BRAINIACS® —

The 1958 Experiments

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Introduction

Our Brainiacs, Geniacs, and Tyniacs - small electric brain machines - have now been evolving since 1950. That year we completed Simon, a complete miniature automatic digital computer using 129 relays, and started on "Simon Half", a simple construction kit for an electric brain.

The first 33 Brainiacs were called Geniacs No. 1 to No. 33, and were published in 1955; they are the same as Brainiacs No. 1 to No. 33. The next 13 Brainiacs (1956) were called Tyniacs No. 1 to No. 13; they are the same as Brainiacs No. 34 to No. 46. The third installment (1957) of 60 small machines or experiments were called "Brainiacs - the New Experiments" and were numbered S1 to S9, Q1 to Q16, C1 to C24, L1 to L5, and M1 to M6; they are the same as Brainiacs No. 47 to No. 106 respectively. The 45 additional machines (1958) are Brainiacs No. 107 to No. 151.

Many of these 1958 Brainiacs have the same circuit diagrams as previous machines, because of the limited variety of simple circuits; so they can be constructed by simply changing appropriately the labels (of switches, positions, and lamps) for a previous machine. About 25 of the 1958 Brainiacs require new circuit diagrams which are here given.

Brainiacs No. 132 to 144 constitute a considerable introduction to the algebra of logic, also called Boolean algebra, named after George Boole, a great English mathematician who lived 1815 to 1864. This algebra is a technique for manipulating AND, OR, NOT, and conditions, statements, or classes. This algebra is becoming rather important in the design of circuits for computing and controlling. In this connection, please see also Brainiacs L1 and L2 in the 1957 collection.

Brainiacs No. 125 to 128 relate to what is called the mathematical theory of groups, but simply give some interesting examples, to stir curiosity.

We hope that you will be amused and entertained, and will find your curiosity whetted by these Brainiacs. We shall be glad to hear from you if you have comments, suggestions, corrections, or new experiments.

Newtonville, Mass
August, 1958

Edmund C. Berkeley

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<u>Section 5. Miscellaneous Machines</u>
(including Signaling and Game-Playing)

E X P E R I M E N T S

107. ATOMIC REACTOR

Problem: An atomic reactor is controlled by the degree to which control rods are in or out of the reactor. It has a warning lamp DANGER. Connected to the rods is an electric sensing button which will light the lamp when the rods are positioned in an unsafe position.

Design a machine which will express the condition.

Solution: The machine will have one switch POSITION OF RODS, which has two switch positions OK, UNSAFE. There will be one lamp marked DANGER.

The circuit diagram is the same as Tyniac No. 1, with the labels appropriately changed.

108. PUFFIN BAY SIGNALING SYSTEM

Problem: In Puffin Bay there is a lighthouse on a rock about a mile from shore, and a coast guard station on the adjacent mainland. Between them is a cable. At each end, there is a key switch, and a signal light. The lighthouse can signal the land station, flashing its signal light; and the land station can signal the lighthouse, flashing its signal light.

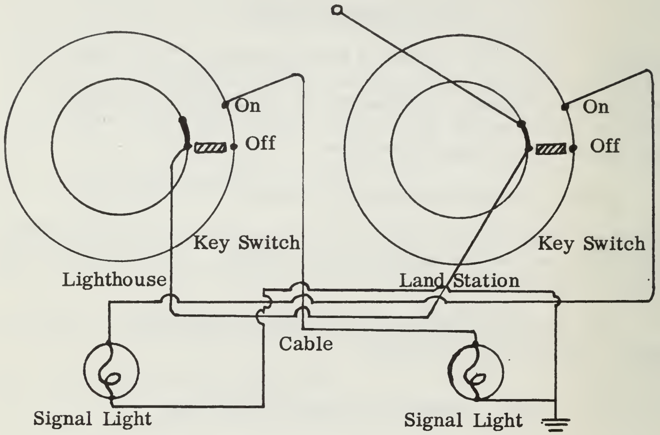
Design a machine which will fulfill these requirements.

Solution: There will be two operating sets, each consisting of one switch and one lamp; one set will be labeled LIGHTHOUSE, the other set will be labeled LAND STATION. Between them will be a cable of four wires. Each of the switches will have two positions OFF and ON. The circuit is shown in Diagram 108.

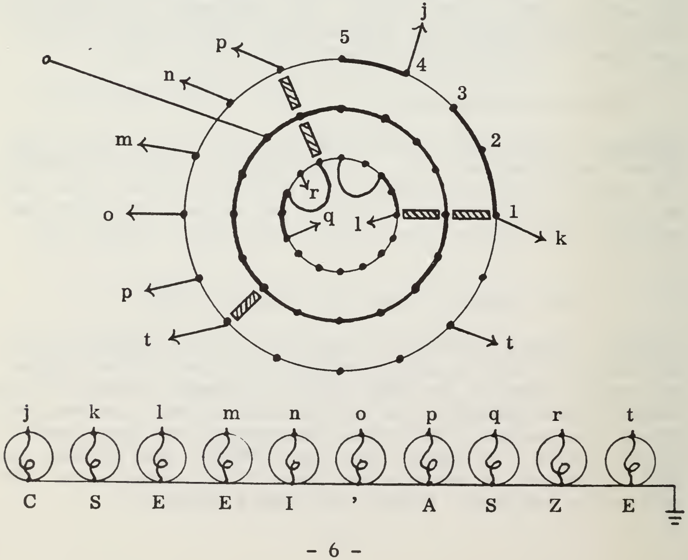
109. BURGLAR ALARM WITH THREE STATIONS

Problem: Hubert Cromwell is positive that if a burglar enters his house, it will be either through the front cellar window, or through jimmying the front door, or through cutting the wire screening and unhooking the kitchen screen door. He sets electrical devices which will detect whether any of these three things happen. He desires two lamps GREEN -- ALL IS WELL, and RED -- BURGLAR, to shine on the front of his house where the police can see them. Design the circuit required.

108. PUFFIN BAY SIGNALING SYSTEM



113. FIVE WORDS THAT SOUND ALIKE



Solution: There will be three switches FRONT CELLAR WINDOW, FRONT DOOR and KITCHEN SCREEN DOOR, each with two positions SHUT and FORCED OPEN. The two lamps have been mentioned. The circuit is the same as Brainiac S5 with the labels changed appropriately.

110. MARIA BENEDETTO'S PERMISSION TO GET MARRIED

Problem: Maria Benedetto can get married only if her mother, Doria, her two Italian grandmothers, Felicia and Fidelia, and her mother's two sisters, Angelina and Alicia, all see the young man, and give their explicit OK.

Design a machine which will show when she can get married.

Solution: There will be five switches DORIA, FELICIA, FIDELIA, ANGELINA, and ALICIA. Each switch will have two positions NO and OK. There will be one lamp, MARIA'S MARRIAGE APPROVED. The circuit is the same as Brainiac S3, with the labels changed appropriately.

111. STREET LIGHTING IN DUNTOWN

Problem: The city of Duntown desires to have its street lamps lighted between a half hour after sunset and a half hour before sunrise, except that when it is darker than a certain standard, the lights should also go on.

Design the circuit.

Solution: There will be two switches. One switch will be TIME OF DAY, with two positions, one BETWEEN HALF HOUR AFTER SUNSET AND HALF HOUR BEFORE SUNRISE, and the other position OTHER TIMES. The second switch will be BRIGHTNESS, with two positions, DARKER THAN A CERTAIN STANDARD, and NOT SO DARK. There will be one lamp labeled STREET LIGHTS LIGHTED. The circuit will be the same as Brainiac S4, with appropriate changes in the labels.

112. PARADISE OR VIOLENT DEATH

Problem: The King of Sandillia has installed a garden of paradise in a secluded valley in his kingdom. He requires each of his prime ministers, after three years in office, to choose one of five corridors in his palace. Four of the corridors lead to precipitous drops into space off mountain-sides, the fifth to the garden of paradise.

Set up these conditions in a machine.

Solution: There will be one switch labeled CHOICE OF CORRIDOR with five positions 1, 2, 3, 4, 5. There will be two lamps, one marked VIOLENT DEATH, the other PARADISE. Connect one of the switch points to the PARADISE lamp, the other four to the VIOLENT DEATH lamp. Let no one know how you have wired your machine. After your friend as prime minister has chosen his corridor, turn the on-off switch to "on", to show the effect of his choice.

113. FIVE WORDS THAT SOUND ALIKE

Problem: There are five words that sound almost exactly alike. Their meanings are: (1) oceans; (2) take; (3) regards; (4) plural of a letter of the alphabet; (5) stop.

Set up a machine that will shine these words in lights.

Solution: There will be one switch MEANING OF WORD with five positions 1, 2, 3, 4, 5. There will be ten lamps C, S, E, E, I, ', A, S, Z, E. The circuit appears in the diagram.

114. WORD PUZZLE WITH C

Problem: Using the nine letters C, D, E, I, P, R, S, T, U, words with the following meanings can be made:

1. a point
2. small open containers
3. severs
4. a god of love
5. tooth with one projection
6. hints
7. dogs
8. short

Design a machine which will show these words.

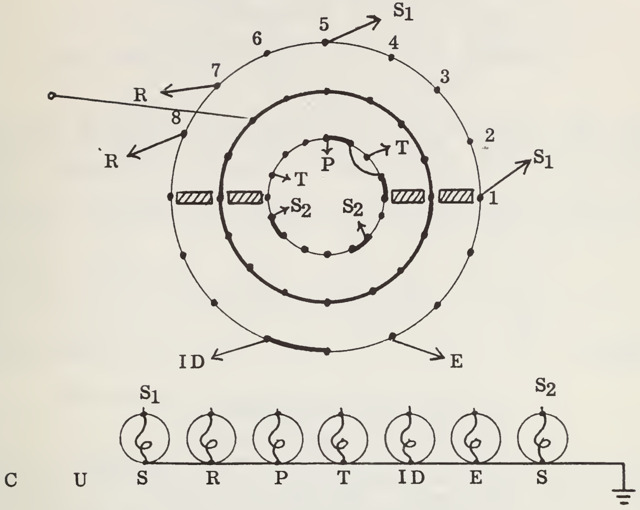
Solution: There will be one switch MEANING OF WORD with eight positions 1 to 8. There will be two labels C, U, at the left, and seven lamps to the right of them with labels S, R, P, T, ID, E, S. The circuit appears in the diagram. (The answers are: CUSP, CUPS, CUTS, CUPID, CUSPID, CUES, CURS, CURT, respectively.)

115. PLANETS OF THE SOLAR SYSTEM

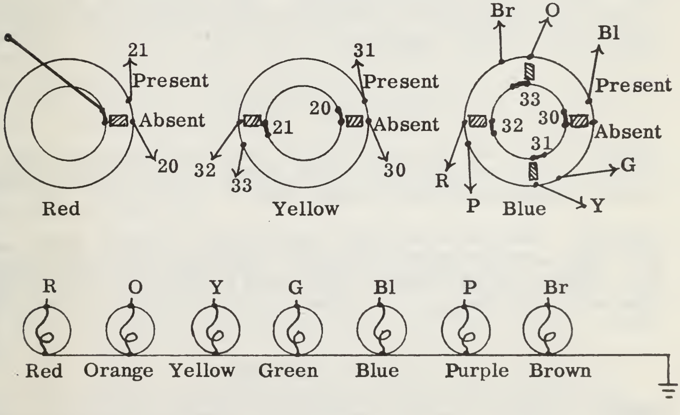
Problem: Make a machine which will answer the following questions:

1. Which planet is farthest from the sun?

114. WORD PUZZLE WITH C



117. COLOR MIXING



2. Which planet is nearest to the earth?
3. Which planet has no atmosphere?
4. Which planet is the biggest?
5. Which planet has a ring around it?
6. Which planet is the most likely to be first visited by men?

Solution: There will be one switch labeled QUESTION, with six positions 1 to 6. There will be six lamps labeled PLUTO, VENUS, MERCURY, JUPITER, SATURN, MARS. (These are the answers to the six questions, respectively.) The circuit diagram is the same as Brainiac Q10, except that positions and lamps 7, 8, 9, 10 are not used.

116. A GEOLOGY QUIZ

Problem: Make a machine which will answer the following questions:

1. In what era was the most coal deposited?
2. What was the earliest horse?
3. What was the largest dinosaur?
4. What was the earliest common crustacean?
5. What was the earliest known bird?
6. What great prehistoric animal is occasionally found frozen and undecayed in the Arctic?

Solution: The solution is the same as the preceding solution, with labels changed appropriately. (The answers to the questions are, CARBONIFEROUS, EOHIPPUS, GIGANTOSAURUS, TRILOBITE, ARCHEOPTERYX, WOOLLY MAMMOTH).

117. COLOR MIXING

Problem: What are the colors which you obtain by mixing any one or more of red, yellow, and blue, the three primary colors? Design a machine which will show them.

Solution: There will be three switches RED, YELLOW, BLUE, each with two positions ABSENT, PRESENT. There will be seven lamps RED, ORANGE, YELLOW, GREEN, BLUE, PURPLE and BROWN. The circuit appears in the diagram.

118. VOLCANO QUIZ

Problem: Design a machine which will answer the following questions:

1. What volcanic explosion caused an island to disappear, and was heard for 2500 miles?
2. What volcano caused 30,000 deaths in the West Indies?
3. What was the greatest volcanic explosion in historic times?
4. What volcano destroyed Pompeii?
5. What is the most famous volcano in Europe?
6. What is the highest volcano in Africa?
7. What is the only volcano in the United States?

Solution: There will be one switch labeled QUESTION with seven positions 1 to 7. There will be seven lamps labeled KRAKATOA, 1883; MONT PELEE, 1902; TAMBORA, 1815; MONTE SOMMA, 79 A.D.; VESUVIUS; KILIMANJARO; LASSEN. (These are the answers to the seven questions, respectively). The circuit diagram is the same as Brainiac Q10, except that positions and lamps 8, 9, 10 are not used.

119. GUESSING A LADY'S AGE

Problem: You have a friend who won't tell how old she is. However, you believe she can be persuaded to answer four questions verbally "yes" or "no" about her age; and you also believe that you can judge what ten-year interval of age (decade) she is in.

Design a machine which will tell how old she is.

Solution: Here is one of many designs. Switch A asks the question: "Does the last digit of your age end in 2, 3, 6, 7, 8, or 9?" Switch B asks the question: "Is your age an odd number?" Switch C asks the question: "Does your age end in 0, 1, 2, or 3?" Switch D asks the question: "Does your age end in 6 or 7?" Each switch will have two positions, YES and NO.

There will be ten lamps numbered with the digits 0 to 9 (the last digit of the lady's age, if she has answered the questions truthfully).

After your friend has answered these questions, take a good look at her, and estimate what decade she is probably in; for example if the lamp that lights is a 5, you should be able to tell by looking at her whether her age is 35, or 45, or 55, etc.

The circuit is the same as the circuit for Brainiac Q5, with appropriate changes of labels.

120. THE IDENTIFICATION OF GOLD

Problem: John O'Leary, prospector, finds a rock with golden yellow particles in it. Is this gold, or altered mica, or pyrite (fool's gold, iron sulphide) or chalcopyrite (copper iron sulphide)?

Design a machine which will identify the specks for him as gold if they are gold.

Solution: There will be three switches, one for each of the following questions; each switch will have two positions, YES, NO.

1. SOFT: Are the golden particles in the rock easily scratched and grooved with a knife? (If yes, may be altered mica, chalcopyrite, or gold; if not, pyrite.)
2. HEAVY: If the particles are mixed with iron fillings in a little glass bottle, do they sink to the bottom? (If yes, probably gold; if not, probably pyrite or chalcopyrite; if float on top, mica.)
3. MALLEABLE: If a particle is gently hammered with a hammer, does it spread out, is it malleable? (If yes, it is gold; if it crushes into a powder, it is not gold.)

There will be one lamp IT IS GOLD. The circuit is the same as Brainiac S2, with appropriate changes of labels.

121. LATIN AND GREEK NUMBER PREFIXES

Problem: Many English words have prefixes that come from the Latin or the Greek. Some common prefixes express number.

Design a machine which will take in the numbers "half, one, two, five, ten, hundred, thousand, many, first" and indicate the Latin or Greek prefix that has that meaning.

Solution: There will be one switch NUMBER with nine positions, one for each number given above. There will be nine lamps. On the first row under each lamp will be the prefix from the Latin; on the second row under each lamp will be the prefix from the Greek.

English (Switch Position)	Latin (Lamp)	Greek (Lamp)
half	semi	hemi
one	uni	mono
two	bi	di

five	quint	penta
ten	deci	deca
hundred	centi	hecto
thousand	milli	kilo
many	multi	poly
first	prim	proto

The circuit is the same as the diagram for Brainiac C18, with appropriate changes of labels.

122. GOOD BETS IN SPELLING

Problem: All English words contain a selection of 43 sounds. There are however only 26 letters to spell them with. Some sounds though can be spelled in one and only one way. These include the sounds b, d, h, l, m, n; if you hear one of these sounds, it is a sure bet that it is spelled using that letter. Some of the other sounds in English words are very good bets. For example, the sound "f" as in "if", is spelled in only three ways; the sound "ng" as in "sing" is spelled in only two ways; the sound "oi" as in "poison" is spelled in only two ways.

Design a machine which will show the good bets for spelling the sounds f, ng, and oi.

Solution: The machine will have one switch labeled ENGLISH SOUND with seven positions: f, 1st spelling; f, 2nd spelling; f, 3rd spelling; ng, 1st spelling; ng, 2nd spelling; oi, 1st spelling; oi, 2nd spelling. There will be seven lamps. The lamps will have labels as follows:

1. Spelled "f", in many short words, and all words from Latin; as in "fox, muff, confident"
2. Spelled "ph" in many words nearly all from Greek; "nymph, graph, telephone"
3. Spelled "gh"; rare; about eight words from Anglo Saxon, and only as the final sound; "cough, rough, tough, laugh, enough, trough, draught, slough"
4. Spelled "ng" almost always; "sing, finger, singer, anger"
5. Spelled "n", in a few words before the sound "k"; "ink, conquer"
6. Spelled "oi" often, usually initial or medial; "oil, poison, avoid"
7. Spelled "oy", usually final, rarely not final; "boy, toy, oyster"

The circuit is the same as for Brainiac C18 or C19, with appropriate changes of labels.

123. EMPLOYMENT IN A COTTON MILL

Problem: The number of persons employed in the Rogers Cotton Mill in Wollaston is reported as follows:

	Married	Unmarried
Male	301	493
Female	582	674

Design a machine which will tell the total number of males, females, married, unmarried and total employees.

Solution: There will be three switches, one with positions MALE, FEMALE, TOTAL, and the other with positions, MARRIED, UNMARRIED, TOTAL. There will be five lamps: TOTAL MALE, TOTAL FEMALE, TOTAL MARRIED, TOTAL UNMARRIED, TOTAL EMPLOYEES. The circuit is shown in the diagram.

124. EMPLOYMENT ON A RAILROAD

Problem: The number of persons employed on the Oklahoma and Alaska Railroad is reported as follows:

	White		Non-White	
	Married	Unmarried	Married	Unmarried
Males	328	225	425	317
Females	193	137	154	132

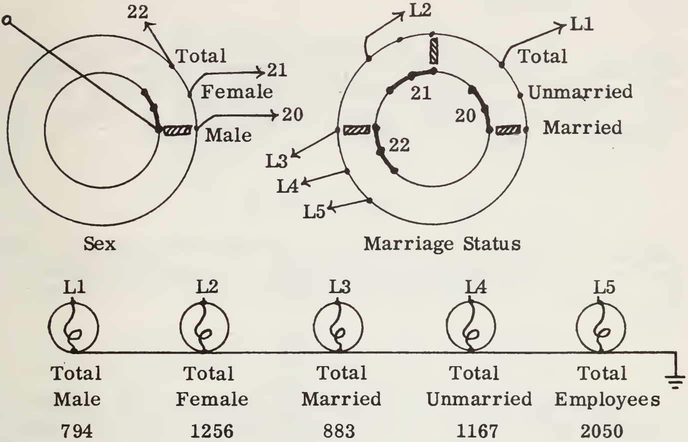
Design a machine which will tell the total number of males, females, married, unmarried, white, and non-white, and total employees.

Solution: There will be three switches: one, with positions MALE, FEMALE, TOTAL; the second, with positions MARRIED, UNMARRIED, TOTAL; and the third, with positions WHITE, NON-WHITE, TOTAL. There will be seven lamps: TOTAL MALE, TOTAL FEMALE, TOTAL MARRIED, TOTAL UNMARRIED, TOTAL WHITE, TOTAL NON-WHITE, TOTAL EMPLOYEES. The circuit is shown in the diagram.

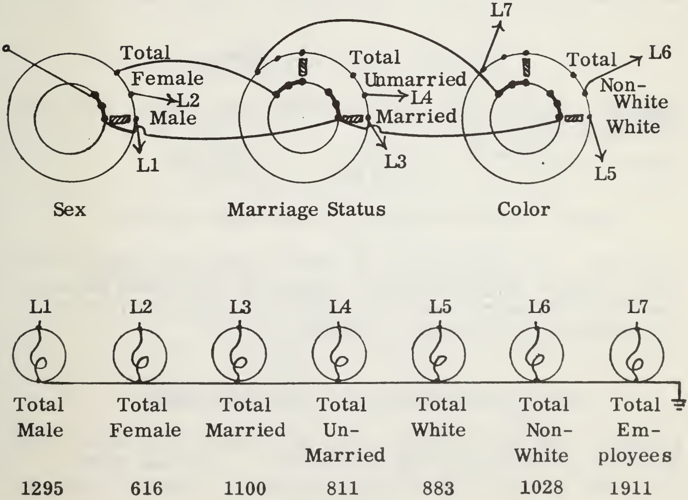
125. TURN OVER, AND TURN AROUND

Problem: Tom Adler, math student, notices that if he takes a rectangle, he can turn it over, or turn it around, or both, and that he will still have a rectangle of the same shape and in the same position as he had to begin with. He marks the original rectangle with the letter R, and notices what happens in each of the four positions with each operation.

123. EMPLOYMENT IN A COTTON MILL



124. EMPLOYMENT ON A RAILROAD



Design a machine which will show what happens to the R for each operation.

<u>Solution</u>: There will be one switch POSITION OF R which will have four positions, R, Я, ꓤ, ᴚ, and a second switch OPERATION which will have three positions TURN OVER, TURN AROUND, and BOTH. There will be four lamps labeled R, Я, ꓤ, ᴚ showing the results. The circuit is shown in the diagram.

126. 2 AND -1 AND ½

<u>Problem</u>: Tom Adler notices that if he takes the number 2, and applies to it the operations ONE MINUS ..., and ONE DIVIDED BY ..., and their repetitions, he obtains only 2, -1, ½, because:

$$1 - (2) = -1, \quad 1 - (-1) = 2, \quad 1 - (\tfrac{1}{2}) = \tfrac{1}{2}$$
$$1 \div (2) = \tfrac{1}{2}, \quad 1 \div (\tfrac{1}{2}) = 2, \quad 1 \div (-1) = -1$$

Design a machine which can be set at any of the numbers 2, -1, ½, and at either of the operations ONE MINUS ..., and ONE DIVIDED BY ... and which will show the correct result.

<u>Solution</u>: There will be two switches, one NUMBER, with the positions 2, -1, ½, and the other OPERATION, with the two positions ONE MINUS ..., and ONE DIVIDED BY .... There will be three lamps 2, ½, -1. The circuit is shown in the diagram.

127. ONE, ZERO, AND INFINITY

<u>Problem</u>: Wondering if there are any other numbers like this, Tom Adler notices that:

$$1 - 1 = 0 \quad 1 - 0 = 1 \quad 1 - \infty = \infty$$
$$1 \div 1 = 1 \quad 1 \div 0 = \infty \quad 1 \div \infty = 0$$

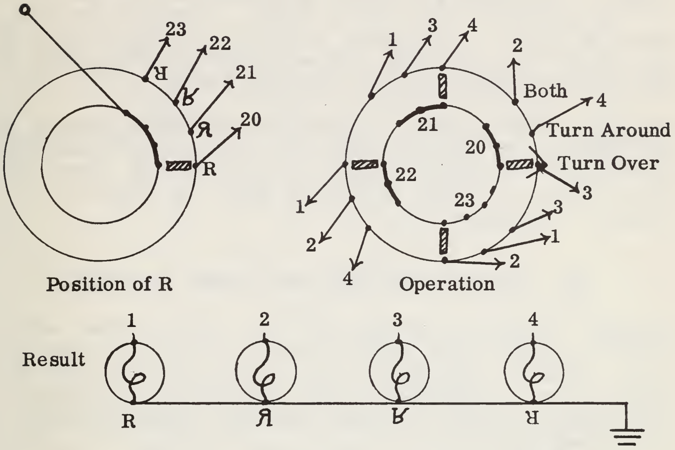
Design a machine which will show these results.

<u>Solution</u>: The same machine as for the preceding problem will apply, except that the labels change and the wiring between the OPERATION switch and the lights is slightly different. The changes can be readily reasoned out.

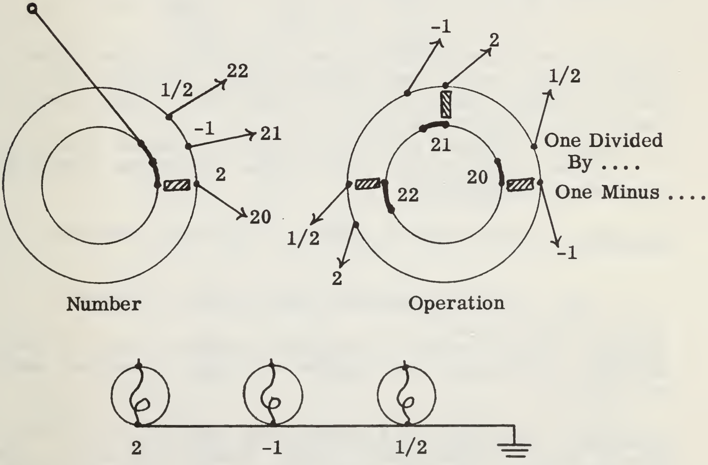
128. ONE DIVIDED BY ..., AND ONE MINUS ...

<u>Problem</u>: Tom Adler notices that if he takes the number 4 and applies the operations ONE DIVIDED BY ... and ONE MINUS ... to 4, and to any of the numbers yielded by repeated applica-

125. TURN OVER, AND TURN AROUND



126. 2 AND -1 AND 1/2



tions of these operations, the only numbers that he gets are 4, -3, 1/4, -1/3, 4/3, and 3/4. He notices that if n is any number, then the only different operations that he gets are 1-n, 1/n, 1/(1-n), n/(n-1), and (n-1)/n. He wants a machine which he can set at any number 4, -3, 1/4, -1/3, 4/3, 3/4 and any of the five operations, and which will show the result of the selected operation on the selected number.

Solution: There will be two switches, one NUMBER with the six positions 4, -3, 1/4, -1/3, 4/3, 3/4 and the other OPERATION with the five positions 1-n, 1/n, 1/(1-n), n/(n-1), (n-1)n. There will be six lamps 4, -3, 1/4, -1/3, 4/3, 3/4. The circuit is shown in the diagram.

129. ANOTHER TRANSLATOR FROM DECIMAL TO BINARY

Problem: Numbers may be expressed not only in decimal notation, the scale of ten using the digits 0 to 9, but also in binary notation, notation in the scale of two using only the digits 0 and 1. Following is the translation of the first ten numbers in decimal notation into their equivalents in binary notation:

Decimal	Binary	Decimal	Binary
0	0	5	101
1	1	6	110
2	10	7	111
3	11	8	1000
4	100	9	1001

In binary notation the positions of the digits count, from right to left, units, twos, fours, eights, sixteens, etc. Thus the binary number 1101 is 1 eight, plus 1 four, plus 0 twos, plus 1 one, or thirteen.

Design a machine which will accept any number from 0 to 9 in decimal notation and shine in four lights its translation into binary notation.

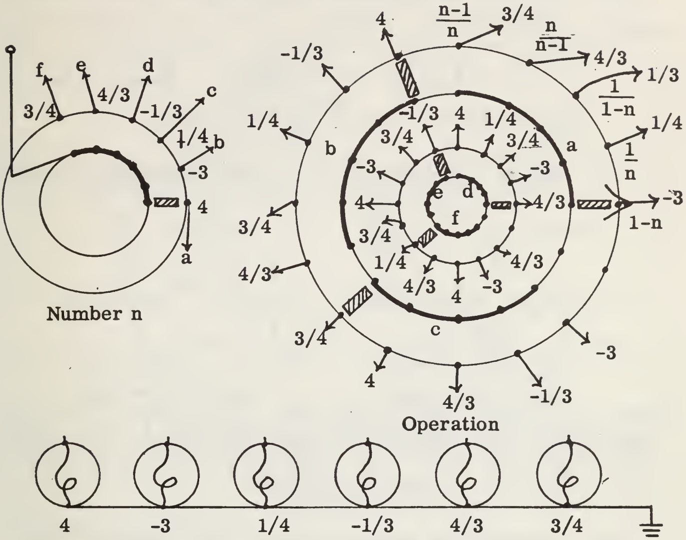
Solution: The solution is shown in the circuit diagram.

130. ANOTHER TRANSLATOR FROM BINARY TO DECIMAL

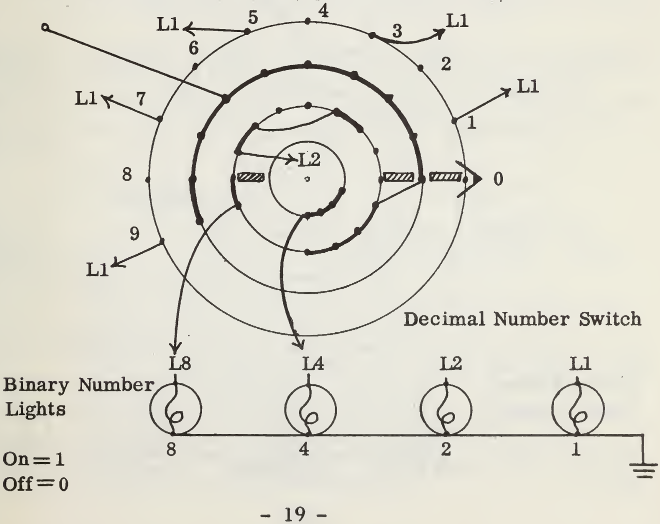
Problem: Given any one of the binary numbers from 0 to 1001, design a machine which will shine in lights the decimal number 0 to 9.

Solution: There will be four switches, one for each of the binary digits: BINARY EIGHTS DIGIT, BINARY FOURS DIGIT, BINARY TWOS DIGIT, and BINARY ONES DIGIT. Each of these switches

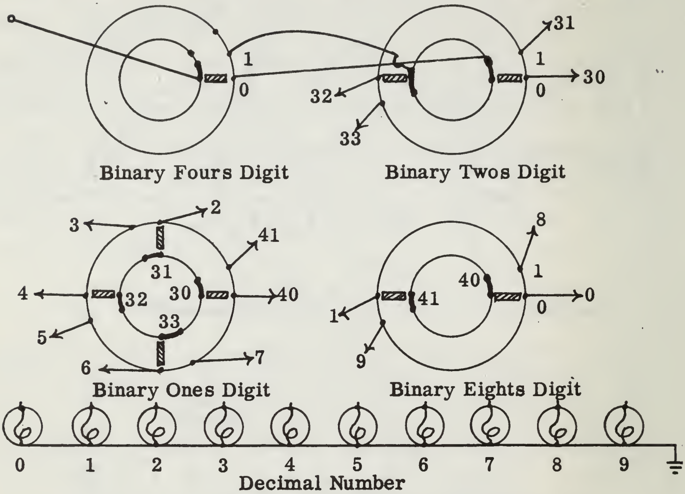
128. ONE DIVIDED BY ..., AND ONE MINUS ...



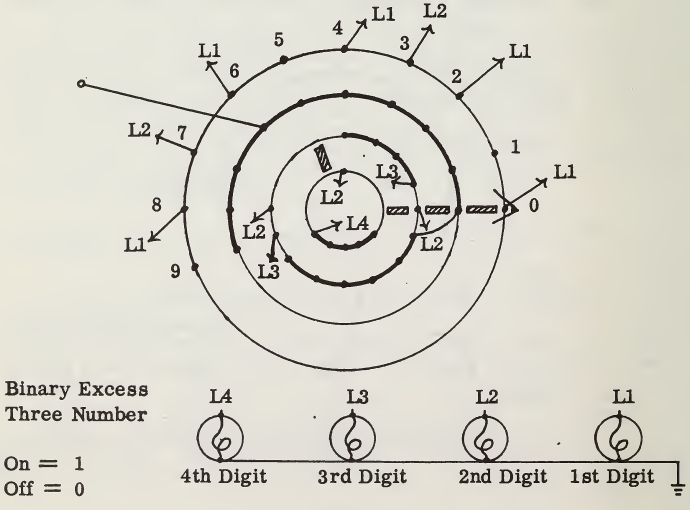
129. ANOTHER TRANSLATOR FROM DECIMAL TO BINARY



130. ANOTHER TRANSLATOR FROM BINARY TO DECIMAL



131. TRANSLATOR FROM DECIMAL INTO EXCESS THREE



will have two positions, 0 or 1. There will be ten lights labeled 0 to 9. The circuit appears in the diagram. Note that this machine will not translate correctly binary numbers greater than 1001.

131. TRANSLATOR FROM DECIMAL TO EXCESS THREE

Problem: The codes for the decimal digits 0 to 9 in what is called "binary excess three" code are as follows:

0	0011	5	1000
1	0100	6	1001
2	0101	7	1010
3	0110	8	1011
4	0111	9	1100

Design a machine which will translate from decimal to binary excess three.

Solution: There will be one switch DECIMAL NUMBER, with positions 0 to 9. There will be four lamps for the four digits of the binary excess three code, from left to right 4TH DIGIT, 3RD DIGIT, 2ND DIGIT, 1ST DIGIT. If a lamp is lighted the digit is 1; if it is not lighted the digit is 0. The circuit appears in the diagram.

132. THE MAIN CONCEPTS OF BOOLEAN ALGEBRA

Problem: Professor Higgins is giving a course in the algebra of logic in Edinburgh University. One day he assigns his students to bring in the next day the answer to "What are the nine important concepts of Boolean algebra, the algebra of classes?"

Design a machine which will answer this question.

Solution: There will be one switch IMPORTANT CONCEPTS OF BOOLEAN ALGEBRA. It will have nine positions 1 to 9. There will be 9 lamps labeled as follows:

1. CLASSES: letters a, b, c, and so forth, stand for classes of things (not numbers)
2. EQUALITY: a = b, a EQUALS b; true if and only if the things contained in the class a are the same things that are contained in class b
3. INEQUALITY: a ≠ b, a DOES NOT EQUAL b; true if and only if there is at least one thing contained either in the class a or the class b which is not contained in the other one.

4. LOGICAL SUM: a v b, read a OR b; meaning a OR b OR BOTH; denoting the class of things contained either in the class a or in the class b or in both.
5. LOGICAL PRODUCT: a·b, or ab, read a AND b; meaning BOTH a AND b; denoting the class of things contained both in the class a and in the class b.
6. THE NULL CLASS: 0; nothing; emptiness; the class which contains nothing
7. THE UNIVERSE CLASS: 1; all; everything; the class which contains all the things being discussed
8. LOGICAL NEGATIVE: a', read a prime, or NOT-a; the class of things being discussed that are NOT contained in the class a
9. LOGICAL INCLUSION: a∊b, read "a is in b", or "a lies in b"; true if and only if all the things contained in a are contained also in the class b

The circuit is the same as the diagram for Brainiac C18, with appropriate changes of labels. It may be desirable to mount the lamp socket vertically, so that adequate labels may be placed next to the lamps. See diagram C19.

133. TRANSLATION INTO STANDARD EXPRESSIONS OF BOOLEAN ALGEBRA

Problem: In another lecture, Professor Higgins writes the following 16 expressions on the blackboard, and asks his students to translate them correctly into standard Boolean expressions:

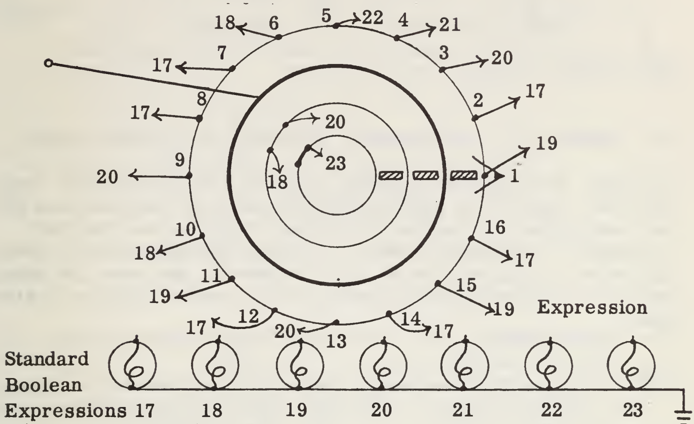
1. A's except B's
2. A's, also B's
3. A's or else B's
4. not both A's and B's
5. neither A's nor B's
6. what are both A's and B's
7. A's or B's
8. A's and B's
9. A's or B's but not both
10. A's that are B's
11. A's without B's
12. A's, B's
13. either A's or B's
14. A's or B's or both
15. A's excluding B's
16. A's and/or B's

Standard Boolean expressions use: OR meaning the inclusive "or", "and/or"; AND meaning "both ... and ..."; NOT; and parentheses (used in the mathematical sense) to mark grouping.

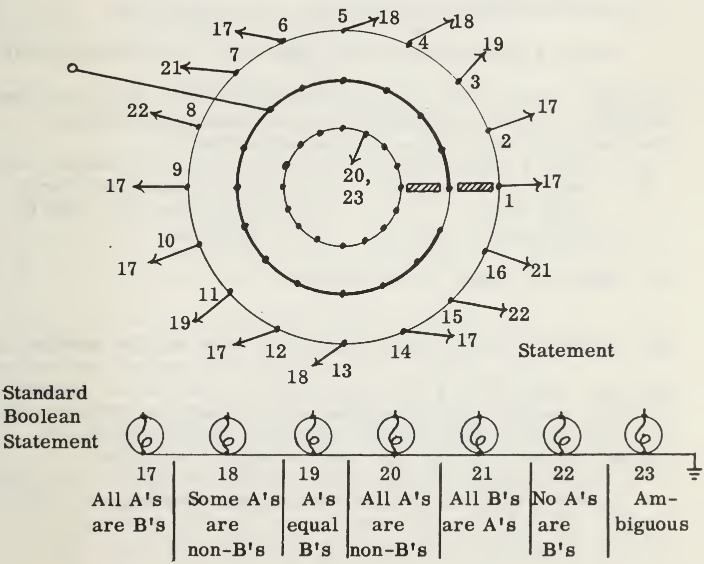
Design a machine which will give the correct translation.

Solution: There will be one switch EXPRESSION, with 16 positions numbered 1 to 16 corresponding with the expressions above. There will be seven lamps as follows:

133. TRANSLATION INTO STANDARD EXPRESSIONS OF BOOLEAN ALGEBRA



134. TRANSLATION INTO STANDARD STATEMENTS OF BOOLEAN ALGEBRA



17. A's OR B's; $A \vee B$
18. A's AND B's; $A \cdot B$
19. A's AND NOT-B's; $A \cdot B'$
20. (A's AND NOT-B's) OR (B's AND NOT-A's); $A \cdot B' \vee B \cdot A'$
21. NOT-(A's AND B's); $(A \cdot B)'$
22. NOT-A's AND NOT-B's; $A' \cdot B'$
23. Ambiguous

The circuit is shown in the diagram.

134. TRANSLATION INTO STANDARD STATEMENTS OF BOOLEAN ALGEBRA

Problem: In Professor Higgins' course in the algebra of logic (Boolean algebra) in Edinburgh University, he lectures one day on translating statements of ordinary English into standard statements in Boolean algebra. Professor Higgins writes the following 16 expressions on the blackboard, and asks his students to translate them correctly into standard Boolean statements.

1. A's are B's.
2. The A's are B's.
3. It is an A if and only if it is a B.
4. A's are not B's.
5. Not all A's are B's.
6. If it is an A, it is a B.
7. It is an A if it is a B.
8. None of the A's are B's.
9. It is an A only if it is a B.
10. A's are included in B's.
11. The A's are the B's.
12. Every A is a B.
13. Not every A is a B.
14. Any A is a B.
15. Not any A is a B.
16. A's include B's.

Design a machine which will give the correct translation.

Solution: There will be one switch EXPRESSION, with positions numbered 1 to 16 corresponding to the expressions above. There will be seven lamps labeled as follows:

17. All A's are B's; $A \subset B$.
18. Some A's are non-B's; $A \cdot B' \neq 0$
19. A's equal B's; $A = B$.
20. All A's are non-B's; $A \subset B'$
21. All B's are A's; $B \subset A$
22. No A's are B's; $AB = 0$
23. Ambiguous

The circuit is shown in the diagram.

135. SUMMARY OF RULES FOR CALCULATING WITH BOOLEAN ALGEBRA -- I

Problem: One day in Professor Higgins' class in the algebra of logic, he gives his students the assignment of bringing in the next day a summary of the rules for calculating with Boolean algebra that do not involve logical negation.

Design a machine that will solve this problem.

Solution: There will be one switch RULE with seven positions 1 to 7. There will be seven lamps labeled as follows:

1. COMMUTATIVE LAW: $a \vee b = b \vee a$; $ab = ba$
2. ASSOCIATIVE LAW: $(a \vee b) \vee c = a \vee (b \vee c)$; $(ab)c = a(bc)$
3. DISTRIBUTIVE LAW: $a(b \vee c) = ab \vee ac$; $a \vee bc = (a \vee b)(a \vee c)$
4. LAW OF TAUTOLOGY: $a \vee a = a$; $a \cdot a = a$
5. LAW OF ABSORPTION: $a \vee ab = a$; $a(a \vee b) = a$
6. LAWS INVOLVING THE NULL CLASS: $a \vee 0 = a$; $a \cdot 0 = 0$
7. LAWS INVOLVING THE UNIVERSE CLASS: $a \vee 1 = 1$; $a \cdot 1 = a$

The circuit is the same as the diagram for Brainiac C18 with appropriate changes of labels.

136. SUMMARY OF RULES FOR CALCULATING WITH BOOLEAN ALGEBRA — II

Problem: The next day Professor Higgins assigns to his students presenting a summary of the remaining rules for calculating with Boolean algebra.

Design a machine that will solve this problem.

Solution: There will be one switch RULE with ten positions. There will be 10 lamps labeled as follows:

1. EVERYTHING IS a OR NOT-a: $1 = a \vee a'$; $1 = (a \vee a')(b \vee b')(c \vee c')\ldots\ldots$
2. NOTHING IS BOTH a AND NOT-a: $0 = a \cdot a'$
3. NEITHER ... NOR: $(a \vee b)' = a' \cdot b'$; $(a \vee b \vee c\ldots\ldots)' = a' \cdot b' \cdot c'\ldots\ldots$
4. NOT BOTH ... : $(ab)' = a' \vee b'$
5. DOUBLE NEGATIVE: $(a')' = a$
6. $ab \vee ab' = a$; $(a \vee b)(a \vee b') = a$
7. $0' = 1$; $1' = 0$
8. $a \subset b$ is equivalent to $ab' = 0$, or $ab = a$, or $b' \subset a'$
9. $a = b$ is equivalent to $ab' \vee a'b = 0$, or $a \subset b$ and $b \subset a$
10. $x \vee y = 0$ is equivalent to $x = 0$ and $y = 0$

The circuit is the same as the diagram for Brainiac C18, with appropriate changes of labels.

137. THE FINANCIAL, GENERAL, AND LIBRARY COMMITTEES

Problem: Professor Higgins states the following problem (due to John Venn) in the algebra of classes:

> A certain club has the following rules: (1) The financial committee (f) shall be chosen from among the general committee (g). (2) No one shall be a member of both the

general and library committee (b) unless he is also on the financial committee. (3) No member of the library committee shall be on the financial committee. Simplify these rules.

He tells his students to bring in the solution to the problem the next day, worked out in a sequence of steps.

Design a machine that will present the solution to the problem.

<u>Solution</u>: There will be one switch STEP NUMBER with ten positions 1 to 10. There will be 10 lamps, with the following labels:

1. TRANSLATING THE GIVEN CONDITIONS: (a) All <u>f</u> are <u>g</u>: $f \subset g$; $fg' = 0$ (b) All that are both <u>g</u> and <u>b</u> are <u>f</u>: $gb \subset f$; $gbf' = 0$ (c) There are no members both <u>b</u> and <u>f</u>: $bf = 0$.
2. $fg' \vee gbf' \vee bf = 0$: To combine given conditions, put each into a form equal to the null class, and connect with OR.
3. $fg' \vee bf'g \vee bf(g \vee g') = 0$: Using the rule $a = a(c \vee c')$
4. $fg' \vee bf'g \vee bfg \vee bfg' = 0$: Using the rule $a(c \vee c') = ac \vee ac'$
5. $(fg' \vee bfg') \vee (bf'g \vee bfg) = 0$: Regrouping
6. $fg' \vee bg(f \vee f') = 0$: Using $a \vee ac = a$ and $ab \vee ac = a(b \vee c)$
7. $fg' \vee bg = 0$: Using $a \vee a' = 1$ and $a \cdot 1 = a$
8. $fg' = 0$, $bg = 0$: If $x \vee y = 0$, then $x = 0$ and $y = 0$
9. $f \subset g = 0$, $bg = 0$: If $ac' = 0$, then $a \subset c$
10. ANSWER: The rules may be simplified as follows: (1) The financial committee shall be chosen from among the general committee. (2) No member of the general committee shall be on the library committee.

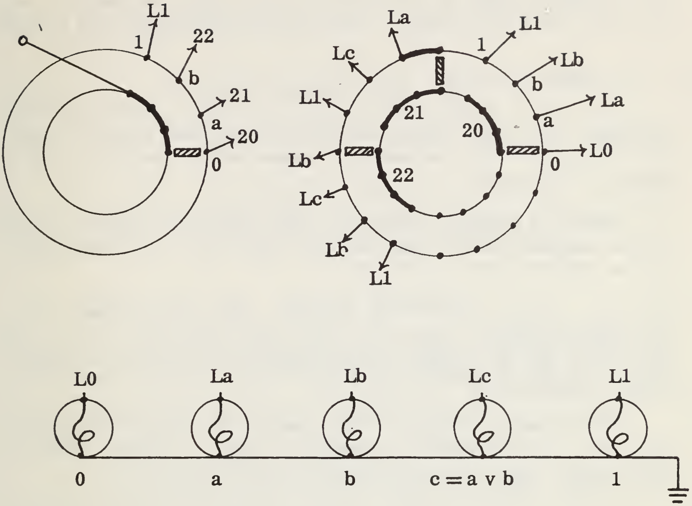
The circuit diagram is the same as diagram C18, with appropriate changes of labels.

138. LOGICAL SUM

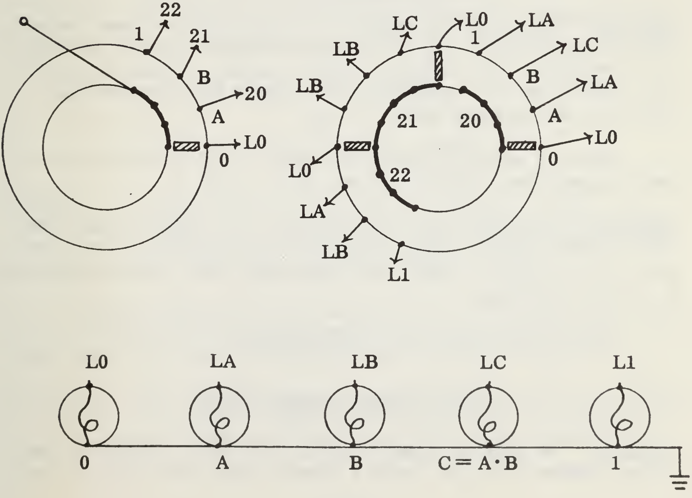
<u>Problem</u>: The logical sum of a class F and a class G is equal to the class every member of which is in F or in G or in both. The logical sum is written F v G where the v stands for the operation "and/or", the "inclusive or". 0 is the null class, the class with no members. 1 is the universe class, the class of all things being discussed.

Design a machine which will give the logical sum of two classes where either one may be 0 or <u>a</u> or <u>b</u> or 1.

138. LOGICAL SUM



140. LOGICAL PRODUCT



Solution: There will be two switches, the FIRST CLASS and the SECOND CLASS. Each will have four positions 0, a, b, 1. There will be five lamps corresponding to the possible logical sums: 0, a, b, c = a v b, and 1. The circuit appears in the diagram.

139. LEAST COMMON MULTIPLE

Problem: The least common multiple of a first number F and a second number G is the smallest number which contains both numbers as factors.

Design a machine which will give the least common multiple of two numbers, where F may be any one of 1, 3, 5, 30, and G may be any one of 1, 3, 5, 30.

Solution: There will be two switches, the FIRST NUMBER and the SECOND NUMBER. Each will have four positions 1, 3, 5, 30. There will be five lamps corresponding to the possible least common multiples 1, 3, 5, 15, 30.

The circuit is exactly the same as the circuit for Logical Sum, with appropriate changes of labels, because this problem has just the same structure as that problem.

140. LOGICAL PRODUCT

Problem: The logical product of a first class F and a second class G is equal to the class every member of which is both in F and in G. The logical product of two classes is written F·G, where the "·" (centered dot) stands for the operator "AND" in the meaning "both ... and ...".

Design a machine which will give the logical product of two classes where either one may be 0, A, B, 1.

Solution: There will be two switches, the FIRST CLASS F and the SECOND CLASS G. Each will have four positions, 0, A, B, 1. There will be five lamps corresponding to the possible products 0, A, B, C = A·B, 1.

The circuit appears in the diagram.

141. HIGHEST COMMON FACTOR

Problem: The highest common factor of a first number F and a second number G is the largest number which will go into both numbers as a factor.

Design a machine which will give the highest common factor of two numbers F and G, where F may be any one of 1, 6, 10, 30 and G may be any one of 1, 6, 10, 30.

Solution: There will be two switches, the FIRST NUMBER and the SECOND NUMBER. Each will have four positions 1, 6, 10, 30. There will be five lamps corresponding to the highest common factors 1, 2, 6, 10, 30.

The circuit is exactly the same as the circuit for Logical Product with appropriate changes of labels, because this problem has just the same structure as that problem.

142. LOGICAL NEGATION

Problem: The logical negative of a class F is equal to the class every member of which is in the class of all things being discussed but is not in the class F. The logical negative of the class F is written F' (read F prime) and is called NOT-F.

Design a machine which will give the logical negative of a class F which may be any one of 0, A, B, A·B, A v B, 1.

Solution: There will be one switch THE CLASS, with six positions 0, A, B, A·B, A v B, 1. There will be six lamps corresponding to the possible negatives 0, A', B', A'·B', A' v B', 1.

The circuit appears in the diagram.

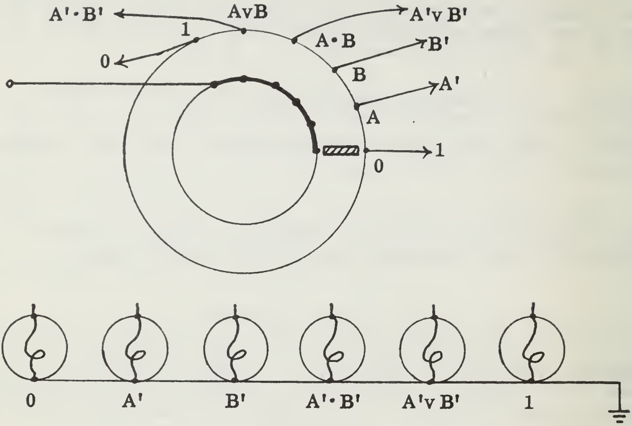
143. COMPLEMENTARY FACTOR

Problem: The complementary factor of a number is equal to the result of dividing this number into the largest number being considered. For example; if 210 is the largest number being considered, the complimentary factor for 30 is 7.

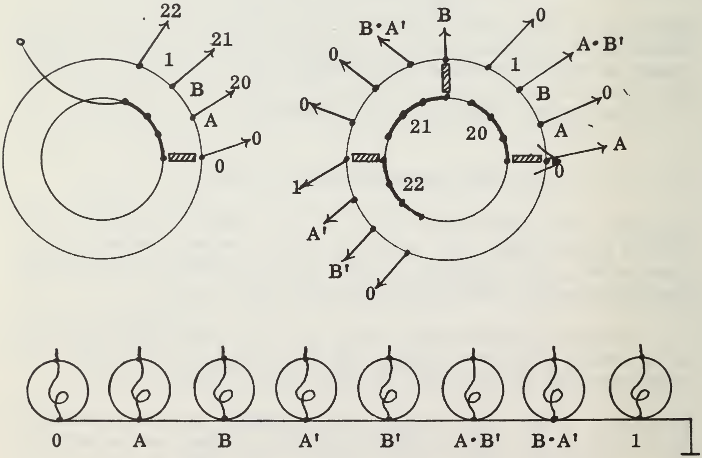
Design a machine which will give the complementary factor of a number which may be any one of 1, 6, 10, 2, 30, 210. (The complementary factors will be 210, 35, 21, 140, 7, 1)

Solution: There will be one switch NUMBER, with six positions 1, 6, 10, 2, 30, 210. There will be six lamps corresponding to the possible complementary factors 210, 35, 21, 140, 7, 1.

142. LOGICAL NEGATION



144. LOGICAL EXCEPTION



The circuit is exactly the same as the circuit for Logical Negation because this problem has the same structure as that problem.

144. LOGICAL EXCEPTION

Problem: The logical operation of exception, as in the case of class F EXCEPT class G, is equal to the class every member of which is a member of F but is not a member of G. The result of F EXCEPT G is equal to $F \cdot G'$ (read F dot G prime) meaning F AND NOT-G.

Design a machine which will give the result of logical exception upon two classes, where either one may be 0, A, B, 1.

Solution: There will be two switches, the FIRST CLASS F and the SECOND CLASS G. Each will have four positions, 0, A, B, 1. There will be eight lamps corresponding to the possible results 0, A, B, A', B', $A \cdot B'$, $B \cdot A'$, 1. The circuit appears in the diagram.

145. MATCHING

Problem: John Cullen has two sets of numbers 3, 6, 8, 9, 13, 19 in one set, and 4, 7, 8, 10, 13, 17 in the other set. He wants a machine which will light a lamp if and only if the numbers set on each switch match each other.

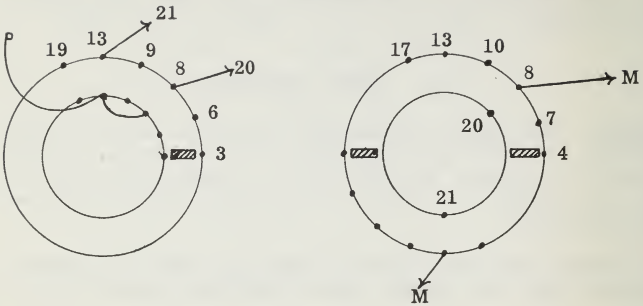
Solution: There will be two switches NUMBER OF FIRST SET and NUMBER OF SECOND SET. The positions of the first switch will be 3, 6, 8, 9, 13, 19. The positions of the second switch will be 4, 7, 8, 10, 13, 17. There will be one lamp, MATCHING. The circuit appears in the diagram.

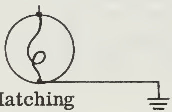
146. MERGING

Problem: John Cullen has two sets of cards numbered 5, 6, 8, 9 in one set and 4, 7, 8, 11 in the other set. He wants a machine which will tell him which set to choose from so that he can put his cards in exact numerical sequence from low number to high number, choosing from the first set in the case of a tie.

Solution: There will be two switches CARD OF FIRST SET and CARD OF SECOND SET. The positions of the first switch will be 5, 6, 8, 9, and of the second switch will be 4, 7, 8, 11.

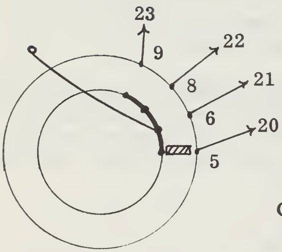
145. MATCHING



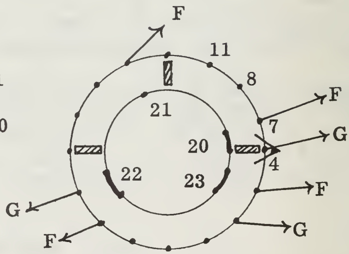


Matching

146. MERGING

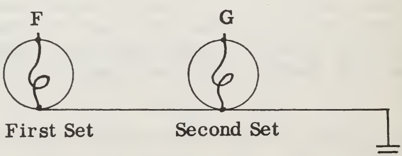


Card of First Set



Card of Second Set

Choose From:



There will be two lamps, one marked CHOOSE FROM THE FIRST SET and the other marked CHOOSE FROM THE SECOND SET. The circuit appears in the diagram.

147. SELECTING

Problem: John Cullen has two sets of numbers, the first set 6, 8, 10, 12, 14 and the second set 9, 16, 25, 36, 49, and also a set of five sealed instructions numbered n = 1 to 5 which will tell him to select the nth number of the first set or the nth number of the second set according to the instruction when he reads it.

He wants a machine which will select the correct number according to the instruction when it is read.

Solution: There will be two switches, one NUMBER OF SELECTION, with positions 1, 2, 3, 4, 5, and the other SEALED INSTRUCTION WHEN READ with two positions, SELECT FIRST NUMBER, and SELECT SECOND NUMBER. There will be ten lights 6, 8, 10, 12, 14 and 9, 16, 25, 36, 49.

The circuit appears in the diagram.

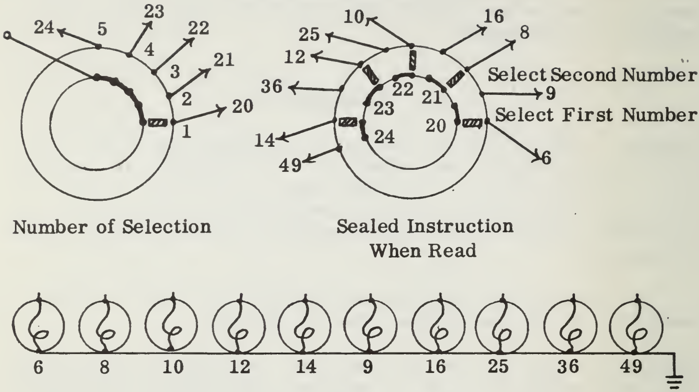
148. THE MERRIMAC AND EASTERN TIMETABLE

Problem: In the Merrimac and Eastern Railroad timetable, the following notes may or may not appear for any train: e, except Saturdays; s, runs Sundays only; m, last trip Nov. 11; k, Saturdays only; d, daily except Sundays; y, first trip Nov. 18. The railroad man making up the timetable, being human, may put down conflicting notes for the same train.

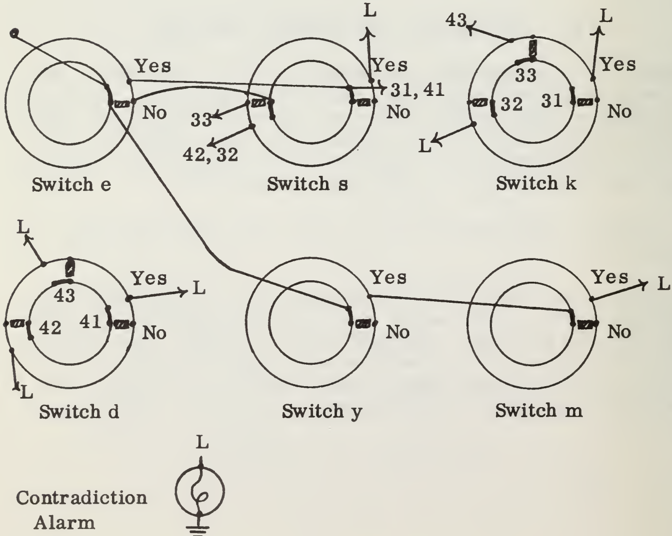
Design a machine which will turn on an alarm for any conflicts.

Solution: There will be six switches, labeled according to the notes above. Each switch will have two positions NO, YES. There will be one lamp: CONTRADICTION -- ALARM. The conflicting combinations that the machine must report are es, ek, ed, sk, kd, my and any more complicated combinations such as esm. The circuit is shown in the diagram.

147. SELECTING



148. THE MERRIMAC AND EASTERN TIMETABLE



149. THE THEATER SIGN "HAMLET"

Problem: The manager of the Squamtick Theater has employed a stock company putting on Hamlet. He wants his marquee sign to show at successive times from 1 to 8, first H, then A, then M, then L, then E, then T, all shining in lights, all holding to the end and for another moment, and then all to go out.

Design a machine for him.

Solution: There will be one switch marked TIME, with positions 1 to 8. There will be 6 lamps labeled H, A, M, L, E, T. The circuit is shown in the diagram. (Note that in this case we succeed in making an 8 position switch with six decks.)

150. THE NEWS SIGN OF THE KALTROIT DISPATCH

Problem: On August 9, 1958, the news sign of the Kaltroit-Dispatch is to show a certain message repeating in ten lights, each light lasting 6 seconds, and the next light coming on in 3 seconds. The message is "Nautilus has crossed Pacific to Atlantic under North Pole icecap".

Design the controlling circuit.

Solution: There will be one switch TIME with positions 0, 3 seconds, 6, 9, 12, and so on up to 33 seconds, and then repeating. There will be ten lights, each one showing one of the ten words of the message. The circuit is shown in the diagram.

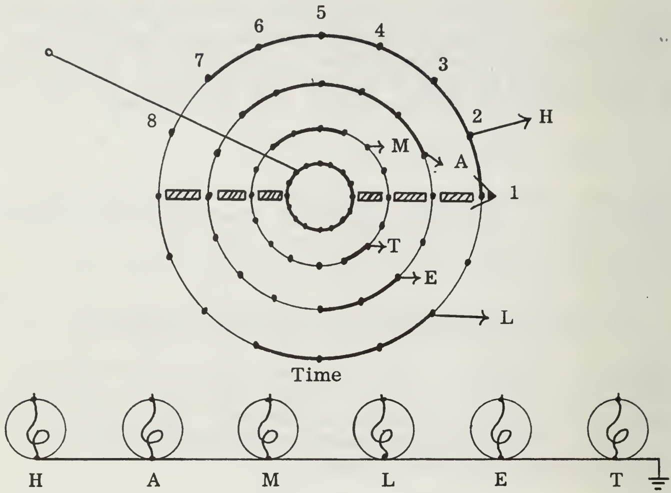
151. A VARIATION OF NIM

Problem: There are several ways of playing the game of Nim. One way is with two piles of matches, 15 in one pile, 12 in the other. The two players take turns. Each player must during his turn take one or more matches from any one pile (and may take the whole pile). The player taking the last match wins the game.

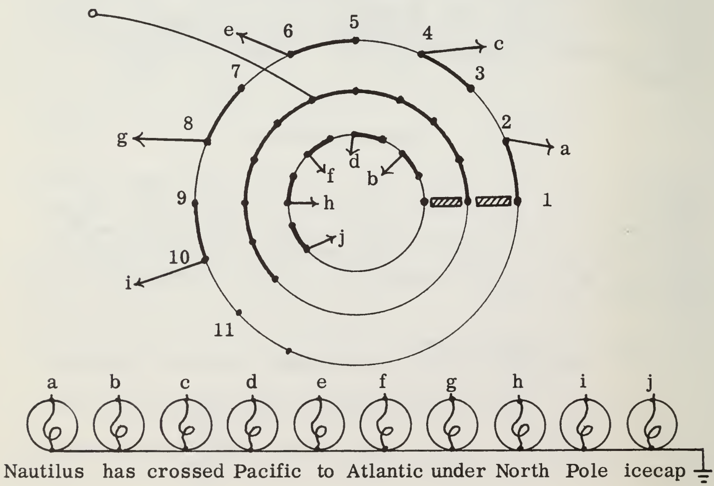
Here is a sample game:

(1) the player going first takes 9 from the 15 pile, leaving 6
(2) the second player takes 10 from the 12 pile leaving 2
(3) the first player takes 4 from the 6 pile leaving 2

149. THE THEATER SIGN "HAMLET"



150. THE NEWS SIGN OF THE KALTROIT DISPATCH



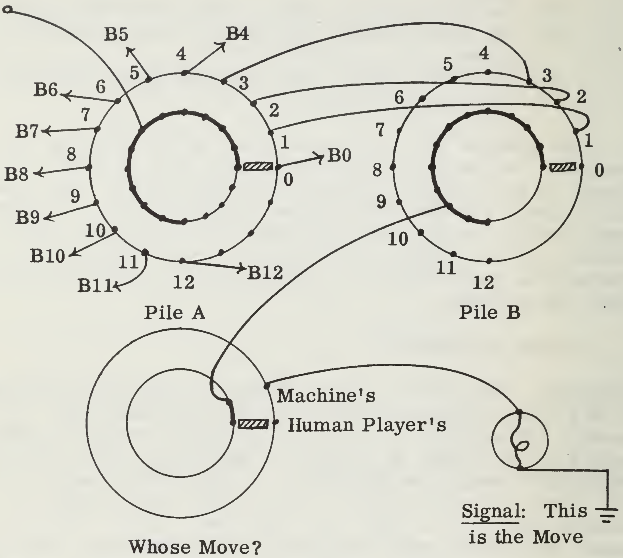
(4) the second player takes 1 from one of the two 2 piles
(5) the first player takes 1 from the other 2 pile
(6) the second player must take 1 from one of the 1 piles
(7) the first player takes the last match from the other pile, and wins.

The problem is to set up this way of playing Nim in a machine. The machine is to signal what move it makes in response to any position left by the human player. The machine is to accept any move by the human player, and is to signal unmistakably its own move. The machine is to play first or second. If the machine plays first, it should always win; if the machine plays second, it should win if the human player makes any mistakes.

Design the machine.

Solution: The circuit for the machine is shown in the diagram. It has three switches PILE A, PILE B, and WHOSE MOVE? To operate the machine, if it is the machine's move, set each switch at the number of matches in each pile. Then turn the WHOSE MOVE? switch to MACHINE'S. If the SIGNAL lamp is not lit, take the switch which is set at the larger number of matches, and turn it down until the lamp lights. This is the number of matches which should be left in that pile after the machine moves, and the machine takes from the pile the number of matches which will leave the number at which the switch is set. If the signal lamp is lit, the machine's move is to take one match from Pile A.

151. A VARIATION OF NIM



How To Go From Brainiacs® and Geniacs® To Automatic Computers

Edmund C. Berkeley

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After a bright student or a resourceful teacher has worked for a while with Brainiacs (the word includes Geniacs and Tyniacs) the question inevitably comes up: "How do you go from these little semi-automatic machines to big automatic machines? What is the relation between these little electric brains and the giant brains?" These are important questions.

1. The Nature of an Automatic Computer

Perhaps the best way to answer these questions is to make clear the nature of an automatic computer, and explain the steps needed to go from a small machine of the electric brain (or Brainiac) type to a large and powerful electric brain.

Automatic computers are of two main kinds, digital and analog. A digital computer handles information in the form of separate and distinct symbols, digits, letters, characters, yeses and noes. Its hardware has sharply different states, which may be for example the positions of a counter wheel marked 0, 1, 2, 3, and so on up to 9, or the two positions "open" (or "O") and "shut" (or "1") of a two-position (or double-throw) switch. An analog computer handles information in the form of a magnitude of something physical that can vary, such as the position of a rod, the amount of rotation of a shaft, or a varying electrical voltage.

All Brainiacs are digital. But if we should put a pointer on a Brainiac disc, mount it on a smooth shaft on which it could spin freely, and then spin it, and measure exactly where the pointer stopped, then we would be treating the disc as expressing the analog form of information.

A digital computer can express letters as well as numbers; an analog computer can express numbers only. A digital computer can deal with numbers of 10 or 20 or more decimal digits; an analog computer can deal with numbers up to an accuracy of 4 or 5 significant figures at the most. A digital computer can handle almost any kind of mathematical or logical, business or scientific problem; an analog computer is nearly always limited to handling mathematical problems involving just one independent variable and up to 100 or more dependent variables. (If any of these phrases are not clear to you, we suggest that you look them up in a good algebra book.) Both digital computers and analog computers are very useful, but usually in different areas.

Brainiacs are not related to analog computers; but they are closely related to digital computers.

Nearly every automatic digital computer has identically the same basic logical design consisting of five units and two channels as shown in Figure 1.

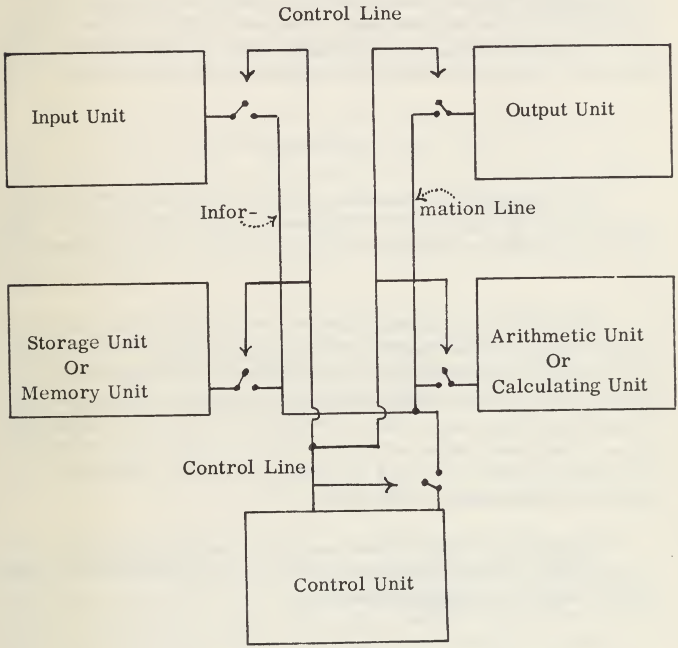

Figure 1 — The Basic Logical Design of an Automatic Digital Computer

2. The Input Unit

The input unit is the section of a computer where information is received from the outside world expressed in machine language, that is, expressed in the physical form which the machine can operate with. In the case of a Brainiac, input is the setting of a switch. In the case of a big computer, input may be punched paper tape, or punched cards, or magnetic tape (tape made of plastic impregnated with magnetic particles, and recorded on by producing a number of magnetically polarized spots, either polarized north-south or south-north).

Different pieces of information are put into a Brainiac by manual changing of the position of a switch. Different pieces of input information go into a big automatic computer by swift feeding of the tape or the cards through the machine, where the punched holes or magnetized spots are read by mechanical or electrical means.

3. The Storage Unit

The storage unit or memory unit of a computer consists of a large number of registers or locations where information is stored or remembered, available for reference by the computer when called for.

An automatic computer may for example store information as polarized spots on the surface of a magnetic drum (a rotating cylinder coated with a magnetic surface). When it is desired for the computer to refer to some information on the drum, the magnetic reading head associated with a certain path or channel around the drum is selected, and a certain time for reading is also selected, so that the pattern of 1's and 0's contained in that information is piped out of the drum at that time.

A Brainiac does not have a separate storage or memory unit. Its sorting or remembering of information is expressed in the position at which the switch has been set.

4. The Arithmetic Unit

The arithmetic unit or calculating unit of an automatic computer is the section of the machine where information is operated on arithmetically or logically. The arithmetic unit is able to perform a number of different operations. Different signals for different operations are sent to it, selecting addition, or subtraction, or multiplication, or division, or square root (in some computers), or comparison, or selection, etc.; and then this particular subprogram will be executed within the arithmetic unit, and then the result is given back to the rest of the machine. For example, if a multiplication is to be performed, this unit pays attention to the successive digits of the multiplier, and selects appropriate multiples of the multiplicand to be added and shifted accordingly. The arithmetic unit is almost a small computer by itself, but it operates with a fixed sequence of operations in order to perform multiplication.

A number of the Brainiacs display this kind of behavior, selection of the operation to be performed, for example, Brainiac No. L2, "A Simple Kalin-Burkhart Logical Truth Calculator", No. C6, "Operating With Infinity", and No. 125, "Turn Over and Turn Around".

All the Brainiacs owe their chief interest to the fact that they display different kinds of rather efficient calculating circuits, circuits typical of those that might appear in a special purpose digital computer. The circuits are often efficient because the Brainiacs make use of a novel and powerful kind of multiple switch, which can be assembled to make many, many varieties of calculating and reasoning circuits.

A big automatic computer on the other hand accomplishes calculating and reasoning by means of a small number of fundamental operations built into the arithmetic or calculating unit, which are then programmed in sequences to solve many very different kinds of problems.

5. The Output Unit

The output unit of a computer is the section of the computer where information is given back to the outside world, usually converted into forms that can be read easily by human beings, such as printed characters on paper. One way in which many automatic computers give back information is by means of an electric typewriter; the keys of this typewriter are driven by successive impulses derived from the computer, and a message is put out which can be read by human beings.

A Brainiac always puts out its information in the form of the lighting or not lighting of lamps. This enables human beings to see what answers are denoted. Even big automatic computers have some lamps — usually a green lamp lighted for good operation, and red lamps for trouble, and frequently signal lamps indicating what parts of the machine require attention.

6. The Control Unit, Etc.

The control unit of an automatic computer is the part of the machine which controls the switches or gates that connect specific registers in the various units to the information line; in this way it controls the sequence of operations in the computer, by means of a program of instructions or commands given to the machine in machine language.

A Brainiac has no control unit outside the human being who chooses to turn the switches to express different situations.

The information line of an automatic computer is a channel, usually of one or more wires along which information flows through the computer in the form of a pattern of signals.

An information line is present in a Brainiac. This is the wiring on the back of the panel. Information in the form of the presence or absence of electric current from the battery to the lights flows along a Brainiac's information channel.

The control line of an automatic computer is the channel, usually a single wire, along which the successive control signals flow, opening or shutting switches or gates.

Since a Brainiac has no control unit, aside from the human being who turns its switches, it has no control line, aside from the arms and hands of the human being who turns its switches.

7. The Steps Needed to Convert a Brainiac into a Small Simple Automatic Computer

What would be needed to convert a Brainiac into a very simple (and undoubtedly slow) automatic computer?

First, the machine would need something that would enable it to operate different circuits at different times, completing a cycle of say 10 or 20 successive operations of circuits, and then repeating. Examples of Brainiacs that indicate how a stepping switch would operate are No. M2, "The Sign That Spells Alice", and No. Q6, "The Missionaries and the Cannibals". But the stepping switch for a more advanced machine should be self-moving, provided with a motor.

Second, the machine would need something that would enable it to store in a register information that might change from time to time. One of the simplest forms this could take would be an electrical relay; this is simply a switch with two positions, of which the leaf (or transfer contact) is normally pulled into one position by a spring, but may be pulled into the other position by magnetizing a piece of iron by running electric current through a coil around it (an electro-magnet). A relay will thus store or remember one binary digit of information, 1 corresponding to the energized position, 0 corresponding to the unenergized position. But a relay is expensive, costing 50 cents to $2 for each changeable binary digit; and it is also slow, requiring on the order of a hundredth of a second to go from one position to the other. For this reason, big automatic computers use for storage mainly polarized spots on magnetic surfaces.

Third, the machine would need something for taking in a sequence of pieces of information and instructions. One of the simplest forms for this would be a paper tape feed that would feed five hole paper tape.

Fourth, as soon as we had made these three changes, we could no longer operate the machine on one flashlight battery. So we would have to have a power supply: this could be in the form of a 24 volt D. C. power supply, which could be operated through a transformer from a wall outlet of 110 volts A. C.

8. Simon

As soon as these changes are made, we leave the class of a $20 kit, and go into the class of $300 of parts bought or picked up second hand from radio and war surplus stores. There seems to be hardly any other way of going about it.

The steps that have just been described have been carried out. A miniature automatic digital computer using a stepping switch, 129 relays, and a five-hole paper tape feed has been made, and more than one of them. The first one was made in 1950, and was called Simon — it was the predecessor of the Brainiac kits.

Simon was an effort we made to make a complete miniature automatic digital computer. It has 16 registers which could store any one of the four numbers 00, 01, 10, and 11. It had nine operations, addition with and without carry, negation, greater than, selection, and some more operations. The five-hole punched paper tape contained the given numbers presented at the start of the problem and a sequence of instructions for combining them. Simon appeared on the front cover of and was described in "Scientific American", November, 1950, and "Radio Electronics", October, 1950. Over 400 sets of Simon plans have been sold, and several other Simons have been constructed.

The biggest drawback to Simon was its very small storage or memory, amounting only to 16 registers of 2 binary digits. So Simon was not able to compute its own instructions or store them internally. The part of the information line (see Figure 1) that goes into the control unit was not present in Simon. However at present writing we have an operating magnetic drum memory (we call it Magdum; cost, $3000, vintage, 1957) of 128 registers of 4 binary digits. Our task currently is to hitch this memory on to Simon the small computer (vintage, 1950), so that Simon will be able to store instructions internally and begin to be able to do useful work.

9. Further Steps

To come closer still to a complete and fast automatic digital computer — one that might be useful in calculations and in instruction in a high school — much more money and labor are needed. The cost of electronic circuits to perform logical and arithmetical operations is much greater than the cost of relay circuits. To troubleshoot relay circuits requires $20 of simple apparatus and some common sense. To troubleshoot electronic circuits requires a good oscilloscope, cost on the order of $500 to $800, and much more knowledge.

Perhaps this situation will change for the better in the future. But in the meantime, simple switching circuits, such as the Brainiacs, and simple equipment using relays, a stepper, and a tape feed, seem to be the main feasible solutions for studying automatic computers in the real, open to the bright student and the resourceful mathematics or science teacher.

BRAINIACS® —

Small Electric Brain Machines

Materials in the Kit and How To Assemble Them

Edmund C. Berkeley

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Introduction

This report and the accompanying kit and literature present Brainiacs ®, small electric brain machines. They are electrical machines which are able to calculate and reason automatically although they are too small to perform operations one after another automatically. They show, with the least hardware that we have yet been able to work out that still allows interesting experiments, the fascinating power and variety of computing and reasoning circuits. There are over 200 experiments.

Each of the machines uses one flashlight battery, not more than ten flashlight lamps, and not more than six multiple switches. All connections are made with nuts and bolts, and no soldering is required; the kit is completely safe. The kit, though inexpensive and convenient for constructing Brainiacs, is however not necessary; and some persons will prefer to construct their Brainiacs using other materials.

The descriptions of the experiments are contained in the book "Brainiacs — 201 Small Electric Brain Machines and How to Make Them". The first thing to do is to read carefully:

Chapter 1 - Small Electric Brain Machines — Some Questions and Answers

Chapter 2 - Circuits and Circuit Diagrams

Then this manual should be read, since it describes the materials in the kit and how to assemble them. Then a simple experiment from the book should be selected, constructed, and tried. It would be sensible to choose experiment No. 1 on page 9, which is also shown in the first template.

If you find that at first you have some difficulty in understanding all that is in this kit, TAKE YOUR TIME and think; make first the simpler machines; then try the more complicated ones. To make a machine that will reason and calculate you too must reason and calculate.

We hope that you find the experiments and the kit interesting, entertaining and amusing, and that you will enjoy playing with the kit and entertaining your friends with the little machines that you make. Any comments, suggestions for new experiments, and corrections, will be gratefully received. We shall be glad to hear from you.

Edmund C. Berkeley

With the Brainiac Electric Brain Construction Kit anyone can put together the machines of the types described in the experiments (and many more besides), so that they will perform operations of reasoning and computing.

The kit is harmless. It runs on one flashlight battery. Wires are connected by fastening them to the same nut and bolt and tightening the connection by gripping them between two bolts. No heat or soldering iron is required. DO NOT CONNECT this kit or any part of it to any home or industrial electrical power outlet; you are likely to destroy the material, and you may hurt yourself.

The kit is simple, but nevertheless it takes effort and work to put the material together to make a functioning electric brain. We urge you to take your time. If necessary, read the instructions several times. If the instructions are still not clear, read ahead and then return.

1. Parts List. The kinds of parts contained in the kit are the following:

Insulated wire
Battery box
Bulbs, flashlight, 1-1/2 volts
Socket parts for flashlight bulbs, holding five together
Short bolts, 6/32, 1/2 inch long
Hexagonal nuts, 6/32, 1/4 inch diameter
Spintite blade
Panel, masonite, rectangular, punched
Multiple Switch Discs, masonite, circular, punched
Long bolts, 6/32, 7/8 inch, for center pivot, etc.
Washers, hard, cardboard
Washers, soft, sponge rubber
Jumpers, metal, brass
Wipers, phosphor bronze

In addition an ordinary size D flashlight battery, 1 1/2 volt, is needed

Each of these items will now be described. (Note: Figures 1 to 13 are not in this manual but in the book "Brainiacs" and should be studied before the Figures in this manual are studied.)

2. Wire. The kit provides a coil of wire covered with insulation. This is like the wire connecting a lamp to a wall plug, for example, but adapted for handling a much smaller amount of electricity. Also, instead of two wires together making two paths for electricity, here is one wire only. In the Brainiac wiring that you will do, the wire follows a single path running from one end of the battery through some kind of loop to the other end of the battery, thus making a complete circuit.

Your wire needs to be cut apart with a cutting pliers into pieces. A convenient length for many pieces is 18 inches, but some pieces can be shorter, about 8 inches long. About 3/4 of an inch of Insulation should be removed at each end of each piece. You can trim this off neatly with a dull knife. Also, a small amount of wire should be stripped of insulation and cut into pieces about 2 inches long. These pieces of bare wire make transfer contacts, as will be explained later.

3. Battery. An ordinary flashlight battery, size D, provides about 1 and 1/2 volts. A volt is a unit of electric pressure or electric potential. A battery acts like a pump, and pumps electricity from one end of the battery around a circuit to the other end of the battery. A flow of electricity is an electric current. The filament of a bulb through which the electricity flows provides a narrowness or a restriction or a resistance to the flow, so that it heats up and glows with "friction" as electricity flows through it.

4. Battery Box. The battery box consists of a scored, glued piece of cardboard which will readily fold into a box of the right size to hold the battery. At each end of the box is a small hole. Through this hole from the inside of the box insert a bolt (on which a washer has been threaded, see Figure 15); then fasten the bolt

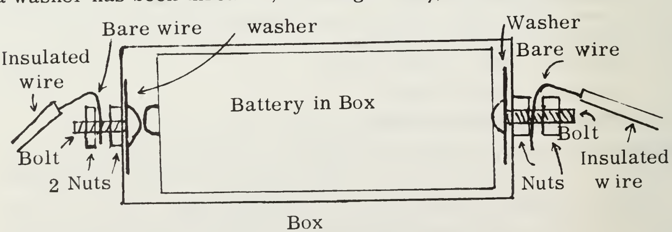

Figure 15

with a nut on the outside of the box. The battery terminal connection is fastened to the projecting bolt with a second nut. The box will now hold a battery snugly, giving good contact. The battery box may be tied securely to the panel with a tight string around it and passing through holes in the panel.

5. Bulbs. You have small flashlight bulbs in the kit. They will glow from a single flashlight battery. In order to make them light, you have to run one wire from the bottom metal plate of the battery to the side of the bulb, and another wire from the top of the flashlight battery to the center of the base of the bulb. Your connections must be clean, not oily, nor corroded. Examine your bulbs closely from time to time to make sure that the filament, the little slender wire that you see inside the glass bulb, is all in one piece. If it is broken, the bulb is spoiled.

6. Socket Parts. You have two "socket parts" for flashlight lamps. Each holds five lamps, in such a way that they can be screwed in and out of their socket holes. Views of the top, side and end of the socket part are shown in Figure 16.

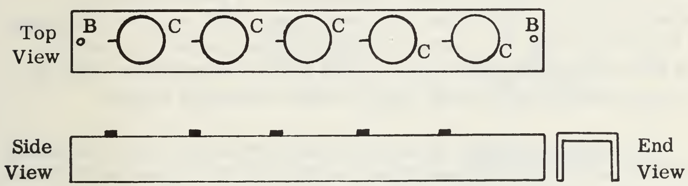

Figure 16 — Views of Socket Part

In order to make use of this part actually assembled in a machine (see Figure 17), first, short bolts (for electrical connections to the individual bulbs) are placed in the panel an inch apart and fastened tightly with nuts (see A in Figure 17).

Second, long bolts for fastening the socket part to the panel are passed (1) through the two small holes at the two ends (see B in both figures) of the socket part, and (2) through the panel, and fastened tightly with nuts. Third, the bulbs are screwed through the large holes in the top of the socket part (see C in Figure 16), and screwed down far enough to make tight, snug contact with the

bolt under the bulb. Since the socket part is metal, one wire connector attached to the end bolt connects all the bulbs together to one side of the battery (see D in Figure 17). Then the screw at the base of each bulb enables it to be connected to its separate source of illumination from the circuit (see E in Figure 17).

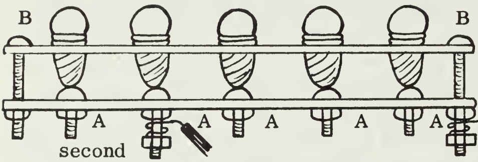

Figure 17 — Assembled Socket Part

7. Nuts and Bolts. For fastenings, connections, and terminals, here and there all over the machine, you have a supply of bolts and a supply of nuts. The nuts and bolts are of rust-proofed steel, and give good electrical connections. A bolt is inserted through any hole; then a nut is screwed down tight on the bolt holding it in position; then the connecting wire is wound around the end of the bolt coming through; then a second nut is screwed down tight on the wire and the bolt so as to give a tight electrical contact.

8. Spintite Blade. In order to fasten your nuts and bolts easily, you will need a small screwdriver, which will fit in the slot of the bolt and enable it to be turned. You also have in the kit a small piece of hexagonal tubing (a spintite blade) which fits over and grips the hexagonal bolt and enables it to be spun quickly down the shaft of the bolt, and tightened, with the screwdriver holding the bolt.

9. Panel. In order to assemble your materials together into a machine, you have a rectangular panel consisting of masonite (thin pressed fiberboard). It contains holes for nuts and bolts so that the various parts of the set may be mounted together and assembled firmly.

If you examine the panel, you will see two patterns of holes. One pattern (see Figure 18) consists of 102 holes arranged in several rows through the middle of the panel from end to end.

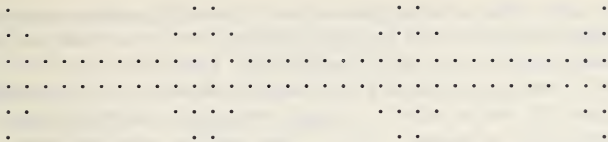

Figure 18

In this set of holes, all the hardware of a Brainiac machine is mounted except the "multiple switches", which will be explained in a moment. The second pattern consists of four rosettes of 65 holes in a circular arrangement (see Figure 19). These are the "bases" of the multiple switches.

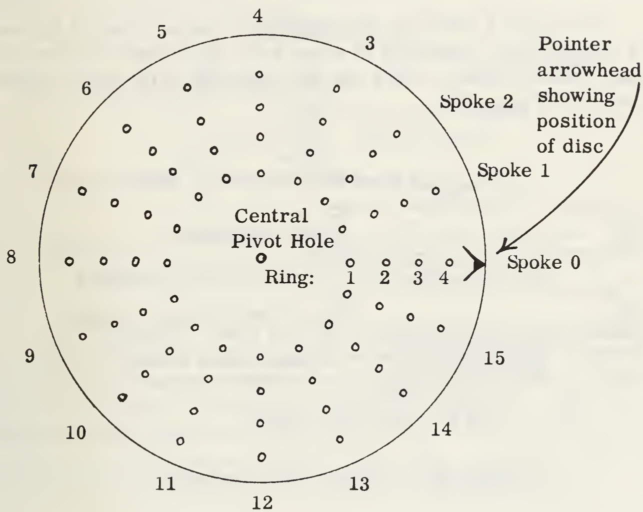

Figure 19 — Pattern of holes in the multiple switch (either the "base" in the panel or the "top", which is the disc). Also, the system of naming the holes.

10. Multiple Switches. The remaining material provided in the kit consists of round pieces of masonite, each containing 65 holes

in the same circular arrangement (see Figure 19), and the hardware for assembling them into multiple switches, switches which are able to switch many circuits at the same time. Each of the circular pieces of masonite is about 4-3/8 inches in diameter, is illustrated in Figure 19, and is called a multiple switch top, or switch disc, or switch dial, or simply a disc. These multiple switches have been patented (2848568).

In the panel each of the exactly similar sets of 65 holes is called a multiple switch base. In an early stage of design, the switch bases were separate pieces of masonite; but then it became evident that mounting of the hardware to make a machine would be better accomplished by having all the switch bases solidly connected together in the panel.

The top of a switch is fastened to the base of a switch by means of a center pivot, consisting of a long bolt, some hard washers, a sponge rubber washer, and a nut; the assembly of the center pivot is shown in Figure 20.

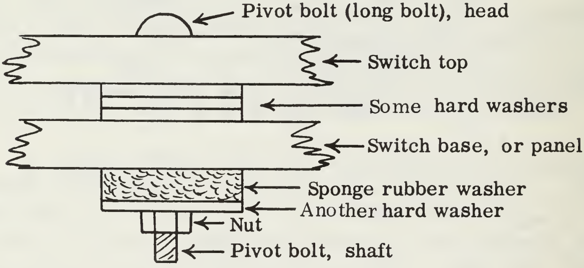

Figure 20 — Center Pivot Assembly

Instead of individual sponge rubber washers, the kit contains a small piece of sheet sponge rubber out of which the individual washers may be cut with a scissors. Cut out each rubber washer to be about the same size as one of the steel washers. Cut or poke a small hole in the middle of washer to allow a bolt to go through it. It is then ready for use; it functions as a compression spring.

The holes (except the center hole) in each switch base and

switch top are arranged in 4 rings and 16 spokes. The rings are called Ring 1, 2, 3, 4 going outward, and the spokes are called Spoke 0, 1, 2, 3, and so on around, to Spoke 15. The counting starts with the spoke directly to the right, and goes counterclockwise. See Figure 19.

Each of the holes in the switch base may or may not contain a short bolt, called a terminal, for making connections. The connections are made using two nuts, one for fastening the bolt securely to the switch base, and the second for holding and tightening a wire around the bolt so as to make a good electrical connection with the bolt (see Figure 21).

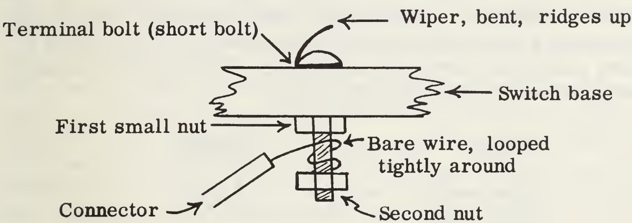

Figure 21 — Assembly of Wiper, Terminal Bolt, and a Wire Connector

11. Jumpers. Each pair of holes in a switch top, from Ring 1 to Ring 2 or from Ring 3 to Ring 4 (or very rarely from Ring 2 to Ring 3) may or may not contain a jumper, a small piece of brass plated metal with two prongs, as shown in Figure 22. The two prongs fit into holes in the switch disc and are pressed down, like a clasp or T fastener, as shown in Figure 23. A jumper serves to make and break electrical contact as the switch is turned.

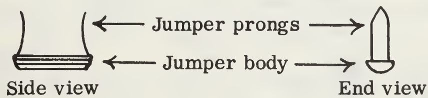

Figure 22 — Jumper, not mounted

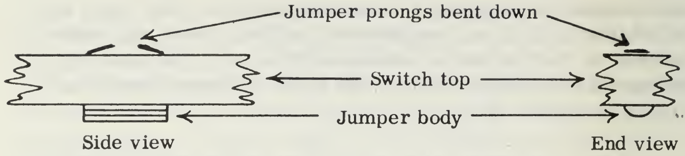

Figure 23 — Jumper, inserted in two adjacent holes along a spoke

12. Wipers. In between the jumper and the bolt, in the assembled multiple switch, is inserted a wiper, a springy piece of phosphor bronze with a hole and two small ridges. The shape of the wiper unbent, as it comes in the small envelope, is shown in Figure 24. The purpose of the wiper is to improve the electrical contact between the top of the switch (the disc containing the jumpers) and the bottom of the switch (the panel containing the bolts and nuts for the terminals). These wipers have been patented (2848568).

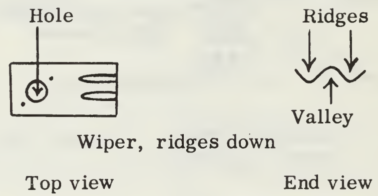

Figure 24 — Unbent wiper

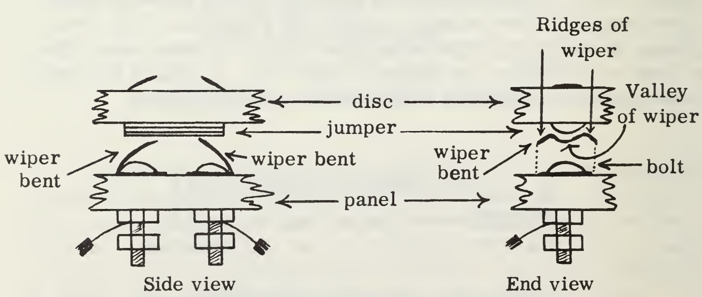

Figure 25 — Assembly of wipers

The way in which the wiper is assembled is shown in Figure 25, and is as follows: (1) thread the bolt through the wiper, with its ridges down; (2) fasten the bolt not too tightly to the panel; (3) align the wiper with the spoke (or radius) of the switch; (4) now fasten the bolt tightly; (5) bend the wiper gently upwards and over the bolt, with the ridges up, in such a way that the wiper will slide neatly on the jumper, resting in its valley between the ridges; (6) assemble the multiple switch with (probably three) washers in between the disc and the panel; (7) adjust the amount of bending the wipers so that they push up and down nicely against the jumpers as the switch turns.

For multiple switches with only two jumpers evenly spaced, or only three jumpers almost evenly spaced, you will not need wipers and should not use them, for such switches will work entirely properly without wipers. In these cases, you will need to make sure that the slots in the heads of the bolts are lined up with the spoke, so that the jumpers themselves will position (or detent) along the spoke right above the bolts. (In assembling a switch without wipers, you need only one or two spacing washers along the center bolt, not three.) For switches with four or more jumpers, you will need wipers, for otherwise the switch is likely to work unreliably.

13. Assembly of the Multiple Switches. Before any of the multiple switches can function, however, it must first be assembled.

Into the base we have to insert a number of nuts and bolts to hold wire connections and wipers. Just where these are inserted depends on the type of switch we desire to construct, two-position, or four-position, or some other type.

Into the top of the switch we must insert a number of jumpers in order to make and break contacts. Each jumper is inserted along a spoke between one ring and the next. Just where the jumpers are inserted again depends on the type of switch we desire to construct.

In order for the switch to stay in a position to which it is turned, the body of the jumper must line up with the valleys between the ridges on the wipers, and these valleys must be in line with the spoke; then the jumpers will have a tendency to catch in the valleys, as they should, to hold the switch in position (see Figure 25, end view).

Note that in some drawings of the multiple switches, the rings and spokes are drawn as thin lines; these lines are not actually drawn on the switch discs nor the switch bases; nor do they represent electrical lines connecting terminals; instead they are drawn to make the arrangement clearer.

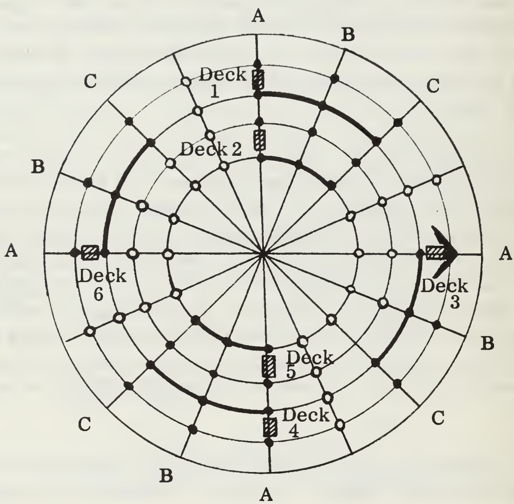

Figure 26 — Three position switch, six decks (or poles or levels)

Now suppose we wanted to assemble a switch which would have any one of three positions A, B, and C, and which would be capable of switching every one of six different circuits. A way in which that switch could be assembled is shown in Figure 26, in which both the top and the bottom of the switch are drawn over each other. Six jumpers are inserted in the top of the switch, shown as ▨ in Figure 26. It is important that jumpers ordinarily be inserted in pairs opposite each other, for reasons of mechanical balancing, so that the top of the switch will stay parallel to the bottom of the switch. A total of six times six or 36 nuts and bolts are inserted in the bottom of the switch, in the spots marked ●

in Figure 26. They are in groups of six called decks (also called poles, or levels); these decks are electrically independent, and they enable us to switch 6 different circuits. In the base, the bolts belonging in any one deck in Ring 1 or Ring 3 are connected together by wire, as shown by the heavy line; they may be connected with one of the short wires 1-1/2 inches long. They are made electrically common; in other words, they are commoned. Together they constitute what is called a transfer contact.

Let us now consider the layout of the spokes and the rings and the 64 holes which they produce. We can see that we can assemble a switch in a number of different ways. This is the advantage of the design of the multiple switch we have chosen (patent 2848568). Here are the types of switches that can be made with these parts:

Number of Positions	Maximum Number of Decks
2	16
3	10
4	8
5	6
6 to 8	4
9 to 16	2

If nuts and bolts did not cost anything, we could insert 64 nuts and bolts into the base of each switch and leave them there — ready for use in any switch. Actually, because the kit has a limited supply, it may be necessary to move nuts and bolts from one switch to another in order to make the different machines we want.

In the case of jumpers and wipers, we shall fairly often have to move them to different places, in order to make different switches for different machines.

14. Additional Material. You may obtain additional or replacement material for this kit by buying it at a local store, or by writing to us. Obviously, if your battery runs down, or if you want more wire, or if you want more nuts and bolts, the easy thing to do is to buy them in your neighborhood. But for more switch discs or more jumpers, etc., you will probably need to write us. Prices for these items are listed on a price list enclosed with the kit or obtainable on request.

15. Labels. The best procedure for making labels is: (1) type them out or write them out neatly on paper; (2) cut them out; (3) fasten

them on the board with cellophane tape.

16. Templates. In work with electrical circuits we need to lay out beforehand what we are going to do. We need to design on paper how we are to connect the different pieces of material. For this purpose, we use circuit diagrams, wiring lists, and templates.

A circuit diagram, as mentioned before, shows the scheme of connection of batteries, switches, lights, etc., in order to make the circuit. In a circuit diagram we pay little attention to the actual physical location of the material; we just show a diagram of its arrangement.

In a wiring list, we name the terminals, by words or letters or numbers, and we state, for every part of the circuit, what terminal is connected to what terminal. In a wiring list again we pay no attention to the actual spatial locations of the terminals. For example, if without drawing the wire, we write "to...", we are using the principle of a wiring list.

In a template, the case is different; we show the actual wiring and the approximate relative spatial location of the different pieces of material used in the circuit. In other words, we draw an accurate geographical map of where the terminals are, and then we indicate the wiring either by drawing lines for the connections or by writing notes showing the connections. For some illustrative Brainiac experiments, templates on a reduced scale are included in the kit.

In each experiment in the Brainiac kit, the important part of the wiring is on the rear side of the panel. Accordingly, each template shows a scaled picture of the rear of the panel. It is therefore a mirror image: what is on the right in the drawing in the manual is on the left in the template; and vice versa. Of course, some of the information appearing on the template belongs on the front side of the board: the labels of the switches, their positions, and the lights; and the location of the jumpers in the discs. If one pays careful attention to the two drawings, one in the manual and one in the template, the way the hardware and labels actually are arranged should become quite clear.

17. Trouble-Shooting. After you have wired up a machine, and start to play with it, you are likely to find that it does not work entirely correctly. All engineers worth their salt who do any kind of significant work with electrical circuits discover when they first

assemble a new piece of equipment that it does not work properly. Finding out the reasons why and removing the causes of malfunctioning, the process known as trouble-shooting, therefore, is an important and essential part of making any piece of equipment start working and stay working; and good trouble-shooting is the mark of a good engineer.

In order to trouble-shoot, it is helpful to have a systematic and logical checklist of questions to be answered one after another, and in addition testing apparatus which will tell whether a part of a circuit actually does what it is supposed to do. In order to test machines made with a Brainiac kit, the essential piece of testing apparatus is what is called a continuity tester. A simple form of such a tester is a flashlight battery, a lamp, and two wires with bare ends, connected as shown in Figure 27. Then, when you take the ends of the two wires, and touch a certain pair of terminals, if you obtain a light, you know that that part of the circuit is connected, is continuous; while if you obtain no light, you know that that part of the circuit is not connected, is isolated. Then, you compare what your tester shows to be actual fact with what you are supposed to have according to the circuit diagram, and you have either verified the correctness of that part of the circuit, or located some trouble.

Here are some checklist questions which make a beginning at trouble-shooting:

(1) Does each wire actually make contact with each terminal to which it is fastened?
(2) Does each jumper actually make contact with the wiper at each terminal, as its switch turns?
(3) Does each lamp really light?
(4) Is there electricity in the battery?
(5) Has any wire broken inside its insulation?
(6) Is there a mistake or typographic error in the diagram or the instructions? (This question must always be asked, because no author or printer is infallible.)
(7) Does each wire go where it should?
(8) Has each label been fastened on in its right place?
(9) Is each jumper in its right place?
(10) Is each terminal in its right place?

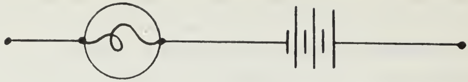

Figure 27 — Continuity Tester

If you can locate and remove trouble skillfully, you can be well satisfied with what you have learned.

18. Design for a Stand. When working on wiring and assembling a Brainiac machine, it is convenient to make a simple stand for holding the panel upright, so that you can work on both sides. Here is a design for a stand which will do this.

1. Take two pieces of rectangular wooden rod about 1 inch by 1 inch by 9 inches long:

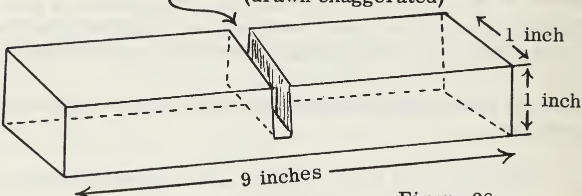

Figure 28

2. Saw a slot in the center of each piece of rod about 2/3 of the way through.

3. With a file, widen and rub down the sides of the slot so that the Brainiac panel fits into the slot snugly, but not too tightly nor too loosely.

4. Then for wiring, assembling, displaying, etc., the panel, held in the stand, looks like:

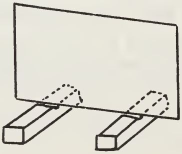

Figure 29

Brainiacs® —

Small Electric Brain Machines —

Introduction and Explanation

Edmund C. Berkeley

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First printing, April, 1959

P59

Introduction

This report and the accompanying kit and literature present Brainiacs®, small electric brain machines. They are electrical machines which are able to calculate and reason automatically although they are too small to perform operations one after another automatically. They show, with the least hardware that we have yet been able to work out that still allows interesting experiments, the fascinating power and variety of computing and reasoning circuits.

The experiments, at present writing amounting to over 150, are described in other publications included in this kit. This report is devoted to introducing and explaining Brainiacs, "Brainy Almost-Automatic Computers".

Each of the machines uses one flashlight battery, not more than ten flashlight lamps, and not more than six multiple switches. All connections are made with nuts and bolts, and no soldering is required; the kit is completely safe. The kit, though inexpensive and convenient for constructing Brainiacs, is however not necessary; and some persons will prefer to construct their Brainiacs using other materials.

We hope that you find the experiments and the kit interesting, entertaining and amusing, and that you will enjoy playing with the kit and entertaining your friends with the little machines that you make.

If you find that at first you have some difficulty in understanding all that is in this kit, TAKE YOUR TIME and think; make first the simpler machines; then try the more complicated ones. To make a machine that will reason and calculate you too must reason and calculate.

Any comments, suggestions for new experiments, and corrections, will be gratefully received. We shall be glad to hear from you.

Edmund C. Berkeley

BRAINIACS —

Small Electric Brain Machines —

INTRODUCTION AND EXPLANATION

Table of Contents

Section 1. General Information

Question: What is an "electric brain machine"?

Answer: An electric brain machine is a machine containing electric circuits which is able to calculate or reason automatically. The bigger electric brains are able to carry out long sequences of reasoning and calculating operations, thus solving complex problems. Such a machine is a true "electric brain machine", for there is no doubt that until such operations began to be done by machines, everyone agreed that such operations constituted thinking and were characteristically the operations carried out by brains.

The first modern electric brain machine was finished at Harvard University in 1944, and has been working there ever since. Now thousands of such machines are in existence, and at work producing knowledge. This development is so important that it is often called the "Second Industrial Revolution".

Question: What is a BRAINIAC?

Answer: A BRAINIAC is an electric brain machine which is small. If expense were no barrier, we could make one using only a small amount of hardware which would run extremely well doing many kinds of problems. But expense of course is a barrier, and the small electric brain machines which we talk about in this report are machines which are made of multiple switches, a panel for mounting them, a flashlight battery, flashlight bulbs, nuts, bolts, and other hardware. The electric brain machines we talk about here will not run by themselves; that is, whenever the machine is supposed to do something, you yourself have to turn the switch representing the machine's action. But nevertheless these machines do calculate and reason automatically, because the way that they are wired expresses the calculating and the reasoning.

Question: What is the origin of the BRAINIACS?

Answer: Most of the Brainiacs (No. 34 and up) were created after December 25, 1955; the first 33 were designed earlier. All of them however are the outgrowth of work which we have been doing since 1946, and which is still continuing — the exploration of intelligent behavior expressed in machines. For this purpose, we maintain a small laboratory, and are continually working on one phase or another of small robots and other machines which display intelligent behavior. Among other steps leading to the Brainiacs are the following.

In 1950, for educational and lecturing purposes, we constructed a miniature electric brain called Simon. Although only 1-1/4 cubic feet in size, and limited in capacity, it was a complete automatic computer, and it could show how a machine could do long sequences of reasoning operations. The picture of Simon appeared on the front cover of two magazines, "Scientific American" and "Radio Electronics"; the machine itself was demonstrated in more than eight cities of the United States. Over 350 sets of Simon plans have been sold. But this machine costs over $300 for materials alone, and is therefore too expensive for many situations in playing and teaching.

Soon after Simon was finished we began work to develop really inexpensive electric brains. By 1955, we had gathered and worked out descriptions of 33 small electric brain machines, which could be made with very simple electrical equipment. These machines were incorporated in a construction kit, which would make any one of these little machines. The name of the kit was "Geniac Kit No. 1"; the word "Geniac" ® came from the phrase "Genius Almost-Automatic Computer", and has been registered as a trademark.

Question: How am I to understand the experiments?

Answer: The first thing to do is not to rush, but to take your time, and read as carefully as you can all the general information. Read particularly this report which talks about circuits and how they work. The circuits which make these machines operate are all of them circuits in which electricity from a flashlight battery flows along wires and causes certain light bulbs to light up. The labels on the switches, on their positions, and on the lights show the meaning which is to be assigned.

In the same way, in the pilot's cabin of an airplane, or on the operating panel of an oil refinery, the switches, the lights, the dials, and the labels tell the meaning of what is going on, so that the airplane or the refinery can be controlled.

Question: How are the circuits like those in the experiments designed? I notice that each experiment is set up as a problem and solution: how would I be able to work out the solution for myself?

Answer: This is an interesting and important subject, the design of switching circuits. If you find the subject really interesting and worth a lot of work, and want to do that work, then you are likely to be well qualified to be an electrical engineer or electronic engineer, or a designer of computing machines, and you may have an excellent professional future lying in front of you.

An introduction to the design of switching circuits given in "Introduction to Boolean Algebra for Circuits and Switching" is included in the kit. This branch of knowledge, a new kind of algebra called Boolean algebra, is one of the best approaches. This is the algebra of AND, OR, NOT, EXCEPT, UNLESS, IF...THEN, IF AND ONLY IF, and some other very common words and expressions of language and logic. This algebra is a part of the subject called symbolic logic, and has an important application to any circuits that make use of circuit elements that can be either on or off, lighted or not lighted, conducting or not conducting, and so forth.

Section 2. Circuits

The small electric brain machines described in the kit are made of: a battery, or source of electric current; wires, which conduct it; switches, which change the paths along which the current flows; lights, which show where the current is flowing; and other hardware, such as nuts and bolts, which enables the whole machine to function together. In all of these machines the current starts from one end of the battery and flows in a path or circuit that eventually returns to the other side of the battery.

Circuit Diagram. The diagram of the circuit or circuit diagram or circuit schematic shows the scheme of connection of the battery, the switches, and the lamps, in order that the machine will function as it is supposed to. The diagram does not necessarily show the physical location of the hardware but only the arrangement of the connections of the hardware.

The symbols used in our circuit diagrams are shown in the accompanying figures. We need to pay attention only to a few kinds of hardware.

Fig. 1. — Battery

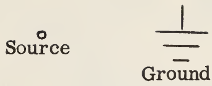

Fig. 2—Battery terminals, when separated

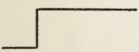

Fig. 3—Wire, or conductor

Fig. 4—Wires joining or crossing with electrical connections

Fig. 5— Wires crossing with no electric connection

Fig. 6—Lamp bulb

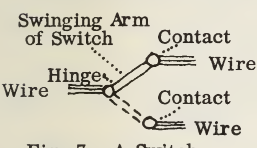

Fig. 7—A Switch

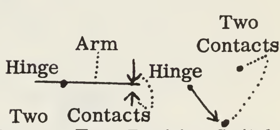

Fig. 8 — Two-Position Switch (two ways of drawing it)

(Note: The line of small dots associates the name with the part named.)

Fig. 9—Three-Position Switch

Fig. 10—Four-Position Switch

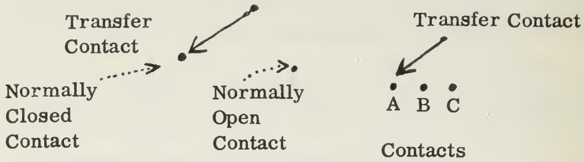

Figure 11 — Contacts, and their Possible Names

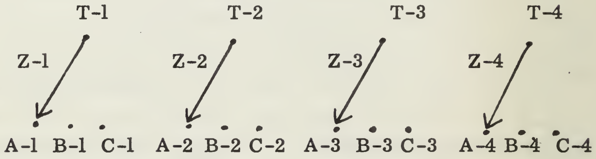

Figure 12 — Four-Deck Three-Position Switch Z
Drawn Schematically

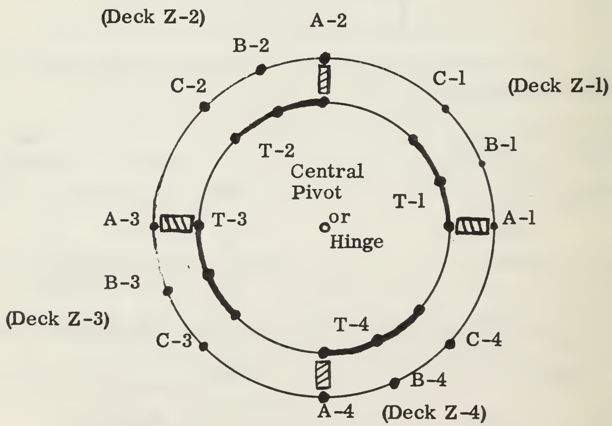

Figure 13 — Four- Deck Three-Position Switch Z
Drawn Pictorially

Battery. Fig. 1 is the diagram for a battery. The long and short lines supposedly represent the two kinds of plates in a battery by means of which the electric current is generated. The number of long and short lines does not symbolize anything, and does not have a special meaning.

Instead of showing the two ends of the battery located next to each other, another method may be used (see Fig. 2). One end or pole of the battery may be shown at one place as a small letter "o" meaning "source of current". The other end or pole of the battery may be shown at another place with the symbol "⏚" meaning the "sink of current" or "ground".

Wire. A line in a circuit diagram (see Fig. 3) represents an insulated wire, a connector from some point to some other point.

Dots (see Fig. 4) represent points where electrical connections are established by fastening two wires together so current can flow easily between them.

In Fig. 5, two wires cross (drawn in either one of two ways) but there is no electrical connection between them. One wire is actually either above or below the other.

Lamps. The diagram of Fig. 6 sketches the glass bulb and the filament of the lamp. The two dots are its connections.

Switches. A switch was originally a device for shifting a train from one track to another. Now in addition, it is a device for turning an electric current from one path to another; see Fig. 7.

In Fig. 8, 9, and 10, appear more abbreviated diagrams of switches; they are diagrams therefore easier to draw.

Switch Contacts. In any switch, the contacts have names. See Fig. 11 for examples of switch contacts and their possible names.

Decks. A single switch may be constructed having two or three or more electrically nonconnecting sections (often called decks or poles) so that as it is turned, it simultaneously switches two or three or more electrically independent paths. In circuit diagrams this property of a switch may be shown by using a name for the switch and numbers 1, 2, 3, etc., for the decks. For example, a switch (named Z) with three positions (A, B, and C) and four decks (named 1, 2, 3, and 4) is diagrammed in Figure 12.

Suppose however we actually wanted to make such a switch; it should have three positions and should enable us at one and the same time to shift four separate circuits. We could make it as shown in Figure 13. We could start with a flat round piece of non-conducting material. We could fasten jumping or bridging conductors along four radii in such a way that when we turn the switch at its central hinge or pivot, each jumper (drawn as ) is shifted simultaneously and transfers current from its transfer points T to its corresponding contact points A, B, C. This idea is at the heart of the patented multiple switch used in the Brainiac, Tyniac, and Geniac kits.

Examine the round discs in the kit. Each has a pattern of 65 holes, a center hole for a hinge or pivot, and four rings of holes arranged along 16 spokes (or radii). With the hardware in the kit, we can assemble these discs to switch many different circuits.

Section 3. Materials in the Kit, and Explanation of Them

With the Brainiac Electric Brain Construction Kit anyone can put together the machines of the types described in the experiments (and many more besides), so that they will perform operations of reasoning and computing.

The kit is harmless. It runs on one flashlight battery. Wires are connected by fastening them to the same nut and bolt and tightening the connection by gripping them between two bolts. No heat or soldering iron is required. DO NOT CONNECT this kit or any part of it to any home or industrial electrical power outlet; you are likely to destroy the material, and you may hurt yourself.

The kit is simple, but nevertheless it takes effort and work to put the material together to make a functioning electric brain. We urge you to take your time. If necessary, read the instructions several times. If the instructions are still not clear, read ahead and then return.

1. Parts List. The kinds of parts contained in the kit are the following:

Insulated wire
Battery, dry cell, flashlight, 1-1/2 volts

Battery clamp with switch
Bulbs, flashlight, 1-1/2 volts
Socket parts for flashlight bulbs, holding five together
Short bolts, 6/32, 1/2 inch long
Hexagonal nuts, 6/32, 1/4 inch diameter
Spintite blade
Panel, masonite, rectangular, punched
Multiple Switch Discs, masonite, circular, punched
Long bolts, 6/32, 7/8 inch, for center pivot, etc.
Washers, hard
Washers, soft
Jumpers, metal, brass
Wipers, phosphor bronze

Each of these items will now be described.

2. Wire. The kit provides a coil of wire covered with insulation. This is like the wire which you will find connecting a lamp to a wall plug, or a telephone to the telephone box, but adapted for handling much smaller currents and voltages. Instead of two wires wound together, here is one wire only. In the wiring that you will need to do, your two wires will be taken care of when you make for yourself a complete circuit, running from one end of the battery around some kind of loop to the other end of the battery.

Your wire will need to be cut apart with a cutting pliers into lengths. A convenient length for much of the wire to be cut into is 18 inches, but some pieces can be shorter, about 8 inches long.

About three quarters of an inch of the insulation will need to be trimmed off at each end of each piece. You can trim this off neatly with a dull knife; you should try to avoid cutting or nicking the wire since this will shorten the length of time it will last.

A small amount of the wire should be stripped of insulation and cut into pieces 1 or 2 inches long. These pieces of bare wire will be used for making transfer contracts on the multiple switches, as will be explained later.

3. Battery. This is an ordinary flashlight battery, of about one and a half volts. A volt is a unit of electric push, or electric pressure, or electric potential. All these terms mean the same thing.

You can think of a battery as a pump, which is able to push electrons, or little marbles of electricity, away from the plus end of the battery and towards the minus end of the battery, waiting for some kind of circuit at the minus end so that the electrons can flow around the circuit back to the plus end of the battery. A flow of electrons is an electric current.

The filament in the bulb through which the electrons flow provides a resistance or restriction or narrowness for the flow of electrons, so narrow in fact that it heats up and glows with friction as the electrons go through it.

4. Battery Clamp and On-Off Switch. This consists of a metal clip that is fastened with nuts and bolts into the panel and which will grip your battery and hold it. You then can fasten connections to the battery clamp and yet snap out your battery when it is weak and snap in another stronger battery in place of it when you need to.

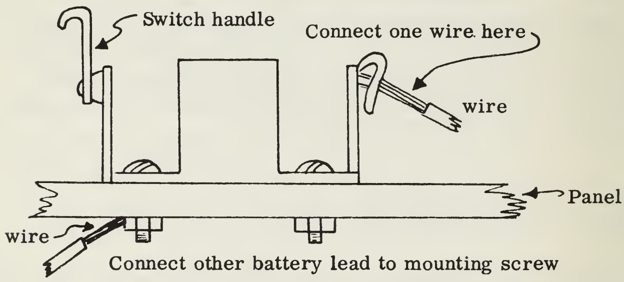

Figure 14 (Side View)

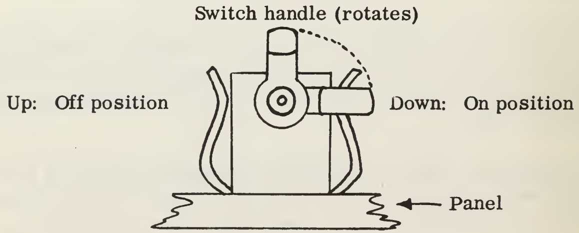

Figure 15 (End View)

The battery clamp has attached to it an on-off switch. Make connections as illustrated in Figure 14. The machine is off when the switch handle is in the upright position. The machine is on when the handle is rotated 90 degrees (see Figure 15).

5. Bulbs. You have small flashlight bulbs in the kit. They will glow from a single flashlight battery. In order to make them light, you have to run one wire from the bottom metal plate of the battery to the side of the bulb, and another wire from the top of the flashlight battery to the center of the base of the bulb. Your connections must be clean, not oily, nor corroded.

Examine your bulbs closely from time to time to make sure that the filament, the little slender wire that you see inside the glass bulb, is all in one piece. If it is broken, the bulb is spoiled.

6. Socket Parts. You have two "socket parts" for flashlight lamps. Each holds five lamps, in such a way that they can be screwed in and out of their socket holes. Views of the top, side and end of the socket part are shown in Figure 16.

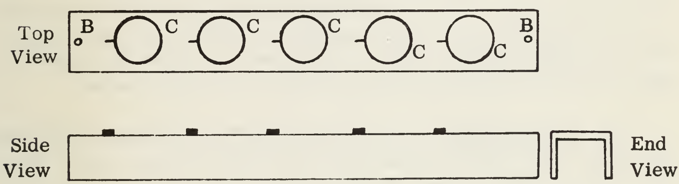

Figure 16 — Views of Socket Part

In order to make use of this part actually assembled in a machine (see Figure 17), first, short bolts (for electrical connections to the individual bulbs) are placed in the panel an inch apart and fastened tightly with nuts (see A in Figure 17).

Second, long bolts for fastening the socket part to the panel are passed (1) through the two small holes at the two ends (see B in both figures) of the socket part, and (2) through the panel, and fastened tightly with nuts. Third, the bulbs are screwed through the large holes in the top of the socket part (see C in Figure 16), and screwed down far enough to make tight, snug contact with the

bolt under the bulb. Since the socket part is metal, one wire connector attached to the end bolt connects all the bulbs together to one side of the battery (see D in Figure 17). Then the screw at the base of each bulb enables it to be connected to its separate source of illumination from the circuit (see E in Figure 17).

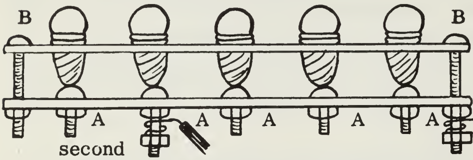

Figure 17 — Assembled Socket Part

7. Nuts and Bolts. For fastenings, connections, and terminals, here and there all over the machine, you have a supply of bolts and a supply of nuts. The nuts and bolts are of cadmium-plated steel, and give good electrical connections. A bolt is inserted through any hole; then a nut is screwed down tight on the bolt holding it in position; then the connecting wire is wound around the end of the bolt coming through; then a second nut is screwed down tight on the wire and the bolt so as to give a tight electrical contact.

8. Spintite Blade. In order to fasten your nuts and bolts easily, you will need a small screwdriver, which will fit in the slot of the bolt and enable it to be turned. You also have in the kit a small piece of hexagonal tubing (a spintite blade) which fits over and grips the hexagonal bolt and enables it to be spun quickly down the shaft of the bolt, and tightened, with the screwdriver holding the bolt.

9. Panel. In order to assemble your materials together into a machine, you have a rectangular panel consisting of masonite (thin pressed fiberboard). It contains holes for nuts and bolts so that the various parts of the set may be mounted together and assembled firmly.

If you examine the panel, you will see two patterns of holes. One pattern (see Figure 18) consists of 102 holes arranged in several rows through the middle of the panel from end to end.

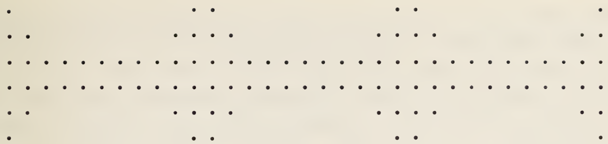

Figure 18

In this set of holes, all the hardware of a Brainiac machine is mounted except the "multiple switches", which will be explained in a moment. The second pattern consists of four rosettes of 65 holes in a circular arrangement (see Figure 19). These are the "bases" of the multiple switches.

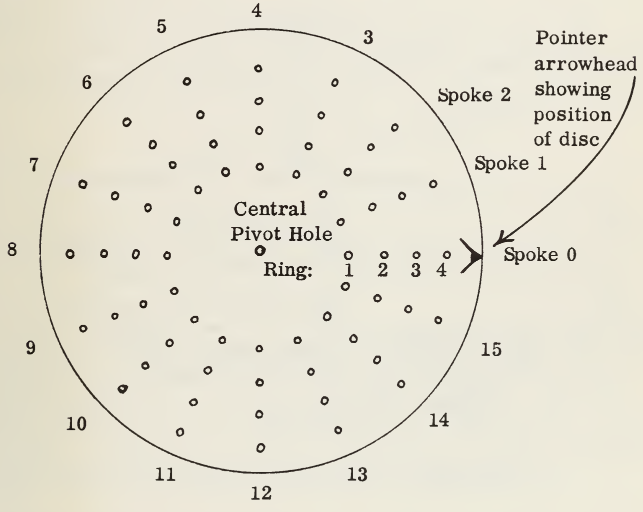

Figure 19 — Pattern of holes in the multiple switch (either the "base" in the panel or the "top", which is the disc). Also, the system of naming the holes.

10. Multiple Switches. The remaining material provided in the kit consists of round pieces of masonite, each containing 65 holes

in the same circular arrangement (see Figure 19), and the hardware for assembling them into multiple switches, switches which are able to switch many circuits at the same time. Each of the circular pieces of masonite is about 4-3/8 inches in diameter, is illustrated in Figure 19, and is called a multiple switch top, or switch disc, or switch dial, or simply a disc. These multiple switches have been patented (2848568).

In the panel each of the exactly similar sets of 65 holes is called a multiple switch base. In an early stage of design, the switch bases were separate pieces of masonite; but then it became evident that mounting of the hardware to make a machine would be better accomplished by having all the switch bases solidly connected together in the panel.

The top of a switch is fastened to the base of a switch by means of a center pivot, consisting of a long bolt, four hard washers, a sponge rubber washer, and a nut; the assembly of the center pivot is shown in Figure 20.

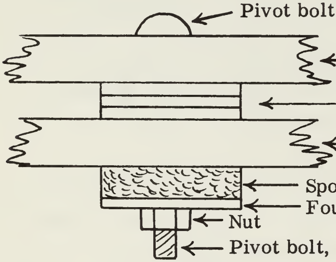

Figure 20 — Center Pivot Assembly

Instead of individual sponge rubber washers, the kit contains a small piece of sheet sponge rubber out of which the individual washers may be cut with a scissors. Cut out each rubber washer to be about the same size as one of the steel washers. Cut or poke a small hole in the middle of washer to allow a bolt to go through it. It is then ready for use; it functions as a compression spring.

The holes (except the center hole) in each switch base and

switch top are arranged in 4 rings and 16 spokes. The rings are called Ring 1, 2, 3, 4 going outward, and the spokes are called Spoke 0, 1, 2, 3, and so on around, to Spoke 15. The counting starts with the spoke directly to the right, and goes counterclockwise. See Figure 19.

Each of the holes in the switch base may or may not contain a short bolt, called a terminal, for making connections. The connections are made using two nuts, one for fastening the bolt securely to the switch base, and the second for holding and tightening a wire around the bolt so as to make a good electrical connection with the bolt (see Figure 21).

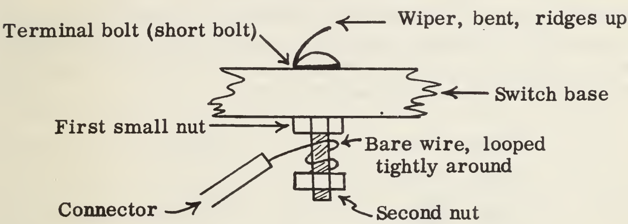

Figure 21 — Assembly of Wiper, Terminal Bolt, and a Wire Connector

11. Jumpers. Each pair of holes in a switch top, from Ring 1 to Ring 2 or from Ring 3 to Ring 4 (or very rarely from Ring 2 to Ring 3) may or may not contain a jumper, a small piece of brass plated metal with two prongs, as shown in Figure 22. The two prongs fit into holes in the switch disc and are pressed down, like a clasp or T fastener, as shown in Figure 23. A jumper serves to make and break electrical contact as the switch is turned.

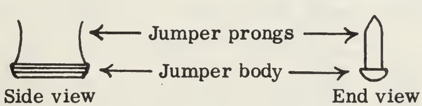

Figure 22 — Jumper, not mounted

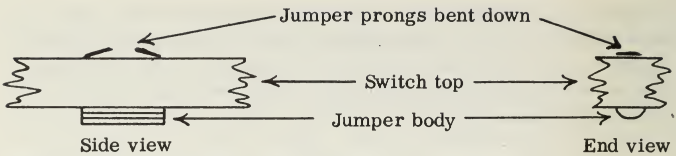

Figure 23 — Jumper, inserted in two adjacent holes along a spoke

12. Wipers. In between the jumper and the bolt, in the assembled multiple switch, is inserted a wiper, a springy piece of phosphor bronze with a hole and two small ridges. The shape of the wiper unbent, as it comes in the small envelope, is shown in Figure 24. The purpose of the wiper is to improve the electrical contact between the top of the switch (the disc containing the jumpers) and the bottom of the switch (the panel containing the bolts and nuts for the terminals). These wipers have been patented (2848568).

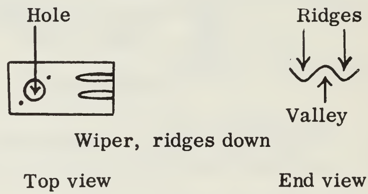

Figure 24 — Unbent wiper

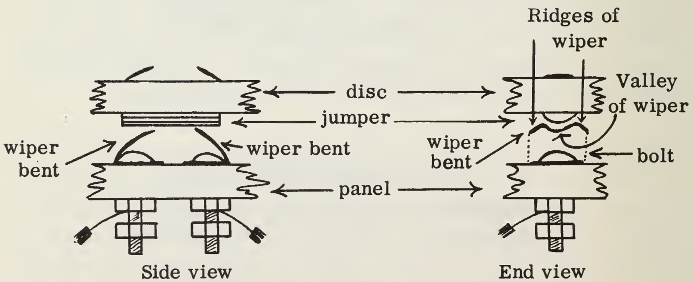

Figure 25 — Assembly of wipers

The way in which the wiper is assembled is shown in Figure 25, and is as follows: (1) thread the bolt through the wiper, with its ridges down; (2) fasten the bolt not too tightly to the panel; (3) align the wiper with the spoke (or radius) of the switch; (4) now fasten the bolt tightly; (5) bend the wiper gently upwards and over the bolt, with the ridges up, in such a way that the wiper will slide neatly on the jumper, resting in its valley between the ridges; (6) assemble the multiple switch with (probably three) washers in between the disc and the panel; (7) adjust the amount of bending the wipers so that they push up and down nicely against the jumpers as the switch turns.

For multiple switches with only two jumpers evenly spaced, or only three jumpers almost evenly spaced, you will not need wipers and should not use them, for such switches will work entirely properly without wipers. In these cases, you will need to make sure that the slots in the heads of the bolts are lined up with the spoke, so that the jumpers themselves will position (or detent) along the spoke right above the bolts. (In assembling a switch without wipers, you need only one or two spacing washers along the center bolt, not three.) For switches with four or more jumpers, you will need wipers, for otherwise the switch is likely to work unreliably.

13. Assembly of the Multiple Switches. Before any of the multiple switches can function, however, it must first be assembled.

Into the base we have to insert a number of nuts and bolts to hold wire connections and wipers. Just where these are inserted depends on the type of switch we desire to construct, two-position, or four-position, or some other type.

Into the top of the switch we must insert a number of jumpers in order to make and break contacts. Each jumper is inserted along a spoke between one ring and the next. Just where the jumpers are inserted again depends on the type of switch we desire to construct.

In order for the switch to stay in a position to which it is turned, the body of the jumper must line up with the valleys between the ridges on the wipers, and these valleys must be in line with the spoke; then the jumpers will have a tendency to catch in the valleys, as they should, to hold the switch in position (see Figure 25, end view).

Note that in some drawings of the multiple switches, the rings and spokes are drawn as thin lines; these lines are not actually drawn on the switch discs nor the switch bases; nor do they represent electrical lines connecting terminals; instead they are drawn to make the arrangement clearer.

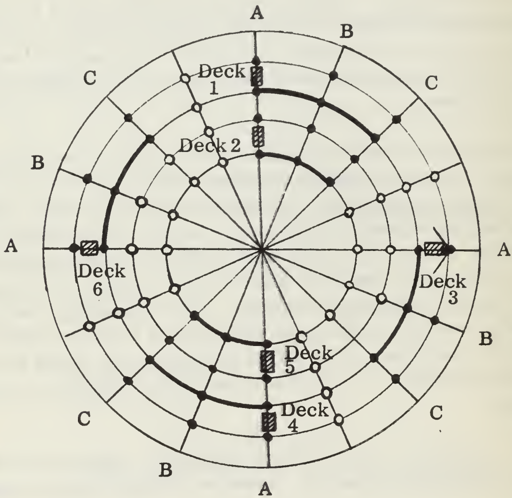

Figure 26 — Three position switch, six decks (or poles or levels)

Now suppose we wanted to assemble a switch which would have any one of three positions A, B, and C, and which would be capable of switching every one of six different circuits. A way in which that switch could be assembled is shown in Figure 26, in which both the top and the bottom of the switch are drawn over each other. Six jumpers are inserted in the top of the switch, shown as ▨ in Figure 26. It is important that jumpers ordinarily be inserted in pairs opposite each other, for reasons of mechanical balancing, so that the top of the switch will stay parallel to the bottom of the switch. A total of six times six or 36 nuts and bolts are inserted in the bottom of the switch, in the spots marked

in Figure 26. They are in groups of six called decks (also called poles, or levels); these decks are electrically independent, and they enable us to switch 6 different circuits. In the base, the bolts belonging in any one deck in Ring 1 or Ring 3 are connected together by wire, as shown by the heavy line; they may be connected with one of the short wires 1-1/2 inches long. They are made electrically common; in other words, they are commoned. Together they constitute what is called a transfer contact.

Let us now consider the layout of the spokes and the rings and the 64 holes which they produce. We can see that we can assemble a switch in a number of different ways. This is the advantage of the design of the multiple switch we have chosen (patent 2848568). Here are the types of switches that can be made with these parts:

Number of Positions	Maximum Number of Decks
2	16
3	10
4	8
5	6
6 to 8	4
9 to 16	2

If nuts and bolts did not cost anything, we could insert 64 nuts and bolts into the base of each switch and leave them there — ready for use in any switch. Actually, because the kit has a limited supply, it may be necessary to move nuts and bolts from one switch to another in order to make the different machines we want.

In the case of jumpers and wipers, we shall fairly often have to move them to different places, in order to make different switches for different machines.

14. Additional Material. You may obtain additional or replacement material for this kit by buying it at a local store, or by writing to us. Obviously, if your battery runs down, or if you want more wire, or if you want more nuts and bolts, the easy thing to do is to buy them in your neighborhood. But for more switch discs or more jumpers, etc., you will probably need to write us. Prices for these items are listed on a price list enclosed with the kit or obtainable on request.

15. Labels. The best procedure for making labels is: (1) type them out or write them out neatly on paper; (2) cut them out; (3) fasten

them on the board with cellophane tape.

16. Templates. In work with electrical circuits we need to lay out beforehand what we are going to do. We need to design on paper how we are to connect the different pieces of material. For this purpose, we use circuit diagrams, wiring lists, and templates.

A circuit diagram, as mentioned before, shows the scheme of connection of batteries, switches, lights, etc., in order to make the circuit. In a circuit diagram we pay little attention to the actual physical location of the material; we just show a diagram of its arrangement.

In a wiring list, we name the terminals, by words or letters or numbers, and we state, for every part of the circuit, what terminal is connected to what terminal. In a wiring list again we pay no attention to the actual spatial locations of the terminals. For example, if without drawing the wire, we write "to...", we are using the principle of a wiring list.

In a template, the case is different; we show the actual wiring and the approximate relative spatial location of the different pieces of material used in the circuit. In other words, we draw an accurate geographical map of where the terminals are, and then we indicate the wiring either by drawing lines for the connections or by writing notes showing the connections. For the experiments in this manual, templates on the actual scale are included in the kit.

In each experiment in the Brainiac kit, the important part of the wiring is on the rear side of the panel. Accordingly, each template shows a full scale picture of the rear of the panel. It is therefore a mirror image: what is on the right in the drawing in the manual is on the left in the template; and vice versa. Of course, some of the information appearing on the template belongs on the front side of the board: the labels of the switches, their positions, and the lights; and the location of the jumpers in the discs. If one pays careful attention to the two drawings, one in the manual and one on the template, the way the hardware and labels actually are arranged should become quite clear.

17. Trouble-Shooting. After you have wired up a machine, and start to play with it, you are likely to find that it does not work entirely correctly. All engineers worth their salt who do any kind of significant work with electrical circuits discover when they first

assemble a new piece of equipment that it does not work properly. Finding out the reasons why and removing the causes of malfunctioning, the process known as trouble-shooting, therefore, is an important and essential part of making any piece of equipment start working and stay working; and good trouble-shooting is the mark of a good engineer.

In order to trouble-shoot, it is helpful to have a systematic and logical checklist of questions to be answered one after another, and in addition testing apparatus which will tell whether a part of a circuit actually does what it is supposed to do. In order to test machines made with a Brainiac kit, the essential piece of testing apparatus is what is called a continuity tester. A simple form of such a tester is a flashlight battery, a lamp, and two wires with bare ends, connected as shown in Figure 27. Then, when you take the ends of the two wires, and touch a certain pair of terminals, if you obtain a light, you know that that part of the circuit is connected, is continuous; while if you obtain no light, you know that that part of the circuit is not connected, is isolated. Then, you compare what your tester shows to be actual fact with what you are supposed to have according to the circuit diagram, and you have either verified the correctness of that part of the circuit, or located some trouble.

Here are some checklist questions which make a beginning at trouble-shooting:

(1) Does each wire actually make contact with each terminal to which it is fastened?
(2) Does each jumper actually make contact with the wiper at each terminal, as its switch turns?
(3) Does each lamp really light?
(4) Is there electricity in the battery?
(5) Has any wire broken inside its insulation?
(6) Is there a mistake or typographic error in the diagram or the instructions? (This question must always be asked, because no author or printer is infallible.)
(7) Does each wire go where it should?
(8) Has each label been fastened on in its right place?
(9) Is each jumper in its right place?
(10) Is each terminal in its right place?

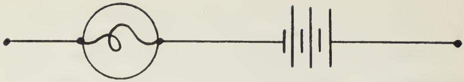

Figure 27 — Continuity Tester

If you can locate and remove trouble skillfully, you can be well satisfied with what you have learned.

18. Design for a Stand. When working on wiring and assembling a Brainiac machine, it is convenient to make a simple stand for holding the panel upright, so that you can work on both sides. Here is a design for a stand which will do this.

1. Take two pieces of rectangular wooden rod about 1 inch by 1 inch by 9 inches long:

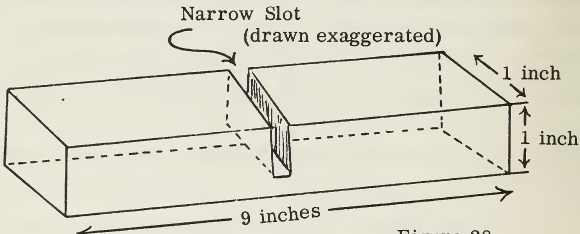

Figure 28

2. Saw a slot in the center of each piece of rod about 2/3 of the way through.

3. With a file, widen and rub down the sides of the slot so that the Brainiac panel fits into the slot snugly, but not too tightly nor too loosely.

4. Then for wiring, assembling, displaying, etc., the panel, held in the stand, looks like:

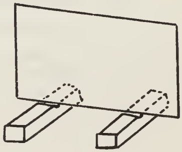

Figure 29

BRAINIACS® —

Small Electric Brain Machines

Materials in the Kit and How To Assemble Them

Edmund C. Berkeley

Published by Berkeley Enterprises, Inc.
815 Washington St., Newtonville, Mass. 02160

First printing, January, 1966

Introduction

This report and the accompanying kit and literature present Brainiacs ®, small electric brain machines. They are electrical machines which are able to calculate and reason automatically although they are too small to perform operations one after another automatically. They show, with the least hardware that we have yet been able to work out that still allows interesting experiments, the fascinating power and variety of computing and reasoning circuits. There are over 200 experiments.

Each of the machines uses one flashlight battery, not more than ten flashlight lamps, and not more than six multiple switches. All connections are made with nuts and bolts, and no soldering is required: the kit is completely safe. The kit, though inexpensive and convenient for constructing Brainiacs, is however not necessary; and some persons will prefer to construct their Brainiacs using other materials.

The descriptions of the experiments are contained in the book "Brainiacs — 201 Small Electric Brain Machines and How to Make Them". The first thing to do is to read carefully:

Chapter 1 - Small Electric Brain Machines — Some Questions and Answers

Chapter 2 - Circuits and Circuit Diagrams

Then this manual should be read, since it describes the materials in the kit and how to assemble them. Then a simple experiment from the book should be selected, constructed, and tried. It would be sensible to choose experiment No. 1 on page 9, which is also shown in the first template.

If you find that at first you have some difficulty in understanding all that is in this kit, TAKE YOUR TIME and think; make first the simpler machines; then try the more complicated ones. To make a machine that will reason and calculate you too must reason and calculate.

We hope that you find the experiments and the kit interesting, entertaining and amusing, and that you will enjoy playing with the kit and entertaining your friends with the little machines that you make. Any comments, suggestions for new experiments, and corrections, will be gratefully received. We shall be glad to hear from you.

Edmund C. Berkeley

With the Brainiac Electric Brain Construction Kit anyone can put together the machines of the types described in the experiments (and many more besides), so that they will perform operations of reasoning and computing.

The kit is harmless. It runs on one flashlight battery. Wires are connected by fastening them to the same nut and bolt and tightening the connection by gripping them between two bolts. No heat or soldering iron is required. DO NOT CONNECT this kit or any part of it to any home or industrial electrical power outlet; you are likely to destroy the material, and you may hurt yourself.

The kit is simple, but nevertheless it takes effort and work to put the material together to make a functioning electric brain. We urge you to take your time. If necessary, read the instructions several times. If the instructions are still not clear, read ahead and then return.

1. Parts List. The kinds of parts contained in the kit are the following:

Insulated wire
Battery box
Bulbs, flashlight, 1-1/2 volts
Socket parts for flashlight bulbs, holding five together
Short bolts, 6/32, 1/2 inch long
Hexagonal nuts, 6/32, 1/4 inch diameter
Spintite blade
Panel, masonite, rectangular, punched
Multiple Switch Discs, masonite, circular, punched
Long bolts, 6/32, 7/8 inch, for center pivot, etc.
Washers, hard, cardboard
Washers, soft, sponge rubber
Jumpers, metal, brass
Wipers, phosphor bronze

In addition an ordinary size D flashlight battery, 1 1/2 volt, is needed

Each of these items will now be described. (Note: Figures 1 to 13 are not in this manual but in the book "Brainiacs" and should be studied before the Figures in this manual are studied.)

2. Wire. The kit provides a coil of wire covered with insulation. This is like the wire connecting a lamp to a wall plug, for example, but adapted for handling a much smaller amount of electricity. Also, instead of two wires together making two paths for electricity, here is one wire only. In the Brainiac wiring that you will do, the wire follows a single path running from one end of the battery through some kind of loop to the other end of the battery, thus making a complete circuit.

Your wire needs to be cut apart with a cutting pliers into pieces. A convenient length for many pieces is 18 inches, but some pieces can be shorter, about 8 inches long. About 3/4 of an inch of insulation should be removed at each end of each piece. You can trim this off neatly with a dull knife. Also, a small amount of wire should be stripped of insulation and cut into pieces about 2 inches long. These pieces of bare wire make transfer contacts, as will be explained later.

3. Battery. An ordinary flashlight battery, size D, provides about 1 and 1/2 volts. A volt is a unit of electric pressure or electric potential. A battery acts like a pump, and pumps electricity from one end of the battery around a circuit to the other end of the battery. A flow of electricity is an electric current. The filament of a bulb through which the electricity flows provides a narrowness or a restriction or a resistance to the flow, so that it heats up and glows with "friction" as electricity flows through it.

4. Battery Box. The battery box consists of a scored, glued piece of cardboard which will readily fold into a box of the right size to hold the battery. At each end of the box is a small hole. Through this hole from the inside of the box insert a bolt (on which a washer has been threaded, see Figure 15); then fasten the bolt

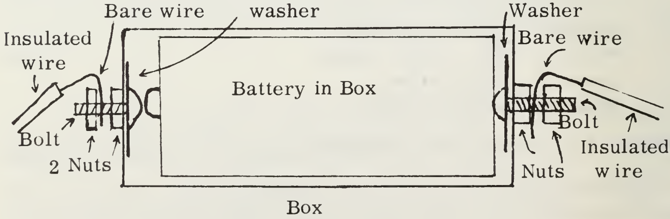

Figure 15

with a nut on the outside of the box. The battery terminal connection is fastened to the projecting bolt with a second nut. The box will now hold a battery snugly, giving good contact. The battery box may be tied securely to the panel with a tight string around it and passing through holes in the panel.

5. Bulbs. You have small flashlight bulbs in the kit. They will glow from a single flashlight battery. In order to make them light, you have to run one wire from the bottom metal plate of the battery to the side of the bulb, and another wire from the top of the flashlight battery to the center of the base of the bulb. Your connections must be clean, not oily, nor corroded. Examine your bulbs closely from time to time to make sure that the filament, the little slender wire that you see inside the glass bulb, is all in one piece. If it is broken, the bulb is spoiled.

6. Socket Parts. You have two "socket parts" for flashlight lamps. Each holds five lamps, in such a way that they can be screwed in and out of their socket holes. Views of the top, side and end of the socket part are shown in Figure 16.

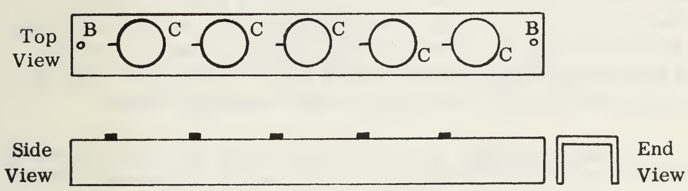

Figure 16 — Views of Socket Part

In order to make use of this part actually assembled in a machine (see Figure 17), first, short bolts (for electrical connections to the individual bulbs) are placed in the panel an inch apart and fastened tightly with nuts (see A in Figure 17).

Second, long bolts for fastening the socket part to the panel are passed (1) through the two small holes at the two ends (see B in both figures) of the socket part, and (2) through the panel, and fastened tightly with nuts. Third, the bulbs are screwed through the large holes in the top of the socket part (see C in Figure 16), and screwed down far enough to make tight, snug contact with the

bolt under the bulb. Since the socket part is metal, one wire connector attached to the end bolt connects all the bulbs together to one side of the battery (see D in Figure 17). Then the screw at the base of each bulb enables it to be connected to its separate source of illumination from the circuit (see E in Figure 17).

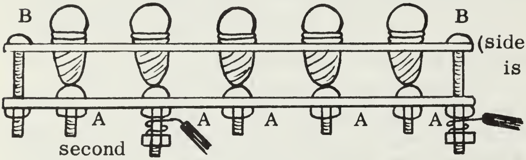

Figure 17 — Assembled Socket Part

7. Nuts and Bolts. For fastenings, connections, and terminals, here and there all over the machine, you have a supply of bolts and a supply of nuts. The nuts and bolts are of rust-proofed steel, and give good electrical connections. A bolt is inserted through any hole; then a nut is screwed down tight on the bolt holding it in position; then the connecting wire is wound around the end of the bolt coming through; then a second nut is screwed down tight on the wire and the bolt so as to give a tight electrical contact.

8. Spintite Blade. In order to fasten your nuts and bolts easily, you will need a small screwdriver, which will fit in the slot of the bolt and enable it to be turned. You also have in the kit a small piece of hexagonal tubing (a spintite blade) which fits over and grips the hexagonal bolt and enables it to be spun quickly down the shaft of the bolt, and tightened, with the screwdriver holding the bolt.

9. Panel. In order to assemble your materials together into a machine, you have a rectangular panel consisting of masonite (thin pressed fiberboard). It contains holes for nuts and bolts so that the various parts of the set may be mounted together and assembled firmly.

If you examine the panel, you will see two patterns of holes. One pattern (see Figure 18) consists of 102 holes arranged in several rows through the middle of the panel from end to end.

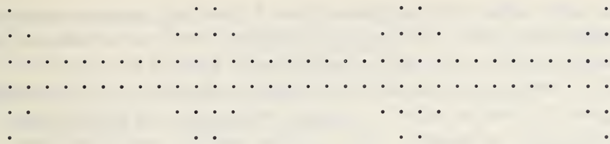

Figure 18

In this set of holes, all the hardware of a Brainiac machine is mounted except the "multiple switches", which will be explained in a moment. The second pattern consists of four rosettes of 65 holes in a circular arrangement (see Figure 19). These are the "bases" of the multiple switches.

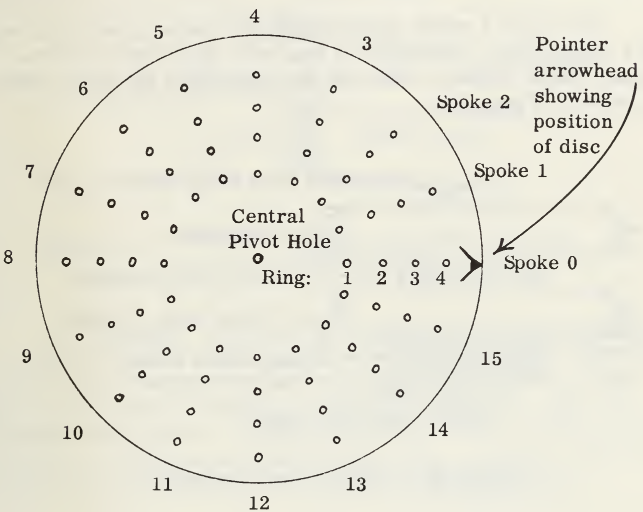

Figure 19 — Pattern of holes in the multiple switch (either the "base" in the panel or the "top", which is the disc). Also, the system of naming the holes.

10. Multiple Switches. The remaining material provided in the kit consists of round pieces of masonite, each containing 65 holes

in the same circular arrangement (see Figure 19), and the hardware for assembling them into multiple switches, switches which are able to switch many circuits at the same time. Each of the circular pieces of masonite is about 4-3/8 inches in diameter, is illustrated in Figure 19, and is called a multiple switch top, or switch disc, or switch dial, or simply a disc. These multiple switches have been patented (2848568).

In the panel each of the exactly similar sets of 65 holes is called a multiple switch base. In an early stage of design, the switch bases were separate pieces of masonite; but then it became evident that mounting of the hardware to make a machine would be better accomplished by having all the switch bases solidly connected together in the panel.

The top of a switch is fastened to the base of a switch by means of a center pivot, consisting of a long bolt, some hard washers, a sponge rubber washer, and a nut; the assembly of the center pivot is shown in Figure 20.

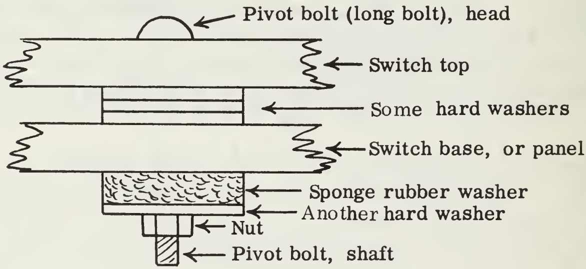

Figure 20 — Center Pivot Assembly

Instead of individual sponge rubber washers, the kit contains a small piece of sheet sponge rubber out of which the individual washers may be cut with a scissors. Cut out each rubber washer to be about the same size as one of the steel washers. Cut or poke a small hole in the middle of washer to allow a bolt to go through it. It is then ready for use; it functions as a compression spring.

The holes (except the center hole) in each switch base and

switch top are arranged in 4 rings and 16 spokes. The rings are called Ring 1, 2, 3, 4 going outward, and the spokes are called Spoke 0, 1, 2, 3, and so on around, to Spoke 15. The counting starts with the spoke directly to the right, and goes counterclockwise. See Figure 19.

Each of the holes in the switch base may or may not contain a short bolt, called a terminal, for making connections. The connections are made using two nuts, one for fastening the bolt securely to the switch base, and the second for holding and tightening a wire around the bolt so as to make a good electrical connection with the bolt (see Figure 21).

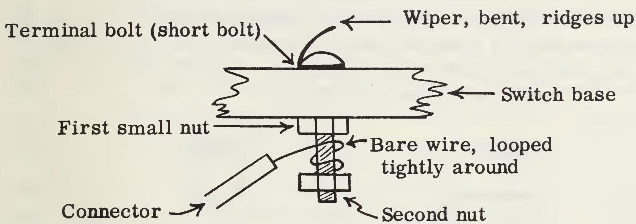

Figure 21 — Assembly of Wiper, Terminal Bolt, and a Wire Connector

11. Jumpers. Each pair of holes in a switch top, from Ring 1 to Ring 2 or from Ring 3 to Ring 4 (or very rarely from Ring 2 to Ring 3) may or may not contain a jumper, a small piece of brass plated metal with two prongs, as shown in Figure 22. The two prongs fit into holes in the switch disc and are pressed down, like a clasp or T fastener, as shown in Figure 23. A jumper serves to make and break electrical contact as the switch is turned.

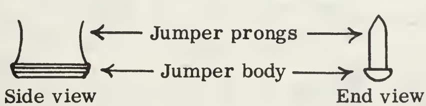

Figure 22 — Jumper, not mounted

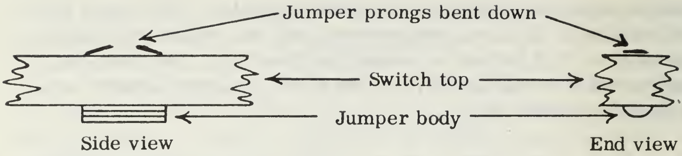

Figure 23 — Jumper, inserted in two adjacent holes along a spoke

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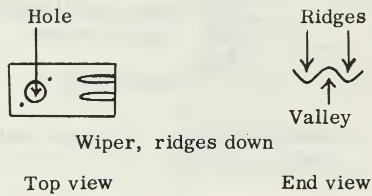

Figure 24 — Unbent wiper

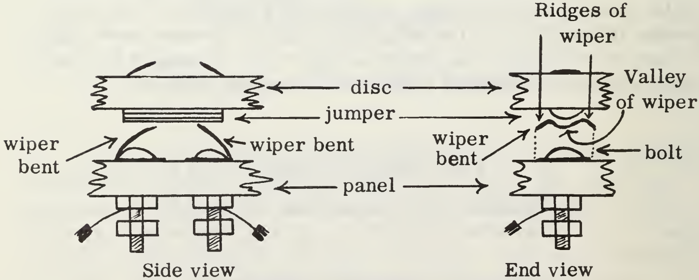

Figure 25 — Assembly of wipers

The way in which the wiper is assembled is shown in Figure 25, and is as follows: (1) thread the bolt through the wiper, with its ridges down; (2) fasten the bolt not too tightly to the panel; (3) align the wiper with the spoke (or radius) of the switch; (4) now fasten the bolt tightly; (5) bend the wiper gently upwards and over the bolt, with the ridges up, in such a way that the wiper will slide neatly on the jumper, resting in its valley between the ridges; (6) assemble the multiple switch with (probably three) washers in between the disc and the panel; (7) adjust the amount of bending the wipers so that they push up and down nicely against the jumpers as the switch turns.

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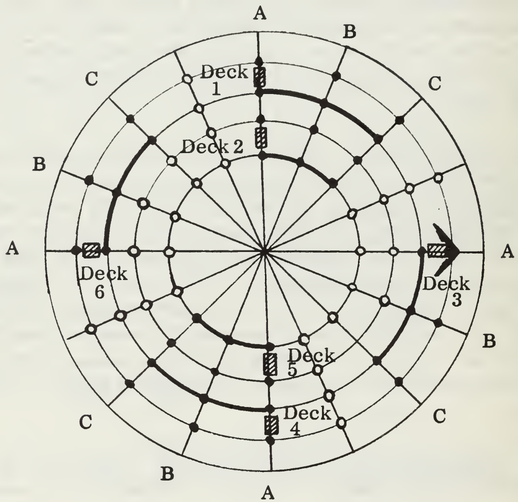


Figure 26 — Three position switch, six decks (or poles or levels)

Now suppose we wanted to assemble a switch which would have any one of three positions A, B, and C, and which would be capable of switching every one of six different circuits. A way in which that switch could be assembled is shown in Figure 26, in which both the top and the bottom of the switch are drawn over each other. Six jumpers are inserted in the top of the switch, shown as  in Figure 26. It is important that jumpers ordinarily be inserted in pairs opposite each other, for reasons of mechanical balancing, so that the top of the switch will stay parallel to the bottom of the switch. A total of six times six or 36 nuts and bolts are inserted in the bottom of the switch, in the spots marked ●

in Figure 26. They are in groups of six called decks (also called poles, or levels); these decks are electrically independent, and they enable us to switch 6 different circuits. In the base, the bolts belonging in any one deck in Ring 1 or Ring 3 are connected together by wire, as shown by the heavy line; they may be connected with one of the short wires 1-1/2 inches long. They are made electrically common; in other words, they are commoned. Together they constitute what is called a transfer contact.

Let us now consider the layout of the spokes and the rings and the 64 holes which they produce. We can see that we can assemble a switch in a number of different ways. This is the advantage of the design of the multiple switch we have chosen (patent 2848568). Here are the types of switches that can be made with these parts:

Number of Positions	Maximum Number of Decks
2	16
3	10
4	8
5	6
6 to 8	4
9 to 16	2

If nuts and bolts did not cost anything, we could insert 64 nuts and bolts into the base of each switch and leave them there — ready for use in any switch. Actually, because the kit has a limited supply, it may be necessary to move nuts and bolts from one switch to another in order to make the different machines we want.

In the case of jumpers and wipers, we shall fairly often have to move them to different places, in order to make different switches for different machines.

14. Additional Material. You may obtain additional or replacement material for this kit by buying it at a local store, or by writing to us. Obviously, if your battery runs down, or if you want more wire, or if you want more nuts and bolts, the easy thing to do is to buy them in your neighborhood. But for more switch discs or more jumpers, etc., you will probably need to write us. Prices for these items are listed on a price list enclosed with the kit or obtainable on request.

15. Labels. The best procedure for making labels is: (1) type them out or write them out neatly on paper; (2) cut them out; (3) fasten

them on the board with cellophane tape.

16. Templates. In work with electrical circuits we need to lay out beforehand what we are going to do. We need to design on paper how we are to connect the different pieces of material. For this purpose, we use circuit diagrams, wiring lists, and templates.

A circuit diagram, as mentioned before, shows the scheme of connection of batteries, switches, lights, etc., in order to make the circuit. In a circuit diagram we pay little attention to the actual physical location of the material; we just show a diagram of its arrangement.

In a wiring list, we name the terminals, by words or letters or numbers, and we state, for every part of the circuit, what terminal is connected to what terminal. In a wiring list again we pay no attention to the actual spatial locations of the terminals. For example, if without drawing the wire, we write "to...", we are using the principle of a wiring list.

In a template, the case is different; we show the actual wiring and the approximate relative spatial location of the different pieces of material used in the circuit. In other words, we draw an accurate geographical map of where the terminals are, and then we indicate the wiring either by drawing lines for the connections or by writing notes showing the connections. For some illustrative Brainiac experiments, templates on a reduced scale are included in the kit.

In each experiment in the Brainiac kit, the important part of the wiring is on the rear side of the panel. Accordingly, each template shows a scaled picture of the rear of the panel. It is therefore a mirror image: what is on the right in the drawing in the manual is on the left in the template; and vice versa. Of course, some of the information appearing on the template belongs on the front side of the board: the labels of the switches, their positions, and the lights; and the location of the jumpers in the discs. If one pays careful attention to the two drawings, one in the manual and one in the template, the way the hardware and labels actually are arranged should become quite clear.

17. Trouble-Shooting. After you have wired up a machine, and start to play with it, you are likely to find that it does not work entirely correctly. All engineers worth their salt who do any kind of significant work with electrical circuits discover when they first

assemble a new piece of equipment that it does not work properly. Finding out the reasons why and removing the causes of malfunctioning, the process known as trouble-shooting, therefore, is an important and essential part of making any piece of equipment start working and stay working; and good trouble-shooting is the mark of a good engineer.

In order to trouble-shoot, it is helpful to have a systematic and logical checklist of questions to be answered one after another, and in addition testing apparatus which will tell whether a part of a circuit actually does what it is supposed to do. In order to test machines made with a Brainiac kit, the essential piece of testing apparatus is what is called a continuity tester. A simple form of such a tester is a flashlight battery, a lamp, and two wires with bare ends, connected as shown in Figure 27. Then, when you take the ends of the two wires, and touch a certain pair of terminals, if you obtain a light, you know that that part of the circuit is connected, is continuous; while if you obtain no light, you know that that part of the circuit is not connected, is isolated. Then, you compare what your tester shows to be actual fact with what you are supposed to have according to the circuit diagram, and you have either verified the correctness of that part of the circuit, or located some trouble.

Here are some checklist questions which make a beginning at trouble-shooting:

(1) Does each wire actually make contact with each terminal to which it is fastened?
(2) Does each jumper actually make contact with the wiper at each terminal, as its switch turns?
(3) Does each lamp really light?
(4) Is there electricity in the battery?
(5) Has any wire broken inside its insulation?
(6) Is there a mistake or typographic error in the diagram or the instructions? (This question must always be asked, because no author or printer is infallible.)
(7) Does each wire go where it should?
(8) Has each label been fastened on in its right place?
(9) Is each jumper in its right place?
(10) Is each terminal in its right place?

Figure 27 — Continuity Tester

If you can locate and remove trouble skillfully, you can be well satisfied with what you have learned.

18. Design for a Stand. When working on wiring and assembling a Brainiac machine, it is convenient to make a simple stand for holding the panel upright, so that you can work on both sides. Here is a design for a stand which will do this.

1. Take two pieces of rectangular wooden rod about 1 inch by 1 inch by 9 inches long:

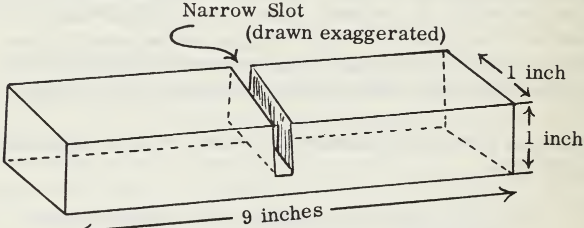


Figure 28

2. Saw a slot in the center of each piece of rod about 2/3 of the way through.

3. With a file, widen and rub down the sides of the slot so that the Brainiac panel fits into the slot snugly, but not too tightly nor too loosely.

4. Then for wiring, assembling, displaying, etc., the panel, held in the stand, looks like:

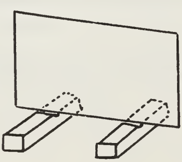


Figure 29

First Booklet

HOW TO ASSEMBLE BRAINIACS®

Containing

Part 1: Brainiac Kit Parts and Their Use

Part 2: NINE Electrical Research Experiments

by
Dorothy D. Zinck

Sold by Cardinal Wood Products
9229 East Prairie Road
Skokie, Ill.

Published by Berkeley Enterprises, Inc.
815 Washington St.
Newtonville 60, Mass.

First printing, August, 1959

Introduction

Booklet 1 contains two parts. Part 1 describes the Brainiac kit parts and explains their use. Part 2 consists of a number of electrical research experiments which will make you familiar with your equipment, help you understand how it is to be assembled, and prepare you for the more advanced experiments in Booklet 2.

If you are already familiar with the principles of electricity, you will be able to do all of the experiments quickly. Be sure not to skip any, however, since you will often use equipment assembled in one experiment for the next experiment.

If you have not had much experience with electricity, you will need to go more slowly. As you complete each experiment, read the "What happened?" section several times, tracing the circuit through the diagram as you read. Do not go on to the next experiment until you are sure you understand not only WHAT you have accomplished, but also WHY the experiment worked.

You will find that the time you devote to this booklet will be well spent. To attempt to complete the experiments in Booklet 2 without finishing the experiments in this booklet would be much like learning advanced algebra or trigonometry without first learning your multiplication tables; or studying English literature, physics, chemistry, or history without first learning to read.

If you DO understand the experiments in Booklet 1, you will have the background information necessary in order to assemble the computing and reasoning machines described in Booklet 2.

Libertyville, Ill. Dorothy D. Zinck, author
August, 1959

Part 1

BRAINIAC KIT PARTS AND THEIR USE

Unpacking your kit

Spread the contents of your Brainiac kit on the table as follows:

1. Remove the items from the small box (but do not open the plastic bags).

2. With the screwdriver pry the staples from the small box so you can remove it.

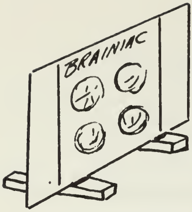
3. Unscrew the two white discs (which look like wheels). You will find there are actually four discs. Put the discs on the table, and the bolts, nuts, and washers in the small box.

4. Remove the large rectangular panel, then the two pieces of wood taped to the kit box. Set the panel upright in the slots of the two pieces of wood.

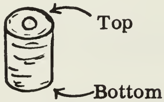
Identifying your Brainiac kit parts

Since you will use the same parts over and over again in your experiments, it is important for you to recognize each part by name and by appearance, and to know its use. While you have the contents of the Brainiac kit on the table before you, read through the list below. Find each part which is described, and examine it carefully. By doing this now, you will be able to understand and complete the experiments much more quickly than would be possible otherwise.

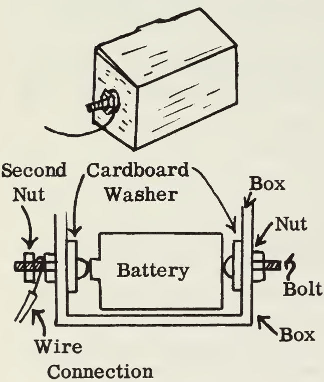
A. Brainiac Panel (the large rectangular panel). The Brainiac panelboard, or panel, has two main purposes: (1) It is a mounting board on which you assemble and fasten your equipment. (2) When you have completed your experiment, it is an instrument panel with round movable switches with which you control your machine. You can write notes directly on the panelboard with an ordinary lead pencil. The marks will erase easily when you are ready for a new experiment.



A. Brainiac Panel (the large rectangular panel)

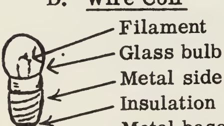


B. Battery

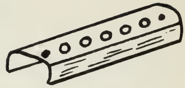


C. Battery Box

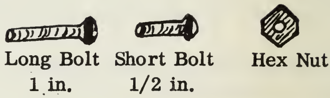
D. Wire Coil



E. Lamp



F. Socket Part

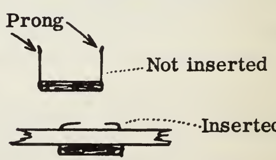


G. Bolts and Hex Nuts

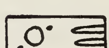
H. Screwdriver

I. Spintite Blade

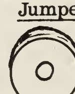
J. Switch Discs



K. Jumper



L. Wiper



M. Hard Washer

N. Soft Washer

B. Battery. The battery supplies the electric current for your experiment or machine. The end with the metal button is the top; the flat end, the bottom. (If you did not receive batteries with your Brainiac kit, you can get the right kind by obtaining a size D flashlight battery of 1-1/2 volts. Batteries are not packed in the kit at the factory because they lose their power if they are kept too long.)

C. Battery Box. The battery box holds the battery in place, and provides ways whereby wires can be connected to each end of it. Read the instructions on the box carefully; then fold it together.

At each end of the box there is a small hole. Insert a bolt through the end of the box from the inside of the box; then fasten it with a nut on the outside of the box. Then the wire connection can be fastened with a second nut. The box should now hold a battery cell properly and give good contact. To fasten the battery box containing the battery to the board, tie a loop of string or wire around the box, and through two holes in the board.

Test the connections from the battery to see that the heads of the bolts rest snugly and firmly against the ends of the battery. If there is not enough pressure from the ends of the cardboard box against the ends of the battery, cut out some cardboard washers, and insert them between the heads of the bolt and the ends of the battery box so as to produce firmer, more positive contact.

D. Wire Coil. The wire coil contains 25 feet of insulated copper wire. The plastic, or insulation, around the wire will not conduct electricity. The wire itself will. For your experiments you will cut the wire from time to time into short lengths and fasten them to various parts to carry electricity from one part to the next. Do not cut the wire now.

E. Lamp. The lamp is a lightbulb such as used in flashlights. It will glow when properly connected to the battery by wires. The parts of the lamp are:

1. The glass bulb, which does not conduct electricity.

2. The filament — a fine wire inside the bulb, which glows as electricity passes through it.

3. The metal side — which provides one way for electricity to go into or out of the lamp.

4. The metal base — which provides the second way for electricity to go into or out of the lamp.

5. The insulation between the metal side and the metal base which prevents them from connecting electrically with each other.

F. Socket Part. The socket part holds the lamps upright. Each socket part has seven holes — a small one at each end to bolt the part to your Brainiac panelboard, and five larger ones for holding lamps.

Each of the larger holes has a bent notch which grips the lamp as you screw it in or out.

G. Bolts and Hex Nuts. Bolts and hexagonal nuts (or hex nuts) are used as "terminals" for fastening wires. They are also used to attach your equipment to the Brainiac panelboard. The long bolts are 1 inch long; the short ones, 1/2 inch long. The screw thread specification is 6/32.

H. Screwdriver. The Brainiac screwdriver is long and slender so it will not get in the way when you work. It has a clip so you can keep it handily in your pocket.

I. Spintite Blade. The spintite blade works something like a screwdriver except the hollow end fits over the hex nut. You hold the bolt steady with the screwdriver, place the spintite blade over the hex nut, then twirl the spintite blade with your fingers so it spins the hex nut onto the bolt. It can also remove a nut from the bolt.

J. Switch Discs. The patented switch discs (the four "wheels" you unscrewed from the Brainiac panelboard) enable you to control your experiment. As you turn a disc it makes or breaks the electrical contact so that the current is transferred from one set of wires to another, or is turned on or off. (Patent No. 2848568)

The discs are all alike. One side is white, the other red. Each has 64 holes set in a pattern which resembles 16 spokes of a wheel, with a 65th hole in the center. These match the holes in the black rectangles on the Brainiac panelboard.

K. Jumper. The jumper is a small piece of brass plated metal with two prongs. It makes and breaks the electrical contact as you turn the switch disc. If the jumper on the disc touches two wired terminals on the panelboard beneath it, it conducts electricity from one to the other.

The jumper is fastened to a switch disc by inserting the two prongs into two holes along a spoke of the disc, and then pressing the ends towards each other and down.

L. Wiper. The wiper, a patented Brainiac part made of phosphor bronze, improves the electrical connection between the jumper in the switch disc and the terminal on the Brainiac panelboard. Wipers are needed only when your switch has four or more jumpers. (Patent No. 2848568)

M. Hard Washer. The hard fiber washer is used for spacing and for holding.

N. Soft Washer. The soft washer is used to put a "spring" into a switch. It is thick and made of sponge rubber.

In addition to the above parts you will need a dull knife, such as a paring knife, and adhesive tape (bandaids will do).

> To get fresh new flashlight batteries or additional bolts, hex nuts, or other parts, try your local hardware store. If they do not have what you need, write to:
>
> BRAINIAC
> Cardinal Wood Products
> 9229 East Prairie Road
> Skokie, Ill.

WARNING! DO NOT attach any parts of your Brainiac equipment to any electrical outlets in your house or elsewhere. They are not made for that purpose.... only for use with a flashlight battery. You may ruin your equipment and hurt yourself if you use any other source of power.

Part 2

ELECTRICAL RESEARCH EXPERIMENTS

The electrical research experiments in this booklet have been designed for two reasons. First, if you do one experiment at a time, in the proper order, you will understand how electricity works. When you have completed all these experiments, you will be ready to work out the problems requiring more thought in Booklet 2, and eventually you will be able to design your own machines. Second, although you are learning while you assemble the parts, the experiments are fun because they DO something when you complete them correctly.

How to Begin

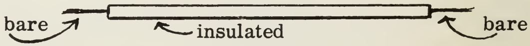
First open the plastic bags of small parts by carefully removing the staples. Keep all parts in their bags except when you use them. Then they won't roll on the floor and get lost, and it will be easy to find what you need. When you are ready to begin an experiment, select the parts needed for that experiment and lay them on the table. If you are not certain what part is meant, look up the code letter (which is shown in ( ) after the part name) under KIT PARTS AND THEIR USE. Keep each experiment assembled until you have checked to see whether it is needed for the next experiment.

Experiment No. 1. LIGHTING A LAMP

You will need: 1 battery (B) wire coil (D) 1 lamp (E) adhesive tape a dull knife

What to do:

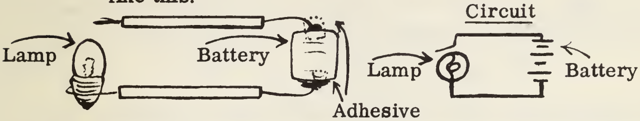
1. Cut two 8-inch long pieces of wire from the coil. At each end, 3/4 inch from the top, run your knife around the wire so it cuts through the plastic insulation. Scrape the insulation off the ends of the wires so they look like this:



2. Wind the bare end of one of the wires around the side of the lamp.

3. Fasten the other bare end to the base (flat part) of the battery with adhesive tape.

4. Fasten one end of the second wire to the top of the battery with adhesive tape. Your equipment should now look like this:



5. Touch the metal button at the base of the lamp with the loose end of the second wire. If your experiment is successful the lamp will light. If not, read Experiment No. 2, then find and correct the cause of the failure.

What happened? You made a complete electrical circuit from your battery to the lamp and back. The battery is like a pump. It builds up a supply of electrons (flowing particles, or tiny drops, of electricity) at the top, and a lack of electrons at the bottom. The electrons flow from the top of the battery through the first wire, into the lamp from the side, through the filament, out the base of the lamp, and back to the battery. They are then "pumped" to the top of the battery, and the circulating flow begins again.

As electrons rush through the filament in the lamp, which is very narrow, the friction of their passing heats the filament until it becomes white-hot, giving light.

Experiment No. 2. TROUBLE-SHOOTING

When a circuit that should work does not work, you have to find and correct the trouble. This is called trouble-shooting. Here are the points to check or verify in your first experiment (or any other experiment) which does not work:

1. Contacts. Do your wires all actually touch the metal parts to which they are attached? If there is an air space between the wire and the metal part, electrons cannot flow through it. Or if there is a bit of material such as insulation from the wire, dirt, or adhesive tape, between the wire and the metal, it will form an insulation that stops the electrons. Scrape the wire ends and metal parts with your knife to clean them.

2. Lamp. The filament or some other important part of the lamp may be broken. Try a new lamp.

3. Battery. Your battery may be "dead", that is, it no longer pumps electrons. Try a new battery.

4. Wire. Your wire may have a break in it somewhere inside the insulation where you cannot see it. Try another wire.

Experiment No. 3. INSTALLING A LAMP SOCKET PART

You will need: Your assembled Experiment No. 1
Brainiac panelboard (A) 1 socket part (F)
2 long bolts, 1 short bolt, 5 hex nuts

What to do:

1. Insert a short bolt into the center hole of one of the 11-hole series in the center section of your Brainiac panelboard. From the back of the panelboard, tighten a hex nut over the bolt.

2. Place the socket part over the 11 holes, with the hollow part next to the panelboard. Pass a long bolt through the the Brainiac panelboard. Tighten a hex nut over each bolt.

3. Attach the bare end of an 8 inch piece of wire to the top of your battery with adhesive tape.

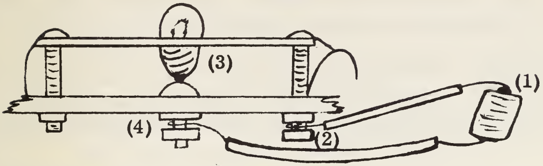
4. Attach the bare end of another 8 inch piece of wire to the bottom of your battery with adhesive tape.

5. Wind the other end of the top-of-the-battery wire around the end of a long bolt (see Step 2). Add a hex nut so the wire is held by the two nuts.

6. Wind the end of the bottom-of-the-battery wire around the end of the short center bolt. Add another hex nut to hold it in place.

7. Screw the lamp into the center hole of the socket part so that it touches the top of the short bolt. The lamp will

light if your experiment is successful. If it does not light, trouble-shoot.



What happened? Electrons flowed from the top of the battery (1), through the wire to the base of the terminal (2) you made from the long bolt and hex nuts, up the bolt, across through the metal socket part and into the side of the lamp (3), through the filament, out the base of the lamp through the second terminal (4) made from the short bolt and nuts, and back through the second wire to the battery, thus making a complete loop, or circuit. (Note: Although the current flowed through the metal socket part from the long bolt to the side of the lamp, it did not flow from the base of the lamp back to the long bolt because the panelboard is made of material which does not conduct electricity.)

Experiment No. 4. INSTALLING THE BATTERY BOX

You will need: Your assembled Experiment No. 3
Battery Box (C) folded and equipped with bolts and nuts at each end
2 short bolts and 3 hex nuts
a piece of string

What to do:

1. Remove the adhesive tape and wires from the battery, and place the battery in the battery box. It does not matter which way the top and bottom go.

2. Fasten the battery box snugly to the panelboard with the piece of string.

3. Wrap the bare end of one wire around one of the battery box end bolts (terminals) and hold it in place with a hex nut.

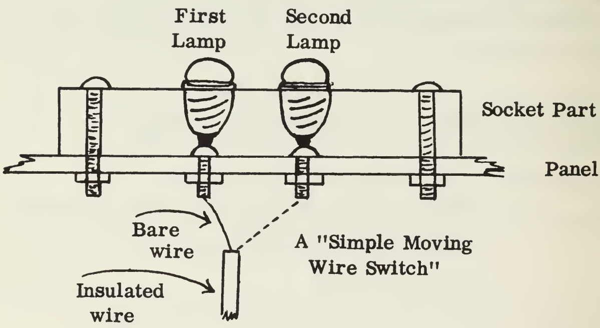
4. Wrap the bare end of the other wire around the other battery box end bolt, and hold it in place with a hex nut.

5. If your experiment is a success, the lamp will light. If it doesn't light — time to trouble-shoot!

What happened? Current flowed from the battery through the battery box end bolt, through the wiring, socket part, and lamp, through the short bolt at the base of the lamp, and through the wire back to the other battery box end bolt.

Experiment No. 5. CONSTRUCTING A SIMPLE MOVING WIRE SWITCH

You will need: Your assembled Experiment No. 4
1 short bolt   1 hex nut   1 more lamp



What to do:

1. Unfasten the socket part. (See diagram)

2. In the Brainiac panelboard insert the short bolt two holes from the center short bolt, so that you have a bolt, a hole, and your second bolt. (See diagram)

3. Attach a hex nut to the bolt, and replace the lamp socket to its original position.

4. Insert a second lamp in the socket, directly over your newly inserted bolt, so the base of the lamp touches the bolt.

5. Remove the wire attached at the back of the panelboard to the bolt at the bottom of the socket of the first lamp.

6. If you have not been working with your panelboard in an upright position, now set it upright in the slots of the two wooden supports.

7. With the loose wire touch first the bolt behind one of the lamps, then the bolt behind the other. If your experiment is successful, each lamp will light in turn. If they do not, you should trouble-shoot until you find and remove the cause.

What happened? When you removed the wire, you broke the circuit and electrons no longer flowed through the lamp. When you touched the wire to the other bolt you completed a circuit to that lamp. The metal socket part conducts electricity between the long terminal bolt and the side of either lamp. The short bolt which touches the lamp conducts current between the base of the lamp and the wire with which you touch the bolt.

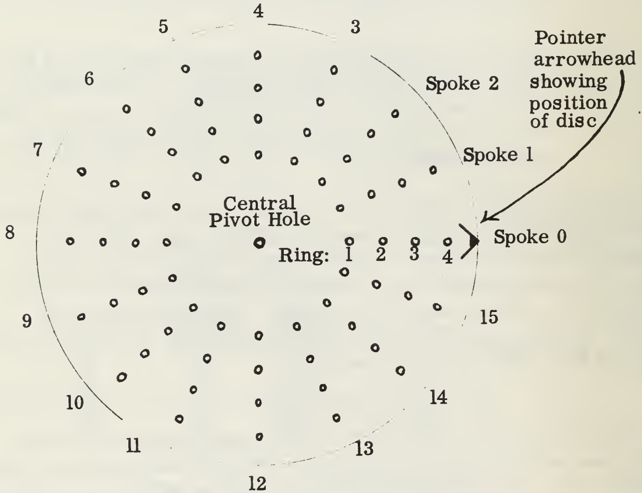
Now before we go ahead with the next experiment, let us talk a little about switches in general, and the switches that you have in the Brainiac kit. An ordinary switch — on a railroad track for example — consists of some rails which can be swung one way or another way so as to route a train either in one direction or another direction. The swinging wire in the previous experiment routes electricity in one way or another way.

In the Brainiac kit our switches are put together from the discs, the panel, and hardware, so that we can route electricity in different directions. How do we do this? Let us look at the discs and the panel.

Each disc contains 65 holes, one in the center and the rest in 4 circular rings of 16 holes each, lined up in 16 spokes. This disc is a multiple switch top.

In the panel each of the exactly similar sets of 65 holes is called a <u>multiple switch base.</u>

The rings are called Ring 1, 2, 3, 4 going outward, and the spokes are called Spoke 0, 1, 2, 3 and so on around, to Spoke 15. The counting starts with the spoke directly to the right, and goes counterclockwise. See Figure 1.



<u>Figure 1</u> — Showing the pattern of the holes in the multiple switch (either the "base" in the panel or the "top", which is the disc); showing also the system of naming the holes.

To put together a switch, the top is fastened to the base of a switch by means of a center pivot, consisting of a long bolt, a sponge rubber washer, a second hard washer, and a nut. The assembly of the center pivot is shown in Figure 2.

Each of the holes in the switch base may or may not contain a short bolt, called a <u>terminal</u>, for making connections. The connec-

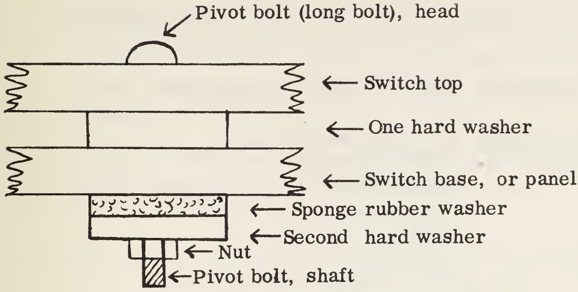


Figure 2 — Center Pivot Assembly

tions are made using two nuts, one for fastening the bolt securely to the switch base, and the second for holding and tightening a wire around the bolt so as to make a good electrical connection with the bolt.

Each pair of holes in a switch top, from Ring 1 to Ring 2 or from Ring 3 to Ring 4 (or very rarely from Ring 2 to Ring 3) may or may not contain a jumper, a small piece of brass plated metal with two prongs, as shown in Figure 3. The two prongs fit into holes in the switch disc and are pressed down, like a clasp or T fastener, as shown in Figure 4. A jumper serves to make and break electrical contact as the switch is turned.

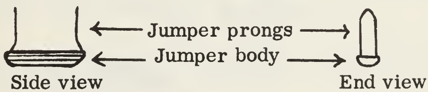


Figure 3 — Jumper, not mounted

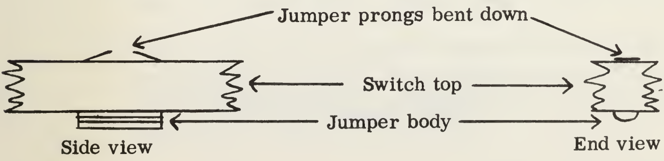


Figure 4 — Jumper, inserted in two adjacent holes along a spoke

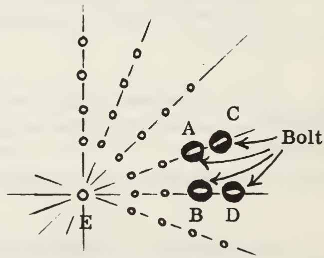
We are now ready to go ahead with the next experiment.

Experiment No. 6. INSTALLING A SWITCH DISC

You will need: Your Experiment No. 5
a switch disc (J)
a jumper (K)
4 short bolts
1 long bolt
5 hex nuts
1 hard washer
1 soft rubber washer
an 8-inch-long piece of wire with insulation scraped off 3/4 inch at each end
a 12-inch-long piece of wire with insulation scraped off 3/4 inch at one end and 1-1/2 inch at the other end

What to do:

1. In one of the rosettes of the Brainiac panelboard insert 4 short bolts on spokes 0 and 1 and rings 3 and 4, as shown by A B C and D in the illustration. Attach hex nuts from underneath the panel. Check the slots in the bolts; if they do not point toward the center hole, turn the bolts so they will.



Part of a "rosette" of 65 holes
in the Brainiac panelboard

2. Pick up the switch disc and the jumper. From the red side of the switch disc insert the prongs of the jumper in the two outer holes of the spoke on which the arrow points. Turn the disc over and bend the prongs of the jumper together.

3. Remove the loose wire from the battery clamp. In its place, put the 12 inch wire, attaching the end on which 3/4 inch is bare.

4. Wind the other bare end of the 12 inch wire once around bolt A , making the loop as near the insulation on the wire as possible. Bring the rest of the bare end of the 12 inch wire to bolt B, and attach. Place hex nuts on bolts A and B to hold the wires in place.

5. Attach a bare end of the 8-inch-piece of wire you removed from the battery clamp to one of the short bolts underneath a lamp, using another hex nut to hold it in place. Bring the other end of the wire to bolt D, wind it around the bolt, and attach a hex nut.

6. Attach a bare end of the remaining 8-inch wire to the short bolt beneath the other lamp, adding a hex nut to hold it in place. Bring the other end to bolt C, attach it, and add a hex nut to hold it in place. This completes the wiring of your Brainiac panelboard.

7. Take a long bolt and hold it head down. Place a switch disc, white side down, on the bolt.

8. Insert the bolt in the center hole of the disc, and add a hard washer.

9. Insert the bolt with the disc into hole E in the panelboard, add a soft rubber washer, a hard washer, and a hex nut.

10. Turn the switch disc so that the jumper is over B and D. It should light one lamp. Turn the switch disc so that the jumper is over A and C. It should light the other lamp. If it doesn't — time to trouble-shoot!

What happened? By moving the switch disc you brought the jumper in the disc in contact with either points A and C, or points B and

D. The jumper, being metal, carried electrons between the two points, completing the circuit for the lamp attached to that set of wires, and causing the lamp to light.

Instead of having a loose and mechanically unsatisfactory switch (the swinging wire), we now have a firm and mechanically sound switch.

Experiment No. 7. INSTALLING A SWITCH DISC TO SWITCH ANY ONE OF THREE LIGHTS

You will need: Your Experiment No. 6; and additional hardware, which, as you will see, is needed from looking closely at Figure 5, —— because you will be using terminals F and G to light a third lamp screwed into the socket part.

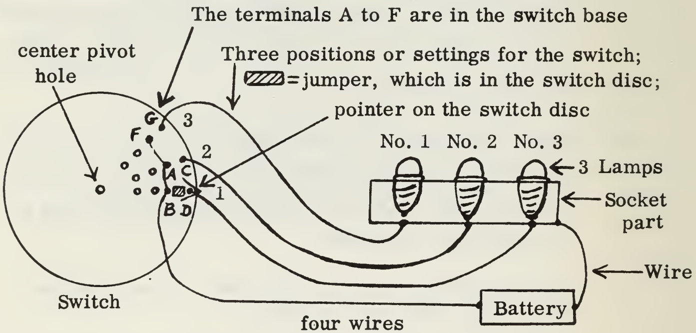


Figure 5

Results: After you have this all put together, when the pointer is at position 1, lamp 1 will light. When the pointer is at position 2, lamp 2 will light. When the pointer is at position 3, lamp 3 will light. Only one lamp will light at any one time. If this does not happen, — time to trouble-shoot!

What happened? Electricity flows along a path, from one end of the battery to the common terminal B A F, and then separates and flows along any one of three paths out of D, C, or G through the respective lamp 1, 2, or 3, and then back along a common path to the other side of the battery.

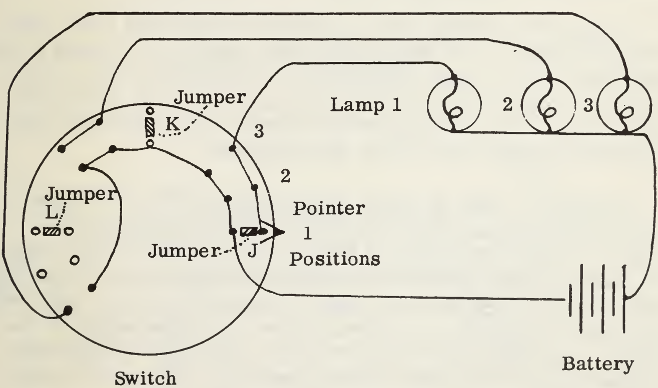
Now suppose that we wanted something different: Lamp 1 to be lighted at switch position 1; both lamps 1 and 2 to be lighted at switch position 2; and all three lamps to be lighted at switch position 3. How shall we do this?

Here is the point at which we begin to make use of the power of the multiple switches in the kit: we have to use switching circuits more elaborately. Let us consider Experiment 8.

<u>Experiment No. 8.</u> INSTALLING A SWITCH DISC TO SWITCH ANY ONE OF THREE OVERLAPPING CIRCUITS

<u>You will need:</u> Your Experiment No. 7; and additional hardware; you will see what is needed from looking closely at Figure 6.

In this circuit we light Lamp 1 from position 1, both Lamps 1 and 2 from position 2, and all three Lamps from position 3.



<u>Figure 6</u>

Results and What happened: At Position 1, the only path that electricity can take is through Lamp 1, because only Jumper J can close a circuit. At Position 2 however Jumpers J and K both close circuits and so both Lamps 1 and 2 light. And at Position 3, all three Jumpers J, K, and L close circuits, and so all three Lamps light.

Now before we go ahead with the last of these nine preliminary experiments in this booklet, we need to talk about the electrical contacts produced by the multiple switch. So long as we have only three jumpers in a switch disc, it is rather easy for all three of them to make contact at the same time; in the same way, it is easy for a three-legged stool to sit steadily on an uneven floor. But as soon as we have circuits with four or more jumpers required in the multiple switch, we are likely not to have good electrical contact at all the points that we need contact, — in the same way as a table with four, five, or more legs may be unsteady on an uneven floor.

To overcome this obstacle, we make use of the wipers, which have been patented (U. S. Patent No. 2848568). They provide more electrically connecting springiness between the switch base in the panel and the switch top in the disc.

A wiper is a springy piece of phosphor bronze with a hole and two small ridges. The shape of the wiper unbent, as it comes in the small envelope, is shown in Figure 7. The purpose of the wiper is to improve the electrical contact between the top of the switch (the disc containing the jumpers) and the bottom of the switch (the panel containing the bolts and nuts for the terminals).

The way in which the wiper is assembled is shown in Figure 8, and is as follows: (1) thread the bolt through the wiper, with its ridges down; (2) fasten the bolt not too tightly to the panel; (3) align the wiper with the spoke (or radius) of the switch; (4) now fasten the bolt tightly; (5) bend the wiper gently upwards and over the bolt, with the ridges up, in such a way that the wiper will slide neatly on the jumper, resting in its valley between the ridges; (6) assemble the multiple switch with a hard washer between the disc and the panel; (7) adjust the amount of bending of the wipers so that they push up and down nicely against the jumpers as the switch turns.

In order for the switch to stay in a position to which it is turned, the body of the jumper must be in line with a spoke, and the valleys between the ridges on the wipers must be in line with the spoke; then the jumpers will have a tendency to catch in the valleys, as they should, to hold the switch in position (see Figure 8, end view).

For multiple switches with only two jumpers evenly spaced, or only three jumpers almost evenly spaced, you will not need wipers and should not use them, for such switches will work entirely properly without wipers. In these cases, you will need to make sure that the slots in the heads of the bolts are lined up with the spoke, so that the jumpers themselves will position (or detent) along the spoke right above the bolts. (In assembling a switch without wipers, you may not need the hard washer at the center.) For switches with four or more jumpers, you will need wipers, for otherwise the switch is likely to work unreliably.

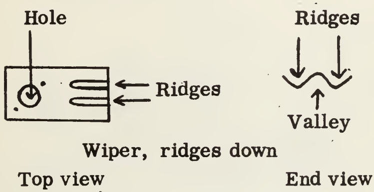


Figure 7 — Unbent wiper

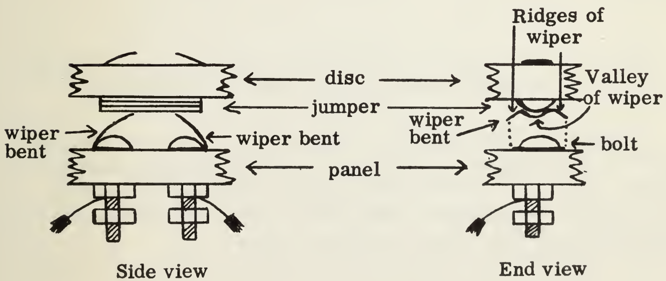


Figure 8 — Assembly of wipers

Experiment No. 9. INSTALLING A SWITCH DISC TO SWITCH ANY ONE OF FOUR OVERLAPPING CIRCUITS

You will need: Your Experiment No. 8; and additional hardware (including wipers), as you will see from looking closely at Figure 9. Every bolt which is a terminal in the multiple switch base will need to have a wiper, placed between the head of the bolt and the panelboard.

In this case, we want the circuit to light Lamps 1 and 2 from Position 1, Lamps 1 and 3 from Position 2, Lamps 1, 2, 3, and 4 from Position 3, and Lamps 2 and 4 from Position 4.

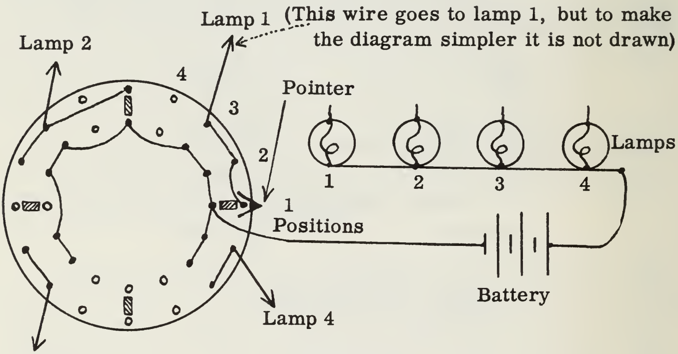


Figure 9

You will have need of 20 wipers, one under the head of the bolt of each of the terminals shown by a black dot in the diagram.

Results and What happened: As you can see from the diagram, and from operating your machine (after all the "trouble" has been "shot"), electricity can flow only to achieve the specified result. For example, at position 4, only Lamps 2 and 4 are lighted, for at that time the machine cuts off Lamps 1 and 3.

Now suppose we wanted to assemble a multiple switch which could have any one of three positions A, B, and C, and which would be capable of switching every one of six different circuits. A way in which that switch could be assembled is shown in Figure 10. Six jumpers are inserted in the top of the switch, shown as ▨ in Figure 10. (It is important that jumpers ordinarily be inserted in pairs opposite each other, for reasons of mechanical balancing, so that the top of the switch will stay parallel to the bottom of the switch.) A total of six times six or 36 nuts and bolts are inserted in the bottom of the switch, in the spots marked ● in Figure 10. They are in groups of six called decks (also called poles, or levels); these decks are electrically independent, and they enable us to switch 6 different circuits at one time. In the base, the bolts belonging to any one deck in Ring 1 or Ring 3 are connected together by wire, as shown by the heavy line. They are made electrically common; in other words, they are commoned. Together they constitute what is called a transfer contact.

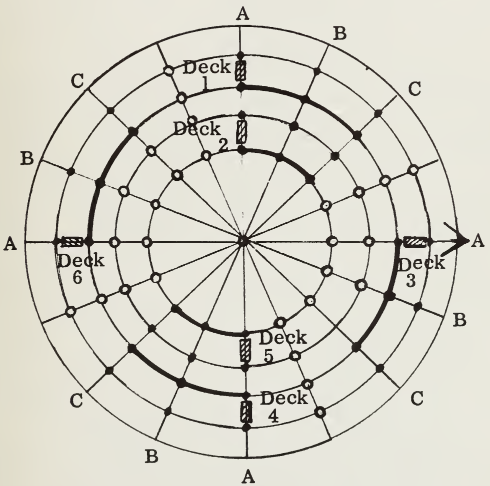


Figure 10 — Three position switch, six decks (or poles or levels)

Note that in drawings of the multiple switches, the rings and spokes may be drawn as thin lines; these lines are not actually drawn on the switch discs nor the switch bases, nor do they represent electrical lines connecting terminals; instead they are drawn to make the arrangement clearer and more evident.

Let us now consider the layout of the 16 spokes and the 4 rings and the 64 holes which they produce. We can see that we can assemble a multiple switch in a great number of different ways. This is the advantage of the design of the multiple switch we have patented.

Here are the types of switches that can be made:

Number of Positions	Maximum Number of Decks
2	16
3	10
4	8
5	6
6 to 8	4
9 to 16	2

Even more variations are possible under some conditions.

CERTIFICATE OF ACHIEVEMENT
(to be filled in by the young scientist if he has correctly completed all nine electrical research experiments)

Date ________________

________________________________ has correctly complet-
(Your Name)
ed as of this date the nine electrical research experiments in Booklet 1 of the Brainiac K20 kit, and is to be commended for his achievements. He is now qualified to assemble the computing and reasoning machines described in Booklet 2. If he completes Booklet 2 with equal care and diligence, he has the qualities of a true scientist, and it is predicted that he will eventually design his own machines, first with this kit, and later with more complicated kits. In fact, it is not unlikely that he will make his career in the field of electricity and modern science.

Dorothy D. Zinck

GENIACS:

SIMPLE ELECTRIC BRAIN MACHINES, AND HOW TO MAKE THEM

Also:
Manual for Geniac Electric Brain Construction Kit No. 1

Edmund C. Berkeley

Published March 1955 by Berkeley Enterprises, Inc.,

36 West 11 St., New York 11, N. Y.

Introduction

In 1944 the first "electric brain", an automatic machine for reasoning and calculating, began to work. In the years since then, more and more people have studied and built machines that handle information in reasonable ways, machines that "think" or at least seem to think. Thousands of such machines have now been made. This development is becoming so important that it is often called the Second Industrial Revolution.

Since 1945 we have been interested in helping people understand these machines and how they behave. And we know that equipment that you can take into your own hands, play with, and do exciting things with, will often teach you more, and give you more fun besides, than any quantity of words and pictures.

In 1950, for educational purposes, we constructed a miniature electric brain called Simon. Although only 1¼ cubic feet in size, and limited in capacity, it was a complete automatic computer, and it could show how a machine could do long sequences of reasoning operations. The picture of Simon has appeared on the front cover of two magazines, "Scientific American" and "Radio Electronics"; the machine itself has been demonstrated in more than eight cities of the United States. Over 350 sets of Simon plans have been sold. But this machine costs over $300 for materials alone, and is therefore too expensive for many situations in playing and teaching.

The same summer that Simon was finished we began work to develop a really inexpensive electric brain. Now, four years later, we have gathered and worked out descriptions of over 30 small electric brain machines, most of them simple, some of them complicated, and all of them interesting, which can be made with very simple electrical equipment. These machines are described in the first part of this report.

In order to make the assembling of these small electric brain machines as easy as possible, we have also developed a construction kit costing less than $16 (in March, 1955) which will make any one of these little machines (with the exception that some of the machines require a few more nuts and bolts). The name of the kit is "Geniac Kit No. 1"; the word "Geniac" comes from the phrase "Genius Almost-Automatic Computer"; and we call the little machines that can be made "Geniacs". This report is also the manual for the kit; and the second part of this report describes the kit and how to assemble machines from it.

The kit contains basically: (1) the materials for six, all-purpose, multiple, electrical switches, of a new and versatile design, for calculating and reasoning; (2) ten flashlight bulbs, for signaling answers; and (3) one flashlight battery for power. Every Geniac, although unable to run automatically, is able to calculate and reason automatically; and the Geniac manual and kit as a whole demonstrate many different and exciting small machines that "think", at least to the extent of reasoning and calculating.

The kit, though inexpensive and convenient for constructing Geniacs, is however not necessary; and some persons will prefer to construct their Geniacs using other materials. We know however that the kit will make any one of more than a hundred simple little electric brain machines.

We hope that you find this report of interest to you, and that you will enjoy playing with the kit, and entertaining your friends with the little machines that you make. And when you work out new electric brain machines, send us the descriptions: we plan to give prizes from time to time for the best ideas sent in to us.

If you find you have at first some difficulty in understanding all that is in this report: TAKE YOUR TIME and think; make first the simpler machines; then try the more complicated ones. To make a machine that will reason and calculate, you, too, need to reason and calculate.

In this report, in stating the design of a number of different circuits, we have used a number of different styles of statement (several styles of drawings, lists of wiring instructions, etc.) A reader may believe that we should have used one and only one style. Such uniformity of style is not practical for two reasons. First, some circuits are simpler and easier to see in one style of statement, while others are simpler and easier to see in another style of statement. Second, the literature on circuits uses different styles of statement; and becoming accustomed to the different styles used here is a better introduction to the literature.

We have had great help from several outstanding computer men in the design of about one third of the Geniac circuits described in this report. We express our thanks to them, and regret that they feel they have to remain anonymous.

It is too much to hope that this report contains no errors. We shall be very grateful to any reader who sends us corrections, and comments and suggestions for later editions of this report.

Edmund C. Berkeley

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CONTENTS

Part I: Simple Electric Brain Machines:

General Description

An electric brain machine is a machine containing electrical circuits which is able to calculate or reason, that is, perform operations that are reasonable or mathematical. For a simple example, consider a flashlight. It performs a single, very reasonable operation: the light turns on when you turn the switch to the "on" position; and the light turns off when you turn the switch to the "off" position.

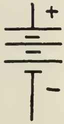
The machines which we shall talk about will be made of: a battery, or source of electric current; wires, which conduct it; switches, which change the paths along which the current flows; lights, which show where the current is flowing. In all of these machines the current starts from one end of the battery and flows in a path or circuit that eventually returns to the other end of the battery.

The diagram of the circuit or circuit diagram shows the scheme of connection of batteries, switches, lights, etc., in order that the machine will function as it is supposed to. The diagram does not necessarily show the physical location of the material but only its relative arrangement, its connections.

The symbols used in circuit diagrams are shown in Table 1. We need pay attention only to five kinds of material.

Table 1

CIRCUIT DIAGRAM SYMBOLS



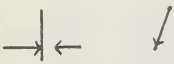
A battery. -- The long and short lines supposedly represent the two kinds of plates in a battery by means of which an electrical current is generated.

Wire. -- A line in a circuit diagram represents an insulated wire, a connector from some point to some other point.

Electrical connections. -- The dots represent points where electrical connections are established, by fastening two wires together so current can flow easily between them.

No electric connection intended. -- Here two wires cross (drawn in either one of two ways) but there is no electrical connection between them. One wire is either above or below the other.

A light. -- This is a light bulb. The two dots are its connections.

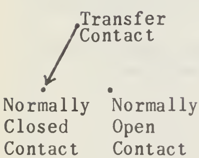


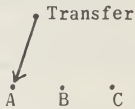
Switches. -- Here is a two-position switch (drawn in either one of two ways).

Here is a three-position switch.

Here is a four-position switch. Etc.

Contacts. -- In any switch, the contacts have names:





A single switch may be constructed having two or three or more electrically nonconnecting <u>sections</u> so that as it is turned, it simultaneously switches two or three or more electrically independent paths. In circuit diagrams this property of a switch is conveniently shown by using a name for the switch and numbers 1, 2, 3, etc., for the sections. In Figure 1 for example two, not three, switches are shown: diagram (a) represents section 1 of the switch called "Wife", diagram (b) pictures section 2 of the same switch, and diagram (c) shows section 1 of the switch called "Husband". Sometimes a section of a switch is called a <u>deck</u> or a <u>pole</u> or a <u>level</u>. In Figure 1 both switches have the same two positions, called "in canoe" and "not in canoe".

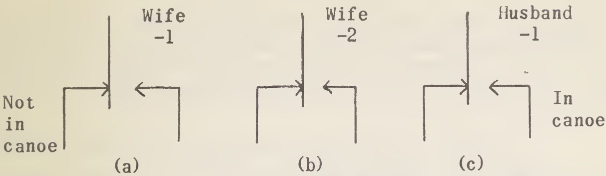


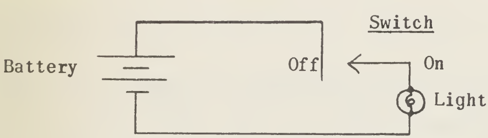
Figure 1 -- Switches, Names of Switches, and Names of Positions

With these preliminaries out of the way, let us consider the first machine.

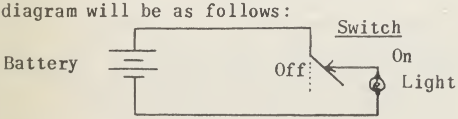
1. THE FLASHLIGHT

<u>Problem</u>: A man desires to make a flashlight, which will shine when he turns the switch on, and go dark when he turns the switch off.

<u>Solution</u>: This is accomplished in the following circuit:



The circuit is regularly drawn with all switches in the <u>off</u> or or <u>zero position</u>. As it is drawn, we can see that no current will flow, because there is a gap; so the light will be off. But when the switch is turned to the <u>on</u> position, then the circuit diagram will be as follows:



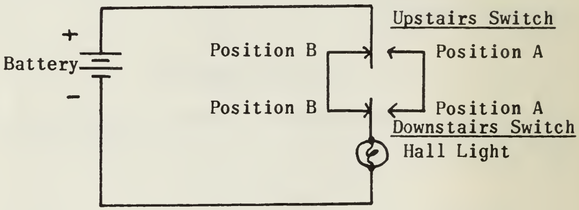
We see that current will now flow and the light will shine. (For the detailed wiring using the kit materials, see p. 59)

2. THE HALL LIGHT

Problem: A man desires to turn off or turn on the downstairs hall light either from the downstairs hall or from the upstairs hall. He wants a circuit so that if either switch is turned, the light will go on if it was off, and will go off if it was on.

This is a practical problem, if you should ever have to install this kind of wiring. And it is not as easy as it may seem at first glance.

Solution: Here is the solution expressed in a circuit diagram:

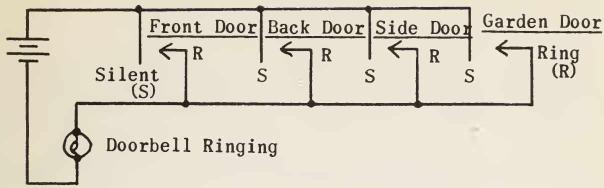


We can see that if both switches are turned to Position B, then the light will shine. If both switches are turned to Position A, then the light will also shine. If only one switch is in Position A and the other switch is in Position B, then the light will not shine. This circuit therefore meets the requirements. (For detailed wiring, see p. 60)

3. THE DOORBELL

Problem: A man has four doors to his house, a front door, a back door, a side door, and a door to the garden. If anyone comes to any of these doors, and rings, the doorbell should ring. What is a circuit that will accomplish this?

Solution:

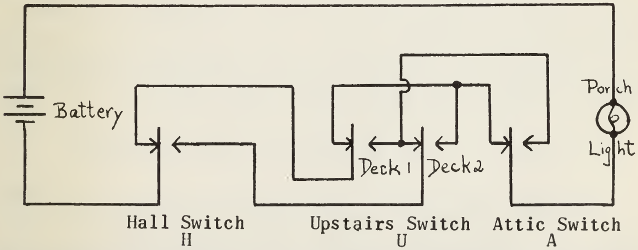


We can see that if all four switches are in the position "Silent", the path is interrupted, and the light that means "Doorbell Ringing" will be dark. But if any one or more of the switches is turned to the "Ring" position, then the light meaning "Doorbell Ringing" will shine. (For detailed wiring, see p. 61)

4. THE PORCH LIGHT

Problem: A man has a light on his front porch which lights up his front steps and his yard. He wants to be able to turn that light on or off from any one of three places: his downstairs front hall (H), the upstairs landing (U), and the attic (A). Three switches are to be put in and wired so that throwing any switch one way turns the light on if it is off, and turns the light off if it is on.

Solution: Here is the circuit. Note that the upstairs switch, Switch U, must have two decks, two sections.

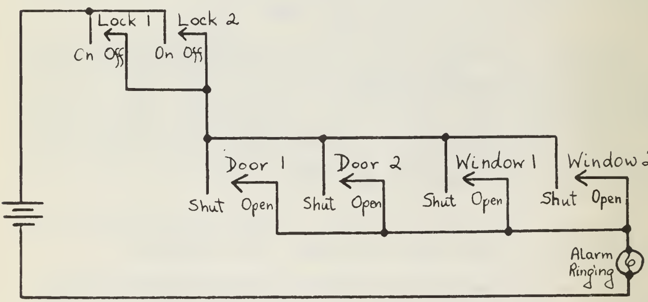


The two decks in the upstairs switch are mechanically fastened together so that when the switch is turned, the two transfer contacts in Deck 1 and in Deck 2 are both turned. Otherwise the circuit would not work. (For detailed wiring, see p. 61)

5. THE BURGLAR ALARM

Problem: A man has two doors to his house, and two large windows on the ground floor. He believes that if a burglar should try to enter his house, the burglar would come in through one of the doors or one of the big windows. He desires an alarm system. If either door is opened or if either one of the two big windows is opened, after either one of two locking switches (one indoors for use at night, one outdoors in the garage for use when the house is left with no one in it) has been closed, then the burglar alarm is to ring.

Solution: We shall need six switches labeled Lock One, Lock Two, Door One, Door Two, Window One, Window Two. Each will be a two-position switch, and only one deck of each switch will be used. Following is a circuit:



In reality, each door and window must be closed shut against a button containing a strong spring, so that when the door or window is opened, the spring pushes the button out and closes a contact. (For the detailed wiring, see p. 62)

6. THE AUTOMATIC OIL FURNACE CIRCUIT

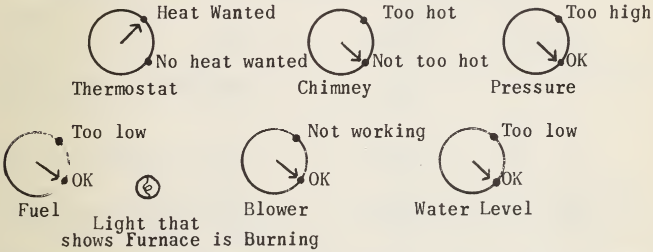
Problem: A man has an automatic oil furnace which burns oil and makes water into steam to heat the radiators in the house. The flame starts when the thermostat in his living room calls for heat, and stops when the thermostat stops calling for heat. But if any one of the following conditions exists, the furnace is not allowed to heat:

-- the chimney is too hot

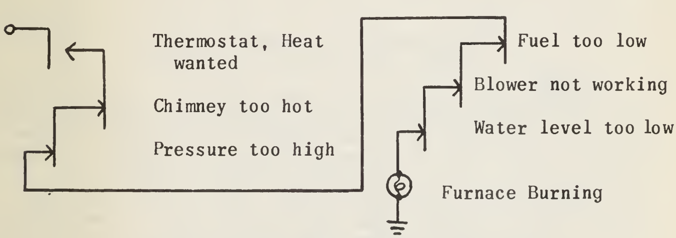
-- the pressure in the boiler is over 15 pounds per square inch above atmosphere
-- the fuel in the tank is too low
-- the blower that mixes air with oil and blows the mixture into the furnace is not working
-- the water level in the boiler is below a certain mark.

Set up a circuit which will imitate the behavior of the automatic oil furnace.

Solution: The front of the panel will look like this:



The circuit is as follows. (NOTE: Here o denotes "source of current" or "one side of battery"; ⏚ denotes "sink of current" or "ground" or "other side of battery"; these are common symbols.)



7. PRIVATE SIGNALING CHANNELS

Problem: Set up a machine so that each one of three boys, George, Tom, and Dick can signal any one of the other two.

Solution: We shall have three switches, one for each boy. Each switch will have two settings, one for each other boy.

There will be six lights, indicating who is signaling and who is being signaled.

The wiring will be as follows:

1. Wire from one end of the battery to the transfer of one deck on each switch.

2. Wire from the outputs of each switch to the lights, as follows, and from the other side of the lights back to the other end of the battery.

Switch	Output	Light
George	Tom	George calling Tom
	Dick	George calling Dick
Tom	George	Tom calling George
	Dick	Tom calling Dick
Dick	George	Dick calling George
	Tom	Dick calling Tom

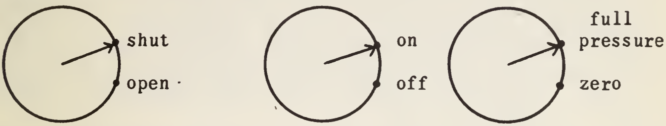
NOTE: In this case, instead of furnishing a circuit diagram, we have given a statement of the circuit in the form of a set of wiring instructions. This is logically equivalent, and often in practical situations a good deal better.

8. MACHINE FOR A SPACESHIP'S AIRLOCK

Problem: The airlock of a space ship has: an inner door that goes from the airlock to the inside of the space ship; an outer door which goes from the airlock to the surface of the strange planet,which is assumed to have no atmosphere; a pump which pumps the air from the airlock into the space ship; a valve which allows air from the space ship to flow into the airlock; and a pressure gage which reports the air pressure in the airlock and which may be either high or low. There are four lights in the airlock: safe to open the inner door; safe to open the outer door; dangerous to open either door, conditions OK; dangerous to open either door, conditions bad. We want a warning circuit and automatic locks corresponding.

Solution: The front of panel will look like the following:

Valve from Spaceship to Airlock	Pump from Airlock to Spaceship	Gage, showing Pressure in Airlock



Light 1: 

Safe to open the inner door; automatic lock of outer door

Light 2: 

Safe to open the outer door; automatic lock of inner door

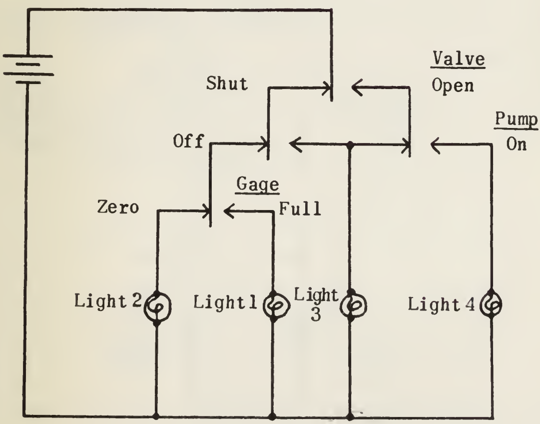
Light 3: 

Dangerous to open either door; automatic lock of both doors; conditions OK

Light 4: 

Dangerous to open either door; automatic lock of both doors; conditions bad

The circuit is as follows:

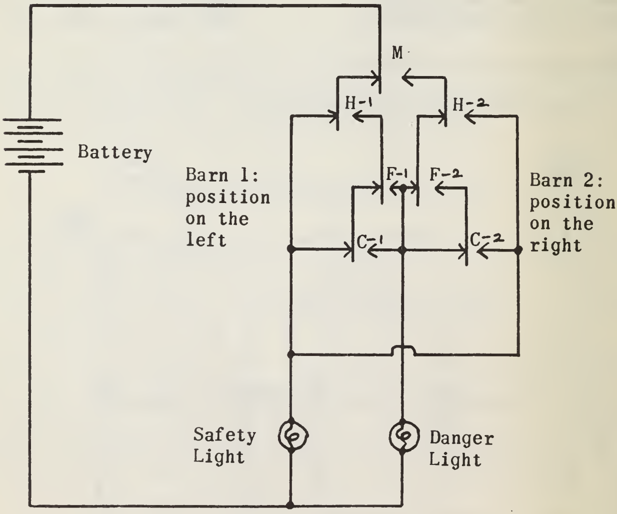


9. THE FOX, HEN, CORN, AND HIRED MAN: THE FARMER'S MACHINE

Problem: A farmer had a fox, a hen, some corn, and a hired man, and two barns, where one or more of them could be at any one time. He did not trust his hired man's carefulness. He wanted a warning robot to shine a danger light (1) when the fox was with the hen in either barn, the hired man being in the other barn, and (2) when the hen was with the corn in either barn, the hired man being in the other barn, and a safety light on other occasions.

There will be a switch for the hired man (M), a switch for the fox (F), a switch for the hen (H), and a switch for the corn (C); and one position of each switch will mean "it is in Barn 1" and the other position will mean "it is in Barn 2".

Solution: Here is the circuit:



10. THE MACHINE FOR THE TWO JEALOUS WIVES

Problem: One summer two families vacation in neighboring bungalows on the shore of a pleasant lake. The two wives are jealous, and one day agree that the husband of either one may not go canoeing alone with the other wife, unless accompanied by a chaperon. They also believe that the chaperon might be more attractive than they would wish, and consequently they agree that neither husband should go canoeing alone with the chaperon.

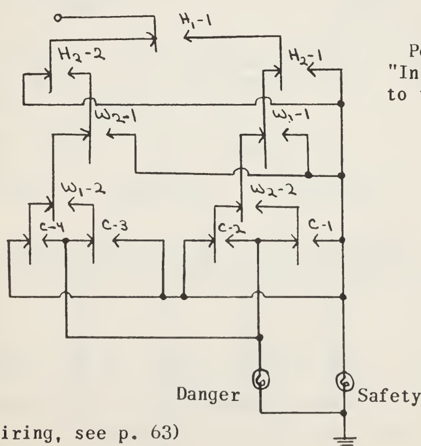
They arrange with an electrician to set up an apparently innocuous wiring system in the boat house, and they arrange with the boat boy to turn switches to show who is out in the canoe. In their living rooms, they arrange a danger light to shine when the situation is contrary to their agreement, and a safety light to shine on all other occasions.

How should the circuit be wired?

There are five two-position switches marked Husband One (H_1), Husband Two (H_2), Wife One (W_1), Wife Two (W_2), Chaperon (C). One position I stands for "in the canoe". The other position N stands for "not in the canoe".

Solution: Following is a circuit which will work. The decks of each switch are numbered; thus C-3 is the 3rd deck of the Chaperon switch.

Position "Not in the Canoe" to the left



Position "In the Canoe" to the right

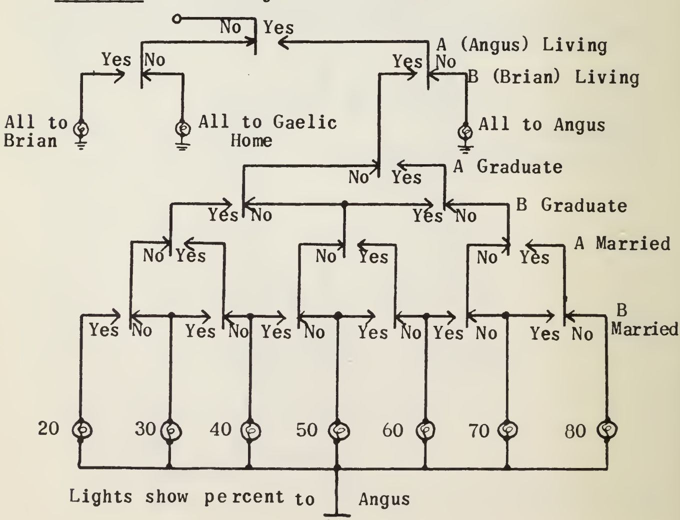
(For detailed wiring, see p. 63)

11. THE MACHINE FOR DOUGLAS MACDONALD'S WILL

Problem: The provisions of Douglas Macdonald's will are as follows: "If my son Angus survives me and my son Brian does not, all my estate goes to Angus. If Brian survives me and Angus does not, all my estate goes to Brian. If neither survives me, my estate is to go to the Gaelic Home for the Aged and Indigent. If both Angus and Brian survive me, and if at the time of my death neither is married nor is a graduate of Edinburgh University, then each shall have 50% of my estate. If both are married and neither is a graduate, or if both are graduates, and neither is married, or if both are married and both are graduates, then each shall have 50% of my estate. If only one of my sons is a graduate, his share shall be increased by 20% of my estate and the other's decreased accordingly. If only one of my sons is married, his share shall be increased by 10% and the other's decreased accordingly." What happens when Douglas Macdonald dies?

We wire up a circuit having six switches showing all the conditions for Angus and Brian (living or not, graduate or not, married or not) and ten output lights, showing what happens in any one of the 64 possible events.

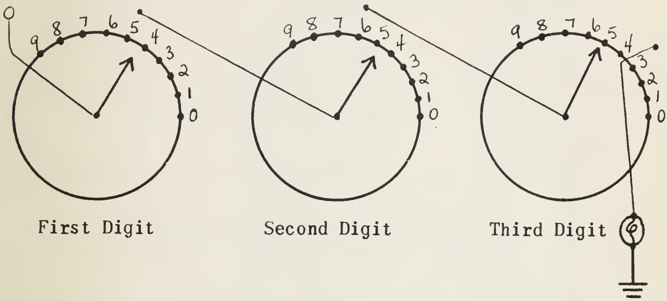
Solution: Following is the circuit:



12. THE SPECIAL COMBINATION LOCK

Problem: Set up a machine with the following properties: each one of three switches may be set at any digit from 0 to 9; when and only when the first switch is set at 5, the second digit at 6, and the third digit at 3, a light "Open" will glow.

Solution: Here is the circuit:

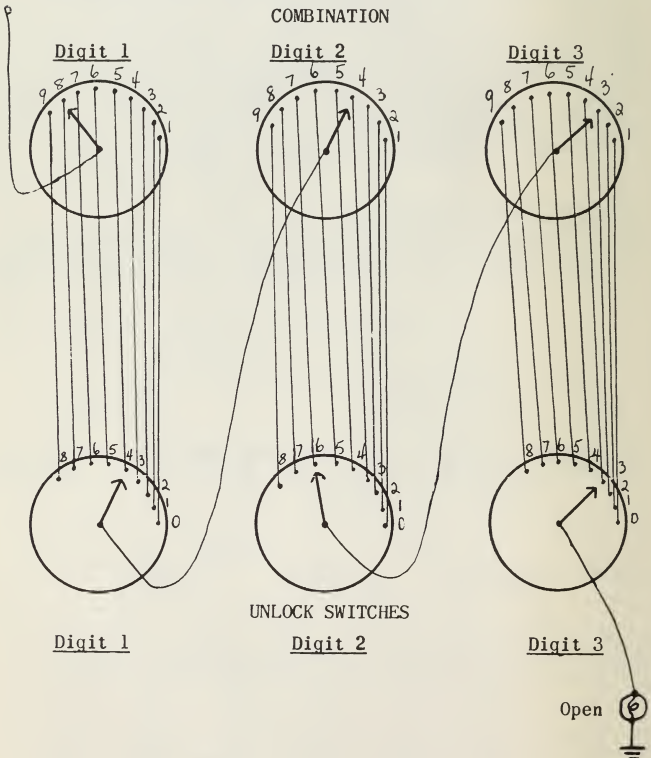


Obviously, the combination can easily and quickly be changed by altering the location of a wire or two.

13. THE GENERAL COMBINATION LOCK

Problem: Set up a machine with the following properties: you may use any three digit combination with digits 1 to 9 on three switches; when and only when three more switches are set with the same combinations but each digit one less, a light "Open" will glow:

Solution: Here is the circuit:

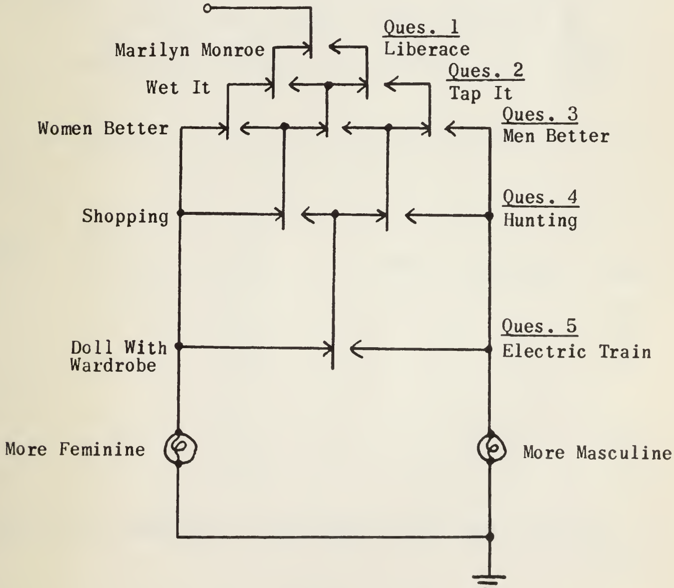


14. MASCULINE-FEMININE TESTING MACHINE

Problem: Set up a machine which will determine whether the person who answers five questions (if he or she answers them truthfully) is more masculine or more feminine:

1. Whom do you prefer: (a) Marilyn Monroe? (b) Liberace?
2. How would you put a thread into a small hole: (a) wet it? (b) tap it?
3. Which would you agree with? (a) Women are better drivers than men because they are more careful. (b) Men are better drivers than women because they get more practice and are more skilled.
4. Would you rather spend a day: (a) Shopping on Fifth Avenue? (b) Hunting in the woods?
5. Which makes a better toy for a child: (a) electric train? (b) a doll with a complete wardrobe?

Solution: Following is the circuit.



15. ADDING MACHINE
16. SUBTRACTING MACHINE

Problem: We have two switches A and B, each able to be set at any one of four positions 5, 6, 7, 8. We have seven lights labeled 10, 11, 12, 13, 14, 15, 16. We want a circuit so that the machine will show the sum of the numbers set on the A and B switches.

Solution: Here are the wiring instructions:

1. Wire one end of the battery to the transfer on one deck of switch A. This deck of switch A has four outputs 5, 6, 7, 8.

2. Wire each one of these four outputs to each one of four transfers on switch B, one on each deck. Call these decks 5, 6, 7, 8, according to the A output wired to it. Now switch B will have sixteen outputs.

3. Wire these outputs to one side of the lights according to the following table of instructions (use column (1)).

Deck	B output	(1) Light	(2) Light
5	5	10	-3
	6	11	-2
	7	12	-1
	8	13	0
6	5	11	-2
	6	12	-1
	7	13	0
	8	14	1
7	5	12	-1
	6	13	0
	7	14	1
	8	15	2
8	5	13	0
	6	14	1
	7	15	2
	8	16	3

4. Wire the other side of each light to the other side of the battery.

Notes: (1) Any four consecutive numbers and their sums can be substituted, using other labels; and the machine will still work correctly. (2) The machine will work as a subtracting machine giving A minus B if the positions of the B switch are labeled 8, 7, 6, 5, instead, and the lights are labeled as shown in column (2) above, instead.

17. MULTIPLYING MACHINE

Problem: We have two switches A and B, each able to be set at four positions 6, 7, 8, 9. We have ten lights labeled 36, 42, 48, 49, 54, 63, 64, 72, 81. We want a circuit so that the machine will show the product of the A and B numbers set on each switch, by shining the appropriate light.

Solution: Here are the wiring instructions:

1. Wire one end of the battery to the transfer on one deck of switch A. This deck of switch A has four outputs 6, 7, 8, 9.

2. Wire these four outputs to each one of four transfers on switch B, one on each deck. Call these decks 6, 7, 8, 9 according to the A output. Thus switch B will have sixteen outputs.

3. Wire these outputs to the lights according to the following table of instructions:

Deck	B Output	Light	Deck	B Output	Light
6	6	36	8	6	48
	7	42		7	56
	8	48		8	64
	9	49		9	72
7	6	42	9	6	54
	7	49		7	63
	8	56		8	72
	9	63		9	81

4. Wire the other side of each light to the other end of the battery.

Note: This same machine can be relabeled according to the following system, and will still tell the truth:

6 7 8 9	36 42 48 49 54 56 63 64 72 81
2 3 4 5	4 6 8 9 10 12 15 16 20 25

In fact any four consecutive numbers, none smaller than 2, and their appropriate products can be inserted.

18. DIVIDING MACHINE

Problem: We have two switches, A and B, each able to be set at any one of 0, 1, 2, 3. We have ten lights labeled 0, 1/3, 1/2, 2/3, 1, 1½, 2, 3, ∞, ? We want a circuit so that the machine will show the quotient of A divided by B, where A and B are the numbers set on the switches.

Solution: Here are the wiring instructions.

1. Wire one end of the battery to the transfer on one deck of switch A. This deck of switch A has four outputs 0, 1, 2, 3.

2. Wire each one of these four outputs to each one of four transfers on switch B, one on each deck. Call these decks 0, 1, 2, 3 according to the A output wired to it. Now switch B will have 16 outputs.

3. Wire these outputs to one side of the lights according to the following table of instructions:

Deck	B Output	Light
0	0	?
	1	0
	2	0
	3	0
1	0	∞
	1	1
	2	1/2
	3	1/3

Deck	B Output	Light
2	0	
	1	2
	2	1
	3	2/3
3	0	
	1	3
	2	1½
	3	1

4. Wire the other side of each light to the other side of the battery.

19. MACHINE FOR ARITHMETICAL CARRYING

Problem: We have two switches, A which may be set at any one of the numbers 3, 4, 5, 6 and B which may be set at any one of the numbers 2, 3, 4, 5, 6, 7. We have two lights Carry One, and No Carry. We want a machine so that these lights will be turned on properly.

Solution: Here are the wiring instructions.

1. Wire one end of the battery to the transfer on one deck of switch A. This deck has four outputs 3, 4, 5, 6.

2. Wire each one of these four outputs to the transfer of each one of four decks of switch B. Call these decks 3, 4, 5, 6 according to the A output wired to it.

3. Wire the outputs of the B switch to one side of the lights as follows:

Deck	B Output	Light	Deck	B Output	Light
3	7	Carry One	5	5 to 7	Carry One
	2 to 6	No Carry		2 to 4	No Carry
4	6, 7	Carry One	6	4 to 7	Carry One
	2 to 5	No Carry		2, 3	No Carry

4. Wire the other side of the lights to the other end of the battery.

Note: Similar machines may be made for other cases of arithmetical carrying. But relabeling this machine for other cases of carrying is not likely to work out very well.

20. COMPARING MACHINE

Problem: We have two switches A and B, each able to be set at any one of four numbers 6, 8, 10, 12. We have three lights labeled GREATER, EQUAL, LESS. We want a circuit that will show whether A is greater than B, or A is equal to B, or A is less than B, where A and B are the numbers set on the switches.

Solution: Here are the wiring instructions.

1. Wire one end of the battery to the transfer of one deck of switch A. This deck of switch A has four outputs 6, 8, 10 and 12.

2. Wire each one of these four outputs to just one of four transfers on switch B, one on each deck. Call these decks 6, 8, 10, 12 according to the A output wired to it.

3. Wire these outputs to one side of the lights according to the following table of instructions:

Deck	B Output	Light
6	6	E
	8	L
	10	L
	12	L
8	6	G
	8	E
	10	L
	12	L
10	6	G
	8	G
	10	E
	12	L

Deck	B Output	Light
12	6	G
	8	G
	10	G
	12	E

4. Wire the other side of the lights to the other end of the battery.

Note: This same machine can be relabeled using any other four numbers in sequence.

21. REASONING MACHINE

Problem: Switch A can be set at any one of these four positions:

1. All fighter pilots are bomber pilots.

2. No fighter pilots are bomber pilots.

3. Some fighter pilots are bomber pilots.

4. Some fighter pilots are notbomber pilots.

Switch B can be set at any one of these four positions:

5. All bomber pilots are jet pilots.

6. No bomber pilots are jet pilots.

7. Some bomber pilots are jet pilots.

8. Some bomber pilots are not jet pilots.

We have six lights:

9. All fighter pilots are jet pilots.

10. No fighter pilots are jet pilots.

11. Some fighter pilots are jet pilots.

12. Some fighter pilots are not jet pilots.

13. Some jet pilots are not fighter pilots.

14. It is not possible to deduce from the given statements any true assertion connecting fighter pilots and jet pilots.

We want a machine which will reason correctly.

Solution: Here are the wiring instructions.

1. Wire one end of the battery to the transfer on one deck of switch A. This deck of switch A has four outputs, 1, 2, 3, 4.

2. Wire outputs 1, 2, 3 to just one of three transfers on three separate decks of switch B, one on each deck. Call these decks 1, 2, 3 according to the A output wired to it. Now switch B will have 12 outputs.

3. Wire these twelve B outputs and the A 4 output to one side of the lights according to the following table of instructions, and wire the other side of the lights to the other end of the battery.

Deck	B output	Light
1	5	9
	6	10
	7	14
	8	14
2	5	14
	6	14
	7	13
	8	14
3	5	11
	6	12
	7	14
	8	14
A output		
4		14

Note: The following replacements of fighter pilots (a's), bomber pilots (b's), and jet pilots (c's), may be made if desired and the same machine will reason correctly:

a's	b's	c's
baseball players	football players	basketball players
associates	colleagues	followers
flesh eaters	leaf eaters	grain eaters
merchants	traders	dealers
clients	customers	patrons
pastry cooks	barbecue cooks	regular cooks

etc., etc.

22. INTELLIGENCE TESTING MACHINE

Problem: Following are six questions, each with five answers, only one of which is correct:

1. What is the middle letter of a nine-lettered word meaning an instrument for talking over a distance along a wire?
   ( )T ( )G ( )R ( )P ( )F

2. The statement "I wonder how he earns his living?" indicates what on the part of the speaker?
   ( )Amusement ( )Jealousy ( )Curiosity
   ( )Eagerness ( )Meditation

3. Which of the words below does not belong in the list?
   ( )Herder ( )Cowboy ( )Gardener
   ( )Keeper ( )Shepherd

4. Wit is to dullness as approval is to:
   ( )Respect ( )Improvement ( )Flattery
   ( )Disliking ( )Disproving

5. If the words below were arranged to make the best sentence, with what letter would the last word of the sentence end?
   ax good keeps sharp lumberjack his a

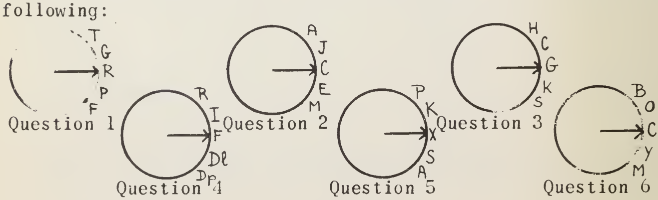
   ( )P ( )K ( )X ( )S ( )A

6. Which of the following words makes the truest sentence?

   A mother is always ..... than her daughter.

   ( )Bigger ( )Older ( )Calmer ( )Younger
   ( )Wiser

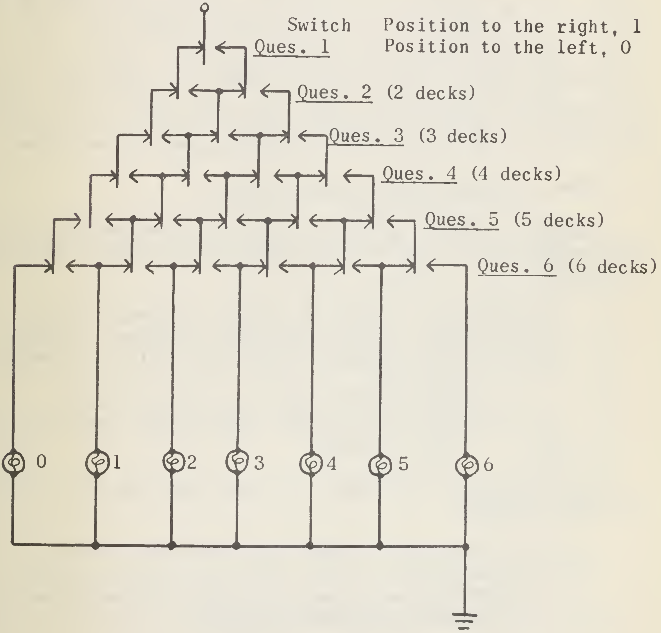
Solution: This problem uses six switches. The front of the board with the switches labeled on it will look like the following:



The desired machine will score the test, and show in seven lights from 0 to 6 the number of correct answers.

The correct answers to the questions are these: 1 - P; 2 - C; 3 - G; 4 - Disliking; 5 - P; 6 - 0. On the other side of the panel mark with 1 the position of the switch that shows this answer. Connect together the other four positions of the switch (on the other side of the panel) and mark them 0. We now have the equivalent of a two-position switch.

The circuit which will give the correct number of answers is now displayed below:



Notes: This machine can be used for any kind of 6-question intelligence test changing a few wires so that differently located alternatives are the correct answers to the questions.

23. THE URANIUM SHIPMENT AND THE SPACE PIRATES

Problem. A uranium shipment from one of Jupiter's Moons, Callisto, to Earth consists of a freighter rocket ship loaded with uranium and a fighter escort rocket ship disguised as a freighter. Space pirates are known to be lurking on one of the two asteroids, Pallas or Hermes. The pirates suspect that one of the rocket ships is a disguised fighter; therefore they may either attack the first ship or wait in hiding for a second ship. The commander of the uranium shipment can send either ship by the Pallas or the Hermes route and can send the fighter either first or second. If the pirate attacks the fighter, the pirate will be destroyed. If the pirate attacks the uranium ship and the fighter has already passed or taken the other route, then the pirate captures the uranium. If the pirate attacks the uranium ship, and the fighter is taking the same route, and is behind the uranium ship, the pirate is destroyed but during the battle, the pirate destroys the uranium ship. Of course, if the pirates do not attack, there is no combat.

What happens to the uranium shipment?

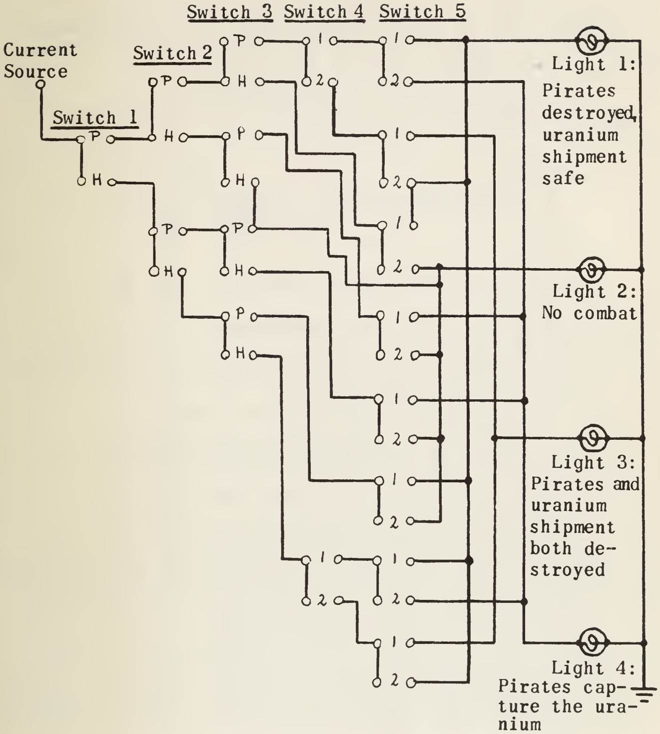
Solution. There will be five two-position switches to express either one of the two possibilities for each of the five conditions:

1. Pirates lurking on Pallas or Hermes (1 deck)
2. Fighter travels via Pallas or Hermes (2 decks)
3. Uranium shipment travels via Pallas or Hermes (4 decks)
4. Fighter travels first or second (2 decks)
5. Pirate attacks first ship or waits for second ship (8 decks)

There will be four lights to express any one of the four possible outcomes:

1. Pirates destroyed, uranium shipment safe
2. No combat
3. Pirates and uranium shipment both destroyed
4. Pirates capture the uranium

Following is the circuit:

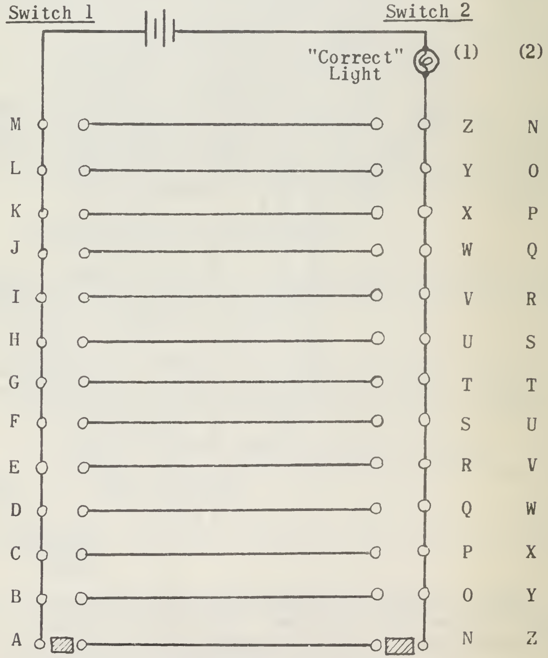


Note: In this case another way of showing the wiring of the switches has been used. The set of terminals on the switches has been shown as a column of pairs of small circles, and the two positions of the switches have been designated with letters or numbers.

24. SECRET CODER
25. SECRET DECODER

Problem. Set up a machine which will encipher a message, putting it into cipher, and which can also be used to decipher the message, putting it back into plain text.

Solution. Following is the wiring for a machine which will do this:



Each of these two switches is a switch with one deck and 13 positions. The lamp signals when the pairing of letters is correct. The sign ▨ designates the jumper.

This machine will both encipher and decipher a message. To encipher, set a letter from the message on whichever dial it occurs. Then turn the other dial until the lamp lights. Use the letter from the second dial for the code message. The same process decodes the message.

The labels in column (1) give a Caesar-type Cipher, so called because this type was used by Julius Caeser.

Here are some messages in the Caesar Code for you to decipher:

JR NER FHEEBHAQRQ FRAQ ERVASBEPRZRAGF

TBYQ VF HAQRE SBEG XABK

BAR VS OL YNAQ NAQ GJB VS OL FRN

If the labels in column (2) are used, the machine expresses a Reverse Caesar Cipher. Here are some Reverse Caesar messages for you to decipher:

ULINFZ RH YVSRMW GSV KRXGFIV LU YRMXLOM

YVDZIV GSV TILXVI SV RH Z IVW HKB

ZOO RH OLHG UOVV ULI BLFI ORUV

You can compose your own secret code by scrambling the wires that run from switch 1 to switch 2. Make sure that one and only one wire runs from each of the 13 positions on switch 1 to each of the 13 positions on switch 2.

There are more than 6 billion different ways of connecting these switches; therefore you may be sure that if you mix the wires up well, no one will stumble on your manner of connection by chance.

Solutions to the Ciphers: (Caesar)

WE ARE SURROUNDED SEND REINFORCEMENTS
GOLD IS UNDER FORT KNOX
ONE IF BY LAND AND TWO IF BY SEA

(Reverse Caesar)

FORMULA IS BEHIND THE PICTURE OF LINCOLN
BEWARE THE GROCER HE IS A RED SPY
ALL IS LOST FLEE FOR YOUR LIFE

26. MACHINE TO PLAY NIM

Problem. There are several ways of playing the game of Nim. One way is to set up four piles of matches, with the number of matches in each pile 4, 3, 2 and 1. The two players take turns. Each player must during his turn take one or more matches from any one pile (and may take the whole pile). The player taking the last match wins the game.

Here is a sample game:

(1) the player going first takes 2 out of the first pile, leaving 2, 3, 2, 1;

(2) the second player now takes 2 out of the second pile, leaving 2, 1, 2, 1;

(3) the first player now takes 1 from the last pile, leaving 2, 1, 2, 0;

(4) the second player now takes 2 from the first pile, leaving 0, 1, 2, 0;

(5) the first player now takes 1 from the third pile, leaving 0, 1, 1, 0;

(6) it is now clear that the second player loses, for whichever match he takes, the first player takes the other one and wins.

The problem is to set up this variation of the game of Nim in a machine. The machine is to signal what move it makes in response to any position left by the human player. The four piles of matches are represented by four switches. Their positions correspond to the number of matches left in the pile at any time. Switch A has positions 0 and 1; Switch B has positions 0, 1, 2; Switch C has positions 0, 1, 2, 3; and Switch D has positions 0, 1, 2, 3, 4. There is also a fifth switch, E, which has two positions, M, for Machine's Turn to Play, and P for Player's Turn to Play.

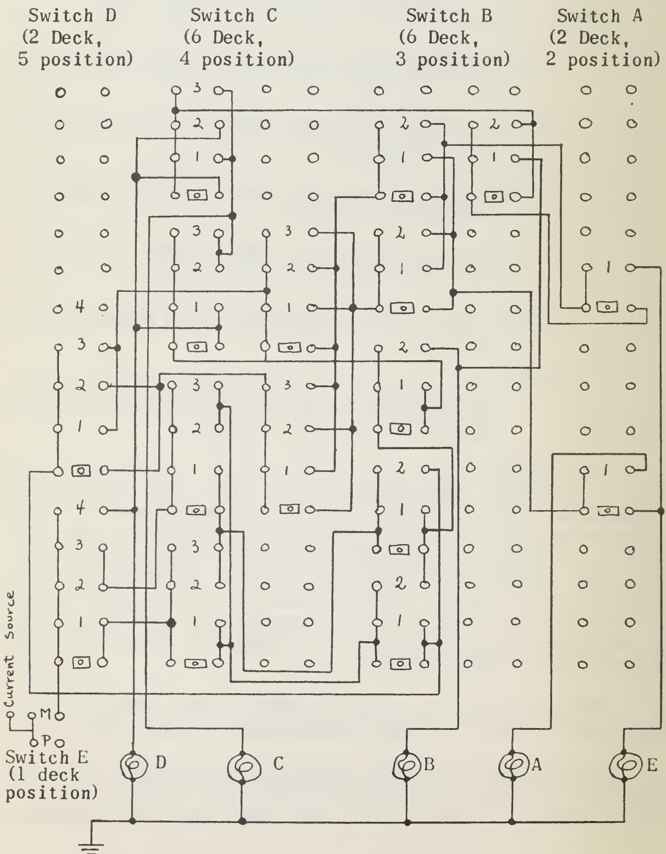
The machine is to accept any move by the human player, and is to be able to signal unmistakably its own move.

The machine is to play either first or second. If the machine plays first, it should always win; if the machine plays second, it should win if the player makes any mistakes.

The game is to start with the switches set in positions A 1, B 2, C 3, and D 4.

How should the machine be designed?

Solution. Following is a circuit for the machine:



To operate the machine, if it is the machine's move, set each switch at the position of the number of matches which is in the corresponding pile. Then turn the switch E to "Machine". If any one of the lamps A, B, C or D is lit, but the lamp E is not lit, turn the corresponding switch down (irrespective of whether other lights flicker on or off) until the lamp E lights. If any one of the lamps A, B, C or D is lit, and the lamp E is also lit, select the switch having the largest setting and turn it down by one. This is the machine's move.

If it is the player's move, turn the switch E to "Player", and then turn down that one of the switches which gives effect to the player's move.

27. MACHINE TO PLAY TIT-TAT-TOE

Problem. The usual way to play tit-tat-toe is of course familiar to nearly everybody. The game is played on a criss-cross set of lines:

and the two players enter naughts "O" and crosses "X" until one player gets three marks together in a straight line and thereby wins. If neither succeeds, the game is a draw.

The problem is to set up a machine which will play tit-tat-toe with a human player, assuming that the machine plays first.

Solution. Here is a solution. Let the squares of the board be numbered as follows:

1	2	3
8	9	4
7	6	5

There are three switches:

1. Machine's Last Move: 2 decks, 10 positions

2. Player's Current Move: a special three-deck switch (see the circuit diagram) with 10 positions and 16 jumpers.

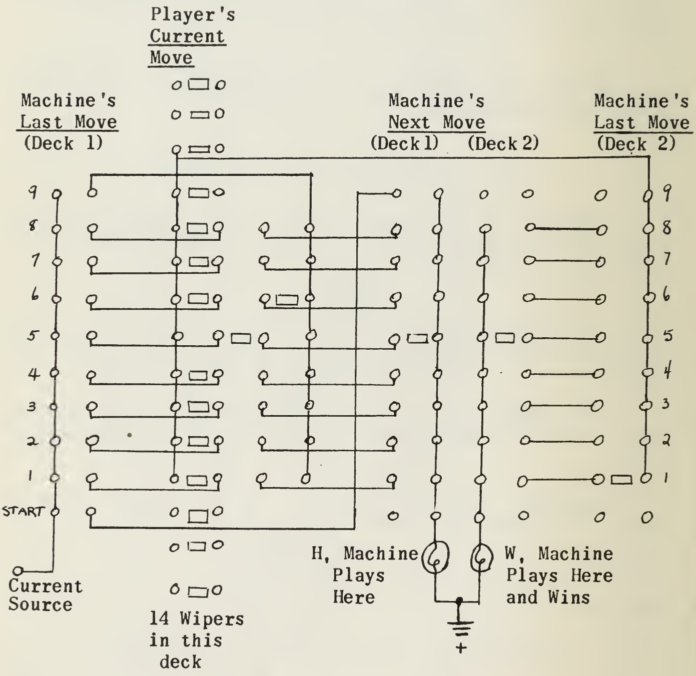
3. Machine's Next Move: 2 decks, 10 positions

There are two lights:

1. H, Machine Plays Here

2. W, Machine Plays Here and Wins

Following is the circuit diagram:



All wipers are shown with the switch in the No. 1 position. Note the special arrangement of the wipers on the Player's Current Move Switch. All switches have positions "start" and 1 through 9.

The rules for playing with this machine are as follows:

(a) The machine plays first; and all switches are turned to the start position.

(b) Turn the Machine Next Move Switch until Lamp H lights

(c) Then enter "X" on the board in the square indicated by the Machine Next Move Switch; and then set the Machine Last Move Switch at the same number as the Machine Next Move Switch.

(d) Then you as the human player enter "O" on the board in the square you choose, and turn the Player's Current Move Switch to indicate the square where you played.

Repeat steps (b) through (d) until the game is over.

If the lamp W lights, the machine plays where indicated, and wins.

If the machine tries to play in a square already occupied, play in the opposite square instead (this happens on the last play when the game is already a tie).

Sample games produced by this machine are shown below:

O_1	X_2	O_3
O_4	X_1	X_4
X_3	O_2	X_5

O_2	X_3	O_4
X_5	X_1	O_1
X_4	O_3	X_2

O_1	X_2	X_4
	X_1	O_3
X_3	O_2	

O_2	X_3	
O_3	X_1	O_1
	X_4	X_2

28. TRANSLATOR FROM BINARY TO DECIMAL

Problem. A kind of notation for numbers which is very widely used in automatic computers, "giant brains", is not decimal notation but binary notation. The first dozen numbers in binary notation are 0, 1, 10, 11, 100, 101, 110, 111, 1000, 1001, 1010, 1011. Here the digits are only 0 and 1, and the successive positions report powers of two. Starting at the right, the positions report 2 to the zero power or one, 2 to the first power or two, 2 to the second power or four, 2 to the third power or eight, etc. In this way, 1011 is one one, one two, no fours, and one eight, or a total of eleven.

The reason why binary notation is very useful in automatic computers is that many devices for storing definitely and calculating rapidly are devices which have just two states: on or off; magnetized north-south or south-north; conducting or not conducting; etc.

Furthermore, the addition and the multiplication tables in binary arithmetic are easy and simple, as follows:

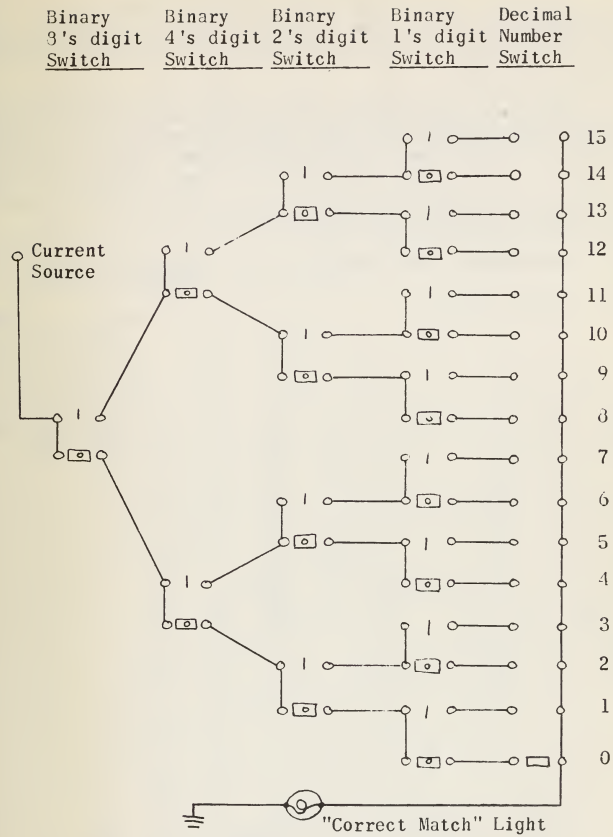
+	0	1
0	0	1
1	1	10

×	0	1
0	0	0
1	0	1

One of the operations needed is to translate from binary numbers to decimal numbers.

What is a machine that will translate the binary numbers from 0 to 1111 into decimal?

Solution. The machine will have five switches: one each for the eights digit, the fours digit, the twos digit, and the ones digit; and a fifth switch for testing the decimal number which corresponds with the binary number. Following is the circuit. All the wipers are drawn in the zero position.



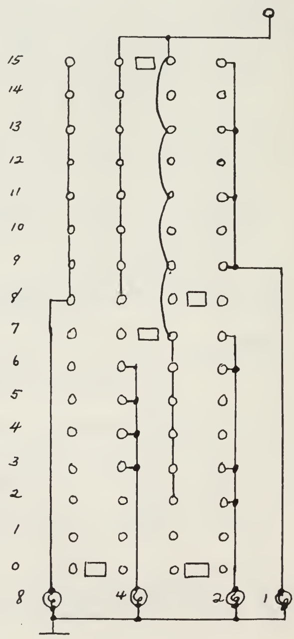
To operate this machine, first set up the binary number on the 4 binary dials. Then turn the decimal dial until the light is lit. The decimal dial indicates decimal equivalent.

29. TRANSLATOR FROM DECIMAL TO BINARY

Problem. Another operation needed is translation from decimal notation to binary notation. What is a machine that will translate from decimal numbers 0 to 15 to binary numbers from 0 to 1111?

Solution. This machine may be obtained by wiring a single switch with sixteen positions and five wipers, using the following circuit. There will be four lamps, for the eights, fours, twos, and ones binary digits. When a lamp glows, it indicates that the binary digit is 1; when the lamp is dark, it indicates that binary digit is zero.

Following is the circuit:



(Wipers are shown with the switch in the zero position; note particularly the wipers for fours digit lamp.)

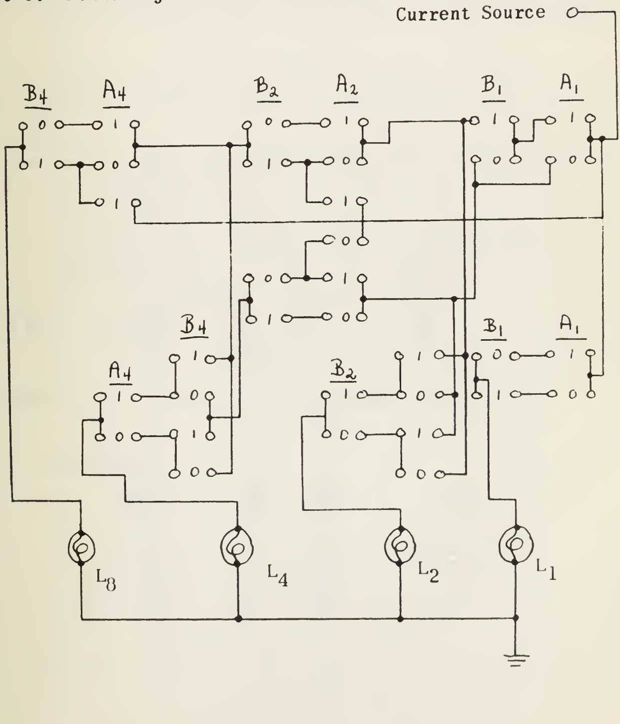
To operate this machine, turn the switch to indicate the decimal number, and the corresponding binary number may be read in the lamps. Here lamp ON = 1, lamp OFF = 0. Note: This translator and previous one can be wired at the same time.

30. BINARY ADDING MACHINE

Problem. Given two binary numbers, each of three digits. What is a machine which will give their sum, in binary?

Solution. The input of this machine is six switches, three for the number A, and three for the number B. The binary digits are called successively the 4, 2, and 1 digits. Each of these switches has two positions, one for digit 0 and one for the digit 1.

The output of this machine is four lamps L_8, L_4, L_2, L_1, corresponding to the 8, 4, 2, and 1 digits. When a lamp glows, it represents the digit 1; when it is dark, it represents the digit 0. Following is the circuit:

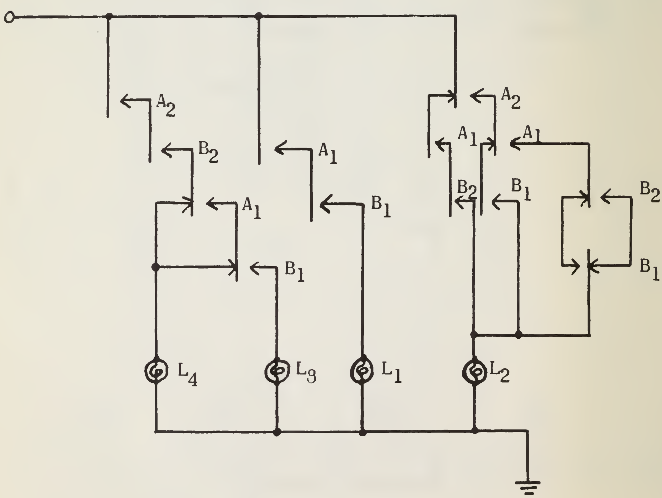


31. BINARY MULTIPLYING MACHINE

Problem. Given two binary numbers, each of two digits. What is a machine which will give their sum, in binary?

Solution. The input of the machine will consist of four switches, A2 and A1 for the number A and B2 and B1 for the number B. Each of these switches will have two positions, one for the digit 0 and one for the digit 1.

The output of this machine will consist of four lamps L8, L4, L2, and L1, corresponding to the four digits in the 8, 4, 2, and 1 columns, of the binary number, which is the product of A and B. When a lamp glows, it will represent the digit 1; when it is dark, it represents the digit 0. Following is the circuit:



32. BINARY COMPARISON MACHINE

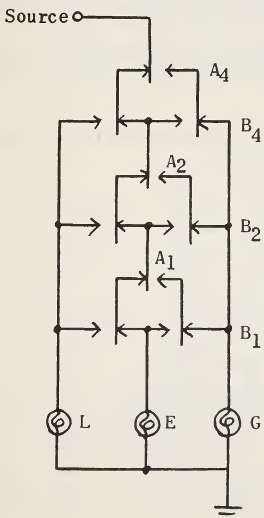
Problem. If we use binary notation, we can within the limits of the same hardware compare two numbers that are larger than we can with decimal notation.

Given two binary numbers each of three digits. What is a machine which will report whether A is greater than B, or A is equal to B, or A is less than B?

Solution. The input of the machine will consist of six switches. Three of the switches will express the three digits, 4, 2, 1 of the number A. The other three switches will express the three digits 4, 2, 1 of the number B. Each of these switches will have two positions, one for the digit 0 and one for the digit 1.

The output of this machine will consist of three lamps, G for "A greater than B", E for "A equal to B", and L for "A less than B".

Following is the circuit:



33. "TWO-OUT-OF-FIVE" CODE TRANSLATOR

Problem. In some computers and some telephone exchanges, there is an advantage in representing decimal digits by selecting just two out of five possibilities (lamps, lines, relays, etc.), no more and no less. In this way if a unit of equipment fails, one or three possibilities will be selected, and an error signal can be at once produced.

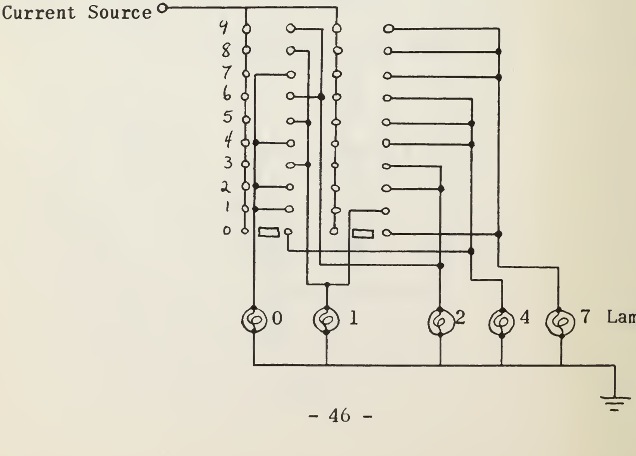
One of the "two out of five" codes which is widely used is the following:

Decimal Digit	2 out of 5 Code	Decimal Digit	2 out of 5 Code
1	0 and 1	6	2 and 4
2	0 and 2	7	0 and 7
3	1 and 2	8	1 and 7
4	0 and 4	9	2 and 7
5	1 and 4	0	4 and 7 (special)

What is a machine that will give this code automatically?

Solution. The input of this machine is one switch, with 10 positions and two decks wired as shown in the following circuit.

The output of this machine consists of five lamps bearing the labels 0, 1, 2, 4, 7.



Part II: Materials in the Geniac Electric Brain Construction Kit No. 1 and Explanation of Them

Part II: Materials in the Geniac Kit, and Explanation of Them

The Geniac Electric Brain Construction Kit is a kit by means of which anyone can put together the machines of the types described in Part I (and many more besides) so that they will perform operations of reasoning and computing.

The kit is harmless. It runs on one flashlight battery. Wires are connected by fastening them to the same nut and bolt and tightening the connection by gripping them between two bolts. No heat or soldering iron is required. DO NOT CONNECT this kit or any part of it to any home or industrial electrical power outlet: you are likely to destroy the material, and you may hurt yourself.

The kit is simple, but nevertheless it takes effort and work to put the material together to make a functioning electric brain. We urge you to take your time. If necessary, read the instructions several times. If the instructions are still not clear, read ahead and then return.

1. Parts list. In Table 2-1 appears a list of the parts contained in the kit. (All figures over 20 are approximate.)

Table 2-1

50 feet	Wire, insulated
1	Battery, dry cell, flashlight, 1½ volts
1	Battery clamp
10	Bulbs, flashlight, 1½ volts
10	Sockets for flashlight bulbs
90	Bolts, brass, 6/32
180	Nuts, steel, 6/32
1	Screwdriver
1	Spintite
1	Crayoff pencil
1	On-Off Switch, assembled
1	Panel, masonite, punched
6	Multiple Switch Tops, circular, masonite, punched
6	Bolts, steel, for center pivot
12	Washers, steel

6	Washers, sponge rubber
25	Jumpers, metal, brass plated
1	Manual

2. Wire. The kit gives you about 50 feet of wire covered with insulation. This is like the wire which you will find connecting a lamp to a wall plug, or a telephone to the telephone box, but adapted for handling much smaller currents and voltages. Instead of two wires wound together, here is one wire only. In the wiring that you will need to do, your two wires will be taken care of when you make for yourself a complete circuit, running from one end of the battery around some kind of loop to the other end of the battery.

Your wire will need to be cut apart with a cutting pliers into lengths. Convenient lengths for the wire to be cut into are: 15 pieces about 6 inches long; 15 pieces about 12 inches long; and 15 pieces about 18 inches long.

About three quarters of an inch of the insulation will need to be trimmed off at each end of each piece. You can trim this off neatly with a dull knife; you should try to avoid cutting or nicking the wire.

Two remaining feet of wire should be stripped of insulation and cut into pieces 1¼ or 1½ inches long. These pieces of bare wire will be used for making transfer contacts on the multiple switches, as will be explained later.

3. Battery. This is an ordinary flashlight battery, of about one and a half volts. A volt is a unit of electric push, or electric pressure, or electric potential. All these terms mean the same thing.

You can think of a battery as a pump, which is able to push electrons, or little marbles of electricity, away from the plus end of the battery and towards the minus end of the battery, waiting for some kind of circuit at the minus end so that the electrons can flow around the circuit back to the plus end of the battery. A flow of electrons is an electric current.

The filament in the bulb through which the electrons flow provides a resistance or restriction or narrowness for the flow of electrons, so narrow in fact that it heats up and glows with friction as the electrons go through it.

If at some time your battery will not light a bulb, or will only make it glow feebly with a dim orange light, then your battery has run down.

4. Battery Clamp. This consists of a metal clip that fastens into the panel and which will grip your battery and hold it. You then can fasten connections to the battery clamp and yet snap out your battery when it is weak and snap in another stronger battery in place of it when you need to.

5. Bulbs. You have ten small light bulbs in the kit. They will glow from a single flashlight battery. In order to make them light, you have to run one wire from the bottom metal plate of the battery to the side of the bulb, and another wire from the top of the flashlight battery to the center of the base of the bulb. Your connections must be clean, not oily, or corroded.

Examine your bulbs closely from time to time and make sure that the filament, the little slender wire that you can see inside the glass bulb, is all in one piece. If it is broken, the bulb is spoiled.

6. Sockets. You have ten sockets for flashlight bulbs. The sockets may be fastened to the frame pieces. They are for holding the light bulbs, so that they can be screwed in and out of their sockets.

7. Nuts and Bolts. For fastenings, connections, and terminals, here and there all over the machine you have a supply of bolts (90) and a supply of nuts (180). The bolts are of brass, the nuts are of steel, and they should give good electrical connections. A bolt is inserted through any hole; then a nut is screwed down tight on the bolt holding it in position; then the connecting wire is wound around the end of the bolt coming through; then a second nut is screwed down tight on the wire and the bolt so as to give a tight electrical contact. (For one or two of the machines you may need a few more nuts and bolts.)

8. Screwdriver and Spintite. In order to fasten your nuts and bolts easily, you have a small screwdriver, which fits in the slot of the bolt and enables it to be turned, or aligned. You also have a small piece of hexagonal tubing (a spintite) which fits over and grips the hexagonal bolt and enables it to be spun quickly down the shaft of the bolt, and tightened.

9. Crayoff Pencil. For writing the names or letters

designating switches, switch-positions, and lights, you have a white "crayoff" pencil. This kind of pencil is made with a soap base formula, and the marks it makes can be wiped off any surface with a wet cloth. Thus you can very easily change the labels from one experiment to the next.

10. On-Off Switch. In the kit is a small assembled switch which is used for turning a machine on or off, and so we call it the on-off switch. This is the switch which enables you to put suspense and drama into your machine; for you set everything the way it should be, then talk about it and explain it, and finally when you have your listener all keyed up and ready, you (or he) throws the switch that turns the machine on. Then you both can see (if everything has been prepared correctly) that the machine behaves as it should.

11. Panel. In order to assemble your materials together into a machine, you have a rectangular panel consisting of masonite (thin pressed fiberboard). It contains holes for nuts and bolts so that the various parts of the set may be mounted together and assembled firmly.

If you examine the panel, you will see two patterns of holes. One pattern (shown in Figure 2-1) consists of 102 holes arranged mainly in two rows through the middle of the panel from end to end.

Figure 2-1

In this set of holes, all the hardware of a machine is mounted except the "multiple switches", which will be explained in a moment. The second pattern consists of 6 rosettes of 65 holes in a circular arrangement (shown in Figure 2-2). These are the 6 "bases" of the multiple switches.

12. Multiple Switches. The remaining material which you have in the kit consists of 6 round pieces of masonite, each containing 65 holes in the same circular arrangement (see Figure 2-2), and the hardware for assembling them into multiple switches, switches which are able to switch many circuits at the same time. Each of the circular pieces of masonite is

about 4 3/8 inches in diameter, is illustrated in Figure 2-2, and is called a multiple switch top (or switch disc, or switch dial).

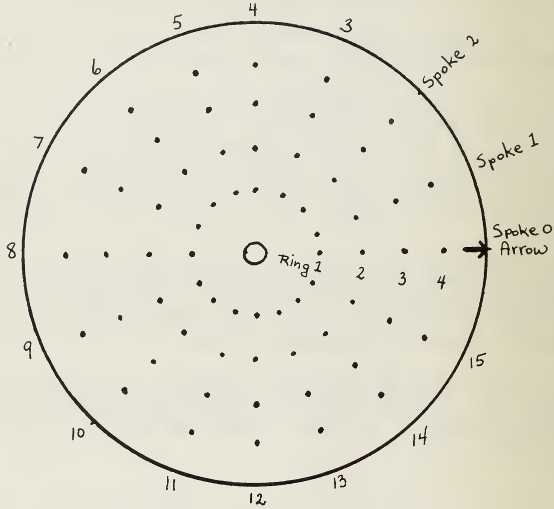


Figure 2-2

In the panel each of the exactly similar sets of 65 holes is called a multiple switch base. In an early stage of the design of the kit, the switch bases were 6 separate pieces of masonite; but then it became evident that mounting of the hardware to make a machine would be better accomplished by having all the switch bases solidly connected.

The top of a switch is fastened to the base of a switch by means of a center pivot, consisting of a long bolt, washers, and a sponge rubber washer; the assembly of the center pivot is shown in Figure 2-3.

The holes (except the center hole) in each switch base and switch top are arranged in 4 rings and 16 spokes. The rings are called Ring 1, 2, 3, 4 going outward, and the spokes are called Spoke 0, 1, 2, 3 and so on around, to Spoke 15, starting with the spoke directly to the right, and going counterclockwise. See Figure 2-2.

Each of the holes in the switch base may or may not contain a brass bolt, called a _terminal_, for making connections. The connections are made using two steel nuts, one for fastening the bolt securely to the switch base, and the second for holding and tightening a wire around the bolt so as to make a good electrical connection with the bolt (see Figure 2-4).

Each pair of holes in a switch top, from Ring 1 to Ring 2 or from Ring 3 to Ring 4 (or very rarely from Ring 2 to Ring 3) may or may not contain a _jumper_ (also called a _wiper_), a small piece of brass plated metal like a T fastener, as shown in Figure 2-5. The two brass arms fit into holes in the switch disc and are pressed down like a clasp. A jumper serves to make and break electrical contact as the switch is turned.

13. _Assembly of the Multiple Switches_. Before any of the multiple switches can function, however, it must first be assembled. Into the base we have to insert a number of nuts and bolts to hold wire connections. Just where these are inserted depends on the type of switch we desire to construct, two-position, or four-position, or some other type.

Into the top of the switch we must insert a number of jumpers in order to make and break contacts. Each jumper is inserted along a spoke between one ring and the next. Just where the jumpers are inserted again depends on the type of switch we desire to construct.

In order for the switch to stay in a position to which it is turned, the body of the jumper must line up with the slots in the heads of the bolts, and these slots must be in line with the spoke, and then the jumpers will have a tendency to catch in the slots of the screws, as they should, to hold the switch in position (see Figure 2-6). Note that in Figures 2-6 and 2-7 the rings and spokes are drawn as thin lines: these lines are not actually drawn on the switch discs nor the switch bases, nor do they represent electrical lines connecting terminals; instead they are drawn to make the layout clearer.

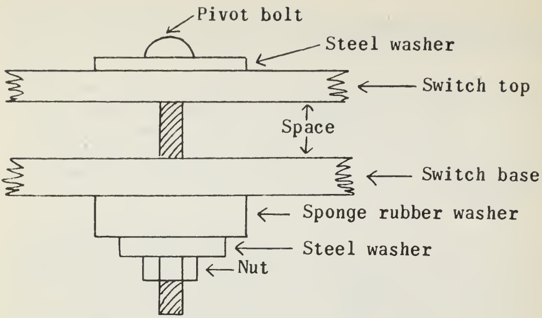


Figure 2-3 -- Center Pivot Assembly

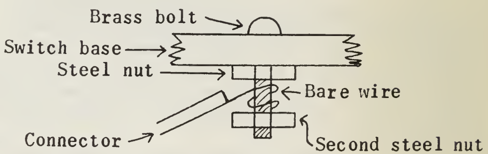


Figure 2-4 -- Assembly of Terminal Bolt and a Wire Connector

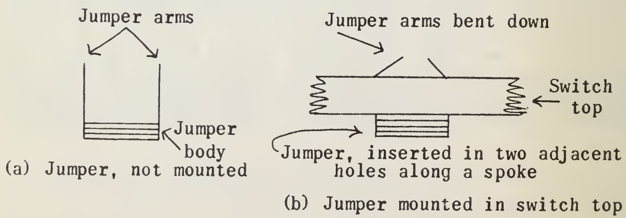


Figure 2-5 -- Jumper

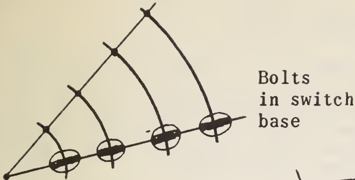


Figure 2-6 --Slots in heads of bolts lined up with the spoke

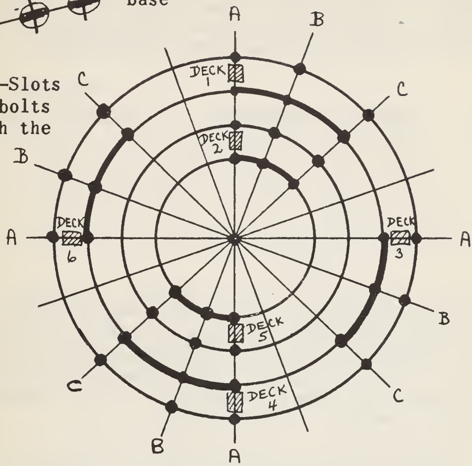


Figure 2-7 — Three Position Switch, Six Decks (or Poles or Levels)

Now suppose we wanted to assemble a switch which would have any one of three positions A, B, and C, and which would be capable of switching every one of six different circuits. A way in which that switch could be assembled is shown in Figure 2-7, in which both the top and the bottom of the switch are drawn over each other. Six jumpers are inserted in the top of the switch, shown as ▨ in Figure 2-7. It is important that jumpers be inserted in pairs opposite each other, so that the top of the switch will stay parallel to the bottom of the switch. A total of six times six or 36 nuts and bolts are inserted in the bottom of the switch, in the spots marked ● in Figure 2-7. They are in groups of six called decks (also called poles, or levels); these decks are electrically independent, and they enable us to switch 6 different circuits. The holes belonging in any one deck in Ring 1 or Ring 3 are connected together by wire, as shown by the heavy line; they are connected with one of the short wires 1½ inches long. They are made electrically common; in other words, they are commoned. Together they constitute what is called a transfer contact.

Let us now consider the layout of the spokes and the rings and the 64 holes which they produce. We can see that we can assemble a switch in a number of different ways. This is the advantage of the design of the multiple switch we have chosen (on which patent is being applied for). Here are the types of switches that can be made with these parts:

Number of Positions	Maximum Number of Decks
2	16
3	10
4	8
5	6
6 to 8	4
9 to 16	2

If nuts and bolts did not cost anything, we could insert 64 nuts and bolts into the base of each switch and leave them there -- ready for use in any switch. Actually, because the kit has a limited supply, it may be necessary to move nuts and bolts from one switch to another in order to make the different machines we want.

In the case of jumpers, we shall fairly often have to move them to different places, in order to make different switches for different machines.

14. Additional Material. You may obtain additional or replacement material for this kit by buying it at a local store, or by writing to us. Obviously, if your battery runs down, or if you want more wire, or if you want more nuts and bolts, the easy thing to do is to buy them in your neighborhood. But for more switch disks or for more jumpers, etc., you will probably need to write us. Prices for these items are listed on a price list which may be obtained on request.

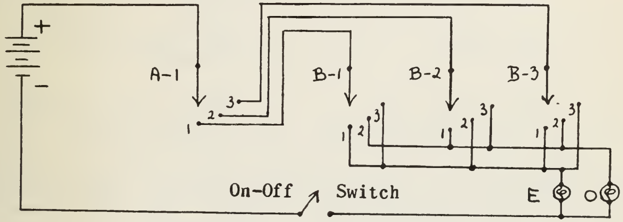
15. Wiring Lists and Templates. In work with electrical circuits we need to lay out beforehand what we are going to do. We need to design on paper how we are to connect the different pieces of material. For this purpose, we use (1) circuit diagrams, (2) wiring lists, and (3) templates.

A circuit diagram, as mentioned before, shows the scheme of connection of batteries, switches, lights, etc., in order to make the circuit. In a circuit diagram we pay little attention to the actual physical location of the material; we just show a diagram of its arrangement.

In a <u>wiring list</u>, we name the terminals, by words or letters or numbers, and we state, for every part of the circuit, what terminal is connected to what terminal. In a wiring list again we pay no attention to the actual spatial locations of the terminals.

In a <u>template</u>, the case is different; we show the wiring and for any difficult portions of the circuit, such as the multiple switches, we show the approximate relative spatial location of the different pieces of material used in the circuit. In other words, we draw a picture of where the terminals are, and then we indicate the wiring either by drawing lines for the connections or by writing notes showing the connections.

16. <u>An Example</u>. Suppose we have a circuit as shown in Figure 2-8. This circuit consists of two switches A and B, each having the positions 1, 2, 3, two lights marked E and O, and a battery. Only one deck of switch A is used but three decks of switch B are used.



<u>Figure 2-8</u> -- A Sample Circuit

What would the wiring list for this circuit be? It would be as follows:

<u>Wire From</u>	<u>To</u>
1. One side of battery, Battery Plus	Transfer of Switch A, Deck 1
2. Switch A, Deck 1, output 1	Transfer, Switch B, Deck 1
3. A-1, 2	B-2, T

	Wire From	To
4.	A-1, 3	B-3, T
5.	B-1, 1	One side of light E, E 1
6.	B-1, 2	One side of light 0, 0 1
7.	B-1, 3	B-1, 1
8.	B-2, 1	0 1
9.	B-2, 2	E 1
10.	B-2, 3	B-2, 1
11.	B-3, 1	E 1
12.	B-3, 2	0 1
13.	B-3, 3	B-3, 1
14.	E 2	0 2
15.	E 2	One side of On-Off Switch
16.	Other side of On-Off Switch	Other side of battery, Battery Minus

Here then is an example of how a list of wiring instructions for a circuit can be prepared. The list specifies where each wire comes from and where it goes. Furthermore, instead of running long wires from certain outputs of the decks of switch B over to one side of the lights, we take short cuts by hitching on at an early point to a wire already running to the desired destination.

Now some circuits are so simple that no wiring list is needed. In many complicated circuits (especially in circuits in computing machines and other kinds of large electric brains), the wiring is so complicated that a written-out wiring list is unavoidable.

What would be the template for this circuit?

The way the template would look is shown in Figure 2-9, although here we have simplified the picture of the switch base and the switch top so that we show only two rings instead of the four rings that it actually contains. We can see that there is a considerable difference between the circuit description of a multiple switch and the template description of a multiple switch; but we can also see the close relation between them.

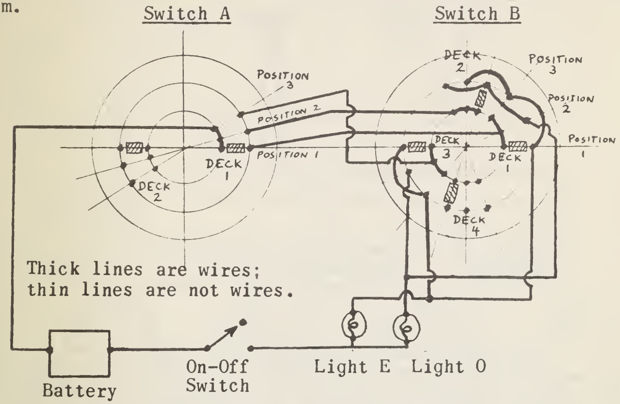
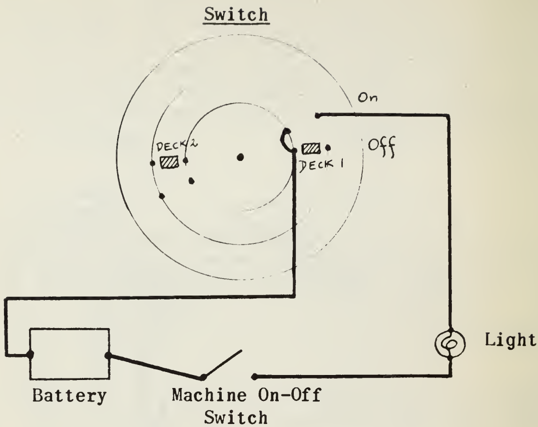


Figure 2-9 -- Template for the Sample Circuit

The question may be asked: Why in putting together the multiple switches, are jumpers, nuts and bolts inserted where they are not electrically necessary, as in Deck 2 of Switch A (in Figure 2-9) and in Deck 4 of Switch B? The answer is that the additional symmetrically placed hardware is needed for mechanical reasons; by putting it in, the central rubber washer which acts as a spring will pull the switch top at right angles instead of obliquely, which would result in poor electrical contact. The mutiple switches should always be constructed symmetrically in this way for mechanical reasons. Since this mechanical aspect can from now on be deduced, we may omit this part of the assembly in the drawings of future templates.

17. Detailed Wiring for "The Flashlight". We shall now consider the details of the assembling and wiring of the kit materials so as to make the first machine, "The Flashlight". Following is the template for this circuit:

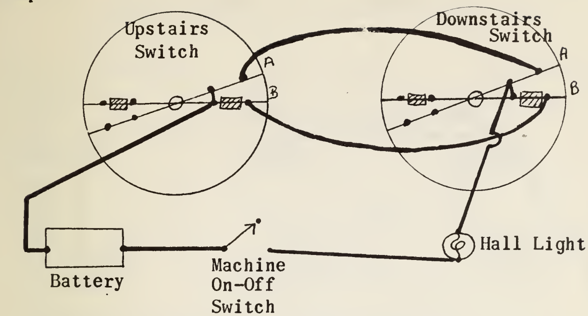


One multiple switch only is needed. The top is fitted with two opposite jumpers. The base is fitted with eight bolts in the pattern shown. The battery is mounted on the panel in the battery clamp; the machine "on-off switch" is also mounted; and a light in its light socket is mounted. Wires run: from one side of the battery to a common terminal of Deck 1; from the "on position" of the switch to one side of the light (light socket); from the other side of the light socket to one side of the machine on-off switch; and from the other side of the machine on-off switch to the other side of the battery.

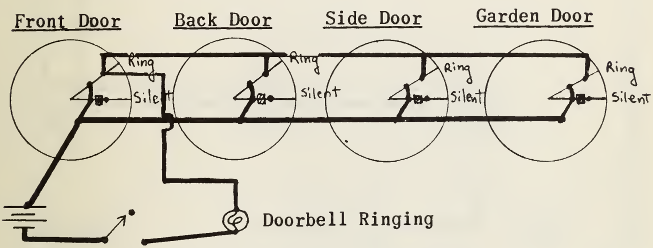
18. Detailed Wiring for "The Hall Light". Wiring list:

From	To
1. Battery, Plus	Upstairs Switch, Transfer
2. Upstairs Switch, Position B	Downstairs Switch, Position B
3. Upstairs Switch, Position A	Downstairs Switch, Position A
4. Downstairs Switch, Transfer	Hall Light, one side
5. Hall Light, Other side	On-Off Switch, one side
6. On-Off Switch, Other side	Battery, Minus

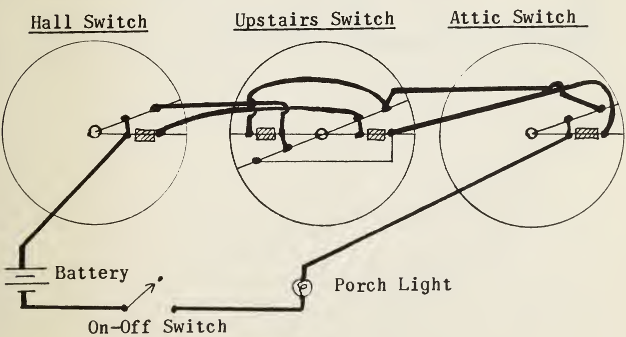
Template:



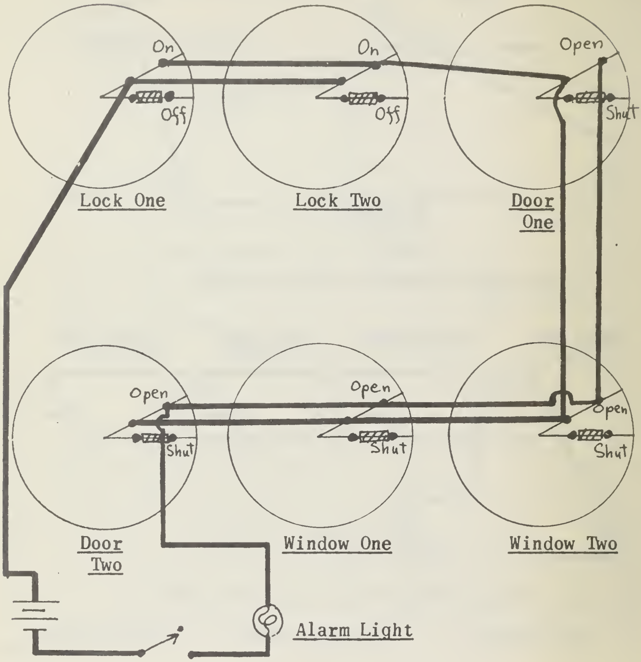
19. <u>Detailed Wiring for "The Doorbell"</u>



20. <u>Detailed Wiring for "The Porch Light"</u>



21. Detailed Wiring for "The Burglar Alarm"

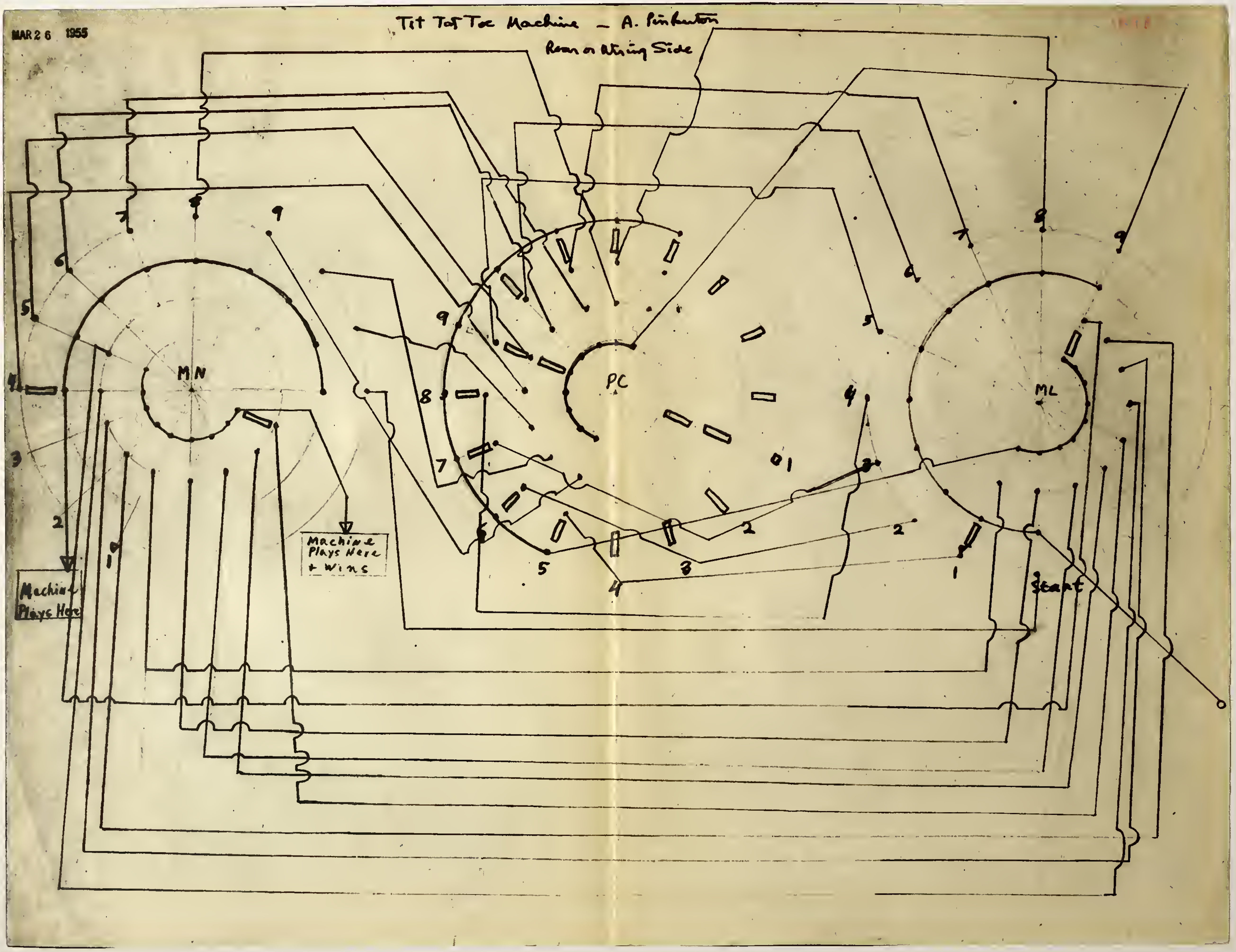


22. Detailed Wiring for "The Two Jealous Wives". Wiring Instructions:

From	To
Minus end of battery	transfer, deck 1, switch H1 (H1-1:T)
H1-1: I	transfer, deck 1, switch H2 (H2-1:T)
H2-1: I	safety light, side 1
H2-1: N	W1-1: T
H2-2: I	W2-1: T
H2-2: N	safety light, side 1
W1-1: I	"
W1-1: N	W2-2: T
W2-1: I	safety light
W2-1: N	W1-2: T
W2-2: I	C-1: T
W2-2: N	C-2: T
W1-2: I	C-3: T
W1-2: N	C-4: T
C-1: I	safety light, side 1
C-1: N	danger light, side 1
C-2: I	"
C-2: N	safety light, side 1
C-3: I	"
C-3: N	danger light, side 1
C-4: I	danger light, side 1
C-4: N	safety light, side 1
danger light, side 2	plus end of battery
safety light, side 2	plus end of battery

In the above, T stands for "transfer contact"; I stands for contact "in canoe"; N stands for contact "not in canoe".

[illegible]


MAR 26 1955
Tit Tat Toe Machine — A. Pinkerton
Rear or Wiring Side
MN
PC
ML
Machine Plays Here
Machine Plays Here + Wins
Start

[illegible]

T Y N I A C S®:

TINY ELECTRIC BRAIN MACHINES, AND HOW TO MAKE THEM

Also:
Manual for Tyniac® Electric Brain Construction Kit (K 2)

Edmund C. Berkeley

Published, March 1956, by Berkeley Enterprises, Inc.
513 Ave. of the Americas, New York 11, N. Y.

Introduction

This report and the accompanying kit present Tyniacs®, tiny electric brain machines, "Tiny (TYNI) Almost-Automatic (A) Computers (CS)". They are electrical machines which are able to calculate and reason automatically although they are too small to perform operations one after another automatically. They show, with the least hardware that we have yet been able to work out that still allows interesting experiments, the fascinating power and variety of computing and reasoning circuits.

This set of thirteen experiments contains several puzzles, two game-playing machines, two arithmetical machines, and several reasoning machines. Furthermore, at least fifteen of the experiments in our earlier and larger kit, our Geniac Electric Brain Construction Kit (K1), can also be performed with the materials in this Tyniac Kit (K3).

Each of the machines in these experiments uses one flashlight battery, not more than four flashlight lamps, and not more than four multiple switches. With the Tyniac kit, all connections are with nuts and bolts, and no soldering is required; the kit is completely safe. The kit, though inexpensive and convenient for constructing Tyniacs, is however not necessary; and some persons will prefer to construct their Tyniacs using other materials.

We hope that you find this report and kit interesting, entertaining and amusing, and that you will enjoy playing with the kit and entertaining your friends with the little machines that you make.

If you find that at first you have some difficulty in understanding all that is in this report, TAKE YOUR TIME and think; make first the simpler machines; then try the more complicated ones. To make a machine that will reason and calculate you too must reason and calculate.

Any comments, suggestions for new experiments, and corrections, will be gratefully received. We shall be glad to hear from you.

8-145(P38 Edmund C. Berkeley

CONTENTS

Part I: Tiny Electric Brain Machines

Section I. General Information

Question: What is an "electric brain machine"?

Answer: An electric brain machine is a machine containing electric circuits which is able to calculate or reason automatically. The bigger electric brains are able to carry out long sequences of reasoning and calculating operations, thus solving complex problems. Such a machine is a true "electric brain machine", for there is no doubt that until such operations began to be done by machines, everyone agreed that such operations constituted thinking and were characteristically the operations carried out by brains.

The first modern electric brain machine was finished at Harvard University in 1944, and has been working there ever since. Now thousands of such machines are in existence, and at work producing knowledge. This development is becoming so important that it is often called the "Second Industrial Revolution".

Question: What is a TYNIAC?

Answer: A TYNIAC is an electric brain machine which is tiny. If expense were no barrier, we could make one using only a small amount of hardware which would run extremely well doing many kinds of problems. But expense of course is a barrier, and the tiny electric brain machines which we talk about in this report are machines which are made of four multiple switches, a panel for mounting them, a flashlight battery, four flashlight bulbs, nuts, bolts, and other hardware. The tiny electric brain machines we talk about here will not run by themselves; that is, whenever the machine is supposed to do something, you yourself have to turn the switch representing the machine's action. But nevertheless these machines do calculate and reason automatically, because the way that they are wired expresses the calculating and the reasoning.

Question: What is the origin of the TYNIACS?

Answer: In one sense all these little machines were created, (of course, using earlier ideas, suggestions, and research) in the five days December 27 to December 31, 1955, when they were designed for this kit. But in a larger sense of course, these little machines are the outgrowth of work which we have been doing for ten years, and which is still continuing -- the exploration of intelligent behavior expressed in machines. For this purpose, we maintain a small laboratory, and are continually working on one phase or another of small robots and other machines which display intelligent behavior. Among other steps leading to the Tyniacs are the following.

In 1950, for educational and lecturing purposes, we constructed a miniature electric brain called Simon. Although only 1-1/4 cubic feet in size, and limited in capacity, it was a complete automatic computer, and it could show how a machine could do long sequences of reasoning operations. The picture of Simon appeared on the front cover of two magazines, "Scientific American" and "Radio Electronics"; the machine itself has been demonstrated in more than eight cities of the United States. Over 350 sets of Simon plans have been sold. But this machine costs over $300 for materials alone, and is therefore too expensive for many situations in playing and teaching.

Soon after Simon was finished we began work to develop really inexpensive electric brains. By 1955, we had gathered and worked out descriptions of over 30 small electric brain machines, which could be made with very simple electrical equipment. These machines were incorporated in a construction kit, which would make any one of these little machines. The name of the kit was "Geniac Kit No. 1"; the word "Geniac" ® came from the phrase "Genius Almost-Automatic Computer", and has been registered as a trademark. This kit made use of six multiple switches, and up to ten flashlight lamps and sockets, about twice as much hardware as the Tyniac kit contains. During 1955, we decided that a smaller, simpler, and better kit would be a good idea. This led to the Tyniac kit.

Question: How am I to understand these experiments?

Answer: The first thing to do is not to rush, but to take your time, and read as carefully as you can all the general information. Read particularly Section 2 of this part which talks about circuits and how they work. The circuits which make these machines operate are all of them circuits in which electricity from a flashlight battery flows along wires and causes certain light bulbs to light up. The labels on the switches, on their positions, and on the lights show the meaning which is to be assigned.

In the same way, in the pilot's cabin of an airplane, or on the operating panel of an oil refinery, the switches, the lights, the dials, and the labels tell the meaning of what is going on, so that the airplane or the refinery can be controlled.

Question: How are circuits like those in the experiments designed? I notice that each experiment is set up as a problem and solution: how would I be able to work out the solution for myself?

Answer: This is an interesting and important subject, the design of switching circuits. If you find the subject really interesting and worth a lot of work, and want to do that work, then you are likely to be well qualified to be an electrical engineer or electronic engineer, or a designer of computing machines, and you may have an excellent professional future lying in front of you.

An introduction to the design of switching circuits is given in Part III of this manual, using one of the best approaches, a new kind of algebra called Boolean algebra. This is the algebra of AND, OR, NOT, EXCEPT, UNLESS, IF... THEN, IF AND ONLY IF, and some other very common words and expressions of language and logic. This algebra is a part of the subject called symbolic logic, and has an important application to any circuits that make use of circuit elements that can be either on or off, lighted or not lighted, conducting or not conducting, and so forth.

Section 2. Circuits

The tiny electric brain machines described in this report are made of: a battery, or source of electric current; wires, which conduct it; switches, which change the paths along which the current flows; lights, which show where the current is flowing; and other hardware, such as nuts and bolts, which enables the whole machine to function together. In all of these machines the current starts from one end of the battery and flows in a path or circuit that eventually returns to the other side of the battery.

Circuit Diagram. The diagram of the circuit or circuit diagram or circuit schematic shows the scheme of connection of the battery, the switches, and the lamps, in order that the machine will function as it is supposed to. The diagram does not necessarily show the physical

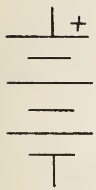


Fig. 1. - Battery

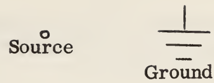


Fig. 2 - Battery terminals, when separated

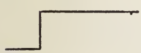


Fig. 3 - Wire, or conductor

Fig. 4 - Electrical connections

Fig. 5 - No electric connection

Fig. 6 - Lamp bulb

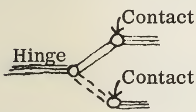


Fig. 7 - A Switch

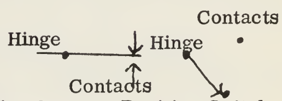


Fig. 8 - Two-Position Switch (two ways of drawing it)

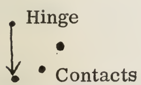


Fig. 9 - Three-Position Switch

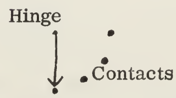


Fig. 10 - Four-Position Switch

location of the hardware but only the arrangement of the connections of the hardware.

The symbols used in our circuit diagrams are shown in the accompanying figures. We need to pay attention only to a few kinds of hardware.

Battery. Fig. 1 is the diagram for a battery. The long and short lines supposedly represent the two kinds of plates in a battery by means of which the electric current is generated. The number of long and short lines does not symbolize anything, and does not have a special meaning.

Instead of showing the two ends of the battery located next to each other, another method may be used (see Fig. 2). One end or pole of the battery may be shown at one place as a small letter "o" meaning "source of current". The other end or pole of the battery may be shown at another place with the symbol "⏚" meaning the "sink of current" or "ground".

Wire. A line in a circuit diagram (see Fig. 3) represents an insulated wire, a connector from some point to some other point.

Dots (see Fig. 4) represent points where electrical connections are established by fastening two wires together so current can flow easily between them.

In Fig. 5, two wires cross (drawn in either one of two ways) but there is no electrical connection between them. One wire is actually either above or below the other.

Lamps. The diagram of Fig. 6 sketches the glass bulb and the filament of the lamp. The two dots are its connections.

Switches. A switch was originally a device for shifting a train from one track to another. Now in addition, it is a device for turning an electric current from one path to another; see Fig. 7.

In Fig. 8, 9, and 10, appear more abbreviated diagrams of switches; they are diagrams therefore easier to draw.

Switch Contacts. In any switch, the contacts have names. See Fig. 11 for examples of switch contacts and their possible names.

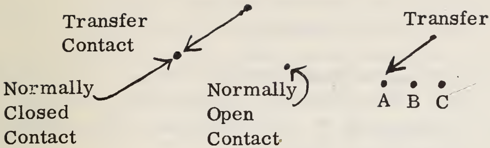


Figure 11 -- Contacts, and their Possible Names

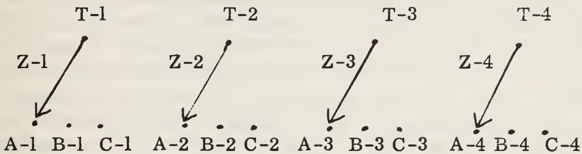


Figure 12 -- Four-Deck Three-Position Switch

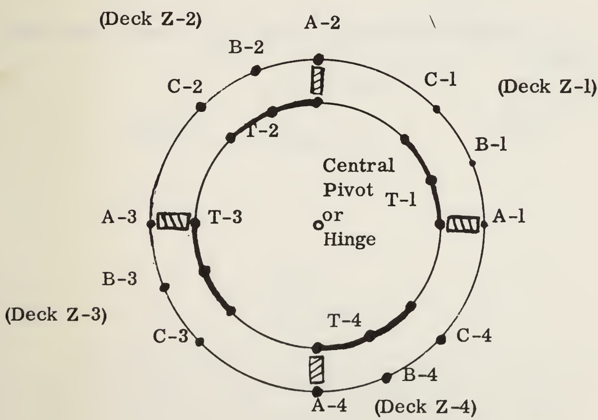


Figure 13 -- Four- Deck Three-Position Switch Z

Decks. A single switch may be constructed having two or three or more electrically nonconnecting sections (often called decks or poles) so that as it is turned, it simultaneously switches two or three or more electrically independent paths. In circuit diagrams this property of a switch may be shown by using a name for the switch and numbers 1, 2, 3, etc., for the decks. For example, a switch (named Z) with three positions (A, B, and C) and four decks (named 1, 2, 3, and 4) is diagrammed in Figure 12.

Suppose however we actually wanted to make such a switch; it should have three positions and should enable us at one and the same time to shift four separate circuits. We could make it as shown in Figure 13. We could start with a flat round piece of non-conducting material. We could fasten jumping or bridging conductors along four radii in such a way that when we turn the switch at its central hinge or pivot, each jumper (drawn as ▨)is shifted simultaneously and transfers current from its transfer points T to its corresponding contact points A, B, C. This idea is at the heart of the multiple switch used in the Tyniac kit (and also the Geniac kit). Examine the round discs in the kit. Each has a pattern of 65 holes, a center hole for a hinge or pivot, and four rings of holes arranged along 16 spokes (or radii). With the hardware in the kit, we can assemble these discs to switch many different circuits; see Part 2 of this manual for the details.

With these preliminaries out of the way, let us consider the first machine.

Part I. Section 3. EXPERIMENTS

1. Joe Savarelli's Rock Quarry

Problem: Joe Savarelli has a rock quarry where he takes out rock, puts it through his rock crusher, and makes crushed rock and gravel to put on roads. He drills holes in the bedrock of the quarry walls, puts in dynamite sticks, and explodes them electrically.

What is the circuit for setting off the dynamite?

Solution: Far enough away from the rock to be exploded, Joe sets a switch. The switch has two positions "Safe" and "Explosion". Next to the switch he sets a battery, and gets ready to connect one side of the battery to the Transfer Contact on the switch. Then he inserts a detonating cap with the dynamite in the hole drilled in the rock, and runs a pair of wires from the detonating cap to the switch and to the battery. (See the circuit below.) When he closes the switch at a distance, the detonating cap explodes and sets off the dynamite (shown by the lighting of the lamp "Dynamite Explodes").

Following is the circuit:

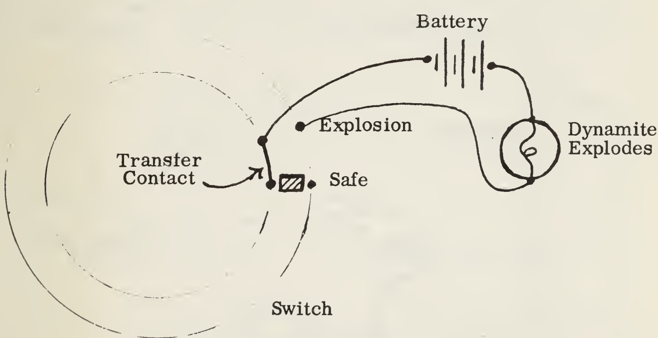


Figure 14

Comments: This is an example of one of the simplest possible circuits: one switch with two positions that either turns off or turns on a light. The same circuit essentially turns off or turns on any room light, any lamp light, any flashlight, etc.

2. Signals on the Mango Blossom Special

Problem: The Mango Blossom Special, a long streamliner, has four passenger conductors, Anderson, Bothwick, Cohen, and Davis. Many of the stations along the railroad have curved platforms; also sometimes they are foggy, since the railroad is near the sea-coast; so the conductors often cannot signal using lanterns. Therefore, each conductor in his section of the train has a switch to signal the engineer's cabin, that all passengers in his section have finished leaving and boarding, and, so far as he observes, it is safe to proceed. In the engineer's cabin, there is a panel light which shines only after all of the conductors have signaled "Go On".

What should the circuit be?

Solution: There will be four switches, named according to each conductor: "Anderson, Bothwick, Cohen, Davis". Each will have two positions, "Wait" and "Go On". There will be one output light. Following is the circuit:

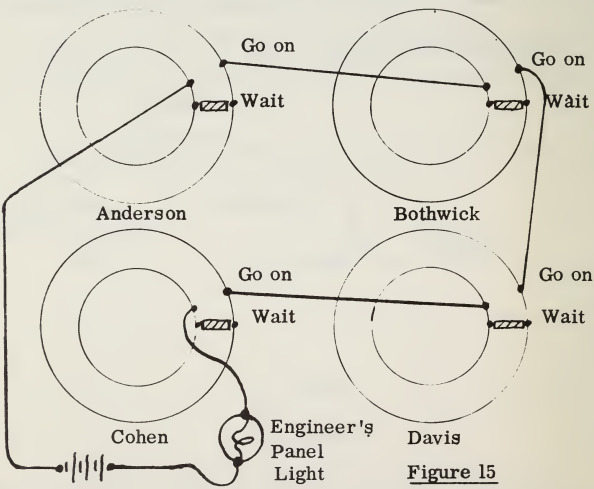


Figure 15

Comments: This circuit is a sample of what is called a series circuit. Only when all of the switches are turned on is the circuit closed.

3. General Alarm at the Fortress of Dreadeerie

Problem: In the heart of the Inaccessible Mountains is located the Fortress of Dreadeerie inhabited by the Singular Dwarfs. They mine uranium; and they are fearful of invasion and conquest from any one of four types of dangers. First, there are the Elves of Kalkain; they are invisible, but they can be detected because they trip the infrared detectors. Second are the Gnomes of Minx; they also are invisible, but can be sensed by ultrasonic detectors. Third, there are the Leprechauns of Freemark; they are also invisible and travel with great speed; but they can be detected by radar because they reflect radar pulses. Finally, there are the Trolls of Southway; they are also invisible, but they can be detected by ultraviolet detectors. The dwarfs desire a general battle alarm just as soon as any one of their four types of detectors reveals the approach of any of these dangers.

What should the circuit be?

Solution: There will be four switches: Infrared Detectors, Ultrasonic Detectors, Radar Detectors, and Ultraviolet Detectors. Each switch will have two positions: Safe, and Danger. There will be one output light: General Battle Alarm. Following is the circuit:

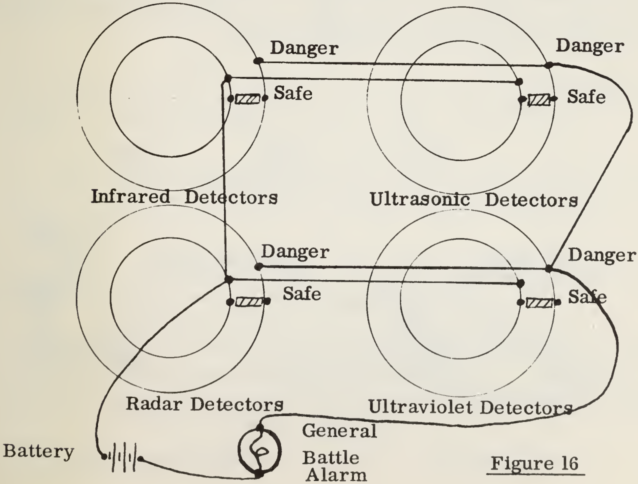


Figure 16

Comments: This is a sample of a kind of circuit called a parallel circuit. When any one of the switches is turned on, then the lamp in the circuit lights.

4. Ebenezer Graham's Garage Light

Problem: Ebenezer Graham has a light over the entrance to his garage, which illuminates his whole yard and enables him to see who is out there. There are four places where he wants to have switches, so that moving any switch either way turns the light on if it was off and turns the light off if it was on. These places are the front hall, Graham's own bedroom upstairs, the porch, and the garage itself.

Set up a circuit which will accomplish this.

Solution: There will be four switches: "Hall Switch, Bedroom Switch, Porch Switch, Garage Switch". Each will have two positions, which we may call A and B. There will be one output light, the "Garage Light". The circuit appears in Figure 17.

Note: If a switch has more than one jumper, we need to have a pointer (drawn as >, over a certain one of the jumpers ▨) to show at what position the switch is set. Even if a switch has only one jumper, it may be helpful to draw the pointer.

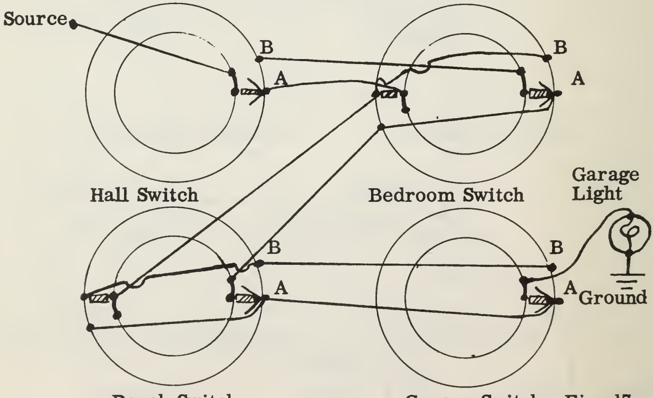


Fig. 17

5. The Game of Twenty-One in Sundorra

Problem: In the little principality of Sundorra, where the Pyrenees Mountains meet the Caspian Sea, a form of the game of Twenty-One is often played.

There are two players who each take turns. Each turn consists of two moves: the first move is the rolling of a die, which will come up, of course, with 1 to 6; the second move consists of choosing a number 1, 2, 3, or 4. The total of points by both players is continually accumulated. The player who makes the accumulated total score nearest to but not exceeding 21 wins the game. If he makes the total go over 21, he loses the game. At his last turn, if the roll of the die makes the total exactly 21, the player does not have to take his second move; but at all previous turns, he does have to.

For example, here is a game between Bill and Ed:

Move No.	Turn	Source of Move	Points	Total Points
1	Bill	Die	3	3
2	"	Choice	1	4
3	Ed	Die	2	6
4	"	Choice	4	10
5	Bill	Die	6	16
6	"	Choice	4	20
7	Ed	Die	3	23

Therefore Bill wins, because his last move left 20 as the qualifying total.

The Syndicate at Sundorra, finding out that the game is a great attraction, orders a number of machines that will play the game with human players.

What is a strategy for these machines, and a circuit by means of which the machine can make its moves?

Solution: The strategy for the machine depends only on the accumulated total score at the time that it moves. A reasonable strategy is expressed in the following table, which is built into the wiring of the circuit shown in Figure 18.

Total Score	Machine's Move
1, 14	4
2, 15	4
3, 16	4
4, 17	4
5, 18	3
6, 19	2
7, 20	1
8	1
9	1
10	1
11	1
12	4
13	4

There will be one switch, the "Total Score Switch", with positions as shown in the "Total Score" of the table above. There will be four output lights showing the "Machine's Move", 1, 2, 3, or 4. Following is the circuit:

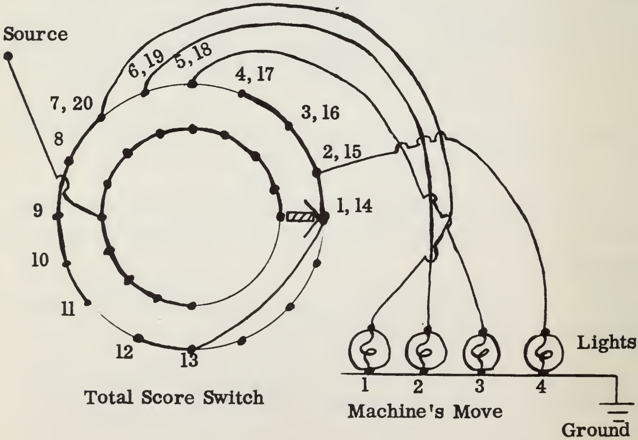


Figure 18

6. The Two Suspicious Husbands at Great North Bay

Problem: One summer two couples vacation in nearby cottages on the shore of Great North Bay. The two husbands, George and Harry, are suspicious, and one day agree that the wife of either one (Violet or Winifred, respectively) may not go boating alone with the other husband. They are handy with electric circuits and they set up a wiring system in the boathouse; they arrange with the boat boy to turn switches to show who is out in the boat. In each of their own cottages they install a danger light to shine when the situation is contrary to their agreement, and a safety light to shine on other occasions.

How should the circuit be wired?

Solution: There will be four two-position switches marked "George, Harry, Violet, Winifred". One position stands for "in the boat". The other position stands for "not in the boat". There will be two lights "Danger, Safety". Following is the circuit:

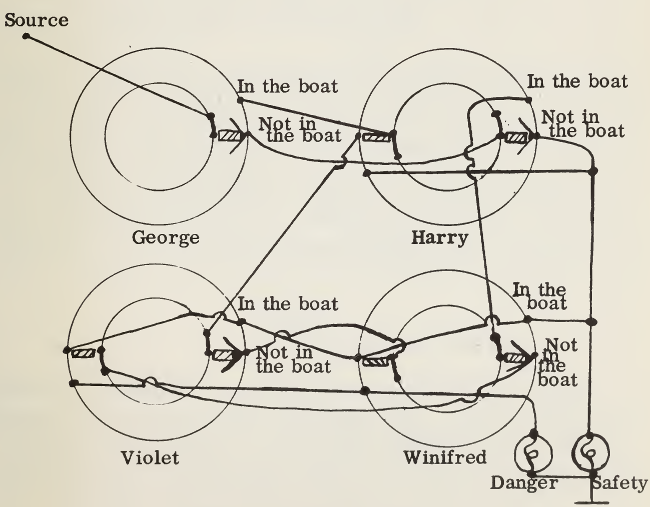


Figure 19

7. The Submarine Rescue Chamber Squalux

Problem: The submarine rescue chamber Squalux has:

— a Main Door for passage to and from the mother ship (the Luxor), when the Squalux is properly connected;

— a Bottom Door for use when the rescue chamber has been lowered through the water and fastened on top of a crippled submarine, to be used for passage through the submarine hatch;

— an Emergency Door, for use in case of accident, allowing some one inside the Squalux to enter the ocean and try to swim to the surface;

— an Air Pump, which pumps air into the Squalux until it reaches the ocean depth pressure;

— an Air Valve which lets air out of the Squalux until it reaches sea level pressure.

The rules are these: (1) you should be able to open the Bottom Door only when the Squalux air pressure equals the ocean depth pressure, the Squalux is properly connected to the crippled submarine, the air valve is closed, and the air pump is off; (2) you should be able to open the Main Door only when the Squalux air pressure is at sea level, the Squalux is properly connected to the Luxor, the pump is off, and the valve is closed; (3) you should be able to open the Emergency Door when the Squalux air pressure is at minimum safe pressure, irrespective of the pump and valve condition, and connections.

How should the circuit be wired?

Solution: There will be four switches: "Connection, Pressure Gage, Pump, Valve". The Connection switch will have two positions: "Complete to the Crippled Submarine", "Complete to the Mother Ship Luxor". The Pressure Gage switch will have three positions: "Ocean Depth Pressure, Minimum Safe Pressure, Sea Level Pressure". The Pump switch will have two positions: "On, Off". The Valve switch will have two positions: "Open, Closed". There will be three output lights: "Light 1, Safe to Open Main Door; Light 2, Safe to Open Bottom Door; Light 3, Safe to Open Emergency Door". Following is the circuit:

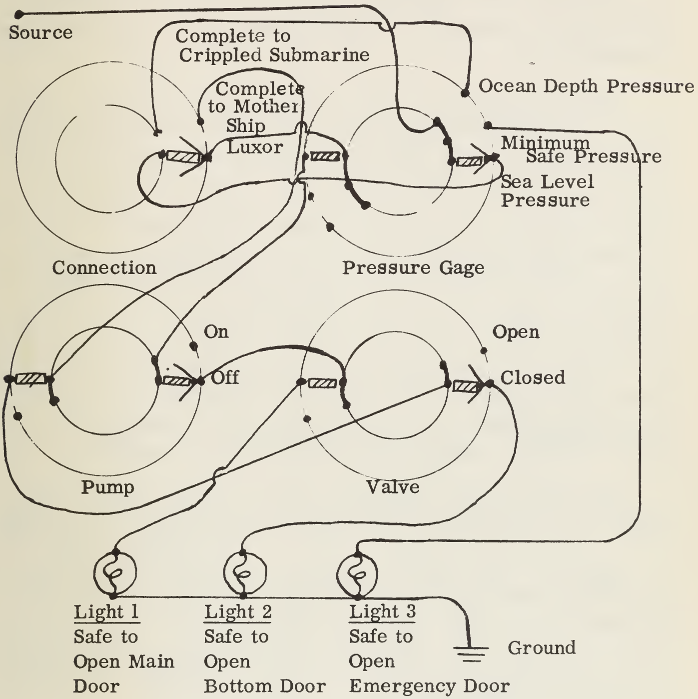


Figure 20

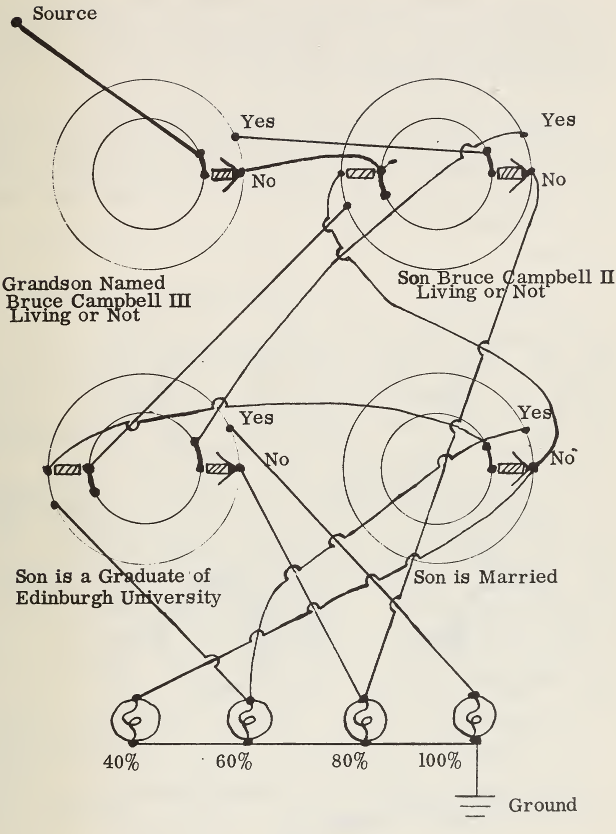
8. Bruce Campbell's Will

Problem: Bruce Campbell, a relative of the old Scotchman Douglas Macdonald, was rather impressed with his kinsman's will, and decided to model his own will somewhat after it. This was Bruce Campbell's will:

If at my death my son, Bruce Campbell II, is not living, and if no son of his and grandson of mine bearing the name Bruce Campbell III, is then living, then 40% of my estate will be paid to the heirs of my son. If my son is living at my death, and is not a graduate of Edinburgh University and is not married, and has no son named Bruce Campbell III, then 40% of my estate will be paid to my son. If my son is living, but is a graduate of Edinburgh University or is married, but has no son named Bruce Campbell III, then 60% of my estate will be paid to my son. If my son is living and has a son named Bruce Campbell III, then my son will get all of my estate if he is a graduate of Edinburgh University but only 80% of my estate if he is not a graduate. If my son is not living but if he had a son named Bruce Campbell III who is living at my death, then 80% of my estate will be paid to Bruce Campbell III or his legal guardian. Any balance of my estate will be paid to the Gaelic Home for the Aged and Indigent.

How much of Bruce Campbell's estate is paid to his son or his son's heirs? What is a circuit which will show quickly what is paid?

Solution: There will be four switches each with two positions: Son Living or Not; Son a Graduate or Not; Son Married or Not; and Grandson Named Bruce Campbell III Living or Not. There will be four output lights: 40%, 60%, 80%, and 100% showing the proportion of Bruce Campbell's estate payable to Bruce Campbell II or his heirs. Following is the circuit:



Source
Yes
No
Yes
No
Grandson Named Bruce Campbell III Living or Not
Son Bruce Campbell II Living or Not
Yes
No
Yes
No
Son is a Graduate of Edinburgh University
Son is Married
40%
60%
80%
100%
Ground

Figure 21

9. The Lock With 65,000 Combinations

Problem: · Make a combination lock which will become "unlocked" only when each one of four switches is set at a particular one of the sixteen letters A to P. For example, choose as the first combination for the lock the combination G J C P.

Solution: There will be four switches each with one deck and sixteen positions. The switch names will be "First Letter, Second Letter, Third Letter, Fourth Letter." The sixteen positions will be the letters A to P inclusive. There will be one output light, "Unlocked." Following is the circuit:

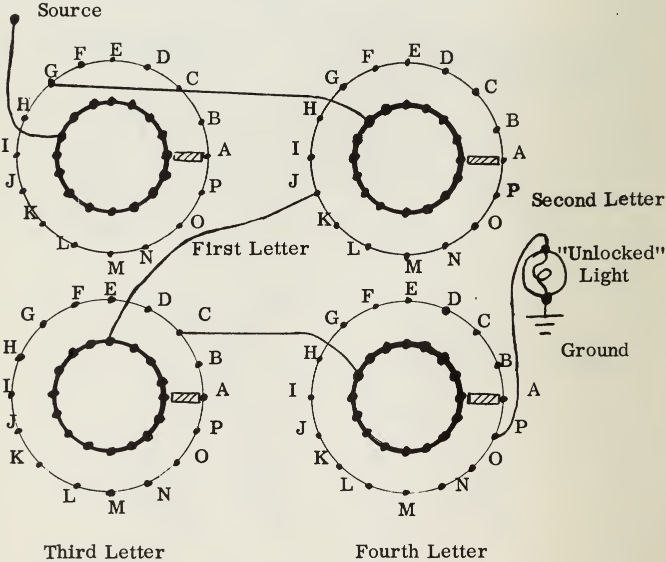


Figure 22

Notes: 1. Clearly, any other four-letter combination (with letters not beyond P) can be easily and quickly set on the switches by changing one of the two connections of each one of four wires. 2. The actual number of the possible combinations is 16 times 16 times 16 times 16, or 65,536.

10. Sammy Buckley's Machine for Adding Dozens

Problem: Sammy Buckley is having trouble remembering the results of adding dozens, such as 36 and 48. So he decides to make himself a machine for checking the results. One switch is the 1st Number to be Added, which may be positioned at 24, 36, 48, or 60. The second switch is the 2nd Number to be Added, which may be positioned at any one of the same numbers. The third switch is the Sum, which may be positioned at any of the numbers 48, 60, 72, 84 96, 108, 120. There is one output light which shines only when the answer is correct.

What should the circuit be?

Solution: Following is the circuit.

Note. In this case, to simplify the wiring between the second switch and the third switch, each wire leaving the second switch is marked with a "tag" telling to what terminal it goes on the third switch. This method saves cluttering up the circuit diagram with very many lines.

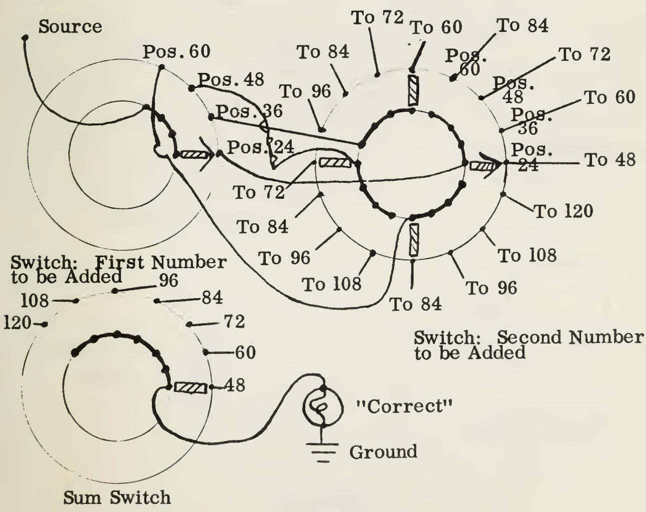


Figure 23

11. Johnny Greer's Machine for Checking Multiplication

Problem: Johnny Greer has trouble remembering the six, seven, eight, and nine times multiplication tables. So he decides to make himself a machine for checking the results. One switch, the Multiplicand, may be set at 6, 7, 8, or 9. The second switch, the Multiplier, may be set at 6, 7, 8 or 9. The third switch, the Product, may be set at any of the ten numbers 36, 42, 48, 49, 54, 56, 63, 64, 72 and 81. There is one output light which shines when the answer is correct.

What should the circuit be?

Solution: Following is the circuit:

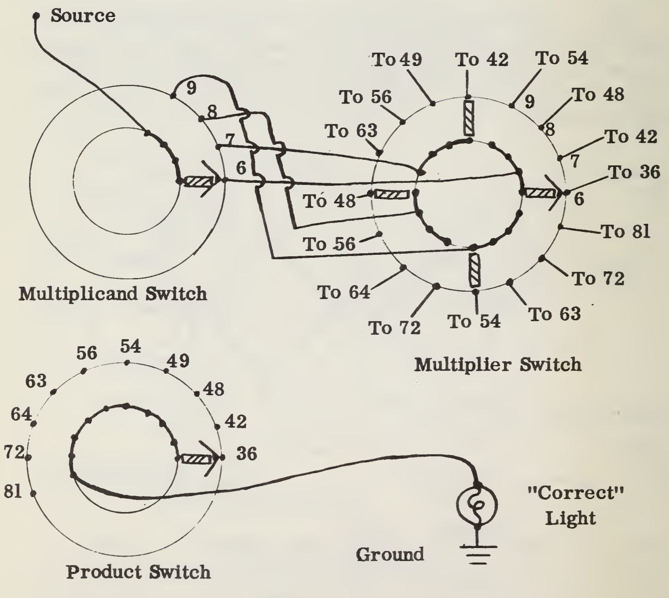


Figure 24

12. The Game of Black Match

Problem: In the game of Black Match, two players start with 22, 23, 24, or 25 matches, one of which is black. Either player may take 1, 2, 3, or 4 matches, when it is his turn, and he must take at least one match. The object of each player is to compel the other player to take the Black Match, the last match.

For example, here is a typical game, begun with 23 matches. The machine has the first move, and takes 2 matches. The player now takes one match. The machine takes 4 matches. The player takes 3 matches. The machine takes 2 matches. The player takes 2 matches. The machine takes 3 matches. There are now left 6 matches. The player takes 4 matches; the machine then takes one match; and the player is left with the last match, the Black Match, which he has to take, and loses.

Set up this game in a machine so that a human player can play the game with the machine; the machine is to have the first move, and the machine is to win all the time.

Solution: There will be three switches. The first switch is the Starting Number Switch, which has four positions 22, 23, 24, and 25 according to the number of matches with which the game is started. The second switch is the Machine's First Move Switch, with two positions: First Move, and Not the First Move. The third switch is the Player's Current Move Switch. The four output lights show, after each move by the human player, the number of matches 1, 2, 3, or 4 that the machine takes at its next move.

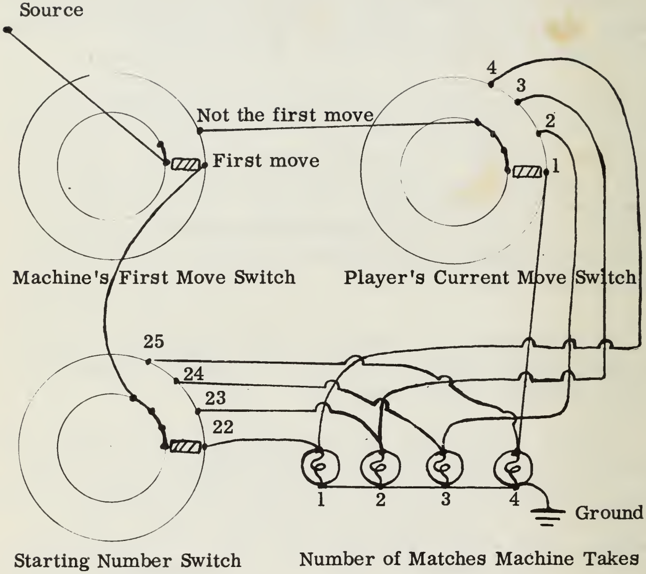

Source
Not the first move
First move
4
3
2
1
Machine's First Move Switch
Player's Current Move Switch
25
24
23
22
1
2
3
4
Ground
Starting Number Switch
Number of Matches Machine Takes

Figure 25

13. James McCarty's Logic

Problem: James McCarty, Prime Minister of Adventularia, in his public speeches reasons as follows:

> All Theodosians attack me.
> General Valorous attacks me.
> Therefore, General Valorous is a Theodosian.

A professor in one of the colleges of Adventularia constructs a machine for handling this and similar kinds of reasoning, a machine called a syllogism machine.

How should it be designed?

Solution: A syllogism machine that will handle this kind of reasoning is as shown in Figure 26. In McCarty's argument, the a's are Theodosians, the b's are those who attack McCarty, and the c's are General Valorous all by himself.

1st Premise (No Switch Required): All a's are b's

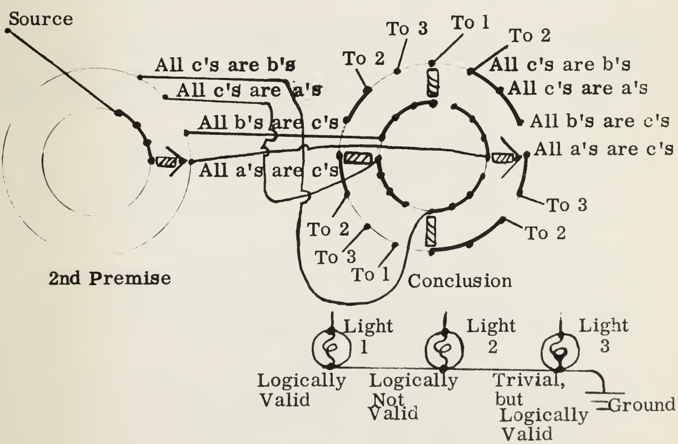


Figure 26

Part II: Materials in the Tyniac Kit, and Explanation of Them

With the Tyniac Electric Brain Construction Kit anyone can put together the machines of the types described in Part I (and many more besides), so that they will perform operations of reasoning and computing.

The kit is harmless. It runs on one flashlight battery. Wires are connected by fastening them to the same nut and bolt and tightening the connection by gripping them between two bolts. No heat or soldering iron is required. DO NOT CONNECT this kit or any part of it to any home or industrial electrical power outlet; you are likely to destroy the material, and you may hurt yourself.

The kit is simple, but nevertheless it takes effort and work to put the material together to make a functioning electric brain. We urge you to take your time. If necessary, read the instructions several times. If the instructions are still not clear, read ahead and then return.

1. Parts List. In the following table appears a list of the parts contained in the kit. (Figures over 20 are approximate.)

TABLE OF PARTS

No.	Item	See Paragraph
1	Coil of 25 feet of insulated wire	2
1	Battery, dry cell, flashlight, 1 1/2 volts	3
1	Battery clamp	4
4	Bulbs, flashlight, 1 1/2 volts	5
4	Sockets for flashlight bulbs	6
60	Short bolts, 6/32, 1/2 inch long	7
140	Hexagonal nuts, 6/32, 1/4 inch diameter	7
1	Spintite blade	8
1	Panel, masonite, punched	9
4	Multiple Switch Discs, circular, masonite, punched	10, 13
14	Long bolts, 6/32, 7/8 inch, for center pivot, etc.	10
16	Washers, hard	10
4	Washers, sponge rubber	10

No.	Item	See Paragraph
8	Jumpers, metal, brass	11
36	Wipers, phosphor bronze	12
1	Manual	-
1	Set of Labels	15
1	Set of Templates	16

Each of these items will now be described.

2. Wire. The kit provides about 30 feet of wire covered with insulation. This is like the wire which you will find connecting a lamp to a wall plug, or a telephone to the telephone box, but adapted for handling much smaller currents and voltages. Instead of two wires wound together, here is one wire only. In the wiring that you will need to do, your two wires will be taken care of when you make for yourself a complete circuit, running from one end of the battery around some kind of loop to the other end of the battery.

Your wire will need to be cut apart with a cutting pliers into lengths. A convenient length for most of the wire to be cut into is 14 inches, but some pieces can be shorter, about 8 inches long.

About three quarters of an inch of the insulation will need to be trimmed off at each end of each piece. You can trim this off neatly with a dull knife; you should try to avoid cutting or nicking the wire since this will shorten the length of time it will last.

A small amount of the wire should be stripped of insulation and cut into pieces 1 or 2 inches long. These pieces of bare wire will be used for making transfer contacts on the multiple switches, as will be explained later.

3. Battery. This is an ordinary flashlight battery, of about one and a half volts. A volt is a unit of electric push, or electric pressure, or electric potential. All these terms mean the same thing.

You can think of a battery as a pump, which is able to push electrons, or little marbles of electricity, away from the plus end of the battery and towards the minus end of the battery, waiting for some kind of circuit at the minus end so that the electrons can flow around the circuit back to the plus end of the battery. A flow of electrons is an electric current.

The filament in the bulb through which the electrons flow provides a resistance or restriction or narrowness for the flow of electrons, so narrow in fact that it heats up and glows with friction as the electrons go through it.

If at some time your battery will not light a bulb, or will only make it glow feebly with a dim orange light, then your battery has run down, and should be replaced.

4. Battery Clamp. This consists of a metal clip that is fastened with nuts and bolts into the panel and which will grip your battery and hold it. You then can fasten connections to the battery clamp and yet snap out your battery when it is weak and snap in another stronger battery in place of it when you need to.

5. Bulbs. You have four small flashlight bulbs in the kit. They will glow from a single flashlight battery. In order to make them light, you have to run one wire from the bottom metal plate of the battery to the side of the bulb, and another wire from the top of the flashlight battery to the center of the base of the bulb. Your connections must be clean, not oily, or corroded.

Examine your bulbs closely from time to time and make sure that the filament, the little slender wire that you can see inside the glass bulb, is all in one piece. If it is broken, the bulb is spoiled.

6. Sockets. You have four sockets for flashlight bulbs. The sockets may be fastened to the panel. They are for holding the light bulbs, so that they can be screwed in and out of their sockets.

7. Nuts and Bolts. For fastenings, connections, and terminals, here and there all over the machine,you have a supply of bolts and a supply of nuts. The nuts and bolts are of cadmium-plated steel, and give good electrical connections. A bolt is inserted through any hole; then a nut is screwed down tight on the bolt holding it in position; then the connecting wire is wound around the end of the bolt coming through; then a second nut is screwed down tight on the wire and the bolt so as to give a tight electrical contact.

8. Spintite Blade. In order to fasten your nuts and bolts easily, you will need a small screwdriver, which will fit in the slot of the bolt and enable it to be turned. You also have in the kit a small piece of hexagonal tubing (a spintite blade) which fits over and grips the

hexagonal bolt and enables it to be spun quickly down the shaft of the bolt, and tightened, with the screwdriver holding the bolt.

9. Panel. In order to assemble your materials together into a machine, you have a rectangular panel consisting of masonite (thin pressed fiberboard). It contains holes for nuts and bolts so that the various parts of the set may be mounted together and assembled firmly.

If you examine the panel, you will see two patterns of holes. One pattern (see Figure 2 - 1) consists of 68 holes arranged in several rows through the middle of the panel from end to end.

Figure 2 - 1

In this set of holes, all the hardware of a Tyniac machine is mounted except the "multiple switches", which will be explained in a moment. The second pattern consists of four rosettes of 65 holes in a circular arrangement (see Figure 2 - 2). These are the four "bases" of the multiple switches.

10. Multiple Switches. The remaining material provided in the kit consists of 4 round pieces of masonite, each containing 65 holes in the same circular arrangement (see Figure 2 - 2), and the hardware for assembling them into multiple switches, switches which are able to switch many circuits at the same time. Each of the circular pieces of masonite is about 4 3/8 inches in diameter, is illustrated in Figure 2 - 2, and is called a multiple switch top, or switch disc, or switch dial, or simply a disc.

In the panel each of the exactly similar sets of 65 holes is called a multiple switch base. In an early stage of design, the switch bases were separate pieces of masonite; but then it became evident that mounting of the hardware to make a machine would be better accomplished by having all the switch bases solidly connected together in the panel.

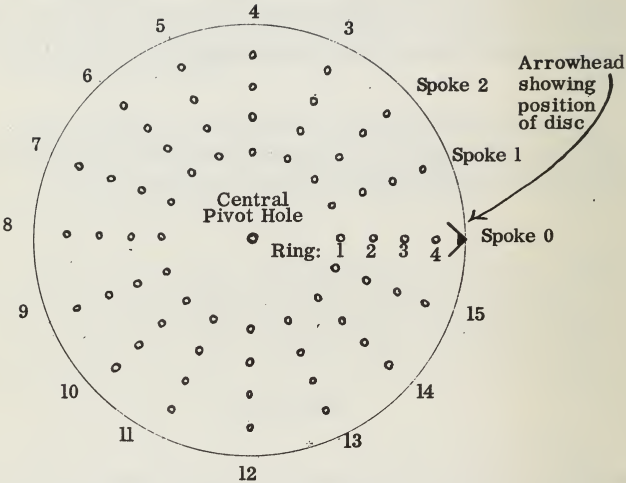


Figure 2 - 2 — Pattern of the holes in the multiple switch (either the "base" in the panel or the "top", which is the disc). Also, the system of naming the holes.

The top of a switch is fastened to the base of a switch by means of a center pivot, consisting of a long bolt, four hard washers, a sponge rubber washer, and a nut; the assembly of the center pivot is shown in Figure 2 - 3.

The holes (except the center hole) in each switch base and switch top are arranged in 4 rings and 16 spokes. The rings are called Ring 1, 2, 3, 4 going outward, and the spokes are called Spoke 0, 1, 2, 3 and so on around, to Spoke 15. The counting starts with the spoke directly to the right, and goes counterclockwise. See Figure 2 - 2.

Each of the holes in the switch base may or may not contain a short bolt, called a terminal, for making connections. The connections are made using two nuts, one for fastening the bolt securely to the switch base, and the second for holding and tightening a wire around the bolt so as to make a good electrical connection with the bolt (see Figure 2 - 4).

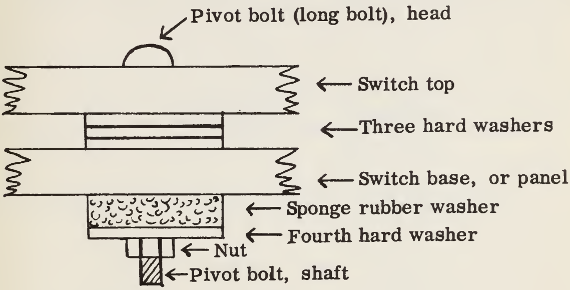


Figure 2 - 3 — Center Pivot Assembly

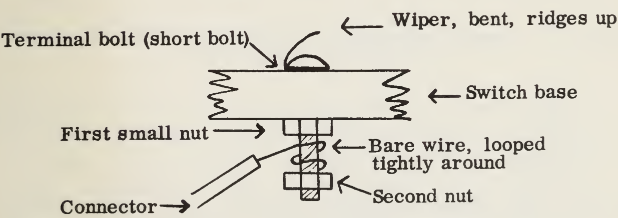


Figure 2 - 4 — Assembly of Wiper, Terminal Bolt, and a Wire Connector

11. Jumpers. Each pair of holes in a switch top, from Ring 1 to Ring 2 or from Ring 3 to Ring 4 (or very rarely from Ring 2 to Ring 3) may or may not contain a jumper, a small piece of brass plated metal with two prongs, as shown in Figure 2 - 5. The two prongs fit into holes in the switch disc and are pressed down, like a clasp or T fastener, as shown in Figure 2 - 6. A jumper serves to make and break electrical contact as the switch is turned.

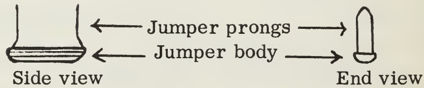


Figure 2 - 5 — Jumper, not mounted

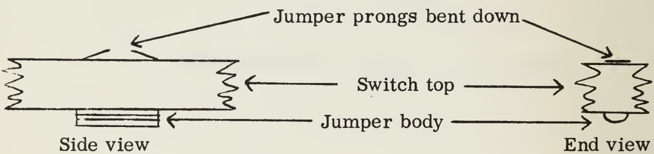


Figure 2 - 6 — Jumper, inserted in two adjacent holes along a spoke

12. Wipers. In between the jumper and the bolt, in the assembled multiple switch, is inserted a wiper, a springy piece of phosphor bronze with a hole and two small ridges. The shape of the wiper unbent, as it comes in the small envelope, is shown in Figure 2 - 7. The purpose of the wiper is to improve the electrical contact between the top of the switch (the disc containing the jumpers) and the bottom of the switch (the panel containing the bolts and nuts for the terminals). Patent is being applied for on these wipers.

The way in which the wiper is assembled is shown in Figure 2 - 8, and is as follows: (1) thread the bolt through the wiper, with its ridges down; (2) fasten the bolt not too tightly to the panel; (3) align the wiper with the spoke (or radius) of the switch; (4) now fasten the bolt tightly; (5) bend the wiper gently upwards and over the bolt, with the ridges up, in such a way that the wiper will slide neatly on the jumper, resting in its valley between the ridges; (6) assemble the multiple switch with (probably three) washers in between the disc and the panel; (7) adjust the amount of bending of the wipers so that they push up and down nicely against the jumpers as the switch turns.

For multiple switches with only two jumpers evenly spaced, or only three jumpers almost evenly spaced, you will not need wipers and should not use them, for such switches will work entirely properly without wipers. In these cases, you will need to make sure that the slots in the heads of the bolts are lined up with the spoke, so that the jumpers themselves will position (or detent) along the spoke right above the bolts. (In assembling a switch without wipers, you need only one or two spacing washers along the center bolt, not three.) For switches with four or more jumpers, you will need wipers, for otherwise the switch is likely to work unreliably.

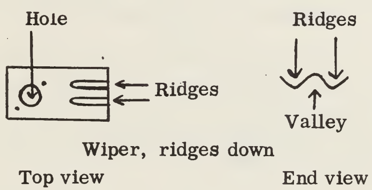


Figure 2-7 —Unbent wiper

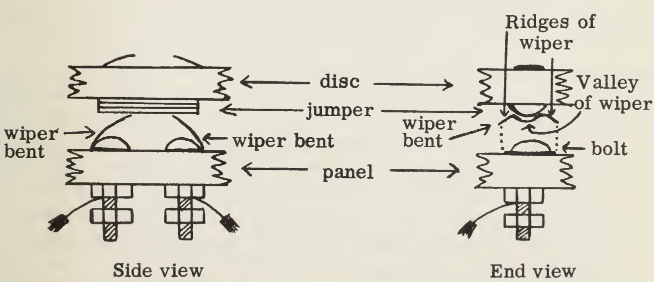


Figure 2-8 — Assembly of wipers

13. Assembly of the Multiple Switches. Before any of the multiple switches can function, however, it must first be assembled.

Into the base we have to insert a number of nuts and bolts to hold wire connections and wipers. Just where these are inserted depends on the type of switch we desire to construct, two-position, or four-position, or some other type.

Into the top of the switch we must insert a number of jumpers in order to make and break contacts. Each jumper is inserted along a spoke between one ring and the next. Just where the jumpers are inserted again depends on the type of switch we desire to construct.

In order for the switch to stay in a position to which it is turned, the body of the jumper must line up with the valleys between the ridges on the wipers, and these valleys must be in line with the spoke; then the jumpers will have a tendency to catch in the valleys, as they should, to hold the switch in position (see Figure 2 - 8, end view).

Note that in some drawings of the multiple switches, the rings and spokes are drawn as thin lines; these lines are not actually drawn on the switch discs nor the switch bases; nor do they represent electrical lines connecting terminals; instead they are drawn to make the arrangement clearer.

Now suppose we wanted to assemble a switch which would have any one of three positions A, B, and C, and which would be capable of switching every one of six different circuits. A way in which that switch could be assembled is shown in Figure 2 - 9, in which both the top and the bottom of the switch are drawn over each other. Six jumpers are inserted in the top of the switch, shown as ▨ in Figure 2 - 9. It is important that jumpers ordinarily be inserted in pairs opposite each other, for reasons of mechanical balancing, so that the top of the switch will stay parallel to the bottom of the switch. A total of six times six or 36 nuts and bolts are inserted in the bottom of the switch, in the spots marked ● in Figure 2 - 9. They are in groups of six called decks (also called poles, or levels); these decks are electrically independent, and they enable us to switch 6 different circuits. In the base, the bolts belonging in any one deck in Ring 1 or Ring 3 are connected together by wire, as shown by the heavy line; they may be connected with one of the short wires 1-1/2 inches long. They are made electrically common; in other words, they are commoned. Together they constitute what is called a transfer contact.

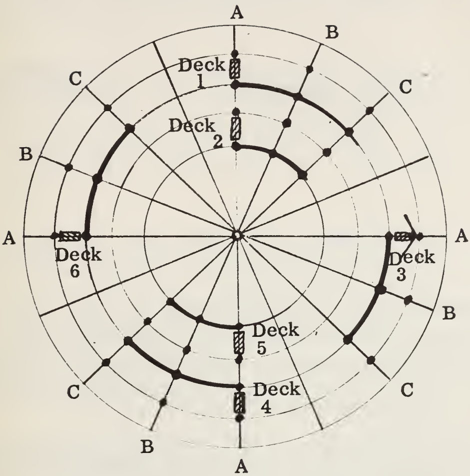


Figure 2 - 9 — Three position switch, six decks (or poles or levels)

Let us now consider the layout of the spokes and the rings and the 64 holes which they produce. We can see that we can assemble a switch in a number of different ways. This is the advantage of the design of the multiple switch we have chosen (on which patent is being applied for). Here are the types of switches that can be made with these parts:

Number of Positions	Maximum Number of Decks
2	16
3	10
4	8
5	6
6 to 8	4
9 to 16	2

If nuts and bolts did not cost anything, we could insert 64 nuts and bolts into the base of each switch and leave them there — ready for use in any switch. Actually, because the kit has a limited supply, it may be necessary to move nuts and bolts from one switch to another in order to make the different machines we want.

In the case of jumpers and wipers, we shall fairly often have to move them to different places, in order to make different switches for different machines.

14. Additional Material. You may obtain additional or replacement material for this kit by buying it at a local store, or by writing to us. Obviously, if your battery runs down, or if you want more wire, or if you want more nuts and bolts, the easy thing to do is to buy them in your neighborhood. But for more switch discs or more jumpers, etc., you will probably need to write us. Prices for these items are listed on a price list enclosed with the kit or obtainable on request.

15. Set of Labels. Included in the kit is a set of labels, which can be cut out and mounted with cellophane tape or rubber cement on the switches, positions, and lights of the various machines so that they will be adequately labeled to show what they are doing.

16. Set of Templates. In work with electrical circuits we need to lay out beforehand what we are going to do. We need to design on paper how we are to connect the different pieces of material. For this purpose, we use circuit diagrams, wiring lists, and templates.

A circuit diagram, as mentioned before, shows the scheme of connection of batteries, switches, lights, etc., in order to make the circuit. In a circuit diagram we pay little attention to the actual physical location of the material; we just show a diagram of its arrangement.

In a wiring list, we name the terminals, by words or letters or numbers, and we state, for every part of the circuit, what terminal is connected to what terminal. In a wiring list again we pay no attention to the actual spatial locations of the terminals. For example, if without drawing the wire, we write "to...", we are using the principle of a wiring list.

In a template, the case is different; we show the actual wiring and the approximate relative spatial location of the different pieces of material used in the circuit. In other words, we draw an accurate geographical map of where the terminals are, and then we indicate the wiring either by drawing lines for the connections or by writing notes showing the connections. For the experiments in this manual, templates on the actual scale are included in the kit.

In each experiment in the Tyniac kit, the important part of the wiring is on the rear side of the panel. Accordingly, each template shows a full scale picture of the rear of the panel. It is therefore a mirror image: what is on the right in the drawing in the manual is on the left in the template; and vice versa. Of course, some of the information appearing on the template belongs on the front side of the board: the labels of the switches, their positions, and the lights; and the location of the jumpers in the discs. If one pays careful attention to the two drawings, one in the manual and one on the template, the way the hardware and labels actually are arranged should become quite clear.

17. Trouble-Shooting. After you have wired up a machine, and start to play with it, you are likely to find that it does not work entirely correctly. All engineers worth their salt who do any kind of significant work with electrical circuits discover when they first assemble a new piece of equipment that it does not work properly. Finding out the reasons why and removing the causes of malfunctioning, the process known as trouble-shooting, therefore is an important and essential part of making any piece of equipment start working and stay working; and good trouble-shooting is the mark of a good engineer.

In order to trouble-shoot, it is helpful to have a systematic and logical checklist of questions to be answered one after another, and in addition testing apparatus which will tell whether a part of a circuit actually does what it is supposed to do. In order to test machines made with the Tyniac kit, the essential piece of testing apparatus is what is called a continuity tester. A simple form of such a tester is a flashlight battery, a lamp, and two wires with bare ends, connected as shown in Figure 2-10. Then, when you take the ends of the two wires, and touch a certain pair of terminals, if you obtain a light, you know that that part of the circuit is connected, is continuous; while if you obtain no light, you know that that part of the circuit is not connected, is isolated. Then, you compare what your tester shows to be actual fact with what you are supposed to have according to the circuit diagram, and you have either verified the correctness of that part of the circuit, or located some trouble.

Here are some checklist questions which make a beginning at trouble-shooting:

(1) Does each wire actually make contact with each terminal to which it is fastened?
(2) Does each jumper actually make contact with the wiper at each terminal, as its switch turns?
(3) Does each lamp really light?
(4) Is there electricity in the battery?
(5) Has any wire broken inside its insulation?
(6) Is there a mistake or typographic error in the diagram or the instructions? (This question must always be asked, because no author or printer is infallible.)
(7) Does each wire go where it should?
(8) Has each label been fastened on in its right place?
(9) Is each jumper in its right place?
(10) Is each terminal in its right place?

Figure 2-10 — Continuity Tester

If you can locate and remove trouble skillfully, you can be well satisfied with what you have learned.

Part III: Introduction to Boolean Algebra for Circuits and Switching

In Part I above, we asked the question, "How are circuits like those in the experiments designed?"; and we said that one of the best approaches to the design of the circuits in the experiments, which are examples of what are called switching circuits, is a new kind of algebra called Boolean algebra. What is Boolean algebra?

Briefly, Boolean algebra is the algebra of "AND", "OR", "NOT", and conditions, and the technique for manipulating them using symbols and methods of calculation. Ordinary elementary algebra includes the ideas expressed in the words PLUS, TIMES, MINUS, and DIVIDED BY, and deals with numbers. In a similar way, Boolean algebra includes the ideas expressed in the words AND, OR, NOT, and some more very common words and expressions of language and logic, and deals with conditions, classes, and statements. Boolean algebra has important applications in the design of any circuits that make use of elements that can be either on or off, lighted or not lighted, conducting or not conducting — any elements that have two mutually exclusive states or conditions.

Just what are the definitions and rules of Boolean algebra. Why is it called "Boolean"? And how does it apply to the design of circuits for the experiments in this manual?

Boolean algebra was named after George Boole, a great English mathematician who lived 1815-1864. His algebra includes not only the ideas expressed by AND, OR NOT, but also the ideas in the words: EXCEPT, UNLESS, IF... THEN, IF AND ONLY IF, OR ELSE, BUT, EITHER... OR, NEITHER... NOR, BOTH... AND, NOT BOTH, ALL, NONE, IS (in several of its half dozen meanings), LIES IN, IMPLIES, and some more words, excluding however words dealing with numerical ideas like MOST, MORE THAN, HALF.

Boole's great discovery, explained in his book "The Laws of Thought", published 1954, was that one actually could make an algebra out of the words AND, OR, NOT as connectives of classes and statements, in a way very similar to ordinary algebra. Boole's original form of the algebra did however contain some inconvenient and partially incorrect ideas; and his algebra was subsequently greatly improved by other mathematicians, particularly Ernst Schröder.

But no one suspected that Boolean algebra could be applied to switching circuits until Claude Shannon, who is now a well-known mathematician at Bell Telephone Laboratories, pointed out in his thesis for the Master's Degree at Massachusetts Institute of Technology in 1938, that Boolean algebra could usefully apply to switching and relay circuits. This is the application we are interested in here, and which we shall now explain.

Use of Letters. In Boolean algebra applied to switching, the same letters are used, a, b, c,.... x, y,.... as are used in ordinary algebra. But now they stand not for numbers (which we may or may not know), but for the states or conditions of on-off circuit elements. (which may be "on" or "off", but we do not know which). For example, in Figure 3 -1, a stands for the "on-ness" or "off-ness", that is, the state, of the on-off switch labeled A, and d stands for the "on-ness" or "off-ness" of the light labeled D. (Although the switch has been drawn in the off position, because of the location of the jumper, this is a regular convention, and does not necessarily mean that the Switch A is off.)

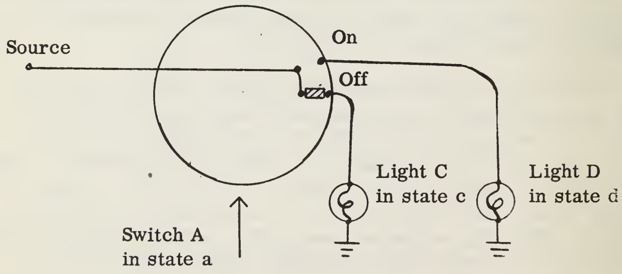


Figure 3 - 1 — A switch and two lights

One and Zero. In ordinary algebra the letters a, b, c, ... stand for or represent numbers. For example, a could have the values 7, or -3, or 2.67, or -12 1/7 and so forth, for an unlimited collection of numbers. If d equals a, then whatever value a has, d has the same value. But in Boolean algebra, it is convenient to consider that the variables have only the value 1 corresponding with the state ON, and the value 0 corresponding with the state OFF. When we say d equals a, we mean that whenever a equals 1, d equals 1, and whenever a equals 0, d equals 0. This is of course a much simpler state of affairs than in ordinary algebra; and it is surprising how useful this simpler algebra of 1 and 0 can still be.

As we look at Figure 3-1, we can see that Light D is on if and only if Switch A is on, and Light C is on if and only if Switch A is off. We express this by saying that the state of D equals the state of A, that is to say, that d equals a.

The Operator NOT. Let us look now at the Light C in Figure 3-1. It is on if and only if the switch is off, and it is off if and only if the switch is on. We can summarize this state of affairs in the following table:

a	c
0	1
1	0

In Boolean algebra, we say that the state c equals the negative of the state a, and we write c = NOT-a = a', which is read a prime or not — a. If we should look for a formula of ordinary algebra which would give the same result, we could say that c = 1 — a; other formulas could be used but this is the simplest.

The Operator OR. a OR b is represented by the circuit shown in Figure 3-2, a parallel circuit.

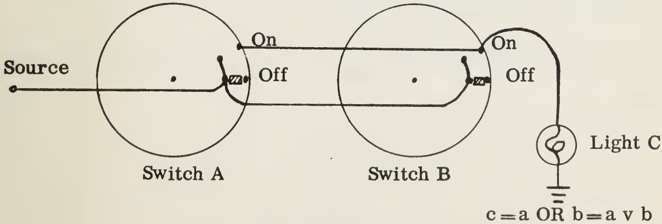


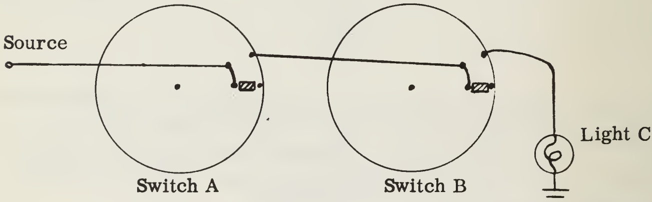
Figure 3-2

Looking at Figure 3 - 2, we can see that the way in which the circuit is wired provides that Light C will be on if Switch A is on or if Switch B is on or if both are on. In other words the state c of the light is equal to a or b, where the following table defines OR for every possible case:

a	b	c
0	0	0
0	1	1
1	0	1
1	1	1

In Boolean algebra, we write $c = a \vee b$, which is read a vee b or a or b. If we should look for a formula of ordinary algebra which would give the same result, we could say that $c = a + b - ab$, a plus b minus the product of a and b; other formulas could be used but this one is the simplest.

The Operator AND. a AND b is represented by the circuit shown in Figure 3 - 3, a series circuit.



$c = a \text{ AND } b = a \cdot b = ab$

Figure 3 - 3

Looking at Figure 3 - 3, we can see that the way in which the circuit is wired provides that Light C will be on if and only if Switch A is on and Switch B is on. In other words the state c of the light is equal to a AND b both, where the following table completely defines AND:

a	b	c
0	0	0
0	1	0
1	0	0
1	1	1

In Boolean algebra, we write $c = a \cdot b$ or $c = ab$, which is read a TIMES b or a AND b or a dot b or ab. This is the same operation as multiplication in ordinary algebra.

Other Connectives and Operators. We can now define EXCEPT. a EXCEPT b is the same as a AND NOT b: $a \cdot b'$. Also, we can now define a OR ELSE b; this is the same as a AND NOT b OR b AND NOT a: $a \cdot b' \vee b \cdot a'$. And we can define many more of the common words of language.

Every now and then we find a case of ambiguity. OR for example is ambiguous. Sometimes it means AND/OR. This is the OR which is the OR of Boolean algebra defined above, and of two switches in parallel. Sometimes OR means OR ELSE. This is the OR we have just defined above as OR ELSE.

A rather full discussion of problems of translating ordinary English into Boolean algebra is contained in two short publications of ours, P 5: "Boolean Algebra and Applications to Insurance" and P 4: " A Summary of Symbolic Logic and its Practical Applications" (both are available from us).

Rules of Boolean Algebra. Some of the more important rules of Boolean algebra are given below with their translations:

$a \vee b = b \vee a$	a OR b is the same as b OR a
$(a \vee b) \vee c = a \vee (b \vee c)$	(a OR b) OR c is the same as a OR (b OR c)
$a (b \vee c) = ab \vee ac$	a AND (b OR c) equals (a AND b) OR (a AND c)
$a \vee bc = (a \vee b)(a \vee c)$	a OR (b AND c) equals (a OR b) AND (a OR c)
$a \vee a = a$	a OR a is the same as a
$aa = a$	a AND a is the same as a
$a \vee 0 = a$	a OR off-ness (zero) is the same as a
$a \cdot 1 = a$	a AND on-ness (one) is the same as a
$a \vee 1 = 1$	a OR on-ness (one) is the same as on-ness (one)
$a \cdot 0 = 0$	a AND off-ness (zero) is the same as off-ness (zero)
$a \vee a' = 1$	a OR NOT-a equals on-ness (one)
$a \cdot a' = 0$	a AND NOT-a equals off-ness (zero)

$(a \vee b)' = a' \cdot b'$	NOT-(a OR b) equals NOT-a AND NOT-b
$(a\, b)' = a' \vee b'$	NOT (BOTH a AND b) equals NOT-a OR NOT-b
$ab \vee ab' = a$	(a AND b) OR (a AND NOT-b) equals a
$(a \vee b)\,(a \vee b') = a$	(a OR b) AND (a OR NOT-b) equals a
$(a')' = a$	NOT-NOT-a is the same as a
$1' = 0$	NOT-on equals off
$0' = 1$	NOT-off equals on

Considerably fuller summaries of Boolean algebra appear in our two publications P 5 and P 4 mentioned above.

A Sample Problem. Let us now consider a sample problem. Suppose we try to design part of the circuit for Experiment 6, The Two Suspicious Husbands at Great North Bay. Suppose we try to turn into a circuit: "They agree that the wife of either one may not go boating alone with the other husband". Then there are two cases for which the danger light should shine, reported in the following table, where ✓ means yes, and ✗ means no.

	In the Boat:			
	George	Harry	Violet	Winifred
(1)	✓	✗	✗	✓
(2)	✗	✓	✓	✗

Let G, H, V, W stand for the states of switches that when they are in their "on" position mean that George, Harry, Violet, Winifred, respectively, are "in the boat". Then, in the Boolean algebra of switching circuits, these cases will be expressed as: $G \cdot H' \cdot V' \cdot W \;\vee\; G' \cdot H \cdot V \cdot W'$. In a completely diagrammed circuit therefore they appear as shown in Figure 3-4. In each line in the circuit, we have shown the "information" or Boolean expression which it contains, as a result of the switches between it and the source of current.

Conclusion. This then is a very brief introduction to Boolean algebra and its application to switching circuits. It is a useful and powerful tool, though not the only one, in the design of switching circuits. And people will doubtless find out and learn more and more interesting and important applications of Boolean algebra as people become more and more accustomed to regarding AND, OR, and NOT as operators for calculating with, much like the operators PLUS, MINUS, TIMES, and DIVIDED BY, yet of course far more frequent in the affairs of men.

For more information about Boolean algebra and its applications, we again refer readers to our publications P 5 and P 4.

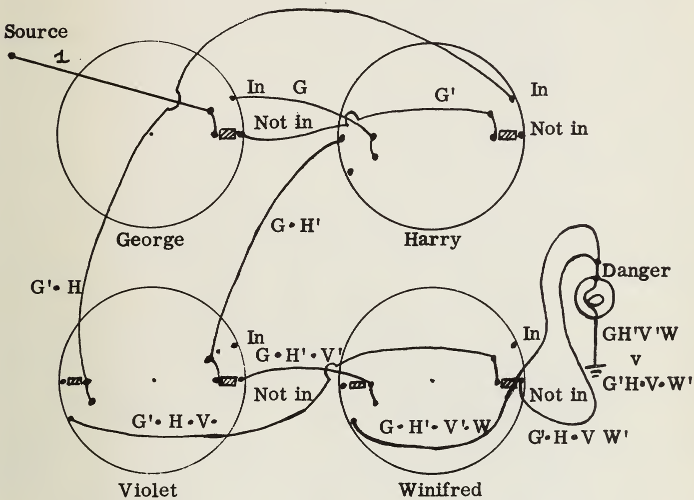


Figure 3 - 4