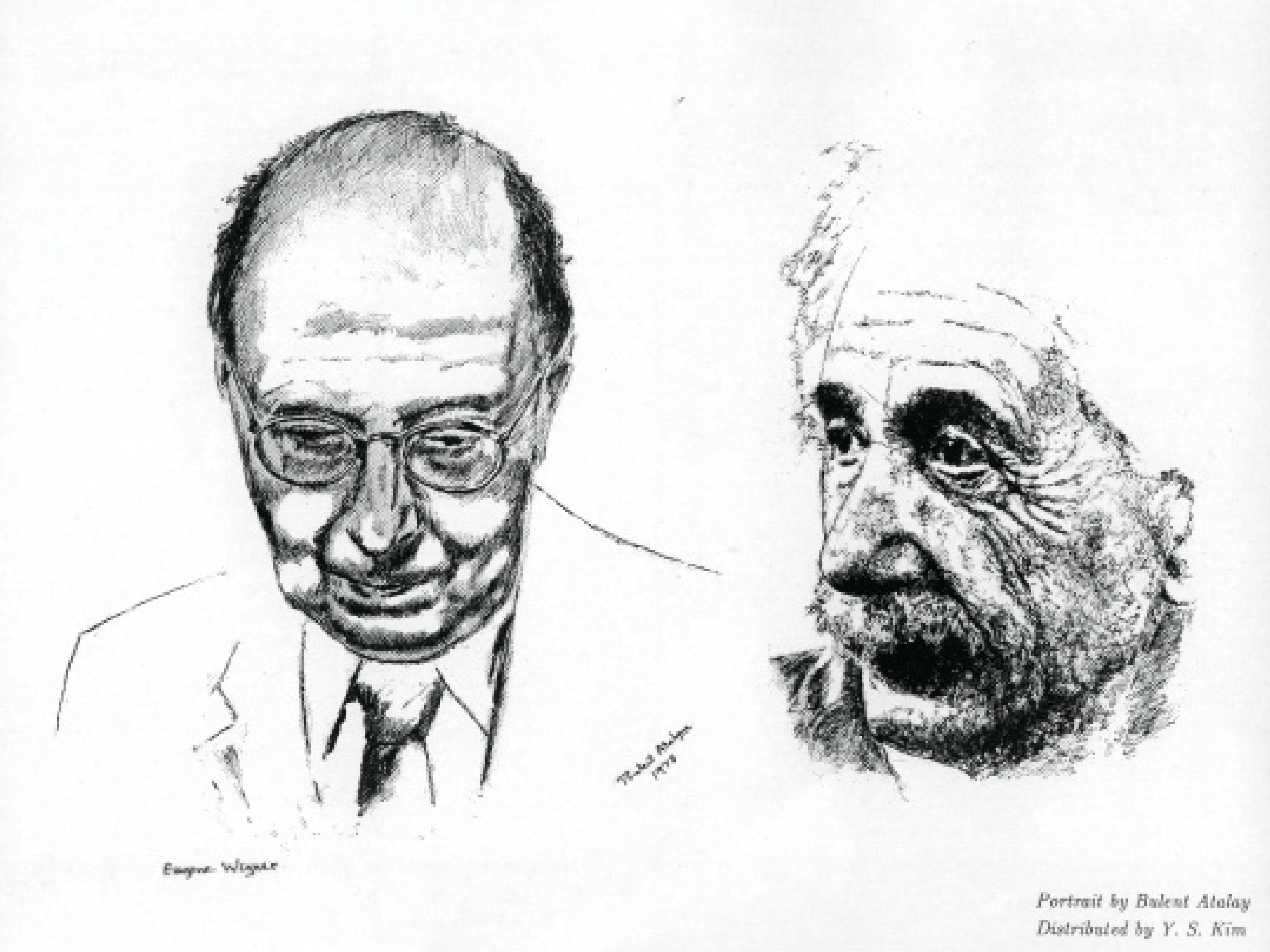
Remembering Eugene Wigner and Pondering his Legacy

László Tisza

We celebrate the centenary of Wigner. He was of the “quantum age” of Heisenberg and Pauli. Yet in 1925 the latter were leading figures of the Copenhagen School while Wigner graduated as chemical engineer in Berlin. The Hungarian physical-chemist Michael Polanyi was among his mentors.



Wigner and Einstein

After graduating Wigner was back in Budapest in the tanning factory where his father was director. He felt frustrated, but Polanyi came to the rescue by arranging an invitation to Berlin in x-ray crystallography.

Wigner resumed attendance at the physics colloquium and felt great attraction to QM. The factory had been a dead-end, but chemical training and his sensitization to mathematics in school and by his friend Johnny von Neumann were positive influences.

Dr. László Rátz – profesor of mathematics at gimnasium

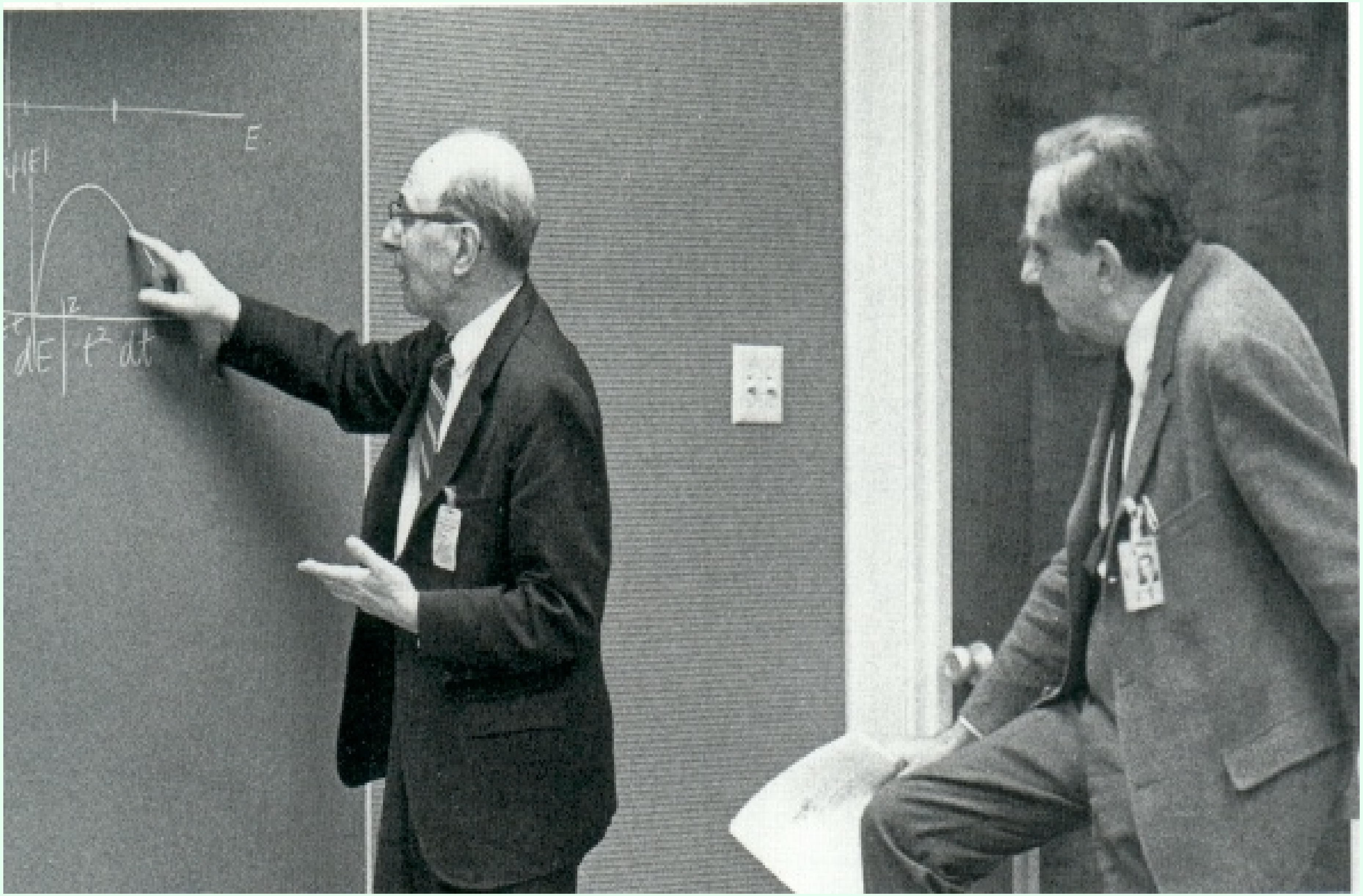
QM was a novel confluence of physics, mathematics and chemistry. (See papers November 1977 "Fizikai Szemle".)
Wigner drifted towards physics. When he was ready to work in QM, the foundation was ready for many applications.
Wigner followed up in his own style.
Eventually he had over 300 papers in physics, chemistry and pure mathematics.

Wigner's life coincided with the 20th century. During this period the relation of the mentioned disciplines has changed radically and Wigner was active in this change. Instead of details of his papers I would sketch out these changes and point at Wigner at all the junctures.

What was the status of chemistry when Wigner began? The tanning factory was not the whole story. John von Neumann and Edward Teller were also directed toward chemical engineering by their fathers. Mathematics and physics did not seem like practical careers. Chemistry did. The critical role of nitrogen fixation for the Central Powers' ability to pursue World War I was well known. Fritz Haber received the Nobel in 1918 for this achievement.

Neumann, Wigner and Teller left chemistry for mathematics or physics. They moved from an empirical craft, chemistry, toward a physics based on mechanics penetrated by subtle mathematics.

An alternative view of the events was that chemistry changed from an empirical craft to a discipline increasingly penetrated by mathematical physics. Wigner contributed to this process.



Wigner discusess beta decay wits Teller

Wigner's chemical engineering training prepared him for his role in the Manhattan Project, where he was in charge of constructing the plutonium producing Hanford facility. He surprised the Dupont people that he was a chemical engineer and it was their cooperation that upgrade traditional techniques to include nuclear effects. Wigner became the foremost pioneer of nuclear engineering.

Wigner's background also shaped his contribution to fundamental QM. X-ray crystallography drew him to symmetry. Combined with his liking for mathematics this culminated in a program of applying the theory of group representations to atomic spectroscopy. His papers in 1927-29, some of them with Neumann, are seminal in the field.

At that time most physicists disliked group theory, referred to as"Gruppenpest". Most classical physicists expected infinitesimal analysis to be the natural mathematics for all of physics, with priority for the differential equations of Newtonian mechanics. It was a widely held assumption that this must be how mathematics is to enter microphysics. One of the reasons that QM is still not accepted with complete assurance is that this is not the way to go.

One of the new ways is provided by group theory. Although the rotation group is continuous, the theory of representations deals with a discrete aspect. This theory is based on a highly esoteric link between discrete and continuous mathematics and one of the non-Newtonian entry ports for mathematics into QM. Neumann informed Wigner on this, culminating in the book "Group Theory & Application to the QM of Atomic Spectra". 1931.

This was not the first book on the subject, but Wigner's pedagogical effort was much appreciated. He helped break the prejudice against groups. It is instructive to recall some history. At the turn of the 20^{th} century spectroscopy was most mysterious. Spectra suggest subtle regularities expressed in code.

Bohr interpreted the code in terms of atomic structure, a discipline taking shape in the no-man's land between physics and chemistry. In the absence of proper mathematics Bohr started from Newtonian mechanics. Its defects are overcome by corrective prescriptions (quantum conditions). The loosening up of rigor made it plastic to become a theory of structure.

Bohr celebrated for extension of physics, but criticized for lack of math rigor. Structures led to their classification, to taxonomy and this seemed alien. Heisenberg lectured in 1925 in Cambridge, a title in the Cavendish was "On Term-zoology and Zeeman-botany." (Max Jammer, Conceptual Development of Quantum Mechanics, p.229.) "Botany" did not catch on, but every one used "zoology" for spectroscopy.

Condescension due to substandard mathematics, and "taxonomy good enough for zoologists but not for us". Actually, taxonomy was part of chemistry. The Periodical Table was taxonomical and Bohr and of Pauli made its theory.

Invoking "zoology" instead of "chemistry" was a bizarre prejudice ignoring growing ties of 19th century physics and chemistry. (Blind spot Copenhagen shared with Einstein It kept them from resolving their dispute). After QM the critique of poor mathematics was met. Group theory was high-powered and dealing with taxonomy.

"Zoology" survived for many years. Condescension was less than ever warranted. Since mid-19th century the use of spectroscopy raised chemical analysis to an unprecedented subtlety and scope. Stellar composition came "down to earth". Taxonomy advanced from "zoology" into a hard discipline. Historians take note!

Although Wigner's book was confined to atomic spectroscopy, he authored group-theory papers also on molecular spectra, solid state and nuclear physics. His contribution to symmetries, particularly in the context of nuclear physics was awarded the Nobel Prize in 1963. My lack of competence in nuclear physics keeps me from discussing the highlights of his principal achievements along these lines.

I turn instead to the rules of application of rigorous mathematics to physics, even more characteristic of his work. There are not many physicists for whom mathematics has intrinsic value, rather than being a useful tool. The advent of QM vastly extended the mathematical arsenal routinely used by physicists.

Everyone learned to deal with the eigenvalues of linear operators that can be transformed to diagonal form. Wigner's group-theoretical spectroscopy brought to an ultimate perfection the mathematatization of atomic structure.

Wigner's book on group theory dealt only with non-relativistic QM, it was plausible to examine the Lorentz group (LG). This case had been discussed by Dirac, but Wigner started out on his own in a highly sophisticated paper aiming at the classification of differential equations of elementary particles. (See Ann. Of Mathematics 1939.) The LG gave rise to purely algebraic complications, which Wigner handled by a highly abstract method of modern algebra.

The mathematical formalism of Wigner's paper is based on a representation space that is utterly different from that of Dirac's relativistic theory of the electron. There are also many other choices in the literature. It would be interesting but too technical for me to examine now an objective preference among alternatives within this specific context.

I prefer to raise this specific problem to a more general level. Is the choice of math a matter of subjective preference or could we be guided by objective criteria?

This is a program with a philosophical flavor and Wigner has a paper in this category: "The Unreasonable Effectiveness of Mathematics in the Natural Sciences." Comm. in Pure and Appl. Math. 13, No.1 1960; reprinted in Wigner, Symmetries and Reflections, Indiana U. Press, Bloomington & London, 1967, p 222.

This is an often reproduced and widely read paper; it has great charm with a sense of humor. It is utterly free of jargon, but has a complex message. First "mathematics is effective in the natural sciences". This important message is not new. It was advanced by Newton, but it is questionable why this should be "unreasonable"? Wigner is known to insist on what is "reasonable". What should we make of his use of "unreasonable" in title paper?

A theory seems unreasonable if it conflicts with traditional common sense. The theory will be "placed on probation". Many theories fall by the wayside and are happily forgotten. Occasionally "unreasonable" theories stubbornly persist.

The “unreasonably” moving earth of Copernicus forced us to abandon the "fixed earth" idea as the relativity of motion was incorporated into a convincing Newtonian mechanics. Our horizons are widened as we grow out of the delusions of early vision.

Today QM has the potential of Copernican liberation. It is essential for our scientific technological infrastructure, yet according to a well-reasoned recent study it is still paradoxical. (F. Laloë, Am. J. Phys, June 2000).

To achieve a Copernican liberation we have to identify the obsolete prejudice at the root. At its birth QM was accepted to be paradoxical. It was not noticed that a Copernican liberation comes about only if the temporary paradox is eliminated as an ancient dogma is abandoned.

Wigner, still within the *zeitgeist*, plays with the possibility that paradox is permanent. He sees the superior qualities of QM and also the flaws of its foundations. He concludes "The miracle of appropriateness of the language of mathematics or the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve.”

This is a "cheerful note" to comfort the pioneer establishing a new bridgehead even if he had to violate “common sense”. Yet, in another sense Wigner endorses a lowering of standards in the association of mathematics with experience. This is in contrast with his austere standards for using mathematics which dictated the motto: "and it is probable that there is some secret here which remains to be discovered." - C. S. Peirce.

This motto challenges us to accept paradox only as a temporary emergency and to integrate the new discoveries into a coherent acquisition.
If QM cannot be harmonized with tradition then I interpret Peirce's secret as a suggestion to harmonize tradition with QM by ridding it from its obsolete dogmatic elements.

Scholars have given due attention to the axiomatics of the Principia and to the paths from precursors to Newton. Little attention is given to Newton as the founder of all of mathematical physics and his connection to Einstein. See, Tisza: The reasonable effectiveness of mathematics in the natural sciences, in Experimental Metaphysics, R. S. Cohen, et al. (eds.) 1997 Kluwer. An obvious take-off on Wigner and sees behind his ambivalence a champion of reason.

These are my paper’s main points. The basic axiom of Newtonian mathematical physics is in the Preface of the Principia: rational mechanics ought to address "motion" with the same precision as geometry handles the size and shape of idealized objects. He demonstrated this expectation by producing the mechanics of the Principia. Newton's combination of empiricism with mathematics is basic. Yet, the concept of "motion" is more than rigid translation.

Newton favored the exclusive application of rigid translations, even for atoms. Einstein concurred. The failure of this idea for the Rutherford atom led to the "breakdown of classical physics". Yet there is an out. Motion can be also spinning and undulation.

In his Optics Newton inferred from his own experiments that light consists of corpuscles that perform undulatory motion. True, he considered his light particles phenomenological. Moreover there was no mathematics for light particles.

Newton does not address the key question whether light particles are identical to the point masses of Newtonian mechanics? Yet it is obvious that the particles of the Optics are destroyed and reconstituted into other structures; we have chemistry.

There is an archetypal difference between the particle concepts of the Principia and the Optics. This was never explicitly acknowledged, yet beginning with Faraday and Maxwell a branch of classical physics emerges that leans more on chemistry than mechanics.

Neither of these reduces to the other, but their joint application yields extraordinary results in 1859 Bunsen and Kirchhoff joined chemical analysis with spectroscopic measurements. The discovery that all the stars are made of the same elements as the earth was easily the largest extension of knowledge ever attained in a single step.

The epistemology of this measurement is entirely different from the Newtonian prediction. Random steps lead to precise knowledge. God does play dice and everyone wins.

Simultaneously with spectrum analysis, the kinetic theory began. The bifurcation of classical physics into mechanical and chemical branches was established, but many of the Greats contributed to both. A crisis developed as atomic physics was opened up. The mechanical branch failed, chemistry cannot be reduced to mechanics, but the two can be jointly used to unparalleled advantage.

In the J. of the Unity of Science I/1 (1988) 5, reprinted in Fizikai Szemle, 92, p. 436 (1992) Wigner wrote: "We can be proud of the unification of physics and chemistry that happened in our century."

The famous Martians

Szilárd Leó

Wigner Jenő

Neumann János

Teller Ede

Polányi Mihály