Variables

Review

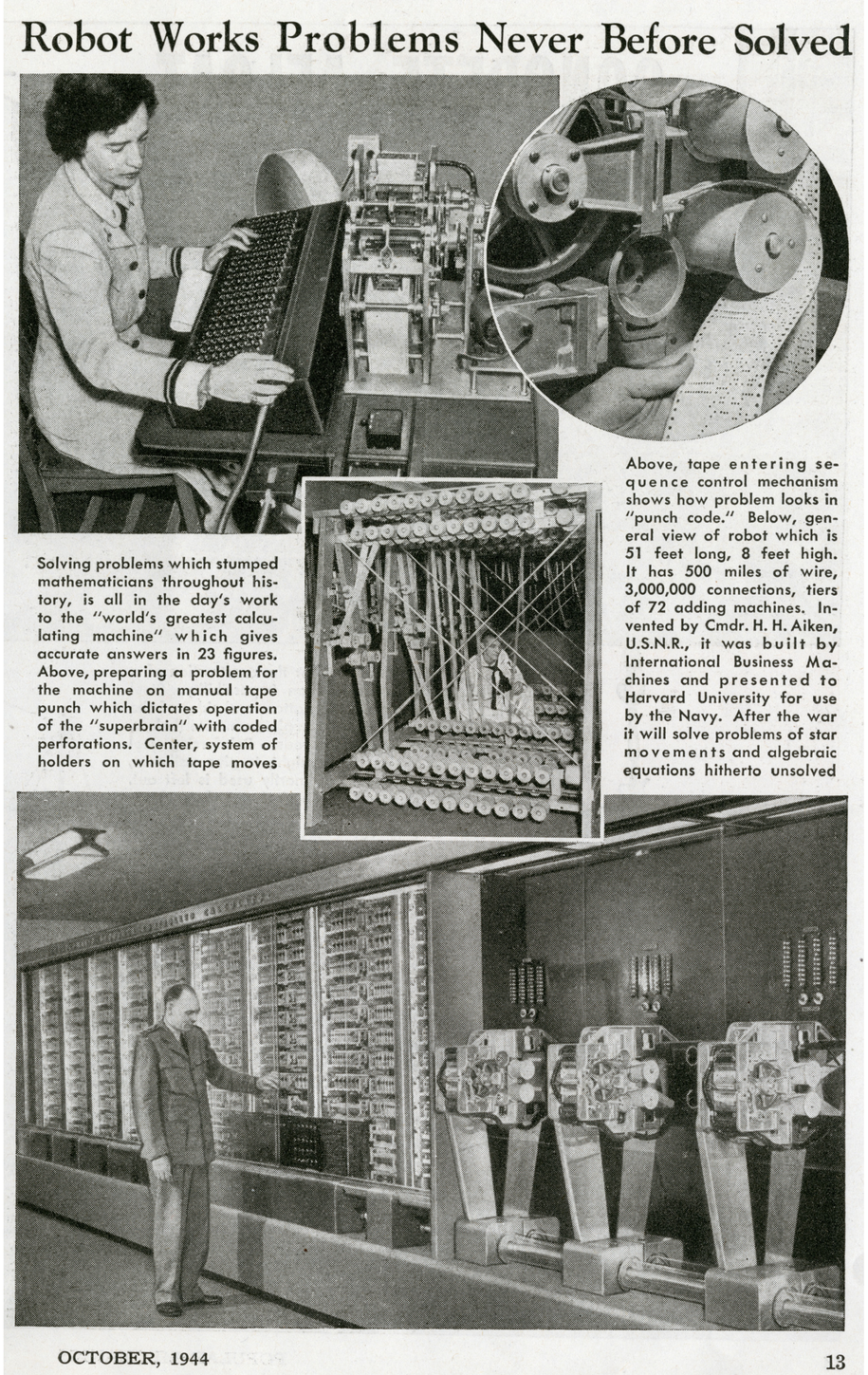
- A variable is a named location in memory.
  - A variable has a type (thereby size) and a location in memory.
- A variable needs to be *declared* before use. Syntax: `type name;`
  - The first assignment to a variable is called *initialization*.
  - A variable contains junk between declaration and initialization.
- An *array* is a *contiguous* block of elements of the *same type*.
  Syntax: `type name[number];`
  - Fixed size
  - Access/modify by index, syntax: `name[index]`. This index is not checked.
- A *string* is a NUL-terminated array of characters.

Relays, Vacuum Tubes, Transistors, and Computation

CS143: lecture 3

Byron Zhong, June 13

IBM Automatic Sequence Controlled Calculator (Harvard Mark I)



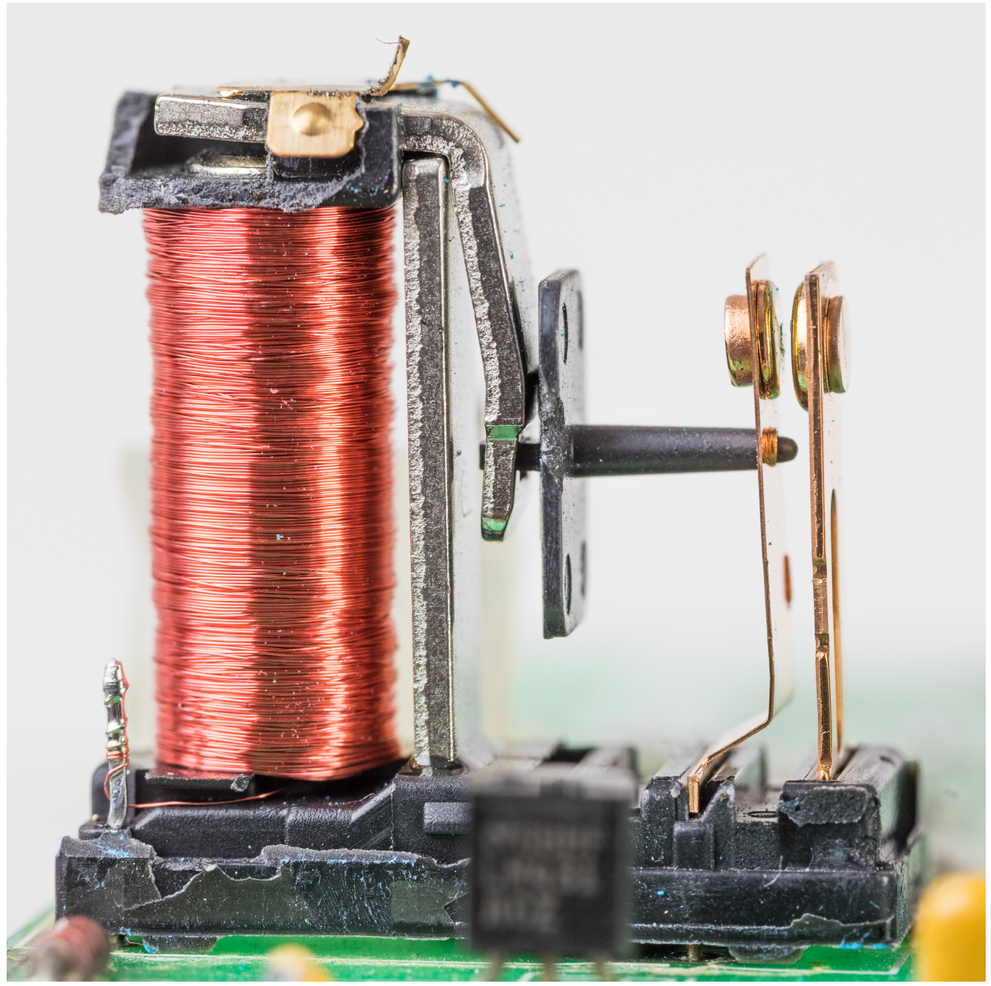
Robot Works Problems Never Before Solved

Solving problems which stumped mathematicians throughout history, is all in the day's work to the "world's greatest calculating machine" which gives accurate answers in 23 figures. Above, preparing a problem for the machine on manual tape punch which dictates operation of the "superbrain" with coded perforations. Center, system of holders on which tape moves

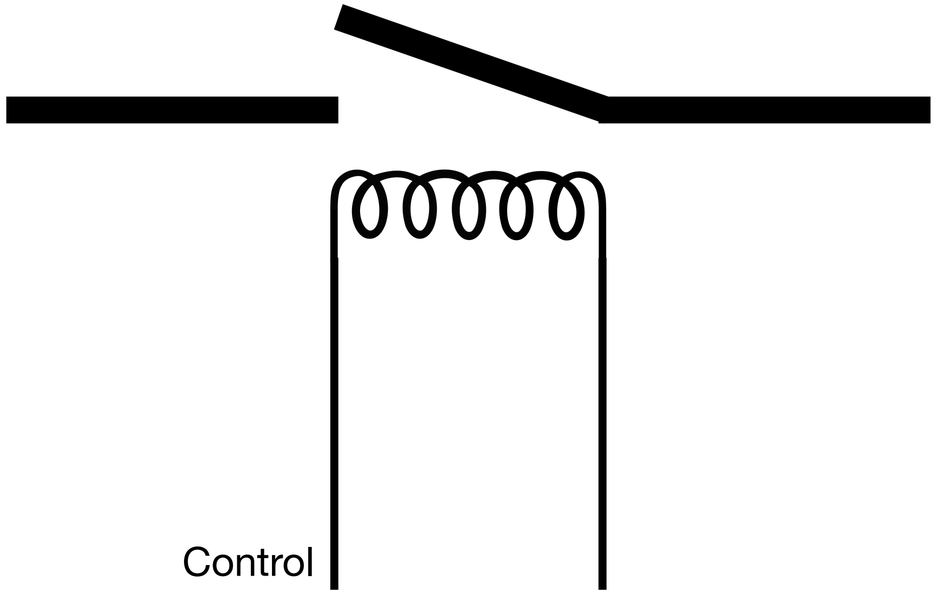
Above, tape entering sequence control mechanism shows how problem looks in "punch code." Below, general view of robot which is 51 feet long, 8 feet high. It has 500 miles of wire, 3,000,000 connections, tiers of 72 adding machines. Invented by Cmdr. H. H. Aiken, U.S.N.R., it was built by International Business Machines and presented to Harvard University for use by the Navy. After the war it will solve problems of star movements and algebraic equations hitherto unsolved

- Designed by Howard H. Aiken in 1937
- Built by IBM and delivered to Harvard in 1944, in operation until 1959
- 765,000 electromechanical components
- 3 million connections
- 500 miles of wire
- Does numerical calculations
- "Computer" used to be a job title

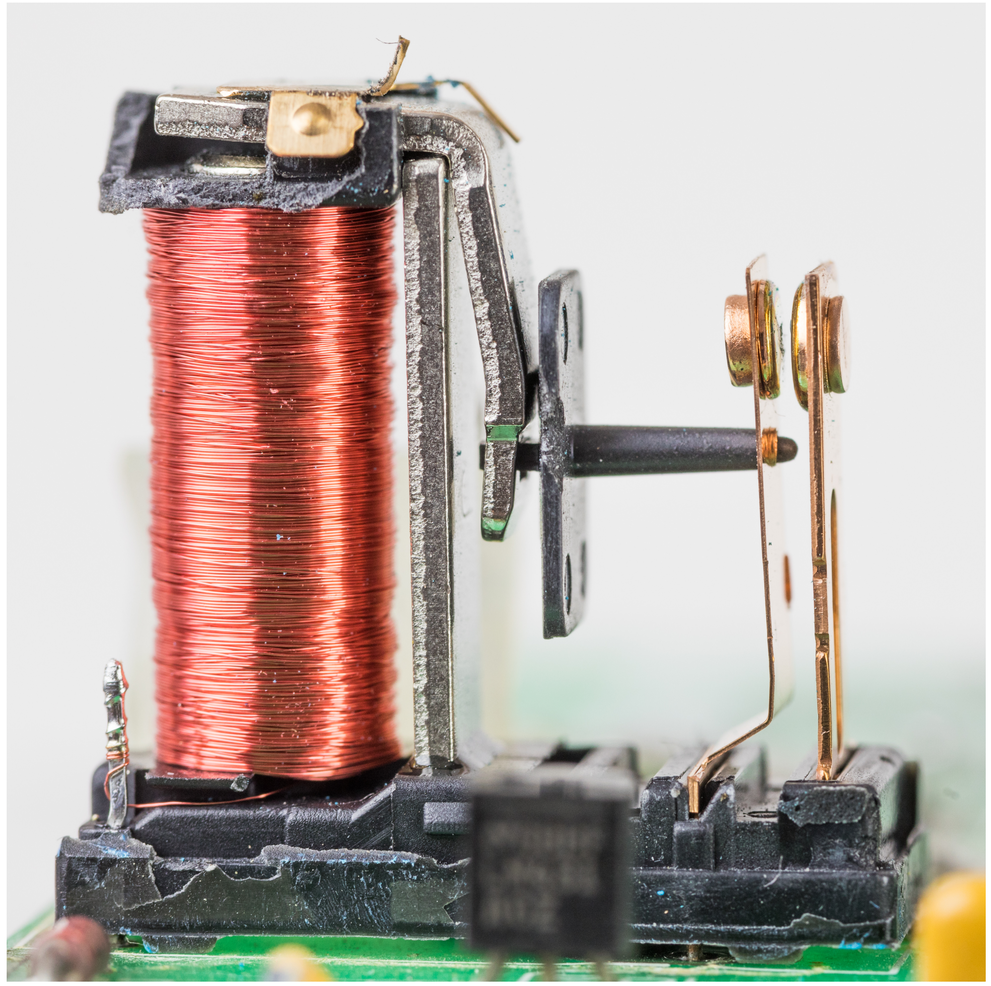
Relay



a relay switch



Relay



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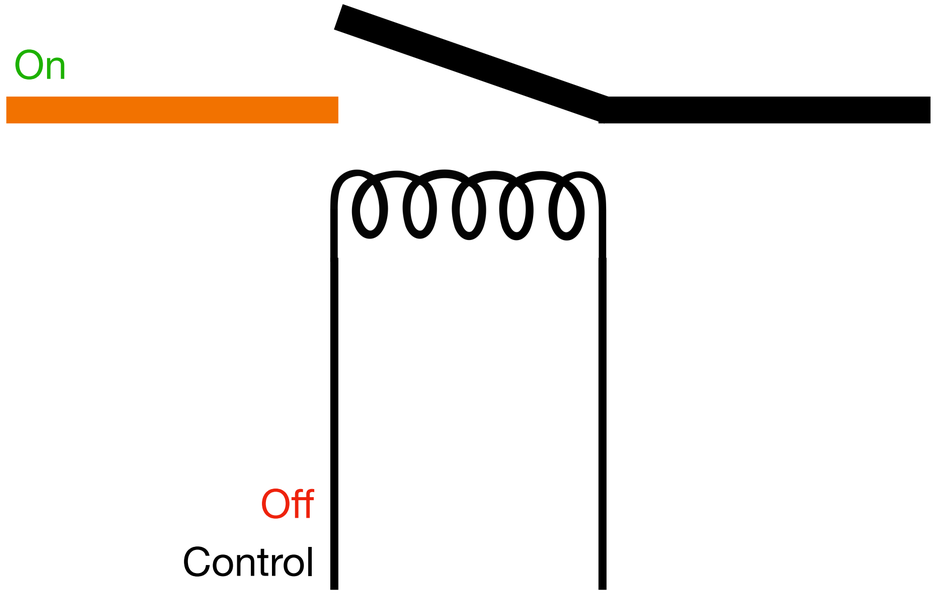
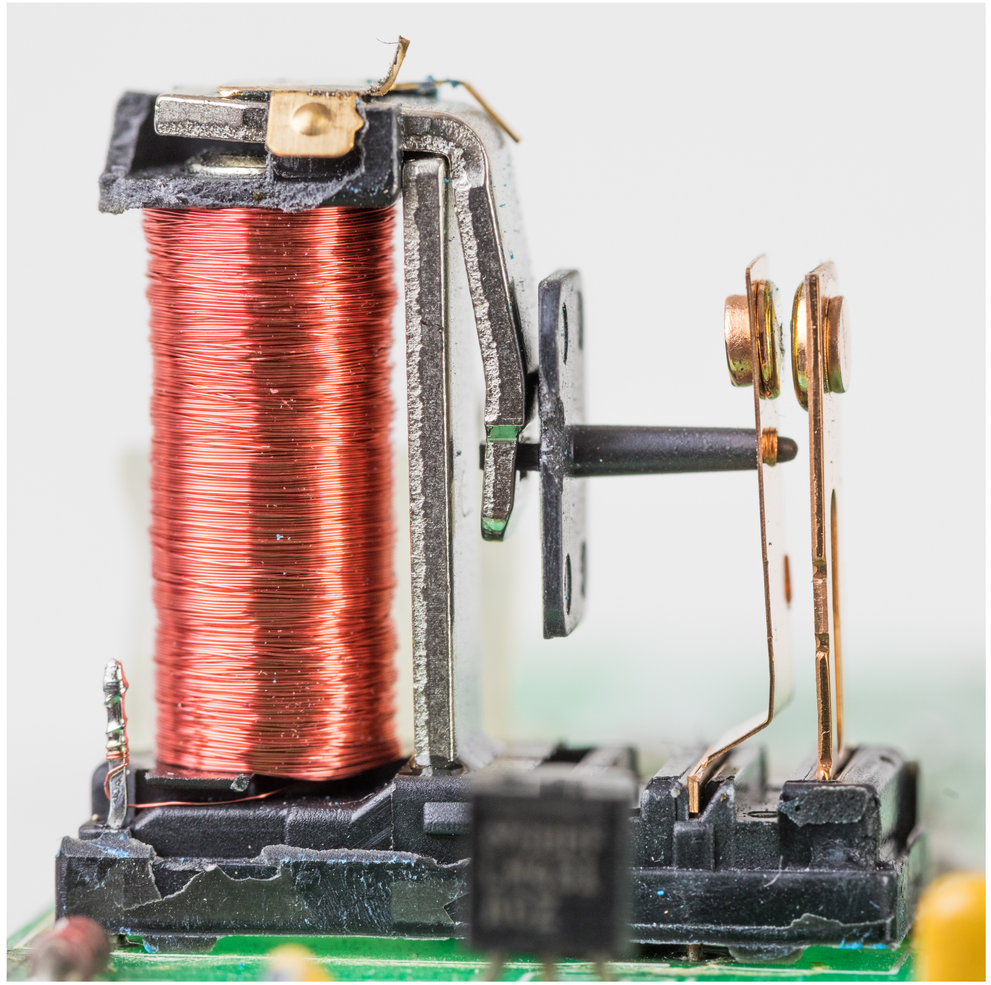
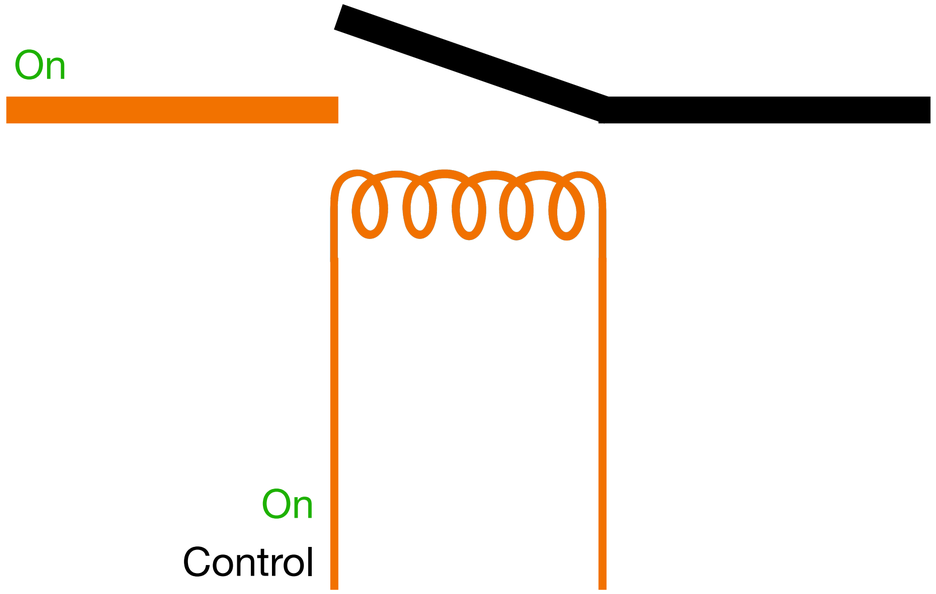


Relay



a relay switch



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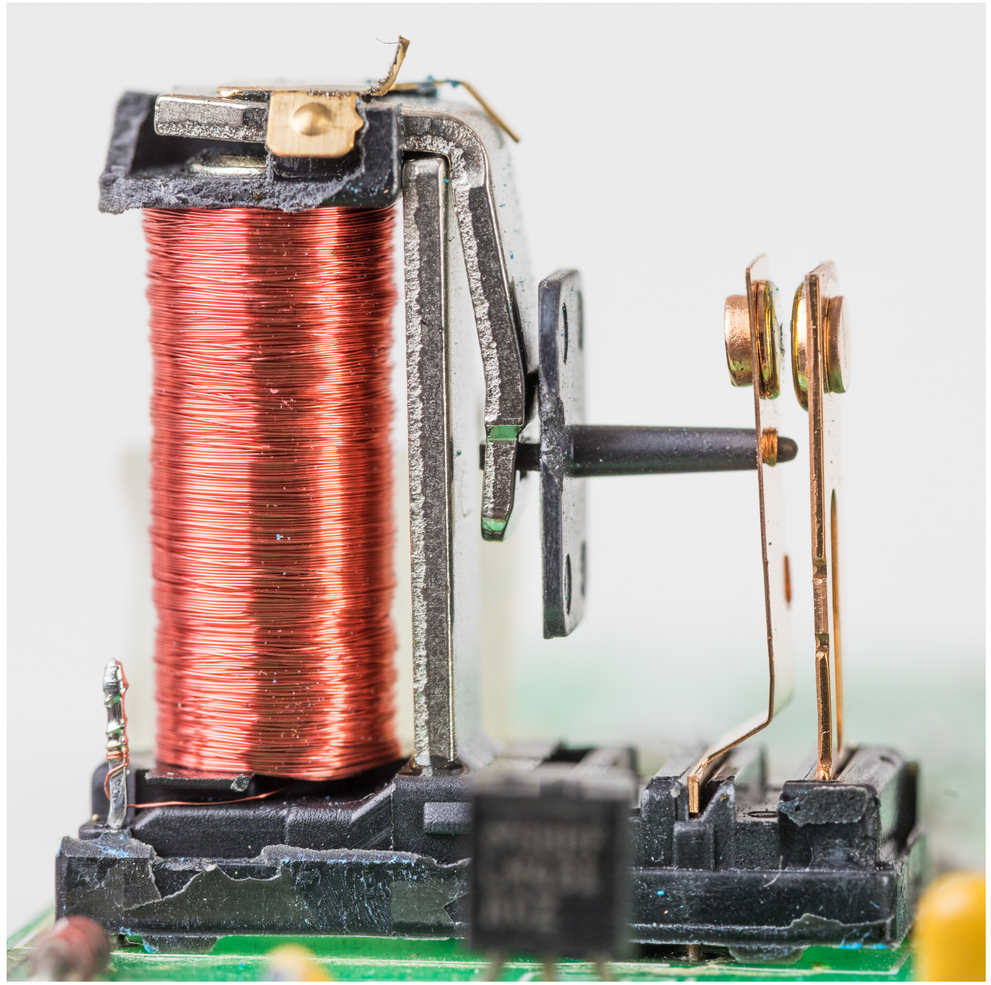

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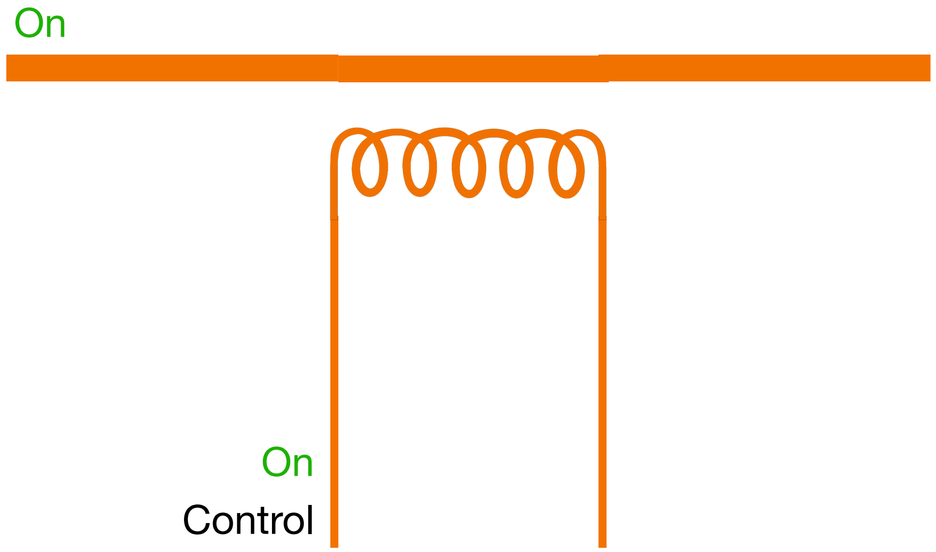

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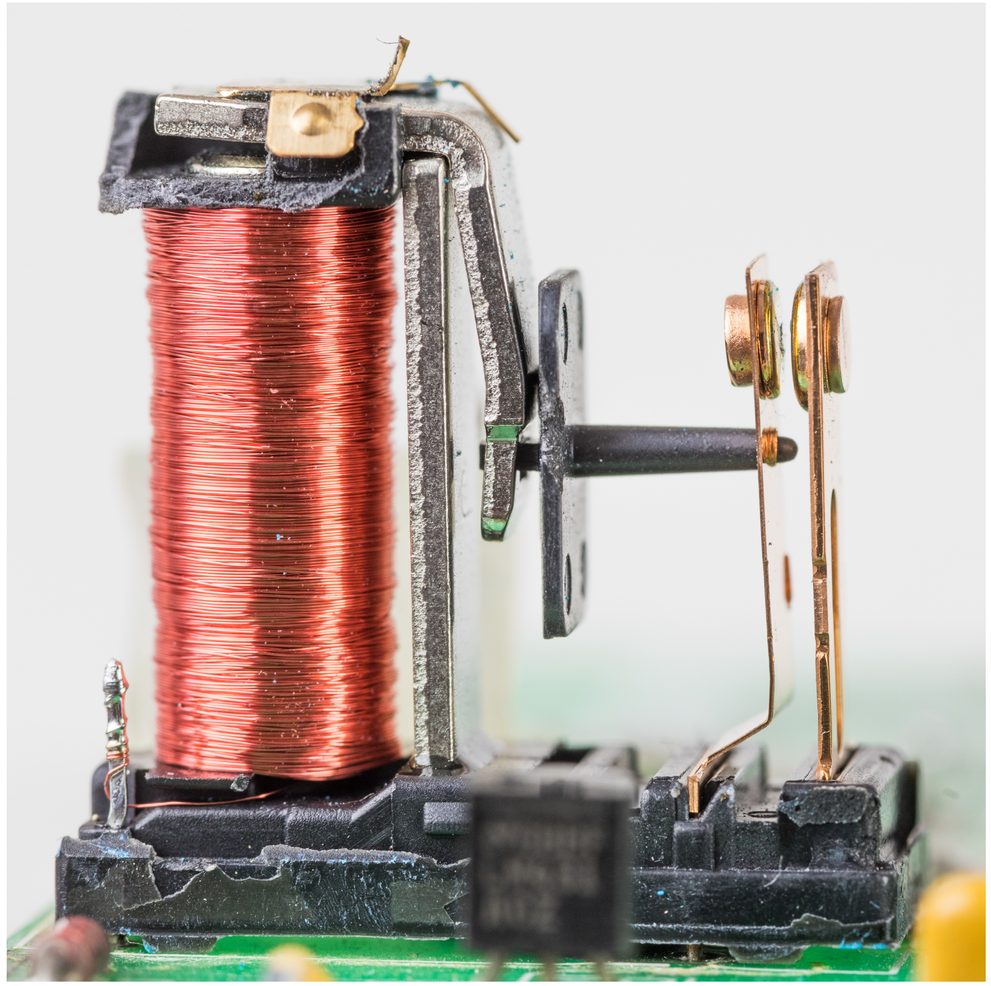

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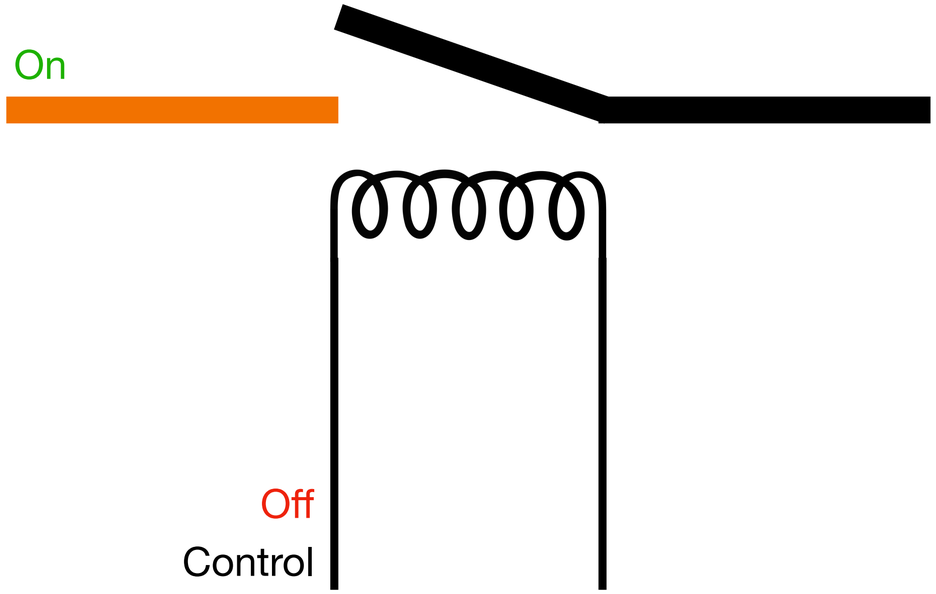
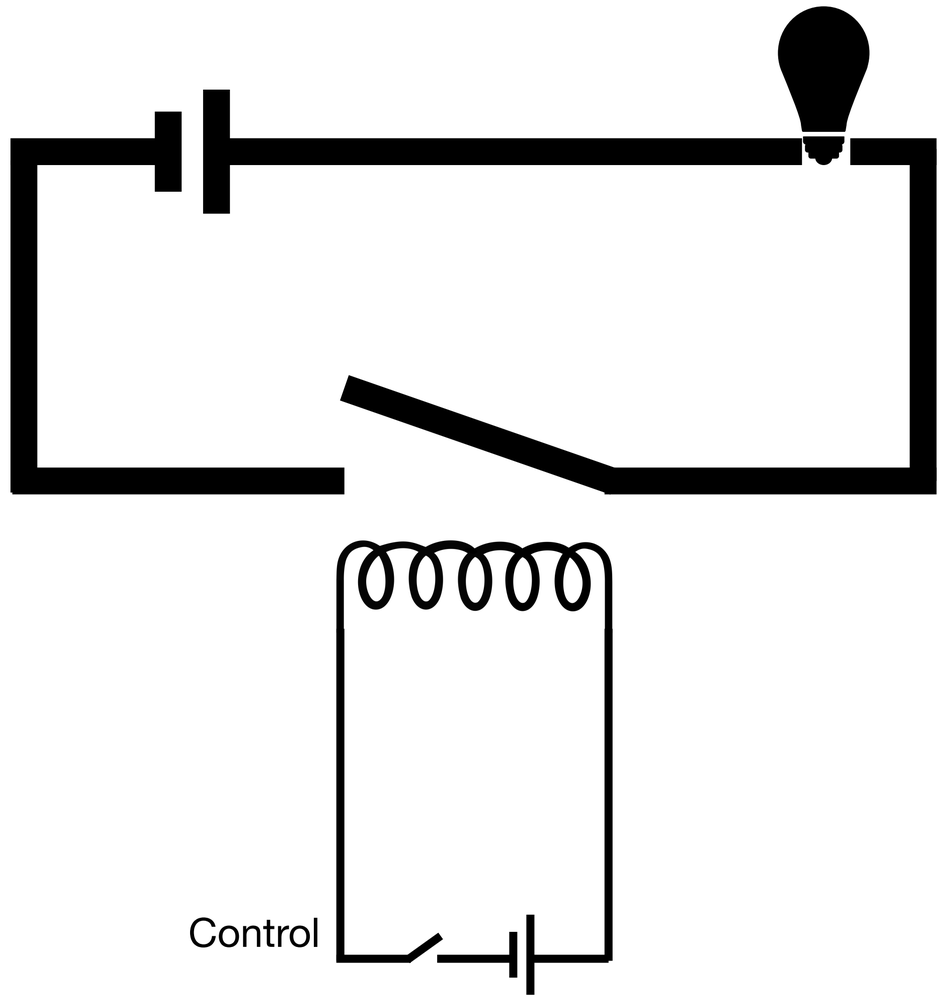
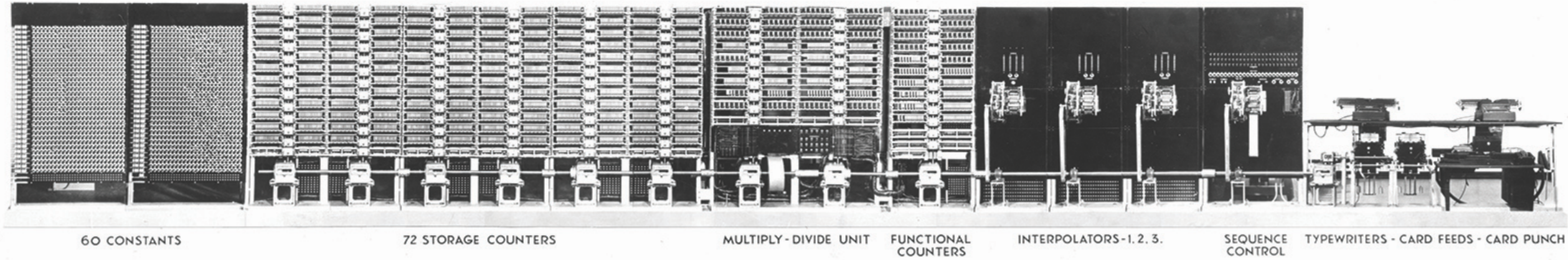


Relay

- Relay telegraph signal over long distance
- Mechanical things that have mass
- Slow: open and close ~15 times a second
- Wear and tear

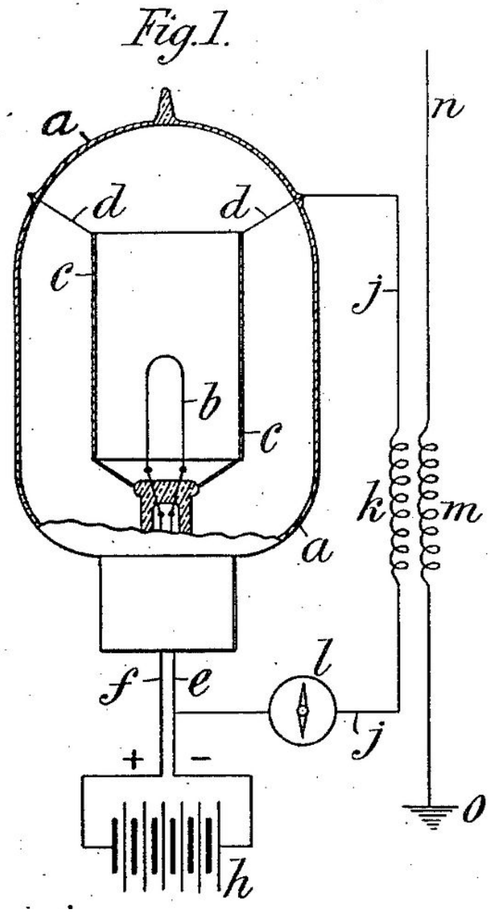


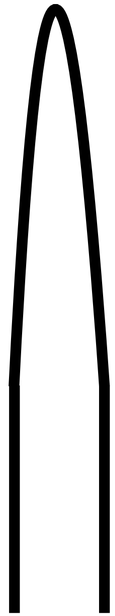


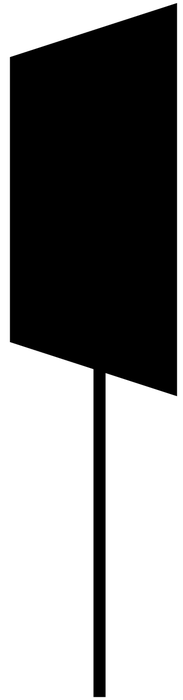
- 3 additions or subtractions per second
- 1 multiplication took 6 seconds; a division took 15.3 seconds
- logarithm or trigonometric functions took over a minute

Vacuum Tube

Fleming Valve, 1904







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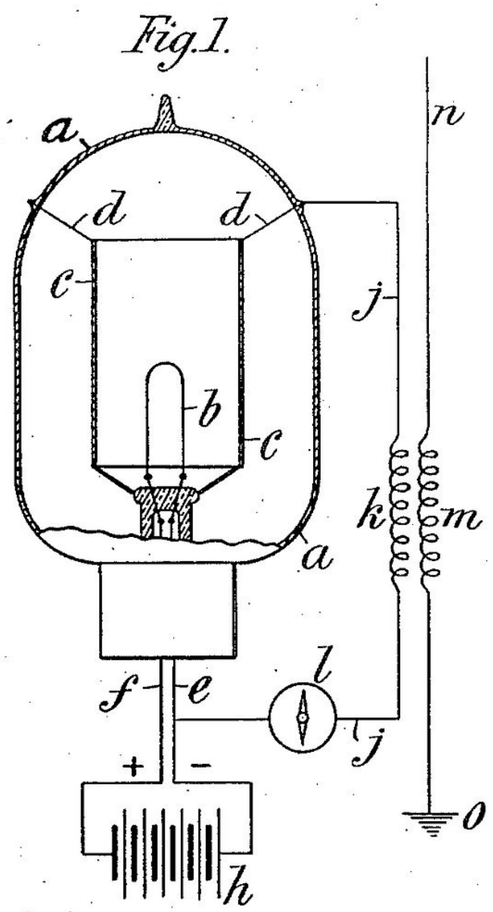
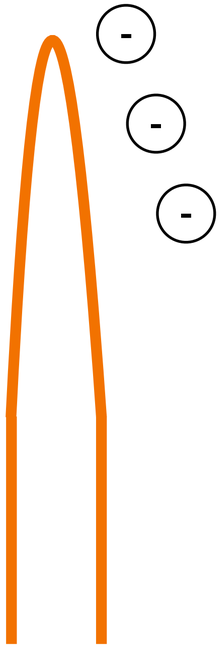
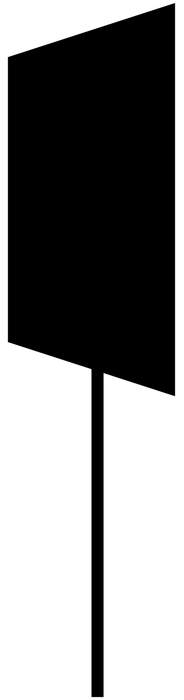
Fleming Valve, 1904







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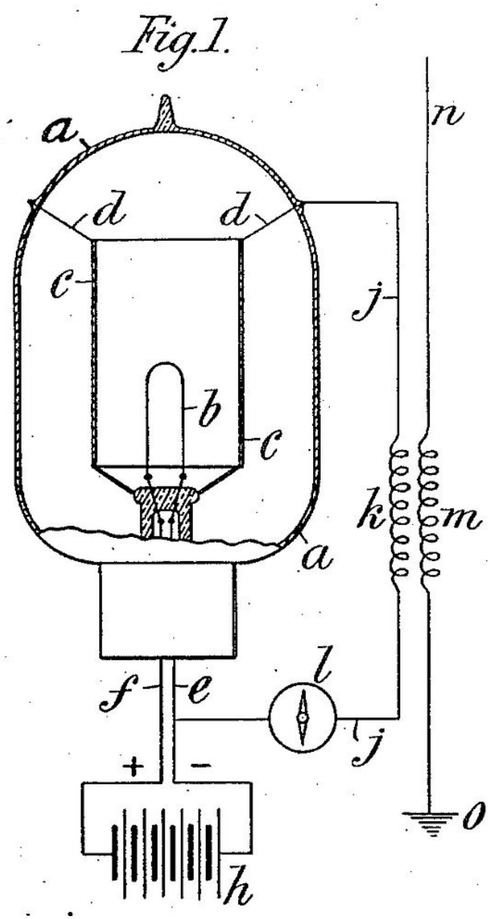
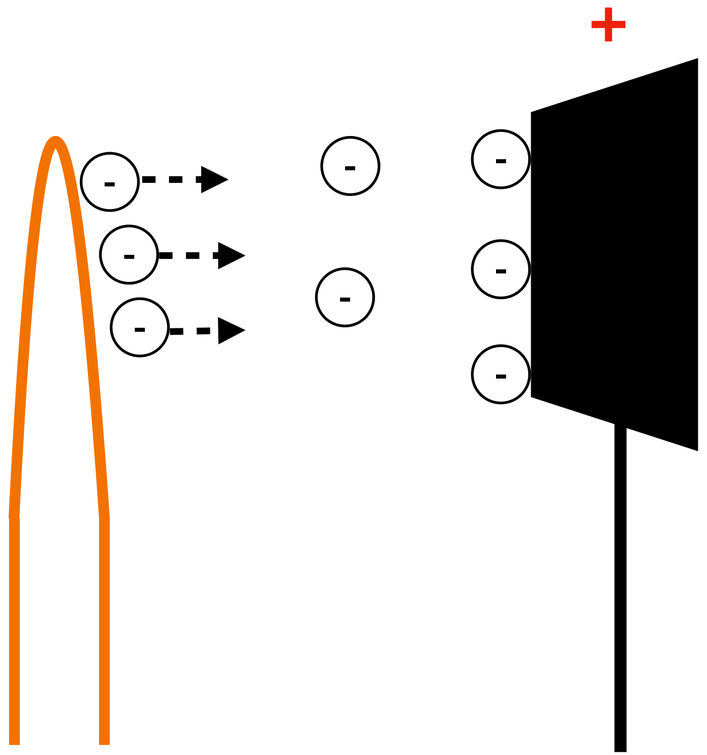
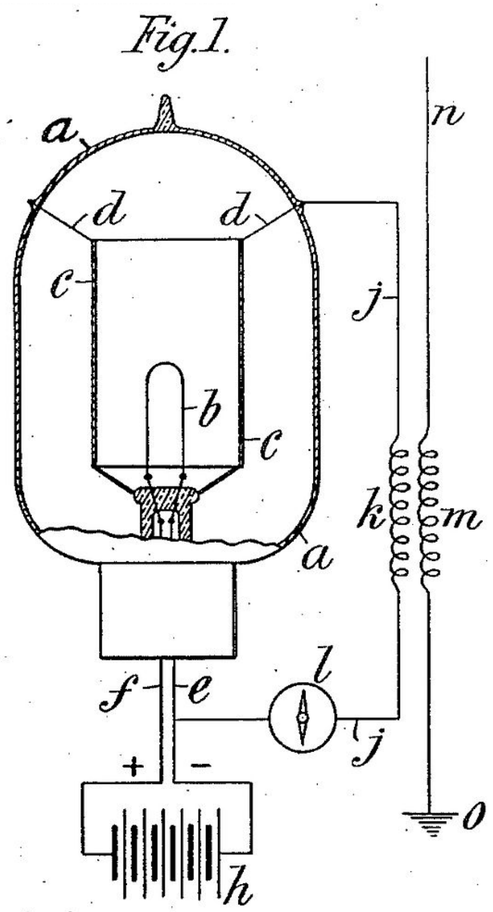
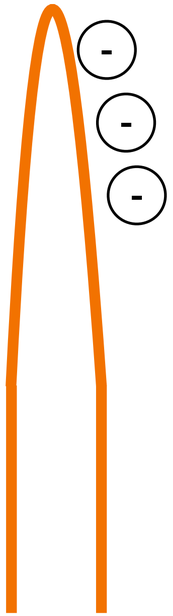


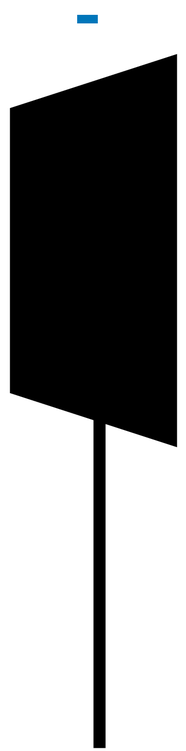


Vacuum Tube

Fleming Valve, 1904







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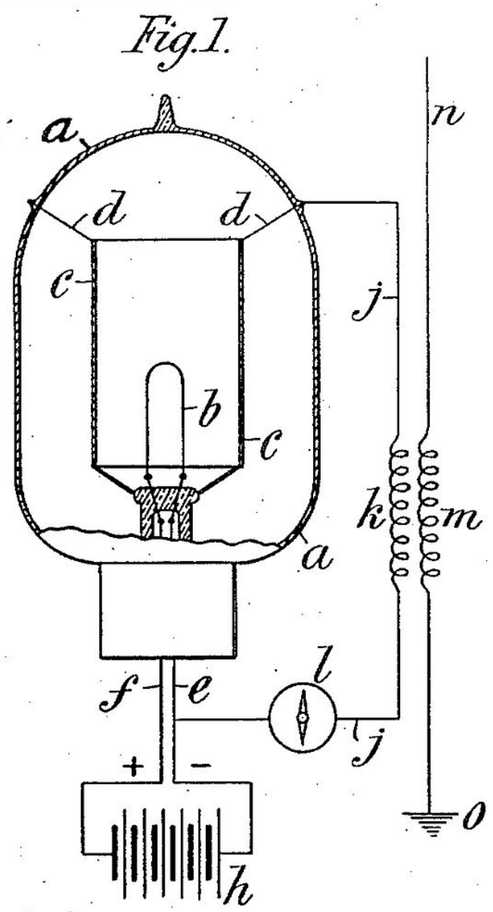
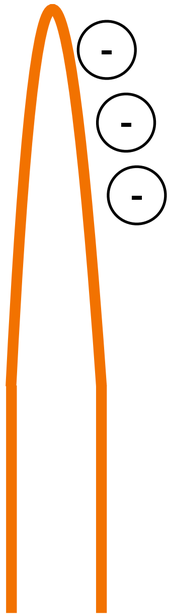
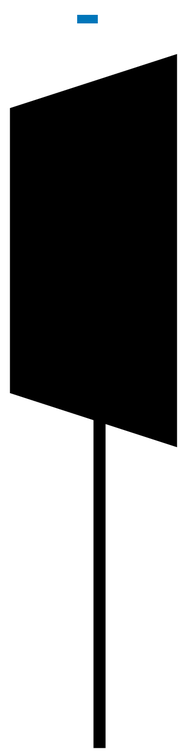
Fleming Valve, 1904







Vacuum Tube

Lee de Forest's Triode, 1906

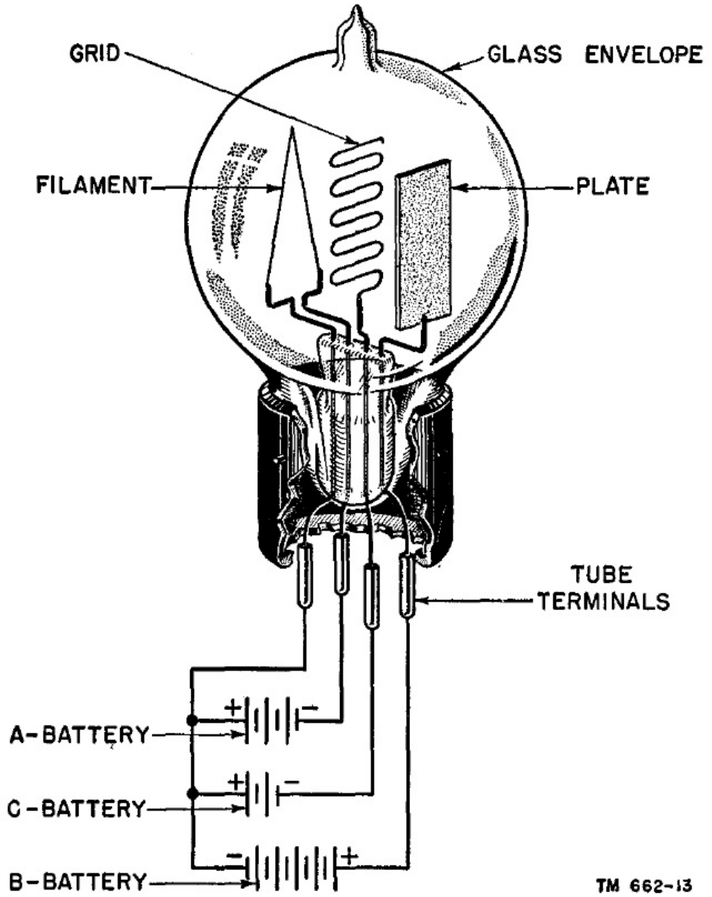
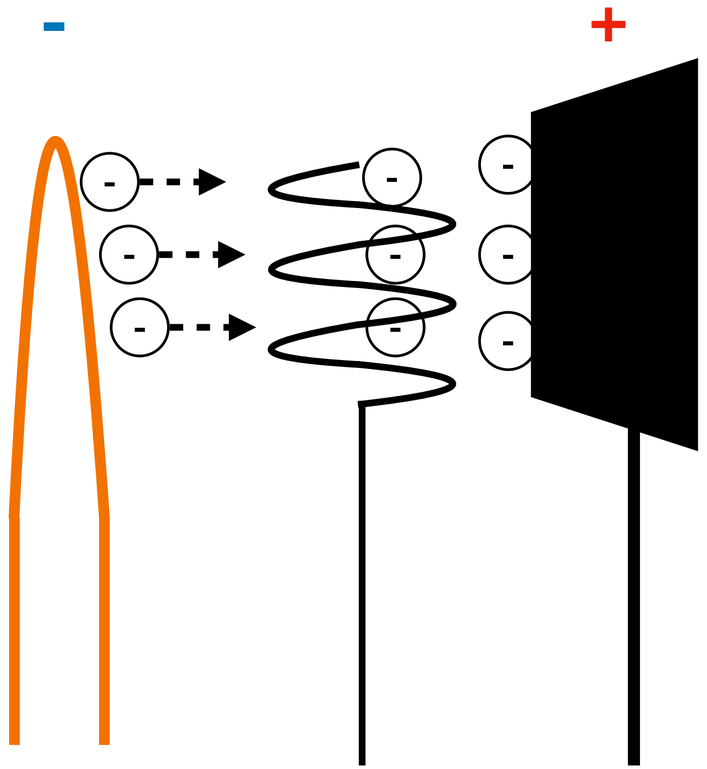


Figure 4. Construction of DeForest's three-element tube, or triode.



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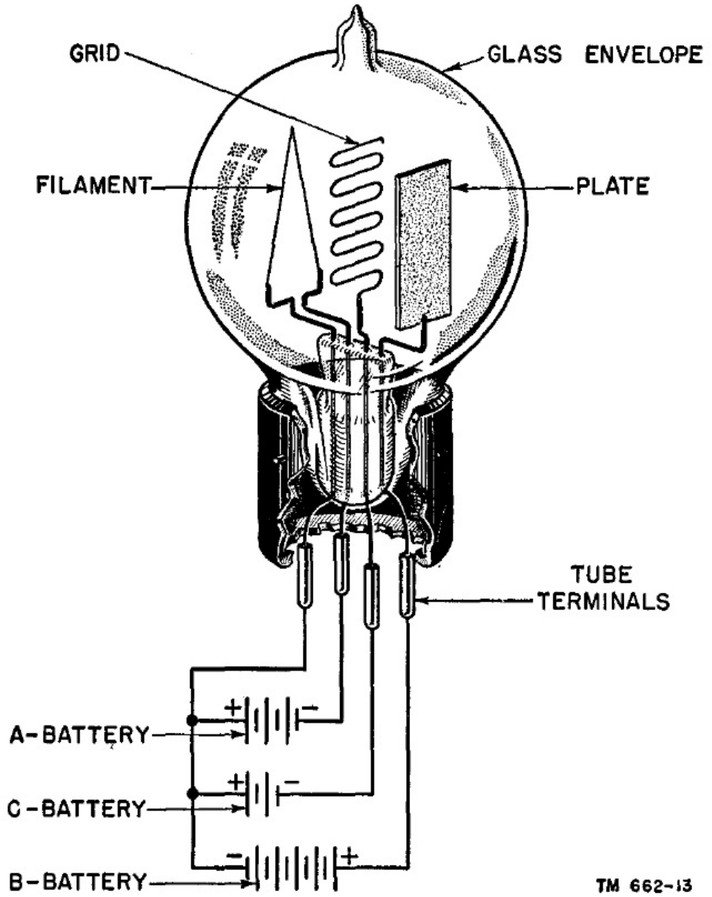

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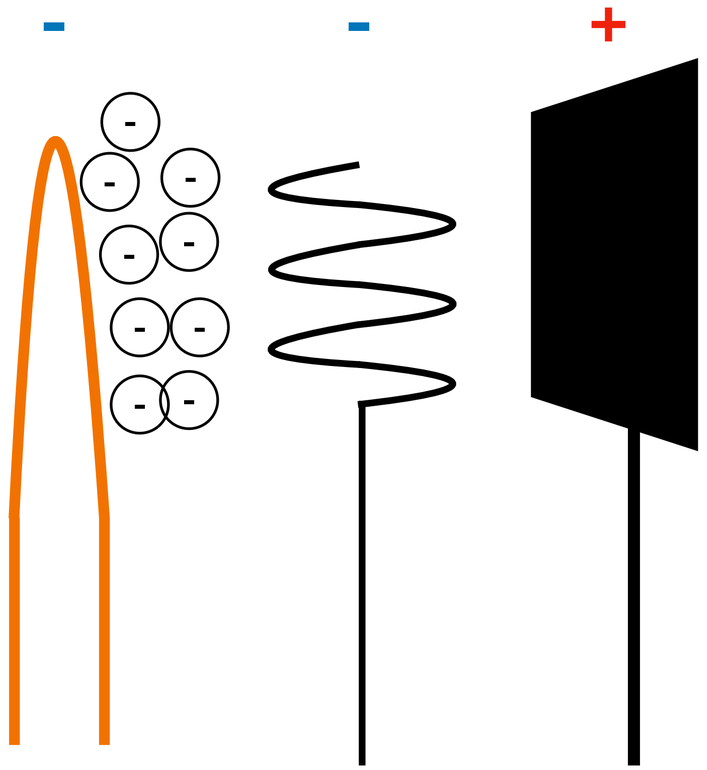

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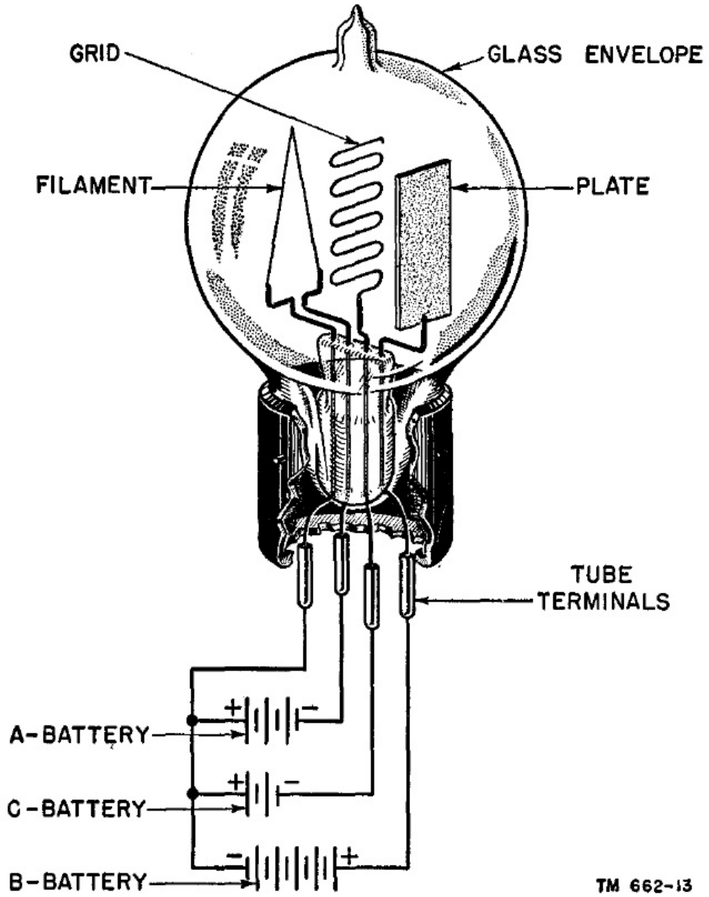

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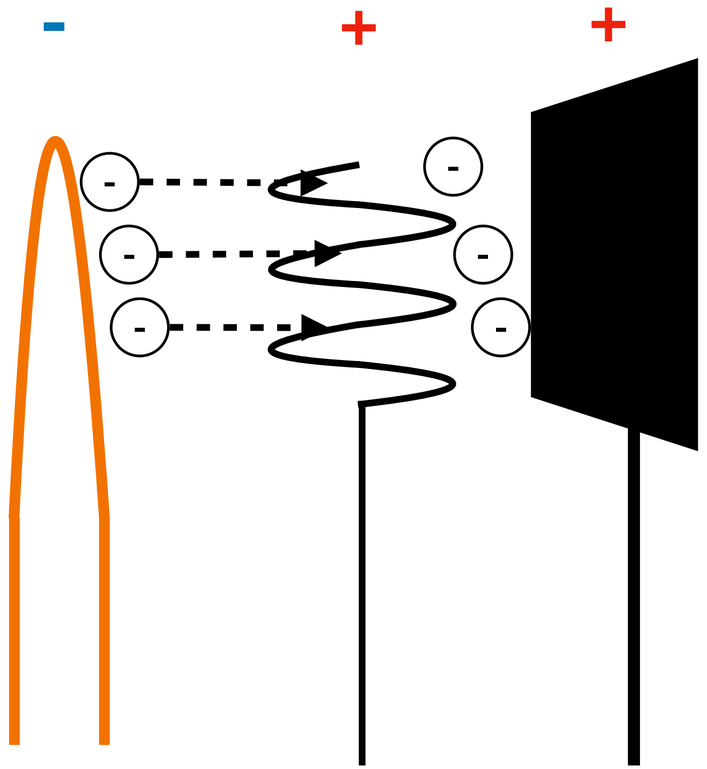

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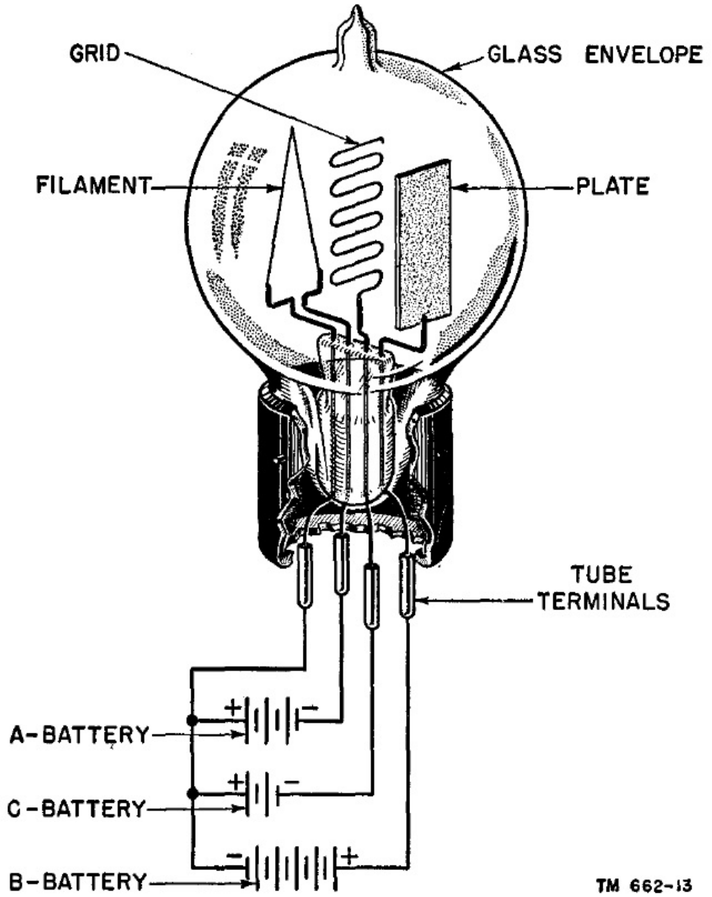
Lee de Forest's Triode, 1906



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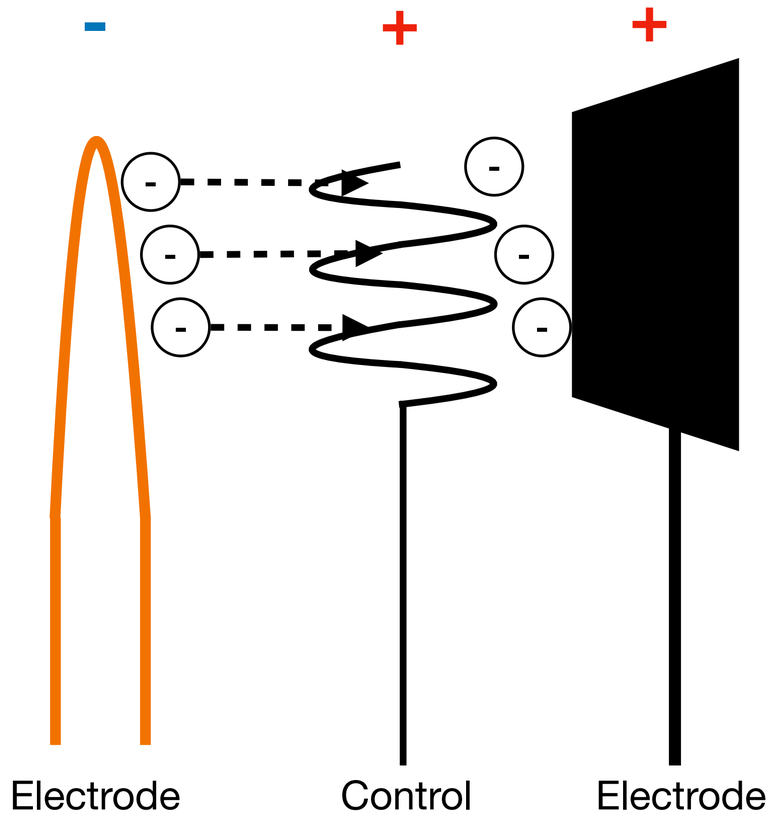
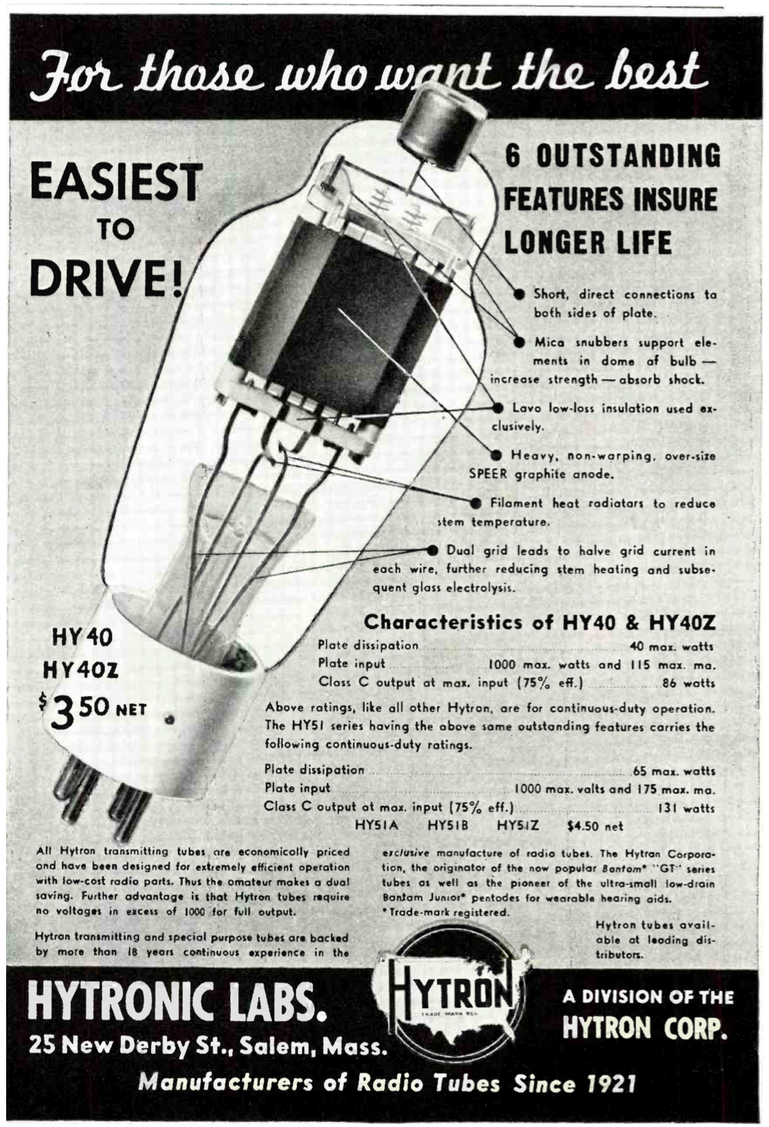


Vacuum Tube

- Just like a relay, but *no moving parts*
- Response is rapid -- kHz level
- Feasible for use in computers by 1940s
- Purely electronic

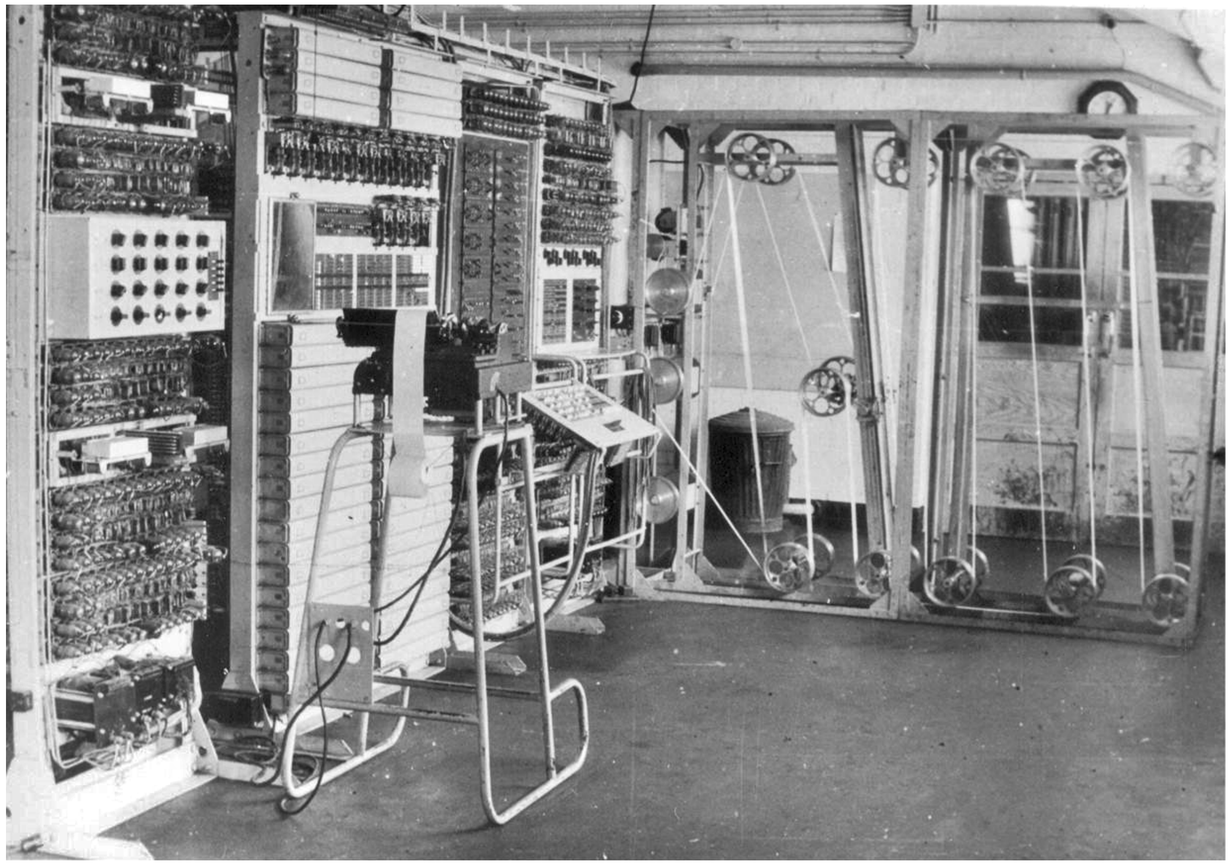


Radio News, January 1940

Colossus

Bletchley Park, 1944

- Built by Tommy Flowers in 1944
- Used to decrypt German encrypted messages
- Used 1,600 tubes

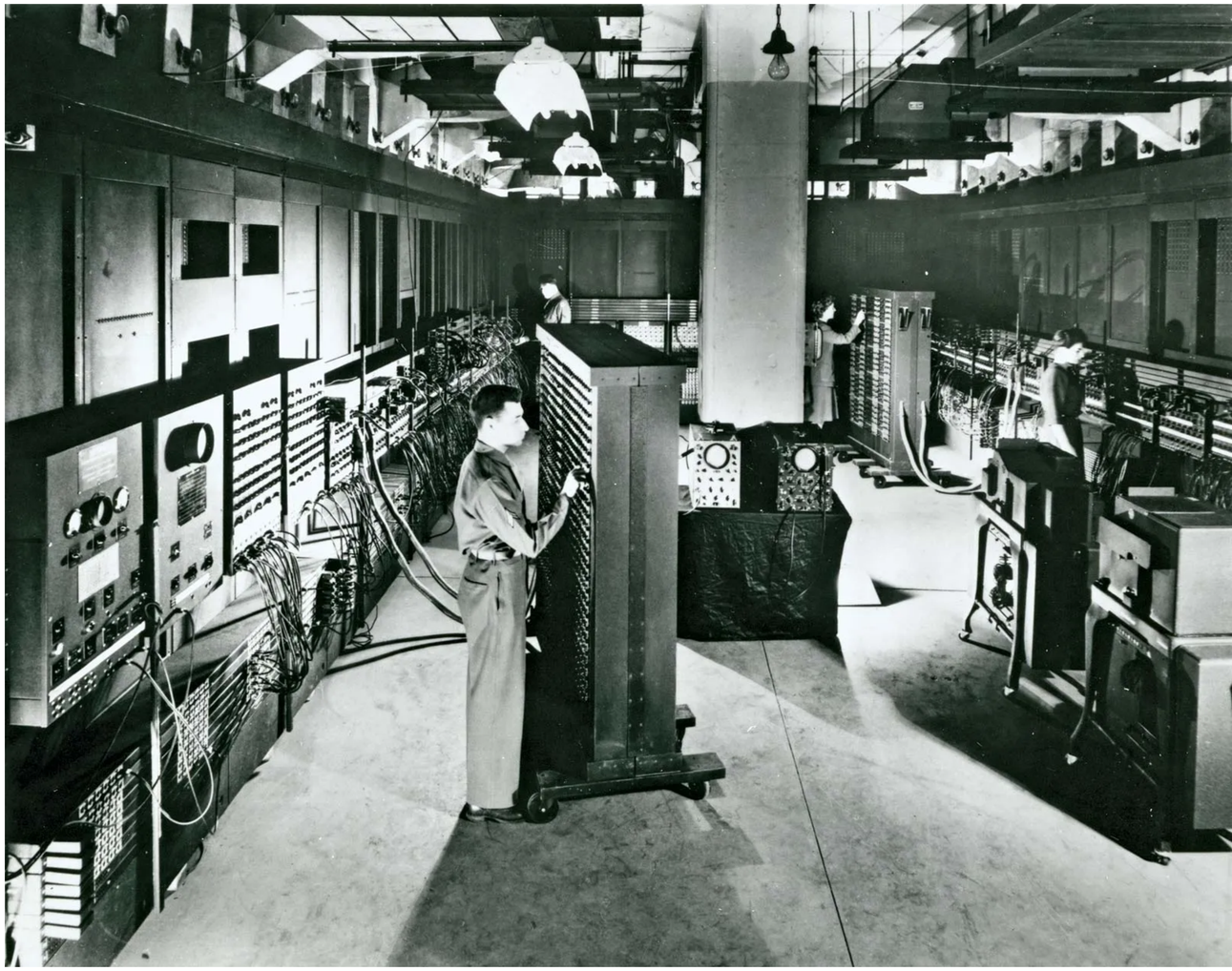


Colossus 10

ENIAC

University of Pennsylvania, 1945

- **E**lectronic **N**umerical **I**ntegrator **a**nd **C**omputer
- 18,000 vacuum tubes
- 5,000 additions/subtractions per second
- 357 multiplications per second
- Operational until 1955



Vacuum Tube

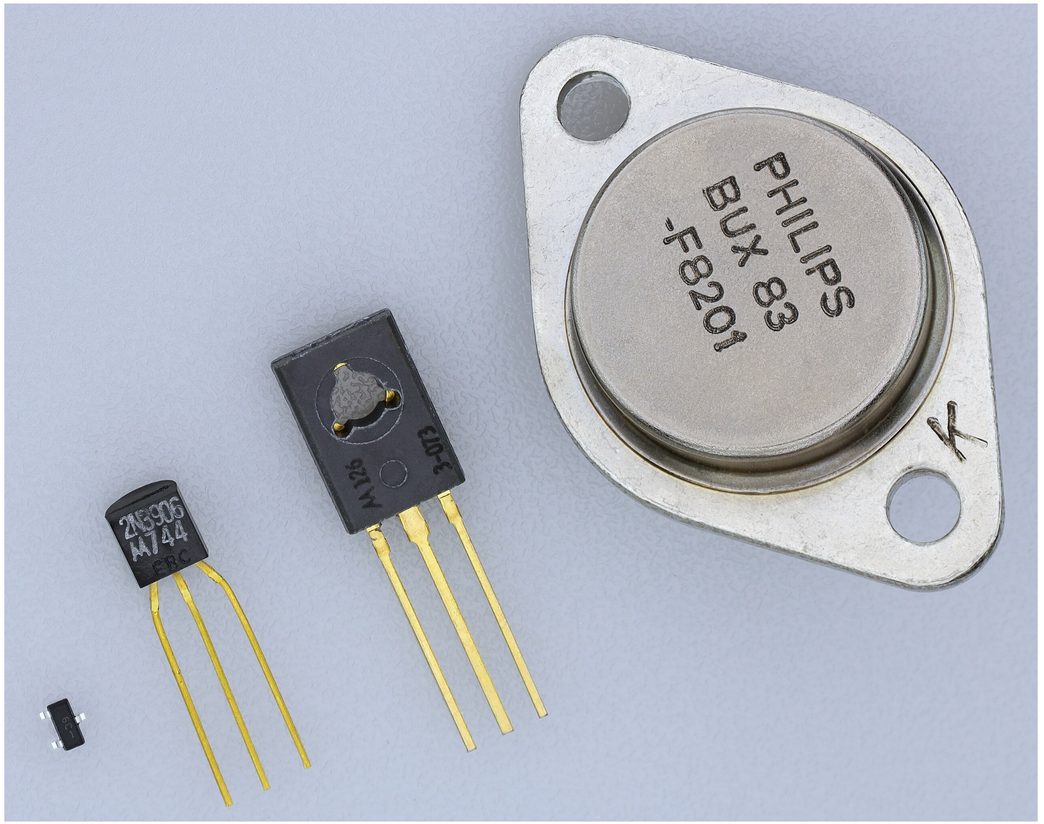
Limitations

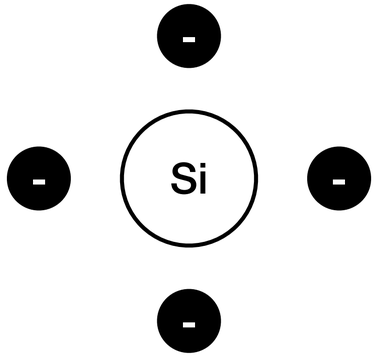
- Bulky, high voltage, inefficient
- Failure rate was high -- ENIAC was usually only operational for half a day
- *Transistors*

Transistors

Bell Lab, 1947

- John Bardeen, Walter Brattain, William Shockley
- Prerequisites:
  - Protons -- positive charge
  - Electrons -- negative charge
  - Opposites attract, likes repel
  - A flow of electrons makes an electric current




-
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Si
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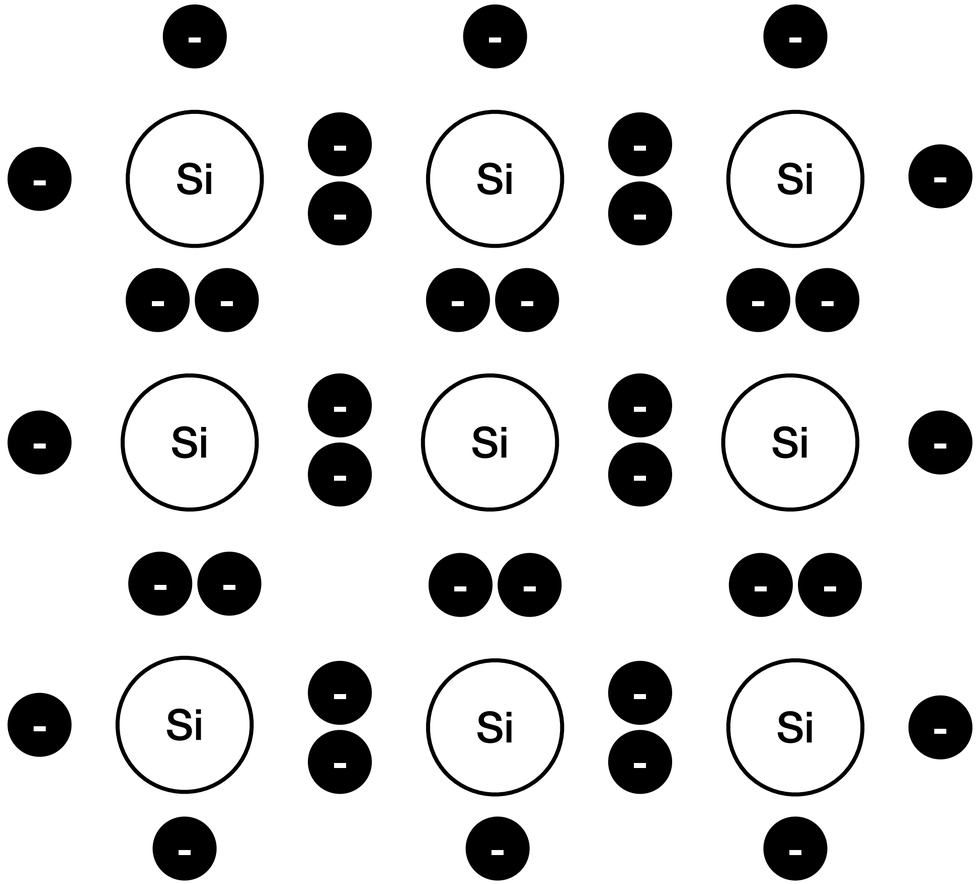
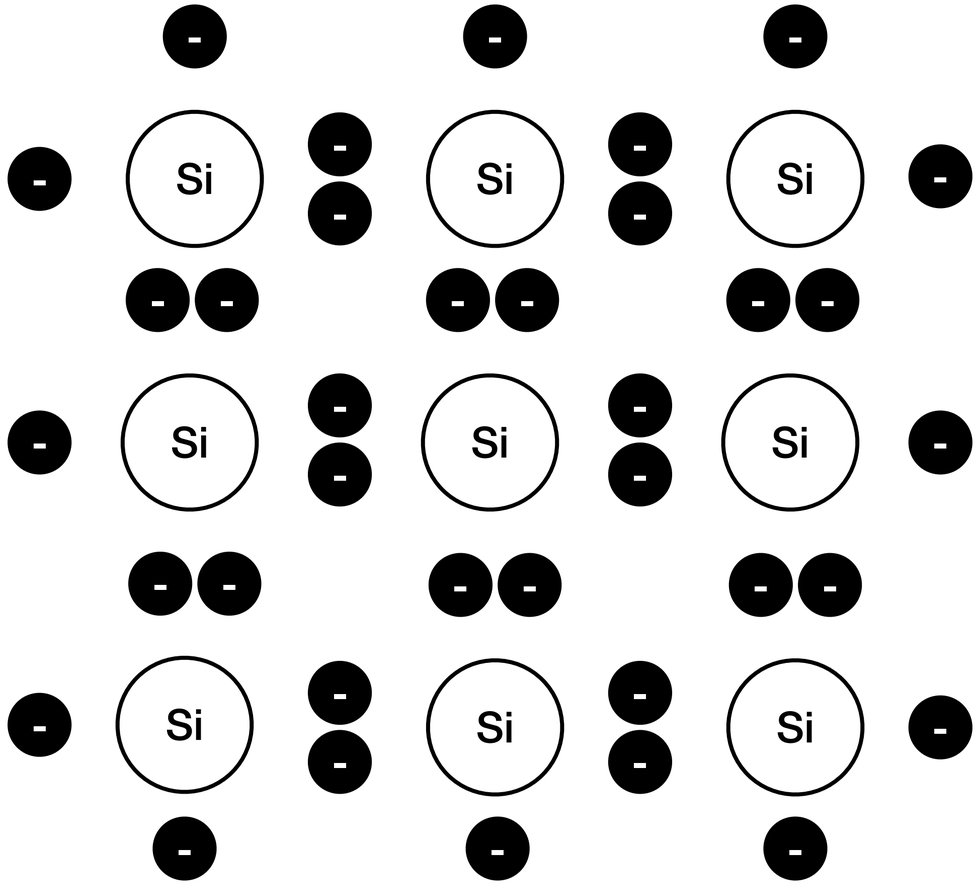
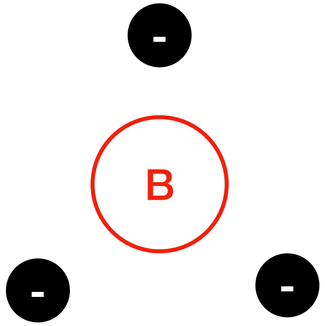


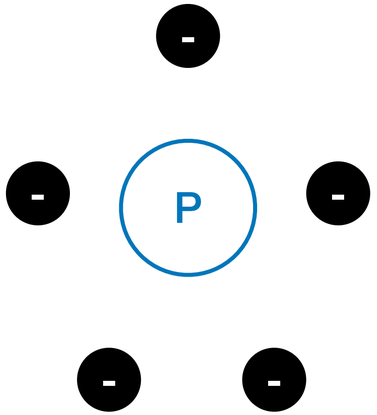
* Actually, they form a tetrahedron.

13 14 15

5 B	6 C	7 N
13 Al	14 Si	15 P
31 Ga	32 Ge	33 As
49 In	50 Sn	51 Sb
81 Tl	82 Pb	83 Bi
113 Nh	114 Fl	115 Mc
67 Ho	68 Er	69 Tm
99 Es	100 Fm	101 Md







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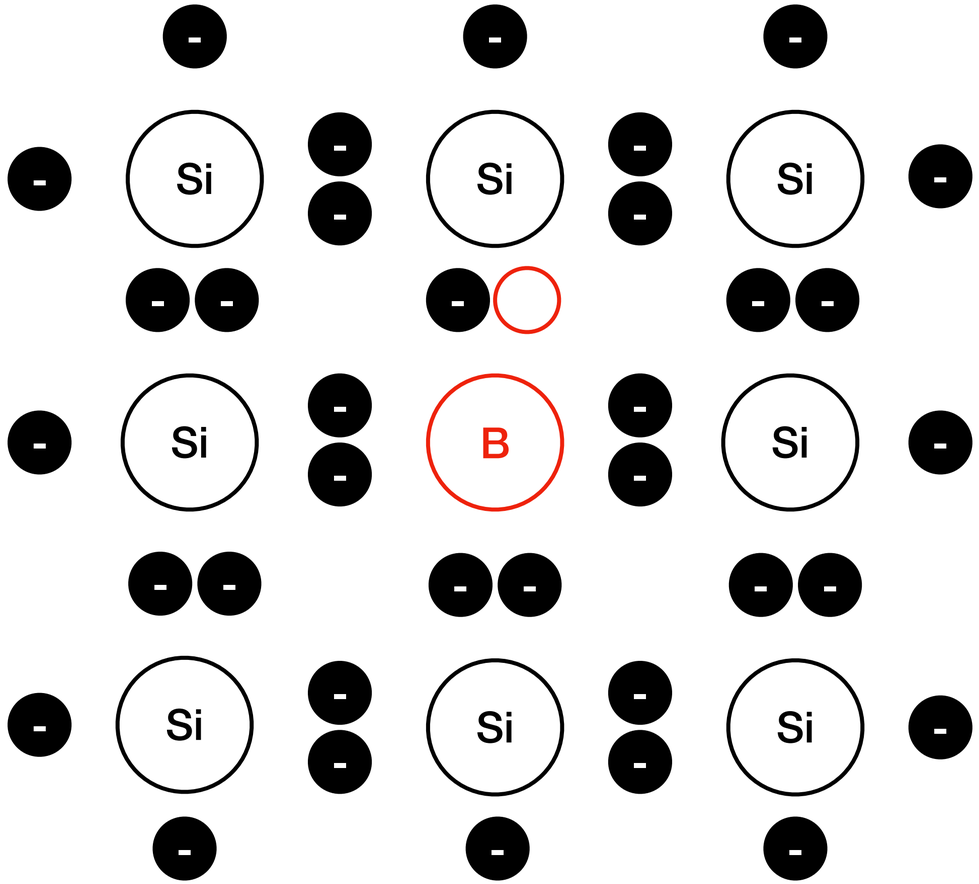

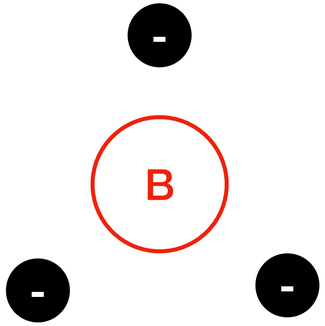

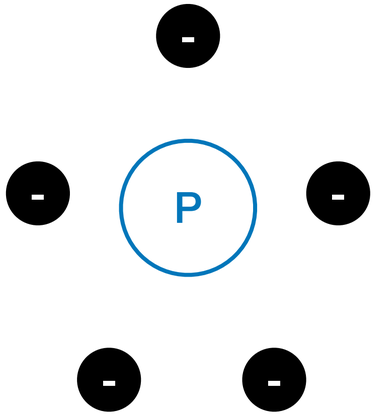

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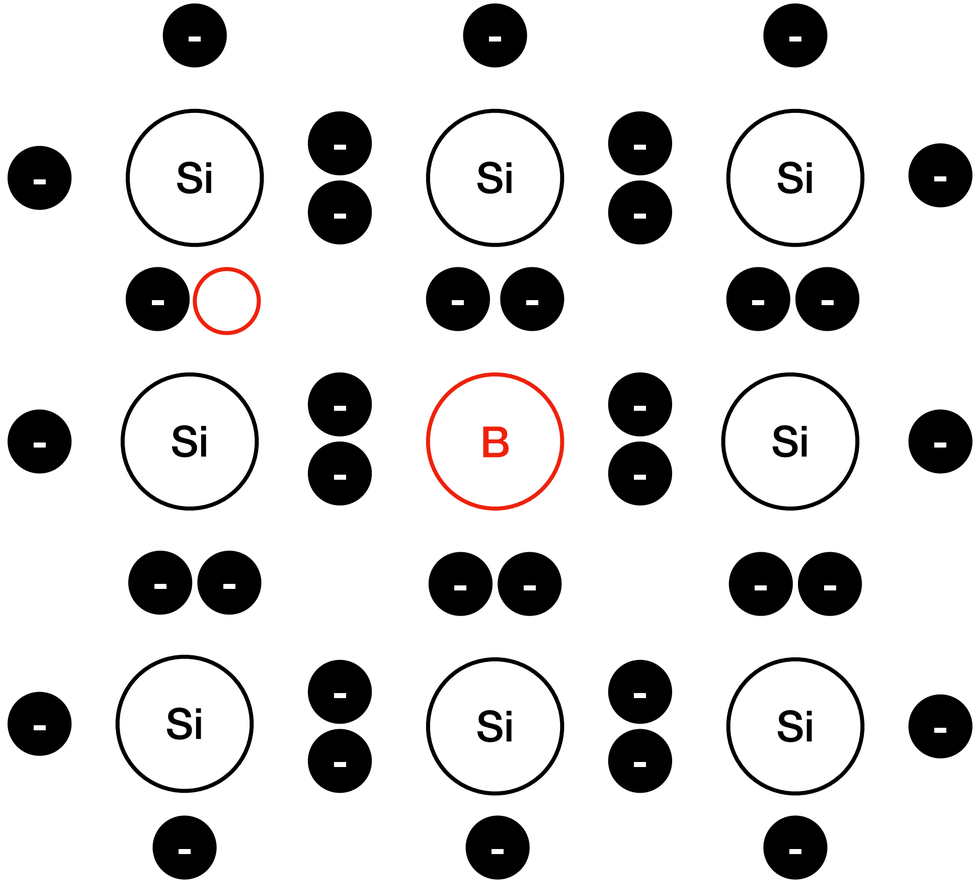

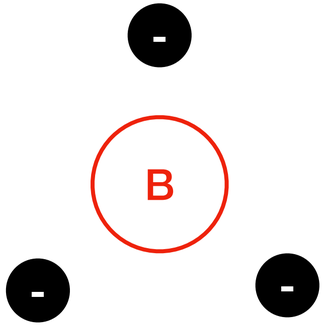

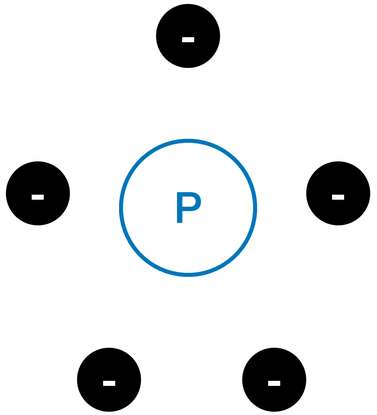

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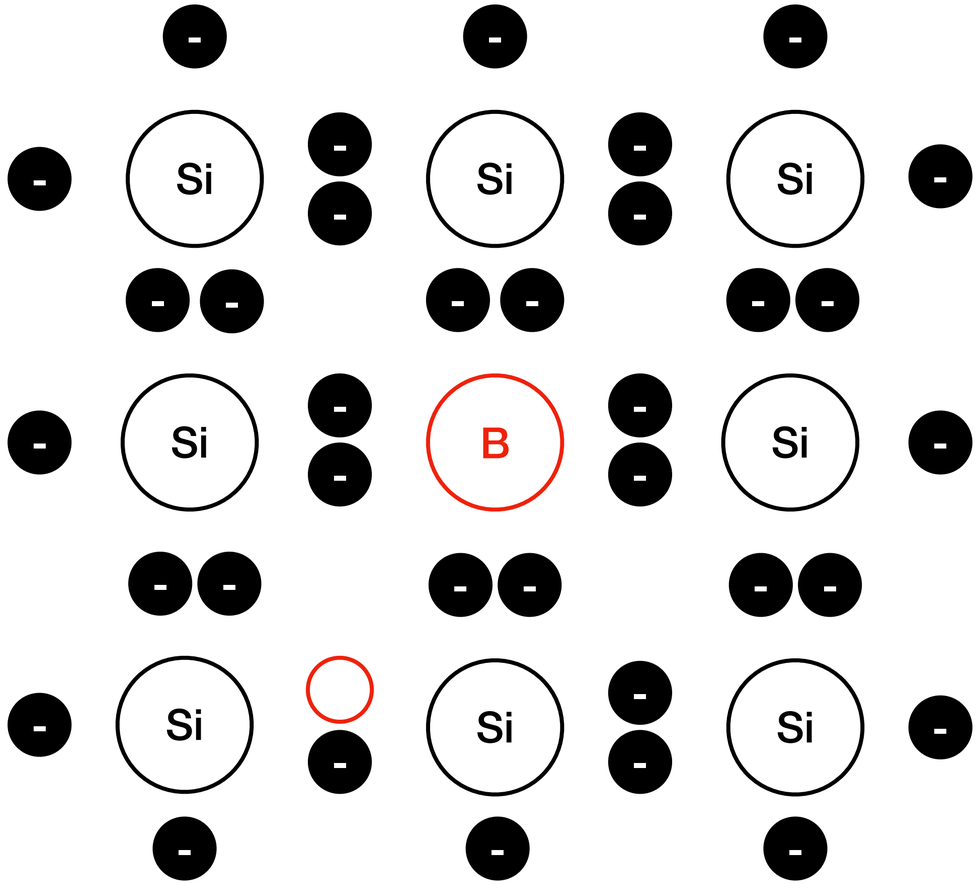
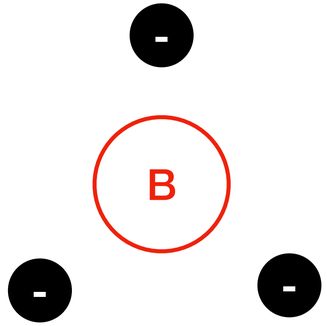
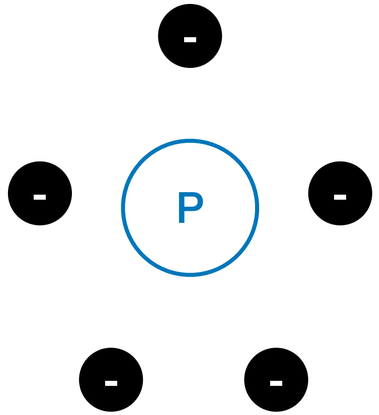
99 Es	100 Fm	101 Md





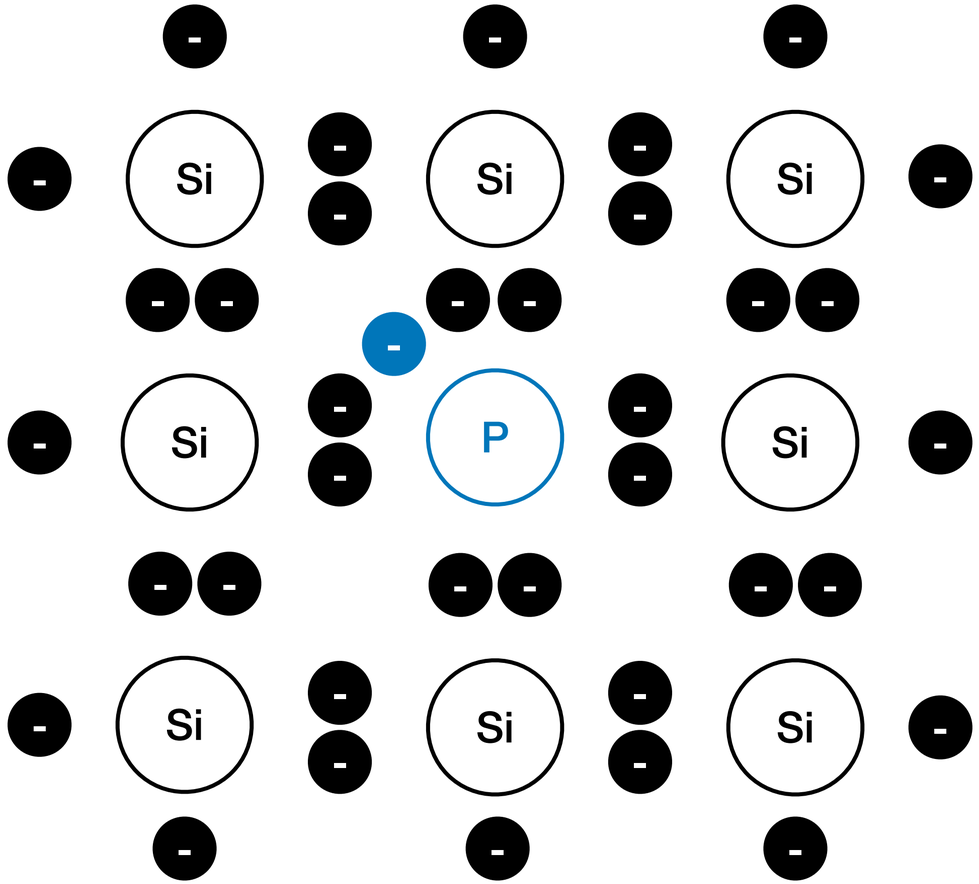


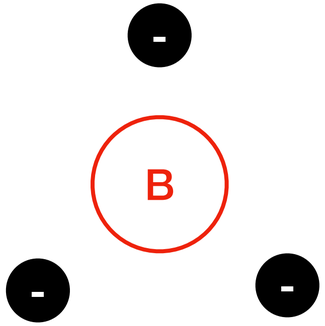
* Actually, they form a tetrahedron.

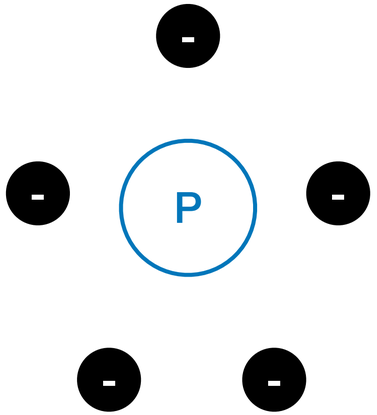
13 14 15

5 B	6 C	7 N
13 Al	14 Si	15 P
31 Ga	32 Ge	33 As
49 In	50 Sn	51 Sb
81 Tl	82 Pb	83 Bi
113 Nh	114 Fl	115 Mc

67 Ho	68 Er	69 Tm
99 Es	100 Fm	101 Md







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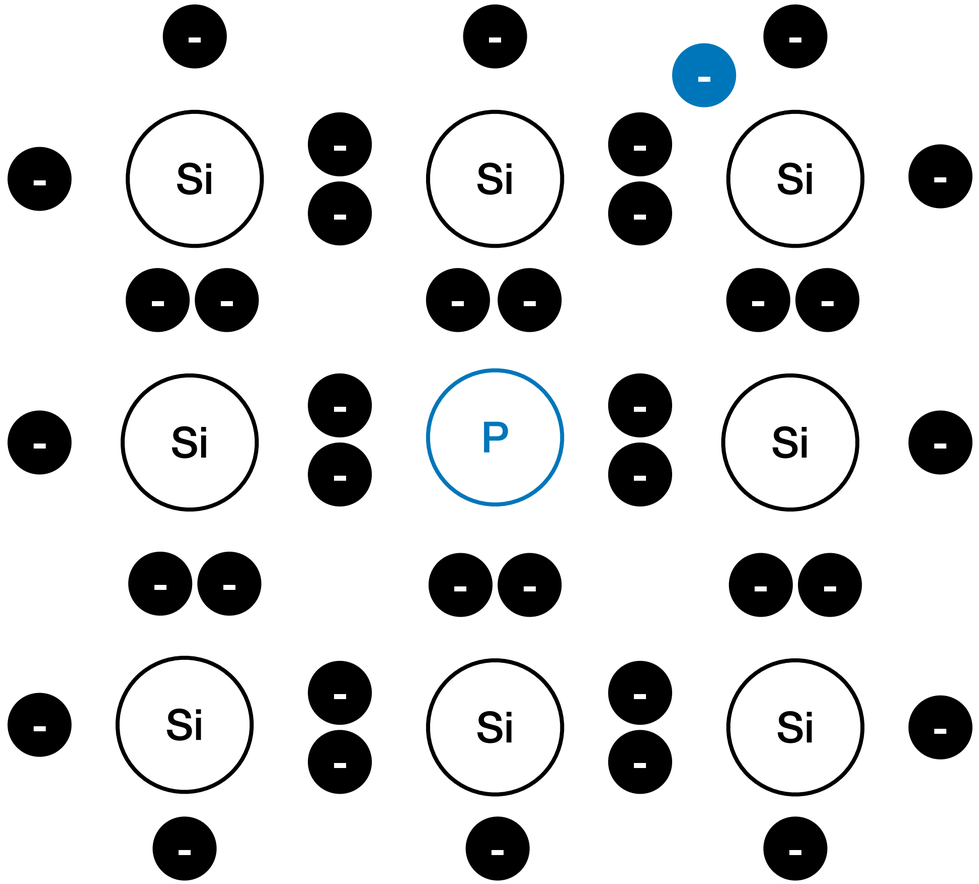

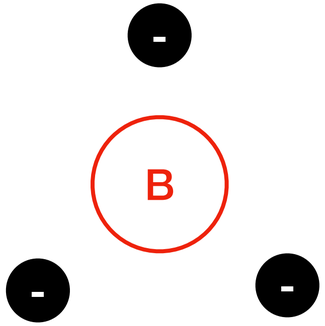

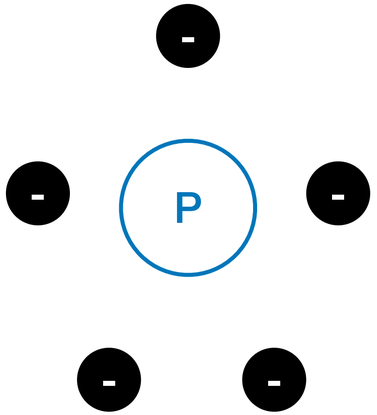

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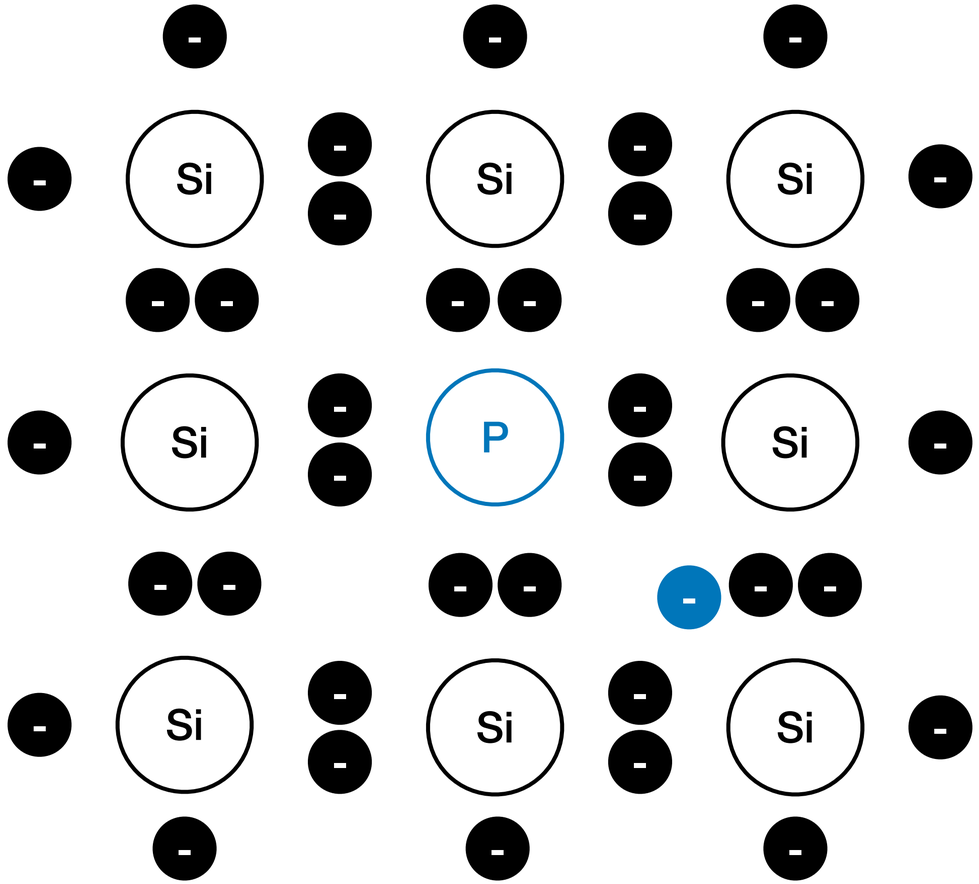

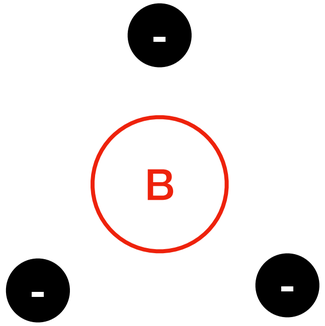

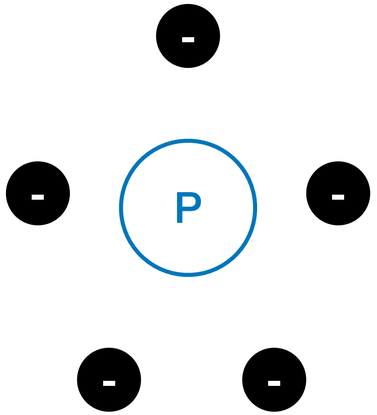

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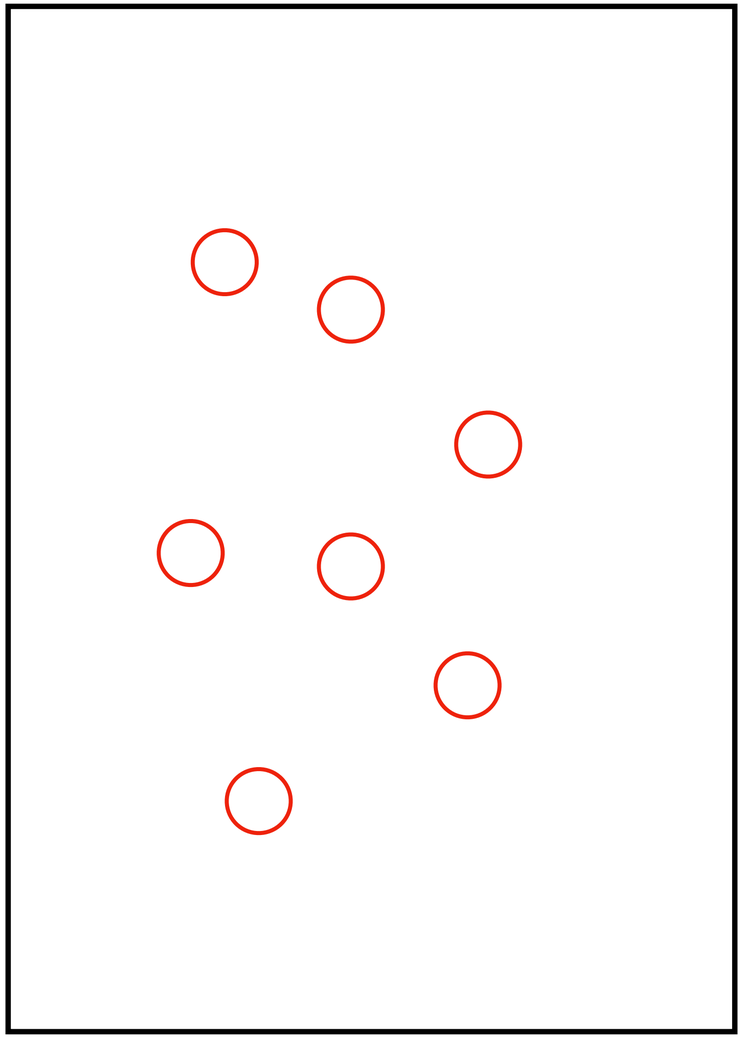
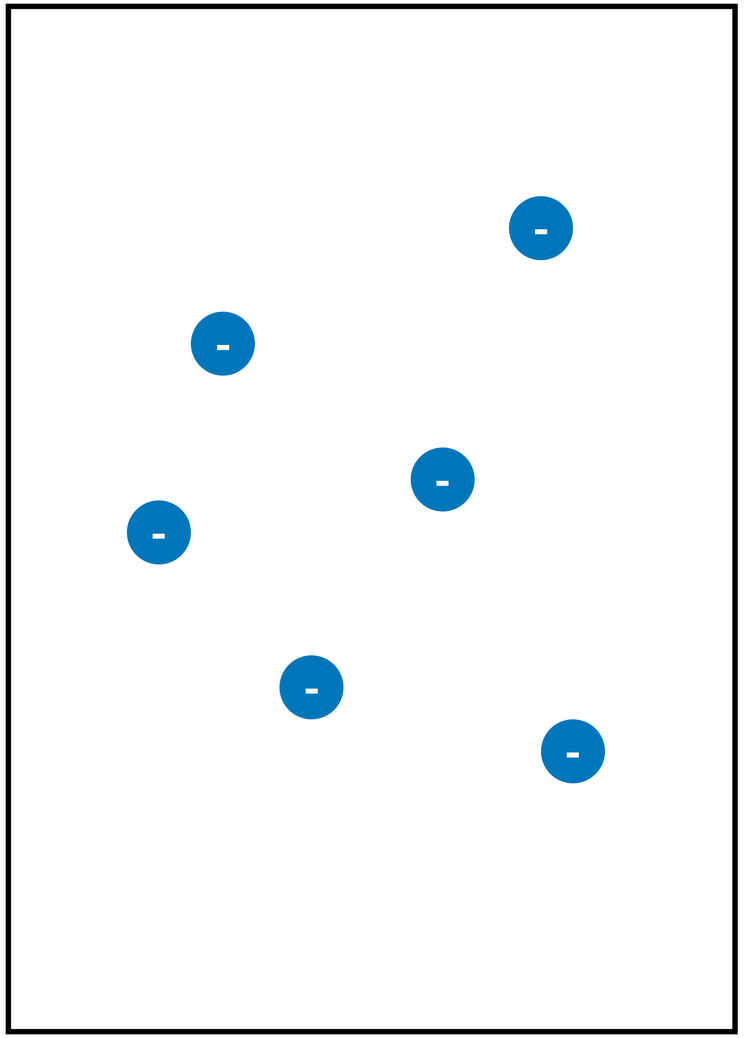
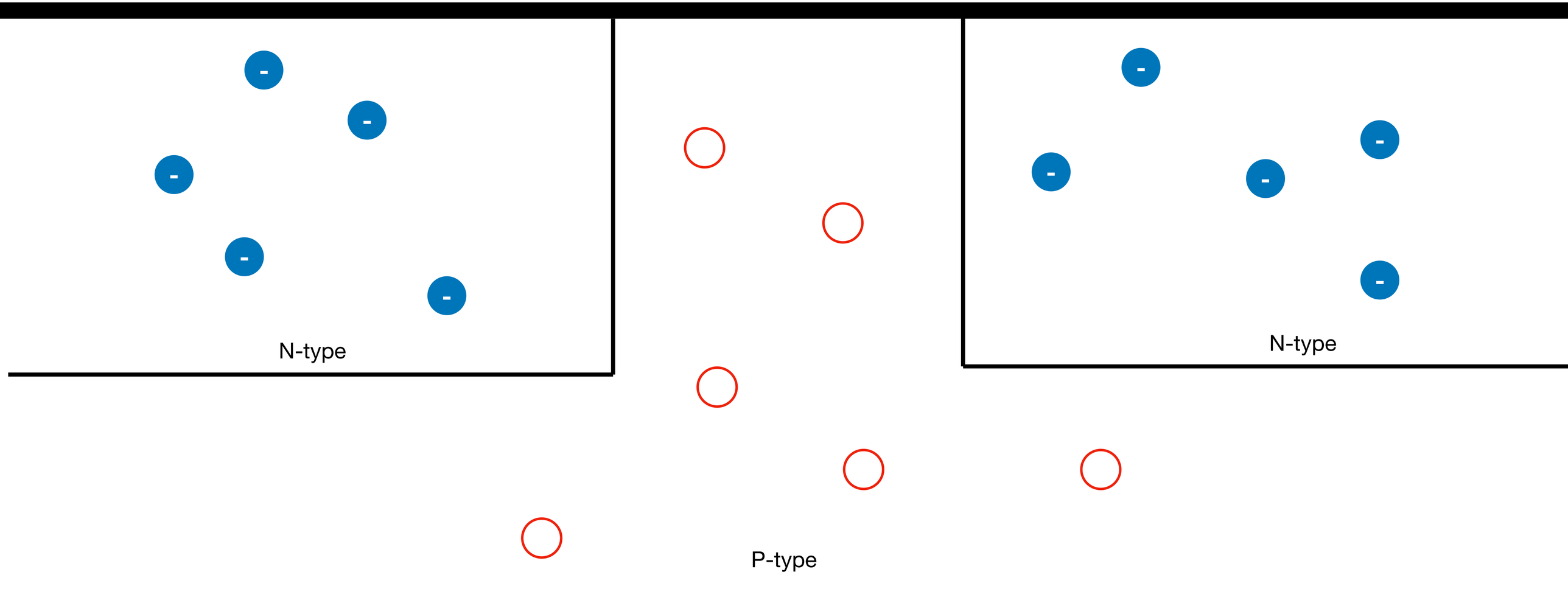
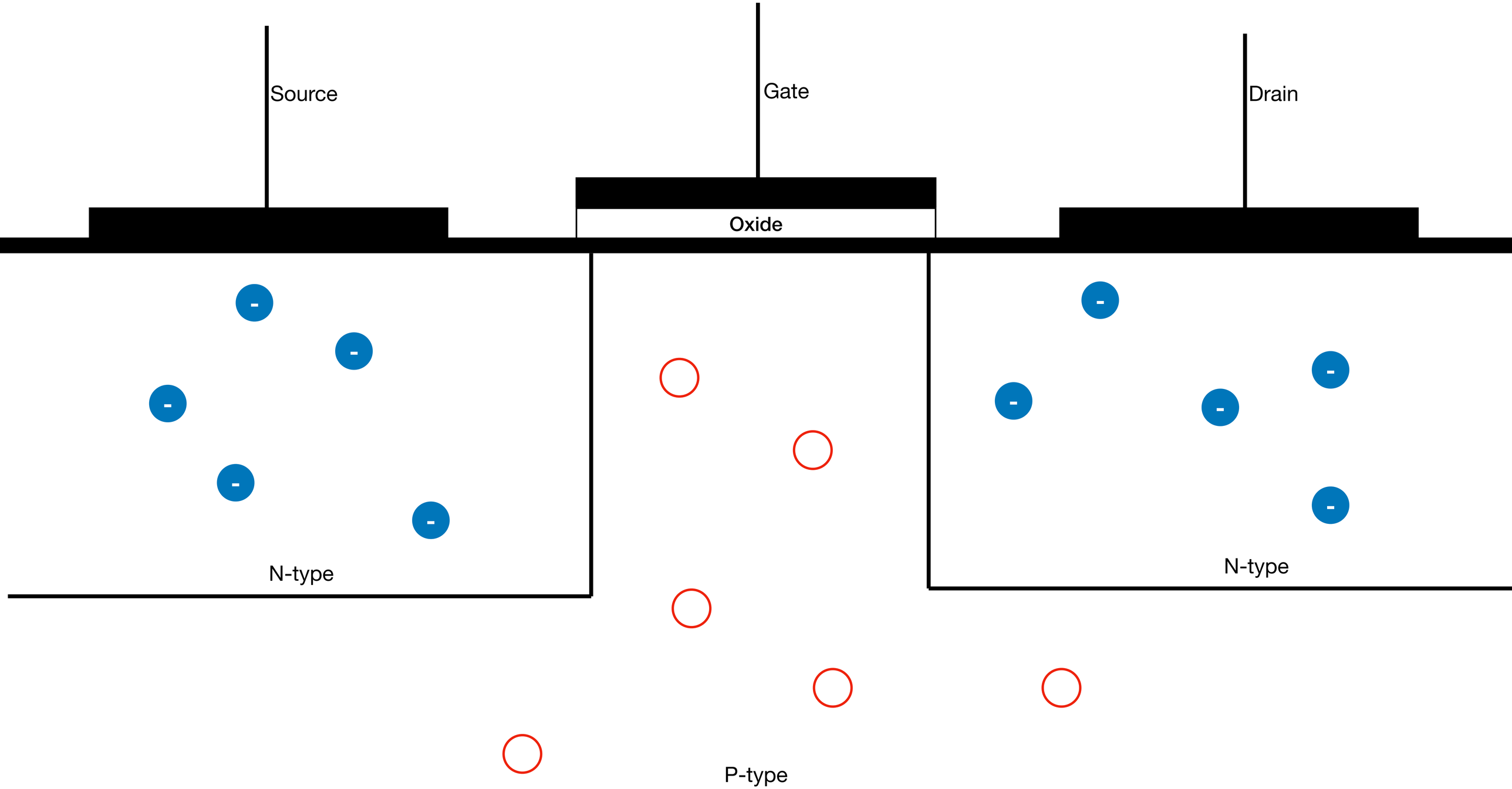


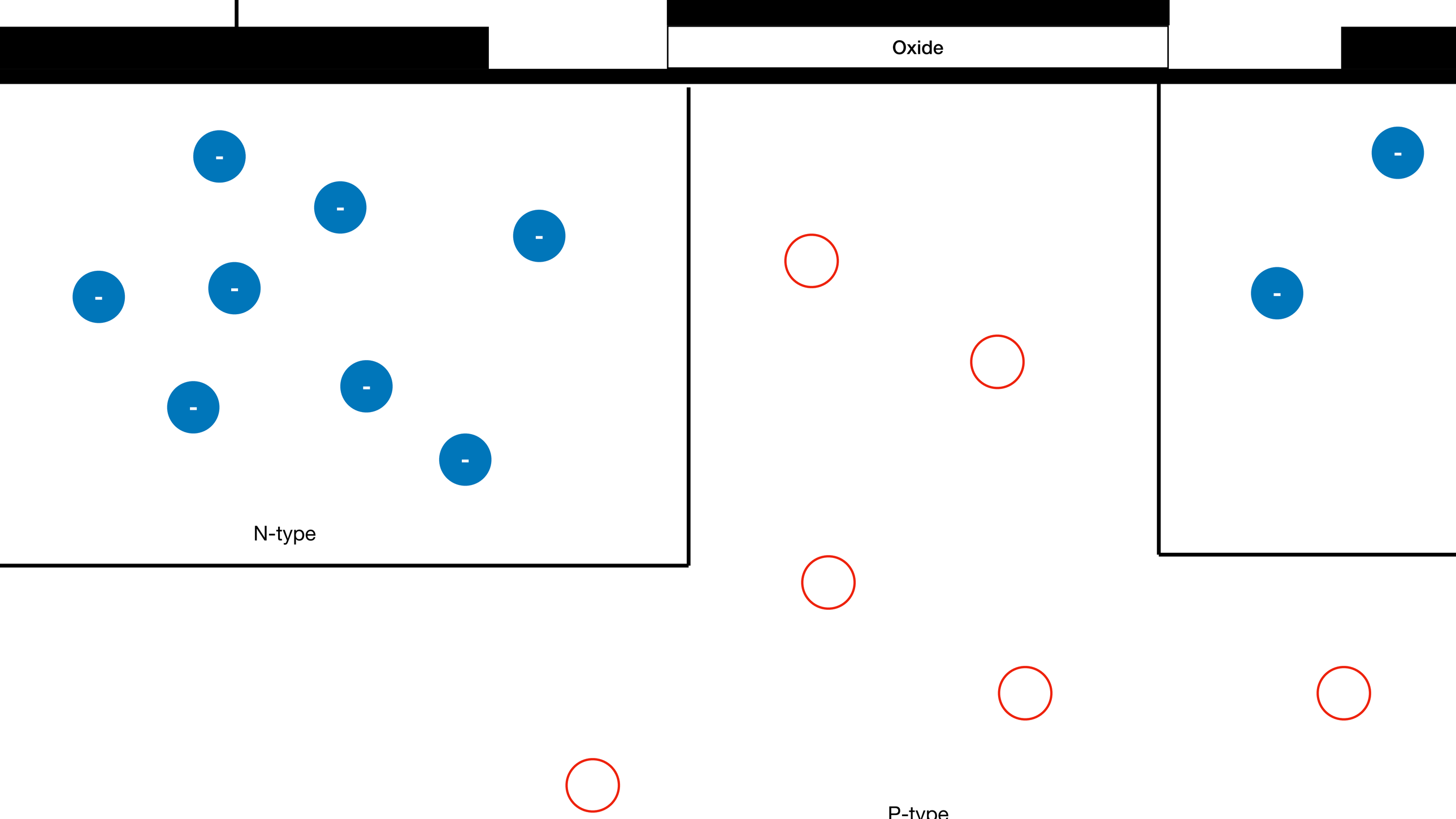
P-type Semiconductor

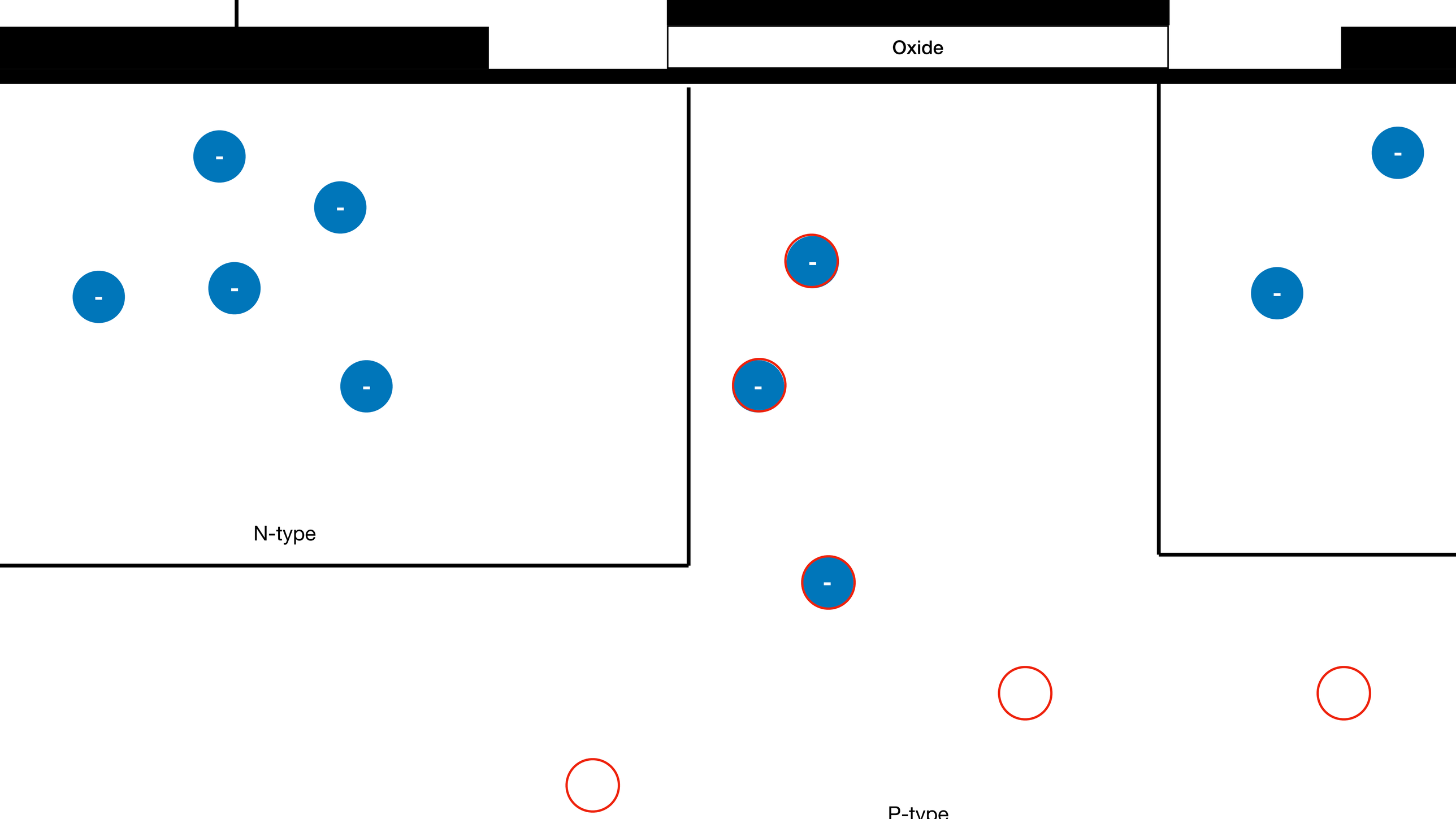


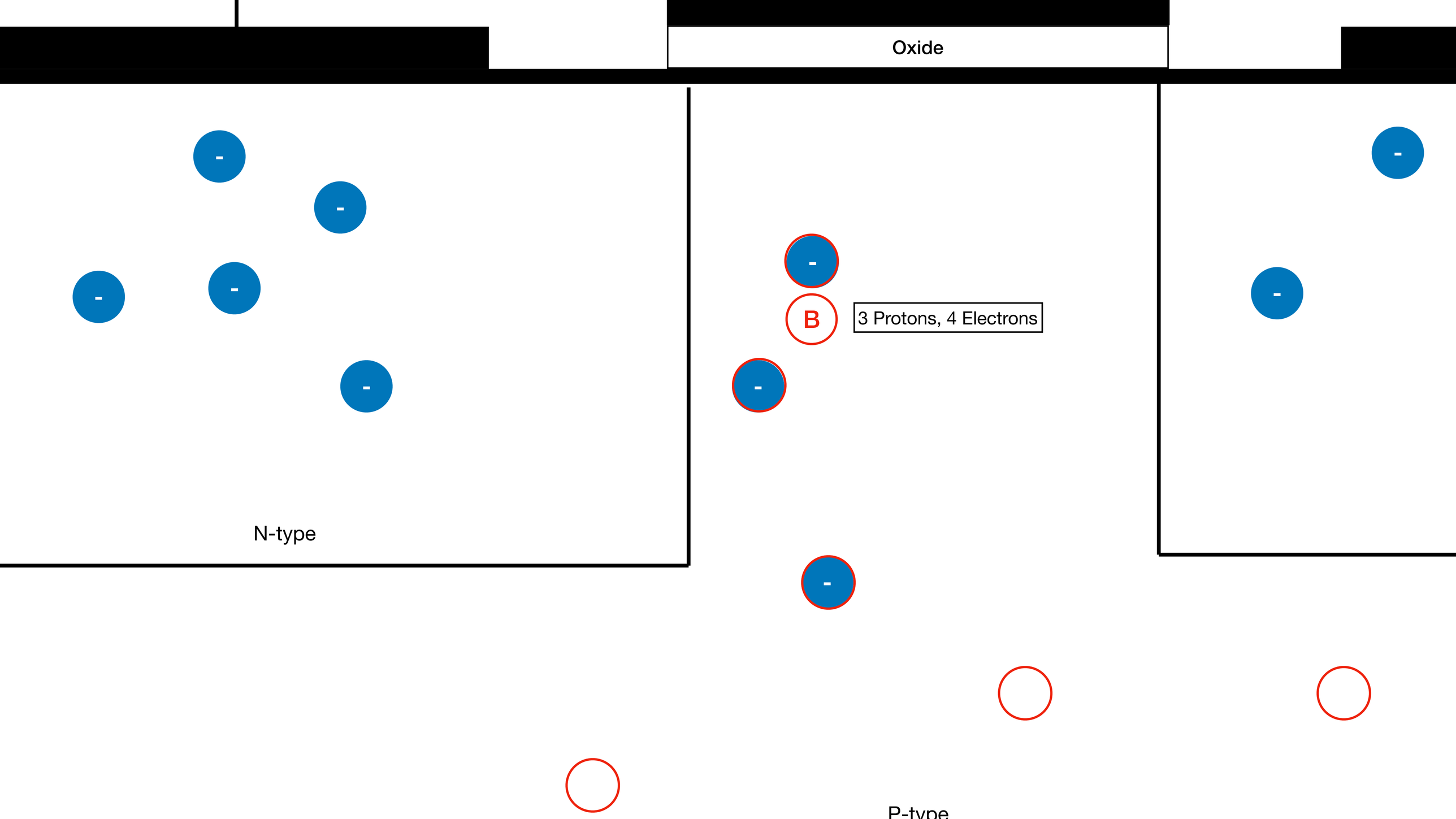
N-type Semiconductor

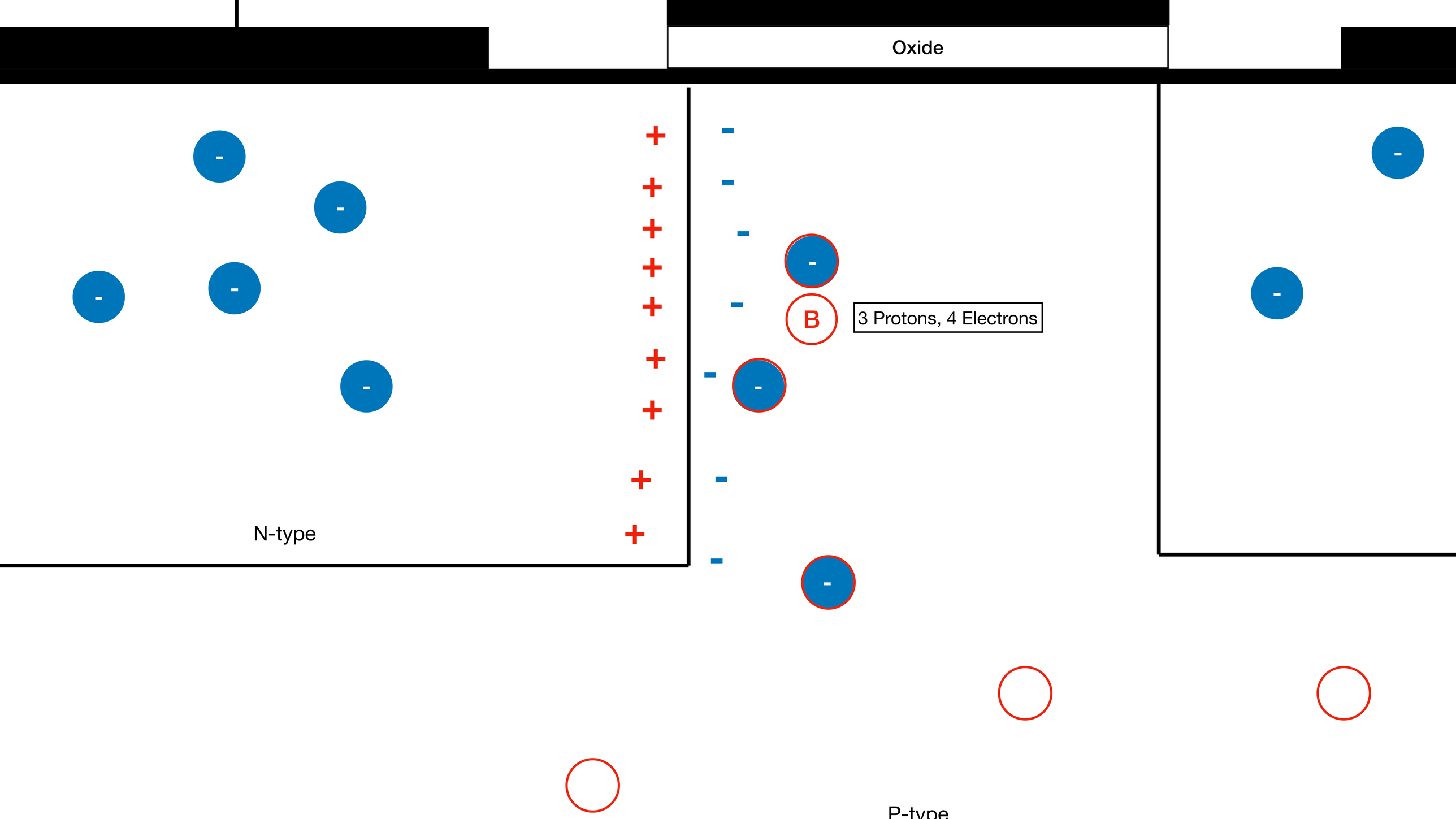

N-type
P-type
N-type

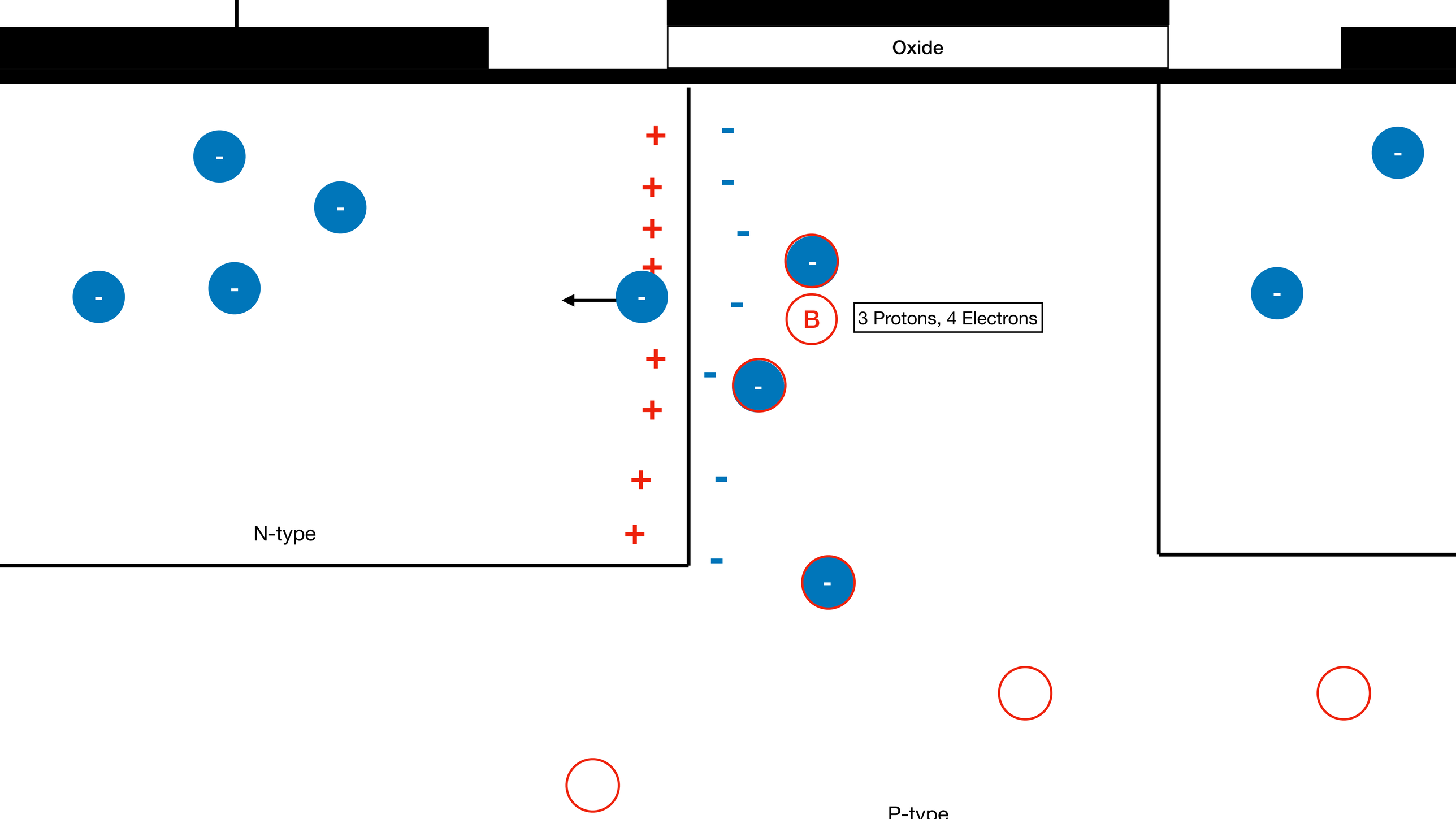

Source
Gate
Drain
Oxide
N-type
N-type
P-type

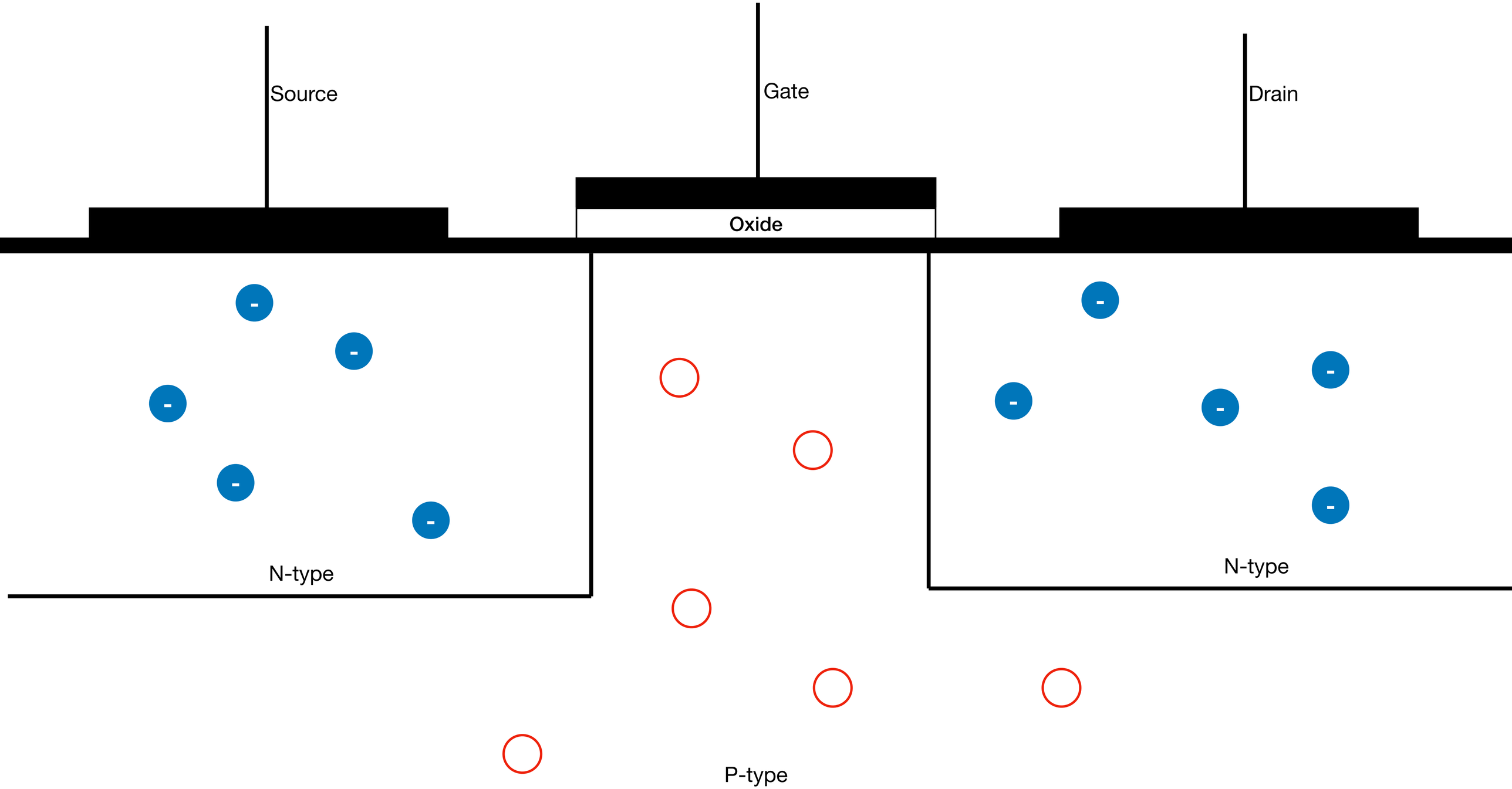

Oxide
N-type
P-type

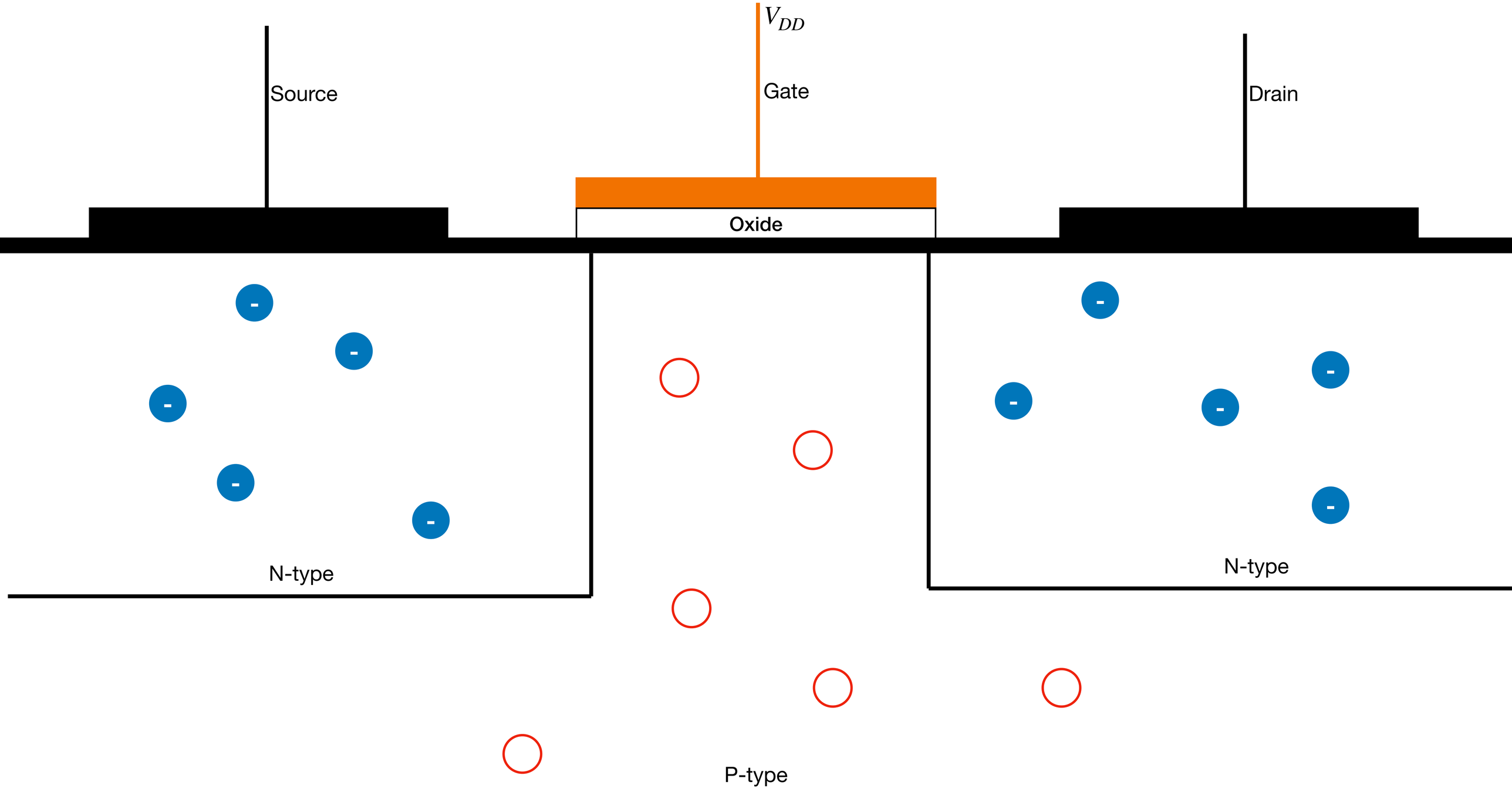

Oxide
N-type
P-type

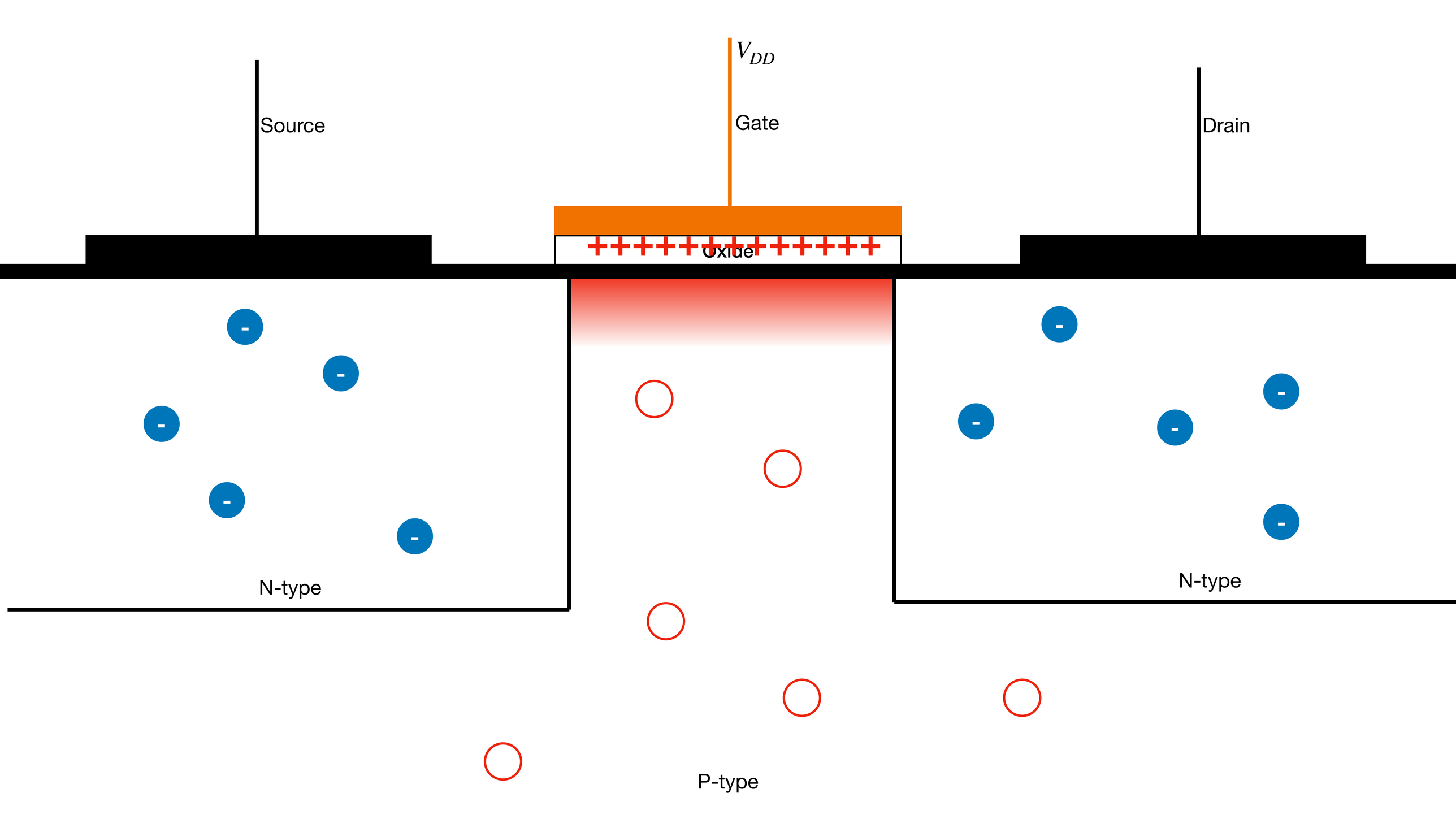

Oxide
-
-
-
-
-
-
-
-
B
3 Protons, 4 Electrons
-
N-type
P-type

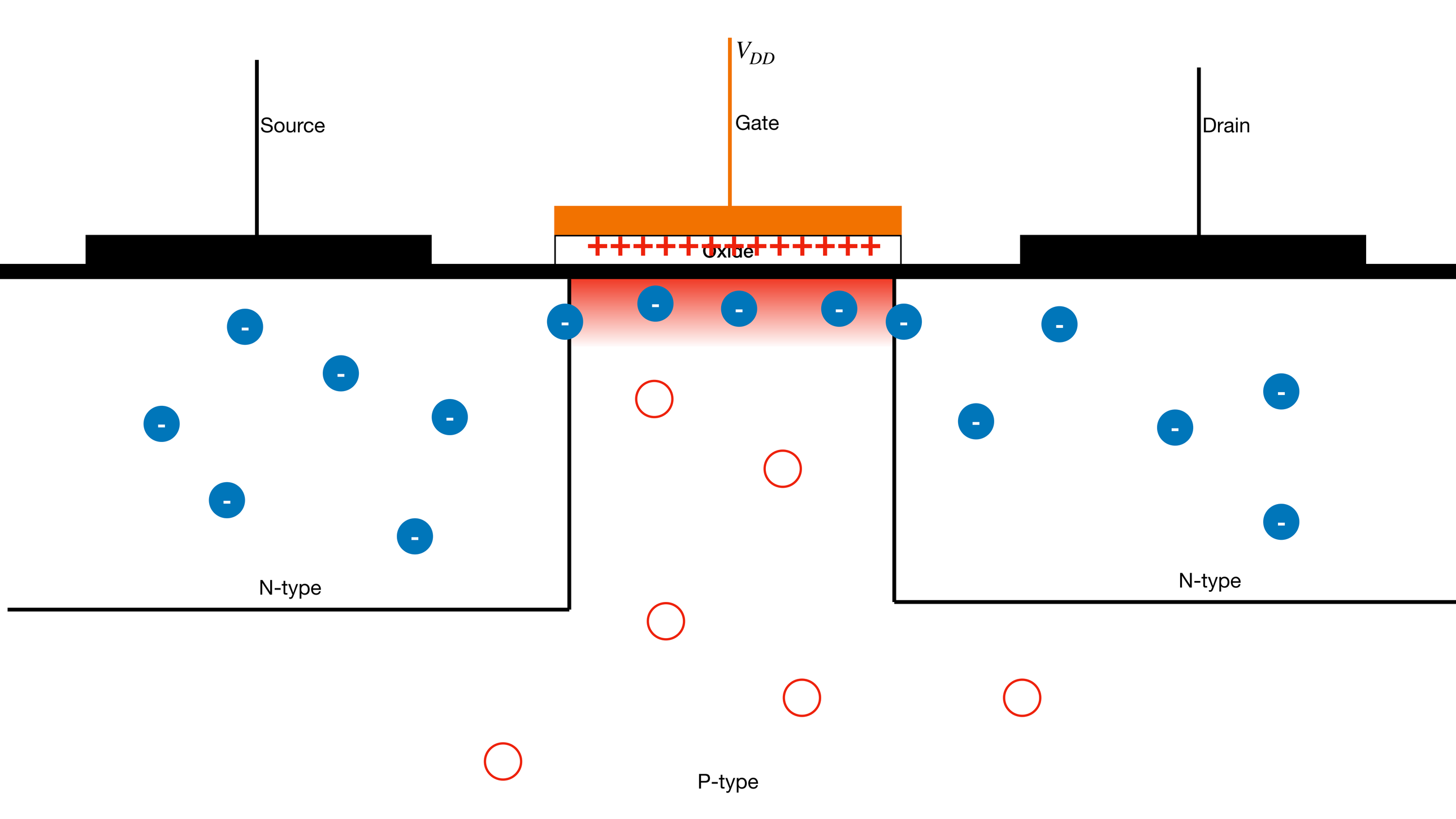

Oxide
B
3 Protons, 4 Electrons
N-type
P-type

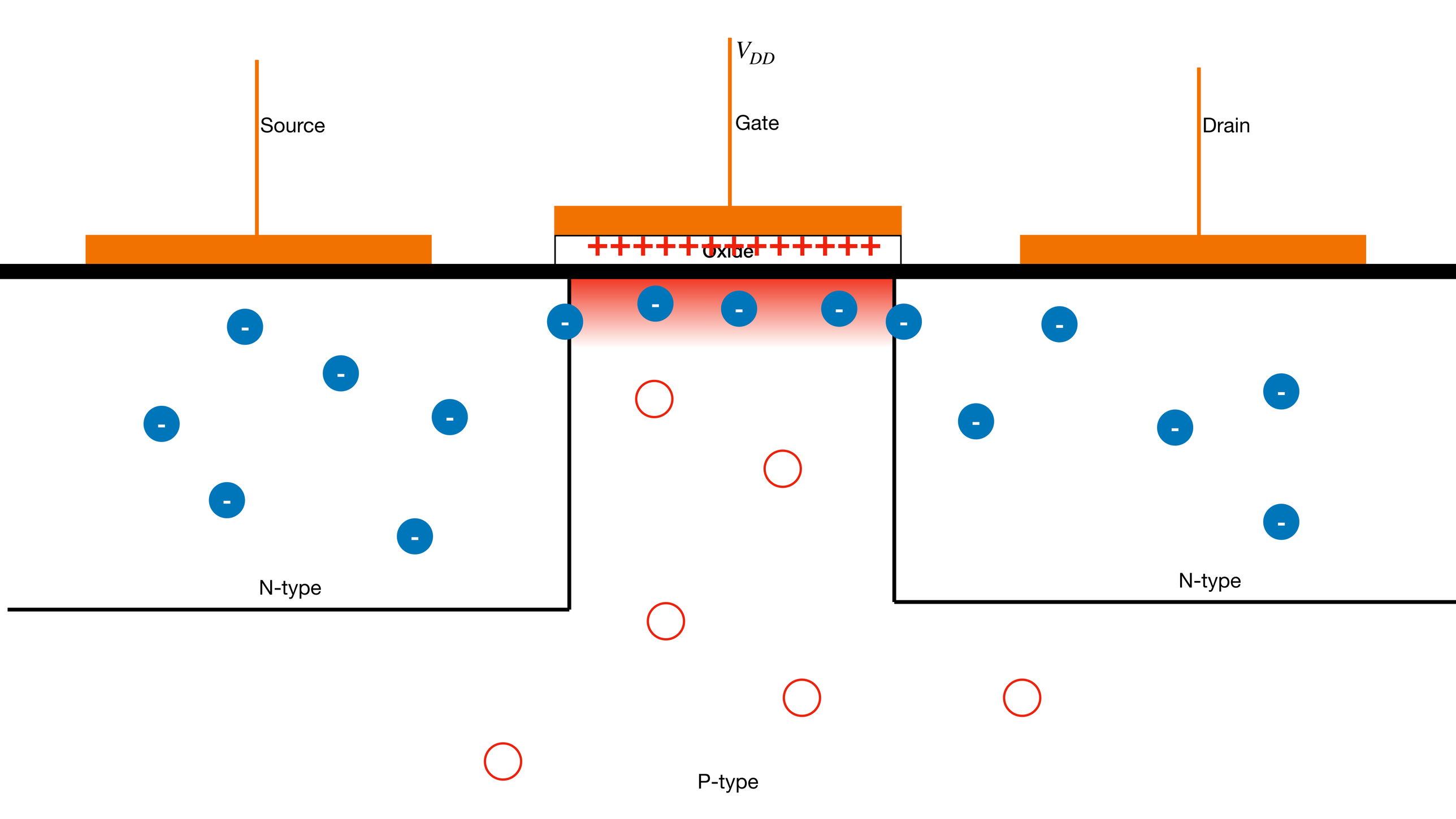

Oxide
B
3 Protons, 4 Electrons
N-type
P-type

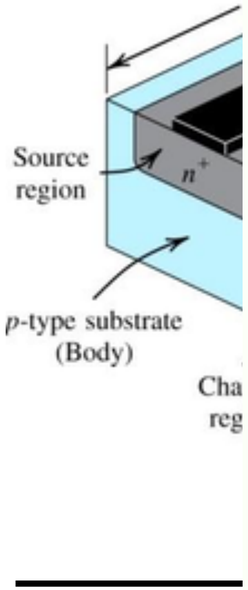

Source
Gate
Drain
Oxide
N-type
N-type
P-type

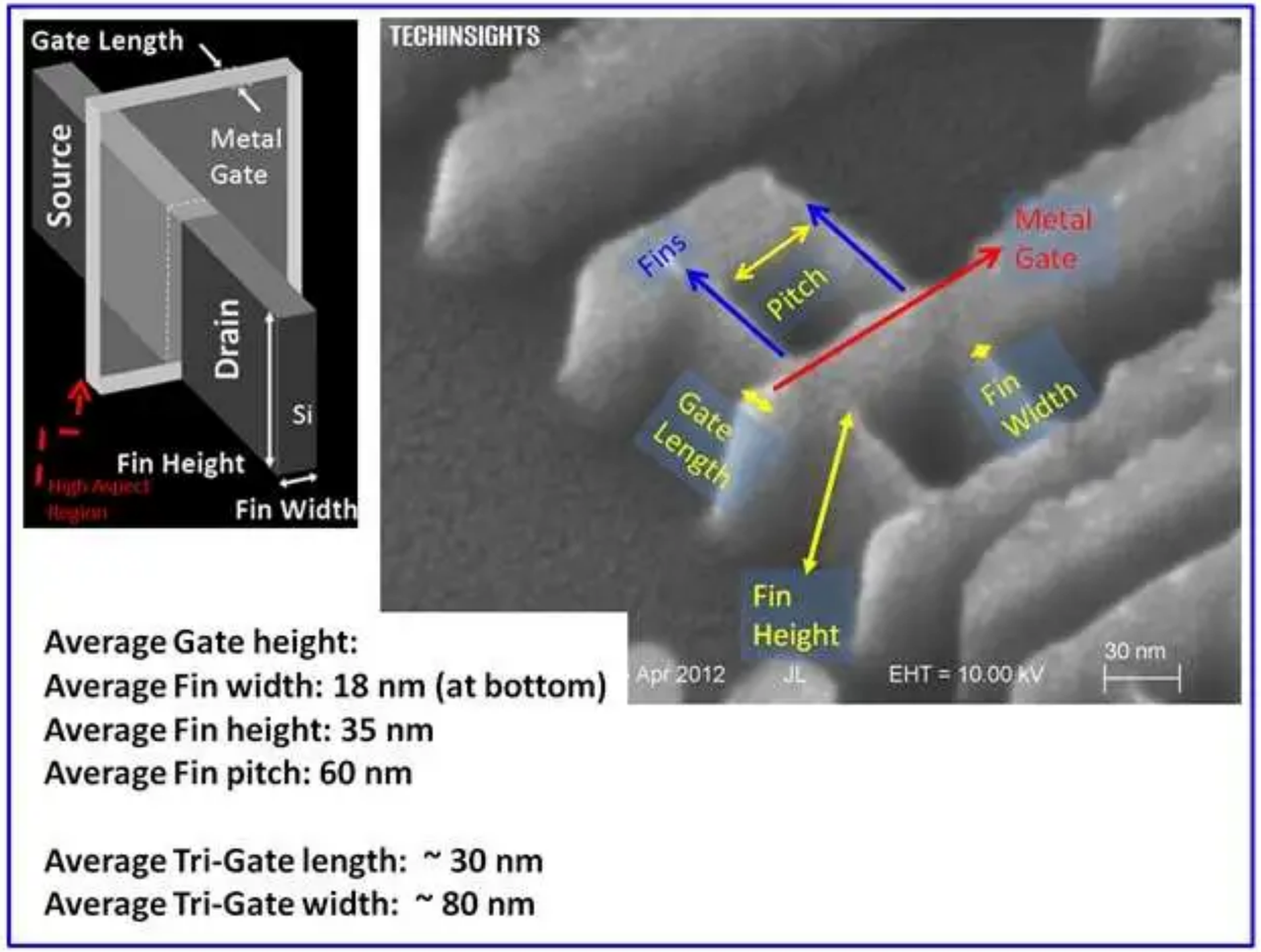

V_{DD}
Source
Gate
Drain
Oxide
N-type
N-type
P-type

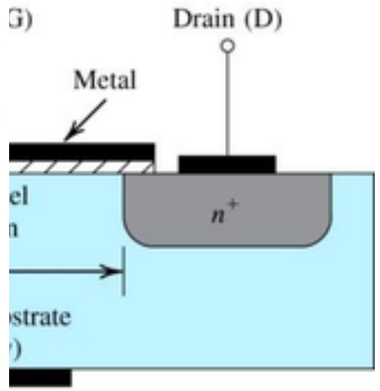

V_{DD}
Source
Gate
Drain
Oxide
N-type
N-type
P-type


V_{DD}
Source
Gate
Drain
Oxide
N-type
N-type
P-type


V_{DD}
Source
Gate
Drain
Oxide
N-type
N-type
P-type

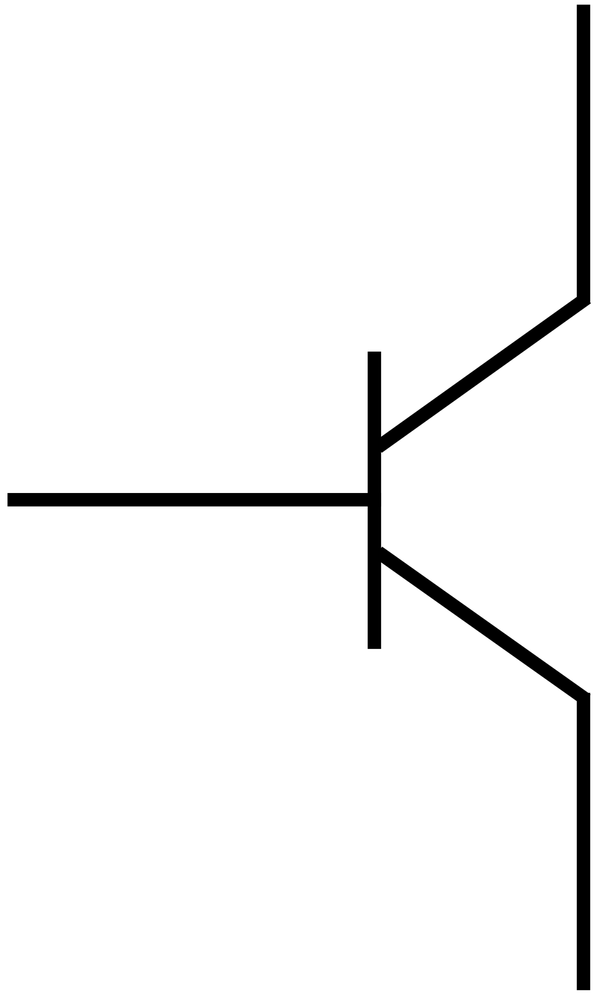


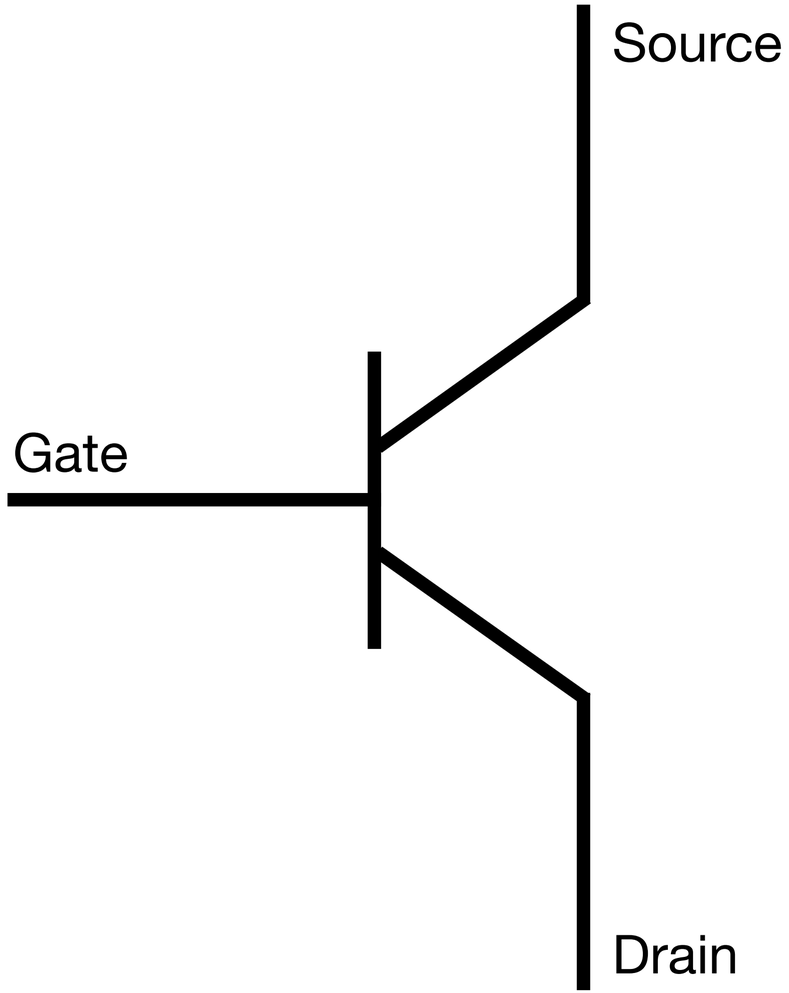


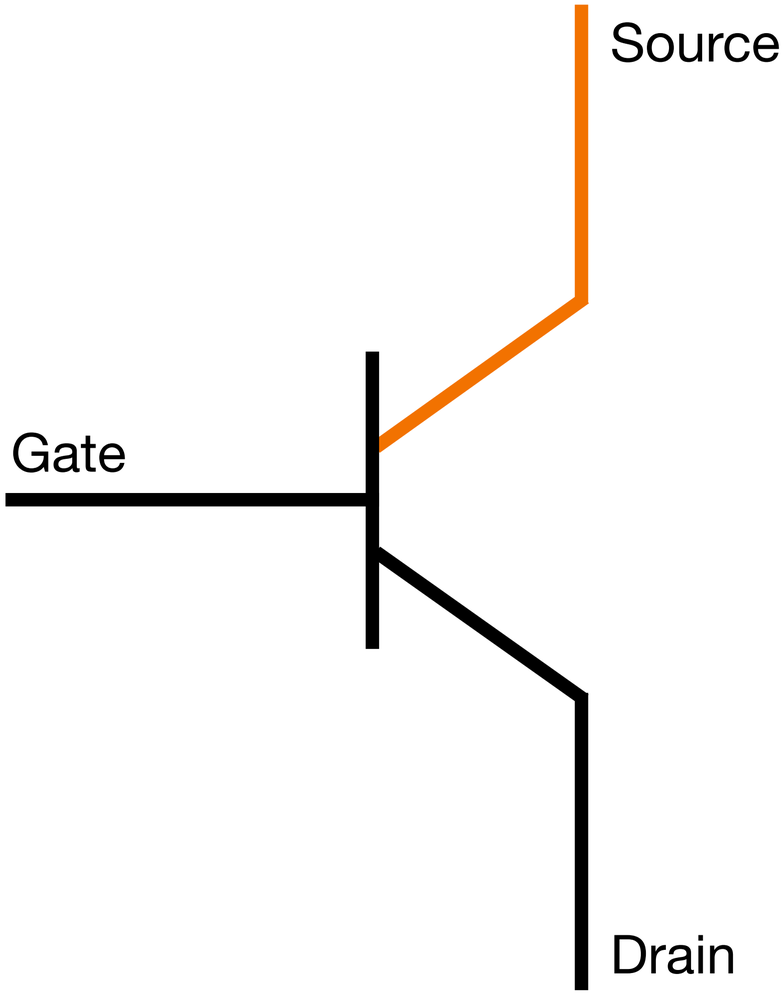


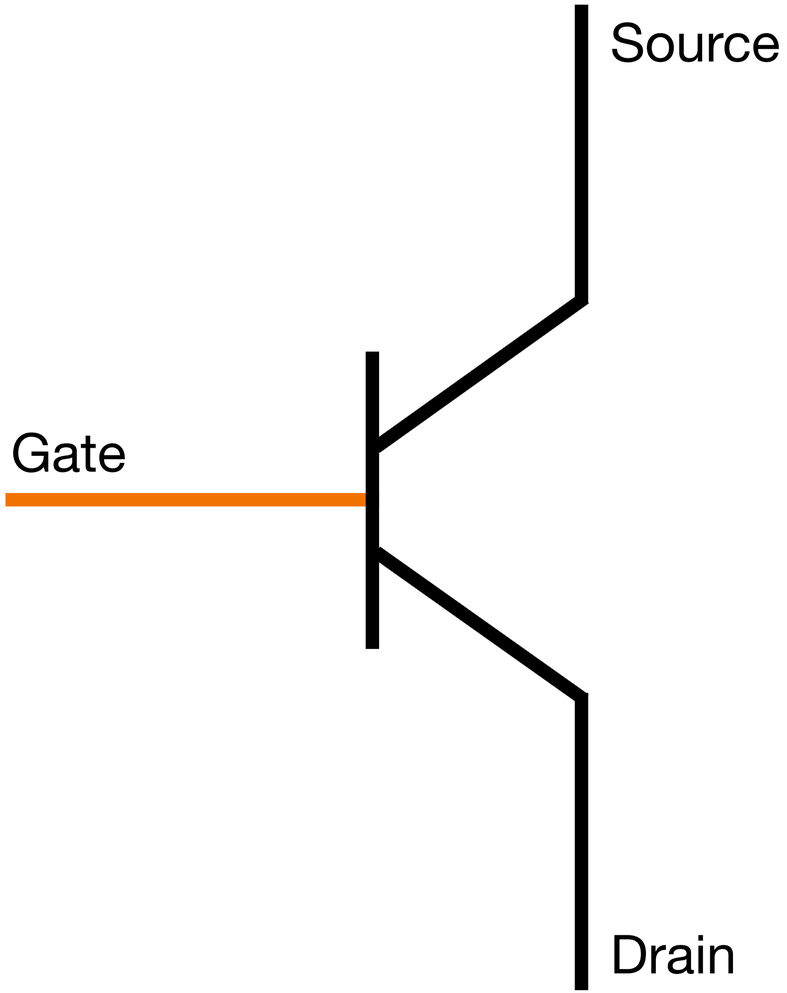
Metal
Oxide
Semiconductor
Field
Effect
Transistor

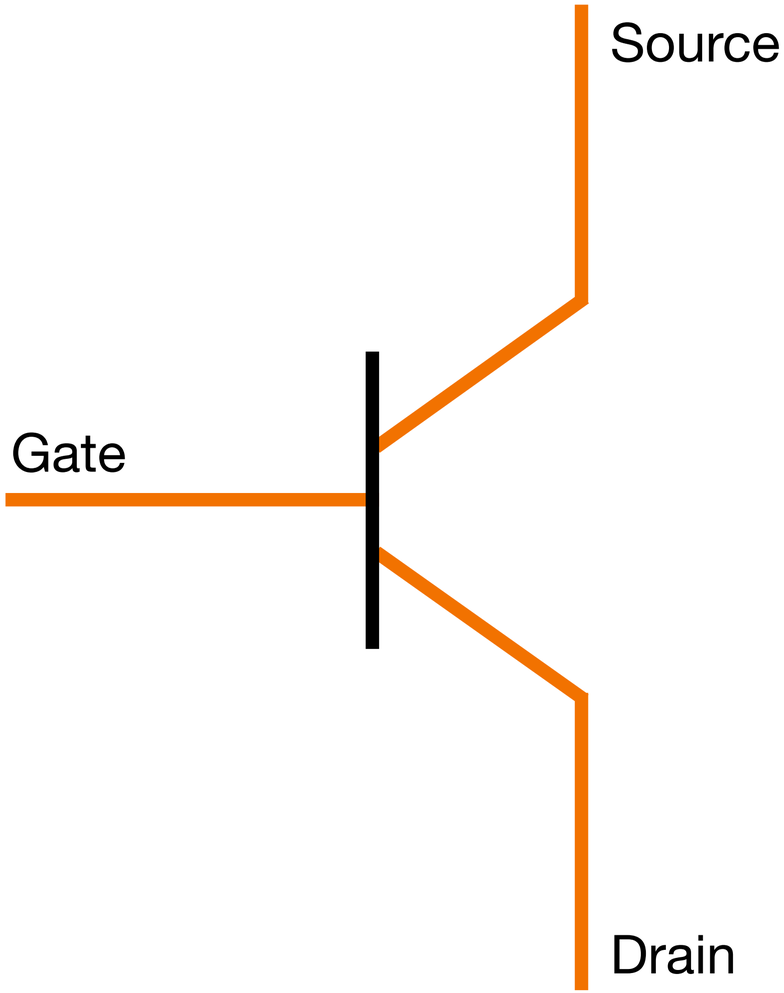
- Invented by John Bardeen, Walter Brattain, William Shockley in 1947
- Solid-state component
- Tiny -- <50 nanometers
- Really, really fast: MHz; really, really reliable




Source
Gate
Drain


Source
Gate
Drain


Source
Gate
Drain


Source
Gate
Drain

Transistors

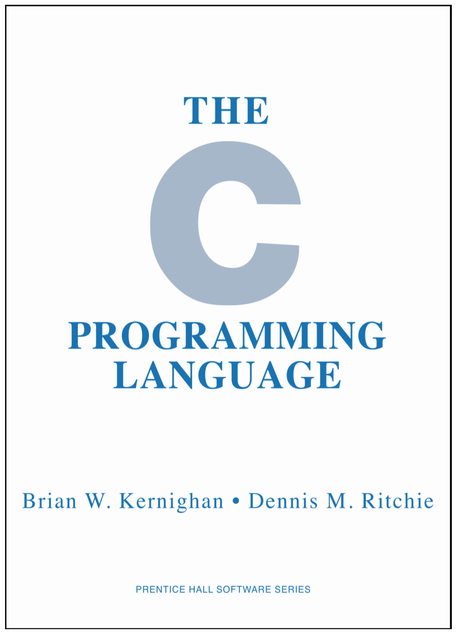
- Relay switches -> Vacuum tubes -> Solid-state transistors
- We can turn electricity on/off with electricity
- We can do it really really fast
- How does it do computation?

Information

Which one contains more information?

The Joseph Regenstein Library

This book:



Information

How about...

Eckhart Library

The John Crerar Library

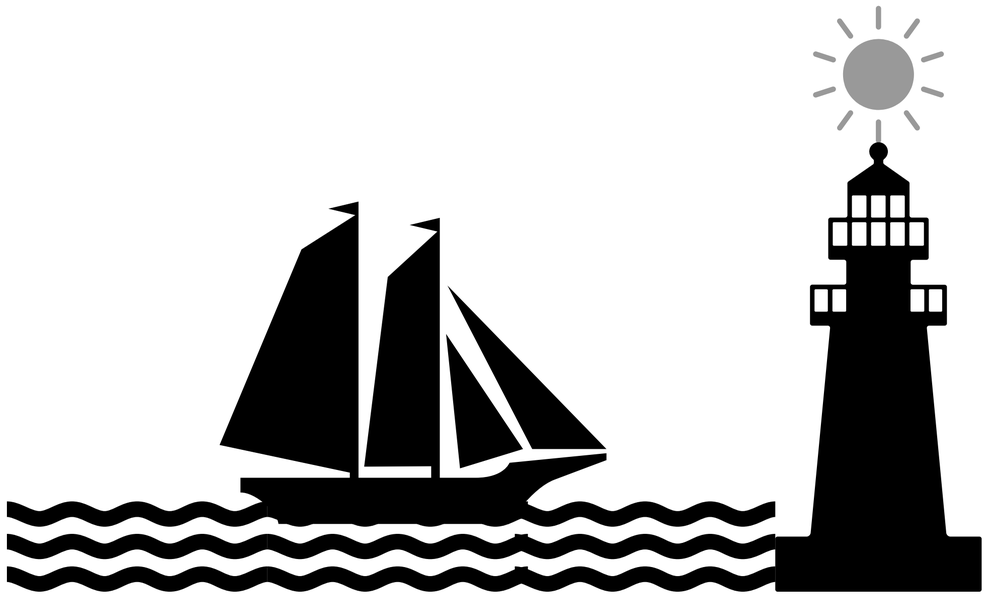
Information

- We can weigh objects
- We can determine the volume of solid objects or liquids
- We can measure the height of walls in this room

- Can we measure information?
- Can we distinguish more information from less?
- What is the unit of information?

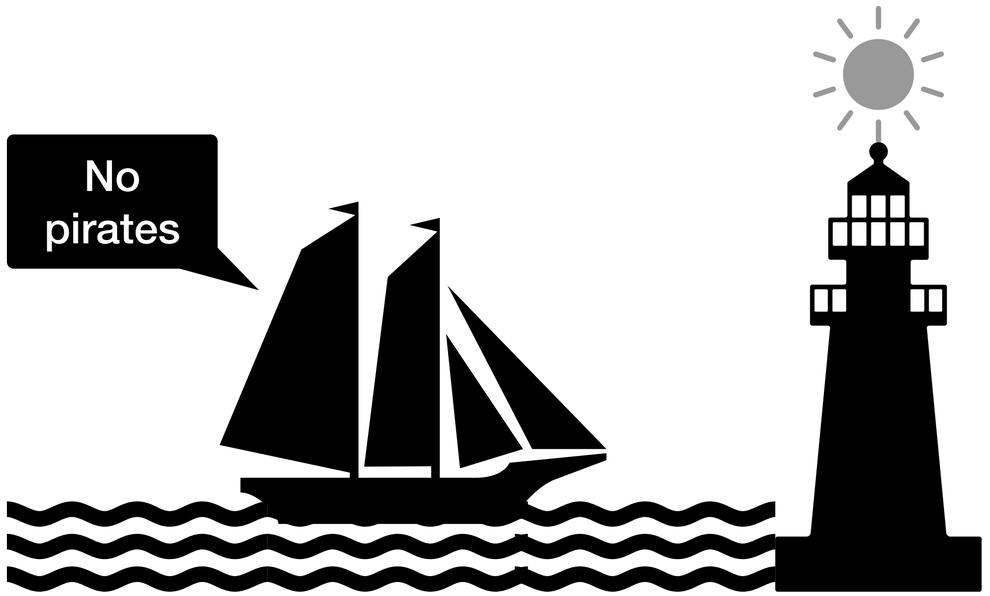
Information

- Example: a lighthouse operator and the captain wanted to communicate if there are pirates ahead. What is the shortest message the lighthouse can send?



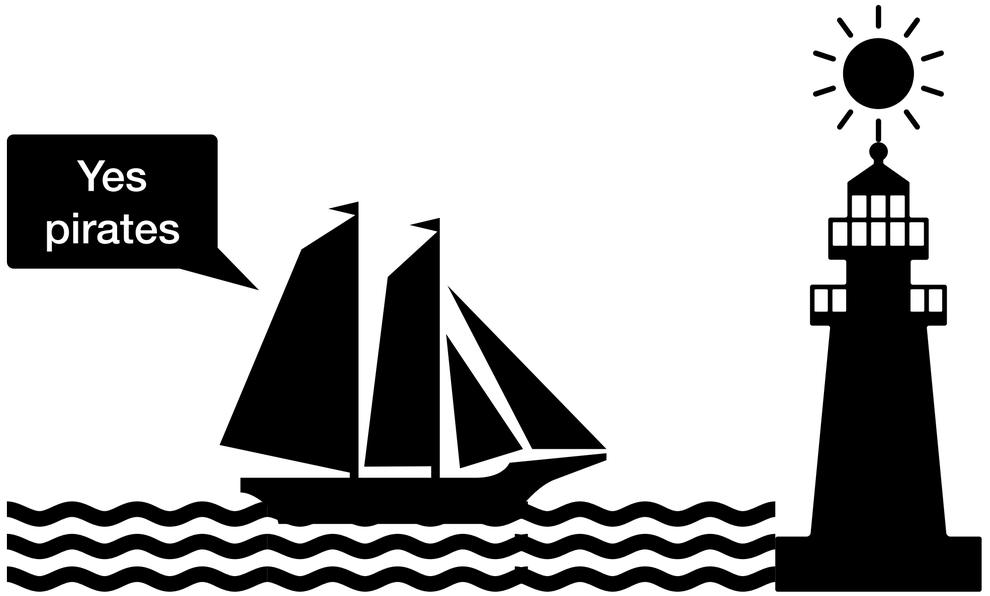
Information

- Example: a lighthouse operator and the captain wanted to communicate if there are pirates ahead. What is the shortest message the lighthouse can send?
- They agree ahead of time:
  - light off -> no pirates



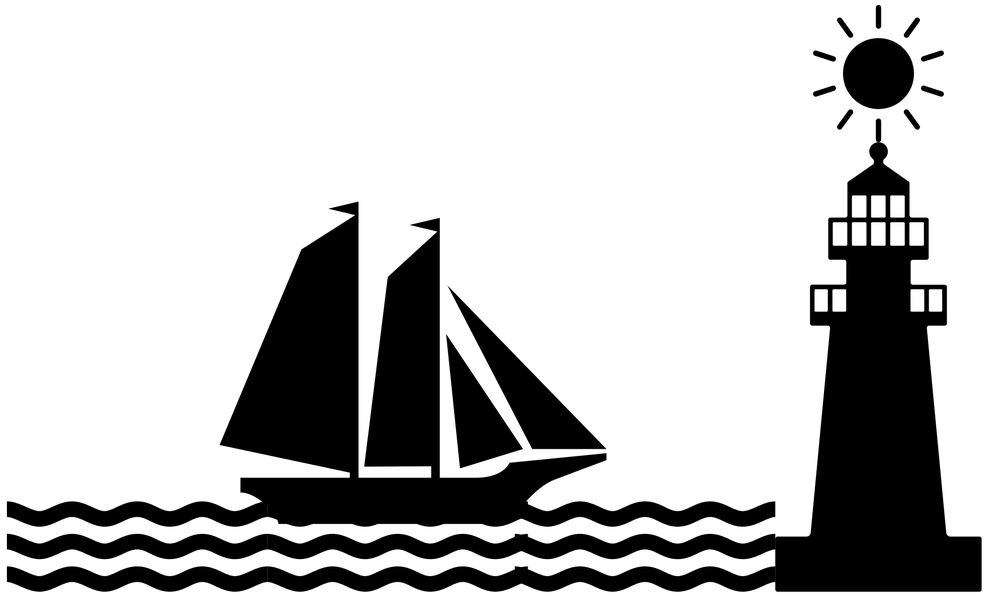
Information

- Example: a lighthouse operator and the captain wanted to communicate if there are pirates ahead. What is the shortest message the lighthouse can send?
- They agree ahead of time:
  - light off -> no pirates
  - light on -> yes pirates



Information

- Example: a lighthouse operator and the captain wanted to communicate if there are pirates ahead *and* *if there is an iceberg*.



Information

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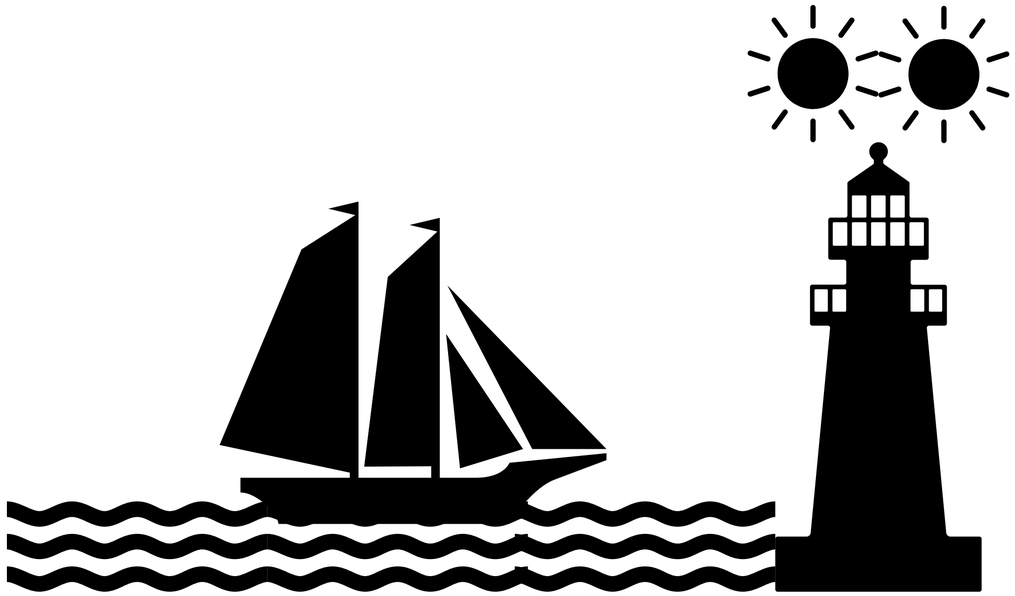
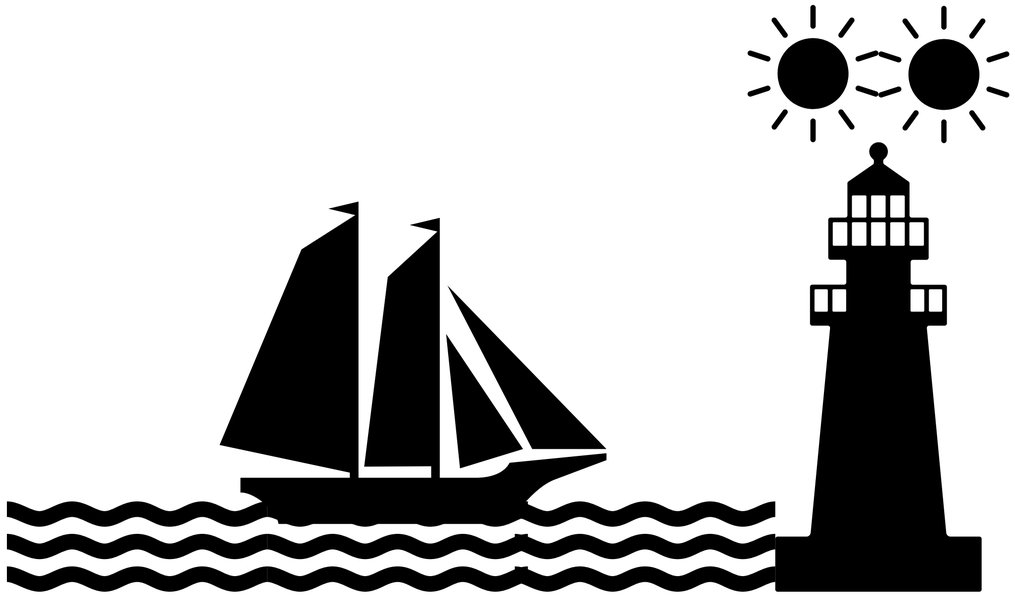


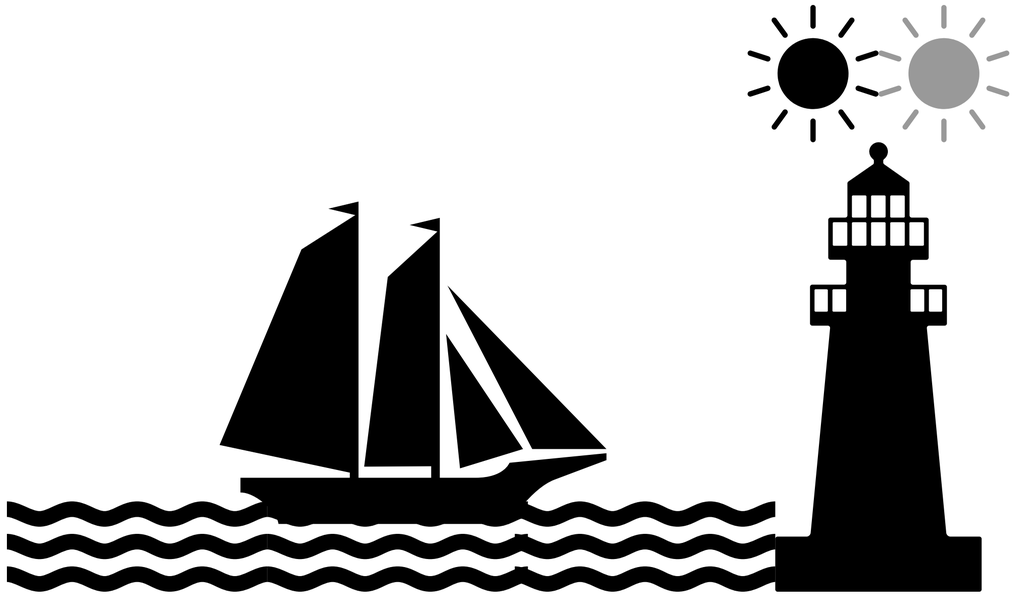
Information

- Example: a lighthouse operator and the captain wanted to communicate if there are pirates ahead *and if there is an iceberg.*
- Agree in advance:
  - On, On -> pirates and icebergs



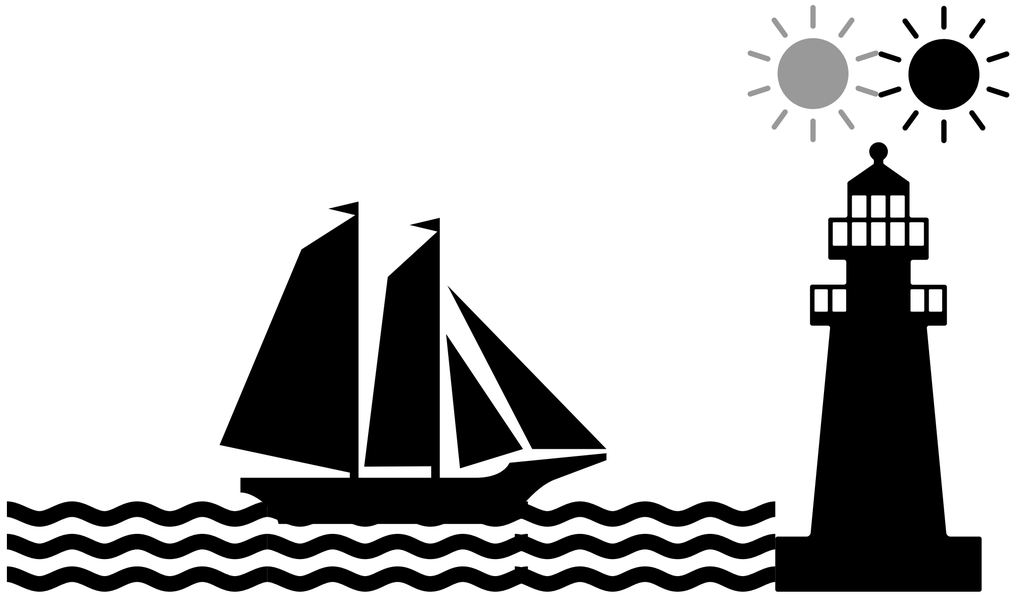
Information

- Example: a lighthouse operator and the captain wanted to communicate if there are pirates ahead *and if there is an iceberg.*
- Agree in advance:
  - On, On -> pirates and icebergs
  - On, Off -> only pirates



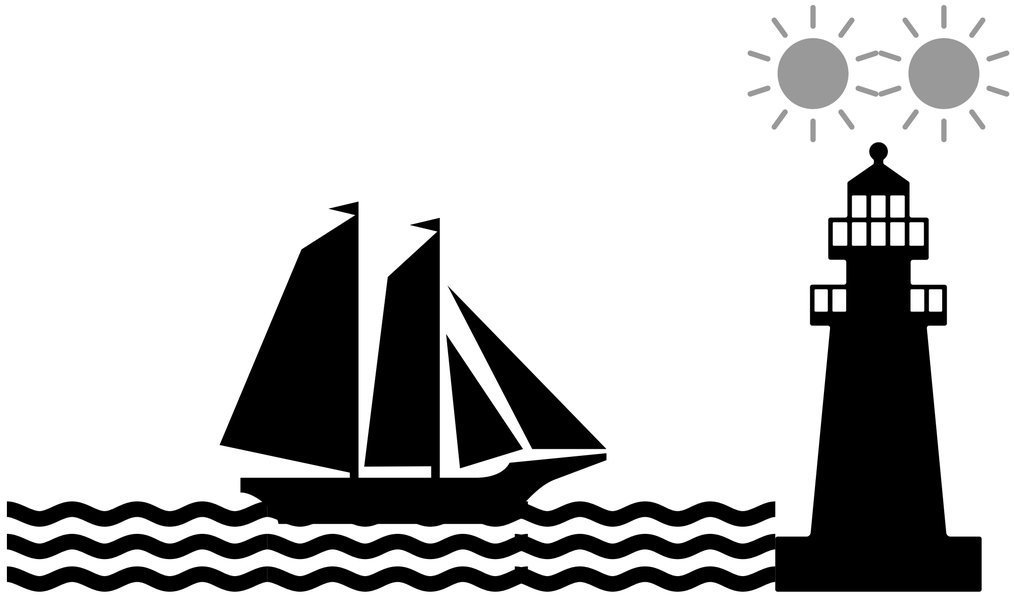
Information

- Example: a lighthouse operator and the captain wanted to communicate if there are pirates ahead *and if there is an iceberg.*
- Agree in advance:
  - On, On -> pirates and icebergs
  - On, Off -> only pirates
  - Off, On -> only iceberg

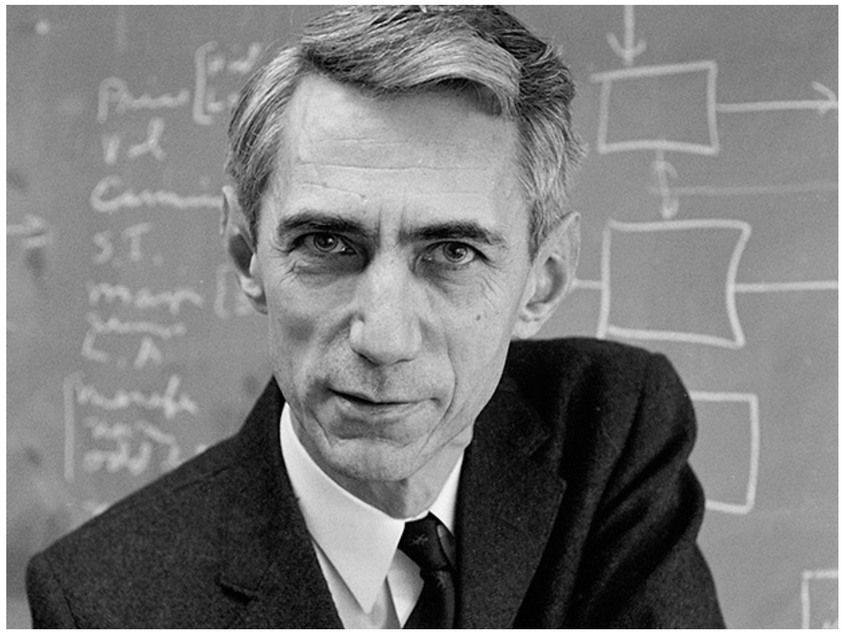


Information

- Example: a lighthouse operator and the captain wanted to communicate if there are pirates ahead *and if there is an iceberg.*
- Agree in advance:
  - On, On -> pirates and icebergs
  - On, Off -> only pirates
  - Off, On -> only iceberg
  - Off, Off -> neither



Information



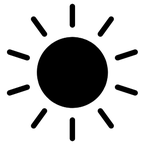
- Claude Shannon (1916 - 2001):
- *A Mathematical Theory of Communication* (1948)

Information

- Insight: whenever two parties communicate, each message is answering one or more yes-or-no questions.
- We call each answer *a bit*.
- Information can be measured in bits.
- "A Symbolic Analysis of Relay and Switching Circuits." Shannon 1938.
- In computers, "on," when the voltage is *high*, represents "yes" or "true;" "off," when the voltage is *low*, represents "no" or "false."
- This is called binary.

Information

Why "yes" or "no"?

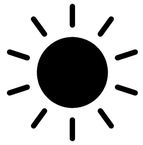


Yes

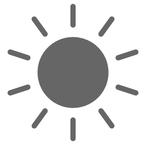
No

Information

Why "yes" or "no"?



Yes



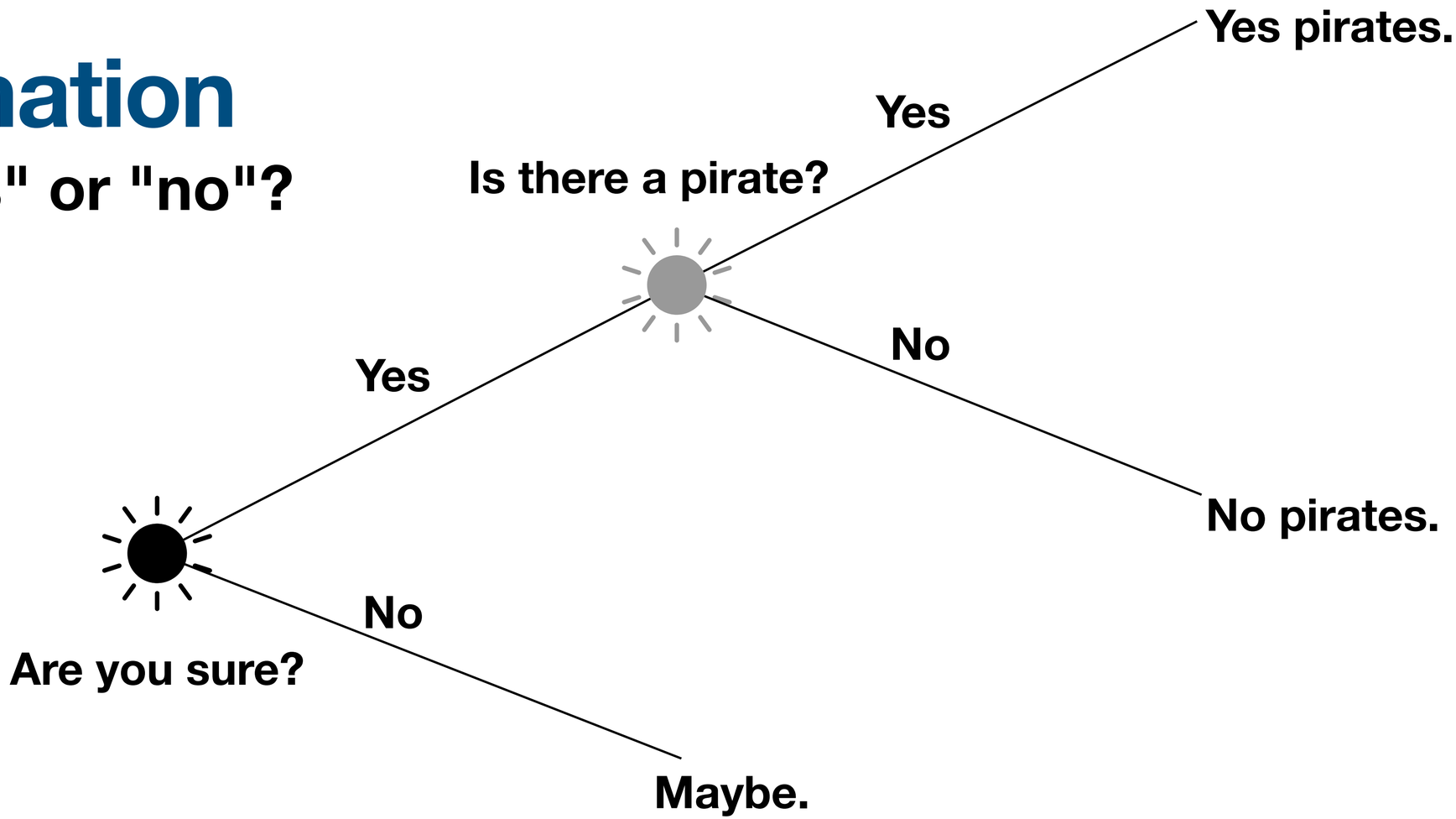
Maybe?

No

- CS answer: "yes" or "no" is the most reduced form.

Information

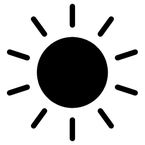
Why "yes" or "no"?



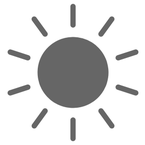
- CS answer: "yes" or "no" is the most reduced form.

Information

Why "yes" or "no"?



Yes



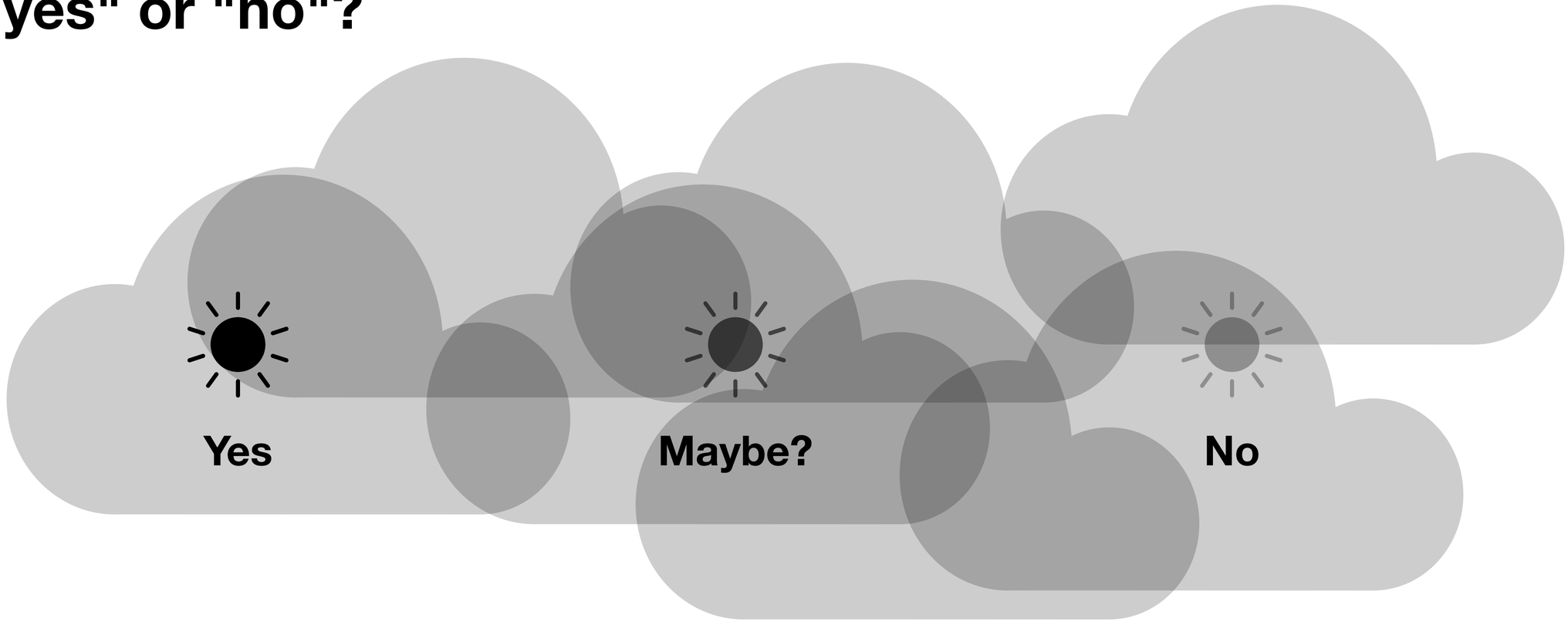
Maybe?

No

- EE answer: the two options can survive a lot of noise.

Information

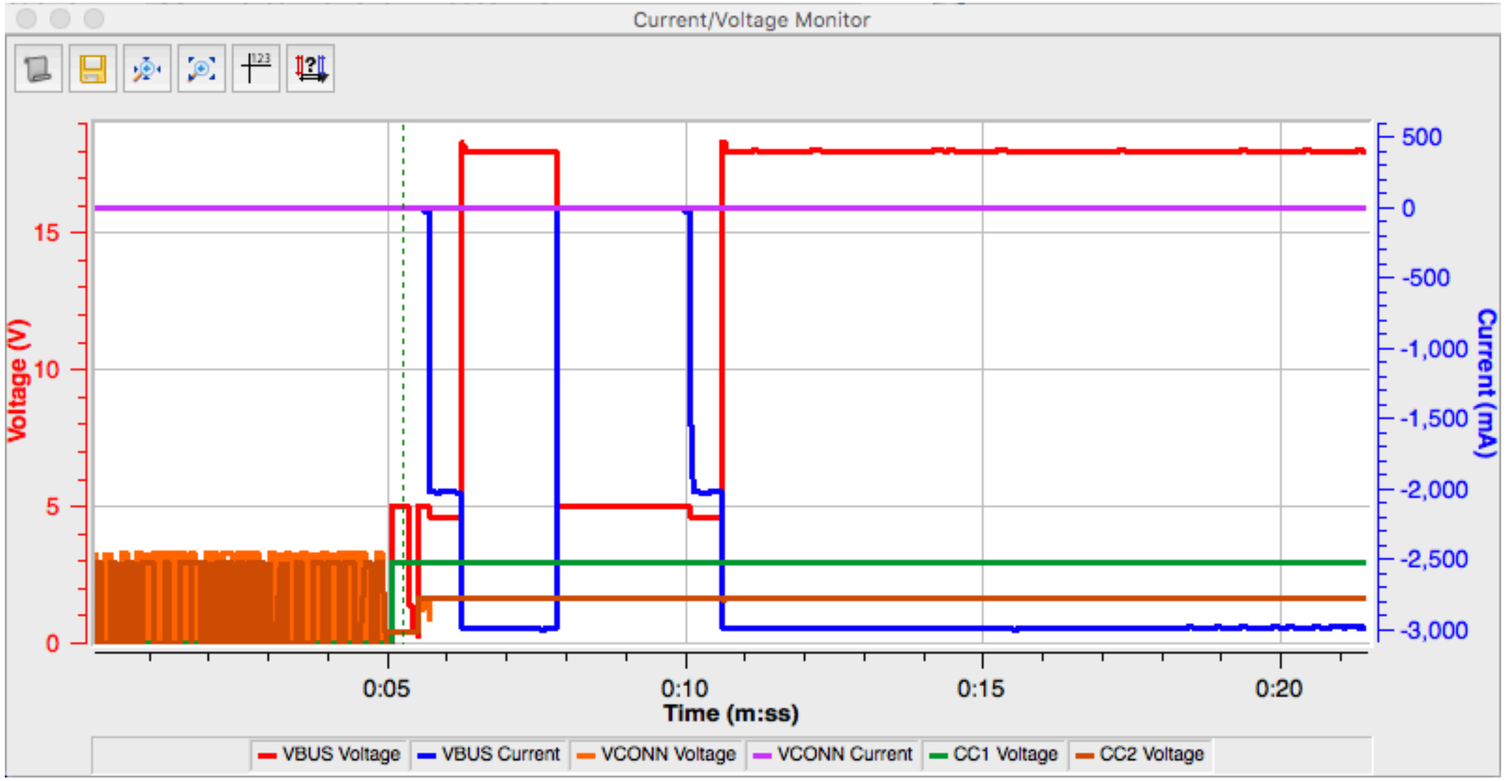
Why "yes" or "no"?



- EE answer: the two options can survive a lot of noise.

Information

Why "yes" or "no"?



- EE answer: the two options can survive a lot of noise.

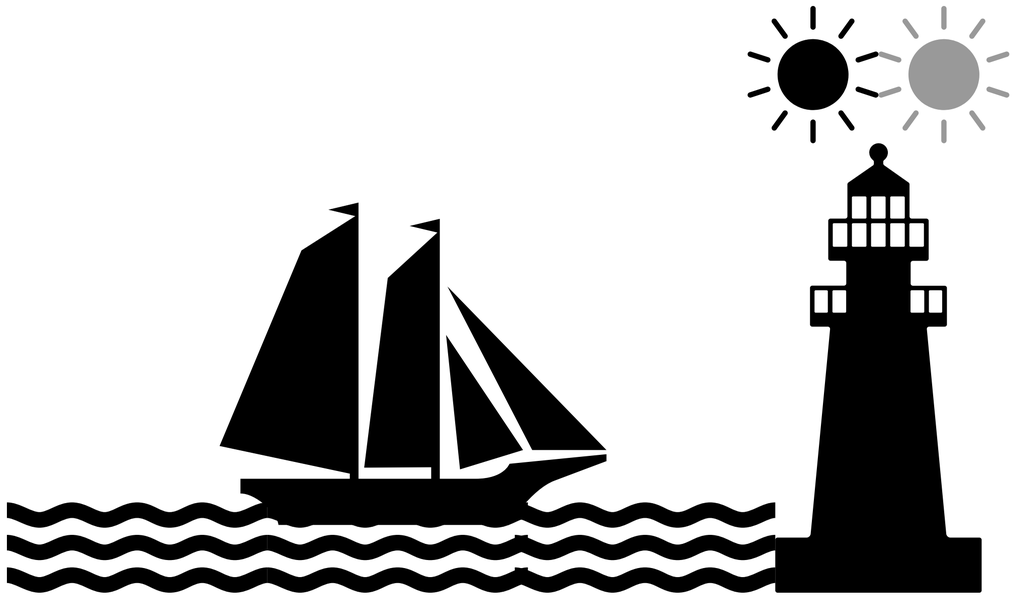
Information

- Just saying "yes" or "no" isn't enough
  - We don't know what *questions* they answer
- We have to agree ahead of time what the choices are.
- The more choices we have to make, the more answers we'll have to communicate.

Information

Protocol

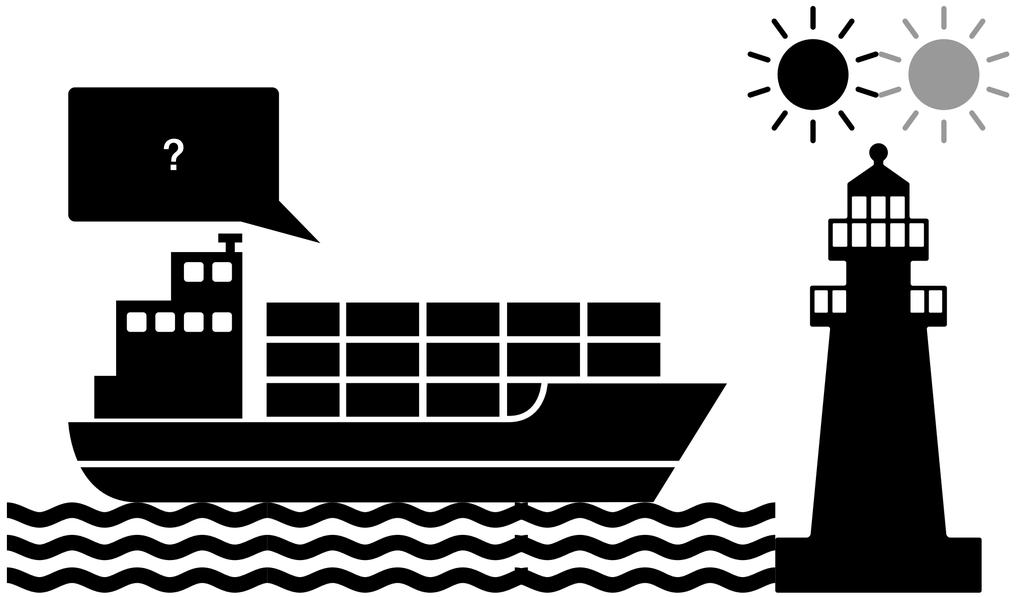
- The captain and the lighthouse *must* agree on the choices in advance.
  - How many choices?
  - Which light answers which?



Information

Protocol

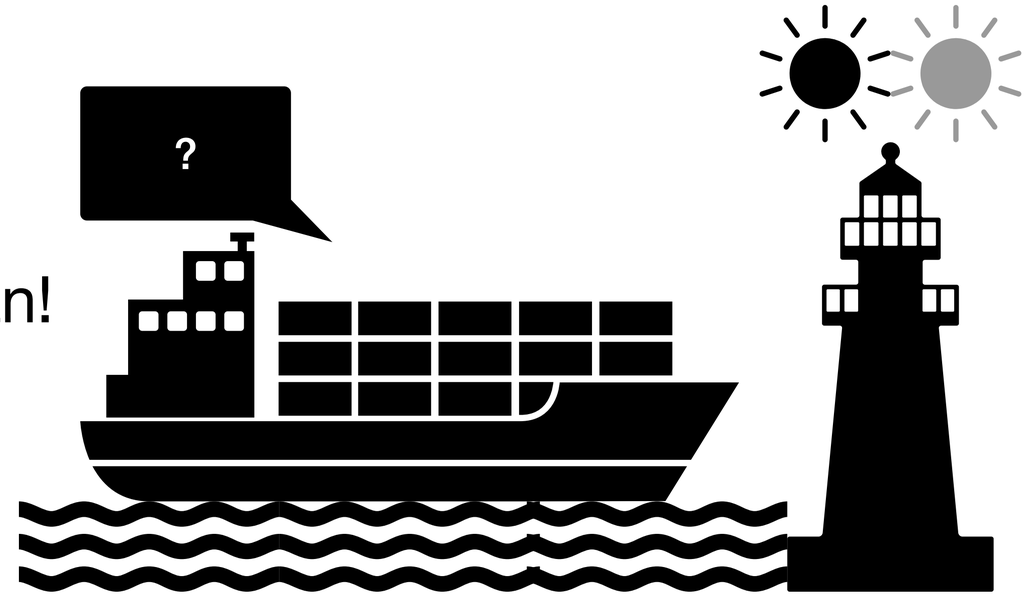
- The captain and the lighthouse *must* agree on the choices in advance.
  - How many choices?
  - Which light answers which?



Information

Protocol

- The captain and the lighthouse *must* agree on the choices in advance.
  - How many choices?
  - Which light answers which?
- If you don't know the context, you don't know what the bits mean!
- This is why we need file format, types, protocols, ...



Information

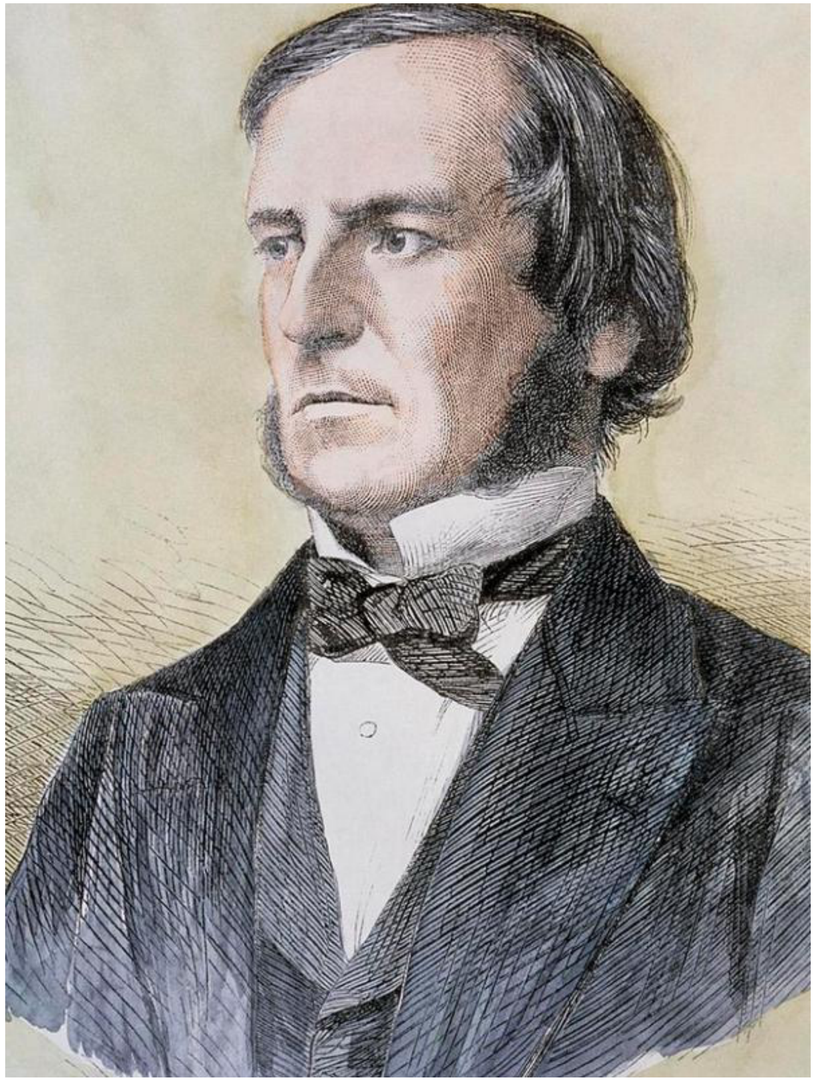
Bits

- A bit is an answer to a yes-no question
- We can model information as a series of yes-no questions
- In order to communicate in bits, we must know:
  - what the questions are;
  - which bit answers which question.
- If we have n bits, we have 2^n choices to communicate.
- If we have n choices to communicate, we need $\lceil \log_2 n \rceil$ bits.

Information

Bits

- George Boole (1814-1864) (49 years)
- "The Mathematical Analysis of Logic." (1847)
- A systematic processing of truth values: Boolean algebra:
  - True and False
  - And, Or, Not
- Transistors can be used to implement Boolean algebra!



Not

Input	Output
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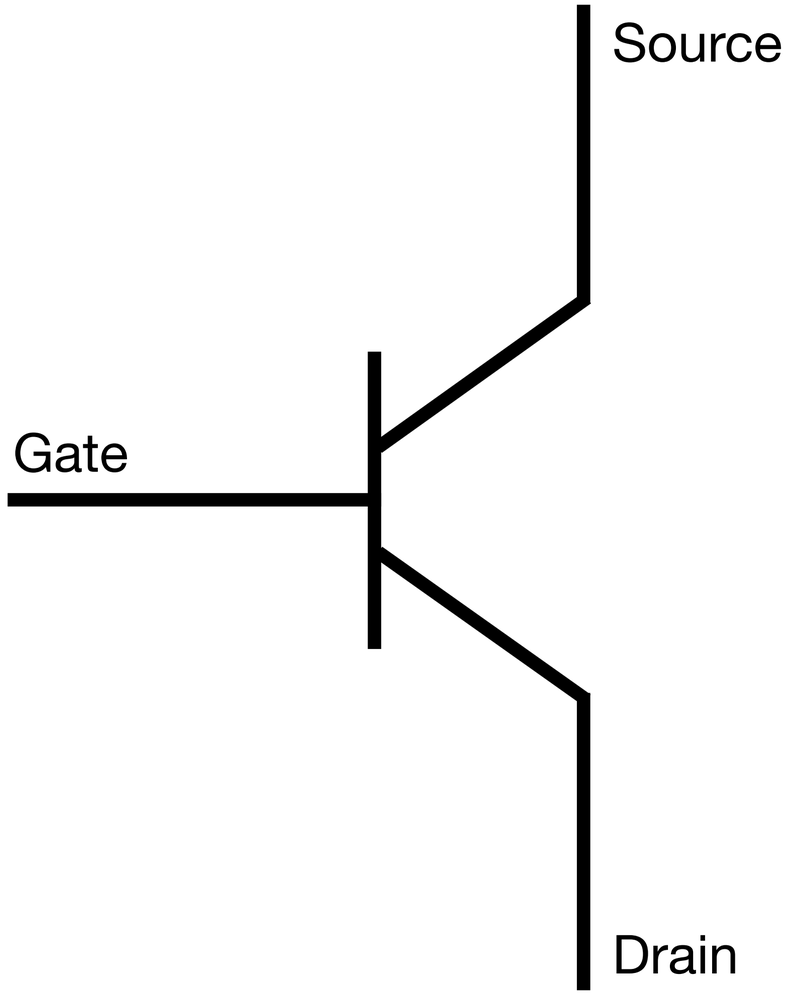
FALSE	TRUE



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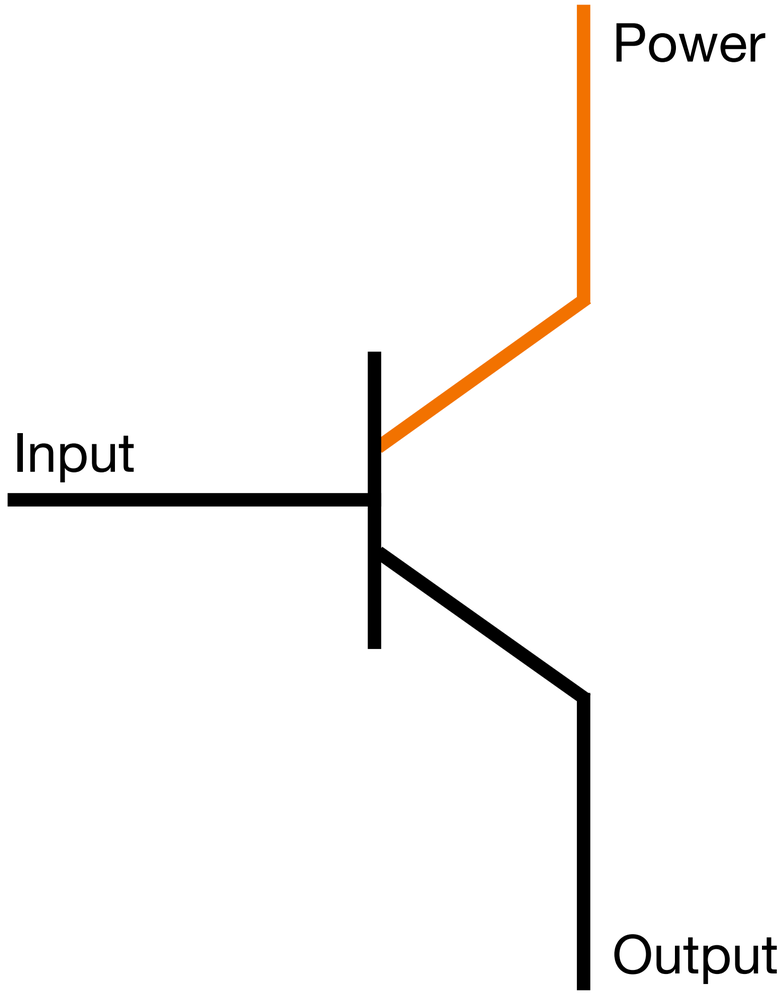

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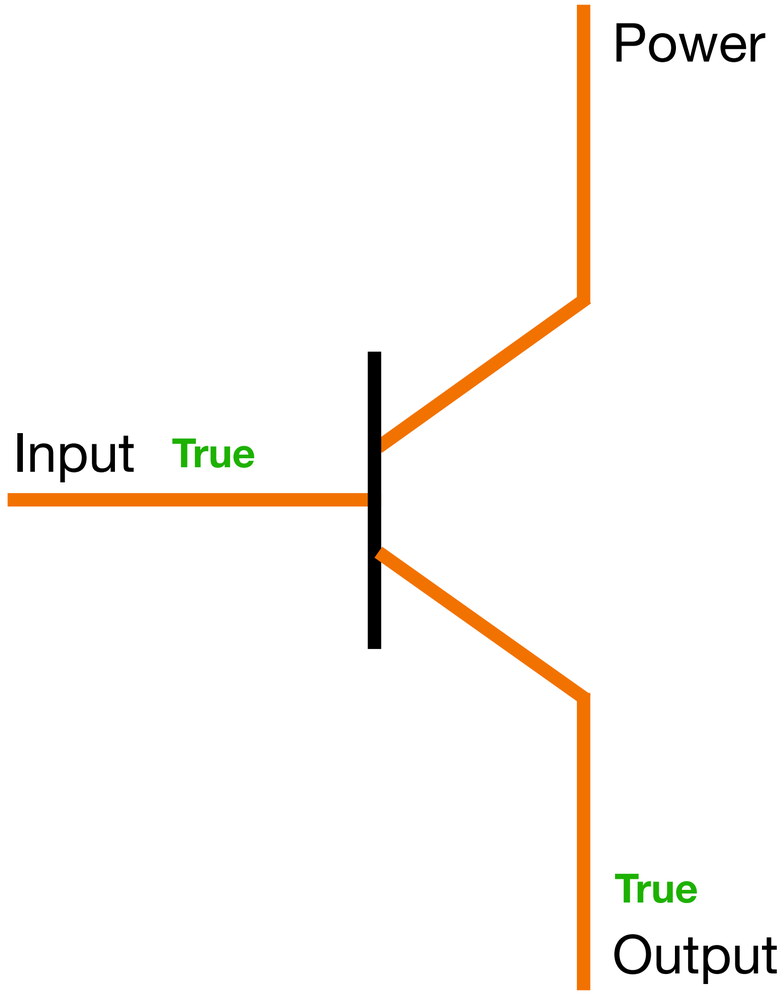

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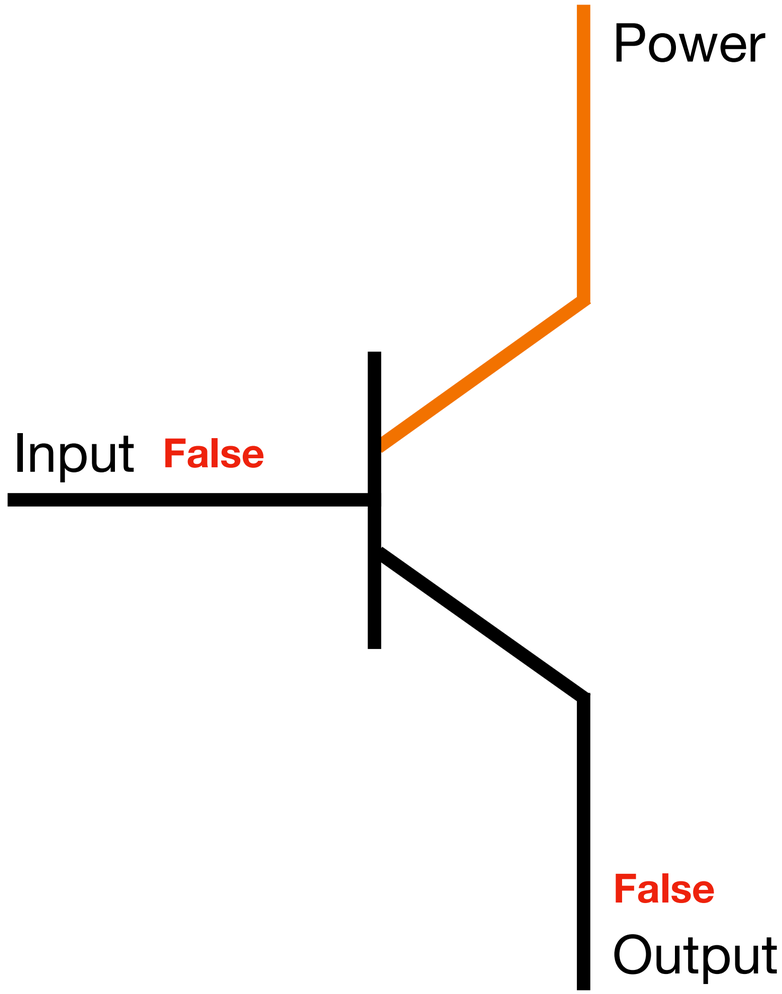

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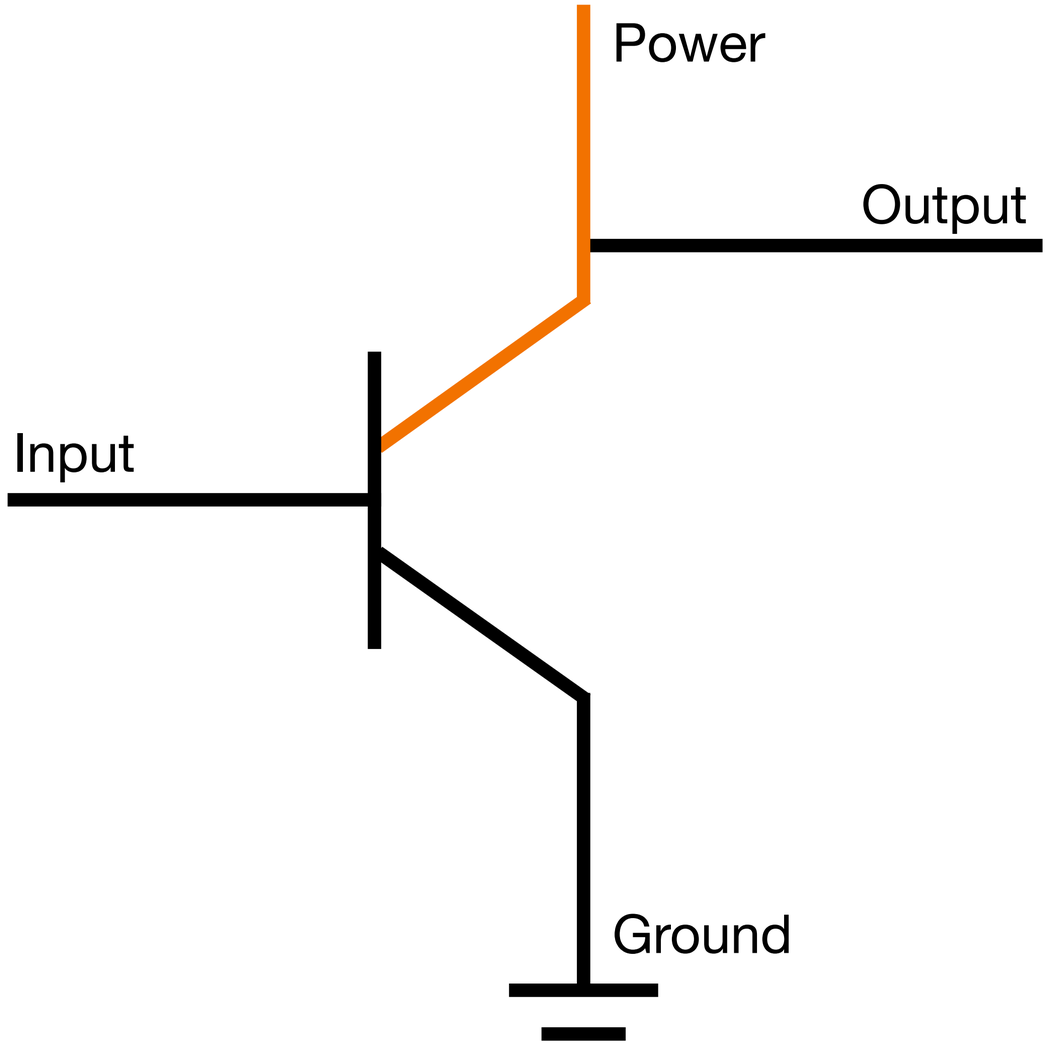

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Input	Output
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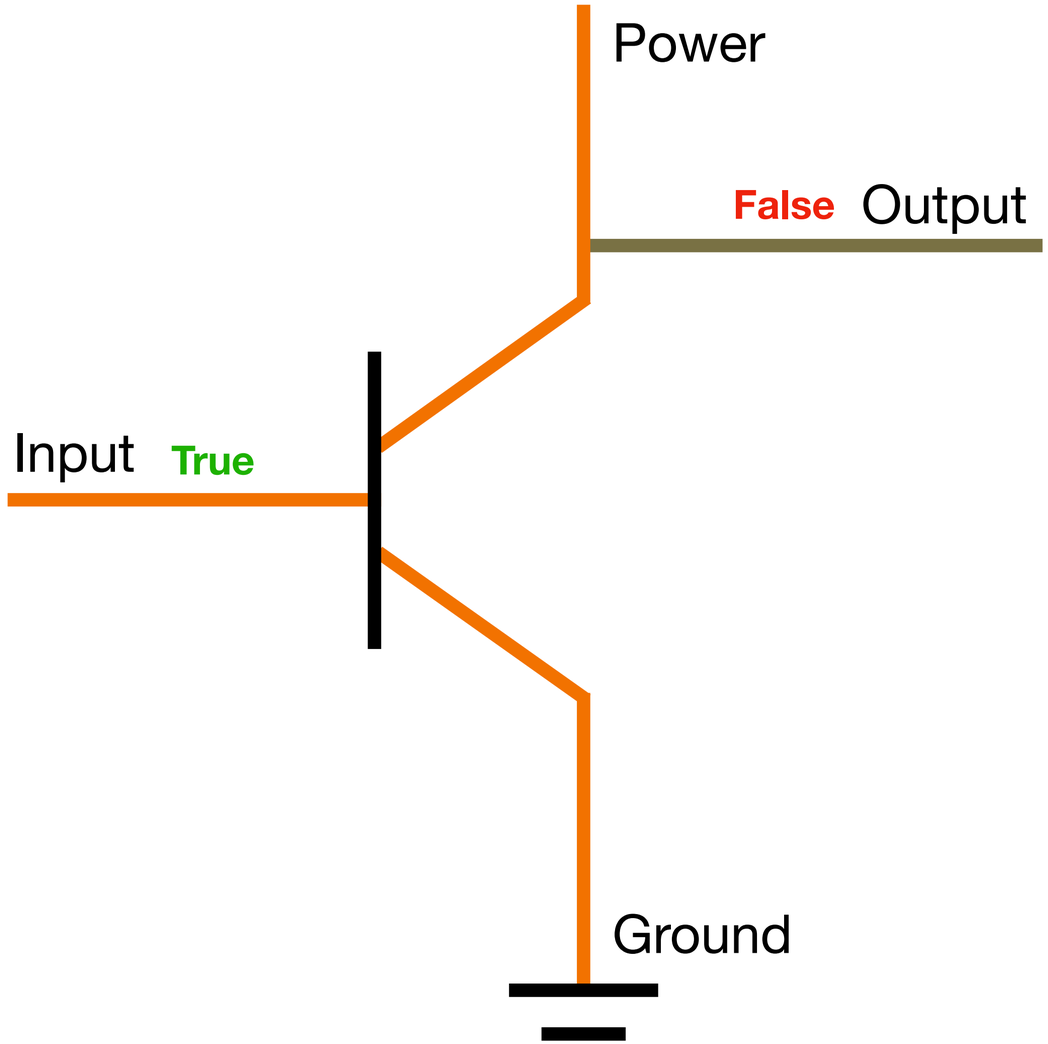

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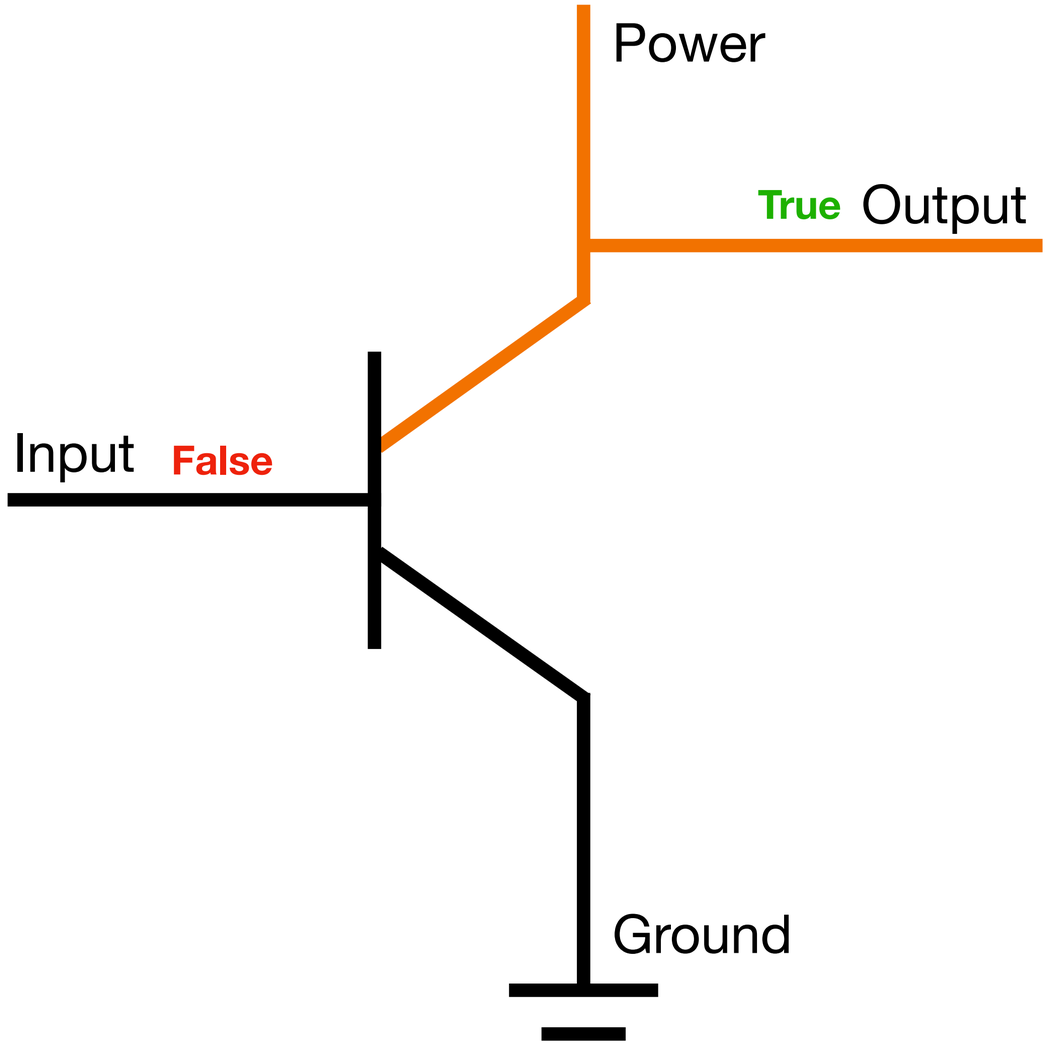
FALSE	TRUE



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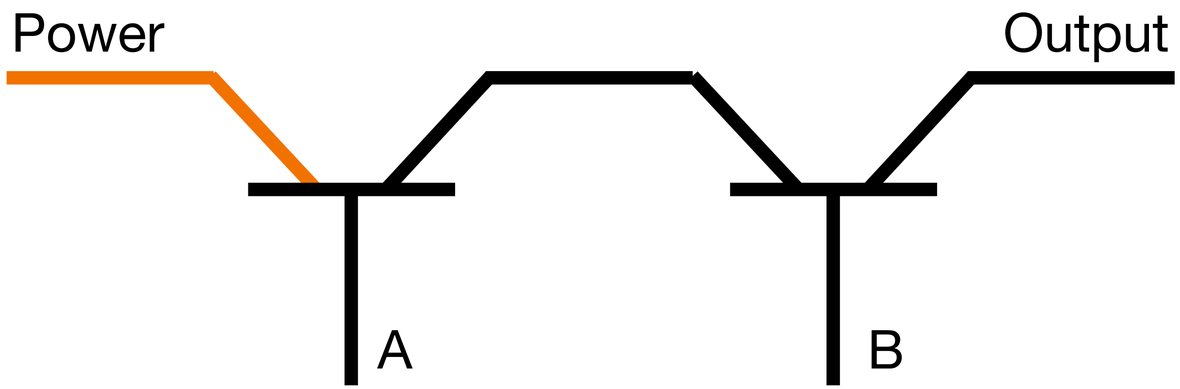
TRUE	FALSE	FALSE
FALSE	FALSE	FALSE



And

A	B	Output
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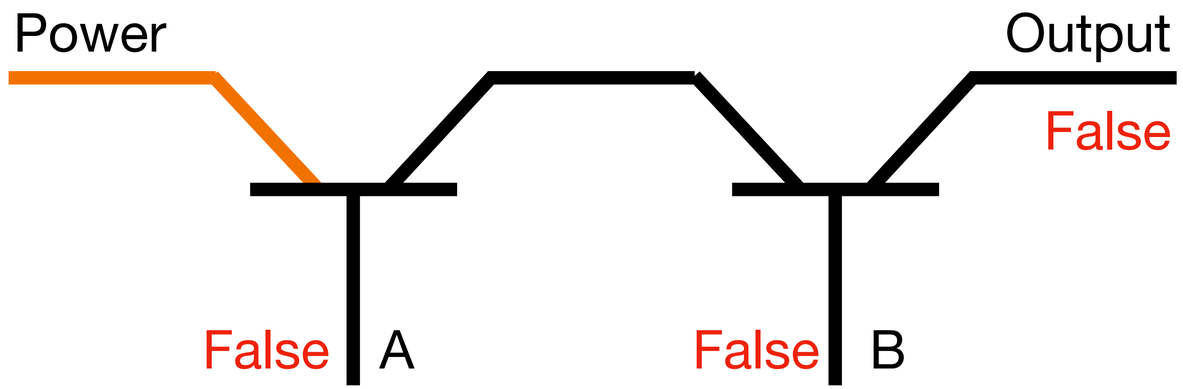
FALSE	TRUE	FALSE
TRUE	FALSE	FALSE
FALSE	FALSE	FALSE



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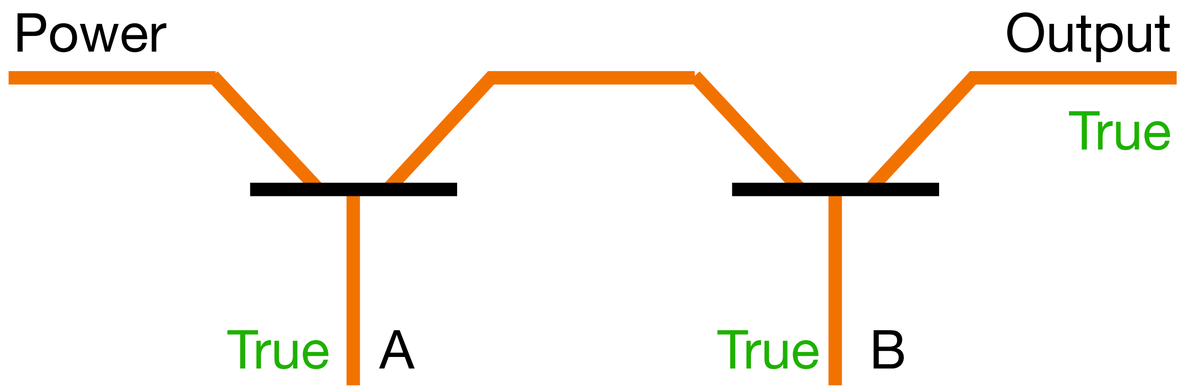

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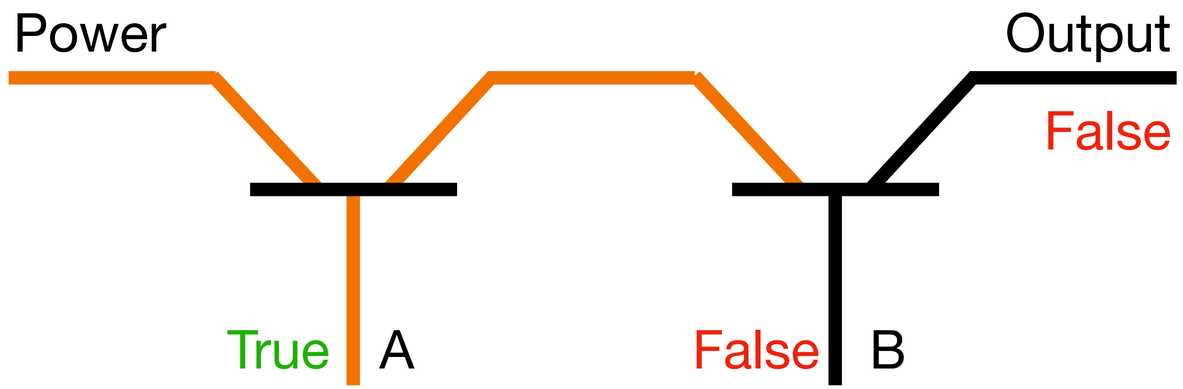

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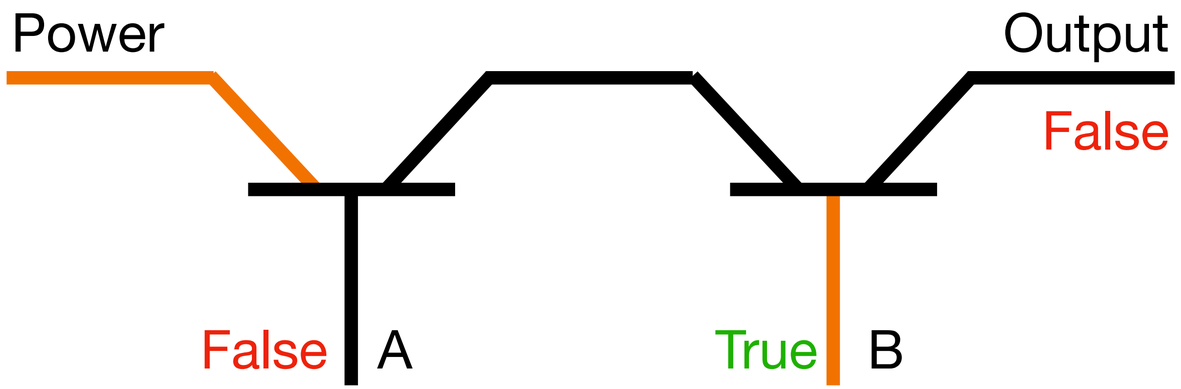

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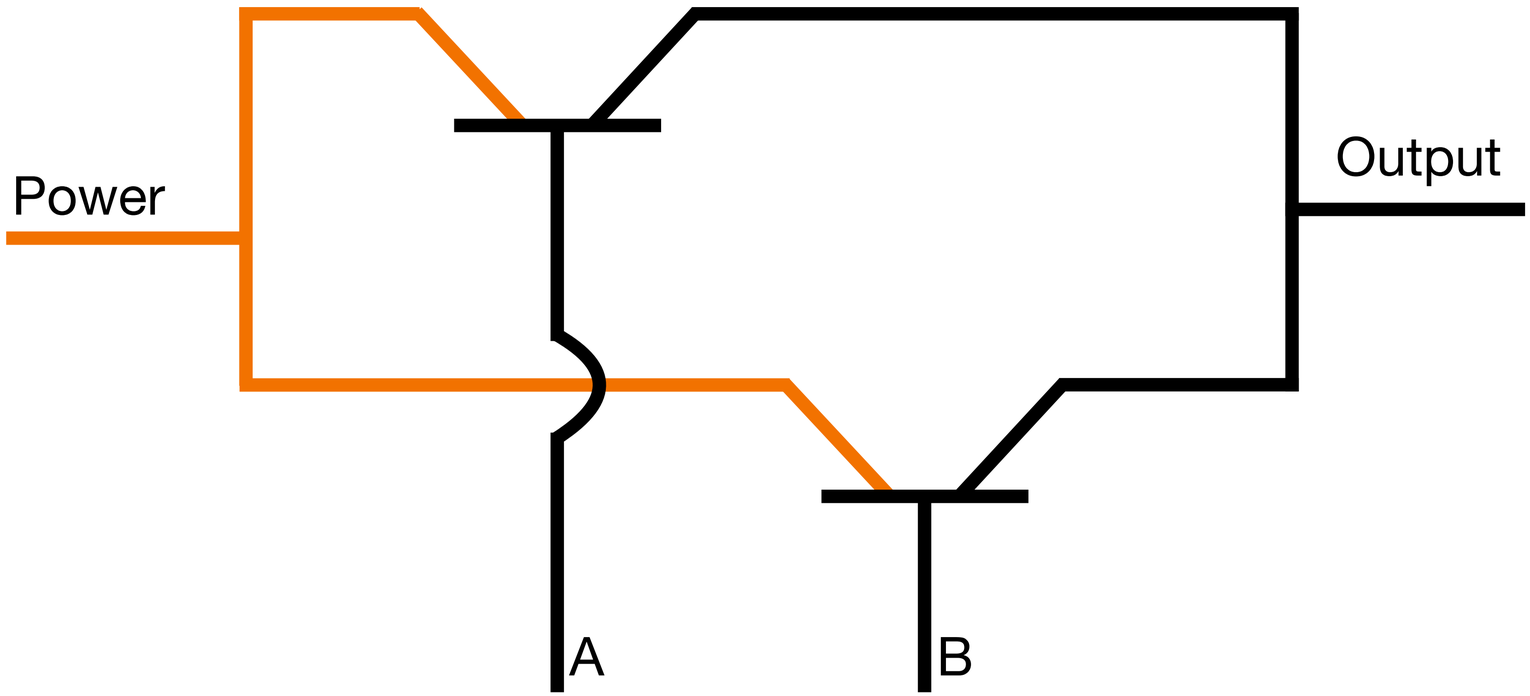

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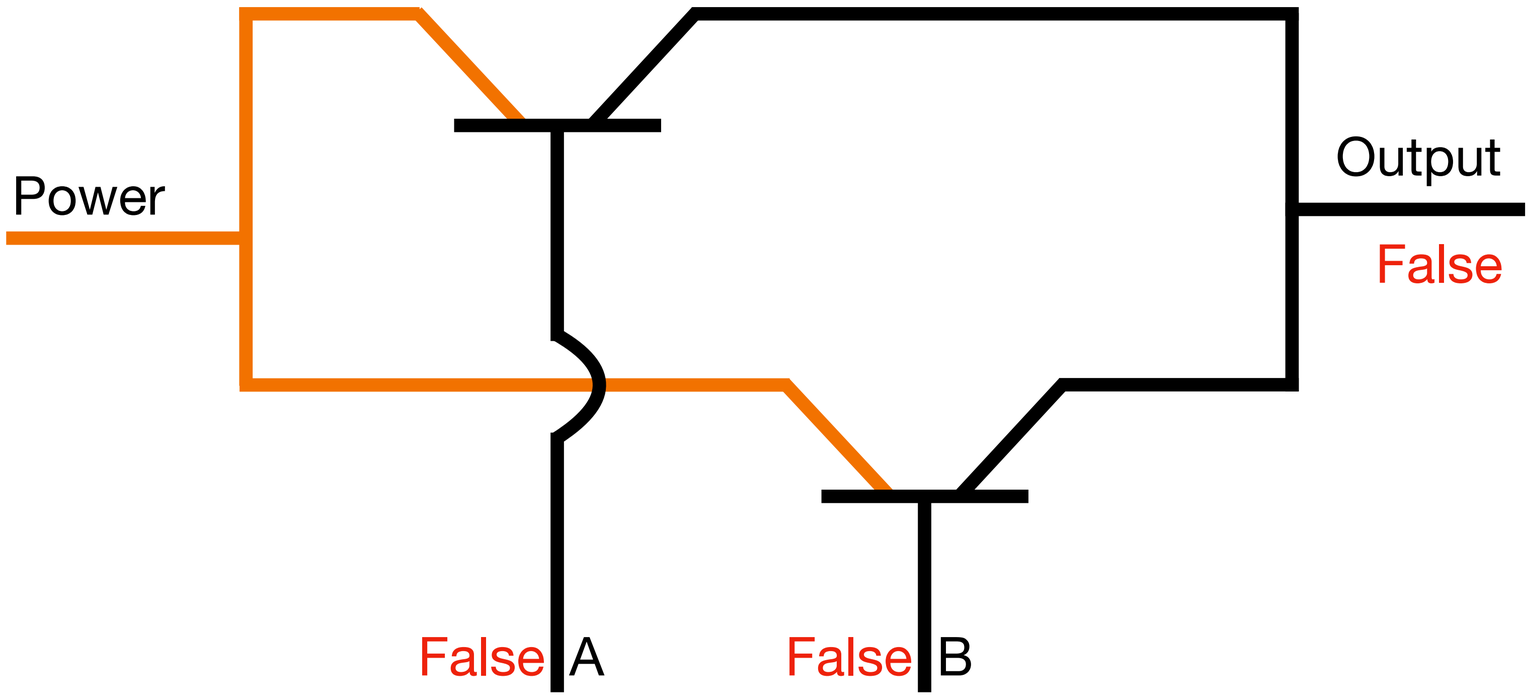

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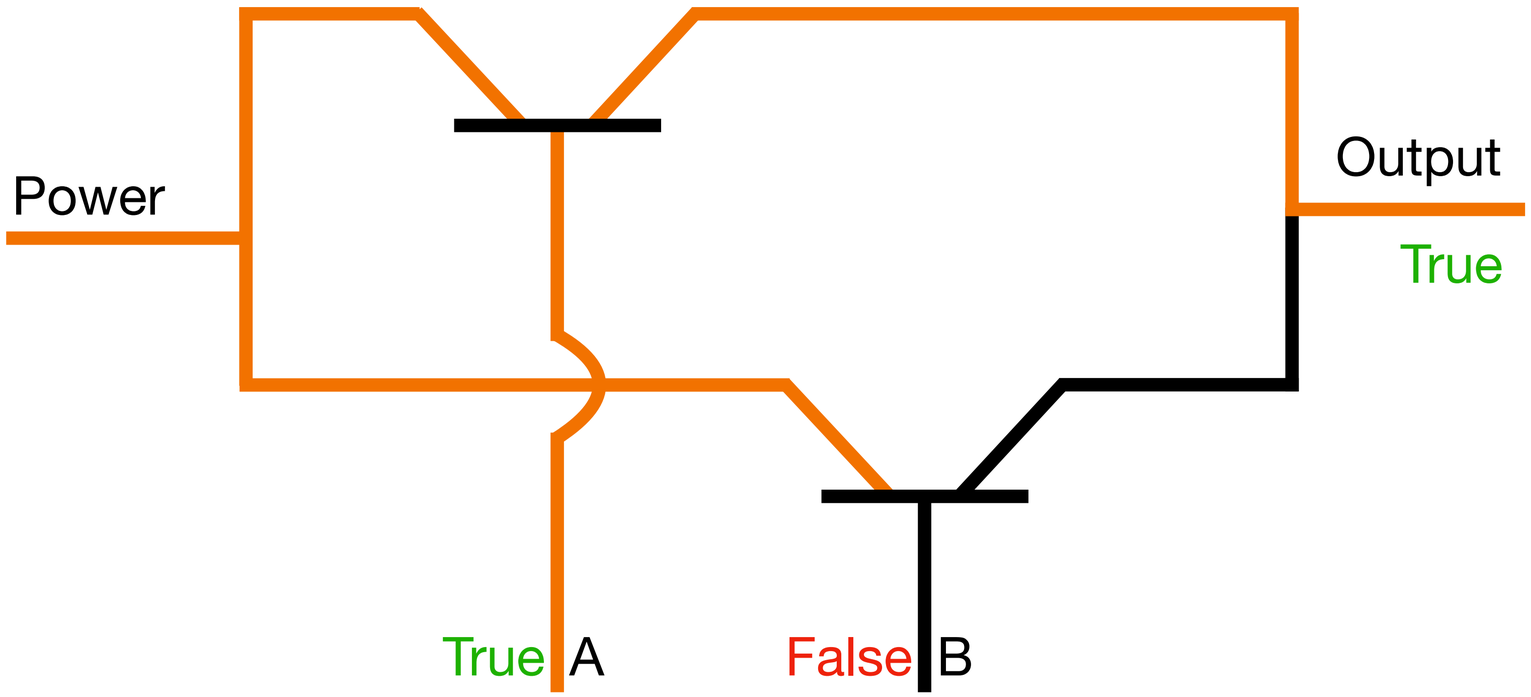

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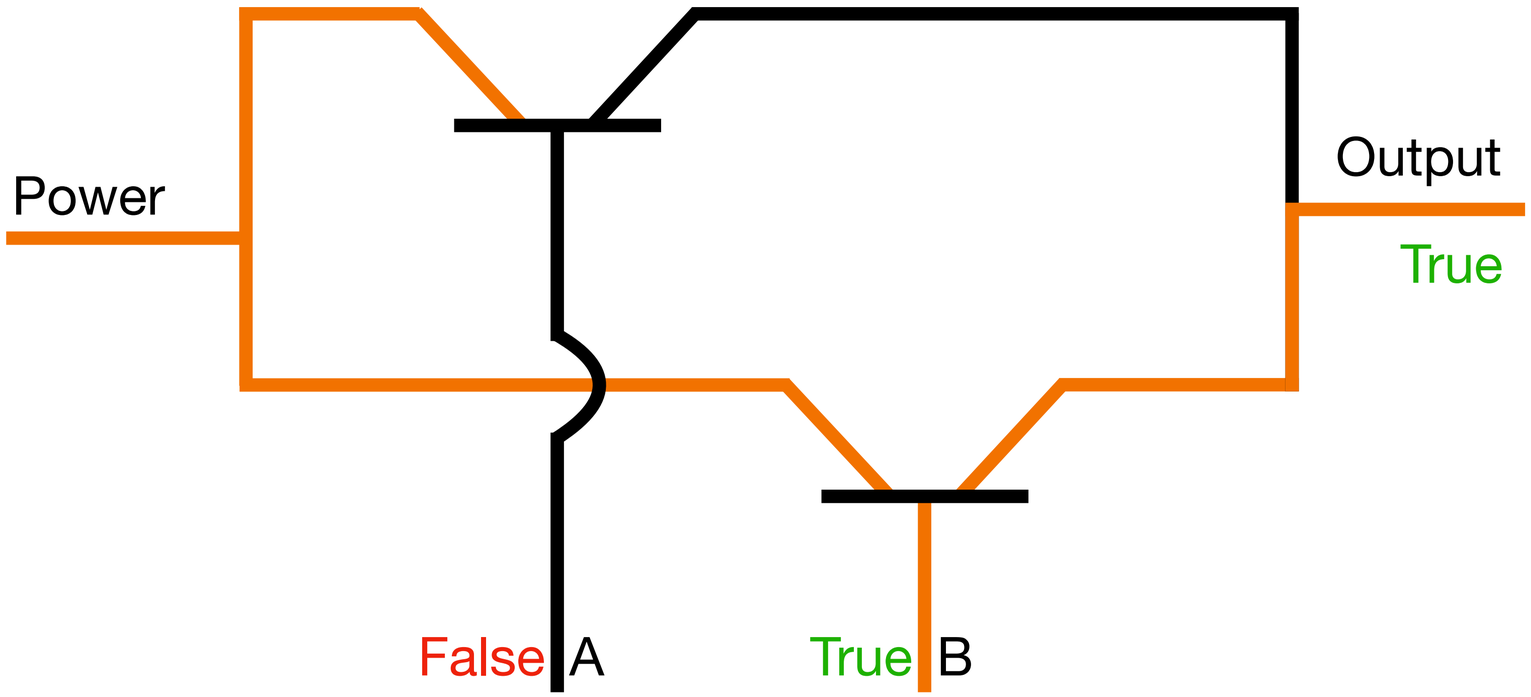

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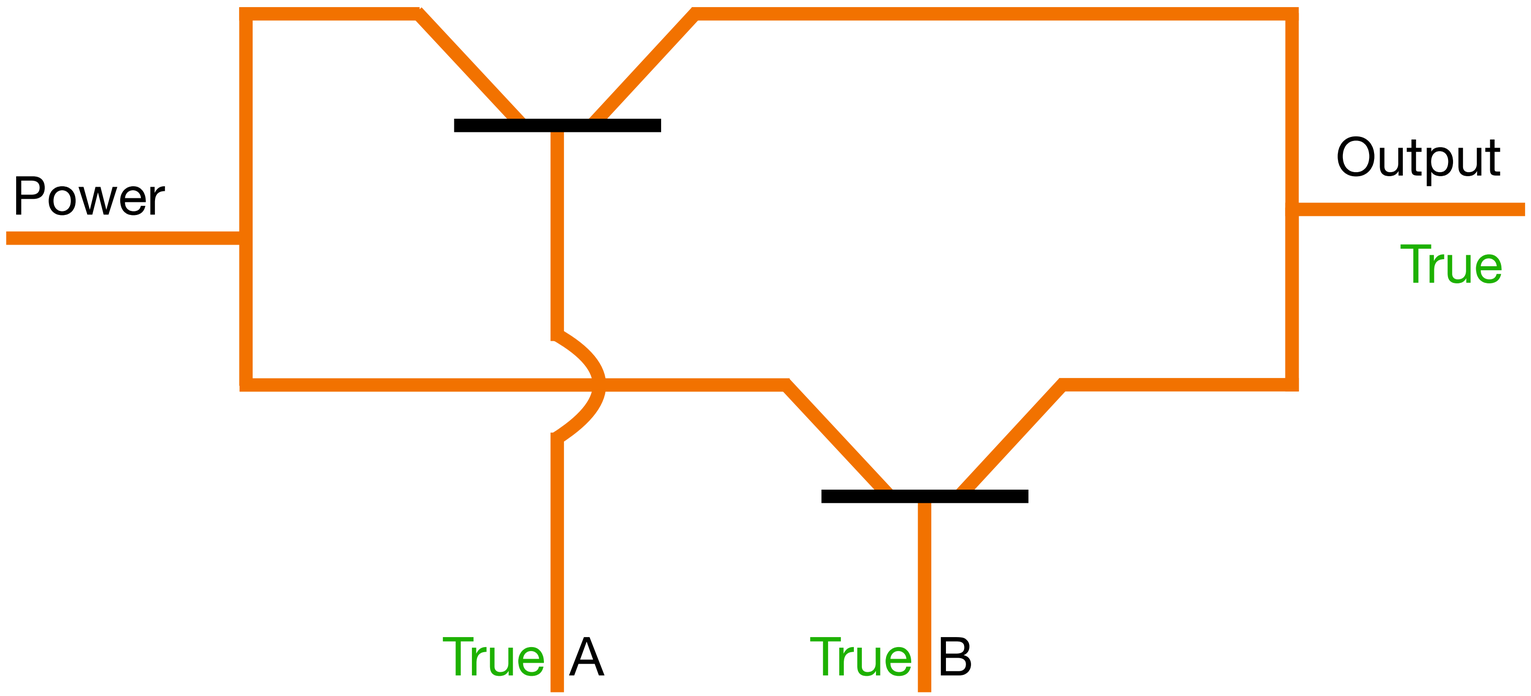

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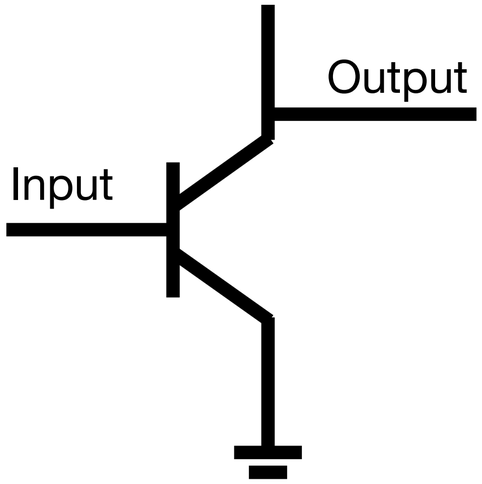

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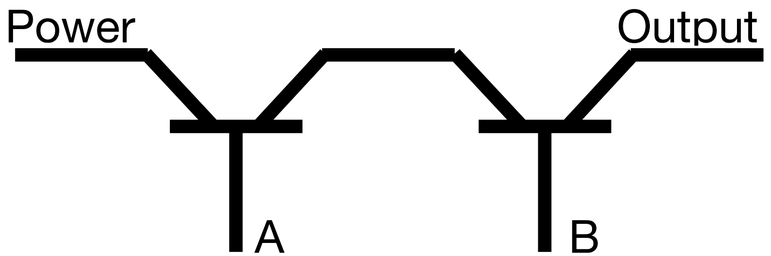

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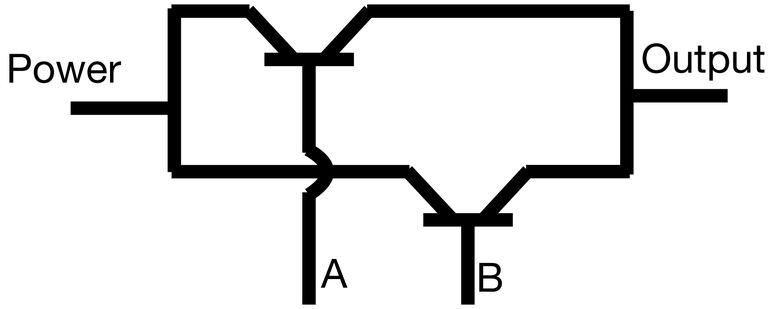

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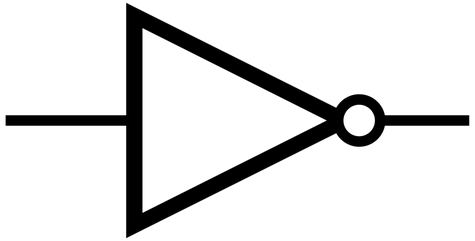

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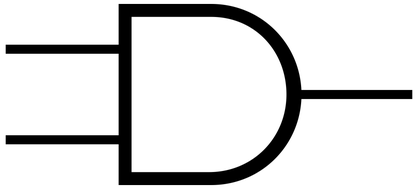

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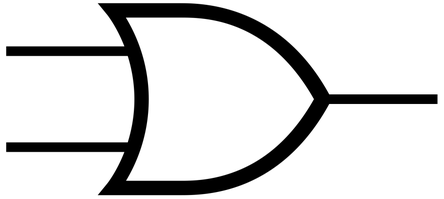

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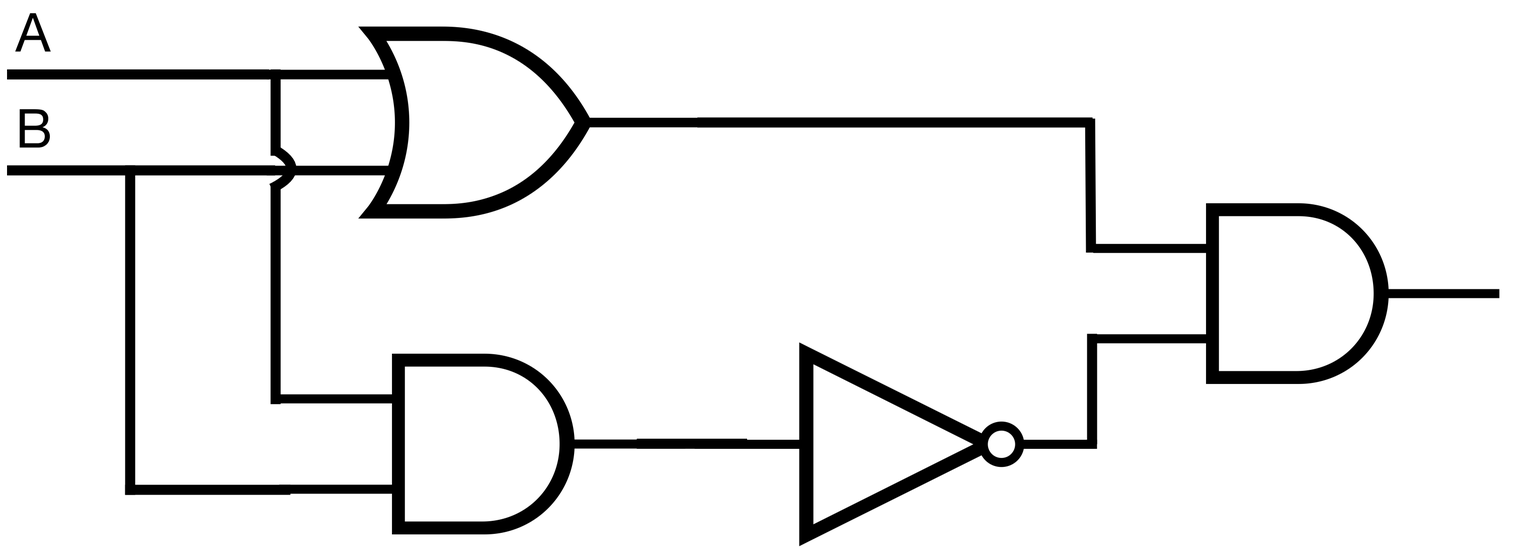

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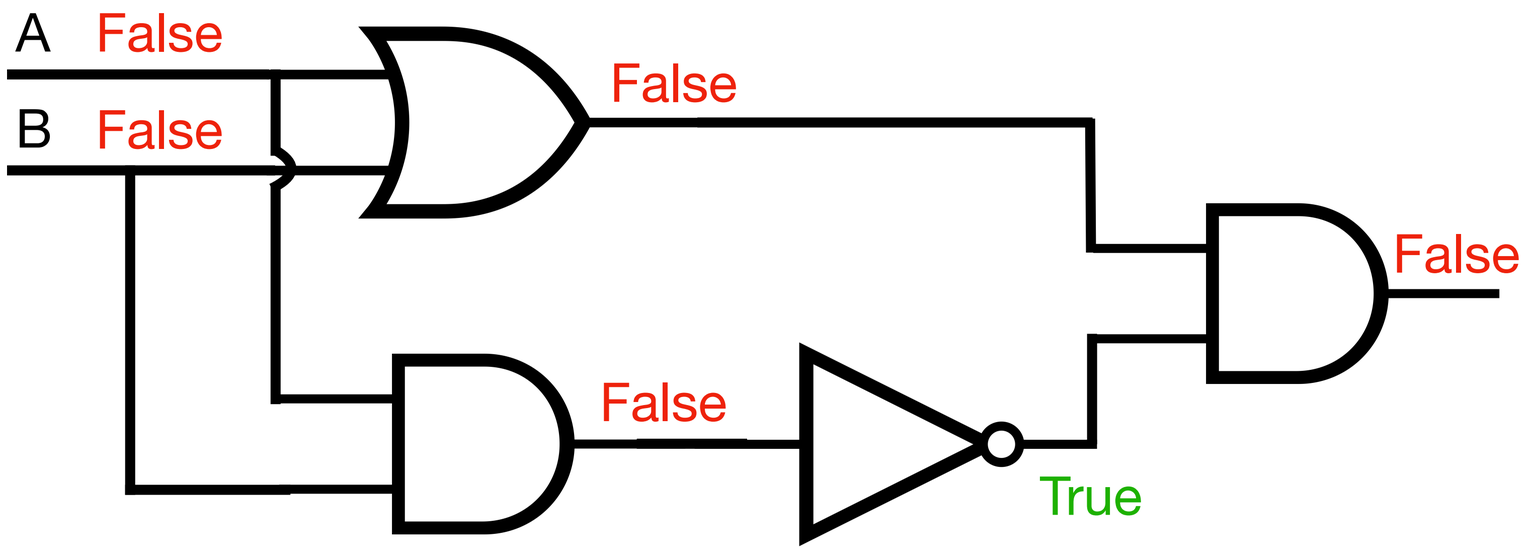

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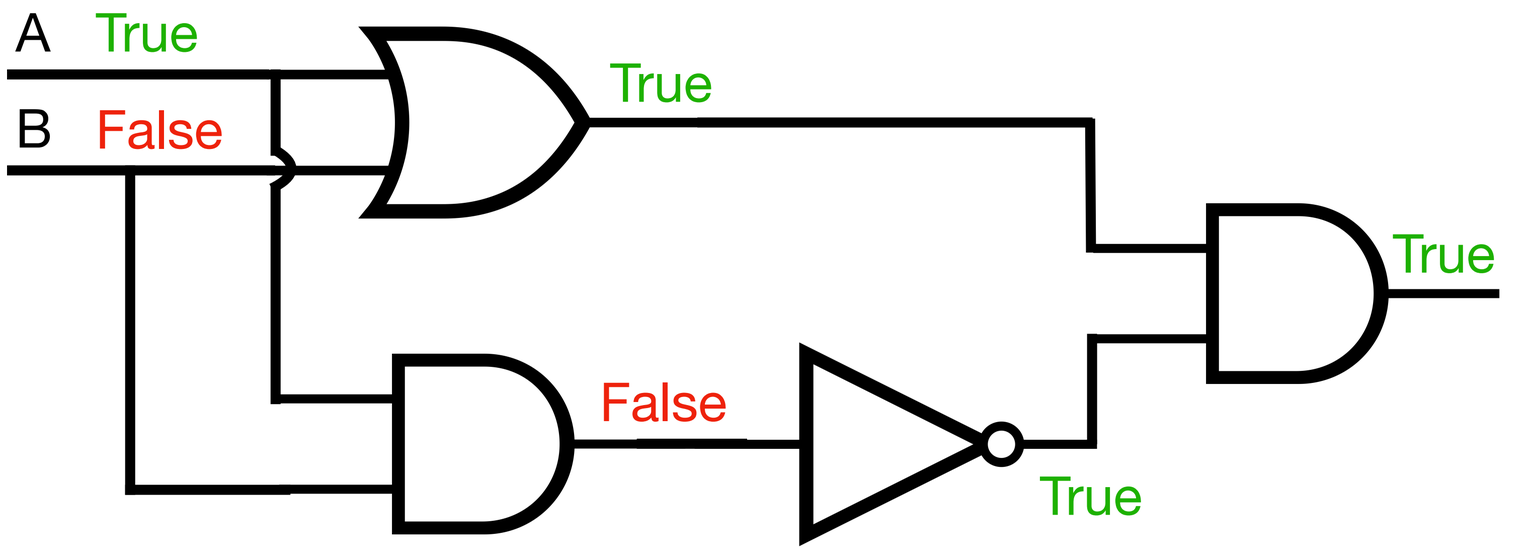

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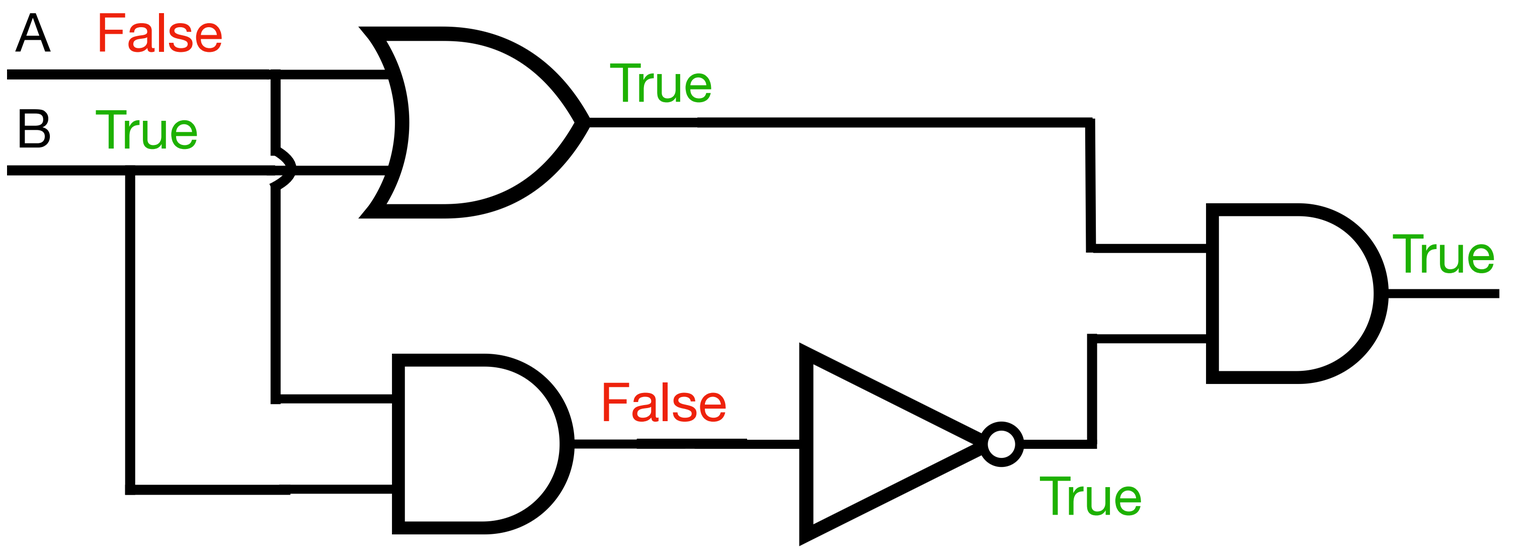

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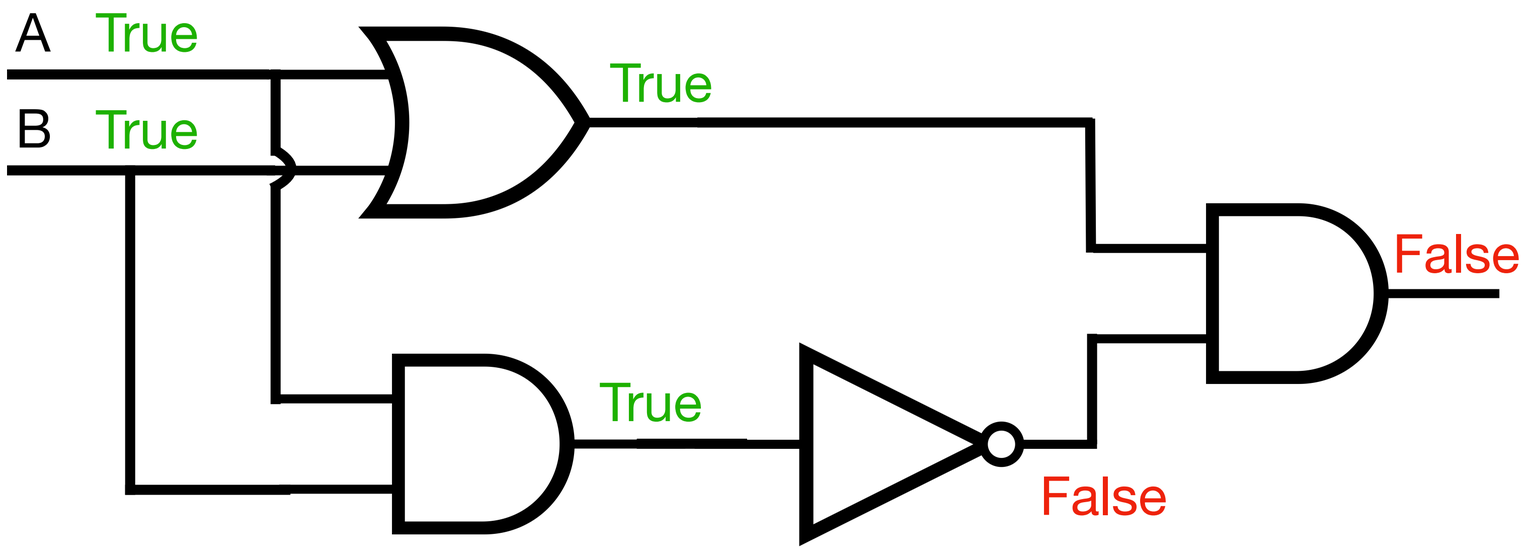

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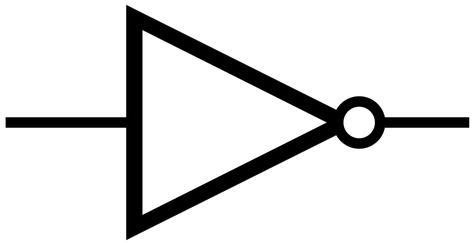

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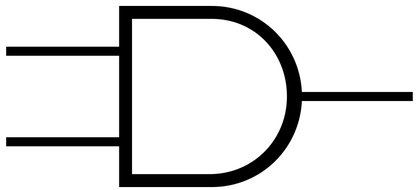

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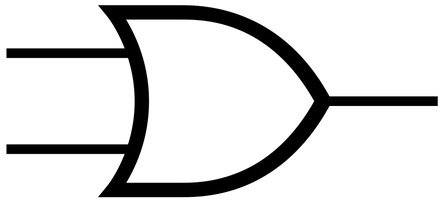

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