LEONARD ROTH

BENIAMINO SEGRE

Leonard Roth was a very distinguished mathematician whose academic life was devoted almost entirely to the study of algebraic geometry, following the methods of the Italian school. His main contributions to the subject concern problems of birationality and unirationality of algebraic manifolds, and the study of group varieties; much of his research continues to be of lasting significance.

He was an excellent and expert lecturer, a charming conversationalist, and maintained a wide range of interests—including the arts, music, history, literature and more general social matters. In all these subjects his knowledge was extensive and deep, in accordance with a high-minded concept of life that is succinctly set forth in the following extract from a passage on *Poetry and Geometry* taken from p. 153 of his book [**47**]:

" It is only too true that many men of science are wholly incapable of appreciating any form of art, while almost all artists and men of letters are blind to the beauties of mathematics. In fact, they can hardly conceive that such beauties exist. This state of affairs is one of the results of a bad system of education, which gives people a wrong outlook on life. We should not want to produce a race of men with one eye, or lacking a hand, or lame in one foot; we should rightly regard them as monstrosities. But the so-called educated person of today is nearly always a monstrosity of this sort, not in his limbs, but in his mind. It has all come about through the bad habit of shutting off one subject from another into a series of watertight compartments, with the result that the flow of our ideas has largely ceased. If we are to return to a better way of thinking and feeling we must break down these compartments. And the sooner the better."

This trenchant declaration also gives an idea of his excellent style and slightly paradoxical approach, as well as of the uncompromising attitude that he took up on most matters. Such a way of thinking was strangely coupled in him with a rare modesty and shyness—which may perhaps explain the fact that, during his lifetime, he did not obtain in Great Britain all the recognition, nor was offered the highest opportunities, that he undoubtedly deserved.

Leonard Roth was born in the London suburb of Edmonton on August 29th, 1904, the son of a merchant. His early life in London's East End was apparently not particularly happy, despite successes at school. His first academic inclination was towards the humanities; but he also showed a talent for mathematics, and this eventually led to his obtaining a scholarship to read mathematics at Clare College, Cambridge, in 1923. There he graduated in 1926, being placed in the first class, and he was declared a Wrangler in the Mathematical Tripos. He left a witty and moving description of the agony involved in this now superseded examination in a manuscript [**91**] which appeared posthumously. Although he probably never intended this to be published, it is nonetheless a delightful and fascinating source of information about mathematical life in Cambridge half a century ago, with vivid anecdotes about the great men of the time such as Forsyth and Littlewood.

Received 5 February, 1975.

[Bull. London Math. Soc., 8 (1976), 194–202]

LEONARD ROTH 1904–1968

Roth's research supervisor was the then Lowndean Professor of Astronomy and Geometry, H. F. Baker. The latter's masterly *Principles of Geometry* was evidently a great source of instruction and inspiration to Roth, and this influence shows unmistakably in his early work, particularly in his remarkable aptitude for applying synthetic arguments to algebraic manifolds in higher projective space.

His first appointment was as Demonstrator at the Imperial College of Science and Technology in the University of London; and there soon followed the award of a Rockefeller Research Fellowship, which enabled him to spend a year in Rome in 1930–31. This stay in Rome was indeed to prove most decisive for his future, not only because it offered him personal contact with the great Italian geometers of that time—Castelnuovo, Enriques, Levi-Cività and Severi—but also, more importantly for him, because he there met Marcella Baldesi, the only daughter of a socialist Member of Parliament at the time of the Fascist coup, whom he was to marry a short while later. She was a very lively and intelligent person with a passionate interest in music—she was an excellent pianist—and together they made a most wonderful couple. Such was their knowledge and awareness of the world about them that there were few things that could not be discussed with them without profit. When, a few years ago, they died together in a car accident, those of us who knew them could only comfort ourselves with the thought that life, for either of them, would have been unbearable without the company of the other—a great tribute to the mutual love and harmony that existed between them.

After his period in Rome, Roth's mathematical production gradually increased in scope, and went on intensely up to the end of his life, save only for a slackening during the war due to the various worries connected with that period, particularly the death of his mother and sister in the wreck of their house during an air raid on London. He was appointed an Assistant Lecturer at Imperial College in 1931, was promoted to a Lectureship in 1938, to a Senior Lectureship in 1946, and finally to a Readership in 1950. Moreover, he was frequently invited abroad to give talks and lecture courses on his researches and related subjects. In particular, he returned many times to Italy—to Rome, Milan, Padua, Turin, Genoa, Varenna—where his work and manner of presentation were highly appreciated, due in no small measure to his familiarity with the Italian language and his general rapport with the country, its culture and, of course, its mathematics; he made many friends and taught many pupils during these visits.

In 1965, Roth went to the University of Pittsburgh as a Visiting Professor, and he returned there at the end of 1967 with a permanent appointment as Andrew Mellon Professor of Mathematics. He was very happy to accept this position and was very popular with his colleagues there; his many-sided activities were much admired and his academic talent was much sought-after. On the day before the accident in which he and his wife lost their lives—which occurred on Thursday, November 28th, 1968—he had delivered two very popular lectures on "Cambridge Mathematicians". This cruel and sudden end of man and wife has been a sad loss for the world of culture and a tremendous shock for their many friends in Great Britain and abroad who knew of their great kindness and rare qualities. For myself, I shall never forget our long-standing close friendship dating from 1930—and particularly the warm welcome, continuous attention and generous hospitality that they showered on me and my family when I went to England as a refugee in April 1939.

By the turn of the first quarter of the present century, projective geometry had already been developing for well over a hundred years. It had given rise to many offshoots, notably the study of algebraic manifolds in higher space, with their many aspects—enumerative, purely geometric, birational and transcendental. Thus a great number of diverse chapters and methods of algebraic geometry had been gradually worked out, with many results as yet incomplete and awaiting further investigation.

A new trend in research was by then emerging, which had as its aim to unify and perfect these results and methods, at the same time giving them more solid foundations; this was in due course carried out by such authors as E. Noether, van der Waerden, Zariski, Weil, Hodge, Hirzebruch, Serre, Grothendieck and many others, often using brilliant new ideas from algebra and topology. This new trend, however, sometimes obscured the underlying intuitive aspects of the geometry and was not always appropriate for coping completely with some of the problems.

A second, and older, procedure still had its part to play. This retained the classical methods and concepts, but sought to extend their range of applicability. This procedure, however, was followed at that time by comparatively few people, since progress in it required great effort and a detailed knowledge of an enormous bulk of (sometimes fragmentary) results from a host of sources; and, it may be said, new results—even when difficult and requiring hard work—could often appear (wrongly) to be mere exercises or trifling generalisations.

Leonard Roth was a follower of this nowadays old-fashioned procedure and he pursued it throughout his life, showing tenacity and great skill in obtaining a large number of valuable results in many areas, as well as a considerable amount of precious experimental material. His gifts are also shown in the book **[49]**, written in collaboration with J. G. Semple, which appeared in 1949; this is a concise and incisive exposition of the first main developments in algebraic geometry, written with a refined geometric good taste and an appropriate degree of informality; no beginner can afford to ignore it since, within a comparatively small number of pages, it gives a clear account of a large number of essential methods and results.

A certain degree of informality may also be traced in all Roth's geometrical papers, together with an increasing neatness and depth. These papers contain the major part of his mathematical production, the residue consisting of a work of historical interest **[1]**, a note on differential equations **[44]**, a few reviews **[92, 93]** and obituary notices **[94, 95]**, and a book on probability **[39]**, written in collaboration with H. Levy, which is a comprehensive and masterly treatise in which the subject is expounded with a view to its applications, as well as linking together its many-sided features—historical, empirical, mathematical, logical, philosophical and psychological. He also wrote an excellent book on elementary geometry **[47]**, from which I have already quoted, to which schoolmasters would do well to pay more attention, on account of its original and keenly human approach—particularly nowadays, when the teaching of geometry tends sometimes to become unduly abstract and little concerned with the mathematical and cultural development of the pupil.

Roth's geometrical investigations complete and extend a great number of classical results due to the Italian school, especially Castelnuovo, Enriques, Fano and Severi. To explain them all in detail would take far too long, but a fairly good idea of the variety and interest of their subjects may be obtained from the list of publications given at the end of this notice and also, in greater measure, from Togliatti's " necrologio ", which appeared in *Boll. Un. Mat. Ital.*, (4) 3 (1970), pp. 326–332.† We shall

†Our list of publications is compiled from this " necrologio ", with the addition of **[47]**, **[70′]** and **[91]**.

therefore confine our attention to just some of his more important contributions, pausing only to remark that his geometrical investigations had a singular unity of purpose—even his minor papers, in which concrete constructions of interesting algebraic manifolds are obtained and investigated, sometimes put to decisive use in his later work.

Roth's first exertions were of a straightforward projective character, as appears for example from the papers **[2, 3, 4, 6, 11]** concerning the involution of pairs of points conjugate with respect to four general quadrics of S_4. Also from this period are a study **[9]** of certain V_{n-2} of S_n which extend Schur's twisted sextic curve; an investigation **[42]** concerning the maximum number of nodes attainable by primals of S_4 or S_5; and a short series of papers **[19, 14, 36, 37]** on surfaces of sectional genus 4, 5 or 6 and the projective classification of algebraic surfaces.

But Roth soon moved on to more difficult problems involving intersections and enumerative geometry, using Cayley's functional method and the correspondence principle. Thus in **[41]** a remarkable expression for the postulation of a multiple surface is obtained, and in **[40]** the arithmetic genus of a V_k in S_r is calculated as a function of its projective characters. Hence, by exploiting some of his earlier results on primals in four dimensions **[20, 29, 33, 34]** and by use of purely projective considerations, he gives in **[56]** a simple new proof of the relations of Pannelli and Severi connecting the invariants Ω_0, Ω_1, Ω_2, P_a and p_3 of a threefold.

It has to be remembered that, in the thirties, although the theory of algebraic curves and surfaces was in a quite satisfactory state, a general birational theory of algebraic varieties was still a distant objective. Even today, little is known of algebraic threefolds and their birational classification; and much of what we do know is due to Roth, as is evident from the lectures he delivered in Turin **[52, 72]**, Milan **[58]**, Genoa **[74, 79]**, Varenna **[77]** and Brussels **[81]**, and especially from the fundamental expository reports **[58]** and **[73]**, the second of which also contains (pp. 99–101) a list of interesting unsolved problems. (Another such problem is posed in the incomplete posthumous paper **[90]**.)

Roth's contributions to the birational theory of varieties may be roughly divided into three main categories: regularity and rationality criteria, the adjunction problem, and group varieties—three strongly interrelated themes. We now review them each in turn.

Interesting new examples and criteria for a surface to be regular or scrollar are given in **[23, 26, 27, 28, 30]**; particularly noteworthy are the results of **[28]**, where the different types of non-singular irregular surfaces of minimum order are obtained.

Simple but useful rationality criteria extending a well known one due to Enriques are established in **[76]**, where, among other things, it is shown that:

Given on a V_d defined in a field K a birational ∞^{d-k} system of varieties V_k, of index $\nu \geqslant 1$, if it is possible to determine rationally, on the generic V_k, a space S_h such that V_k is unirational in $K(S_h)$, then V_d is unirational. If, further, $\nu = 1$, and V_k is birational in $K(S_h)$, then V_d is birational.

As an application, it is proved in **[54]** that, if $r \geqslant \frac{1}{2}m^2 - 2$, the intersection of m ($\geqslant 2$) generic quadrics of S_{r+m} is unirational and representable upon an involution of order $2m-2$. Moreover, in **[57]**, by purely algebro-geometric methods and the preliminary study of linear congruences of k-spaces in a given r-space, several remarkable properties of Grassmannians and of Schubert varieties are established or re-obtained; in particular, for the section of a Grassmannian by a general linear space of sufficiently high dimension (and also for the sections by general primals of certain low orders), the uni- or birationality is obtained together with the respective representation.

Fano's V_3^{2p-2} of S_{p+1} and their generalizations to V_r^{2p-2} of S_{p+r-2} are deeply investigated in [**38**, **43**, **48**, **50**]. So-called semi-rational types among the former are considered in [**43**]; while in [**48**] it is shown that these V_r are all rational if $p > 6$, $r > 3$ and also if $p = 5$, $r > 4$ or $p = 6$, $r = 5$. The papers just quoted and [**73**], while criticizing some of Fano's basic work, constitute additions to it deserving full attention and suggesting further investigations.

Interesting rationality questions for V_3 containing a linear system of surfaces of linear genus $p^{(1)} \leqslant 1$ or a congruence of rational or elliptic curves are dealt with in [**62**] and [**60**] respectively, thus extending classical criteria for an algebraic surface to be birational or scrollar.

Similar investigations for V_r containing suitable systems of rational, elliptic or hyperelliptic curves are carried out in [**51**, **55**, **67**, **68**], involving at the same time some points of contact with the other two themes mentioned earlier. For example, in [**68**], the existence of rational curves on V_3 leads to questions about unisecants and concerning the adjunction process. Although [**67**] affects only threefolds and may be considered as a sequel to [**65**], [**66**] gives results and partial classifications to do with certain Abelian varieties, obtained by algebro-geometric methods more illuminating than the usual transcendental procedure (which throws little light on the underlying geometry).

Paper [**53**] investigates the threefolds which are completely regular, with base number 1 and such that the process of adjunction terminates after a finite number of steps. Among other things, by using [**50**, **51**, **52**] it is shown that such threefolds are of 16 different kinds, 14 of which are unirational or birational in a suitable extension of their ground fields.

Completely regular threefolds with all their plurigenera zero, on which the adjunction process terminates, are also studied in [**61**] with a view to establishing whether they are strictly unirational or not. This has some analogy with what is done in [**59**] for completely regular threefolds possessing an effective anticanonical system of positive order, which implies that the adjunction process certainly terminates; such threefolds are classified, some of them being birational, some unirational but not birational, while others are not unirational. This implies that a unirational threefold is "in general" non-birational, while interesting examples of irrational involutions are incidentally obtained in any linear space of dimension $\geqslant 3$.

A rough classification of the algebraic varieties of any dimension d which admit an anticanonical system is given in [**86**], where a number of properties and unirationality criteria are established for them, acquiring particular significance for $d = 2, 3, 4$.

The case $d = 3$ is also considered in [**64**] which, among other things, contains an interesting example of an irregular threefold, not containing a pencil of rational surfaces, on which the adjunction process terminates.

As a sequel to [**59**], it is shown in [**78**] that, if an irregular threefold V contains an irreducible anticanonical system $|A|$ free from base points, then the generic A is a Picard surface. Moreover, V contains a rational congruence of elliptic curves, to which $|A|$ belongs, and an elliptic pencil of rational surfaces which are unisecant to the congruence; the geometric genus and plurigenera of V are all zero, and the arithmetic genus and superficial irregularity are equal to unity. Finally, if the elliptic pencil is free from fundamental surfaces, then V (with a terminology explained later on) is an elliptic threefold of determinant unity.

An ample survey of the algebraic threefolds of absolute curvilinear genus unity is made in [**65**], where other important contributions to the difficult problem of classifying algebraic threefolds are obtained. In fact, the above varieties are there divided into four main classes, for each of which a number of interesting properties and examples are thoroughly proved and investigated.

The group varieties assume for many reasons a central position in algebraic geometry, as appears for instance from the two Picard varieties classically attached to any irregular algebraic variety (cf. for example [**84**], §4); but they are also of great interest in themselves. Little is known even today about the algebraic varieties admitting an infinite *discontinuous* group of birational automorphisms; hence [**46**] has to be particularly noticed, notwithstanding its exploratory character, since—following a model due to Severi—it connects the study of such varieties with the determination of the linear automorphisms of certain homogeneous polynomials with integer coefficients furnished by the theory of the base.

The situation is quite different with respect to *continuous* groups, whose study leads in the well-known manner to Abelian varieties W_p, i.e. p-dimensional varieties the co-ordinates of whose generic point are expressible as Abelian functions, of genus p, of p independent complex variables u. Such a W_p has a rank r ($\geqslant 1$), given by the number of distinct points in a primitive period parallelepiped of the real ($2p$)-dimensional Euclidean space, of the variables u, which correspond to the generic point of W_p; and W_p is called a Picard variety—to be denoted by V_p—if, and only if, $r = 1$ (which is the only case occurring for $p = 1$, when V_p becomes an elliptic curve). A Picard variety—supposed, as it is not restrictive, to be non-singular—is characterized by the property of admitting a *completely transitive* continuous Abelian group of ∞^p automorphisms. Since Poincaré, it was known that a general V_p, i.e. a V_p having general moduli, contains no Picard subvariety V_q ($0 < q < p$); however if such a V_q exists, in which case V_p is said to be special of type q (or $p-q$), then on V_p there is a congruence $\{V_q\}$, as well as a second congruence $\{V_{p-q}\}$ of Picard varieties V_{p-q}.

The above situation was studied under more general circumstances by Roth, with the introduction [**70**] of what he calls pseudo-Abelian varieties, special cases of which had already been investigated by Dantoni [*Annali di Mat.*, (4) 24 (1945), 177]. A pseudo-Abelian variety of type q is a W_p which admits a continuous Abelian group G of ∞^q automorphisms ($0 < q < p$). Then the trajectories of G constitute a congruence $\{V_q\}$, the generic member of which is irreducible and birationally equivalent to G; moreover, W_p contains a Picard congruence $\{V_{p-q}\}$ of ∞^q birationally equivalent V_{p-q}, cutting the generic V_q in sets of an involution i_d without coincidences, where $d = [V_q\, V_{p-q}] \geqslant 1$ is the so-called determinant of W_p. This situation allows one to map W_p on an analogous d-ple product manifold, of determinant unity, in such a way that the coincidence locus (if any) consists of a number of varieties (possibly of different dimensions) generated by trajectories V_q; hence a lower limit to the superficial irregularity of W_p and the various canonical systems may be obtained, incidentally showing that all the canonical invariants of W_p are zero.

The study of Abelian and pseudo-Abelian varieties is amply pursued by Roth in several further papers [**75, 80, 81, 83, 84, 85, 87, 88**], in connection too with the properties of Severi's quasi-Abelian varieties and the analysis of possible torsions. The picture becomes suitably integrated by the introduction of interesting special classes, like those of the para-Abelian [**69**] and of the improperly Abelian varieties [**71**].

Among the numerous results thus obtained, the following may be mentioned:

(i) Any pseudo-Abelian W_p admits (effective or virtual) canonical varieties of dimension $h = 0, 1, ..., p-1$ whose orders are zero.

(ii) Any irreducible p-dimensional algebraic variety of superficial irregularity p, with a pure canonical hypersurface of order zero and not containing a congruence of irregularity p, is a Picard variety.

(iii) Every Abelian W_p having some positive plurigenus and superficial irregularity q with $0 < q < p$ is quasi-Abelian of type q, and so it may be represented parametrically by means of algebraic functions of Abelian functions of genus q and other Abelian functions of genus $p-q$.

(iv) Every group variety having some positive plurigenus is either Picardian or pseudo-Abelian.

Special attention has been paid by Roth to the case of varieties of dimension $p = 3$, which was also effectively dealt with by R. Hall [*J. London Math. Soc.*, 29 (1954), 419]. A W_3 which is not Abelian may only be a pseudo-Abelian variety of type $q = 1$ or $q = 2$; and these two cases have been investigated in [**66**], [**63**], the W_3 then being called elliptic or hyperelliptic respectively. We confine ourselves to noticing a result for the latter varieties, according to which a hyperelliptic threefold contains a congruence of rational curves if, and only if, its 12-genus P_{12} is zero. Moreover, in [**75**], it is shown that the Picard threefolds are the only threefolds which admit a finite continuous group of automorphisms and for which the canonical surface and canonical curve are both effective of order zero.

I am most grateful to Dr. Florencio Gonzales Asenjo of Pittsburgh University for his kind help in tracing the manuscripts of the papers [**89**, **90**, **91**], which appeared posthumously. I believe Roth left many other unpublished and valuable manuscripts, not all of a mathematical character, ranging from a study on Brahms and a detective story to a work on topics in advanced geometry dealt with from an elementary point of view. I would be most interested if any of this work could be traced—perhaps with the help of the London solicitor through whom the Roths left all their belongings to charity.

PUBLICATIONS OF L. ROTH

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