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THE BEGINNINGS OF MECHANICAL COMPUTING IN POLAND[*]

Abstract. The paper presents the first computing devices which were constructed in Poland in the 18th and 19th centuries. Most of the attention has been devoted to the inventions of Abraham Stern, Chaim Słonimski and Izrael Staffel, especially to the construction and the rules of operating on their calculating machines. Presented inventors were Jewish artisans who, in spite of difficult conditions, succeeded in creating numerous interesting inventions (including calculating machines). This suggests the existence of a dynamic Jewish artisan community in Warsaw at that time.

Keywords: history of mechanical computation, calculating machines, inventors of calculating machines

1. Introduction

The history of mechanical computation is long and interesting, but very often researchers limit it to inventors from Western Europe such as Schickard, Pascal, Leibniz and their successors. Since the aim of this paper is to present calculating machines built in Poland (Eastern Europe), similar machines built at that time or earlier in Western Europe[1] have been completely omitted here. There are only a few papers concerned with this subject. The article has been based mainly on archival sources: contemporary newspapers, publications of scientific associations, materials from exhibitions and descriptions of the machines drawn by their constructors.

Probably the oldest mechanical calculating machine in the Polish territory (then belonging to Russia) was the invention of Gevna Jakobson who before 1770 built a machine for addition, subtraction and multiplication of

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[1] There are many publications on the history of calculating machines in Western Europe, in particular papers in IEE Annals of the History of Computing.

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10-digit numbers. It is extremely difficult to find in source materials descriptions of this machine and the way of operating it. The only available data say that Jakobson's machine was a brass case 34 cm × 21,8 cm × 3,4 cm size, built with gears serving to transfer digits from one row to another similarly to Schicard's construction. Jacobson's calculating machine is preserved in the Łomonosov Museum of Science in St. Petersburg, though very difficult to investigate.[2]

No mention of calculating machines built on Polish territory in the period between 1770 to the 19th century can be found either in the press or others source materials. The first information on the subject concerns three inventors: Abraham Stern, Chaim Słonimski and Izrael Staffel.[3] All of them were Jewish artisans who spent most of their lives in Warsaw (the present capital of Poland) which was part of the Russian Empire at that time. Their Jewish origin and social background affected not only their personal lives but also the history of their inventions (including calculating machines). Therefore it is worth describing briefly the political and economic situation in Warsaw of that time.

Warsaw was the capital of the Polish-Lithuanian Commonwealth until 1795, when it was annexed by the Kingdom of Prussia to become the capital of the province of South Prussia. Liberated by Napoleon's army in 1806, Warsaw was made the capital of the newly created Duchy of Warsaw. Following the Congress of Vienna of 1815, Warsaw became the centre of the Congress Poland (called also the Kingdom of Poland), a constitutional monarchy under a personal union with Imperial Russia. At that time Warsaw was the centre of Poland's national life; many Polish patriotic organizations had their seats there. In 1897 Warsaw was the third-largest city of the Russian Empire after St. Petersburg and Moscow. According to the Russian population census of 1897 the territory of the Kingdom was inhabited by six nations; the second nation (after the Poles) were the Jews, who constituted 13.8% of the whole population [Eberhardt, 2003, pp. 76–77].

The situation of the Jews in Warsaw in the 19th century had been changing together with the changes in the political and economic situation of the city. In 1791 tsarina Catherine the Great created a special region of Russia, in which permanent residency of the Jews was allowed (beyond

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[2] In spite of many attempts we did not succeed in getting permission from the museum's management to investigate Jacobson's machine.

[3] We concentrate on Abraham Stern, Chaim Słonimski and Izrael Staffel because their inventions are sufficiently documented.

that region, Jewish permanent residency was generally prohibited) called the Settlement of Pale, which included lands formerly belonging to Poland. In the 19th century most of the Jews in the Pale (including Warsaw) were poor, living and working in very bad conditions. One of the reasons was the tremendous growth of the Jewish population in Warsaw; others were political and legal regulations. The Jews were obliged to live in special areas in most cities;[4] they faced restrictions on education, business activities, and occupation. Additional taxes were imposed on members of the Jewish community. Jewish boys were obliged to serve in the Russian army, where they were often forced to convert to Christianity. That situation combined with too many artisans in the same area resulted in the reduction of orders and a lack of work, which in consequence led to the pauperization of the Jewish artisan community. The legislation was changing along with tsars. Tsar Nicolas introduced special restrictions against the Jews (among others Cantonist Laws which kept the traditional double taxation on the Jews). Those restrictions were softened by tsar Alexander II (also known as Alexander the Liberator) and reintroduced by tsar Alexander III who tightened restrictions on where Jews could live in the Pale of Settlement and restricting the occupations that Jews could attain.[5]

The Jews at that time formed rather a hermetic community with a separate religion and system of education. Jewish children either were not educated at all or attended Jewish religious schools. Most Jews could read neither Polish nor Russian – this made impossible learning about the latest technical and scientific achievements. It is worth remarking here that Chaim Zelig Słonimski[6] (detailed presentation included below), first in history, began writing and publishing science books in Hebrew to enlighten the Jewish population and in 1862 launched the popular science magazine "Hazefirah", the first Hebrew journal with an emphasis on science, which continued after his death in 1931.

In contrast to the restrictions mentioned above, in the 19th century Haskalah, the Jewish Enlightenment, began on the Polish territory. Supporters of that movement stressed secular ideas and values and pressed for assimilation and integration into European society and for educational development in secular studies. In spite of the that fact, most Polish Jews were

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[4] The special area with restriction on the permanent residency of Jewish was founded in Warsaw in 1809 [Dubnow, 1916–1920, p. 145].

[5] Detailed information about the history of Jews on Polish and Russian territory can be found in [Dubnow, 1916–1920; Klier, 1986].

[6] More information about Ch. Z. Słonimski can be found in section 3.

indifferent to Haskalah; they focused on a continuation of religious tradition as a base of their lives. Nevertheless the Jewish Enlightenment had prominent supporters mainly in Warsaw, including Abraham Stern and Chaim Zelig Słonimski.

Abraham Stern, Chaim Słonimski, and Izrael Staffel, like most Jewish artisans, lived in poverty – that made their living conditions hard. They often contended with financial problems which prevented them from developing their talents (including the construction of prototypes of their inventions). However, despite the fact that Jewish inventors lived in isolation, had difficult access to the knowledge of technical and scientific achievements, and faced financial problems, they were very talented inventors and their inventions were not limited to calculating machines.

Summing up, in spite of the difficulties that the Jews faced in 19th century Warsaw, Jewish artisans succeeded in creating numerous interesting inventions (including calculating machines). It can be supposed that there was a dynamic Jewish artisan community in Warsaw at that time.

2. The calculating machines of Abraham Stern

One of the members of that community was Abraham Stern. ABRAHAM STERN (1769–1842) was born in a poor Jewish family in Hrubieszów (Eastern Poland). Thanks to help from Polish nobleman and scientist Stanislaw Staszic, Stern moved to Warsaw, where he designed several inventions: among others, a mechanical harvester, a rangefinder, a "topographical cart" which allowed the drawing of maps of regions to scale (a cart was pulled by horses along the boundary of a region and at the same time the map of the region was drawn on paper), a thresher, a mechanical brake for droshky, a sawmill, and a series of calculating machines. Due to a shortage of money, Stern did not manage to build prototypes of most of his machines. Stern was not only an inventor, he wrote poems and was known as an expert in Hebrew writings. He was also engaged in political activity to support the Jews. There is the following mention about Abraham Stern in a book by S. Dubnow [1916–1920, pp. 248–249]:

> In 1825 the Polish Government appointed a special body to deal with Jewish affairs. It was called "Committee of Old Testament Believers," though composed in the main of Polish officials. It was supplemented by an advisory council consisting of five public-spirited Jews and their alternates. Among the members of the Committee, which included several prominent Jewish merchants of Warsaw, such as Jacob Bergson, M. Kavski, Solomon Posner and

T. Teplitz, was also the well-known mathematician[7] Abraham Stern, one of the few cultured Jews of that period who remained a steadfast upholder of Jewish tradition.

At the end of his life he became the Rector of the School for Rabbis. He died in 1842 in Warsaw.

Stern gained the reputation of a splendid inventor. He presented his inventions a couple of times at the Society's meetings. His calculating machines Stern presented to the Royal Warsaw Society of the Friends of Science (predecessor of the Polish Academy of Science): his first machine for only four arithmetical operations in December 1812, a second machine for extracting square roots in January 1817 and finally a combined machine for four operations and square roots in April 1818.[8] The last machine was probably the first machine for five arithmetical operations in Europe [Trzesicki, 2006].

There are two pictures of Stern's machine: the first one is only a fragment of the machine visible in a portrait of Stern by Antoni Blank (1823, The National Museum in Poznań) and the other one (published in [Sawicka and Sawicki, 1956]) is a picture of a copy which was exhibited in the Museum of Industry in Kraków, between the wars (however, the copy has not been preserved to our times). Because of this, the description of the machine and its use is based on a presentation by Abraham Stern given at meetings of the Royal Warsaw Society of the Friends of Science (see [Stern, 1818]).

The machine was a cuboid with five rows of wheels. In the first row there were 13 wheels with discs, on which there were ordinary digits of numbers engraved. They were seen singly through the apertures. Each wheel corresponded to one position in number: from units, tens, hundreds, etc. The 13 wheels of the second row were only a part of the machine's mechanism and didn't have any engravings. The next two rows of wheels with engraved digits (visible by the windows) were on a carriage which was moving with the use of cylinders. There were 7 wheels in the first row on the carriage and 8 wheels in the second one. There were also seven small folding cranks attached to 7 wheels in the first row on the carriage (this row was called by the inventor "crank row") and one big removable crank on the cover of the machine. Above the carriage Stern placed the fifth row of

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[7] There is no evidence that Abraham Stern was interested in mathematics, so it is a mistake to call him a mathematician [my remark – I. B.-K.].

[8] For his inventions he was admitted to the Royal Warsaw Society of the Friends of Science as a corresponding member in February 1817, then as a qualifying member (in February 1821), and finally as a full member (in January 1830).

seven wheels with engraved digits visible through apertures. Besides these five rows of wheels, there were two more rows of wheels on the cover of the machine: one above the first row of apertures and the other one above the last row of apertures (above the lowermost row). On the wheels in these two rows there were Roman numerals engraved which were visible singly through the apertures. These two rows were used to check the results of calculations.

Abraham Stern in his presentation in Warsaw (see above) described in detail the way of using the machine. To prepare the machine to carry out four basic arithmetic operations, the operator had to place the carriage using a handle in such a position that on a carriage on the left-hand side, the word Species showed through an aperture and all the numerical apertures of the second row were covered. Then the operator with two handles on the right and left-hand side of the machine moved the carriage up – if the operation to carry out was addition or multiplication – and down if the operation to carry out was subtraction or division. At the same time the words: *Addition – Multiplication or Subtraction – Division* (respectively) were seen on the machine through the aperture and the machine was ready to perform.

To add or subtract two numbers, the operator put one of them in the uppermost row, and the other one in the crank row on the carriage. Then he performed the operation by a single circular rotation of a big crank in the middle of the carriage. The machine had a brake, located on the left-hand side of the carriage which stopped further movement of the crank. The result of the operation appeared in the uppermost row of apertures (replacing the first number). Thanks to that the machine helped to add long rows of numbers, because the current sum was always in the first row, the added numbers were placed one after another in the crank row. Additionally, the machine had a counter which showed how many numbers had been added, which facilitated adding long rows or tables of numbers without mistakes like adding the same number twice or skipping some numbers.

To carry out multiplication the operator put one factor in the crank row in the carriage, and the other in the lowermost row. In the uppermost row there were only zeroes. Then the carriage was moved from the right to the left side, to the very end of the machine, by the handle placed on the left-hand side of the carriage. After releasing the handle, the carriage returned by itself, and stopped in an appropriate position. In this position the operator started the rotation of the main crank. During the rotation, the carriage moved by itself from one number to the other towards the right-hand side, back through the end of the machine. The ringing of a bell (built into the machine) informed about the operation's completion. At the same

time the desired product appeared in the uppermost row. This method of multiplication enabled calculating the sum of any number of products. The operator put the factors of the first product in the machine and operated until the ring of the bell indicated to stop; then without putting zeros in the uppermost row he put the factor of the second product, third, and so on, and when after the last operation the ring of the bell indicated to stop the rotations, at that time the sum of all the products appeared in the uppermost row. Stern stated that [1818, p. 118]:

> [...] the Machine has a particular superiority over calculations in an ordinary manner, that from several given multiplications one can obtain a general product without performing an addition operation, that is, without combining individually calculated products together.

To divide numbers, the operator set the dividend in the uppermost row, the divisor in the crank row of the carriage and zeroes in the lowermost row (designated for the quotient). Then he moved the carriage towards the left-hand side, until the divisor stood straight under the dividend number. At that time the main crank was rotated as long as the dividend number became smaller than the divisor, at which point the operator pressed with a finger a flap situated on the right-hand side of the carriage. As a result, the carriage moved by itself towards the right-hand side and stopped at the appropriate place, where further operation continued in a similar manner till the divisor placed in the carriage "passed" the dividend. The quotient appeared in the lowermost row. If the quotient was a whole number then in the uppermost row there were only zeroes; if it was a fraction, then the numerator appeared in the uppermost row and the denominator in the crank row of the carriage.[9]

Most interesting was extracting square roots from numbers. First of all an operator had to prepare the machine to carry out this operation by: 1) placing the carriage on the right-hand side (the word Species disappeared and the word Radices was visible through an aperture; numerical apertures of the second row of the carriage opened), 2) moving the carriage (using two handles on the right and left-hand sides of the machine) from the top to the bottom (the inscription Extraction appeared in an aperture on the machine, 3) removing the main crank in the middle of the carriage. Then the machine was ready to perform.

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[9] The way of carrying out four basic arithmetic operations using Stern's machine was very similar to operating Staffel's calculating machine (described below).

To calculate the square root of a given number, the operator set this number in the uppermost row and zeros in the first and second rows of the carriage except the position of units in the second row, where the number 1 was set. At the apertures for ordinary numbers of the uppermost row, there were various signs dividing this row into sections (there were signs at units, hundreds, tens of thousands, millions, and so on). Identical signs were on small folding cranks so that each crank corresponded to two wheels of the uppermost row (the first crank from the right corresponded to units and tens, the second one – hundreds and thousands, and so on). The last sign, at the given number, indicated the crank from which the operation had to start. For example, if the number was 144 (ended on the wheels of the second sign) the operation started with the second crank from the right (having the same sign). The folding crank indicated this way was unfolded and the carriage was moved to the left until this crank stopped in front of the last sign of the given number. Then the operator rotated this crank as long as the number on the uppermost row, in front of the rotating crank, became smaller than or, at least, equal to the number positioned in front of the same crank in the second row of the carriage. Next, this crank was folded and the crank on the right of it was unfolded. By pressing a flap on the right-hand side of the carriage, the carriage moved by itself to the right- hand side, until it was stopped by a folded crank, just in front of the previous section and the same operation was performed. This was repeated for all sections of the given number. After completing the operation, if a given number was a full square, it was replaced by zeroes and the square root in the crank row in the carriage appeared. Otherwise, except for the whole number root, an additional fraction resulted (the numerator on the uppermost row and the denominator in the second row in the carriage).

The machine was also prepared for approximating the square roots in decimal fractions. For example, to compute the square root of 7 approximated with two decimal digits, zeros were set in two sections (4 wheels) and the given number 7 was set in the third section, which was on the 5th wheel of the uppermost row. On the machine there was a small hand to distinguish between the number actually given and the zeroes attached to it. The given number 7 was under the third sign, so the operator had to unfold the third crank and perform the operations as described above. The result appeared on 3 crank wheels as the number 264. Cutting off two digits for a decimal fraction (as the hand indicated), the result was understood as 2.64. In addition, in the uppermost row there was the number 304, as a numerator, and in the second row of the carriage 529, as a denominator of the ordinary fraction.

Above, the structure of Stern's machine and the way of using it was presented. However, there is one part of the machine which was described, but the purpose of designing it has not been explained yet – two rows of wheels with Roman numerals. Stern put these wheels into the machine for checking (testing) the results of arithmetical operations. The way of performing such tests was presented in the case of multiplying (division was tested in a similar way).

While carrying out the multiplication, the digits of one of the factors (set in the lowermost row) disappeared and were replaced by zeroes one by one. To make visible, after the work, which factor was a part of the problem, the operator set it in advance in a Roman numbered row located above the apertures of the lowermost row. After completing the operation, the result (the product) was on the uppermost row; in the lowermost row there are only zeroes. The operator shifted as many zeroes to the number 9 as the number of digits of the factor in the Roman numbered row, except for the first digit, being meaningful, on the right-hand side of the factor, where zero remains. Then the carriage was moved to the left and stopped by itself at the last number 9. After that the rotation of the main crank lasted as long as the number appeared was equal to the Roman numeral right above it (the same which had previously disappeared). At that time, the operator pressed a flap on the right-hand side of the carriage, the carriage moved to the right and the rotations proceeded further, as before, until the given factor fully appeared in its first place, that is, in the lowermost row. After this work, if it turned out that there were as many digits in the factor in the lowermost row as the number of zeroes in the uppermost row, at the right-hand side, and the numbers following them were equal to the numbers in the crank row of the carriage, then it was clear that the product (the result of the process of multiplication) was true, otherwise it was false.

In the case of testing the result of division the operator proceeded in a similar way, but only to retain digits of the dividend (which disappeared during the work, having been replaced by zeroes) the row of wheels with Roman numerals above the row of the dividend's digits was used.

Stern's machines were highly valued, among others by the Royal Warsaw Society of the Friends of Science, but they were never manufactured, maybe because of the intricate mechanisms which resulted in high costs of production. Stern did not have a sufficient amount of money to begin mass-production of his machine, but the machine was finally produced and used.

3. Between mathematics and machines – the invention of Chaim Zelig Słonimski

Continuing after Abraham Stern was his son-in-law Chaim Zelig Słonimski. CHAIM ZELIG SŁONIMSKI was born on 31ˢᵗ March, 1810 in Białystok, (Eastern Poland). He was a deeply knowledgeable Talmudist and a self-educated scientist. Słonimski had wide interests; he was interested in philosophy, astronomy, physics and mathematics. He was the first to begin writing and publishing science books in Hebrew to enlighten the Jewish population in Eastern Europe. He introduced to Hebrew an entire vocabulary of technical terms. Słonimski was a born popularizer; at the age of 23, he composed a brief practical guide on the foundations of mathematics. The first part of the guide, dedicated to algebra, was published in 1834. In 1835, inspired by the general interest in the passing of Halley's Comet, he published a book on astronomy, "Comet", describing Halley's Comet and explaining the laws of Kepler. In 1838 he published another book on astronomy in which he described his own research on the calculations of eclipse dates and on composing the Hebrew calendar. Later in life, he started publishing a popular science magazine "Hazefirah", the first Hebrew journal with an emphasis on science, which continued after his death, till 1931. He was also the author of a biography of Alexander von Humboldt. Słonimski died on May 15ᵗʰ, 1904 in Warsaw.

Słonimski was a talented inventor. He invented several devices and processes of various sorts. In 1853 he invented a chemical process for plating iron vessels (dishes) with lead, and in 1856 an electrochemical device for sending quadruple telegrams (the system of multiple telegraphy perfected by Lord Kelvin in 1858 was based on Słonimski's discovery). Among other of Słonimski's inventions, calculating machines were worth noting. He invented and produced two calculating machines, one for addition and subtraction, and the other one for multiplication. The most interesting is the second one, which was based on a theorem of number theory called Słonimski's Theorem.

Słonimski's Theorem Let Z be any natural number and $z_1, z_2, z_3, z_4, \ldots$ be the (decimal) digits of this number (denoted from the right to the left). If we write down the number Z and its multiples $2Z, 3Z, 4Z, 5Z, 6Z, 7Z, 8Z$ and $9Z$ in such a way that single digits, decimals, hundreds and so on form vertical lines, then the last vertical line passing by the last digit z_1 of the number Z will contain *the second* digits of multiples $2z_1, 3z_1, 4z_1, 5z_1, 6z_1, 7z_1, 8z_1$ and $9z_1$. But in every other line the situation is

different, for example the line passing by z_ε does not contain the second digits of multiples $2z_\varepsilon, 3z_\varepsilon, 4z_\varepsilon, 5z_\varepsilon, 6z_\varepsilon, 7z_\varepsilon, 8z_\varepsilon$ and $9z_\varepsilon$. To obtain these digits a special sequence (called a "complementary sequence") must be added to the sequence of multiples of z_ε. This complementary sequence depends on the digits after the number Z. There are only **twenty-eight** different complementary sequences. To obtain digits of the vertical line passing by z_ε, the sequence multiples of z_ε should be added to complementary sequences corresponding to the digits, which follow z_ε in number Z.

To understand Słonimski's theorem let us consider for example the number $Z = 1246$. Then $z_1 = 6, z_2 = 4, z_3 = 2$ and $z_4 = 1$. If we write down Z and its multiples $2Z, 3Z, 4Z, 5Z, 6Z, 7Z, 8Z$ and $9Z$ as follows:

		z_4	z_3	z_2	z_1
Z		1	2	4	6
$2Z$		2	4	9	2
$3Z$		3	7	3	8
$4Z$		4	9	8	4
$5Z$		6	2	3	0
$6Z$		7	4	7	6
$7Z$		8	7	2	2
$8Z$		9	9	6	8
$9Z$	1	1	2	1	4

then the last vertical line passing by the last digit 6 of the number 1246 will contain *the second* digits of multiples $6, 12, 18, 24, 30, 36, 42, 48$ and 54 (see the column marked in the table above). The theorem states that "[...] in every other line the situation is different, for example the line passing by z_ε does not contain the second digits of multiples $2z_\varepsilon, 3z_\varepsilon, 4z_\varepsilon, 5z_\varepsilon, 6z_\varepsilon, 7z_\varepsilon, 8z_\varepsilon$ and $9z_\varepsilon$. To obtain these digits a special sequence (called a "complementary sequence") must be added to the sequence of multiples of z_ε." So, in every other line decimals of multiples are carried to the next left column. To illustrate this, let us examine the table below where digits in brackets were carried to the next left column (missing in the columns of the table above), where they were printed in bold:

		z_4	z_3	z_2	z_1
Z		1	2	4	6
$2Z$	0	$02 + \mathbf{0} = (0)2$	$04 + \mathbf{0} = (0)4$	$08 + \mathbf{1} = (0)9$	$(1)2$
$3Z$	0	$03 + \mathbf{0} = (0)3$	$06 + \mathbf{1} = (0)7$	$12 + \mathbf{1} = (1)3$	$(1)8$
$4Z$	0	$04 + \mathbf{0} = (0)4$	$08 + \mathbf{1} = (0)9$	$16 + \mathbf{2} = (1)8$	$(2)4$
$5Z$	0	$05 + \mathbf{1} = (0)6$	$10 + \mathbf{2} = (1)2$	$20 + \mathbf{3} = (2)3$	$(3)0$
$6Z$	0	$06 + \mathbf{1} = (0)7$	$12 + \mathbf{2} = (1)4$	$24 + \mathbf{3} = (2)7$	$(3)6$
$7Z$	0	$07 + \mathbf{1} = (0)8$	$14 + \mathbf{3} = (1)7$	$28 + \mathbf{4} = (3)2$	$(4)2$
$8Z$	0	$08 + \mathbf{1} = (0)9$	$16 + \mathbf{3} = (1)9$	$32 + \mathbf{4} = (3)6$	$(4)8$
$9Z$	1	$09 + \mathbf{2} = (1)1$	$18 + \mathbf{4} = (2)2$	$36 + \mathbf{5} = (4)1$	$(5)4$

In such a way, passing over the first row (for Z), the bold digits form complementary sequences as follows: $(0,0,0,0,0,0,0,0)$ for z_1, $(1,1,2,3,3,4,4,5)$ for z_2, $(0,1,1,2,2,3,3,4)$ for z_3 and $(0,0,0,1,1,1,1,2)$ for z_4. Now the question arises: how many complementary sequences may occur, regardless of the digits of number Z? Słonimski found that exactly 28 different complementary sequences can occur.[10] That is the content of Słonimski's theorem presented above.

This theorem was derived from the Farey sequence.[11] Słonimski does not seem to have published the theorem. He presented it to the St. Petersburg Academy but he never proved it himself. However, a German mathematician August Leopold Crelle, who was familiar with the theorem because of Słonimski's personal communication during his visit to Berlin in 1844, proved Słonimski's Theorem and published the result in his own journal [Crelle, 1846]. Using his theorem, Słonimski composed a table with 280 columns, each of them containing 9 numbers. This table was the main component of the multiplication machine which showed products of all ranks for a given number.[12]

Słonimski's machine was a box sized 40 cm × 33 cm × 5 cm. There were some cylinders inside, which could both revolve around the axis and move along it. The table of digits derived from Słonimski's theorem was placed (engraved) on the main cylinders. There were two small cylinders beside it

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[10] Crelle marks the complementary sequences with and shows it as a table in the proof of Słonimski's theorem published in [Crelle, 1846].

[11] Farey's sequence of order n is a sequence of completely reduced fractions between 0 and 1 which, when in lowest terms, have denominators less than or equal to n, arranged in order of increasing size. Each Farey sequence starts with the value 0, denoted by the fraction 0/1, and ends with the value 1, denoted by the fraction 1/1. F1 = 0/1, 1/1, F2 = 0/1, 1/2, 1/1, F3 = 0/1, 1/3, 1/2, 2/3, 1/1, F4 = 0/1, 1/4, 1/3, 1/2, 2/3, 3/4, 1/1,…

[12] The tables are in the book [Knight, 1847].

with digits from 0 to 9 on one of them and letters a, b, c, d together with digits 1 to 7 on the other one. The cylinders were driven with the use of handles fastened to the shaft end. While the small cylinders were immobile, the main cylinders were moved along their axis with toothed gearing, driven with screws mounted on the cover of the machine. There were also eleven rows of apertures on the cover. By these apertures the signs engraved on the cylinders were visible.

The use of Słonimski's machine was very simple. The multiplicand was set on the lowermost (the first) row of apertures with handles mounted on the cover. After that, both letters and numbers appeared in the apertures of the second and third row. Their combination formed the code which informed the operator which screw should be turned (and which cylinder was to be shifted). Then in the rows of the 4th–11th apertures appeared the resulting numbers. In the 4th row was the product of multiplication by 2, the 5th row by 3, the 6th row by 4 etc. Finally, the products of all ranks were displayed. After adding them on the paper, the desired product was obtained. Needless to say, the convenience of this method was rather questionable, and it is no wonder that there is no evidence of its systematic practical usage. But Słonimski's machine got high recognition during his lifetime. On 8th August, 1844 he demonstrated his device to the Royal Prussian Academy of Sciences in Berlin. Słonimski's work was highly appreciated.

The next year, on April 4, 1845, he presented the machine and explained its design to the Academy of Sciences in St. Petersburg during a seminar at the department of physics and mathematics. The academician V. A. Bunyakovski and the scientific secretary P. N. Fuss (Voss) composed a very positive official review of the invention. They emphasized the solid mathematical ground of the presented work because the discovery of the basic feature of numbers was the principlal but not the only condition for composing this calculating machine. In the review the shrewdness of Słonimski was appreciated, because he arranged the aforementioned tables and invented also the code which the operator used to calculate the products. So the surface of cylinders was covered with a complicated system of 2280 numbers and 600 letters. In November 1845 Słonimski received a 10 year patent for his invention.[13] He was also awarded the Demidov prize of the Second grade amounting to 2000 rubles [Trzesicki, 2006].[14]

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[13] He also applied for patents in the U.S. and Britain, but unsuccessfully.

[14] The Demidov family were Russian industrial magnates of the 18th and 19th centuries. The family established a foundation in support of science and education. The Second grade prize amounted to 2500 Rubles.

Summing up, Słonimski's machine was a simple device, whose construction was based on a theorem in number theory. This theorem, named after its inventor, enabled Słonimski to arrange a table of numbers, which was the basis of construction for the calculating machine. Thanks to the theorem Słonimski's machine had a very simple construction and was cheap. At that time only a few calculating machines existed which were based on such a good theoretical background. That was the "mathematical art" of the device, but unfortunately the machine did not survive to our times.

4. The machine of Izrael Abraham Staffel

Another machine which did not survive to the present day is an invention of a clockmaker from Warsaw, Abraham Staffel. ABRAHAM IZRAEL STAFFEL (1814-1885) was born in Warsaw. At the age of only 19 he opened a clockmaster's shop, where he worked till his death. Most of his life Staffel spent on developing various inventions. He designed an automatic taximeter for cabs which was controlled automatically: it started during the getting on of passengers and stopped after their getting off. In 1851 Staffel presented at an exhibition in London a probe for determining the contents of alloys based on Archimedes law. It was used for testing the authenticity of coins. Staffel designed also: an anemometer (which besides showing the direction also measured the force of the wind), a device for destroying locusts, a press for printing multicolor stamps, a machine for preventing the forging of documents and securities, a series of fans (or rather air conditioning) installed in many buildings, hospitals, and in The Royal Castle in Warsaw. Staffel was also the designer of a "small amusing underground train going from the kitchen to the dining room". Despite the fact that he was a well-known and appreciated inventor, he had financial troubles all his life. Staffel died in poverty after a long disease in 1885.

Abraham Staffel designed and built also calculating machines. For the first time he presented a machine for four basic arithmetical operations, exponentiation, and extracting square roots, in 1845 at the industrial exhibition in Warsaw. Unfortunately this machine didn't survive to our times, so its construction and way of performing operations can be found only in the contemporary press and in reports on exhibitions.

The mechanism of the machine Staffel put in a box sized 20 inches × 10 inches × 8 inches. There were 13 apertures for showing the digits of the result on the case. Below, there was a cylinder with 7 rollers placed on it. There were apertures for putting numbers on the rollers. At the bottom of

the machine there were 7 apertures for setting the digits of the multiplier and for showing the result of division. On the cover of the machine there were also a crank and a hand to select the type of operation (by setting the handle on one of the inscriptions: *extractio*, *substractio/divisio and additio/multiplio*).

The modern (for those days) construction of the machine enabled performing not only simple calculations but also calculating more complicated expressions like, for example:[15]

To calculate the above expression the operator put number a on the rollers of the machine, turned the hand on the engraving *substractio/divisio* and turned the crank. Then he put number b on the rollers and turned the crank and finally put number c on the same place. After turning the crank the sum $a + b + c$ was visible in the upper row of apertures. To continue calculation the operator put the hand on the inscription *substractio/divisio* and putting numbers d and e one by one turned the crank in the opposite direction than in the case of addition. The partial result appeared in the upper row of apertures. Then the operator put the hand on the *substractio/divisio* and performed to calculate the product in the bracket. In order to do that he set number g on the cylinder and the number h in the lower row of seven apertures and turned the crank until the digits in the apertures of the lower row all became zeros. After that the value of the expression appeared in the upper row of apertures. Then, after setting the hand on the *substractio/divisio* the operator calculated in the same way the product $m \times m$ and obtained the value of the numerator of the above fraction. To complete the calculation he put the number n on the cylinder and zeros in the lowermost row of apertures (the hand there was still on the inscription *substractio/divisio*). After turning the crank in the lowermost row of apertures the value of whole expression appeared and in the upper row of apertures there was still the value of the numerator of this expression.

Staffel's machine could serve as a tool for extracting square roots. To calculate the square root of a given number, the operator set this number in the upper row of apertures, zeros on the cylinder, zeros in the lowermost row except the position of units in the row where number 1 was set and put in the handle on the inscription *extractio*. No description of performing calculations has survived to our times, but the procedure was probably similar to extracting square roots on Stern's machine.

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[15] This example and the description of using the machine was taken from [TI1, 1867].

Staffel introduced a few improvements to his machine. In the case of division, if the result wasn't the integral then the value of the numerator of the result was in the upper row of apertures and the denominator was in the lower one. In the machine a ring was built which indicated a mistake in the case when the result of subtraction was negative (when the numbers were set in the wrong order) and when the divisor is bigger than the dividend while performing division.

The machine of Abraham Staffel was presented in at least three exhibitions. At the exhibition in Warsaw, which was mentioned above, Staffel received a silver medal for his invention. Articles in contemporary newspapers pointed out that the machine considerably shortened the calculation (tables comparing the time of calculations in seconds were published). In 1846 Staffel presented his machine to the Russian Academy of Sciences in St. Petersburg. Two famous mathematicians, V. Bunyakovski and B. Jacobi, gave it a very positive opinion and Staffel was awarded a Demidov prize amounting to 1500 rubles[16] but he never patented it. The machine was also presented at The Great Exhibition in London in 1851 in one group with the arithmometer of Xavier Thomas de Colmar. Two machines were awarded: Staffel's and Colmar's. After the London Exhibition a brief note in Scientific American appeared saying [SA1, 1851]:

> An extraordinary calculating machine, says the London Times, is now placed in the Russian Court. It is the invention of a Polish Jew, named Staffel, a native of Warsaw, and works addition, subtraction, multiplication and division, with a rapidity and precision that are quite astonishing.

At the end of his life Staffel handed over his invention to the Russian Academy of Science. After the collapse of tsarism the collection of Academy broke down. Probably Staffel's machine was destroyed then and did not survive to our times.

5. Conclusion

The calculating machines described above, despite the recognition they gained, were not mass-produced. The following question which arises is: why were these machines not universally used in manufactures, banks, and scientific institutions, as happened in the case of Xavier Thomas de Colmar's arithmometers? Probably the main reason was the complexity of the

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[16] Compare with the prize which Słonimski received.

machines' construction. The production of single parts of the machines was very problematic and expensive, so would result in very high prices for the machines. Moreover the machines described above were invented by Jewish artisans living in the region of Poland under the rule of Russia who had not much freedom of activity and not enough money to realize their ideas.

Abraham Stern, Chaim Słonimski, and Izrael Staffel were Jewish artisans who lived at the same time in the same place. Perhaps it was no coincidence. It should be supposed that there was a dynamic Jewish artisan community in Warsaw in the 19th century, though there is no evidence for personal relations either between Staffel and Stern or between Staffel and Słonimski. There is also no evidence that Staffel investigated Stern's or Słonimski's machines.

It is worth underlining that inventors in Polish territory (particularly the Jews) very rarely traveled abroad and therefore did not have contact with inventions from Western Europe at that time. As was mentioned above, the Jews had very limited access to the knowledge of technical and scientific achievements (most of them could read neither in Polish nor in Russian). In spite of that, these Jewish artisans succeeded in creating numerous interesting inventions including calculating machines, which were comparable with calculating machines produced in Western Europe at the time. Their construction was rewarded during exhibitions in the Russian Empire and abroad. Stern's, Słonimski's, and Staffel's calculating machines were not the oldest constructions of such type in Europe, but taking into account the hard conditions in which they worked they can be considered as forming an interesting part of the history of mechanical computing in Europe.[17]

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