

Calculators

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How to use the Schickard calculator

In recent years, a number of Schickard calculator replicas have appeared both in various museums and private collections (see the sidebar, “Types of Reconstructed Schickard Calculators”). For the owners of these calculators, and for others, it may be interesting to learn how to operate them. In several previously published papers, I have explained the purpose for which Schickard designed this calculator as well as where his calculator fit into the mathematical community of the 17th century.¹⁻³

For a better understanding, let me briefly review the basic construction of the Schickard calculator. The calculator is composed of the following three units (top to bottom):

- the multiplication unit,
- the adding machine (henceforth called the adder), and
- the memory unit.

These three units are independent of one another; they are not mechanically interconnected (see Figure 1).

The calculator provides the means to perform the following basic operations: multiplication, addition, and subtraction. Divisions are difficult to perform but can be avoided by multiplying with the reciprocated value of the divisor. Taking into consideration that in the 1600s divisions in trigonometric calculations were circumvented by the introduction of secants and cosecants, and taking further into consideration that reciprocal value tables were already known prior to that time, it becomes obvious that the Schickard calculator was predominantly intended as a multiplication machine. In other words, the Schickard calculator is a three-species calculator.

The multiplication unit (the top portion of the calculator) consists of six vertically positioned, turnable cylinders, which have the values of the complete multiplication table (including zero) imprinted around their circumference (see Figure 2).

The turn knobs on top provide the means to enter the value of the number to be multiplied (the multiplicand). This number will subsequently appear in the permanently open windows underneath. The partial products achieved via the multiplier digits (digits 2 to 9) are made visible by operating the window slides, as later explained. Only one of these slides is in the calculating position at any one time. In the rest position, the calculator's window slides are pulled fully toward the right and all dials of the adder and the memory unit must show zero.

The adding machine, the middle portion of the calculator, provides the means to add the partial products (produced by the multiplication unit) in properly aligned fashion to obtain correct results. This machine is quite remarkable, because it lets the operator perform subtractions simply by turning the dials in the reverse direction. The calculator automatically takes any negative carries into consideration. In Schickard's papers, there is not even a hint toward the

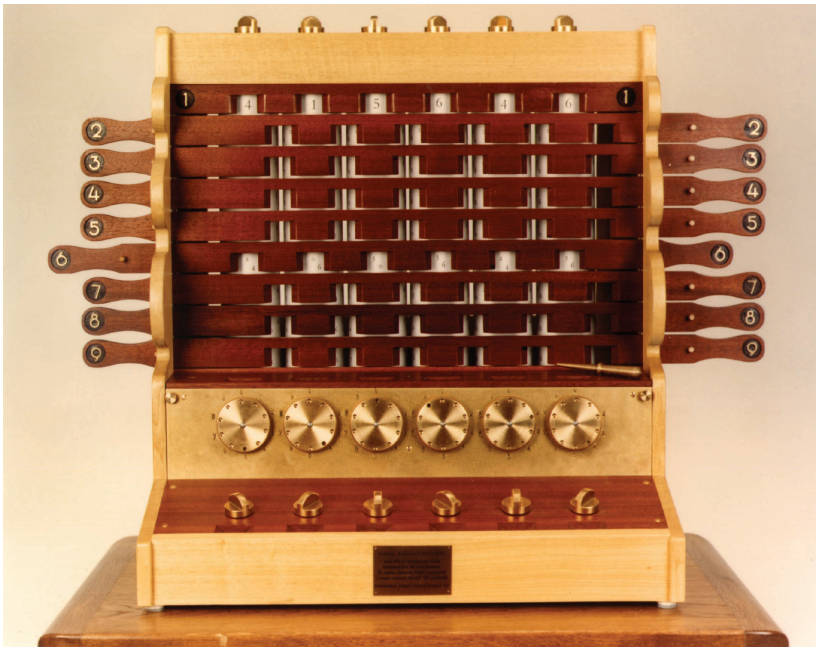


Figure 1. The Wilhelm Schickard calculator of 1623–1624, showing a front view from an elevated position. The middle section is the adding machine with the result windows. The adding machine's base contains dials, which are used to enter the partial products that are taken from the multiplication unit above. Notice the stylus on the right-hand side, which is used to operate the calculator. The calculator's pedestal shows the memory unit's dials. (Photo courtesy of IBM Germany.)

need for generation of a complementary value for the subtrahend as required for the indirect subtraction method used by Pascal.

The third and final unit of the calculator, the memory unit, can temporarily record intermediate results. It can also be used as an operating guide by recording which multiplier digit has been taken care of, so as to keep the proper sequence of operations (see following examples).

The six cylinders of the multiplication unit determine the calculator's capacity, that is, the calculator can multiply two 3-digit numbers with each other, at maximum.

Operating instructions

Let us start out with a simple example. Multiply 498 by 35 using the elementary school method, which is multiplying from right to left. Perform the following steps:

1. Pull all window slides all the way to the right to reset the calculator. The adder and memory dials must show zero.
2. Enter the number to be multiplied (the multiplicand) by turning the top knobs, beginning with the rightmost knob that you turn until the digit 8 appears in the window underneath. Turn the next knob to its left until 9 appears in the associated window. Then, turn the third knob until 4 appears in the third window. You should now see the right aligned number 498 in the windows.
3. Since the multiplication "by 35" is to be conducted right-to-left, push the window slide that bears the number of the rightmost multiplier digit (5) all the way to the left until it hits the stop.
4. Observe the slide windows. They should show 00 00 00 20 45 40.
5. Add these partial products by using the adder dials, as follows (use the stylus to turn the dials, if you like):
 - A. Leave the rightmost adder dial (the units position) untouched because zero is to be added; hence nothing needs to be done there.
 - B. At the next adder dial toward the left (the tens position), dial the digit 4 (four tens).
 - C. In the same position, dial the digit 5 (five tens). Notice that the window above will now show the result 9 (4 plus 5).
 - D. At the third adder dial (counting from right to left), dial the digit 4 to enter the hundreds position.
 - E. Since the zero of the third partial product requires no action, proceed to the fourth number dial (the thousands position) and set it to the digit 2. Since the other partial products are all zero, no further addition is required for the time being. The adder's windows should now display 2490.
6. At the memory unit of the calculator, dial the number 5 into the units position (rightmost memory dial) as a reminder that you have just worked off the multiplier's units position, which was the digit 5, then restore the slide number 5 by pulling it all the way to the right.
7. Now multiply with 30 (multiplier digit 3) by pushing slide number 3 all the way to the left. The windows should show 00 00 00 12 27 24. These partial products must be added to the already existing amount, again from right to left, but this time beginning in the tens position because the units position of the multiplier has already been processed, which is indicated by 5 in this position. Proceed as follows:
 - A. At the second adder dial (counting from

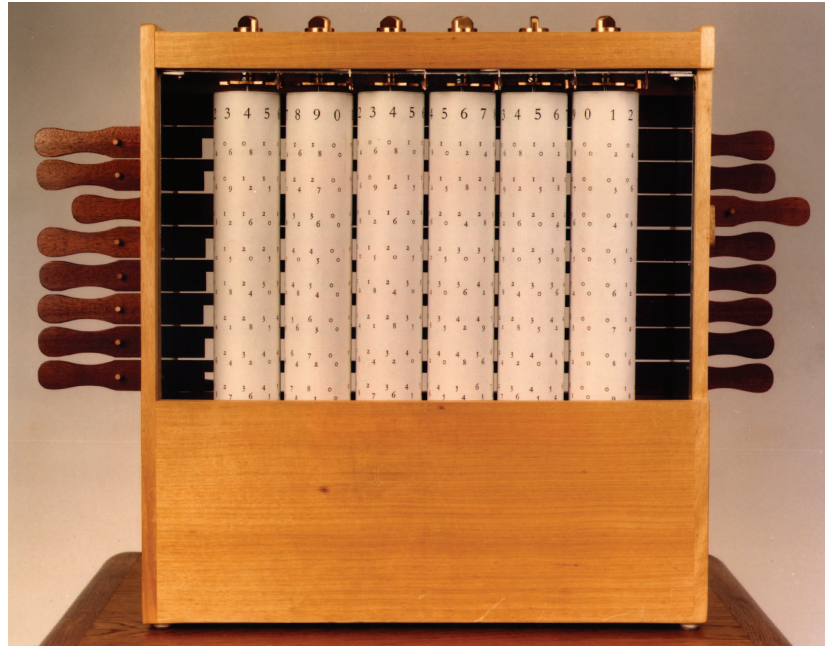


Figure 2. Rear view of the calculator, showing the six cylinders of the multiplication unit. At the front, these cylinders are hidden behind eight horizontal window slides. (Photo courtesy of IBM Germany.)

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- right to left), dial first 4, then 2 in the next position. (Did you notice the carry?)
- B. At the third adder dial, enter first the digit 7, then the digit 2 in the next position. (Did you notice the carry?)
- C. At the fourth adder dial, enter first 2, then 1 in the next position. This completes the addition of the partial products.
8. At the memory unit, dial 3 into the tens position as a reminder for the second multiplier digit that you have just finished processing. Then, pull slide number 3 all the way to the right.
9. Since there is no further multiplier digit to take care of, the final result is visible in the adder windows while the multiplier is retained in the memory dials. If you have obtained the result 17430, you did good work. Congratulations!
10. As the final step, and in any case of error, reset the calculator as follows:
- Turn all memory dials to zero.
 - Set the adder to zero.
 - Pull all window slides to the right, if that hasn't already been done.
 - Turn all top knobs to zero.

The calculator is now ready for a new calculation.

With any calculator, exercise and experience is necessary to become proficient and obtain correct results quickly. The demonstrated method is good for multiplications up to 999 by 999. Larger numbers can be multiplied by splitting them into smaller portions, computing them separately, and then adding the partial sums. This was the method used from the medieval times onward, using the then customary multiplication tables first computed by Herwart von Hohenburg (1610) and later by August Leopold Crelle (1820) and others.

Multiplication from left to right

Around 1600 the astronomers had to calculate with the natural values of sine and cosine. They did not use the radius $r = 1$, but set $r = 100,000$ or $1,000,000$. So they dealt with large numbers, sometimes up to more than 10 digits.

I won't go into details because I have explained the calculating techniques in another publication.¹ I will, therefore, give an example of multiplying decimal fractions and get results with up to seven decimals and taking the eighth decimal into consideration. This example needs no further explanation.

Multiplying two 6 place decimals

$$.123456 \times .987654$$

123456	input of multiplicand
o 9	push slide 9 to the left
18	bell rings
27	tens carry going out; put a ring on a finger
36	
45	
54	

The tens carry that occurs when 1 is added to 9 will be stored by placing a ring on one finger of the operator's hand, which is here shown as a small circle.

o 111104	first intermediate result dial 9 into highest memory position
08	retract slide 9 and push slide 8 to the left

16	
24	
32	
40	
4 8	

o 209868	add 1 for rounding
o 209869	second intermediate result dial 8 into next position of the memory unit
07	retract slide 8 and push slide 7 to the left

14	
21	
28	
3 5	
42	

o 218510	add 1 for rounding
o 218511	third intermediate result dial 7 into next position of the memory unit
06	retract slide 7 and push slide 6 to the left

12	
18	
2 4	
30	
36	

o 219251	fourth intermediate result dial 6 into next position of the memory unit
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	05		retract slide 6 and push slide 5 to the left
	10		
	1	5	
		20	
		25	
		30	

- o |219312| add 1 for rounding
- o |219313| Fifth intermediate result dial 5 into next position of the memory unit

	04		retract slide 5 and push slide 4 to the left
	0	8	
		12	
		16	
		20	
		24	

- o 219317 add 1 for rounding
- o 219318 sixth intermediate result dial 4 into next position of memory unit

Remember, the small ring (o) stands for 1 (outside the calculator).

.1219318 result
 .121931812224 the fully computed result

Note that there are two possibilities to take the rounding into consideration.

- Direct rounding as done in the example.
- Cumulated rounding. That is, placing rings on another finger and adding the number of rings to the result. The example would have four rings on the finger. For an understanding of the calculating methods in Schickard's time I refer to my corresponding publications.

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