
IC DATA PROCESSING MACHINE
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ELECTRONIC DATA PROCESSING MACHINE

THE ELECTRIC BRAINS

THE BRAIN AT REST

ALONG ONE wall of the room tall gray cabinets are ranged. They contain the "gray matter" of the electronic brain. From the front they look as blank as a face without a thought. But open the doors at the back and you will see thousands upon thousands of tiny electric circuits wired with pink, blue, green, and orange wires. Those are the "nerve cells" of the brain.

Along another wall in smaller cabinets the brain's "slow memory" or reference library is stored. Its "fast memory" is on a magnetized drum or other device inside the machine.

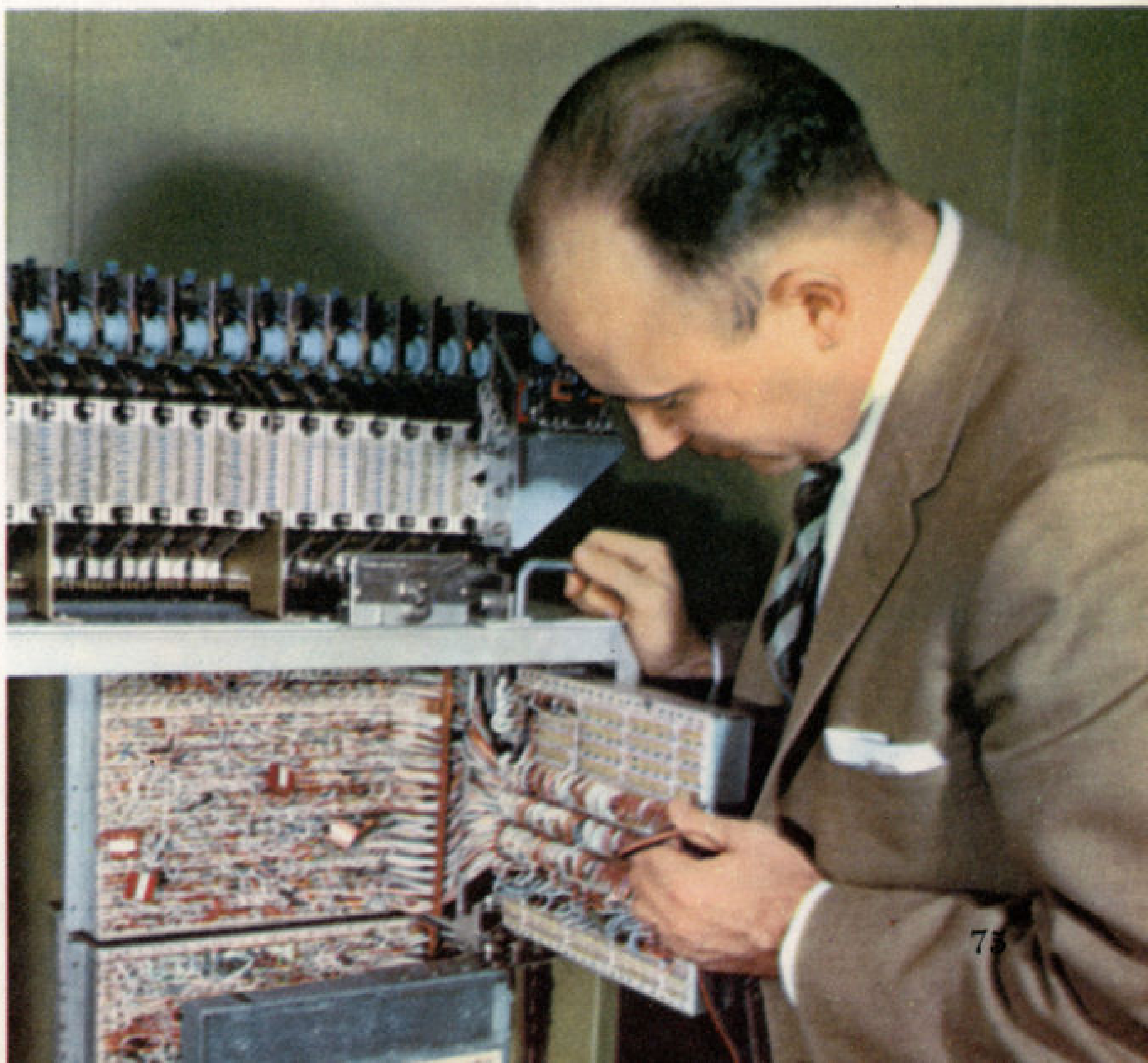
A neat, desk-sized set-up in the center of the room is what we might call the brain's "ear." This is where it receives its instructions.

Over at one side of the room a young man is preparing some of those instructions, tapping them off on a small keyboard. The instructions are punched onto rolls of tape or stacks of punch cards. And an electric typewriter makes another copy for reference.

When the operator is ready to put his giant to work, he simply fits the spools of the tape rolls onto his machine. Or if his machine uses punch cards, he fits a stack into place and puts a cover on it.

What are these instructions like? How do you give instructions to a machine which really has no ears and no brain? It cannot understand or make use of words, either spoken or written. Actually, as we learned in discussing circuit theory on page 72, all the computer can do is make choices between closing a circuit or leaving it open. It can only use numbers, and num-

At the left is a technician at the control console of an electronic computer.



To the right you can see the intricate wiring necessary for the functioning of a small electronic brain.

bers based on two. (But most of the signals to our brains from our eyes and ears, for example, are also just "yes-no" or base-two signals.)

Let us take a look at these base-two, or binary, numbers.

BASE-TWO NUMBERS

We are accustomed to numbers based on tens. Thus the number 142857 stands for:

1 (10 x 10 x 10 x 10 x 10) hundred thousand (10^5)
4 (10 x 10 x 10 x 10)s or ten thousands (10^4)
2 (10 x 10 x 10)s or thousands (10^3)
8 (10 x 10)s or hundreds (10^2)
5 (10)s or tens (10^1)
7 (1)s or ones (10^0)

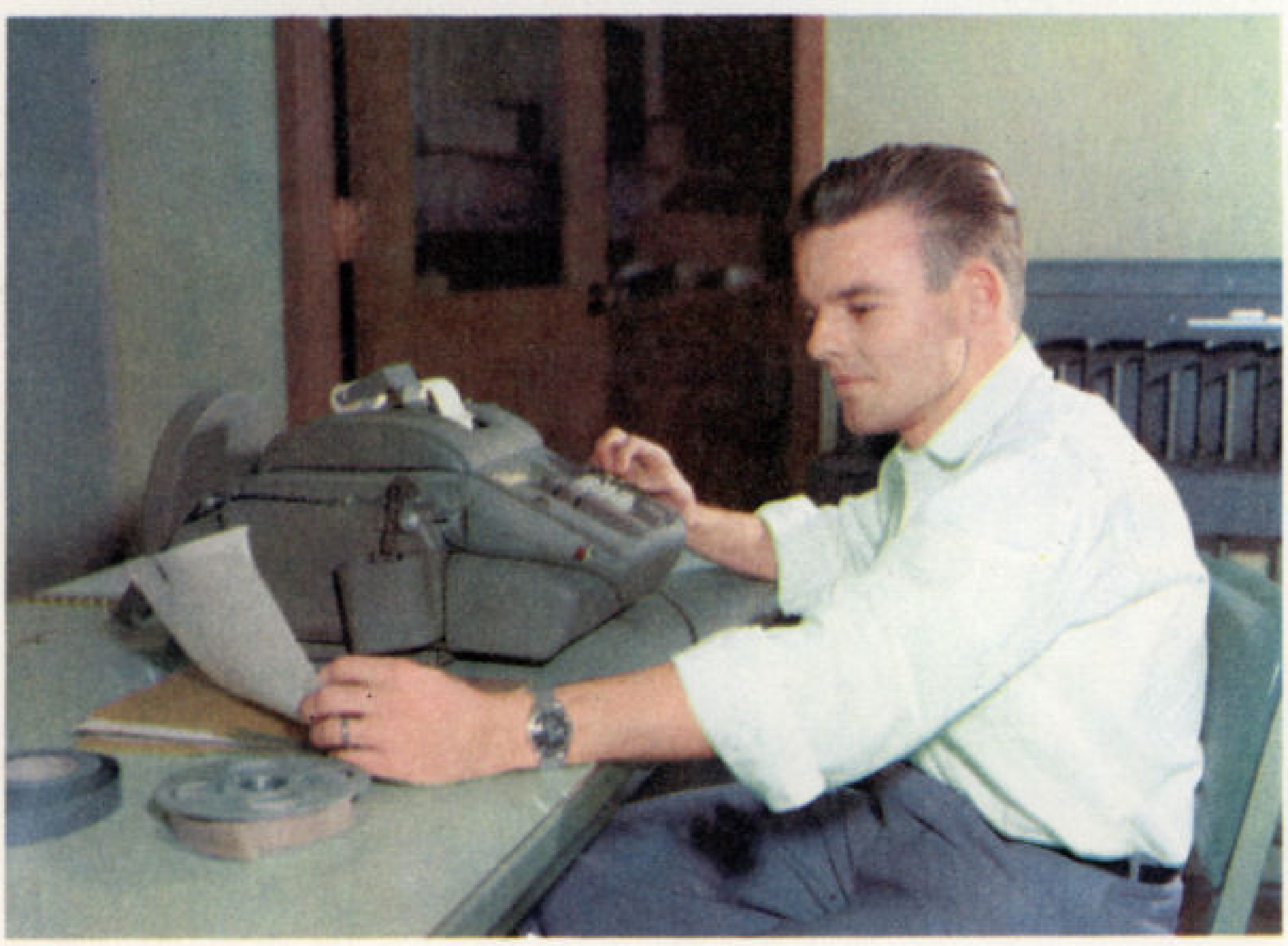
In numbers based on twos instead of tens, this same number, 142857, would become:

1 0 0 0 1 0 1 1 1 0 0 0 0 0 1 0 0 1

How do we get this? Instead of multiplying 10 x 10 etc., we multiply 2 x 2 x 2 etc. 10^5 *(above)* means 10 multiplied by 10, the product (100) multiplied by 10, that product (1000) multiplied by 10, and that product (10,000) multiplied by 10 – four multiplications, and the original 10 makes ^{5}. 2^5 means 2 multiplied by 2 four times, and the original 2 makes ^{5}.

Here is the table:				This is the method:	
$2^0 = 1$	Our number is				142857
$2^1 = 2$	It contains:	1	2^{17}	−	131072
$2^2 = 4$		0	2^{16}		11785
$2^3 = 8$		0	2^{15}		
$2^4 = 16$		0	2^{14}		
$2^5 = 32$		1	2^{13}	−	8192
$2^6 = 64$		0	2^{12}		3593
$2^7 = 128$		1	2^{11}	−	2048
					1545
$2^8 = 256$		1	2^{10}	−	1024
					521
$2^9 = 512$		1	2^9	−	512
$2^{10} = 1024$		0	2^8		9
$2^{11} = 2048$		0	2^7		
$2^{12} = 4096$		0	2^6		
$2^{13} = 8192$		0	2^5		
$2^{14} = 16384$		0	2^4		
$2^{15} = 32768$		1	2^3	−	8
					1
$2^{16} = 65536$		0	2^2		
$2^{17} = 131072$		0	2^1		
		1	2^0		1

This looks like a long process. But it is quite easy once you know the multiplication table of 2's. Had you been trained in school to use this binary multiplication table, and later tried to use



Instructions prepared for the electronic brain are recorded on rolls of tape or on punch cards, depending on the type of machine being used.

the decimal system, the decimal system would seem as strange as this does now.

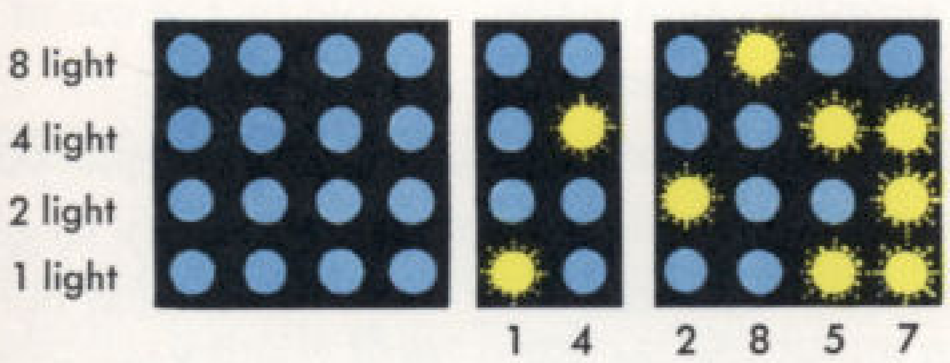
Try turning 19 into a base number 2. Look on the table of 2's for the biggest number that will fit into 19. How many down the list is it? There will be that many digits in the binary number_ _ _ _ _. Put a 1 in the space at the left. Subtract the number you picked from 19. Will the next number up on the list fit into the remainder? Put a 1 if it does or 0 if it does not in the next space to answer this. And so on up the list until you have finished it. You will find the right answer at the bottom of this page.

Would you like to try another? Turn 234 into a base-two number. How will it look? Check your result with the answer at the bottom of the page.

TALKING MACHINE LANGUAGE

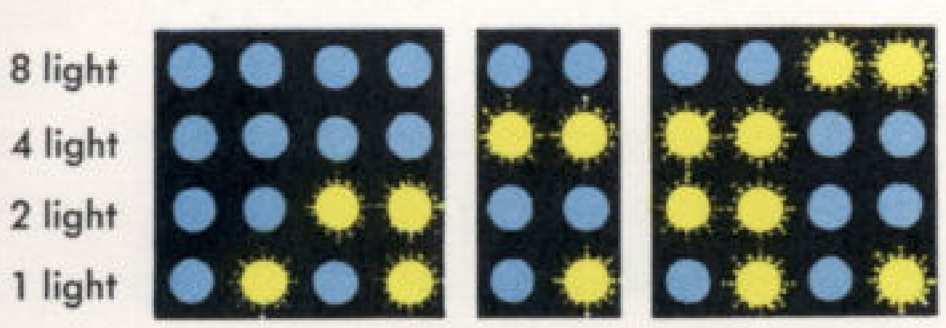
Base-two numbers, as you can see, take a lot of space. As a result, many computing machines do not use them in that form. They use instead a combination of base-two and base-ten (or *decimal system*) numbers.

On a decimal computer, our number 142857 might look like this:

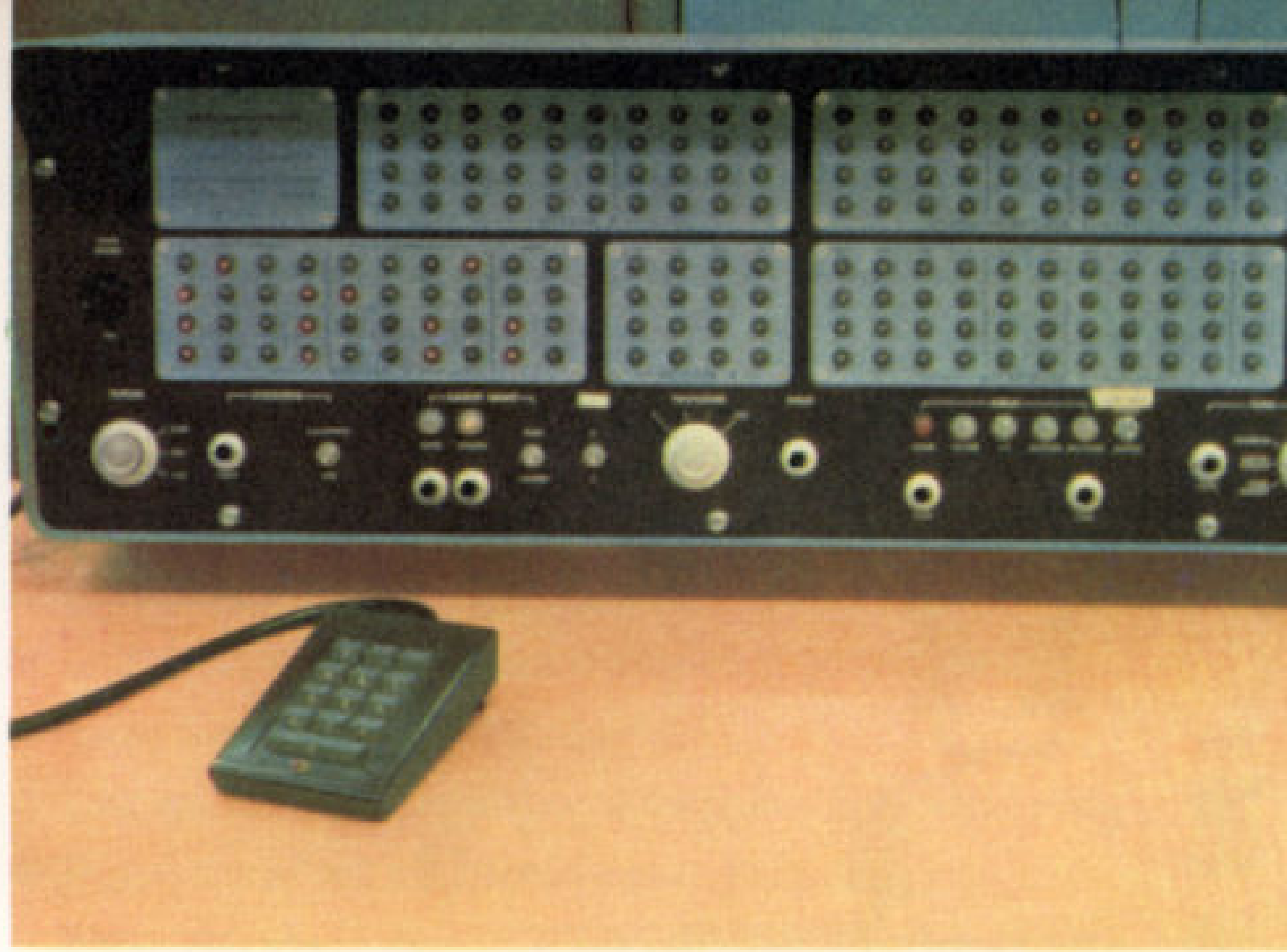


What number would these lights in the box below represent?

(Answer is below.)



ANSWERS: 19's base-two number is 10011.
234's base-two number is 11101010.
ANSWER: The number in the box is: 123456789.



Address block on magnetized drum showing how photoelectric cells magnetize spots on drum to match holes on cards or tape.

The control panels of some computer machines have boxes that look much like the diagrams in the previous column.

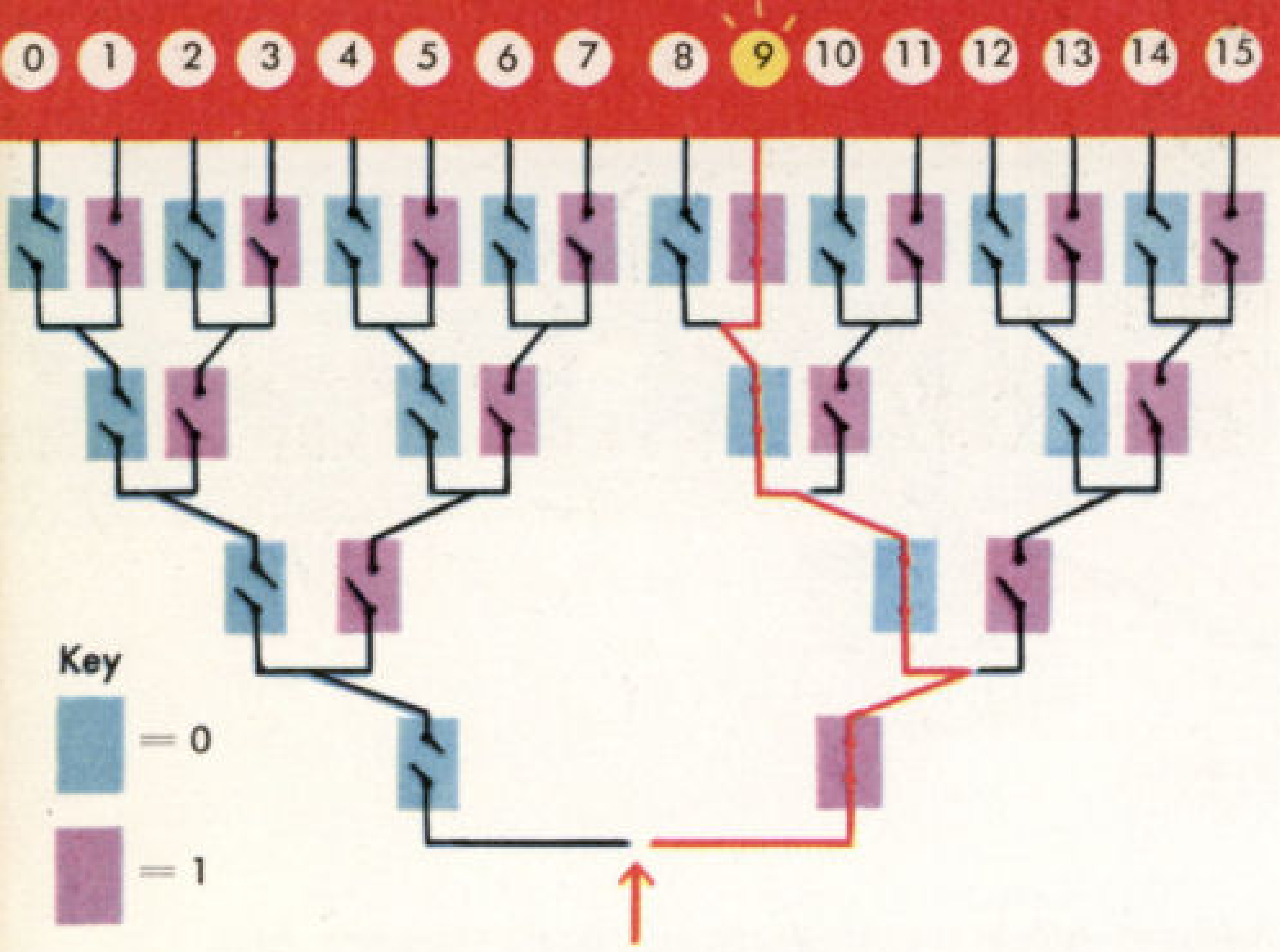
The magnetized drum inside the machine has boxes rather like this too. Some of these boxes, or address blocks, or storage cells hold numbers to be worked with. Some hold "commands." For it is not enough to feed numbers into the machine. We must also give the machine commands to add, subtract, or to do whatever we want done.

Since the machine can use only digits, not words, the commands have to be given in digits too. A language has to be invented for the machine. In this language digits will have to stand for words.

"Add," for example, in certain systems is written as 74. "Subtract" is written as 75. These "words" are always written in the middle two columns of the ten. The four columns at the right give the "address" or storage box numbers where the numbers to be added or subtracted can be found. These storage boxes of course are in the machine's "memory" drum. For use, the number is brought up to a storage cell called a register.

Let us take an example of some commands. We must feed them in one simple step at a time, like this:

1. Place the contents of box 1301 in register.
2. Add number in box 1302 to number in register.
3. Place result of addition in box 1303.

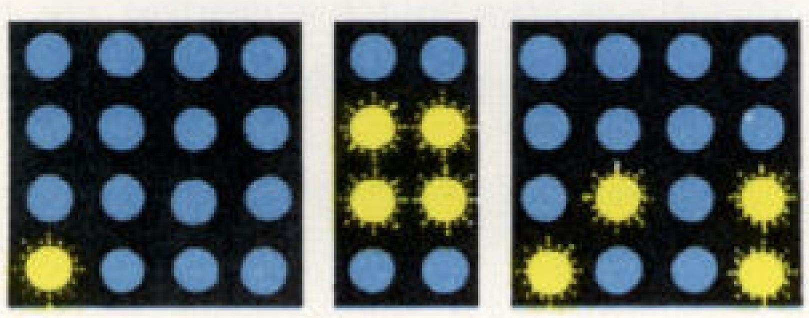


Here is an electric circuit set up to register the number 9. As a binary number, 9 becomes 1001. You will see that at each branching the proper circuit has been magnetized or closed.

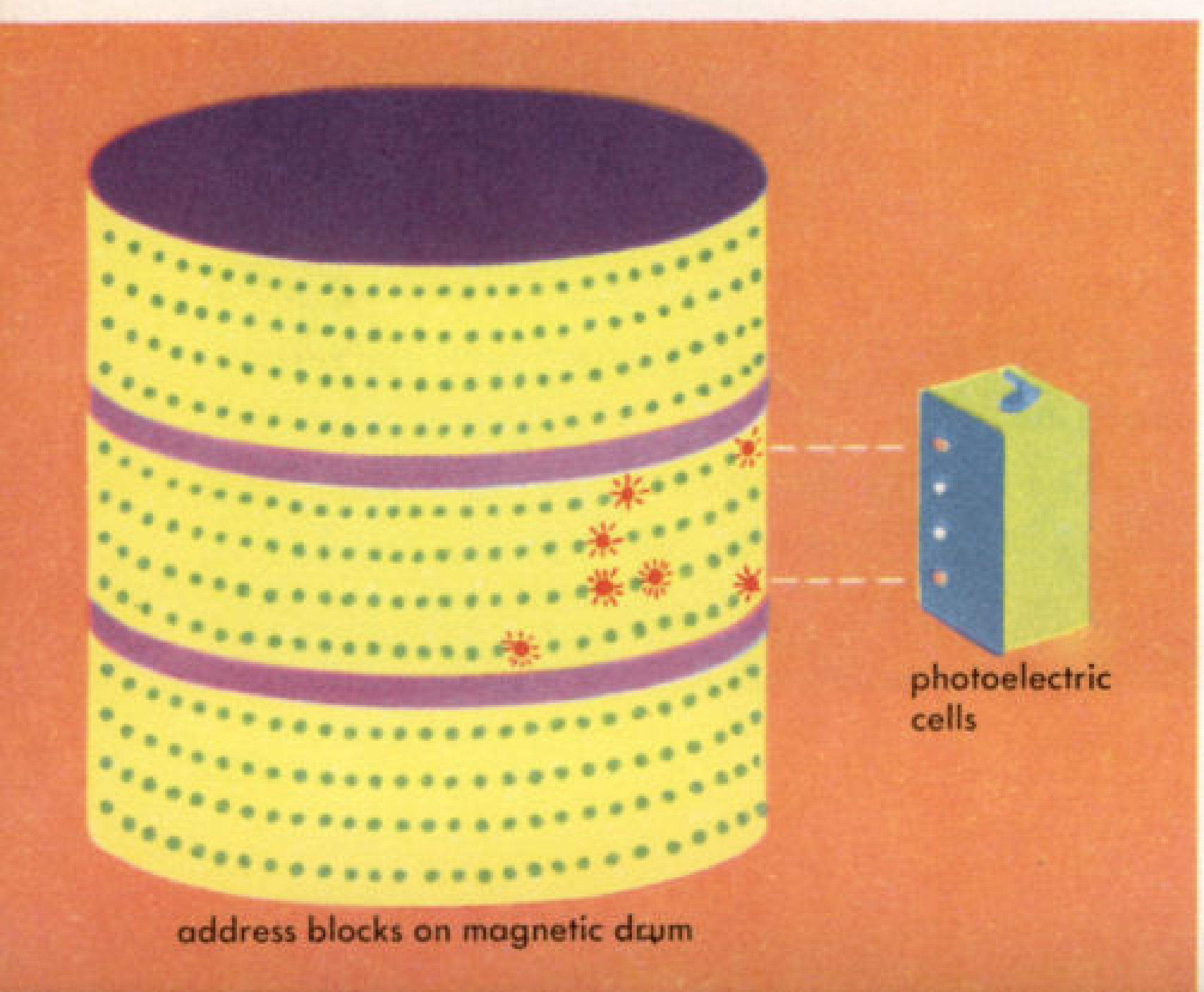
Each of these commands is fed in the form of a number. This is the way the three steps just given might appear on the instruction sheet:

1. 1000 64 1201
2. 1000 74 1202
3. 1000 66 1203

This is how one of those three steps will look on the drum. Which of the three is it? (Answer is below.)



ANSWER: The command shown is step 3.



FEEDING THE MACHINE

The operator is ready now to feed the problem into his machine. He slips tape or cards into place.

When the electric power is turned on, the holes punched in the tape allow tiny electric pulses to travel to certain matching spots on the magnetized drum inside. Both tape and drum keep turning, so that the electric pulses keep striking new sets of holes (new commands) and magnetizing new spots on the drum (to close new circuits).

If the machine uses punch cards instead of tape, tiny feelers under the card respond to the holes punched in the card. And matching positions on the drum are then magnetized.

Each number of command—each "word" in the machine language—fills a box on the drum like the boxes we have seen. A track of zeros on each side separates each word from its neighbors.

Every position is either magnetized (and the circuit closed) or it is not (the circuit is open). The current can flow through or it cannot. There are only two choices. Think back to page 77 and your turning 19 into a base-two number. As you worked down the list, there were only two possibilities in each case. Either your remainder fitted into the next power of two, or it did not. That is the simplification made possible by the use of the base-two numbers.

When all the instructions have been placed on the rotating drum, the machine is ready to go to work. Actually, the only basic numerical operation the machine can perform is addition. But this is the vital one. We saw on page 65 how the Egyptains managed to multiply by adding repeatedly. It is also possible to subtract, to divide, to do any sort of arithmetic, based on just adding numbers.

THE MACHINE'S MEMORY

You would never feed into the machine just one problem at a time. It would be a waste of the machine. For preparing the instructions is rather slow work. It takes time for the mathematician to figure out the problem. It takes minutes to transfer the handwritten numbers to tape or cards. But once the machine starts work, it can do its calculations very, very fast, in thousandths of a second.

So you set up a program of many steps for the machine. In a factory you might have the machine keep track of the earnings of 1,000 employees working different numbers of hours at various rates of pay. Each employee would have an address box where his or her record would be kept in the machine's memory. Other storage boxes would hold the various pay rates, numbers of hours, and other information. Step by step the machine would open sets of circuits and put the information together.

Before starting the machine, you would fill the drum with sets of addresses and commands. Even a small drum can accommodate 4,000 of these.

One drumful of problems is as much as a machine can hold in its "fast memory." It can work with these instantly. If you have vast numbers of records or problems, you can put them all on magnetic tape or cards, to be fed into the machine 2,000 or so at a time. And this whole library of tape or cards is called the "slow memory" of the machine.

GETTING RESULTS

At the end of the problem, the machine prints out its results. Usually these results come out on magnetic tape. The spools of tape are then attached to the side of a special electric typewriter. And the typewriter types off on paper all the results. This again is a slow process compared to the lightning speed of the computer. But the whole operation is ever so much faster and more accurate than having it done by one person or many persons. Computers find uses in many and varied fields. They are used to speed up chemical research, to keep factory or department store accounts, to design new airplane models—and even to help mathematicians in many kinds of research.

One of these research fields is number theory.

NUMBER THEORY

Number theory is one of the oldest and most delightful subjects in mathematics. It seems far removed from businesslike computers. For it is concerned with the "grave and beautiful dances" of numbers, the endless fascinating patterns they form in accordance with rules.

Let us take one simple example. For this we will not need an electronic computer.

First divide 1 by 7. Your answer to the sixth place should be 0.142857. If you keep on dividing after this point, the same set of numbers will keep repeating itself. Now multiply this 0.142857 in turn by 1, 2, 3, 4, 5, and 6. Your answers should be:

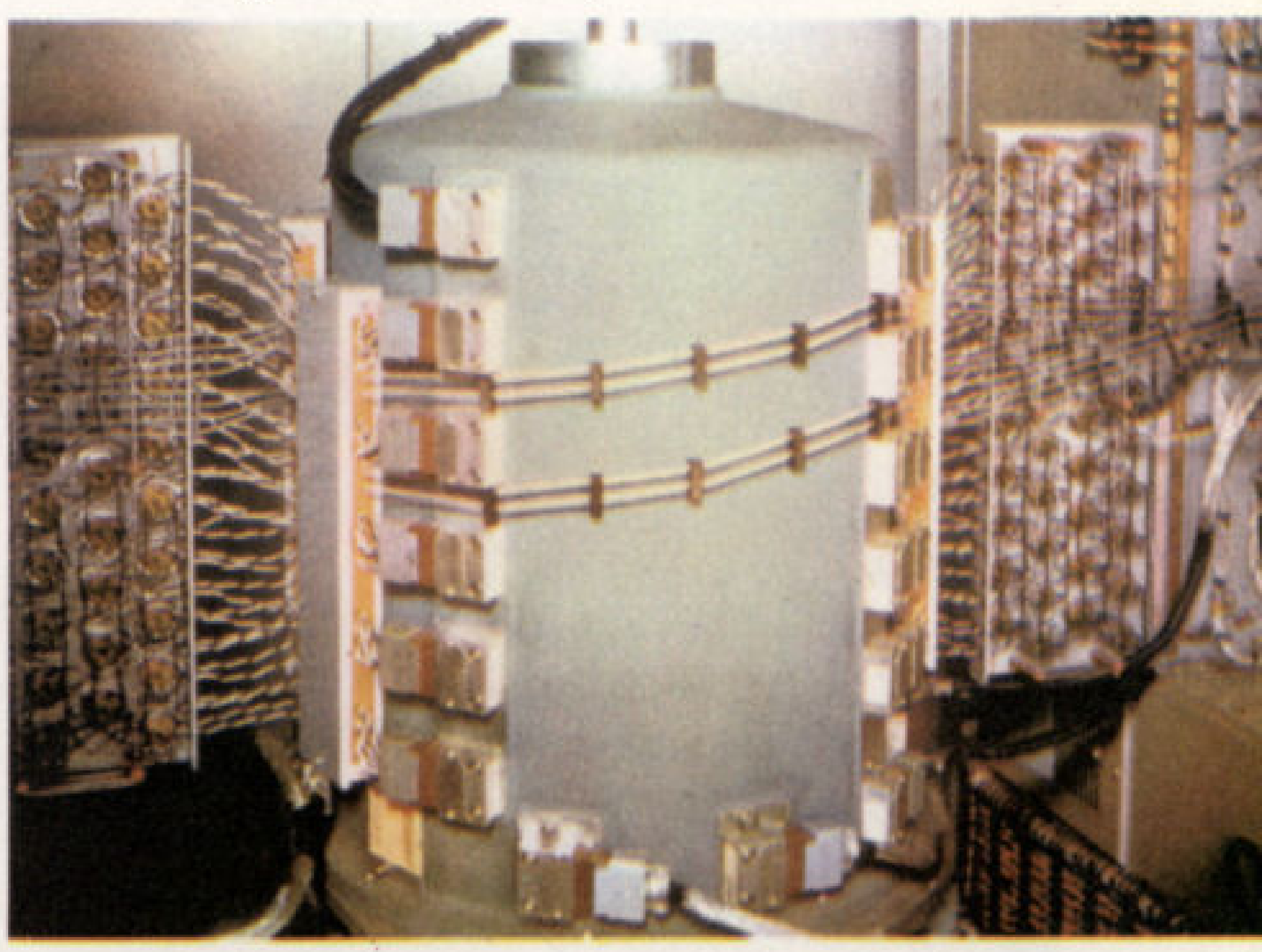
.142857
.285714
.428571
.571428
.714285
.857142

Do you see the pattern? Each number contains the same digits, in the same order, but starting at a different point in the cycle.

What if you multiply 0.142857 . . . by 7? Your answer will be .999999 . . ., roughly 1 again.

This is just a simple example of the patterns waiting in numbers to be uncovered. Mathematicians are always trying to find new ones. They sometimes even put computers to work on them.

The magnetized drum of the address block.



PRIME NUMBERS

Prime numbers are numbers greater than 1 which can be divided only by themselves or by one. 2, 3, 5, 7 are prime numbers. Is 9? No, it can be divided by 3. Is 11? Yes, and so is 13. As high as you may count, you will continue to find prime numbers scattered along the way.

Men interested in number theory have long been trying to find patterns in the prime numbers. There seems to be no pattern in the way they are scattered among the other numbers. But there may be. Perhaps the pattern will be found.

What you do in number theory is to set up a very simple-sounding problem. Then you try to prove it. And you find that is very hard.

One of these problems (mathematicians call them *conjectures*) is: "Every even number greater than 4 is the sum of two prime numbers."

Think of some even numbers—8, for example. It is the sum of 5 and 3. Or 16. It is the sum of 11 and 5. Take any even number greater than 4. There are two prime numbers which add up to it.

But how do you prove that this is true of every even number?

A JOB FOR COMPUTERS

You can often prove a conjecture by logic. But no one has yet been able to do so with "Even numbers are the sum of two primes."

You can try all the arithmetical possibilities. Some men have worked for years doing this, but the job is endless. And this is where the computers are helpful.

A computer can be set to work adding together prime numbers, to see if they will account for every even number within checking range. The machine can thus "almost prove" the conjecture, though actually its job would never end. For numbers go on to infinity.

The machine can, we say, give the conjecture a "high probability." This will be discussed in statistics (pages 82 to 86).

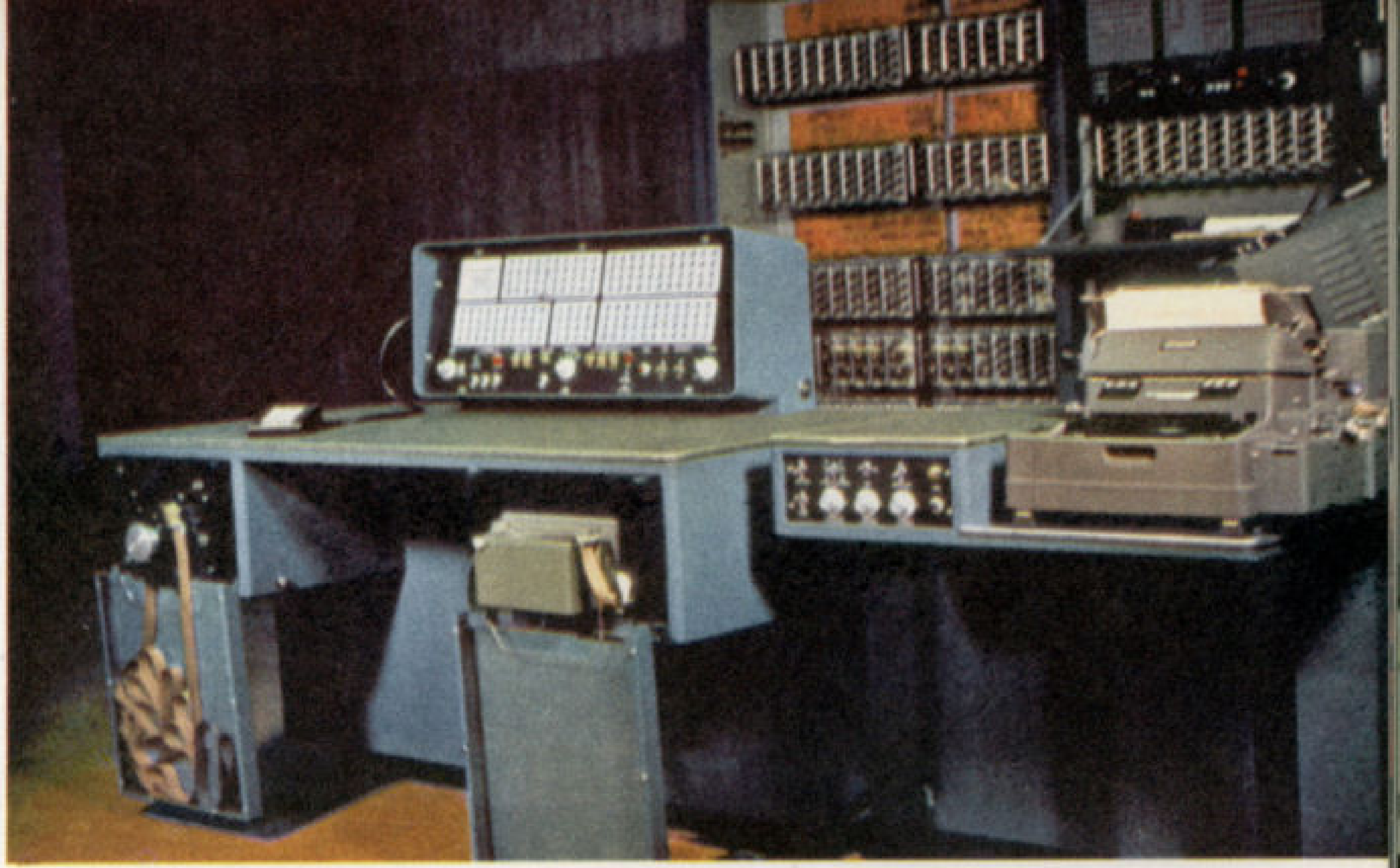
Or it might settle the question by disproving the conjecture, finding an example on the other side. In this case it would have to find an even number which was not accounted for by adding together any pair of primes.

GAME THEORY AND SOCIAL SCIENCE USES

Hundreds of years ago, mathematics and physics were almost the same. Men looked at the physical world around them, and to express very exactly what they saw they built up the language of mathematics.

That was a great work. And it is still under way. For as we shall see in other chapters, man's view of the world is expanding and sharpening every year. But it seemed for a while that the language

The results of the computer are typed out automatically on a special electric typewriter.



This computer installation includes (at left front) magnetic tape; on table top control console showing address boxes; (at right) electric typewriter to type off results.

for describing it had been pretty well worked out. It seemed that all the exciting work of the mathematicians had been done.

Then men began to turn away from counting and measuring and describing things around them. They turned to the world of ideas, of abstractions. And they found many sorts of new excitement there.

One of the directions in which these abstractions led them is called Game Theory. Mathematicians would take a game of checkers, for example. At each move they analyzed the choices. And they figured what strategy or series of plays would give the player the greatest gain.

Gain! That word had a familiar ring. In the world around them, mathematicians saw that everyone was trying to gain more money or power or friends—or whatever they thought was most important to have.

Mathematicians took a logical look at the world of business. And at every step they saw there were choices to be made, just as in a game. Some would lead to gain. Some would not. They wondered how their principles of Game Theory would work in business.

The science of business is called economics. Mathematicians tried to express the basic ideas in their mathematical terms. This was not easy, they found. In business there are so many choices, so many things that change (mathematicians call these choices variables).

This is where computers became important. The computer can take a problem and figure it out with all sorts of different values for each variable. It can take every possible price raw materials might cost and every possible price per hour workmen might demand and all the different factory costs. Using this information it can find out what price will have to be charged for a product, so the factory can make a profit.

This sort of figuring would take a very great deal of time, done by hand. But as we know, the computer can do many thousands of problems in a second.

So computers are opening up a whole new field in economics, and also in psychology and other sciences we call the social sciences. These sciences have to do with the study of society, of people and how they live together. They are much younger sciences than the physical and natural sciences covered in this book.

Look at the front page of any newspaper, and you will see that people do not get along as well as they should, at home, in school, at work, on the highways, in governments.

We need to learn much more about the social sciences quickly. And electronic computers may be a great help.

Another branch of mathematics at work in the social sciences, one which also makes excellent use of computers, is statistics, which we shall take a look at next.