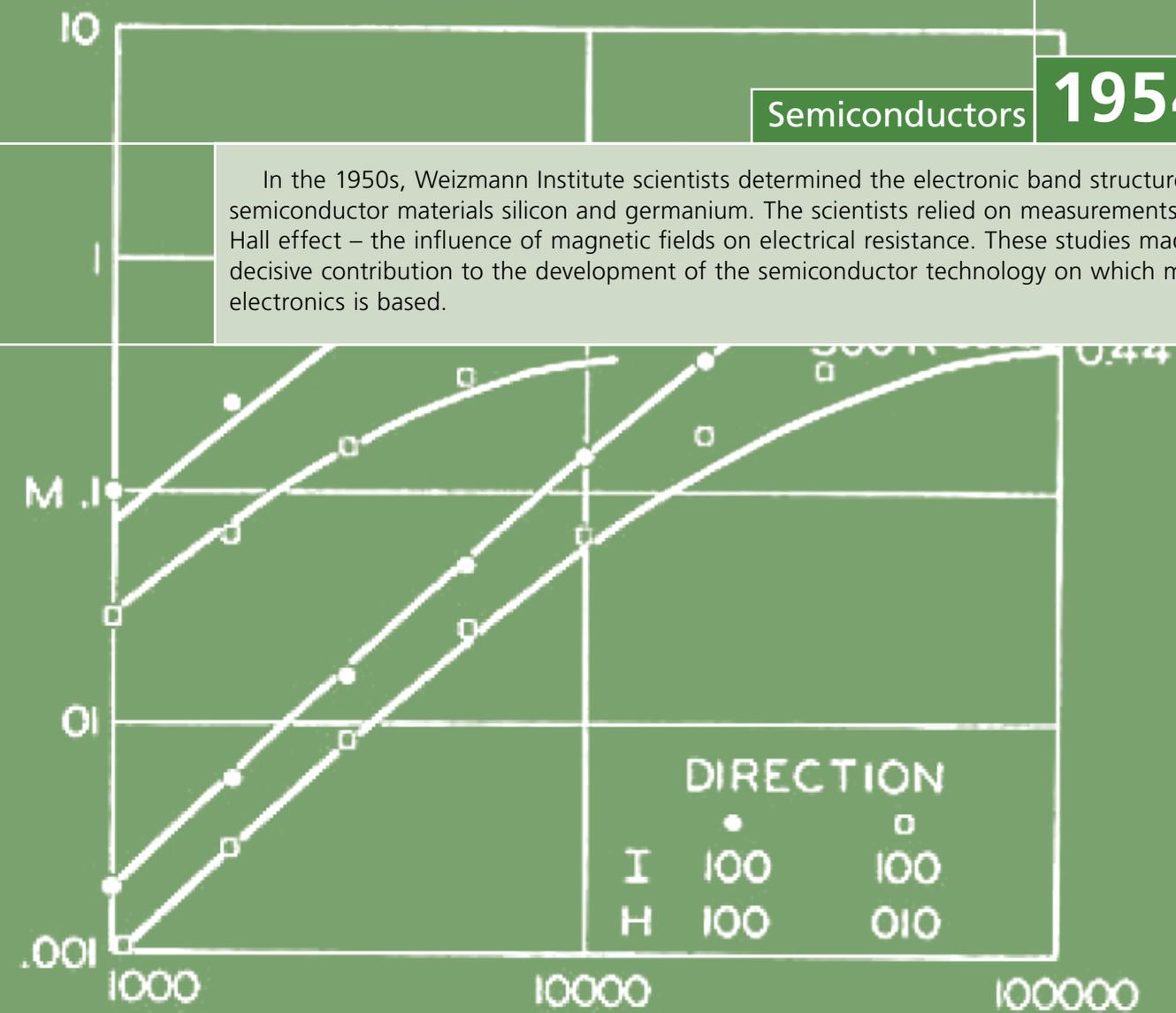
Weizmann Institute scientists constructed a high-resolution nuclear magnetic resonance (NMR) spectrometer, only the second such device in the world. The machine was used for a pioneering study of chemical reaction rates under equilibrium conditions, as well as the study of molecule structure and behavior. Later, Institute scientists developed a method of measuring the movement of molecules in molecular crystals using quadrupole nuclear resonance.



100 Milestones in Physics at the Weizmann Institute of Science

## Semiconductors 1954

In the 1950s, Weizmann Institute scientists determined the electronic band structure of the semiconductor materials silicon and germanium. The scientists relied on measurements of the Hall effect – the influence of magnetic fields on electrical resistance. These studies made a decisive contribution to the development of the semiconductor technology on which modern electronics is based.



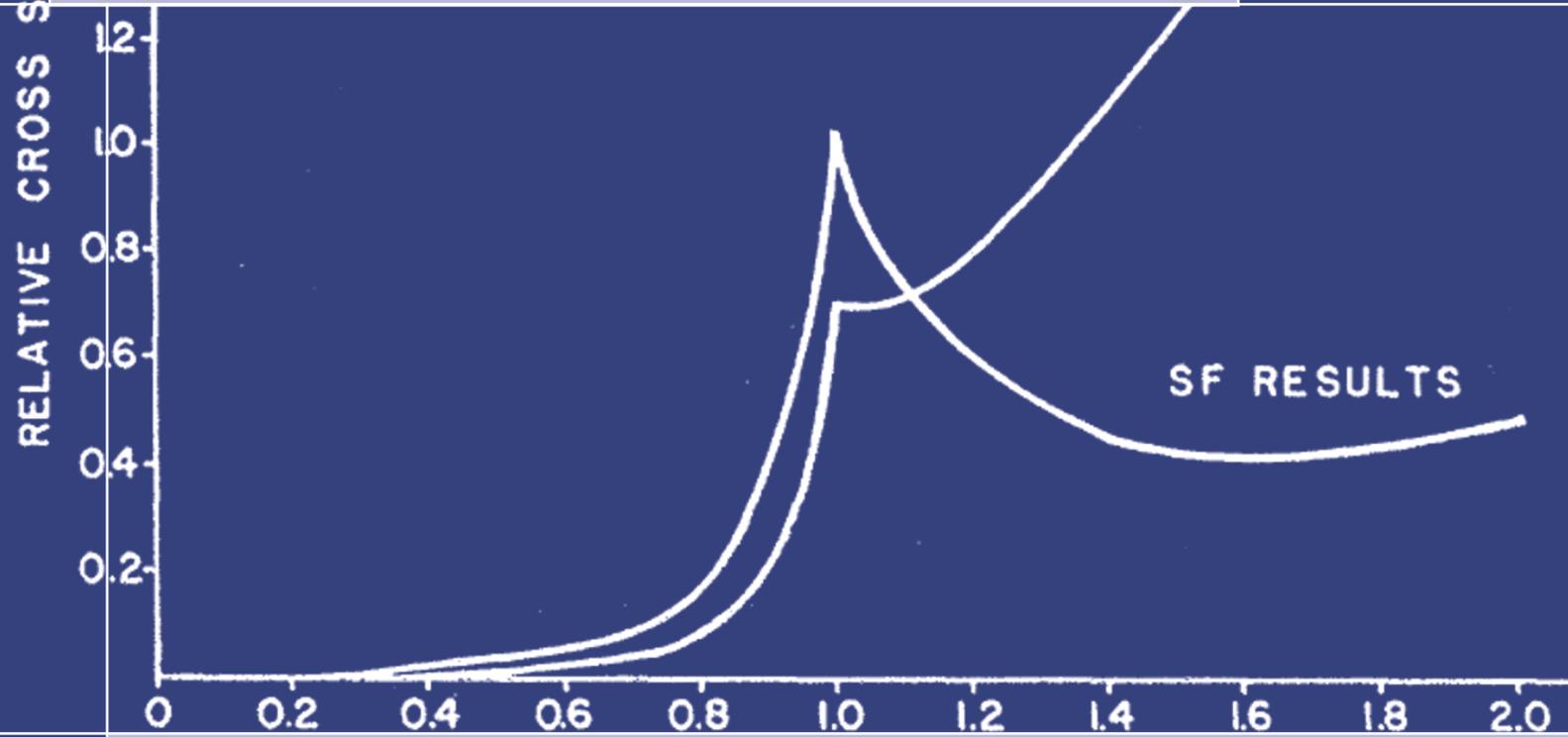
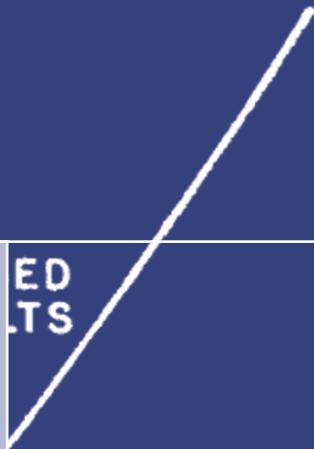
1954

Unknown Particle Reveals Its Identity

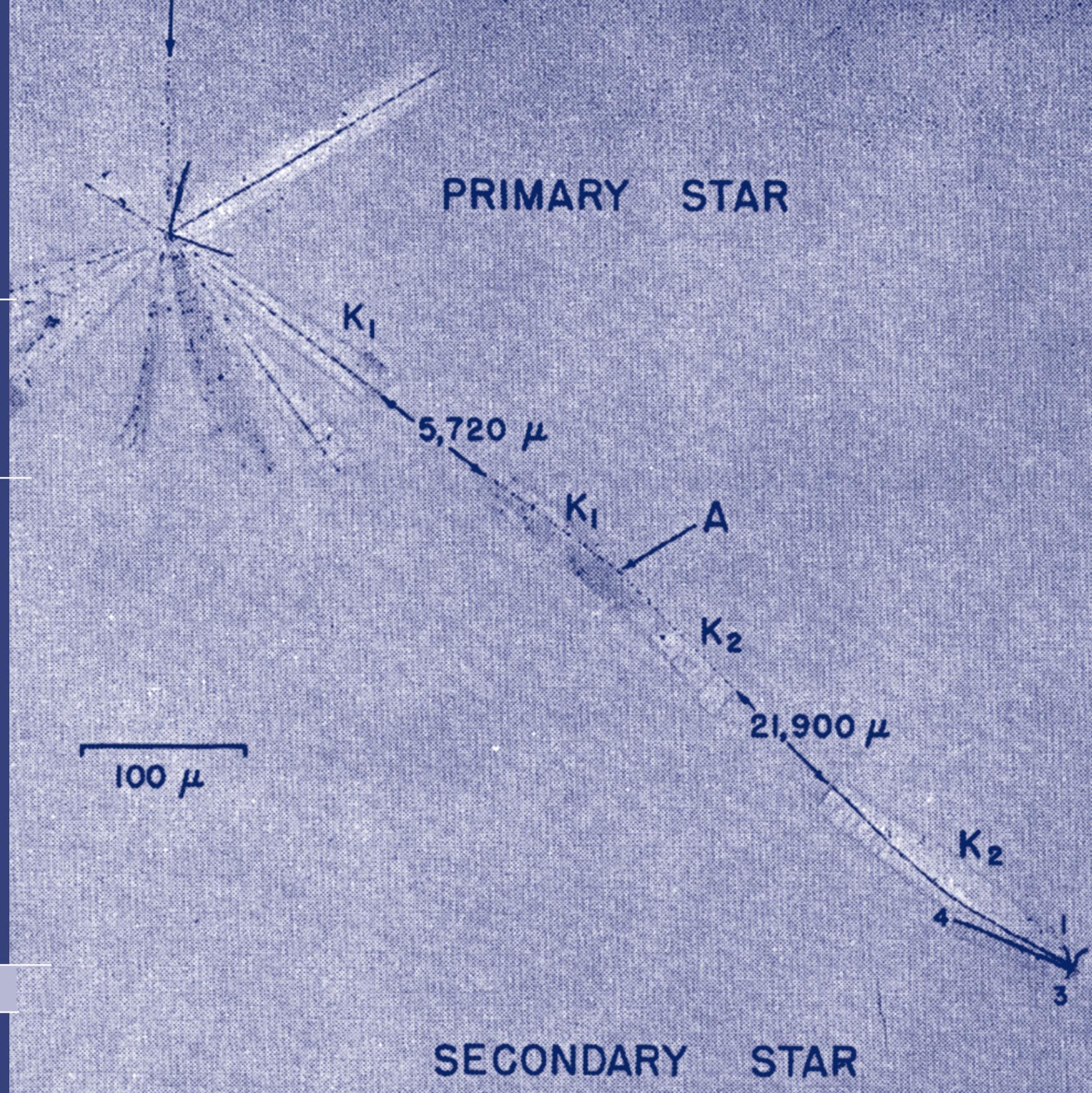
Using particle detectors based on photographic emulsions, Weizmann Institute scientists identified a particle with unknown and unanticipated properties. For some ten years this event remained an enigma; but when the omega-minus particle was discovered elsewhere, it became clear that this was the mysterious particle that had left its imprint on the Institute's detector. The discovery of this particle confirmed the "eightfold way" theory, which states that certain properties of particles (i.e., "strangeness" or electrical charge) can take on only specific values (for instance, whole numbers, fractions with a denominator of two, etc).

RELATIVE CROSS SECTION

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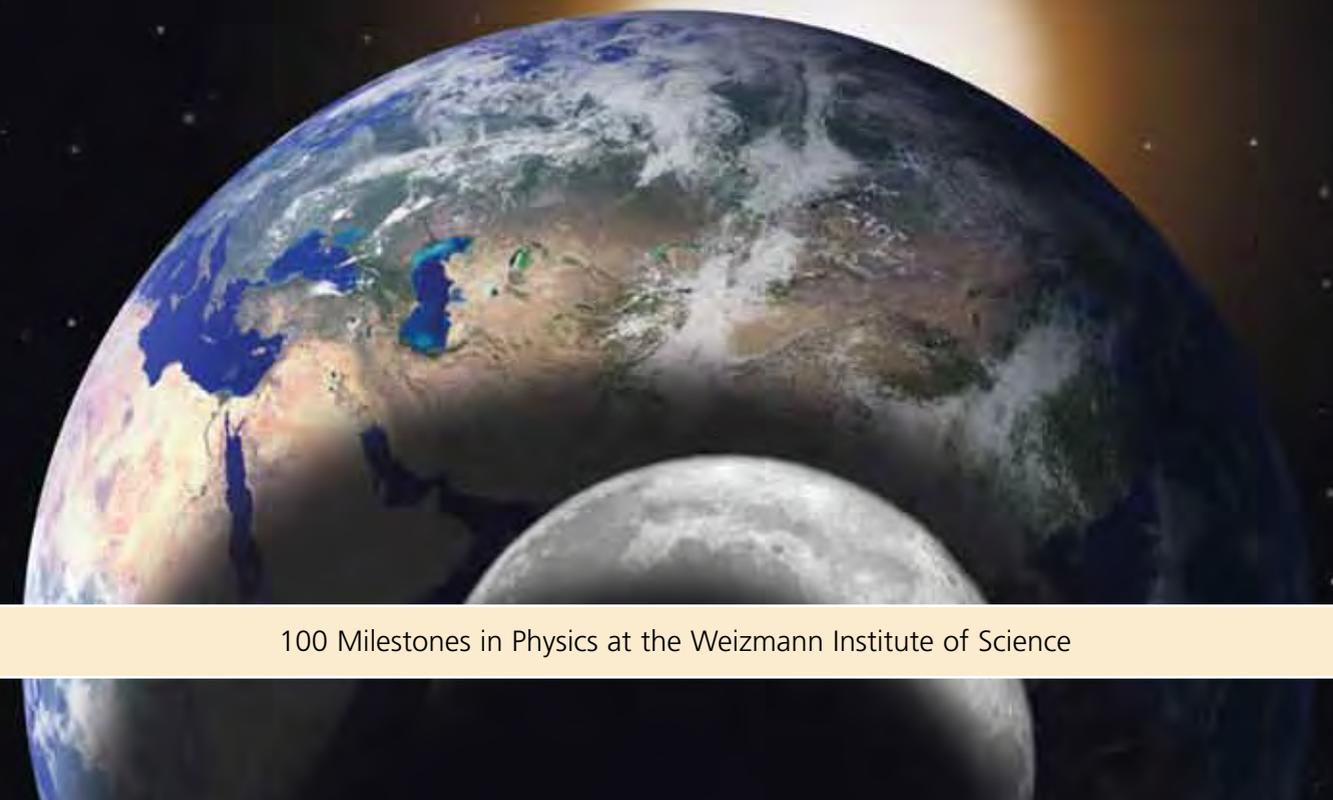
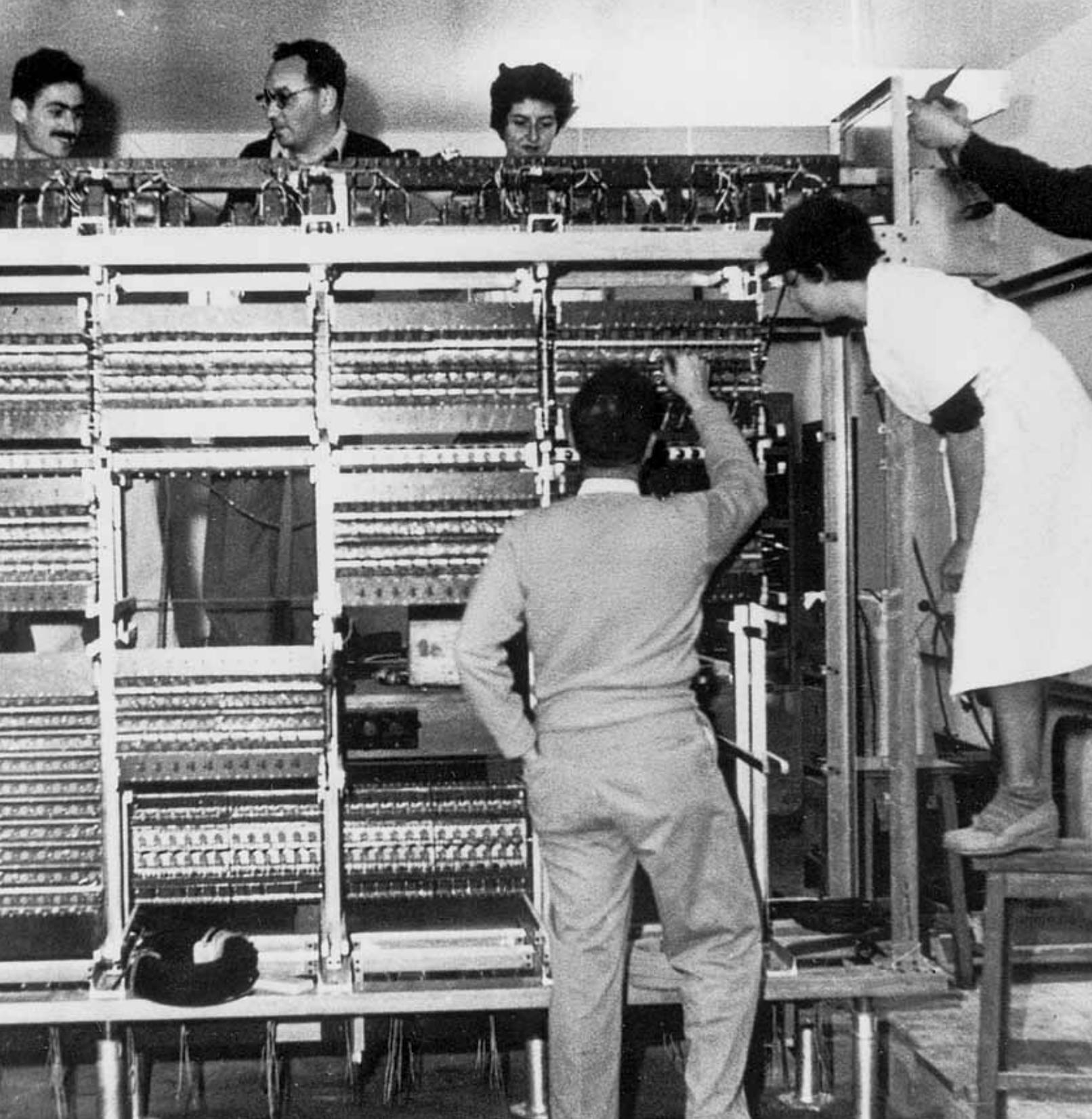


100 Milestones in Physics at the Weizmann Institute of Science



## Pioneering Computer 1955

WEIZAC, one of the first electronic computers in the world, and the first in Israel, operated into the early 1960s. WEIZAC was used for such theoretical research as calculating the spectrum of a helium atom – a so-called three-body problem incorporating the dynamics of the atom's nucleus and two electrons – and searching for a solution to the problem of mid-ocean tides. These types of problems are considered extremely complex and, despite all of today's computing power, their complete solution still eludes us.

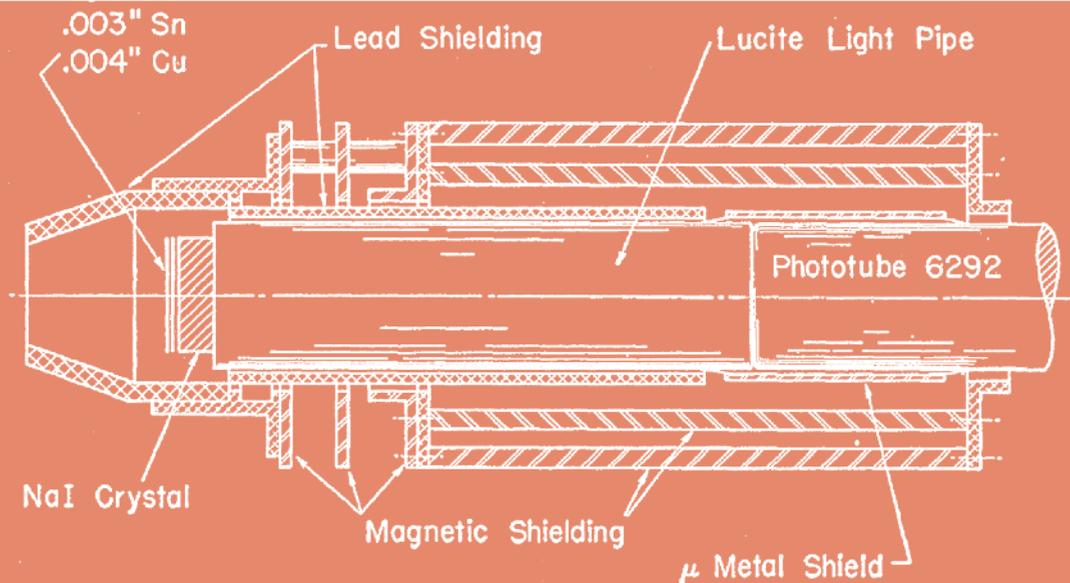


1956

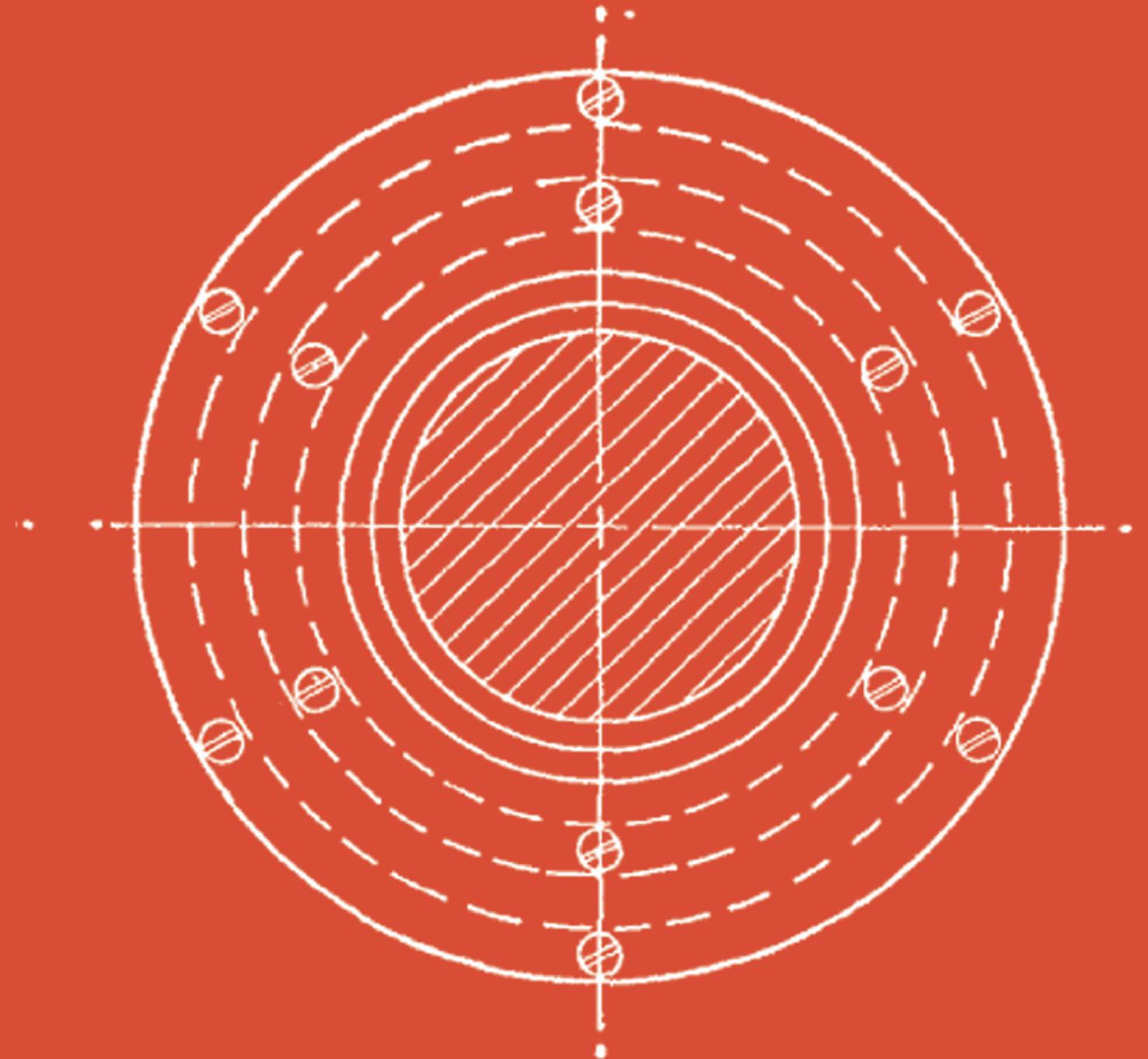
## Collective Movement

Weizmann Institute scientists made a decisive contribution to understanding the collective movement of nucleons (protons and neutrons) observed in a number of atomic nuclei. The scientists demonstrated that, contrary to common assumptions, not all nucleons participate in the collective motion. Rather, the number and nature of the nucleons involved is governed by subtle features of nuclear structure.

This breakthrough employed innovative experimental techniques based on the magnetic interaction between nucleons and an atom's electrons. The experiments were carried out with excited nuclei in the Institute's three particle accelerators: the Van de Graff, the Heineman Tandem and the Koffler Pelletron. Some of these techniques were taken up by research centers around the world.



100 Milestones in Physics at the Weizmann Institute of Science



## Physics Conference 1957

In September 1957, the Weizmann Institute hosted an international conference on nuclear structure – the first international scientific conference in Israel. Such events were mostly held in established research centers, so the fact that this important conference took place in Rehovot was a sign of the high regard in which researchers in the Institute's nascent physics department were held by the global nuclear physics community.

Some 220 physicists signed up for the conference, 155 of them coming from 18 different countries. Among the participants were scientists who had recently proved the non-conservation of parity, as well as the developers of the collective model, the shell model and others. The conference captured the imagination of Israeli journalists, who sent daily reports to their papers. Prime Minister David Ben-Gurion and Golda Meir both attended an official conference dinner at the Institute.

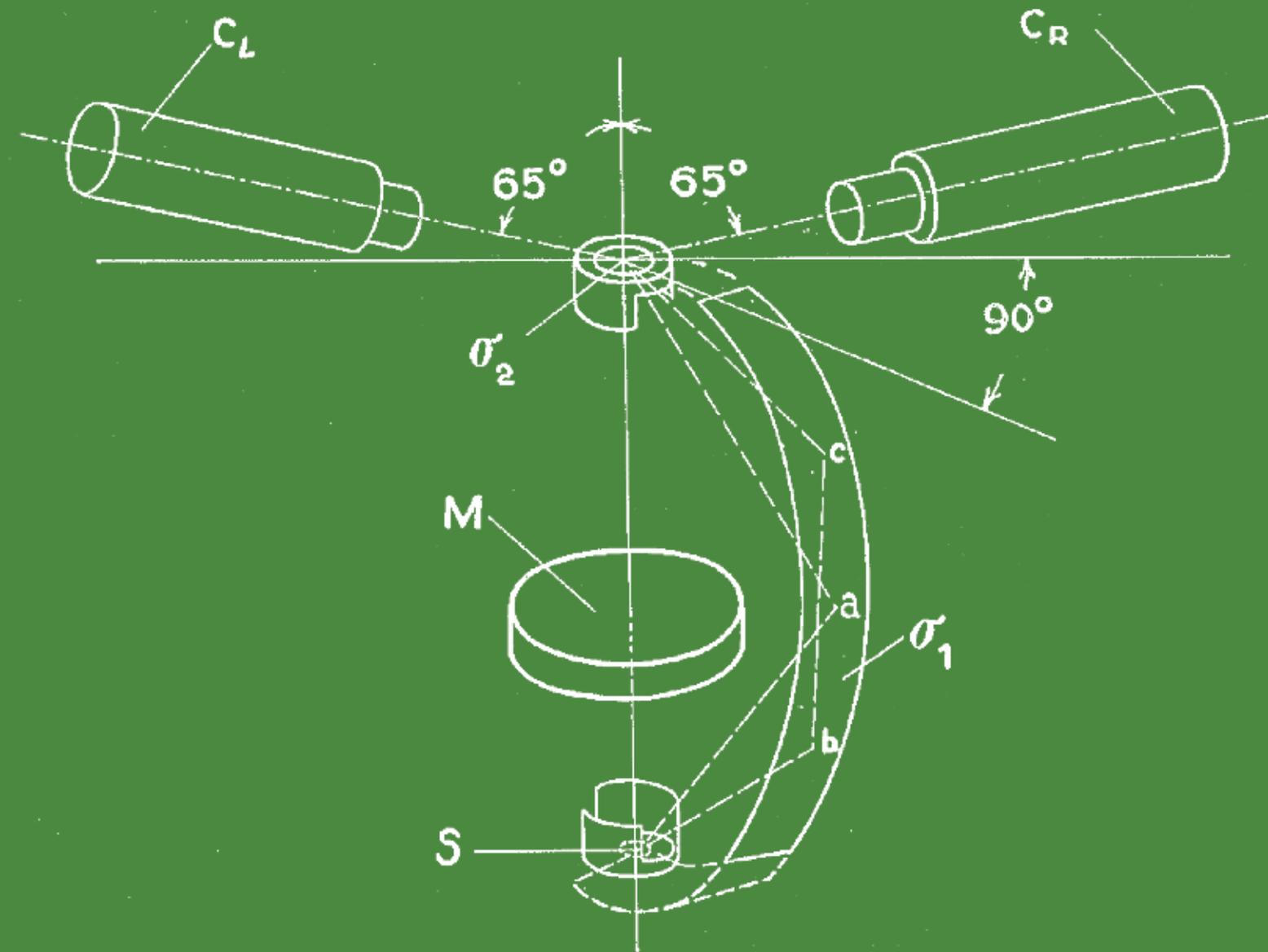
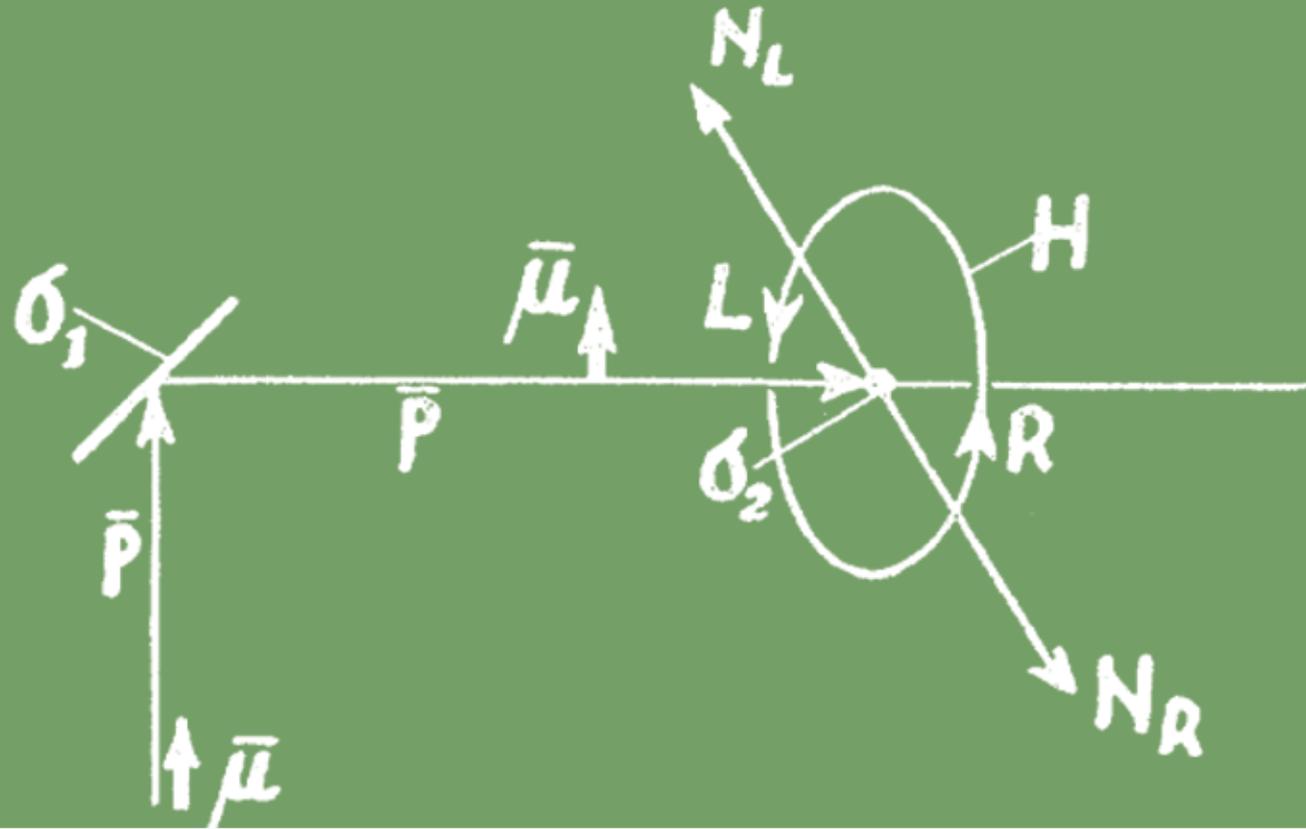


100 Milestones in Physics at the Weizmann Institute of Science

1957

## Polarized Electrons

Weizmann Institute scientists developed a method for measuring the polarization of electrons emitted in radioactive beta decay. The results, showing that beta-decay electrons were spinning like left-handed screws, helped researchers paint a picture of beta radiation. The method was later used to plan and build a number of research devices.

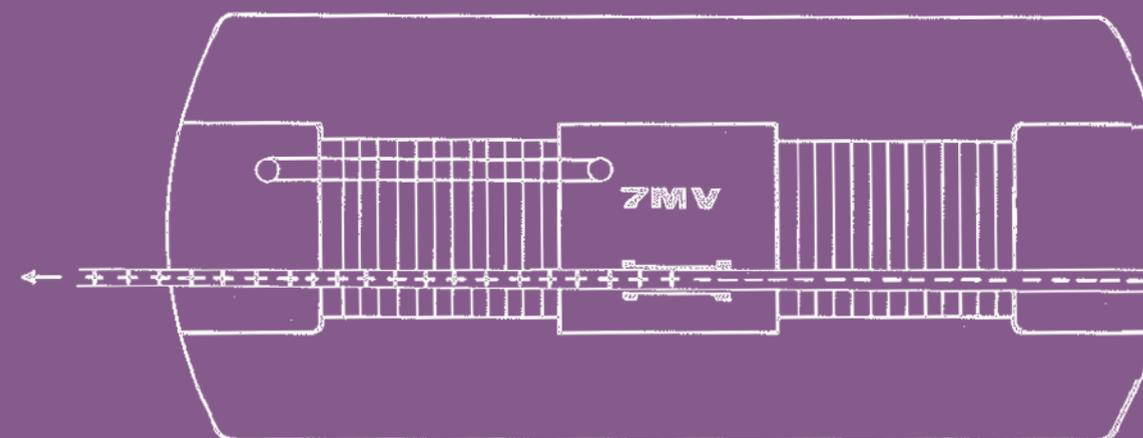


## First Particle Accelerator in Israel

1958

The Van de Graaff particle accelerator was dedicated in May 1958, together with a new building for the Physics Department (today the Edna and K. B. Weissman Building of Physical Sciences). At the time, the Van de Graaff was the latest in global technology, and it enabled Institute scientists to work at the cutting edge of nuclear physics. Experiments conducted in its first year of operation already made use of a computer, one of only two places in the world doing so in those years. The first experiment in the world that included both a particle accelerator and a transistor was also conducted in the Van de Graff.

The veteran accelerator turned 40 in 1998, and those who showed up to celebrate included many young scientists who had found new uses for it in their pioneering research: By the 1980s, the old accelerator had become an essential tool for polymer research, for the development of various types of sensors, for testing the radiation defense mechanisms of satellites and for investigating semiconductors. Advanced solar physics research conducted in this accelerator is the 100<sup>th</sup> milestone described in this book.



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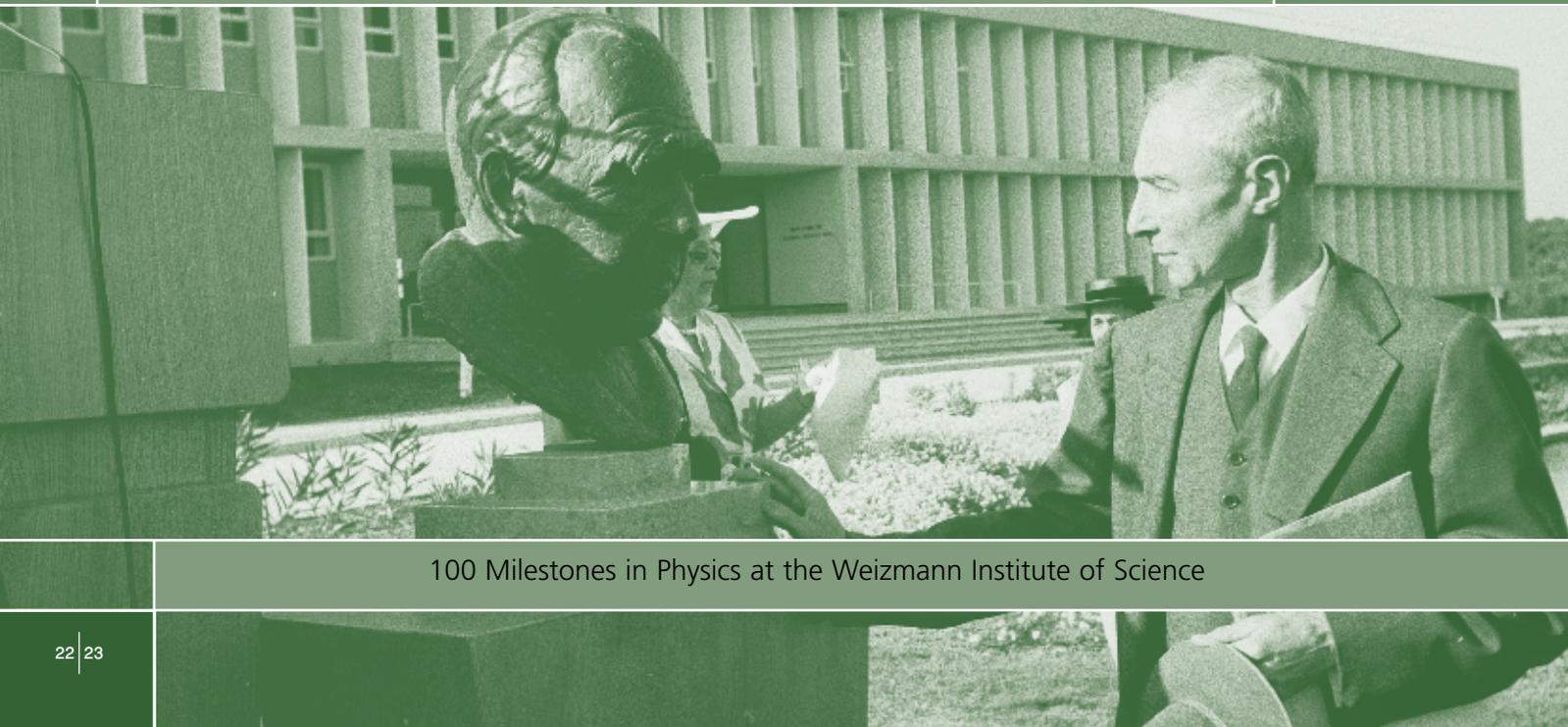
## 1958

### Edna and K. B. Weissman Building of Physical Sciences

The Edna and K. B. Weissman Building of Physical Sciences, designed by the architects Arieh Sharon, Nachum Zalkind and Benjamin Idelson in 1957, at first glance appears to be typical of the Functionalist-Minimalist style based on the repetition of components, as was common in office and public buildings at the time. The protrusion of the floors beyond the line of the windows on the façade suggests the internal division of the building into two stories and a basement. The height-to-length ratio (length: 72 meters) is 1:9, giving the building a long, flat appearance.

To break up the long, horizontal effect, the architects opted for vertical shading panels. Looked at from the side, these panels alter the impression of the building's façade, as the dense sequence of panels seems to conceal the windows as though they were obscured by a lattice.

The repetitiveness and symmetry of these shading panels are abruptly halted at the building's entrance: Two round columns support the frame of the canopy and the red terrazzo of the threshold continues indoors with the floor tiles of the lobby and the staircase that rises to the second floor – like a long red carpet.



100 Milestones in Physics at the Weizmann Institute of Science

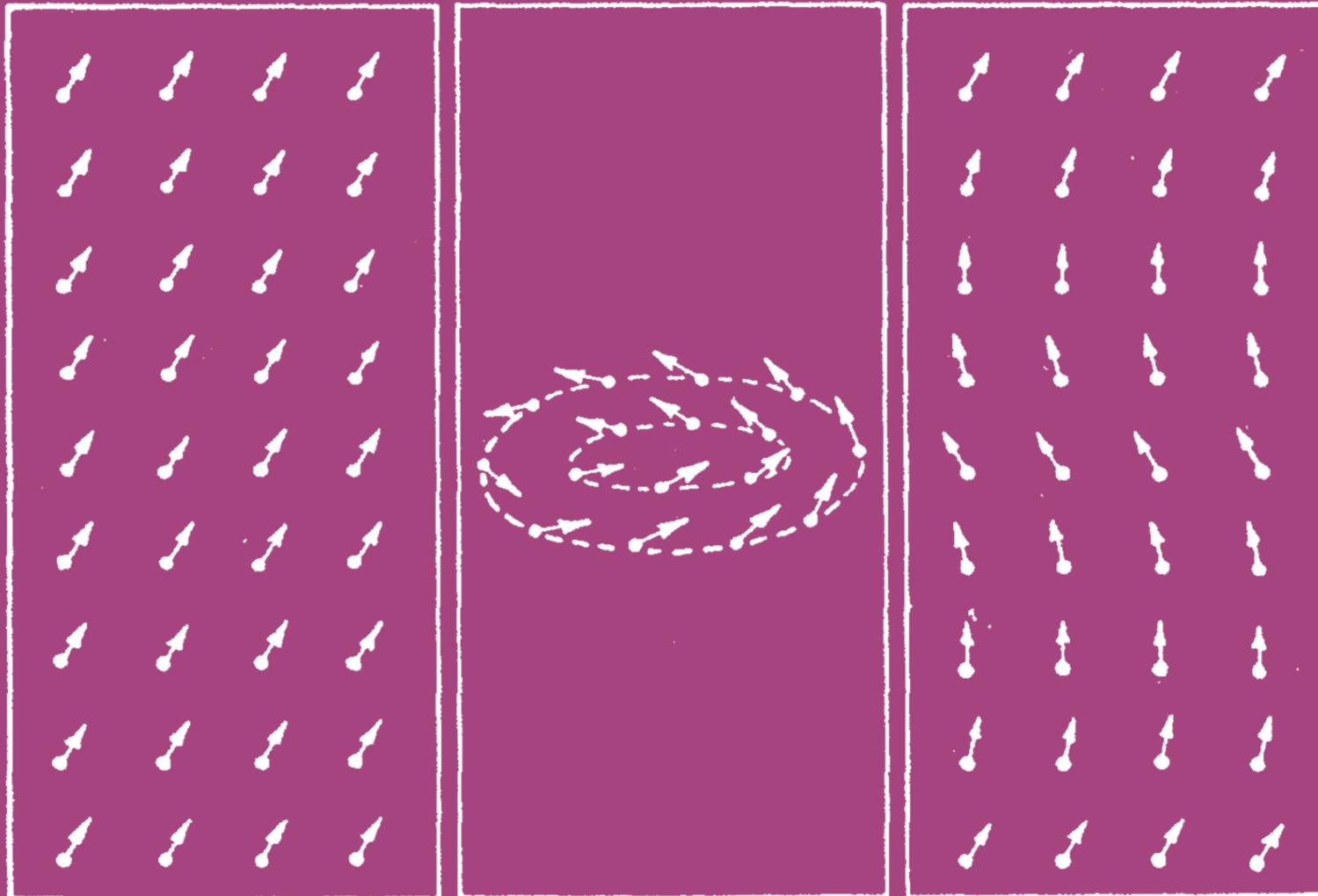


## Rotation in Unison

Miniature Magnetism

1961

Weizmann Institute scientists developed a theory that explains how changes in a magnetic field influence changes in the orientation of minuscule magnetic particles found in the field. This theory explains, among other things, how recording and erasing are implemented on magnetic tape.



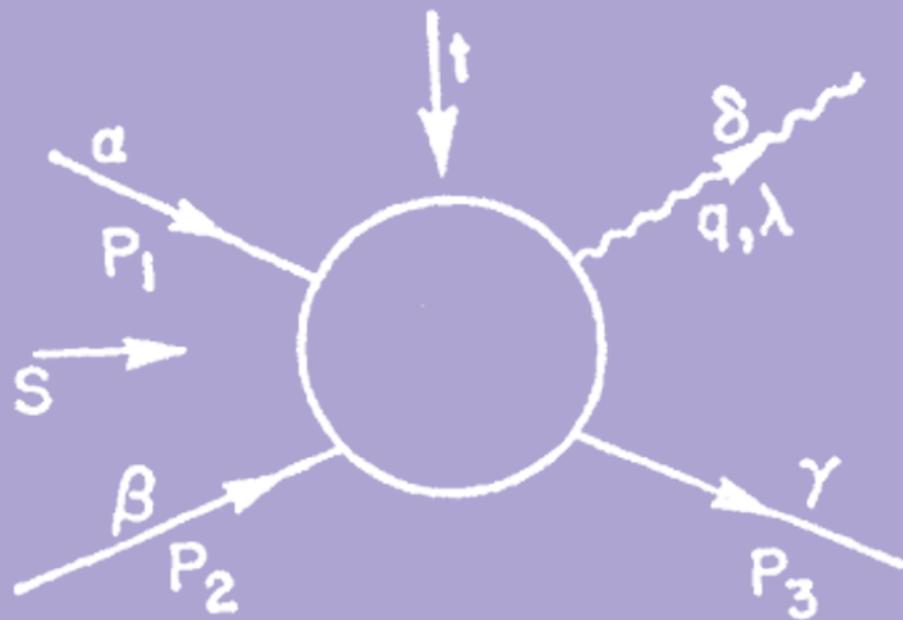
Buckling

Curling

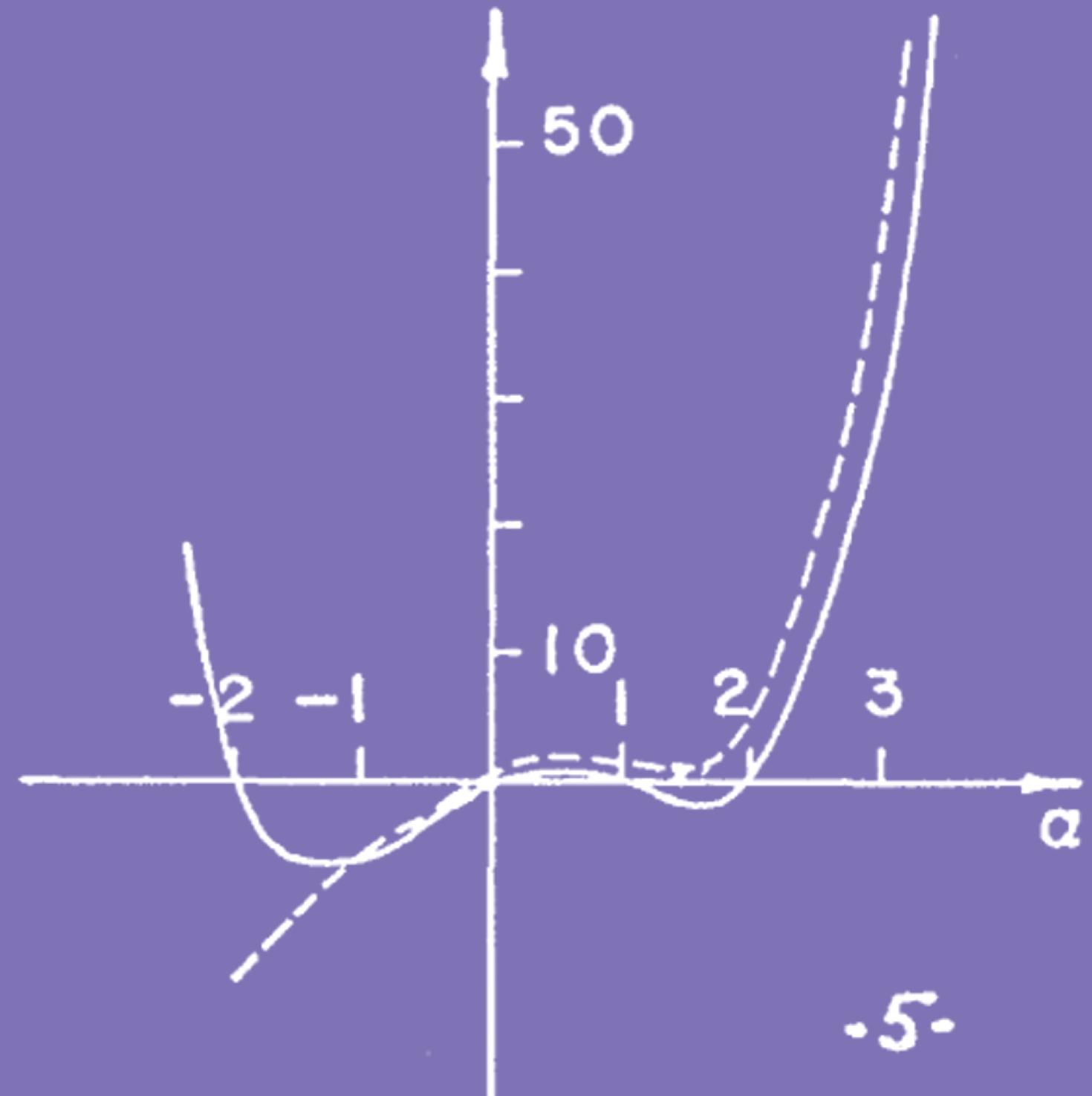
1961

## Why Scattering Matters

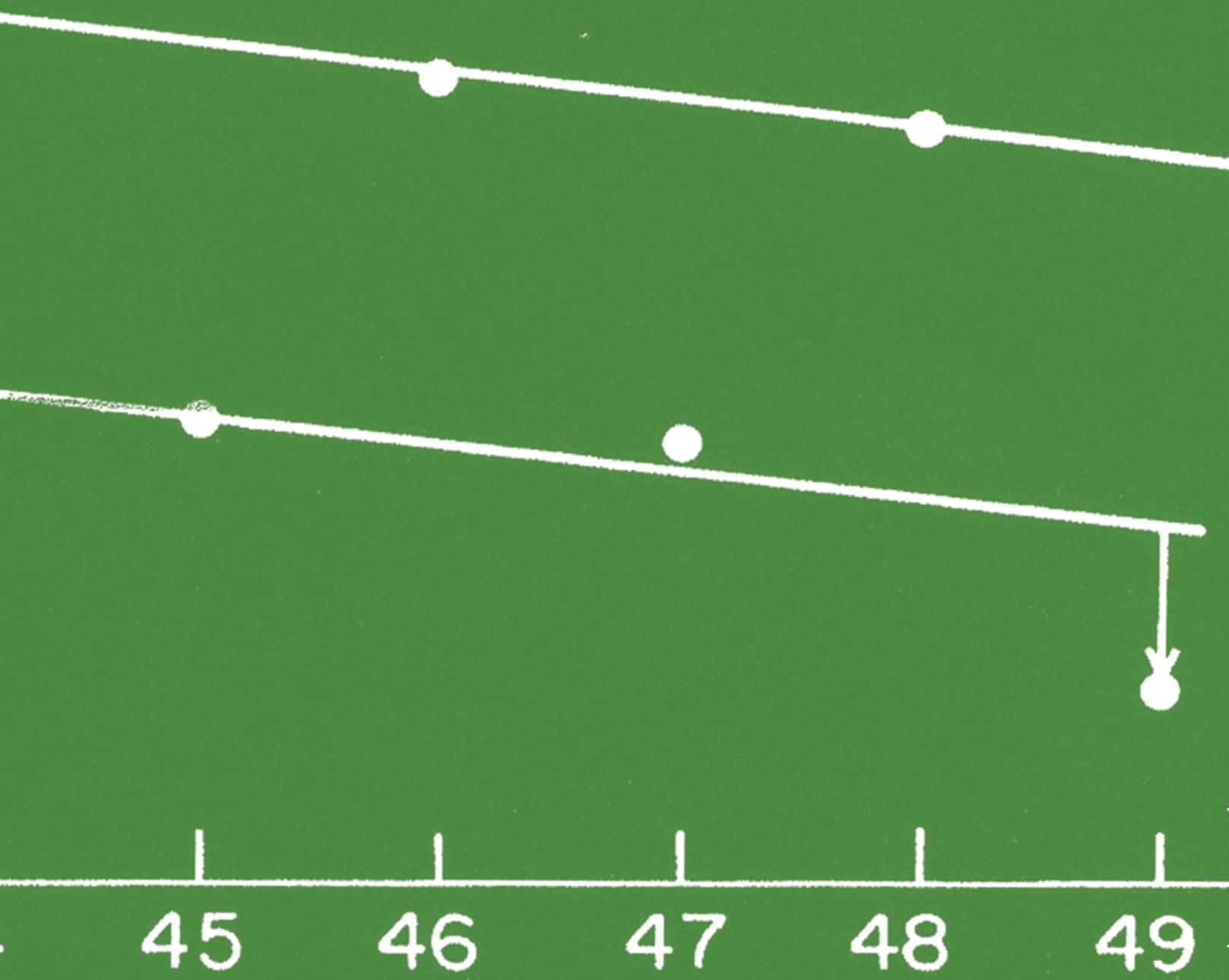
Weizmann Institute scientists studying the phenomenon of duality in the physics of hadrons (such particles as protons, neutrons and pions that interact strongly with one another) developed a formula describing how these particles scatter following head-on collisions. This includes instances in which the collisions change the nature of these particles, so the originals and the final products don't match. This particular formula gave impetus to understanding the entire scattering process.



100 Milestones in Physics at the Weizmann Institute of Science



Nuclear Shells 1963



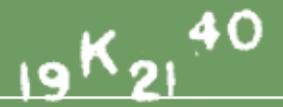
Institute scientists contributed to our understanding of the structure of the atomic nucleus by developing methods for calculating the energies of nuclei in various states.

In an atomic nucleus, the strong nuclear force between protons (with positive charges that repel one another) and the neutrally charged neutrons holds them together, thus permitting the existence of stable atomic nuclei. Scientists in various labs around the world realized that the nuclear constituents move in layered orbits, similar to the motion of electrons revolving around the nucleus (the shell model). The protons and neutrons constantly move around inside a field that is the average of the forces working among all the particles in the nucleus.

Since these forces are very strong, but only at very short range, it was quite difficult to predict the orbits of protons and neutrons and to calculate the energies of nuclei in various states. Extremely complex calculations are needed to obtain values for these forces that can be applied to the shell model. Even today, these calculations are mostly too complex to carry out.

Institute scientists developed a method to circumvent this difficulty. In this method, "effective forces" that fit into the shell model are obtained from experimental measurements of nuclear energies. Using the results of several measurements, the scientists were able to obtain the information needed for predicting the results of new experiments. With this method, they developed a simple formula for the masses of groups of nuclei. The information extracted from experimentation led to an understanding of the important features of the effective forces.

This significant method was adopted throughout the world, and even now, many years later, it still serves as a basic tool in the calculation of nuclear properties, enabling scientists, among other things, to predict the energy of atomic nuclei in various states. Several calculations in this field have recently been carried out on supercomputers, and the values agree with the experimental results.



100 Milestones in Physics at the Weizmann Institute of Science

EXPERIMENTAL

CALCULATED

P. R. 10

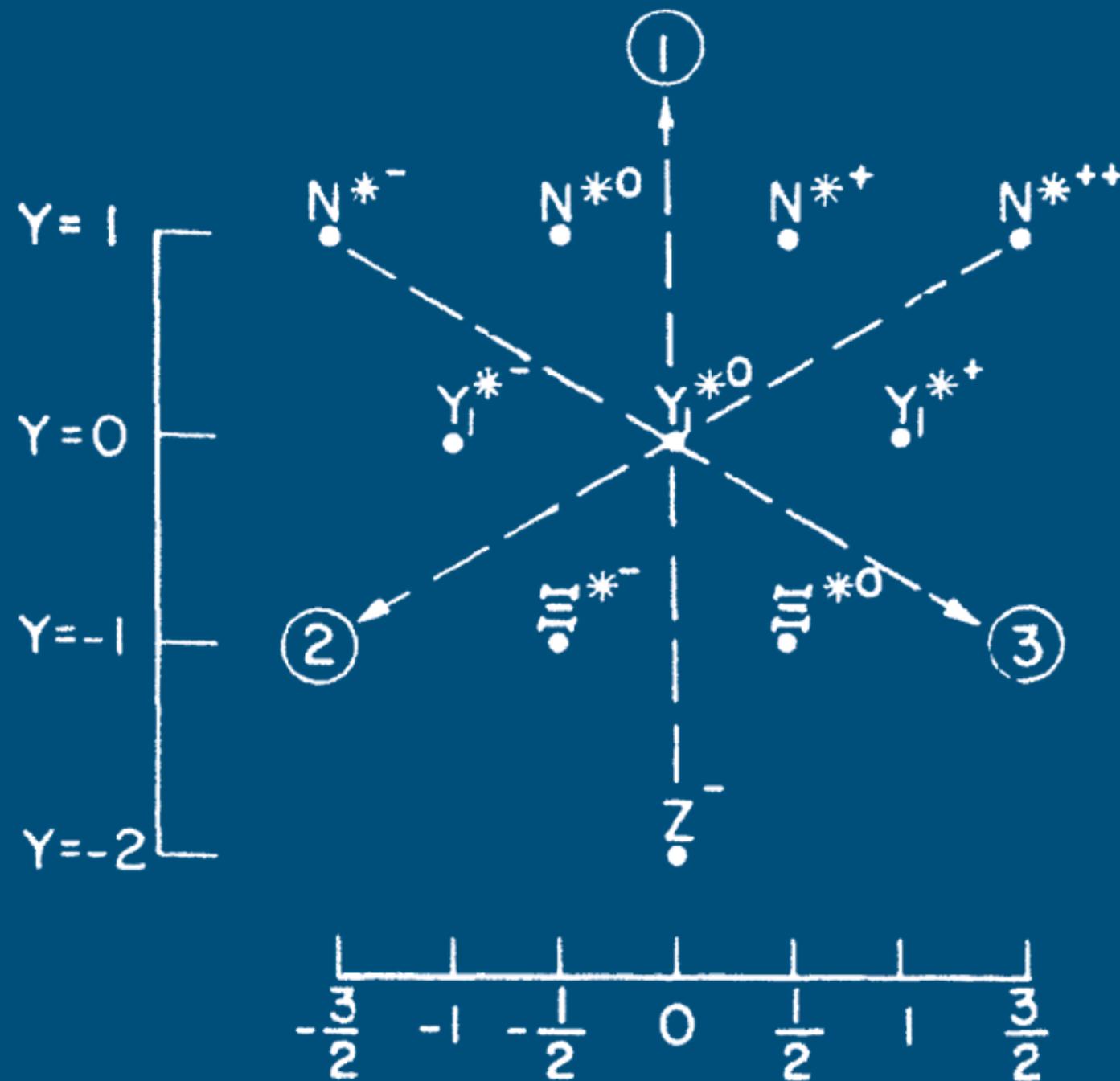
1963

## Symmetry in Fundamental Particles

By the 1960s, about a hundred elementary particles had been discovered in nature. Some are quite common, others extremely rare, but almost all of them are very short-lived, soon disintegrating into other particles. These particles are called "hadrons," the best-known examples being the protons and neutrons that make up all atomic nuclei. The existence of so many particles with no apparent plan or logical order was a central riddle of basic physics. Weizmann Institute scientists made important contributions to finding those laws of symmetry that would put hadrons into a framework. These laws enable the prediction of some of the properties of known particles, as well as certain conclusions about the existence and properties of new particles.

Later, when a model emerged showing that all particles are made up of three kinds of more basic building blocks called quarks, Institute scientists were among the first to suggest experimental tests of this theory, and many of these tests then provided evidence to support the idea that the quark model does, indeed, represent the composition of hadrons.

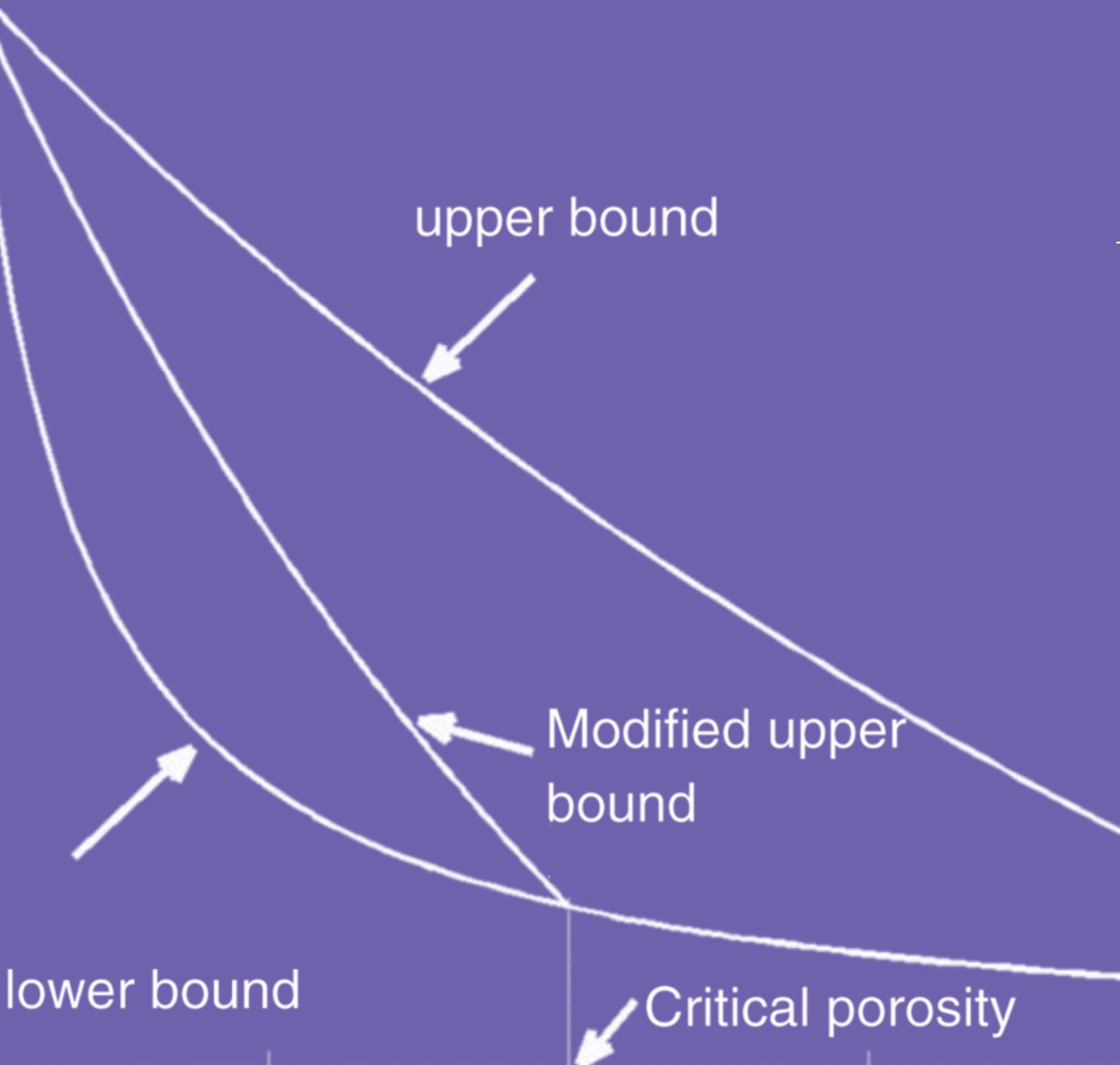
$$(\pi^- p | Y_1 *^0 K *^0) = -A/\sqrt{2}.$$



Artificial composite materials (composed of the fibers of one substance embedded in another substance) are used today to construct airplane wings, satellite parts, bicycle helmets and even innovative tools and kitchen utensils. Many scientists around the world investigate and develop new composite materials for various purposes, and one of the main questions they face in their work is how the properties of composite materials are affected by the characteristics of their individual components.

Weizmann Institute scientists discovered upper and lower bounds for a range of properties in a composite material, based on the known properties of the substances of which it is composed. This discovery assisted in the planning of composite materials with the desired characteristics.

$$\frac{1}{K^*_0} = \sum_{r=1}^{r=n} \frac{v_r}{K_r},$$

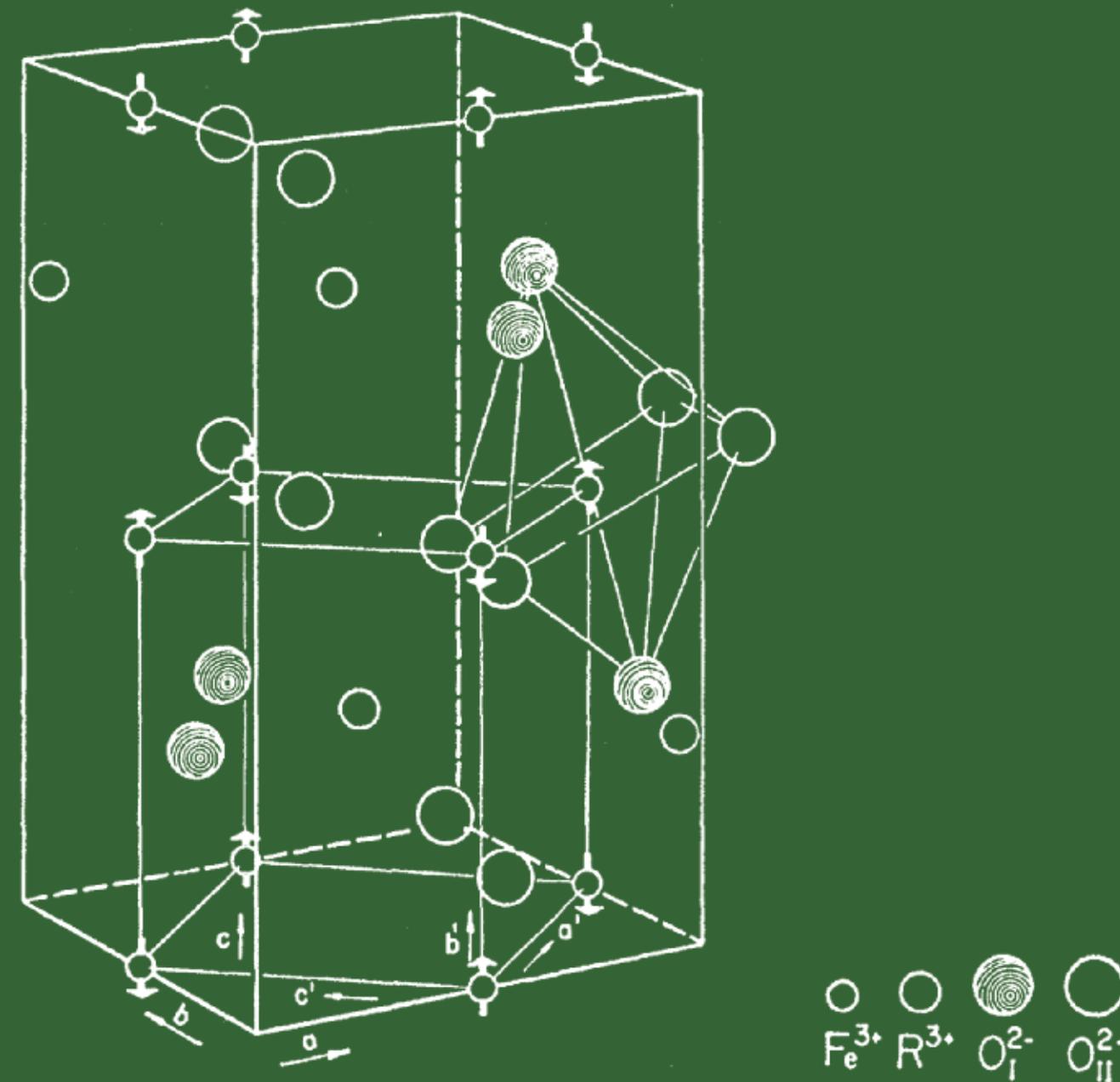


1966

Recoil-Free

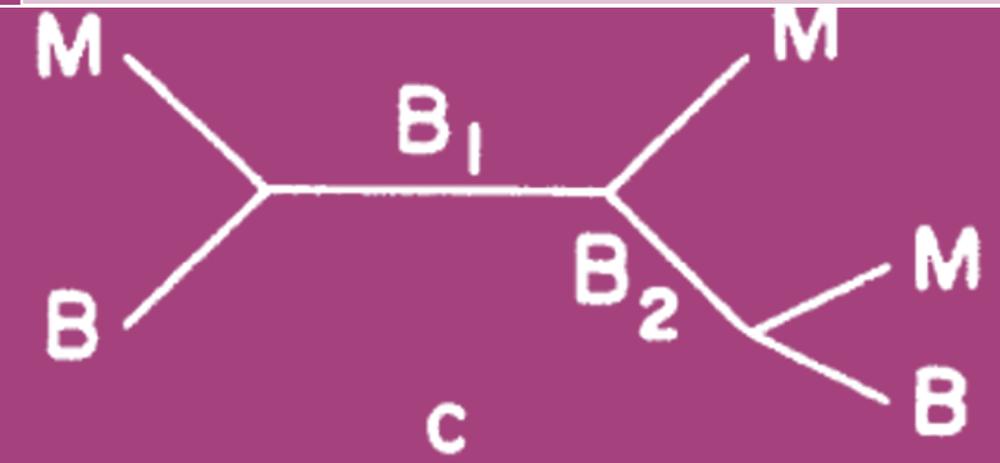
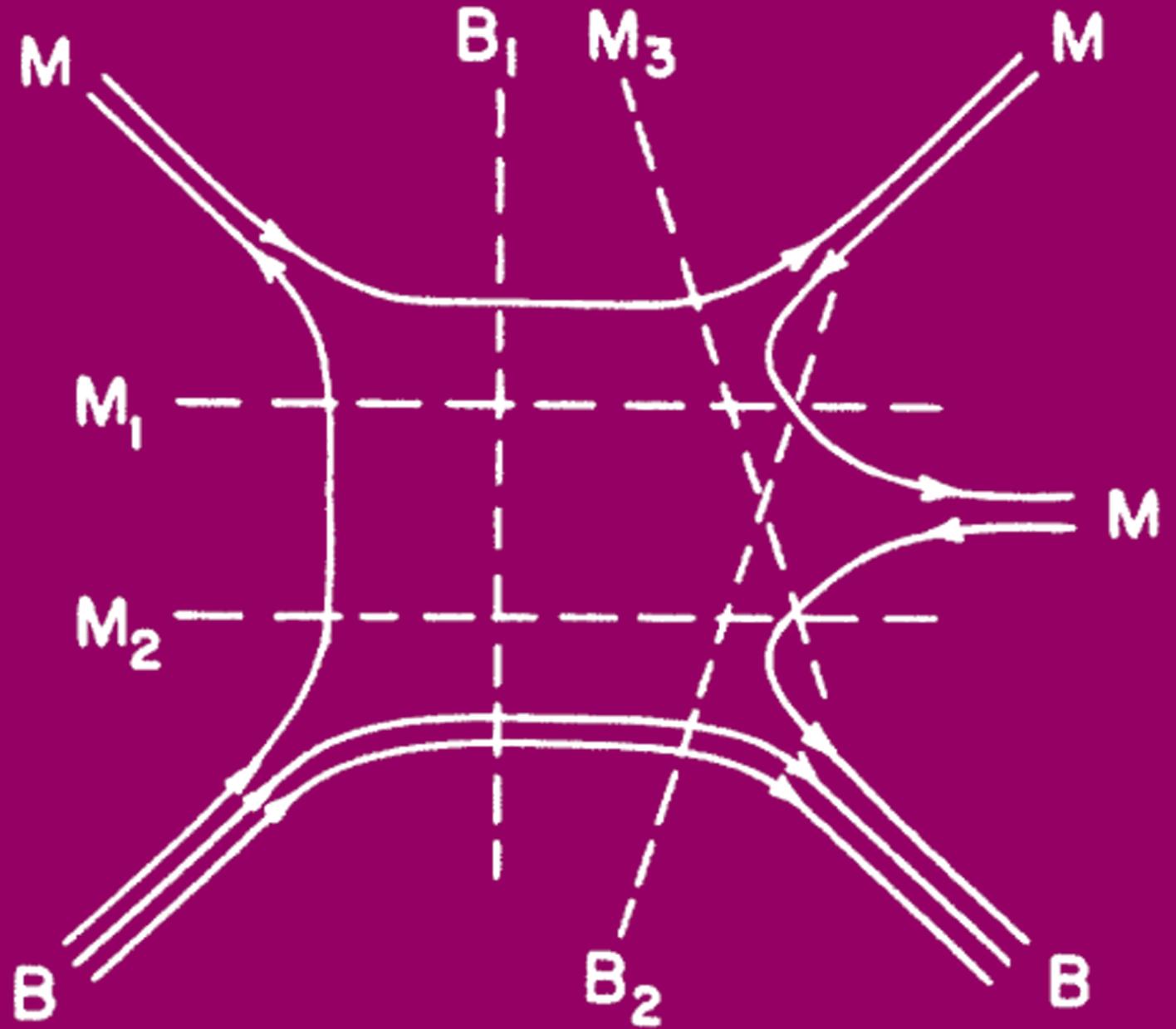
Weizmann Institute scientists planned and constructed a device for measuring the Mössbauer effect, which describes the recoil-free absorption and emission of radiation. These measurements are important in ascertaining the properties of magnetic materials and understanding different phase transitions in them. Weizmann scientists who used this device were able to verify calibration theories for magnetic materials near phase transitions. Later, it was used with synchrotron radiation to provide new methods for studying the structure of crystals.

On the basis of the Weizmann designs, large numbers of these devices were built and sold to scientists and technicians throughout the world, and they became the cornerstone of one of Israel's first advanced industries.



Duality – An Identity Crisis 1968

When two elementary particles collide, two new particles are often created (in something resembling a chemical reaction). For years, physicists believed that this process can take place in two different ways: Either the two particles join to form a composite particle that immediately splits into two new particles; or else one particle transmits a fragment of itself to the second one so that both particles – the loser and the gainer – undergo a change in identity. To everyone's great surprise, these phenomena were discovered to be two different versions of the same mechanism: The collisions could be described by both explanations, implying a duality. Weizmann Institute scientists were among the world leaders in this field. They were the first to explain what takes place when the colliding particles do not undergo a change in identity. Later, they succeeded in explaining the phenomenon of duality, using diagrams of the trajectories of quarks (the building blocks of elementary particles). They were also the first to develop a mathematical equation that fully describes this type of duality. All of this led, many years later, to the development of string theory, one of the cornerstones of present-day particle physics.



1969

Prof. Amos de-Shalit (1926–1969)

Prof. Amos de-Shalit stood out, even among the group of outstanding young Israelis who, following the War of Independence, dedicated themselves to the study and teaching of physics. This generation of physicists gained an international reputation for their work. Abba Eban said of de-Shalit: "The short chapter of his life was a ray of light in the history of Israel." De-Shalit was born in Jerusalem in 1926, received a master's degree in science from the Hebrew University of Jerusalem in 1949 and a doctorate from the Swiss Federal Institute of Technology, Zurich, in 1951. From 1947 to 1949 he served in Hemed, the Israel Defense Forces' Science Corps.

From 1952 to 1954 he carried out advanced studies at Princeton University, the Massachusetts Institute of Technology (MIT) and the Institute for Atomic Research in Saclay, France. Upon returning to Israel in 1954, he was appointed head of the new Nuclear Physics Department. He held this position for ten years, shaping the department and building it from the ground up, laying the foundations of physics research at the Institute and bringing it world renown. In parallel with his responsibilities at the Institute, he served as scientific adviser to the Ministry of Defense.

De-Shalit was appointed Scientific Director of the Institute in 1961, a position he held until 1963, after which he served an additional two years as Director General of the Institute. In 1963 he was elected to the Israel Academy of Sciences and Humanities. In 1965 he received the Israel Prize in the natural sciences together with Prof. Yigal Talmi, with whom he wrote a paper on Nuclear Shell Theory and a book of the same name.

In the last years of his life, de-Shalit became deeply involved in science education and in 1964 was appointed chairman of the Committee for the Advancement of Education in Science and Mathematics. He invested much of his time and energy in striving to improve teaching methods and science and math curricula in high schools. In 1968 he established the Science Teaching Department at the Institute and became its head.

His premature death at age 43 was a great loss for the Institute, and he was mourned by many friends and acquaintances in Israel and around the world.



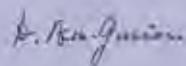
1969

The following are excerpts from letters exchanged between Prof. Amos de-Shalit and Prime Minister David Ben-Gurion:

Jerusalem  
January 13, 1957

To Dr. Amos de-Shalit – Shalom and Greetings,  
Our previous conversation has not been out of my mind. I am troubled by your position, as a physicist, on the question of human consciousness and intelligence. Do you truly imagine that it is possible to build two machines that could write letters back and forth on matters of art, philosophy and science, something like Spinoza's letters; or that one could plan a machine that could travel around the world gathering facts and then come up with Darwin's theory? Do you imagine that a machine could write the Book of Job, Plato's Republic or Einstein's theory of relativity?

David Ben-Gurion

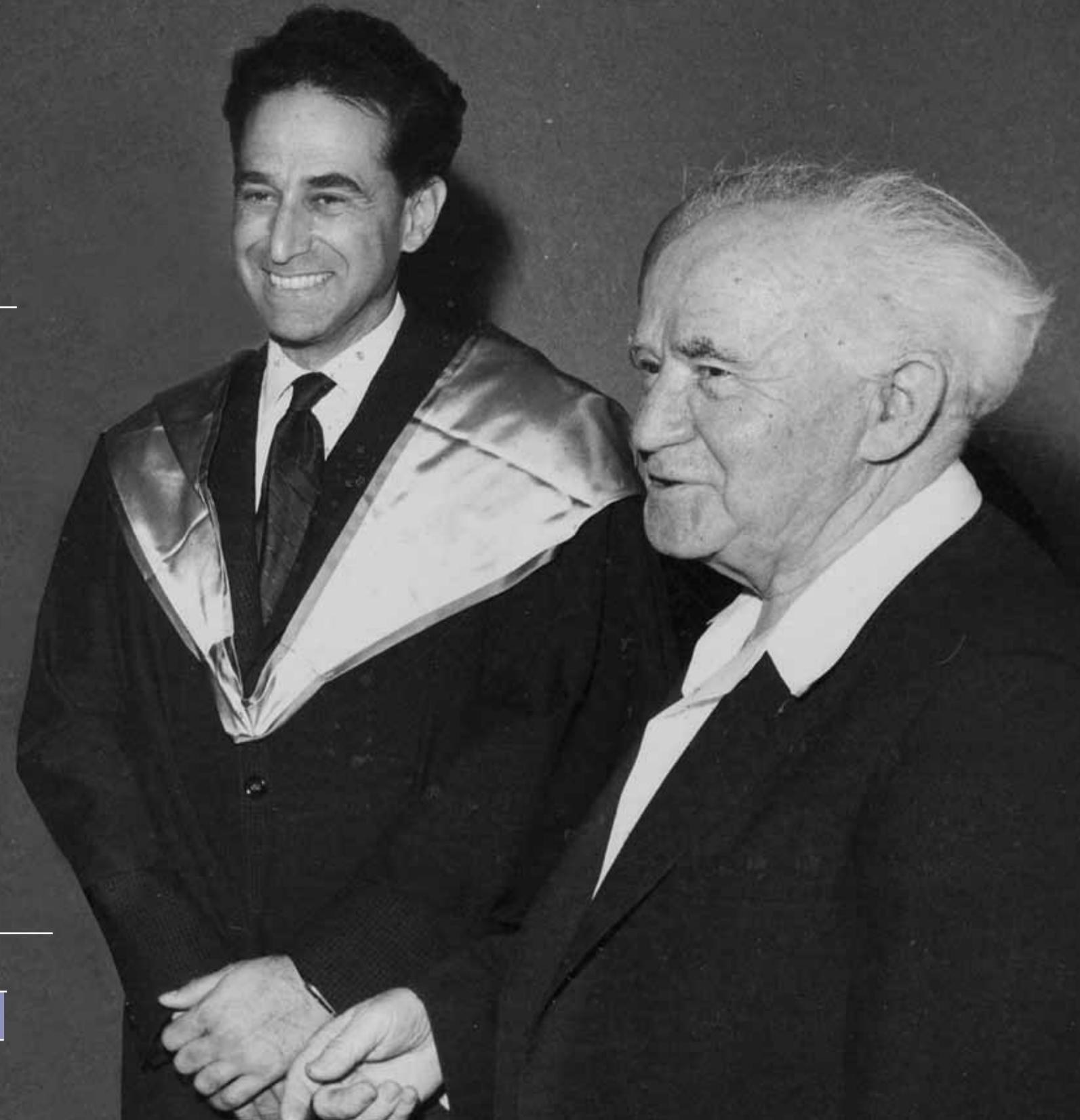


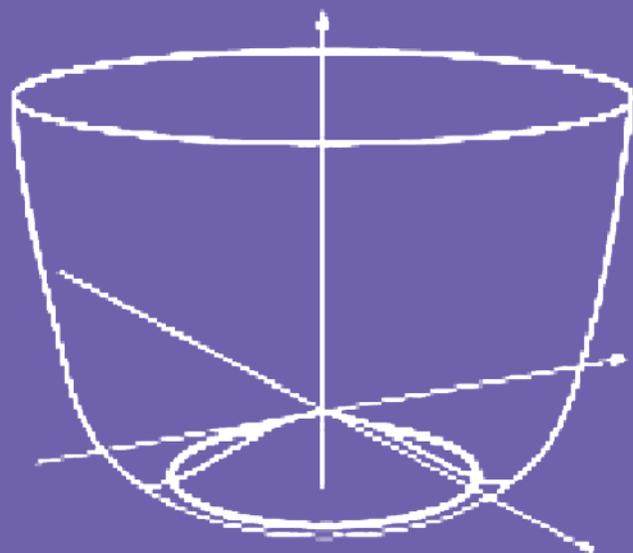
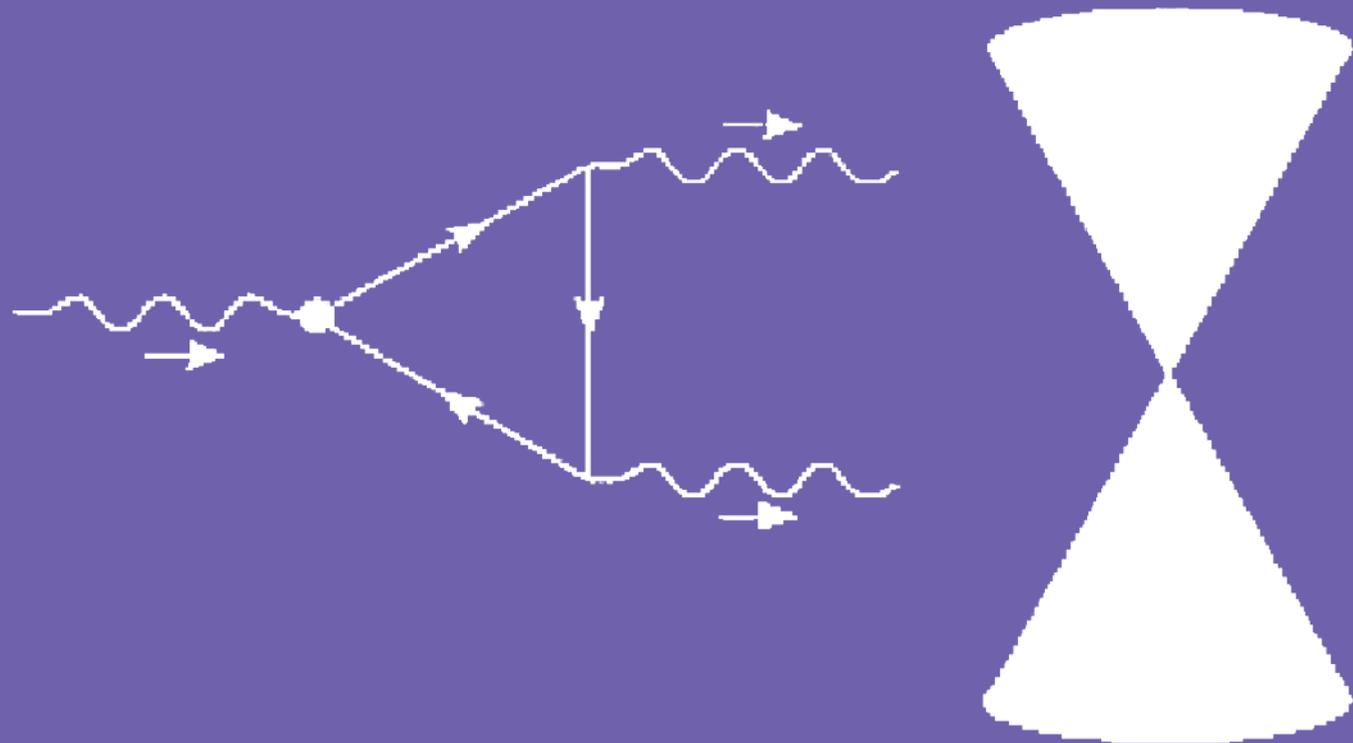
Dear Mr. Ben-Gurion,

For the sake of simplicity, let us assume that it is sufficient for our discussion to clarify to what extent a machine can replace a thinking person in just one of his functions. A range of functions could be obtained by adding machine to machine according to their various activities.

I will assume that in our conversation we have been referring solely to the ability, or lack of ability, of a machine to replace a human being in processing information. The acts of obtaining information and transferring it are technical in nature, and therefore not germane to this discussion.

Physics recognizes values that can only be significant when dealing with a large number of systems. The temperature of a gas, for example, is a value that applies to a large number of atoms together, and there is no sense in speaking of the temperature of a single atom. I can imagine that in the coordinated actions of a large number of machines, phenomena might be discovered that couldn't be found in a single machine, much in the same way that one can't talk about the temperature of this atom or that. It is possible that that which we call the "soul" is such a program, but if so, it arises, nonetheless, from physical processes in the body, just as surely as temperature arises from the mechanical motion of molecules.





Varying Forces

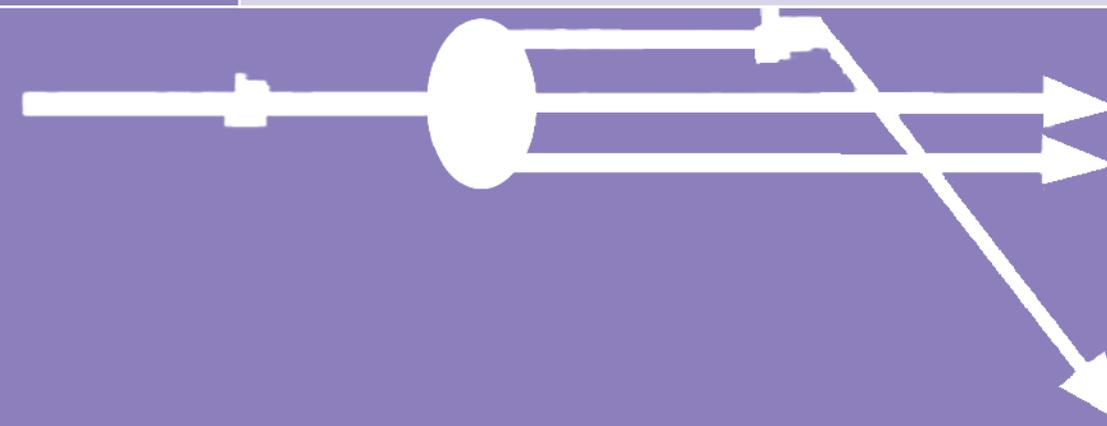
1970

On the basis of studies in relativistic quantum field theories, and motivated by experiments of deep inelastic scattering of leptons on nuclei, a law was proposed for “light-cone” expansion, for products of weak and electromagnetic currents.

Later, a complete expression was found for energy and momentum in certain models, as a product of currents. This expression is used, among other things, to investigate string theory.

A few years later, Weizmann scientists developed a method for testing various proposed models for the structure of matter. This method, based on the anomaly equations that describe the relationship between the properties of currents of the electromagnetic force and the weak force, is a key scientific tool in this field. Proposed models are rejected if they fail to pass the threshold of the Institute’s evaluation method. However, crossing this threshold does not guarantee that a proposed model is correct; additional analysis is required.

Institute scientists investigated non-Abelian gauge theories, for the purpose of describing the interactions between particles involving strong force at varying intensities. In this framework, from the 1980s on, they used two-dimensional models to calculate masses in various situations, as well as different kinds of scattering.

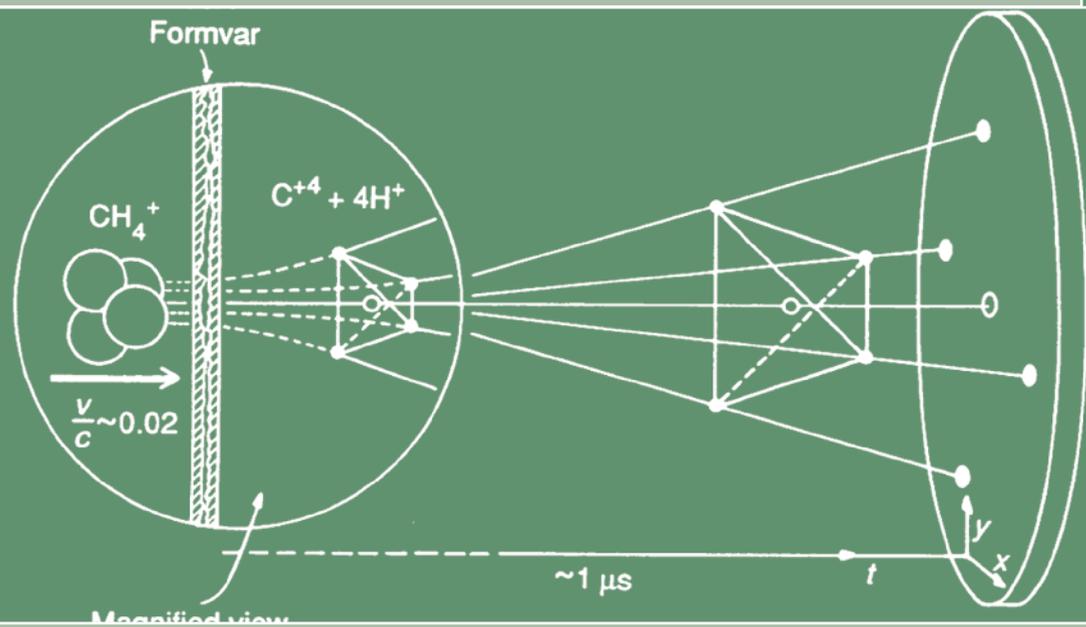


1973

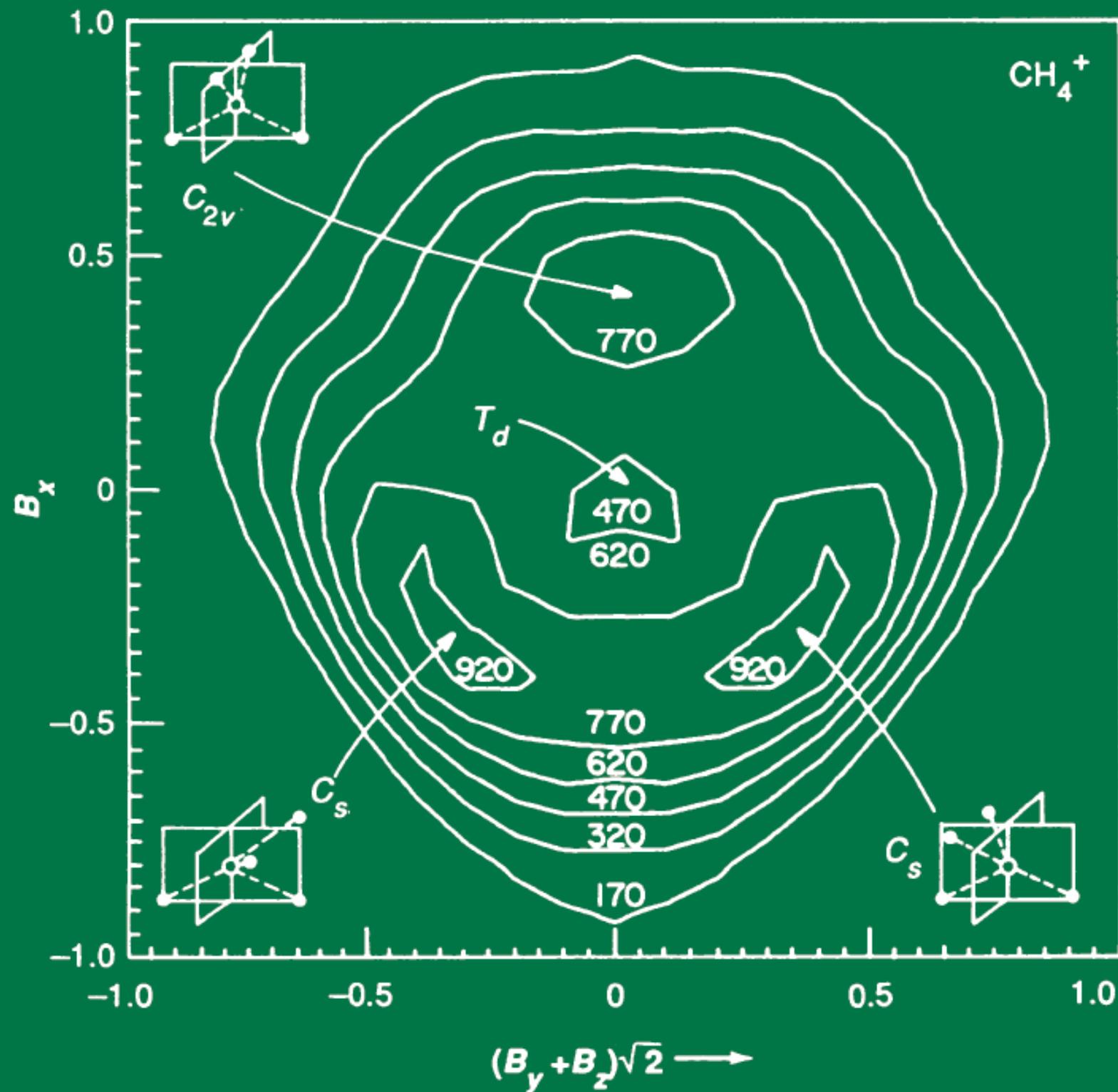
## Molecular Structure

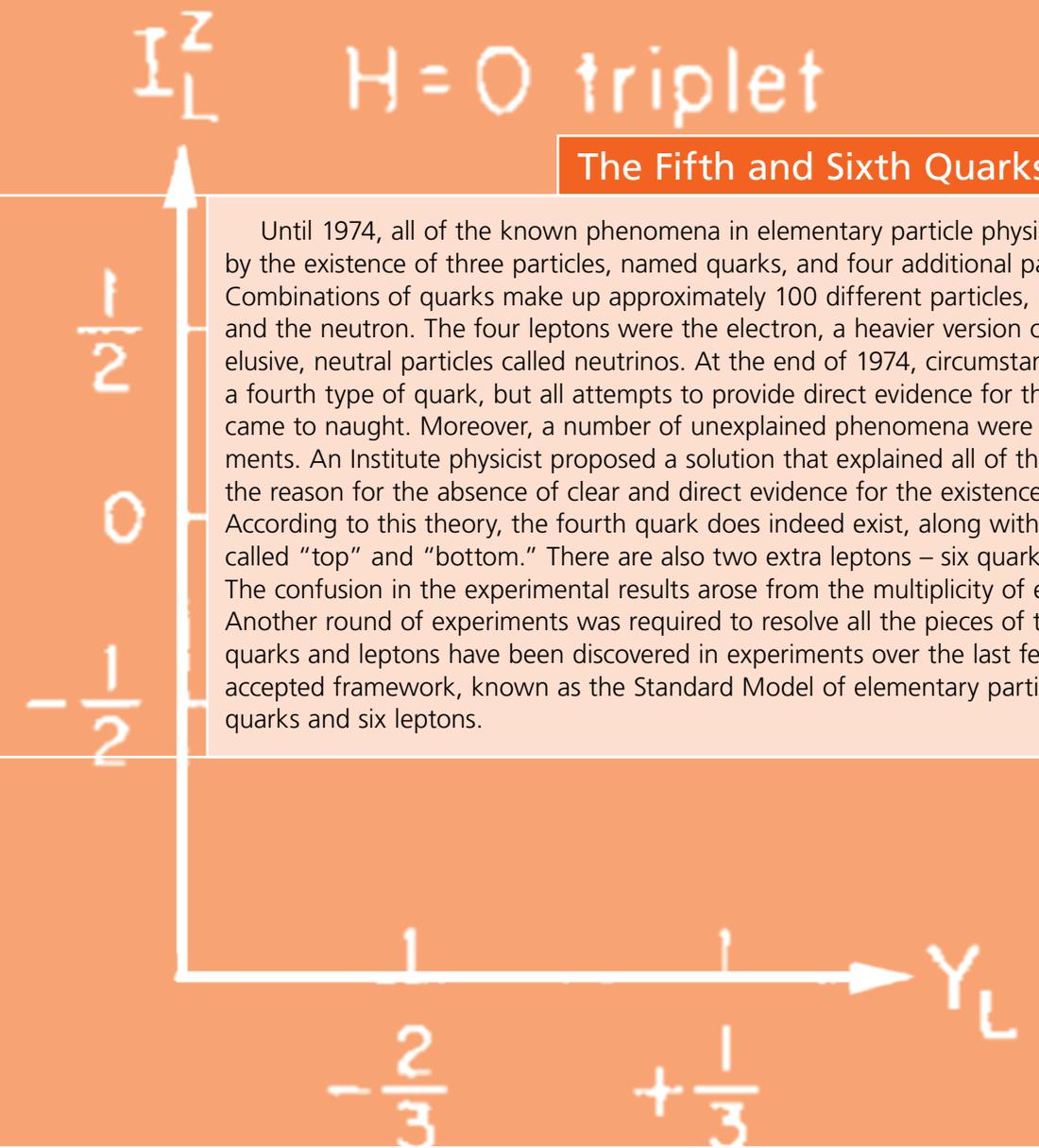
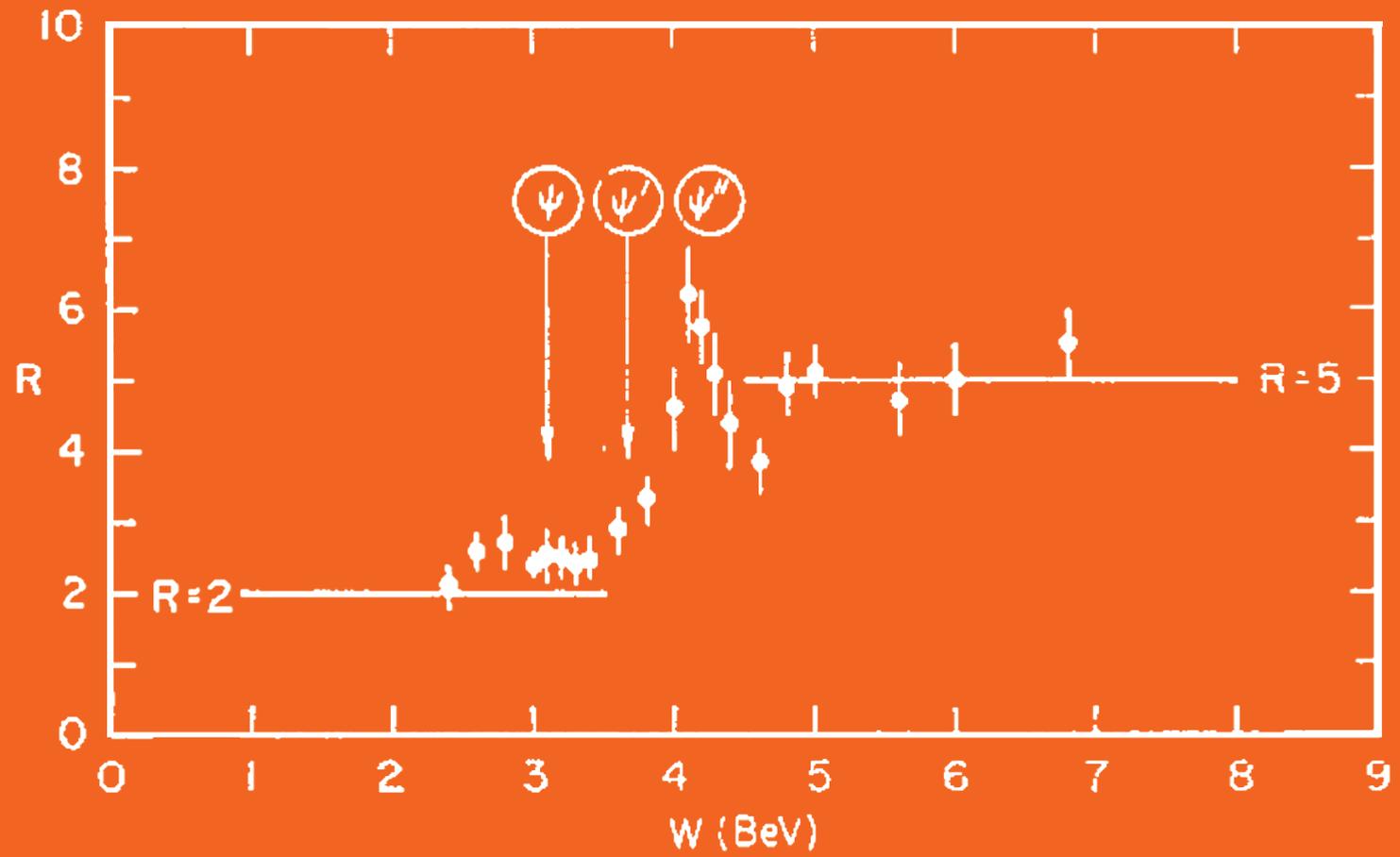
Understanding the spatial structure of a molecule is an important factor in determining how it functions chemically and physically. Weizmann Institute scientists developed a new imaging method that can elucidate the structure of various molecules on the basis of a phenomenon known as a "Coulomb explosion." The technique provides geometrical pictures of single molecules without requiring any prior hypotheses. This made it possible to determine several previously unknown molecular structures.

The researchers have also applied this method to examine the helical direction of molecules, to see if they have a right-handed or a left-handed helix-like structure. This property of left- or right-handedness in molecules is of great importance in industry, the life sciences and drug development.



100 Milestones in Physics at the Weizmann Institute of Science





The Fifth and Sixth Quarks **1975**

Until 1974, all of the known phenomena in elementary particle physics could be explained by the existence of three particles, named quarks, and four additional particles, called leptons. Combinations of quarks make up approximately 100 different particles, including the proton and the neutron. The four leptons were the electron, a heavier version of the electron, and two elusive, neutral particles called neutrinos. At the end of 1974, circumstantial evidence pointed to a fourth type of quark, but all attempts to provide direct evidence for the new quark's existence came to naught. Moreover, a number of unexplained phenomena were showing up in experiments. An Institute physicist proposed a solution that explained all of the anomalies as well as the reason for the absence of clear and direct evidence for the existence of the fourth quark. According to this theory, the fourth quark does indeed exist, along with two additional quarks called "top" and "bottom." There are also two extra leptons – six quarks and six leptons in all. The confusion in the experimental results arose from the multiplicity of effects and particles. Another round of experiments was required to resolve all the pieces of the puzzle. All of these quarks and leptons have been discovered in experiments over the last few decades. And the accepted framework, known as the Standard Model of elementary particles, is now based on six quarks and six leptons.

1975

## Nondestructive Testing

Weizmann Institute scientists developed a holographic system for nondestructive, real-time tests of such industrial components as aeronautics parts. Holography is an imaging method based on “freezing” a sample through wave interference scattered from the surface of a three-dimensional object.

The holographic system developed at the Institute maps – accurately and in real time – the weak points in the object being tested. This mapping is conducted by applying limited pressure on the object without causing any damage to it.

