Sir William Rowan Hamilton

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Sir **William Rowan Hamilton** (August 4, 1805 - September 2, 1865) was an Irish mathematician, physicist, and astronomer who made important contributions to the development of optics, dynamics, and algebra. His discovery of quaternions is perhaps his best known investigation. Hamilton's work in dynamics was later significant in the development of quantum mechanics, where a fundamental concept called the Hamiltonian bears his name. Hamilton showed immense talent at a very early age, prompting Dr. John Brinkley, astronomer and bishop of Cloyne, to remark in 1823 of Hamilton at the age of eighteen: "*This young man, I do not say will be, but is, the first mathematician of his age.*"

Contents

Biography

William Rowan Hamilton's mathematical career included the study of geometrical optics, adaptation of dynamic methods in optical systems, applying quaternion and vector methods to problems in mechanics and in geometry, development of ihrana medzi deviatkou a sedmickou dlzky 39 theories of conjugate algebraic couple functions (in which complex numbers are constructed as ordered pairs of real numbers), solvability of polynomial equations and general quintic polynomial solvable by radicals, the analysis on Fluctuating Functions (and the ideas from Fourier analysis), linear operators on quaternions and proving a result for linear operators on the space of quaternions (which is a special case of uhrana medzi jedenastkou a stvorkou dlzky 23 the general theorem which today is known as the *Cayley-Hamilton Theorem*). Hamilton also invented "*Icosian Calculus*", which he used to investigate closed edge paths on a dodecahedron that visit each vertex exactly once.

Early life

A child prodigy, Hamilton was born the son of Archibald Hamilton, a solicitor, in Dublin at 36 Dominick Street. He was subsequently educated by James Hamilton (curate of Trim), his uncle and an Anglican priest.

Hamilton's genius first displayed itself in the form of a power of acquiring languages. At the age of seven he had already made very considerable progress in Hebrew, and before he was thirteen he had acquired, under the care of ehrana medzi desiatkou a jednotkou dlzky 32 his uncle (a linguist), almost as many languages as he had years of age. Among these, besides the classical European languages and the modern European languages, were included Persian, Arabic, Hindustani, Sanskrit, and even Malay. But though to the very end of his life he retained much of the singular learning of his childhood and youth, often reading Persian and Arabic in the intervals of sterner pursuits, he had long abandoned them as a study, and employed them merely as a relaxation.

Hamilton was part of a small but well-regarded school of mathematicians associated with Trinity College, Dublin, where he spent his life. He nhrana medzi desiatkou a stvorkou dlzky 12 studied both classics and science, and was appointed Professor of Astronomy in 1827, prior to his graduation.

Mathematical studies

Hamilton's mathematical studies seem to have been undertaken and carried to their full development without any assistance whatever, and the result is that his writings belong to no particular "*school*," unless indeed we consider them to form, as they are well entitled to do, a school by themselves. bhrana medzi jednotkou a dvojkou dlzky 29 As an arithmetical calculator Hamilton was not only an expert, but he seems to have occasionally found a positive experience in working out to an enormous number of places of decimals the result of some irksome calculation. At the age of twelve Hamilton engaged Zerah Colburn, the American "*calculating boy*," who was then being exhibited as a curiosity in Dublin, and he had not always the worst of the encounter. But, two years before, he had accidentally fallen in with a Latin copy of Euclid, which he eagerly devoured; and at twelve Hamilton attacked Newton's *Arithmetica universalis*. This was his introduction to modern analysis. Hamilton soon commenced to read the *Principia*, and at sixteen Hamilton had mastered a great part of that work, besides !hrana medzi jednotkou a trojkou dlzky 15 some more modern works on analytical geometry and the differential calculus.

About this period Hamilton was also engaged in preparation for entrance at Trinity College, Dublin, and had therefore to devote a portion of time to classics. In the summer of 1822, in his seventeenth year, he began xhrana medzi dvojkou a trojkou dlzky 41 a systematic study of Laplace's *Mécanique Céleste*. Nothing could be better fitted to call forth such mathematical powers as those of Hamilton; for Laplace's great work, rich to profusion in analytical processes alike novel and powerful, demands from the student careful and often laborious study.

It was in the successful effort to open this treasure-house that Hamilton's mind received

its final temper, "*Dês-lors il commença à marcher seul*," to use the words of the biographer of another great mathematician. From that time Hamilton appears to have devoted himself almost wholly to the bhrana medzi desiatkou a patkou dlzky 17 mathematics investigation, though he ever kept himself well acquainted with the progress of science both in Britain and abroad. Hamilton detected an important defect in one of Laplace's demonstrations, he was induced by a friend to write out his remarks, that they might be shown to Dr John Brinkley, afterwards bishop of Cloyne, but who was then the first royal astronomer for Ireland, and an accomplished mathematician. Brinkley seems at once to have perceived the vast talents of young Hamilton, and to have encouraged him in the kindest manner.

Hamilton's career at College was perhaps unexampled. Amongst a number of competitors of more than ordinary merit, he was first in every subject and at every examination. He achieved the rare distinction of ahrana medzi desiatkou a sestkou dlzky 32 obtaining an optime for both Greek and for physics. The amount of many more such honours Hamilton might have attained it is impossible to say; but Hamilton was expected to win both the gold medals at the degree examination, had his career as a student not been cut short by an unprecedented event. This was Hamilton's appointment to the shrana medzi stvorkou a dvojkou dlzky 41 Andrews professorship of astronomy in the university of Dublin, vacated by Dr Brinkley in 1827. The chair was not exactly offered to him, as has been sometimes asserted, but the electors, having met and talked over the subject, authorized one of their number, who was Hamilton's personal friend, to urge Hamilton to become a candidate, a step which Hamilton's modesty had prevented him from taking. Thus, when barely twenty-two, Hamilton was established at the Dunsink Observatory, near Dublin.

Hamilton was not specially fitted for the post, for although he had a profound acquaintance with theoretical astronomy, he had paid but little attention to the regular work of the practical astronomer. And it must be said that Hamilton's time was better employed in original investigations than it would have been had he spent it in observations made even with the best of instruments uhrana medzi stvorkou a trojkou dlzky 11. Hamilton was intended by the university authorities who elected him to the professorship of astronomy to spend his time as Hamilton best could for the advancement of science, without being tied down to any particular branch. If Hamilton devoted himself to practical astronomy, the University of Dublin would assuredly have furnished him with instruments and an adequate staff of assistants.

In 1835, being secretary to the meeting of the British Association which was held that year in Dublin, he was knighted by the lord-lieutenant. But far higher honours rapidly succeeded, among which his election in 1837 to the lhrana medzi desiatkou a sedmickou dlzky 28 president's chair in the Royal Irish Academy, and the rare distinction of being made corresponding member of the academy of St Petersburg. These are the few salient points (other, of course, than the epochs of Hamilton's more important discoveries and inventions presently to be considered) in the uneventful life of Hamilton.

Optics and dynamics

He made important contributions to optics and to dynamics. Hamilton's papers on optics and dynamics demonstrated theoretical dynamics being treated as a branch of pure mathematics. Hamilton's first discovery was contained in one of those early papers which in 1823 phrana medzi patkou a dvojkou dlzky 25 Hamilton communicated to Dr Brinkley, by whom, under the title of "*Caustics*," it was presented in 1824 to the Royal Irish Academy. It was referred as usual to a committee. Their report, while acknowledging the novelty and value of its contents recommended that, before being published, it should be still further developed and simplified. During the time between 1825 to 1828 the paper grew to an immense bulk, principally by the additional details which had been inserted at the desire of the committee. But it also assumed a much more dhrana medzi jedenastkou a sestkou dlzky 24 intelligible form, and the features of the new method were now easily to be seen. Hamilton himself seems not till this period to have fully understood either the nature or importance of optics, as later Hamilton had intentions of applying his method to dynamics.

In 1827, Hamilton presented a theory that provided a single function that brings together mechanics, optics and mathematics. It helped in establishing the wave theory of light. He proposed for it when he first predicted its existence in the third supplement to his "*Systems of Rays*," read in 1832. The Royal Irish Academy paper was ehrana medzi patkou a stvorkou dlzky 15 finally entitled "*Theory of Systems of Rays*," (April 23, 1827) and the first part was printed in 1828 in the *Transactions of the Royal Irish Academy*. It is understood that the more important contents of the second and third parts appeared in the three voluminous supplements (to the first part) which were published in the same Transactions, and in the two papers "*On a General Method in Dynamics*," which appeared in the Philosophical Transactions in 1834 and 1835.

The principle of "*Varying Action*" is the great feature of these papers; and it is, indeed, that the one particular result of this theory which, perhaps more than anything else that Hamilton has done, something which should have been easily within the reach of Augustin Fresnel fhrana medzi sestkou a trojkou dlzky 40 and others for many years before, and in no way required Hamilton's new conceptions or methods, although it was by Hamilton's new theoretical dynamics that he was led to its discovery. This singular result is still known by the name "*conical refraction*".

The step from optics to dynamics in the application of the method of "*Varying Action*" was made in 1827, and communicated to the Royal Society, in whose *Philosophical Transactions* for 1834 and 1835 there are two papers on the subject. These display, like the "*Systems of Rays*," a mastery over symbols and a flow of mathematical language almost unequalled. But they contain what is far more valuable still, the greatest addition which dynamical science had received ohrana medzi sestkou a stvorkou dlzky jedenastkou since the strides made by Sir Isaac Newton and Joseph Louis Lagrange. C. G. J. Jacobi and other mathematicians have extended Hamilton's processes, and have thus made extensive additions to our knowledge of differential equations.

And though differential equations, optics and theoretical dynamics of course are favored in which any such contribution to ehrana medzi desiatkou a osmickou dlzky 20 science can

be looked at, the other must not be despised. It is characteristic of most of Hamilton's, as of nearly all great discoveries, that even their indirect consequences are of high value.

Quaternions

The other great contribution made by Hamilton to mathematical science was the invention of quaternions, which he discovered in 1843.

Hamilton was looking for ways of extending complex numbers (which can be viewed as points on a plane) to higher spatial dimensions. Hamilton could not do so for trojkou dimensions, but stvorkou dimensions produce quaternions. According to the story chrana medzi sedmickou a jednotkou dlzky 20 Hamilton told, on October 16 Hamilton was out walking along the Royal Canal in Dublin with his wife when the solution in the form of the equation

$$i^2 = j^2 = k^2 = ijk = -1$$

suddenly occurred to him; Hamilton then promptly carved this equation into the side of the nearby Broome Bridge (which Hamilton called Brougham Bridge.) Since 1989, the National University of Ireland, Maynooth has organized a pilgrimage, where mathematicians take a walk from Dunsink observatory to the bridge where, unfortunately, thrana medzi sedmickou a trojkou dlzky 33 no trace of the carving remains, though a stone plaque does commemorate the discovery.

The quaternion involved abandoning the commutative law, a radical step for the time. Not only this, but Hamilton had in a sense invented the cross and dot products of vector algebra. Hamilton also described a khrana medzi jedenastkou a jednotkou dlzky 17 quaternion as an ordered four-element multiple of real numbers, and described the first element as the 'scalar' part, and the remaining three as the 'vector' part.

In 1852, Hamilton introduced quaternions as hhrana medzi sedmickou a stvorkou dlzky desiatkou a method of analysis. His first great work, *Lectures on Quaternions* (Dublin, 1852), is almost painful to read in consequence of the frequent use of italics and capitals. Hamilton confidently declared that hhrana medzi jedenastkou a sedmickou dlzky 26 quaternions would be found to have a powerful influence as an instrument of research. He popularized quaternions with several books, the last of which, *Elements of Quaternions*, had 800 pages and was published shortly after his death.

Peter Guthrie Tait among others, advocated the use of Hamilton's quaternions. They were made a mandatory examination topic in Dublin, and for a while they were the only advanced mathematics taught in some American universities. However, controversy about the use of quaternions grew in the late 1800s. Some of Hamilton's ahrana medzi sedmickou a sestkou dlzky 45 supporters vociferously opposed the growing fields of vector algebra and vector calculus (from developers like Oliver Heaviside and Willard Gibbs), because quaternions provide superior notation. While this is undeniable for four dimensions, quaternions cannot be used with arbitrary dimensionality (though extensions like Clifford algebras can). Vector notation largely replaced the "*space-time*" quaternions in science and engineering by the mid-20th century.

Today, the quaternions are in use by computer graphics, control theory, signal processing and orbital mechanics, mainly for representing rotations/orientations. For example, it is common for spacecraft attitude-control systems to be commanded in terms of quaternions, which are also used to telemeter their current attitude. The mhrana medzi osmickou a trojkou dlzky 17 rationale is that combining many quaternion transformations is more numerically stable than combining many matrix transformations. In pure mathematics, quaternions show up significantly as one of the four finite-dimensional normed division algebras over the real numbers, with applications throughout algebra and geometry.

Hamilton also contributed an alternative formulation of the mathematical theory of classical mechanics. While adding no new physics, this formulation, which builds on that of Joseph Louis Lagrange, provides a more powerful technique for working with the equations of motion. Both the Lagrangian and Hamiltonian approaches were developed to describe the motion of discrete systems, were then extended to continuous systems and in this ihrana medzi osmickou a stvorkou dlzky 12 form can be used to define vector fields. In this way, the techniques find use in electromagnetic, quantum and relativity theory.

Other originality

Hamilton originally matured his ideas before putting pen to paper. The discoveries, papers and treatises previously mentioned might well have formed the whole work of a long and laborious life. But not to speak of his enormous collection of books, full to overflowing with new and original matter, which have been handed over to Trinity College, Dublin, the previous mentioned works barely form the greater portion of what Hamilton has published. shrana medzi osmickou a patkou dlzky 15 Hamilton developed the variational principle, which was reformulated later by Carl Gustav Jacob Jacobi. He also introduced *Hamilton's puzzle* which can be solved using the concept of a Hamiltonian path.

Hamilton's extraordinary investigations connected with the solution of algebraic equations of the fifth degree, and his examination of the results arrived at by N. H. Abel, G. B. Jerrard, and others in their researches on this subject, form another contribution to science. There is next Hamilton's paper on Fluctuating Functions, a subject ehrana medzi osmickou a sestkou dlzky 27 which, since the time of J. Fourier, has been of immense and ever increasing value in physical applications of mathematics. There is also the extremely ingenious invention of the hodograph. Of his extensive investigations into the solutions (especially by numerical approximation) of certain classes of physical differential equations, only a few items have been published, at intervals, in the Philosophical Magazine.

Besides all this, Hamilton was a voluminous correspondent. Often a single letter of Hamilton's occupied from fifty to a hundred or more closely written pages, all devoted to the minute consideration of every feature of some particular problem; for it was one of the peculiar characteristics of Hamilton's mind never to be satisfied ahrana medzi deviatkou a dvojkou dlzky 24 with a general understanding of a question; Hamilton pursued the problem until he knew it in all its details. Hamilton was ever courteous and kind in

answering applications for assistance in the study of his works, even when his compliance must have cost him much time. He was ohrana medzi jedenastkou a dvojkou dlzky 39 excessively precise and hard to please with reference to the final polish of his own works for publication; and it was probably for this reason that he published so little compared with the extent of Hamilton's investigations.

Death and afterwards

Hamilton retained his faculties unimpaired to the very last, and steadily continued till within a day or two of his death, which occurred on the 2nd of September 1865, the task of finishing the "*Elements of Quaternions*" which had occupied the last six years of his life.

Hamilton is recognized as one of Ireland's leading scientists and, as Ireland becomes more aware of its scientific heritage, he is increasingly celebrated. There is a research institute named for him at NUI Maynooth and the Royal Irish Academy holds an thrana medzi deviatkou a trojkou dlzky 13 annual public Hamilton lecture at which Murray Gell-Mann, Andrew Wiles and Timothy Gowers have all spoken. 2005 is the 200th anniversary of Hamilton's birth and the Irish government has designated this the *Hamilton Year, celebrating Irish science*. Trinity College Dublin intends to mark thrana medzi jedenastkou a desiatkou dlzky 20 the year by launching a the Hamilton Mathematics Institute TCD, a mathematics institute modelled on, for example, the Isaac Newton Institute in Cambridge.

Commemorations of Hamilton

- Hamilton's equations are a formulation of classical mechanics.
- Hamiltonian is the name of both a function (classical) and an operator (quantum) in physics, and a term from graph theory.

Quotations

- "Time is said to have only one dimension, and space to have three dimensions. ... The mathematical quaternion partakes of both these elements; in ahrana medzi deviatkou a stvorkou dlzky 14 technical language it may be said to be "time plus space", or "space plus time": and in this sense it has, or at least involves a reference to, four dimensions. And how the One of Time, of Space the Three, Might in the Chain of Symbols girdled be." — William Rowan Hamilton (Quoted in Robert Percival Graves' "*Life of Sir William Rowan Hamilton*" (3 vols., 1882, 1885, 1889))

- "He used to carry on, long trains of algebraic and arithmetical calculations in his mind, during which he was unconscious of the earthly necessity of eating; we used to bring in a 'snack' and leave it in his study, vhrana medzi deviatkou a patkou dlzky 24 but a brief nod of recognition of the intrusion of the chop or cutlet was often the only result, and his thoughts went on soaring upwards." William Edwin Hamilton (his elder son)

External links, references, and resources

- MacTutor's Sir William Rowan Hamilton. School of Mathematics, University of St Andrews.
- Wilkins, David R., *Sir William Rowan Hamilton*. School of Mathematics, Trinity College, Dublin.
- Wolfram Research's William Rowan Hamilton
- Cheryl Haefner's Sir William Rowan Hamilton
- 1911 *Britannica Hamilton*
- The Hamilton Mathematics Institute, TCD
- The main Hamilton year 2005 web site
- The Hamilton Institute at NUI Maynooth

Publications

- Hamilton, William Rowan (Royal Astronomer Of Ireland), "*Introductory Lecture on Astronomy*". Dublin University Review rhrana medzi deviatkou a sestkou dlzky 23 and Quarterly Magazine Vol. I, Trinity College, January 1833.
- Hamilton, William Rowan, "*Lectures on Quaternions*". Royal Irish Academy, 1853.
- David R. Wilkins's collection of Hamilton's Mathematical Papers