Robinson, Abraham | Encyclopedia.com

(*b*. Waldenburg, Germany [now Walbrzych. Poland], 6 October 1918; *d*. New Haven, Connecticut, 11 April 1974)

mathematics, logic, aerodynamics.

Abraham Robinson was the second son of Hedwig Lotte Bähr and Abraham Robinsohn. His father, a scholar and secretary to the Zionist leader David Wolffsohn (and curator of the papers of Wolffsohn and Theodor Herzl), died in 1918 before Abraham was born. His mother, a teacher, moved to her parent’s home in Waldenburg and later settled in Breslau, where she found work with the Keren Hayesod (the Zionist organization set up to aid the emigration and settlement of Jews in Palestine).

In 1933, as the National Socialists were beginning their attacks on Jews in all walks of life, the Rob-insohns emigrated to Palestine. There, in Jerusalem, Robinson finished his secondary education and entered Hebrew University in 1936, where he studied mathematics with Abraham Fraenkel and Jakob Levitzki, as well as physics with S. Sambursky and philosophy (especially Leibniz) with L. Roth. In 1939 Robinson won a French government scholarship to the Sorbonne, where he studied in the spring of 1940 until the German invasion of France in June forced him to flee. Making his way to the coast on foot and by train, he managed to reach Bordeaux, where he embarked on one of the last boats to leave France with refugees for England.

Having resettled in London, Robinson soon changed the spelling of his name (dropping the “h” from Robinsohn). In 1940 he enlisted with the Free French Air Force, and from 1942 to 1946 served with the Royal Aircraft Establishment in Farnbor-ough, where he was a scientific officer specializing in aircraft structures and aerodynamics, particularly in supersonic wing theory. During the war he met Re nee Kopel, an actress and fashion designer from Vienna; they were married on 30 January 1944, exactly one year after they met.

In light of the success of his work in aerodynamics at Farnborough, Robinson was offered a position in 1946 as senior lecturer in mathematics at the newly founded College of Aeronautics at Cranfield. Later that year Hebrew University awarded him an M.Sc. degree, primarily for the high-level scientific research he had done during the war. By then, thanks to his technical publications, Robinson had come to be regarded as one of the world’s authorities on supersonic aerodynamics and wing theory. As a result, he was invited to serve as a member of the Fluid Motion Committee of the Aeronautical Research Council of Great Britain.

Robinson returned to the study of advanced mathematics in the late 1940’s, enrolling as a graduate student at Birkbeck College, University of London. Working with Roger Cooke, Paul Dienes, and others, he received his Ph.D. in 1949 for a dissertation on the metamathematics of algebraic systems (published as a book in 1951). This was a pioneering work in model theory. Subsequently Robinson’s many contributions to the study of relations between axiom systems and mathematical structures helped to provide the classic foundations for the subject.

It was largely on the strength of his work in aerodynamics that Robinson was offered a position in 1951 as associate professor of applied mathematics at the University of Toronto, where he succeeded Leopold Infeld. Increasingly, however, Robinson’s research concentrated on pure mathematics. One of the most important early successes of his application of model theory to algebra was a model-theoretic solution (published in 1955) of Hilbert’s seventeenth problem, for which he achieved a considerably simpler solution than the original algebraic one given by Emil Artin in 1927.

After six years in Canada, Robinson received an offer of the chair of his former professor, Abraham Fraenkel, at Hebrew University in Jerusalem. This proved irresistible, and the Robinsons left Canada for Israel in 1957. There Robinson’s work was increasingly devoted to algebra and model theory. It was during this period that Robinson found a model completion for the axioms of differential fields, which then served as models of the “closure” axioms associated with this completion. Angus Macintyre said of this accomplishment, “It would be appropriate to say that he *invented* differentiably closed fields.”[1]

Robinson spent the academic year 1960–1961 as a visiting professor in the department of mathematics at Princeton University, where he had the inspiration for his best-known discovery, nonstandard analysis. In the spring of 1961 he also visited the department of philosophy at the University of California at Los Angeles; a year later UCLA succeeded in negotiating a joint appointment for Robinson as professor of mathematics and philosophy, a position he held from 1962 to 1967. There the chance to build a program in logic where he could teach graduate students and interact with a large faculty having diverse interests proved extremely productive for Robinson. While he was at UCLA, he began to develop in earnest the basic features of nonstandard analysis.

The last academic move Robinson made was in 1967, when Yale University appointed him professor of mathematics; after 1971 he was Sterling professor. There the department of mathematics provided a congenial and stimulating environment where Robinson's talents as a teacher flourished, as did his publications. Late in 1973, at the height of his career, he was diagnosed as suffering from incurable cancer of the pancreas. In less than six months, at the age of fifty-five, Robinson died at Yale University Hospital.

In the course of his prematurely curtailed career, Robinson wrote more than 135 articles and 9 books. He held a number of visiting positions, including appointments at Paris, Princeton, Heidelberg, Rome, and Tubingen, as well as at the California Institute of Technology, the Weizmann Institute, and St. Catherine's College, Oxford. From 1968 to 1970 he served as president of the Association for Symbolic Logic. In 1972 Robinson was made a fellow of the American Academy of Arts and Sciences, and in 1973 he was awarded the Brouwer Medal by the Dutch Mathematical Society. The following year he was elected (posthumously) to membership in the U.S. National Academy of Sciences.

Aerodynamics . At the Royal Aircraft Establishment in Farnborough, Robinson not only tutored himself to pass examinations in aeronautical engineering but also took flying lessons in order to complement his theoretical knowledge of structures and aerodynamics with some hands-on experience. At first he dealt with fundamental problems related to structural weaknesses in aircraft design; development of the jet engine toward the end of the war, however, not only greatly increased aircraft speeds but also made questions of supersonic flow of considerable theoretical and practical interest. In the latter field Robinson made essential contributions to the understanding of delta-form wings.

After the war, having established himself as an expert on aerodynamics, Robinson was invited to join the staff of the newly founded College of Aeronautics at Cranfield, just outside London. There he taught mathematics, and by 1950 had been named deputy head of the department of aerodynamics. Although he had just begun to write a book on wing theory with a recent graduate of the college, J. A. Laurmann, Robinson left Cranfield in 1951 to accept an offer from the University of Toronto. From then on, although his interests were drawn more and more to logic and model theory, he continued to read papers at aerodynamics symposia in Canada, and to publish papers of considerable interest and sophistication on wave propagation and structural analysis. In 1956 Robinson was promoted to professor, the same year in which his book on *Wing Theory* (coauthored with Laurmann), was published.

Algebra . Robinson's career as a mathematician was typified primarily, but not exclusively, by deep research into the interconnections between algebra and symbolic logic. The first two papers he wrote (while still a student at Hebrew University) were on the independence of the axiom of definiteness in Zermelo-Fraenkel set theory and on nil-ideals in ring theory. His first book, based upon his dissertation (University of London, 1949), *On the Meta-mathematics of Algebra* (1951), was a pioneer in model theory and the application of mathematical logic to algebra. Many of Robinson's most important contributions to modern mathematics concern fertile hybridizations of algebra and model theory. In algebra, for example, he introduced model completeness, and in model theory he developed the idea of differentially closed fields.

Model Theory. Model theory studies the relationship between a set of axioms and various models that may satisfy the axioms in question. Among early-twentieth-century proponents of model theory, Löwenheim, Skolem. Gödel, Malcev, Tarski, and Henkin all made important contributions before Robinson's first book. *On the Metamathematics of Algebra*, appeared in 1951. This book set the tone for much of Robinson's later work, and served as a guiding force in the development of model-theoretic algebra in the decades after it was written.

One of the major tools Robinson developed was model completeness, which he introduced in 1955. This is basically an abstract form of elimination of quantifiers. It may also be regarded, in the study of algebraically closed fields, as a generalization of Hilbert's *Nullstellensatz*. Robinson's book *Complete Theories* (1956) developed the notion of the theory of algebraically closed fields and showed that real closed fields and modules over a field, among other familiar algebraic theories, are model complete. One of the most important examples of model completion in algebra is Robinson's 1959 discovery that the theory of differential fields of characteristic zero has a model completion: differentially closed fields of characteristic zero.

In 1970 Robinson developed another important method of constructing models based upon an extension of the earlier idea of model completion. This method, known as Robinson forcing, bears a close similarity to the method of forcing in set theory introduced by Paul Cohen in 1963, The paper "Model Theory as a Framework for Algebra" provided an excellent introduction to the subject of forcing. Closely related, and also influential in the work of later mathematicians, was Robinson's development of generic and existentially closed models.

Nonstandard Analysis . Robinson's best-known discovery is nonstandard analysis, which provides a means of introducing infinitesimals, or "infinitely small" quantities, rigorously into the body of mathematics. The basic idea of nonstandard analysis makes use of model-theoretic concepts that provide for the first time, 300 years after its invention by Newton and Leibniz, a rigorous foundation for the differential and integral calculus using infinitesimals. But the great interest of nonstandard analysis for mathematicians is not foundational, nor is it due to the intuitiveness with which infinitesimals can be taught to students (which is considerable). What is impressive and of great utility is the power nonstandard analysis brings to the solution of difficult and significant mathematical problems.

The source of this strength is not merely the addition of infinitesimals to mathematics but lies in Robinson's use of model theory, which makes it possible to establish a fundamental connection between the set of real numbers **R** and the nonstandard model **R** * of **R** that contains the infinitesimals (as well as infinitely large nonstandard numbers). What Robinson established is the fact that **R** * is an elementary extension of **R** . In terms of Robinson's transfer principle, this means that the infinitesimals in **R** * behave like the real numbers in **R** .

Because of the extraordinary breadth of Robinson's knowledge, he was able from the beginning to apply nonstandard analysis with impressive results in many areas of mathematics. In the years following his death, more and more mathematicians have found that nonstandard analysis can be applied to great advantage in an increasingly large number of special areas. For example, important applications have already been made to functional analysis, number theory, mathematical economics, and quantum physics. Much of this work was first done by Robinson with colleagues or graduate students, many of whom have gone on to establish significant reputations in model theory and mathematical logic, including nonstandard analysis.

Arithmetic . Class field theory and Diophantine geometry were areas in which Robinson made especially significant contributions through applications of nonstandard methods. Here "enlargements" of algebraic number fields were the key insight—"enlargements" being considered as completions in a universal sense. Thus, in terms of mathematical logic, transfer principles are extremely powerful, and consequently they prove to be of great utility, as well as of great generality, in dealing with problems of arithmetic.

In the last decade of his life Robinson became increasingly interested in these questions, especially the extent to which nonstandard methods could serve to establish new results or improve old ones. His last major work was a nonstandard treatment, developed with Peter Roquette, of the finiteness theorem on Diophantine equations of Siegel and Mahler.

Computers . Robinson spent several summers in the early 1960's at the IBM Watson Research Center in Yorktown Heights, New York. There he collaborated with Calvin C. Elgot on a paper that developed a more realistic model of a digital computer (using programming languages with semantics) for random-access stored program (RASP) machines than that provided by a Turing machine. One major result they were able to establish was a proof that particular RASP machines could compute all partial recursive functions. This work was later extended to multiple-control RASP's with the capacity for parallel processing with programs able to handle computations in partial rather than serial order. Robinson coauthored a paper on the subject of "multiple control" with Elgot and J. E. Rutledge that was a pioneering work on the subject of parallel programming when it was published in 1967. Here the problem of programming highly parallel computers was treated formally, based upon a mathematical model of a parallel computer.

Character and Influence . Again and again, those who knew Abraham Robinson remarked on his capacity for "organic growth", especially his ability to bring together vastly different areas of mathematics and respond to new ideas and techniques that united them in his mind to produce fruitful and stimulating results. As Simon Kochen put it, ". . . his viewpoint was that of an applied mathematician in the original and best sense of that phrase; that is, in the sense of the 18th and 19th century mathematicians, who used the problems and insights of the real world (that is, physics) to develop mathematical ideas."[2]

Robinson was a man of great simplicity, modesty, and charm. He loved to travel and enjoyed meeting people. He studied ancient Greek, and was fluent in French, German, Hebrew, English, and several other languages. On various occasions he lectured in Italian, Portuguese, and Spanish.

Perhaps Robinson's overall character and significance as a mathematician were best captured by the logician Kurt Gödel, who at the time of Robinson's death said that he was a mathematician "whom I valued very highly indeed, not only as a personal friend, but also as the one mathematical logician who accomplished incomparably more than anybody else in making this logic fruitful to mathematics."[3]

NOTES

1. As reported by George B. Seligman in his "Biography of Abraham Robinson," in *Selected Papers of Abraham Robinson*, H. J. Keister *et al*., eds. (New Haven, 1979). I, xxiv.

2. Simon Kochen. "The Pure Mathematician. On Abraham Robinson's Work in Mathematical Logic," in *Bulletin of the London Mathematical Society*, **8** (1976), 313.

3. Kurt Gödel, in a letter to Mrs. Abraham Robinson, 10 May 1974; Robinson Papers, Sterling Library, Yale University.

BIBLIOGRAPHY

I. Original Works. A selection of Robinson's most important publications, including one of his earliest papers not previously published ("On Nil-ideals in General Rings," 1939), is in *Selected Papers of Abraham Robinson* H. J. Keisler, S. Körner, W. A. J. Luxemburg, and A. D. Young, eds., 3 vols. (New Haven, 1979). Readers should also consult the special historical and critical introductions in each volume. Robinson's papers, including correspondence and lecture notes, are in the archives of Yale University, Sterling Library, New Haven.

II. Secondary Literature. Joseph W. Dauben, "Abraham Robinson and Nonstandard Analysis: History, Philosophy, and Foundations of Mathematics," in William Aspray and Philip Kitcher, eds., *History and Philosophy of Mathematics* (Minneapolis, 1988), 177–200; Martin Davis. *Applied Nonstandard Analysis* (New York, 1977); W. A. J. Luxemburg, *Non-standard Analysis Lectures on A. Robinson's Theory of Infinitesimals and Infinitely Large Numbers*, 2nd, rev. ed. (Pasadena, Calif. 1964), and *Introduction to the Theory of Infinitesimals* (New York, 1976), with K. D. Stroyan; Angus J. Macintyre. "Abraham Robinson, 1918–1974," in *Bulletin of the American Mathematical Society*, **83** (1977), 646–666; George B. Seligman, "Biography of Abraham Robinson," in Robinson's *Selected Papers* (see Notes); and Alec D. Young, Simon Kochen, Stephan Körner, and Peter Roquette, "Abraham Robinson," in *Bulletin of the London Mathematical Society*, **8** (1976), 307–323.

Joseph W. Dauben