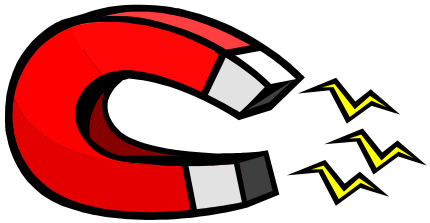
Fun with Physics and Computers



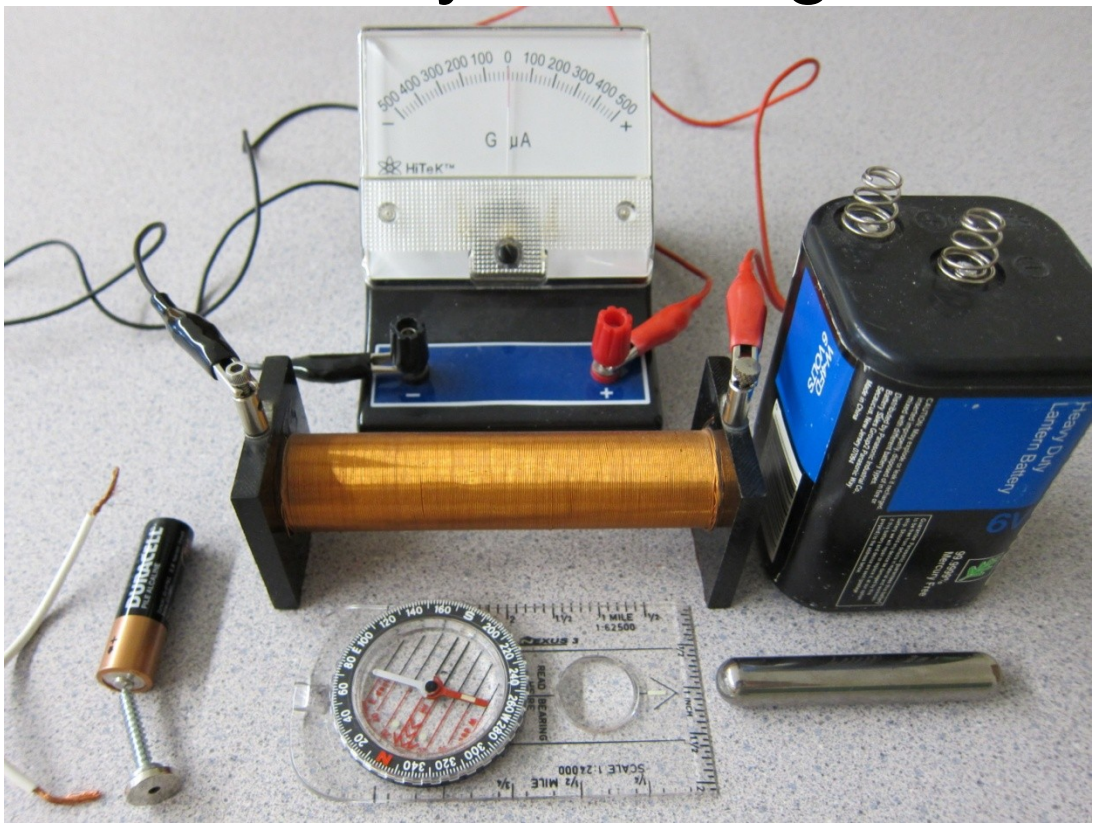
Anne Denton (Computer Science)

Alan Denton (Physics)

North Dakota State University

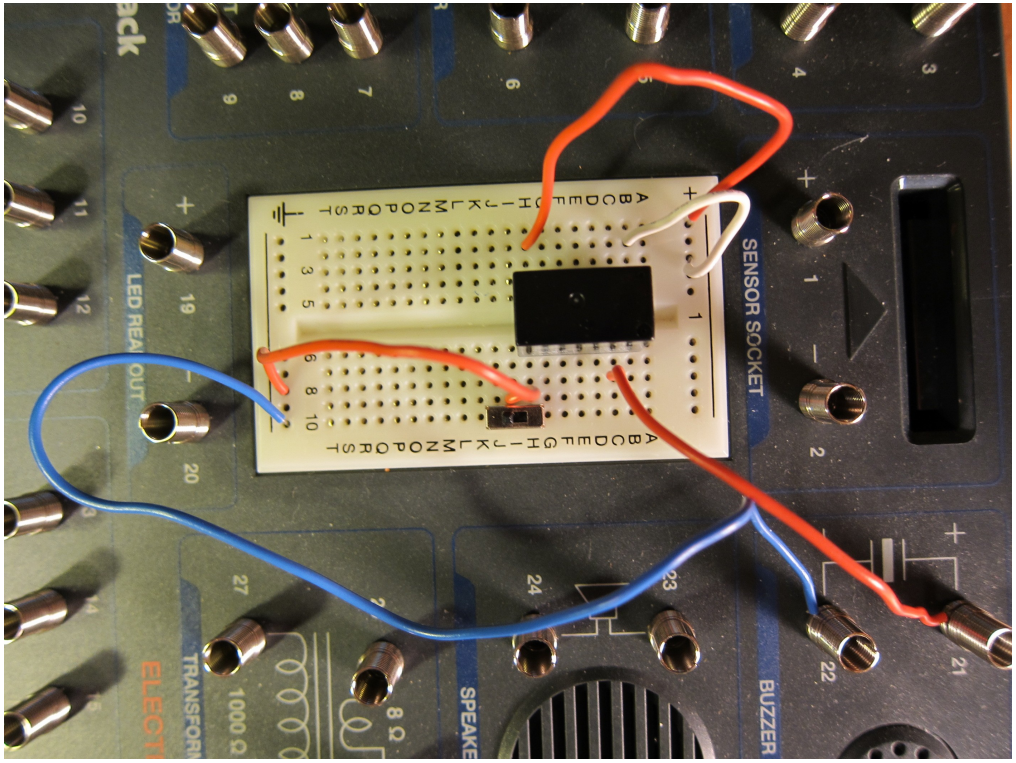
Electricity and Magnetism

- Using a battery, compass, magnet, and wire coil, we'll uncover the connections between electricity and magnetism.



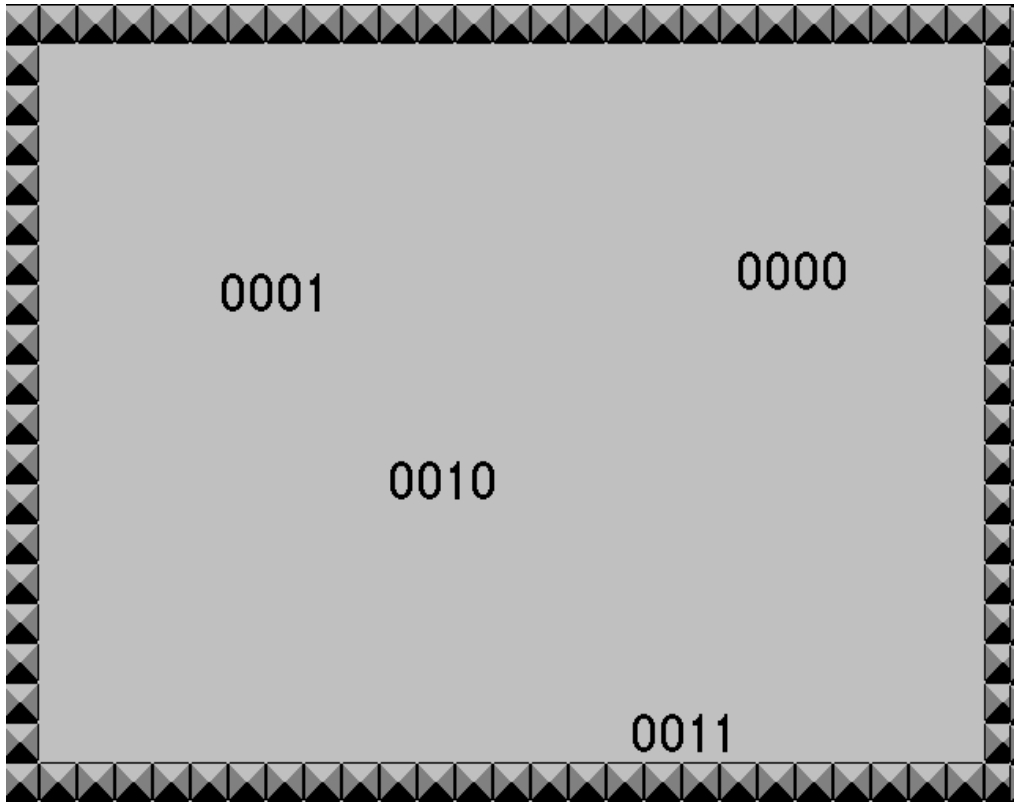
How Computers Store Information

- By building simple electric circuits (gates), we'll explore how computers can store information and perform logical operations.



From Zeros and Ones to Infinity

- Using the free “Game Maker” software, we’ll learn to count with binary numbers and start programming a computer.



Why Should We Care ?

- Physics explains the magic of magnets and lays the foundation for modern computers.
- Magnetic materials store binary numbers:

  ↑↓↓↑↓↑↑↑↓↓↑ = 01101000110 = 838
- Computers use binary numbers to perform basic arithmetic (adding, multiplying, etc.).
- Once we understand how computers work, we can program them and have fun!

Activity 1: Electricity & Magnetism

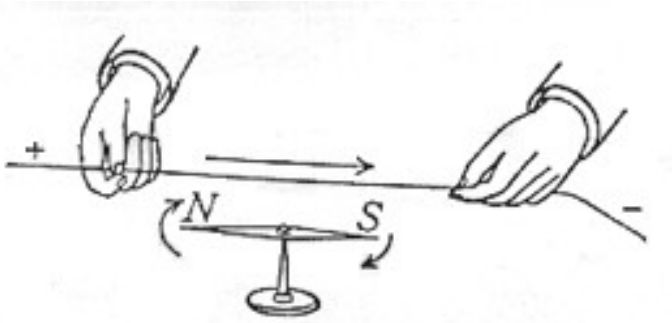
- Using a compass, first find magnetic North.
- Now lay a bar magnet on a sheet of paper, move the compass around the magnet, and draw the direction of the needle on the paper.

What do the arrows on the paper represent?

What is the direction of magnetic force near the two ends (poles) of the bar magnet?

From Electricity to Magnetism

Hans Christian Oersted (1777-1851), Danish physicist and chemist, discovered (in 1820) that an electric current induces magnetism.



During a lecture, he noticed that the needle of a magnetic compass was deflected when current from a battery was switched on.

His simple observations first demonstrated the connection of electricity to magnetism.

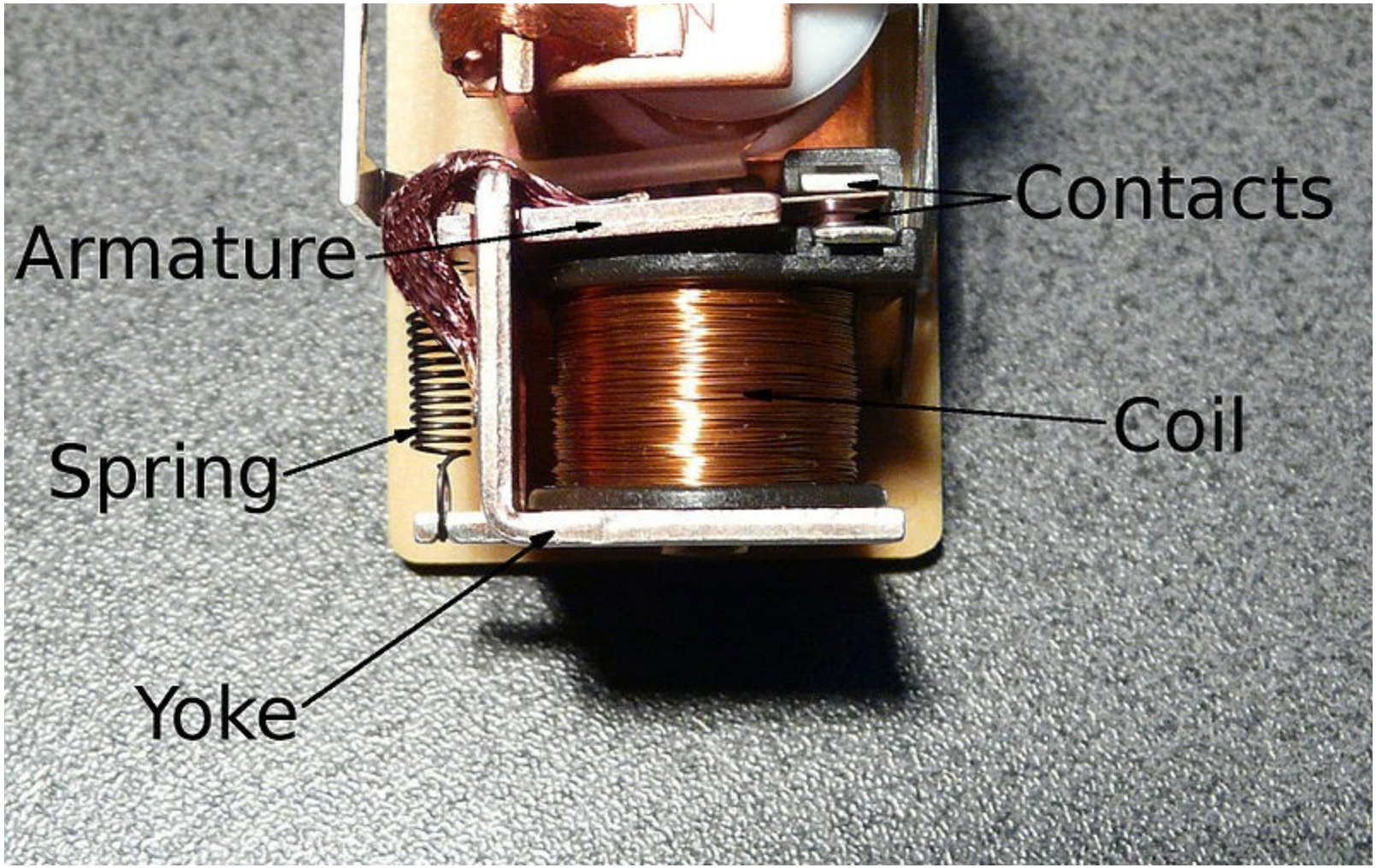
Magnetic Field Around a Wire

- Tape a straight length of wire (pointing north) onto a sheet of paper (leave slack at ends).
- Connect the ends of the wire to the terminals of a battery to send current through the wire.
- Place a compass on the paper near the wire.

  What is the direction of the magnetic force?

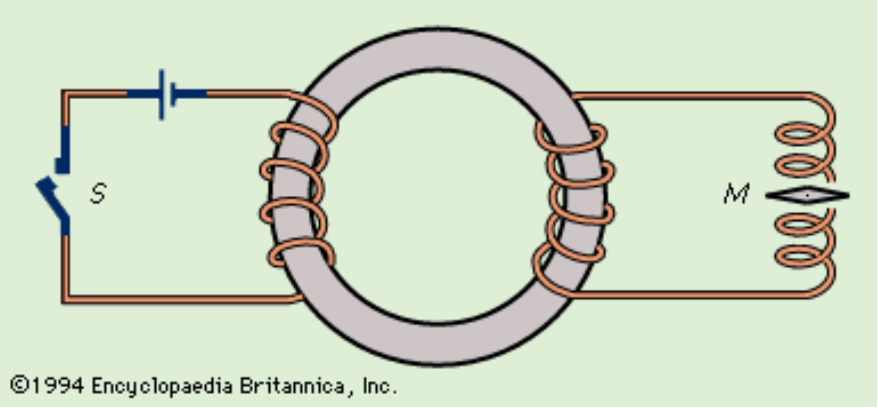
- Finally connect a coil of wire to a battery and explore the magnetic force around the coil.

Electromagnetic Relay (Switch)



From Magnetism to Electricity

Michael Faraday (1791-1867), a British physicist and chemist, discovered (1831) that a moving magnet induces electric current.



His observations showed that a changing magnetic field produces an electric field.

Electricity ↔ magnetism connections make possible electric motors and generators.

Current from a Moving Magnet

- Using wires with alligator clips, connect a coil of copper wire to a galvanometer.
- Insert the bar magnet into the coil and then remove the magnet.

What moves the galvanometer's needle?

Does the direction of current depend on the motion of the magnet?

A Simple Electric Motor

- Stick the disk magnet to the screw head and hang the screw tip from the positive (bumpy) end of the battery.

  Why must we use a steel screw?

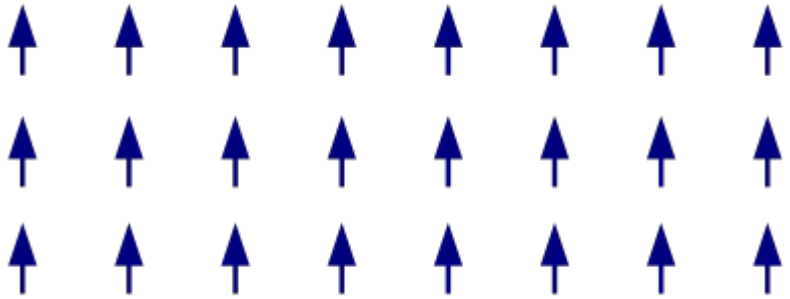
- Tape one end of the wire to the negative (flat) end of the battery and touch the edge of the magnet with the other end of the wire.

  Why does the screw turn?

Ferromagnets

Some materials (Fe, Ni) become *ferromagnets* below a critical temperature (770° C for iron).

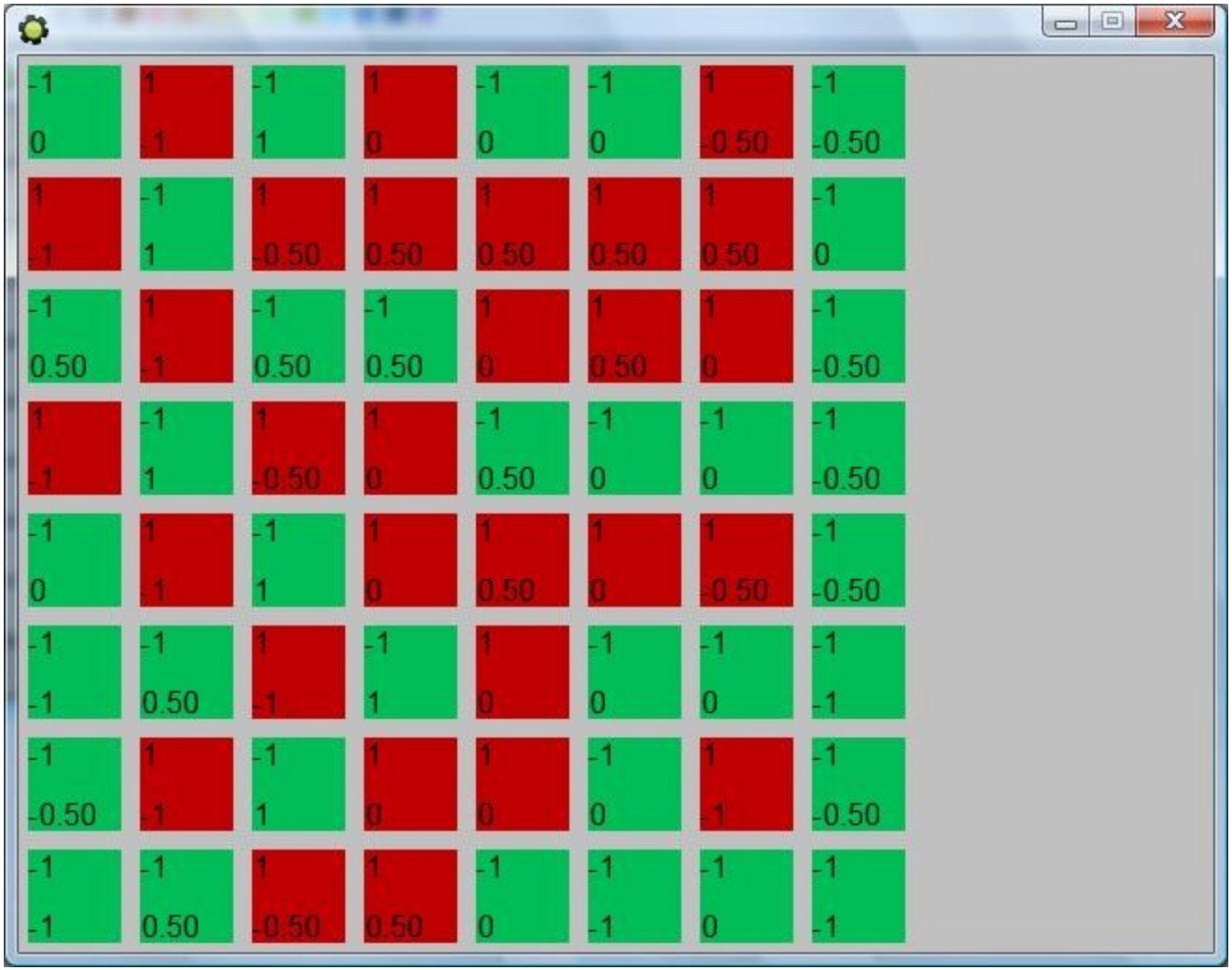
In a ferromagnet, magnetic moments of atoms (domains) can be aligned by a magnetic field.



In a *paramagnet*, the magnetic domains point in all different directions.

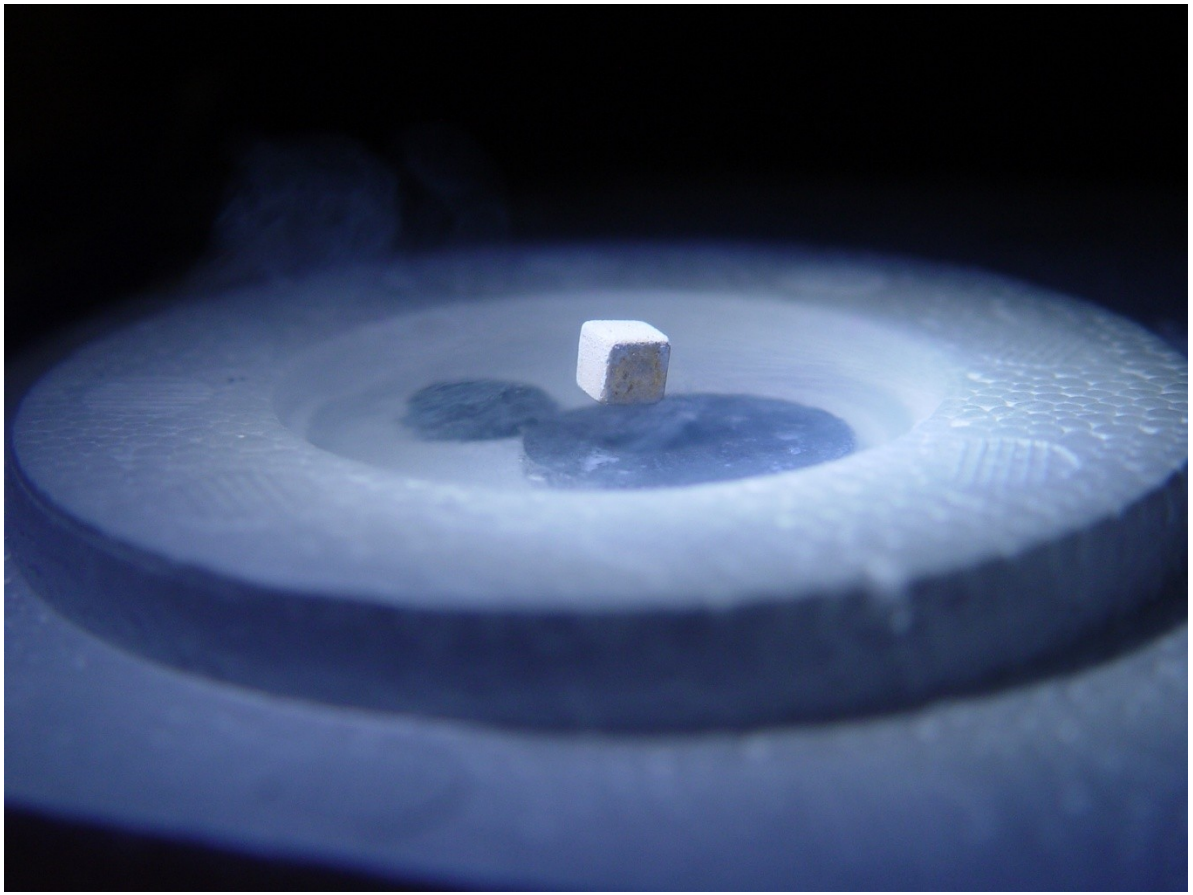
Simulation of a Magnet

Magnetic domains can point up (green) or down (red).



Demonstration: Superconductivity

Ceramic disk, cooled with liquid nitrogen, levitates a tiny (but strong) magnet.



High-Speed "Maglev" Trains

Superconducting magnets levitate a train above magnetic rails, minimizing friction.

JR-Maglev train at Yamanashi, Japan test track in 2005 (581 km/h)

Activity 2: Logic Circuits

Computers store and process information (use information to create new information).

Magnets are very important for representing and storing information in computers.

Can you think of any materials that can be permanently magnetized?

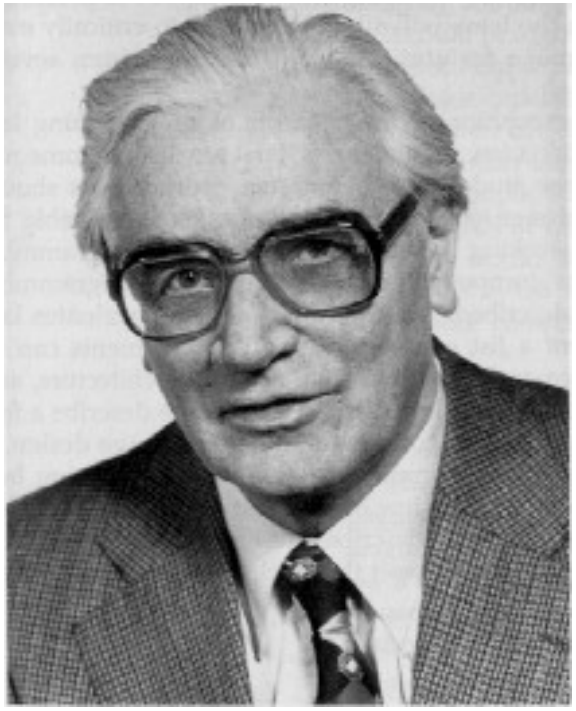
Hard Disk Drives

Modern computers use magnetism in hard disk drives: A rotating magnetic disk holds many tiny points with magnetic domains that can point up or down to represent bits.

The First Digital Computer

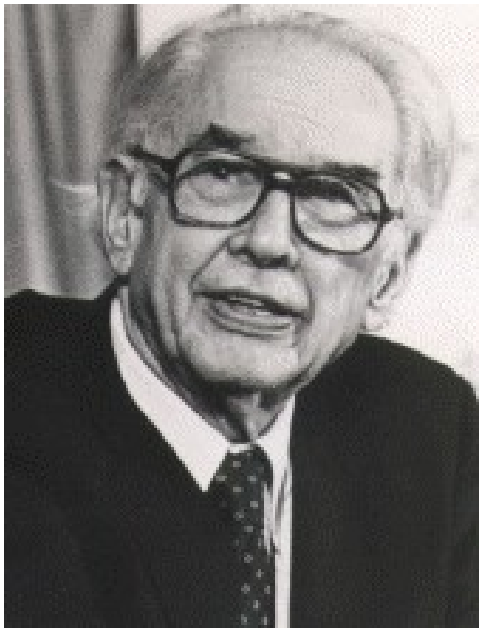
Konrad Zuse (1910-1995), German engineer:

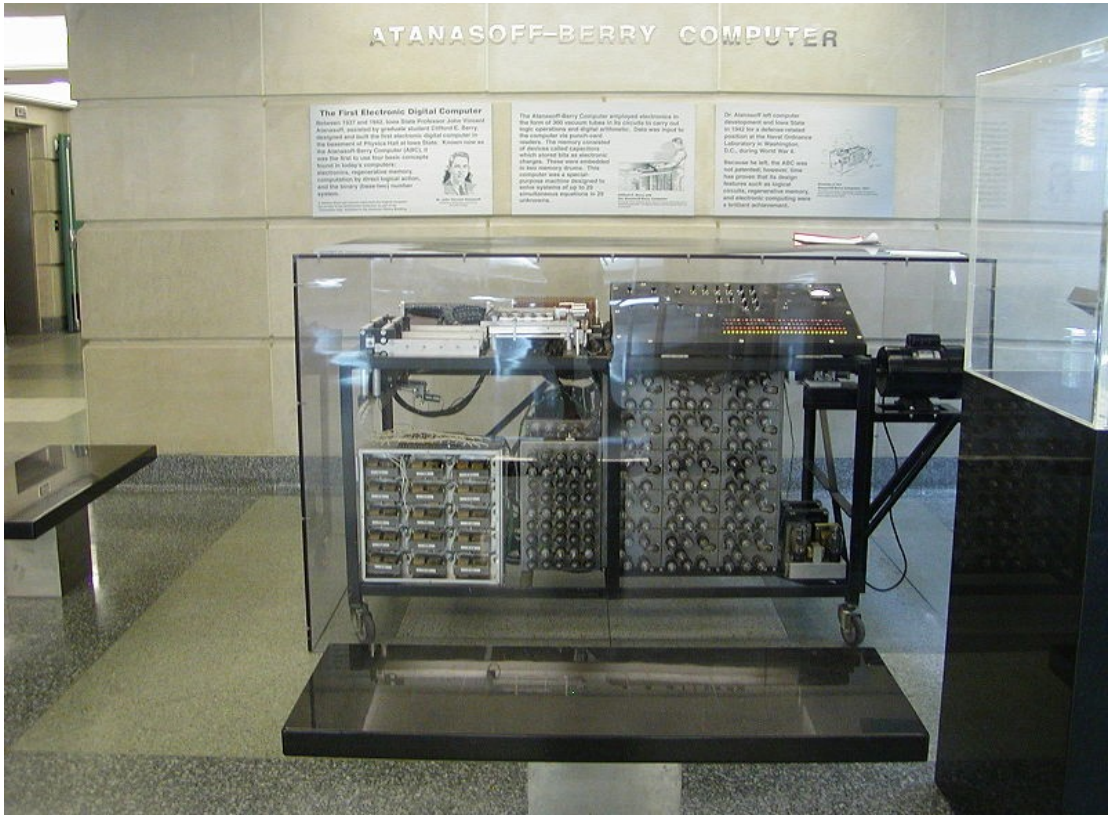
The first program-controlled digital computers (1938-1941) used magnetic relays.



The First Electronic Computer

John V. Atanasoff (1903-1995), American physicist and mathematician: first automatic electronic digital computer (Iowa, 1939).

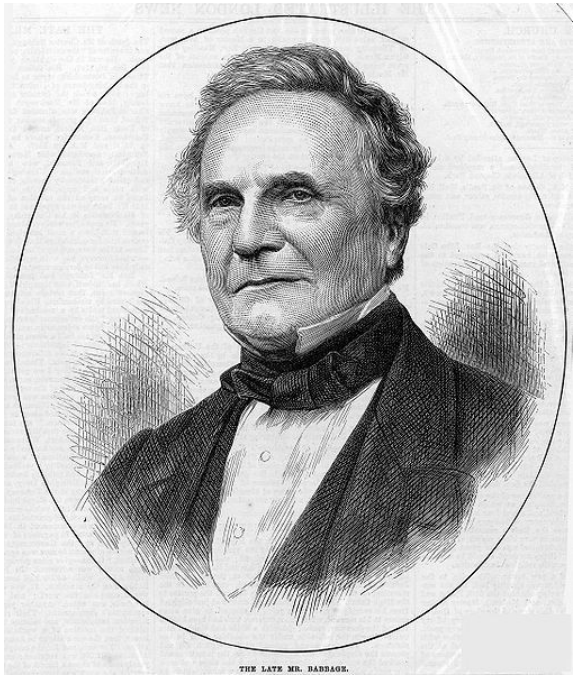


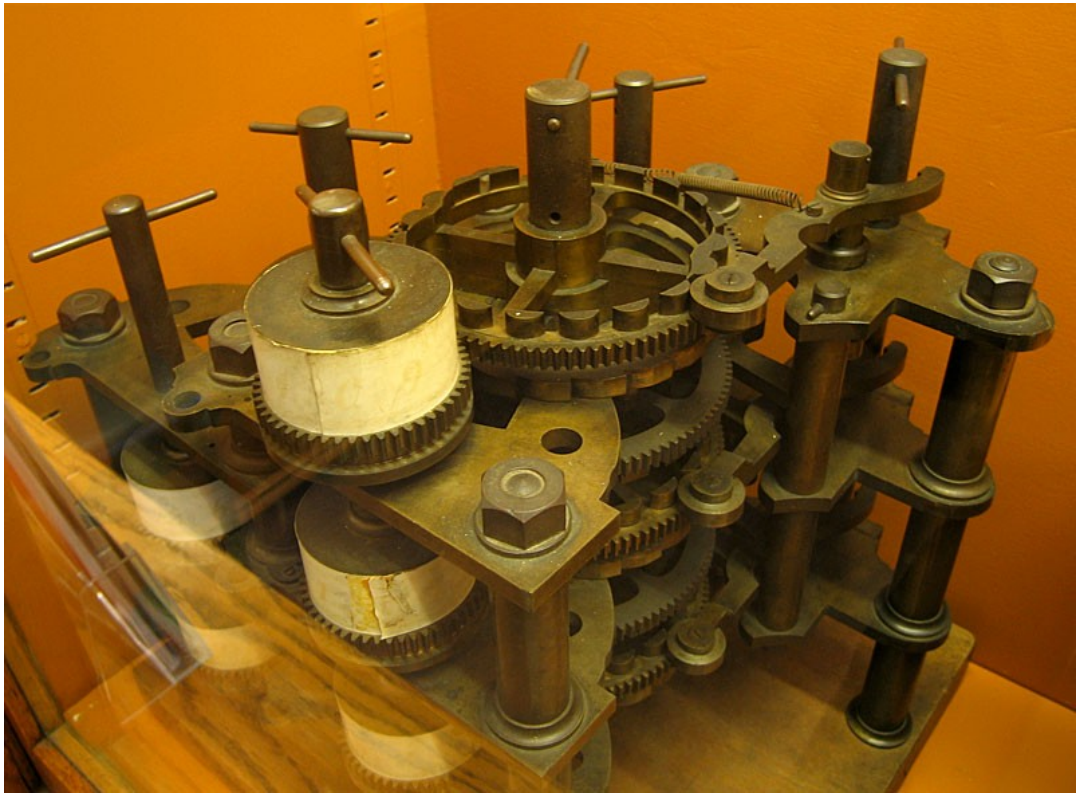


Early Computer Concepts

Charles Babbage (1791-1871), English mathematician, philosopher, engineer:

first programmable computer (mechanical).





Magnets Store Information

N	N	S	S	S	S	N	N	N	N	S	S	N	S	N	N
S	S	N	N	N	N	S	S	S	S	N	N	S	N	S	S

How does this pattern store information?

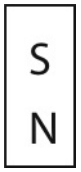
Let's assume we only want to distinguish between the digits 0 and 1.

How could we do that with this magnet?

Representing Numbers

Let's assume we define 

to stand for 0,

and we define 

to stand for 1.

How can we store the number 2 ?

Let's think about decimal numbers:

We can store values up to 9 in one digit.

How can we store numbers > 9 ?

Place Value of Numbers

To store 10 in the decimal system we introduce a second digit with a "place value" of 10.

For example, the number 14 is really 1*10 + 4*1.

What does the number 23 represent ?

Back to the problem of storing 2 in a computer, where each digit can represent only two values:

How many digits do we need for 0, 1, and 2 ?

There are only 10 types of people in this world:

those who understand binary numbers …

and those who don't !

More on Binary Digits (bits)

What does the binary number 11 represent?

Binary Number	Decimal Number
00	0
01	1
10	2
11	**?**

How do we represent the number 4 ?

How Many Bits Do We Need

How many numbers can we represent with 3 bits?

How many numbers can we represent with 4 bits?

Keep going to 8 bits: $2*2*2*2*2*2*2*2 = 2^8 = 256$

8 bits is also called 1 byte.

1KB is 2^{10} = 1024 bytes, or about 1000.

1MB is 2^{20} (about 1 million) bytes.

1GB is 2^{30} (about 1 billion) bytes.

Calculating with Binary Numbers

What are the results of the following additions, in binary numbers ?

0 + 0 =

0 + 1 =

1 + 0 =

1 + 1 =

We can build these with on/off switches!

Switches: Mechanical, Magnetic, and Electronic

In this activity, we switch electric current using mechanical and magnetic (relay) switches.

Modern computers use electronic switches (transistors) made of semiconductors.

The principle of how to do calculations is the same for all types of switch!

Goal of our Calculations

From two input bits (0 or 1)

0 + 0 = 00

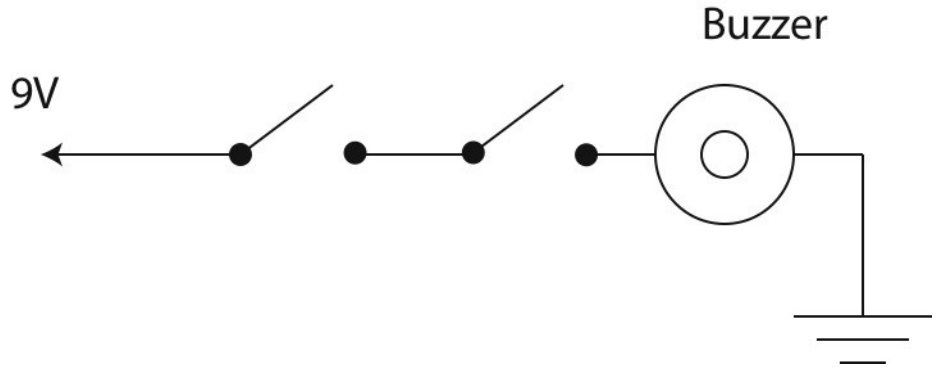
0 + 1 = 01

1 + 0 = 01

1 + 1 = 10

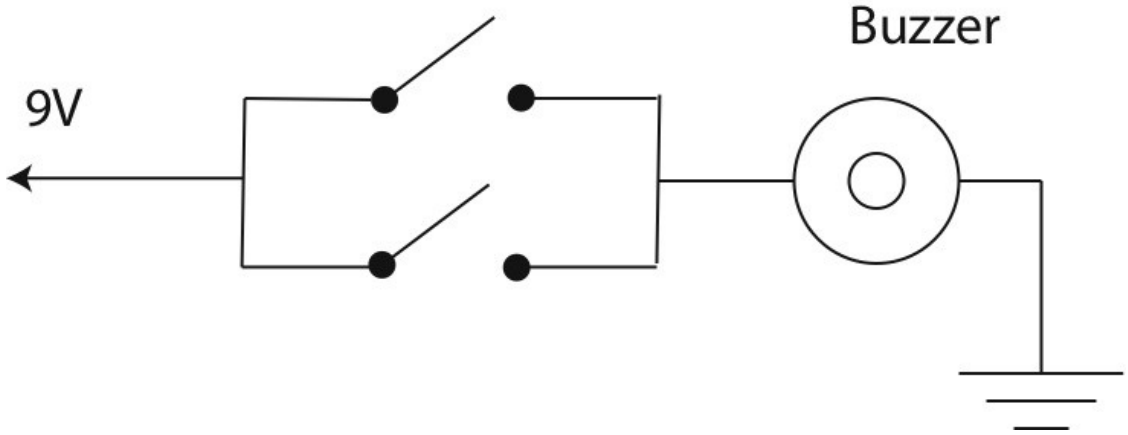
we want to produce two output bits!

Series Circuit (AND)



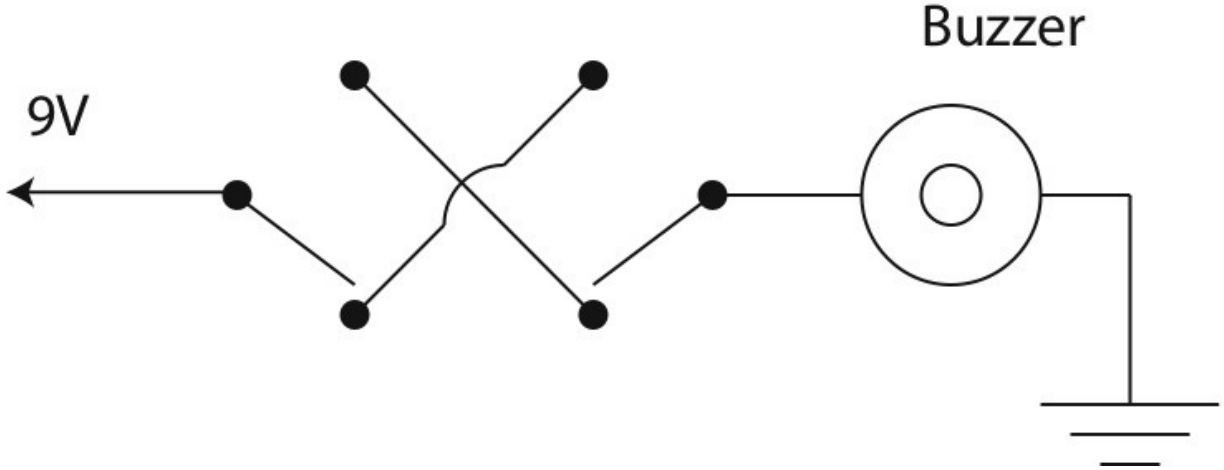
First Switch	Second Switch	Buzzer
off (0)	off (0)	
off (0)	on (1)	

Parallel Circuit (OR)



First Input	Second Input	Output
0	0	
0	1	
1	0	
1	1	

Alternating Circuit (exclusive OR / XOR)



First Input	Second Input	Output
0	0	
0	1	
1	0	
1	1	

OR vs. Exclusive OR

When parents ask a child:

"Would you like candy or ice cream?"

which of the logical possibilities do they mean?

Do they mean OR or Exclusive OR?

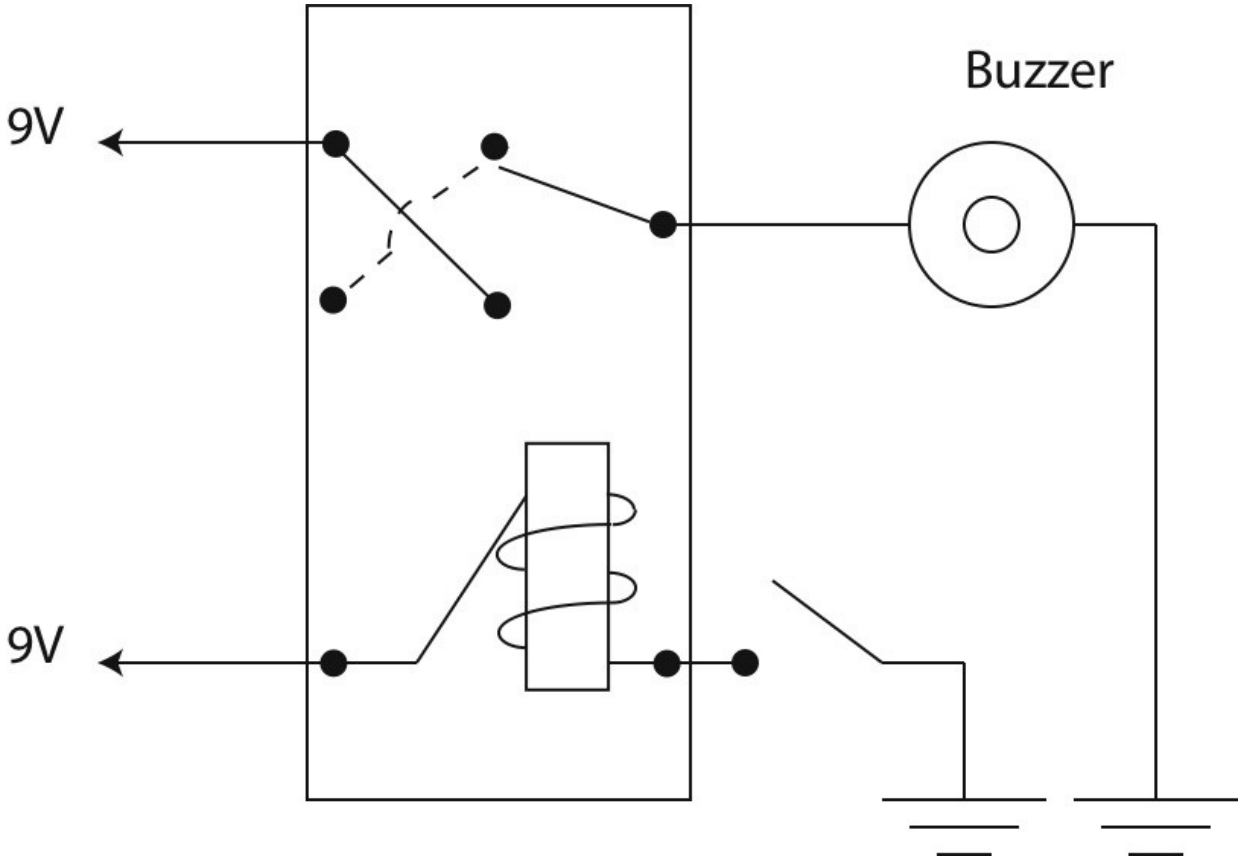
Hint: Do they consider “candy and ice cream” to be a reasonable answer?

Do Any of the Circuits Help Us with Adding Bits?

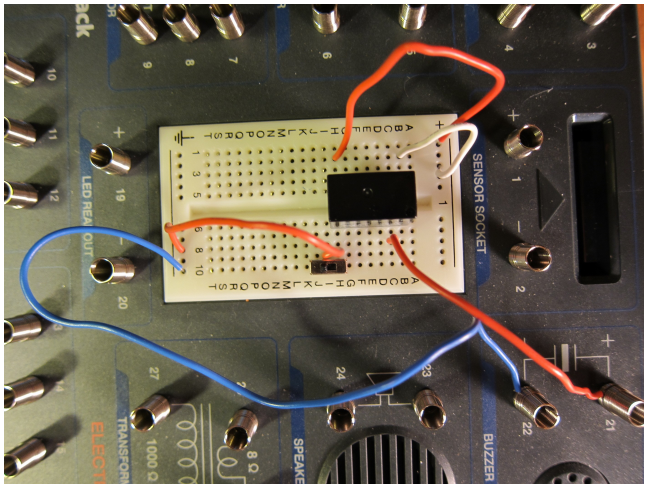
First Input	Second Input	First Output (place value 2)	Second Output (place value 1)
0	0		
0	1		
1	0		
1	1		

Switching Using Magnets

A relay is an electromagnetic switch:

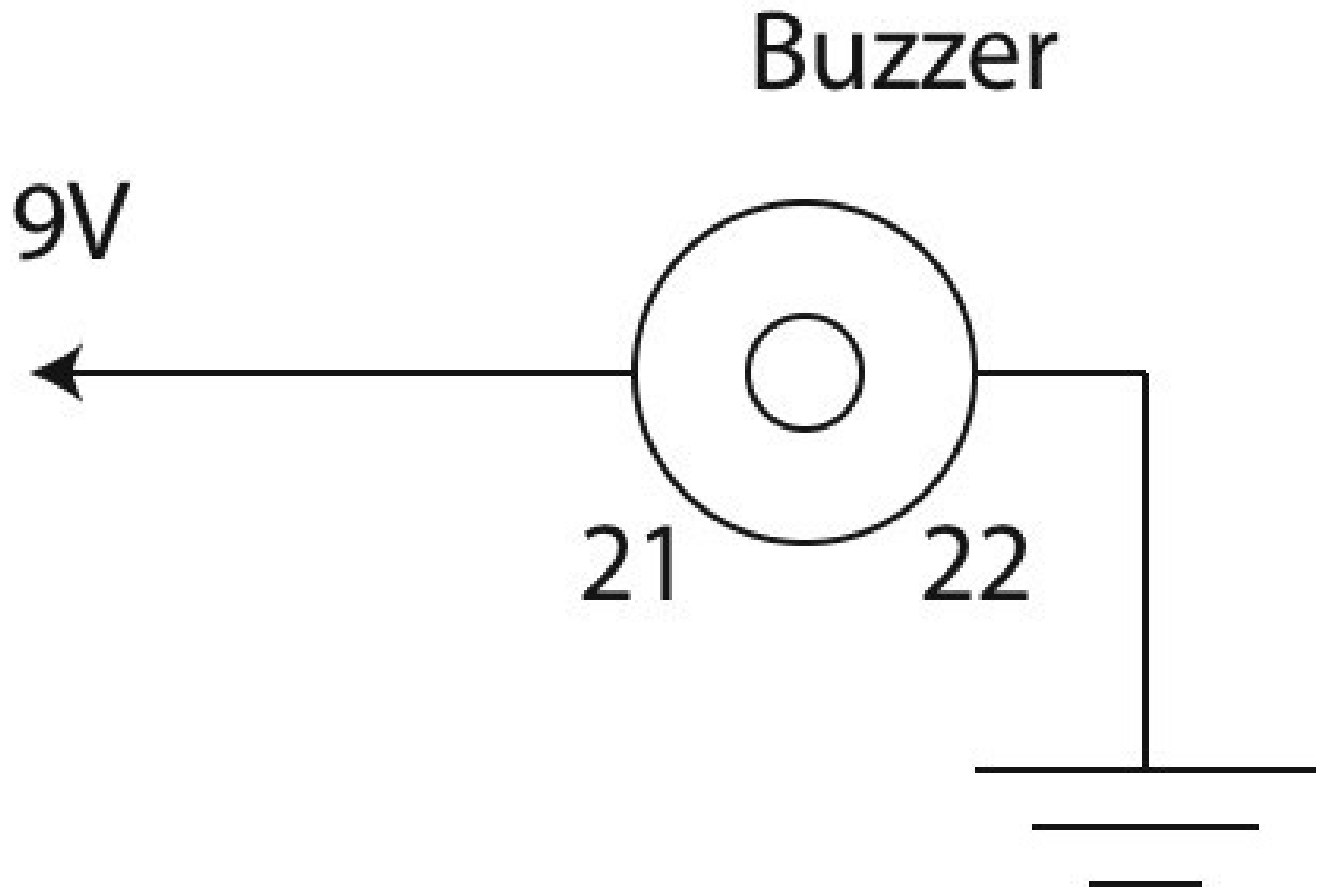


Logic Circuits on a Bread Board

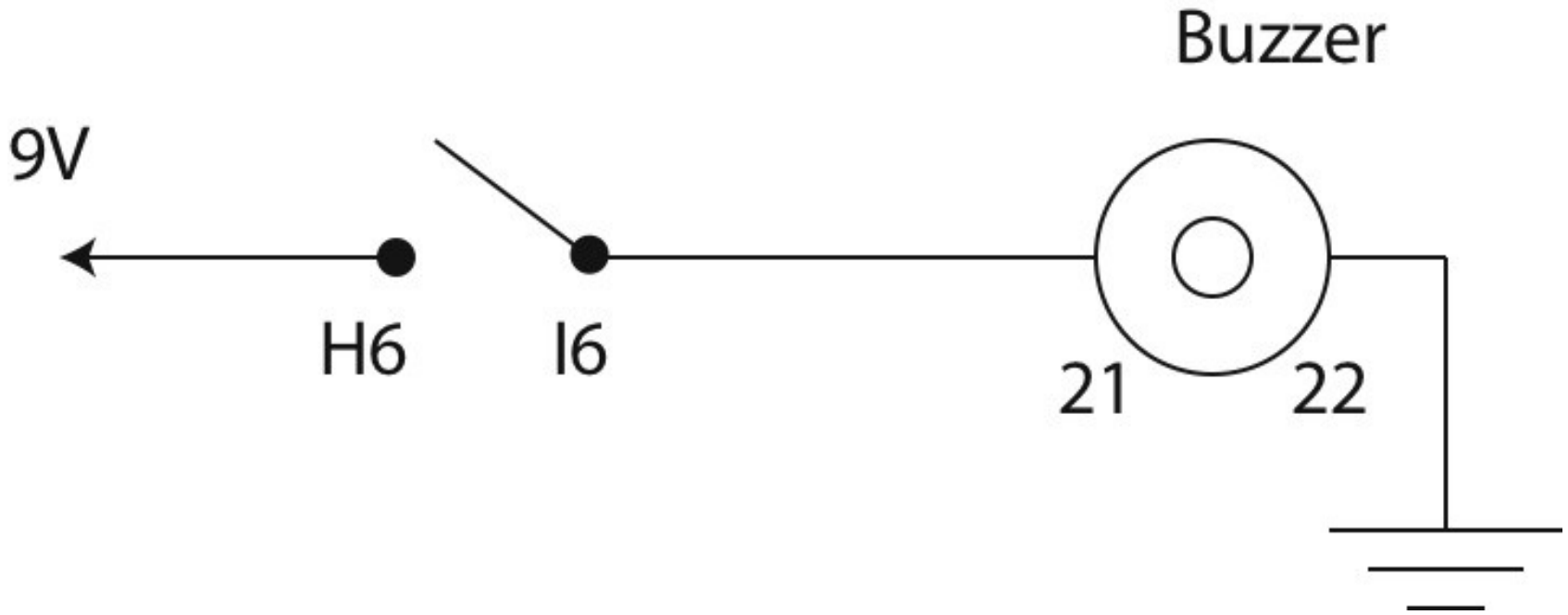


- On a bread board, build an electric circuit with a battery, switch, and buzzer.
- Using two switches, build circuits to perform basic logic operations (AND, OR, XOR).
- Explore how binary numbers can be stored [e.g., switch open/closed (off/on) = 0 or 1] and how simple logic gates work.

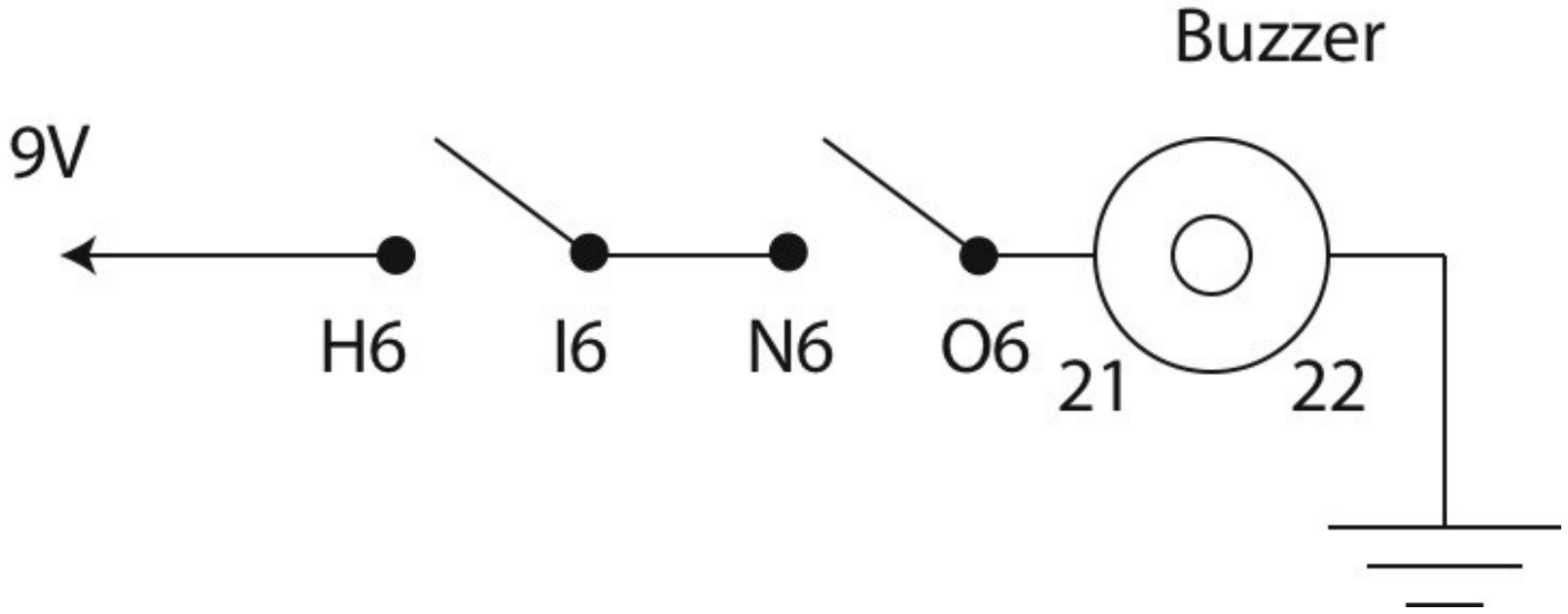
Testing the Buzzer



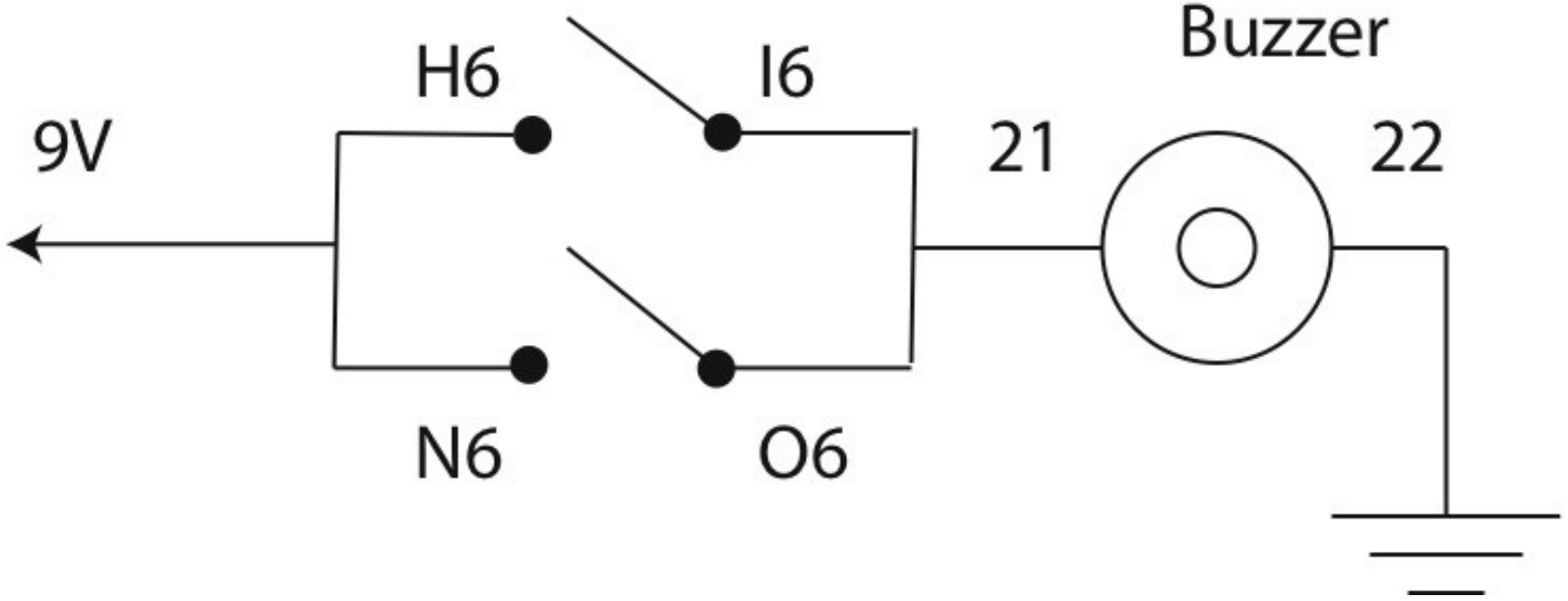
Testing a Switch



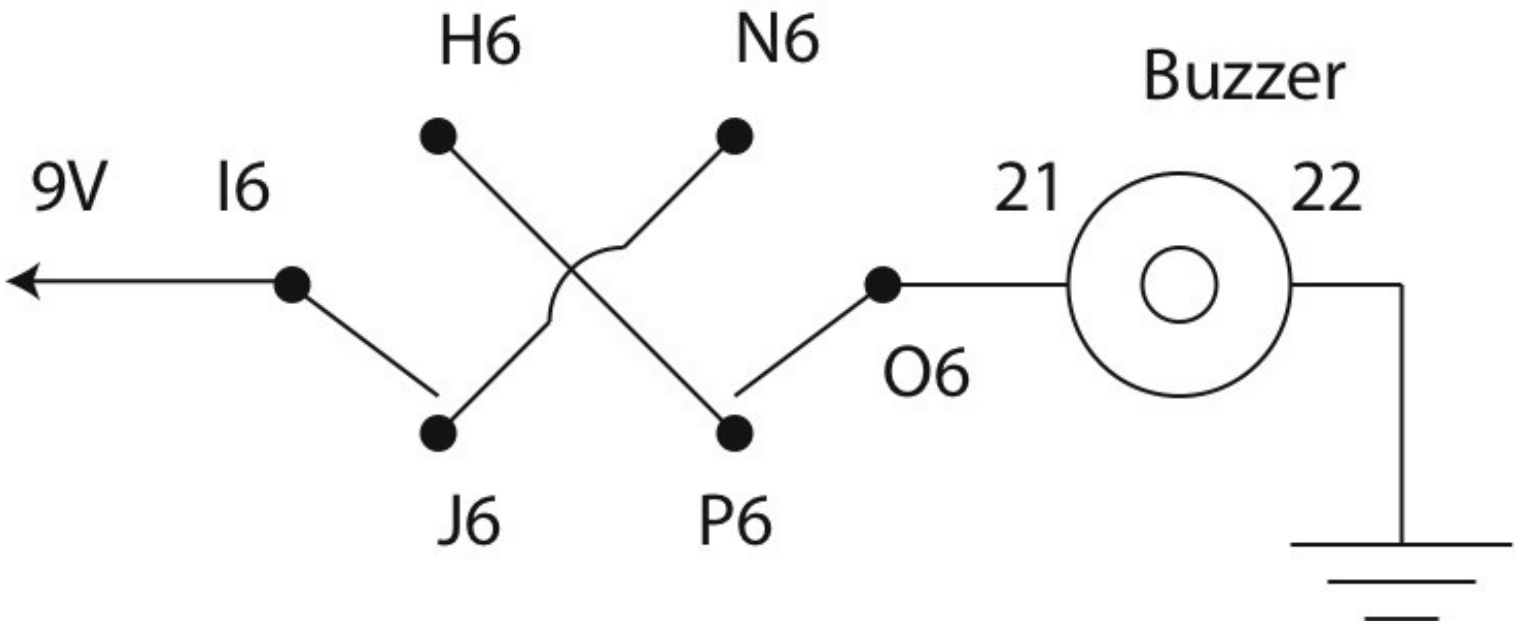
Two Switches in Series



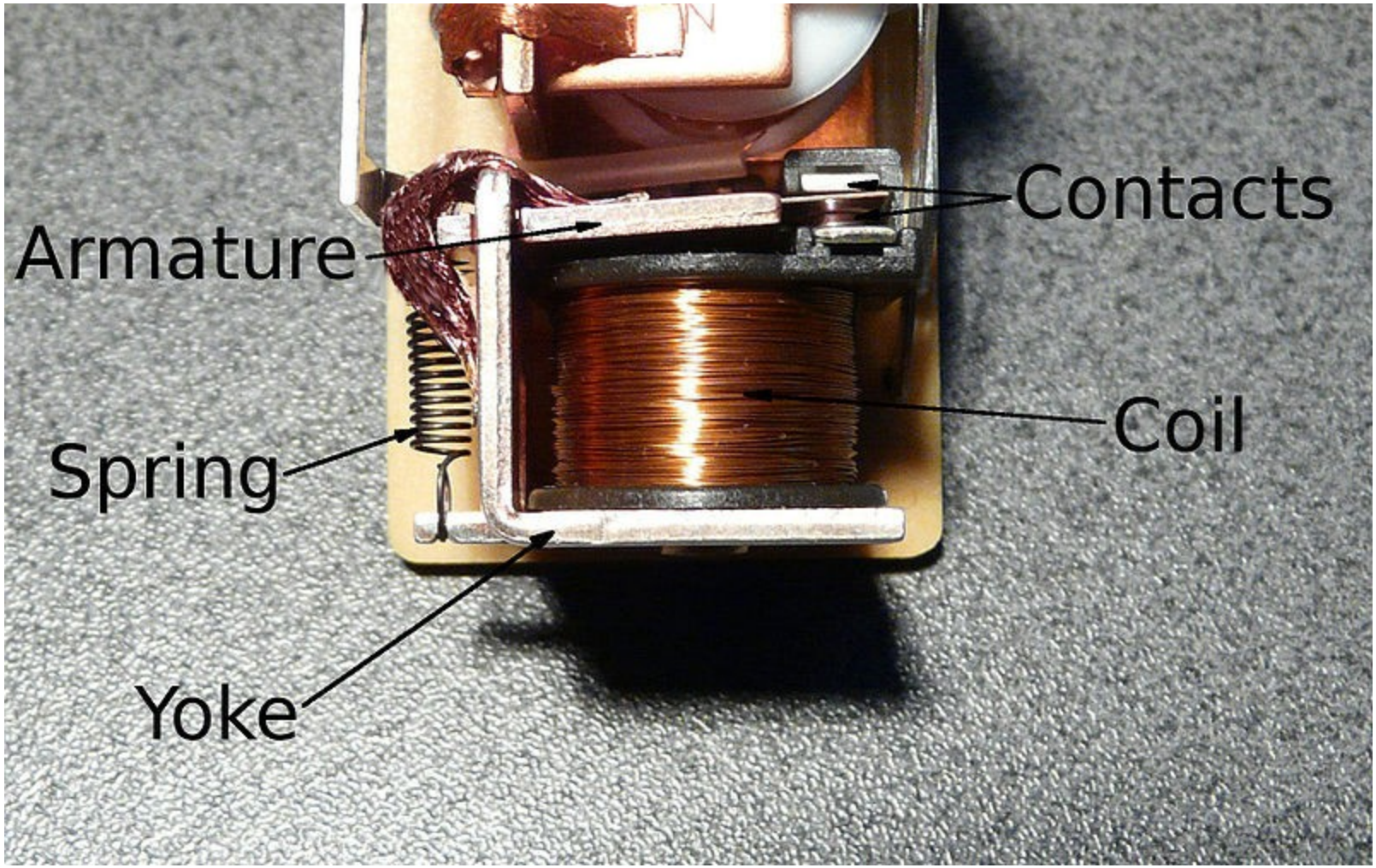
Two Switches in Parallel



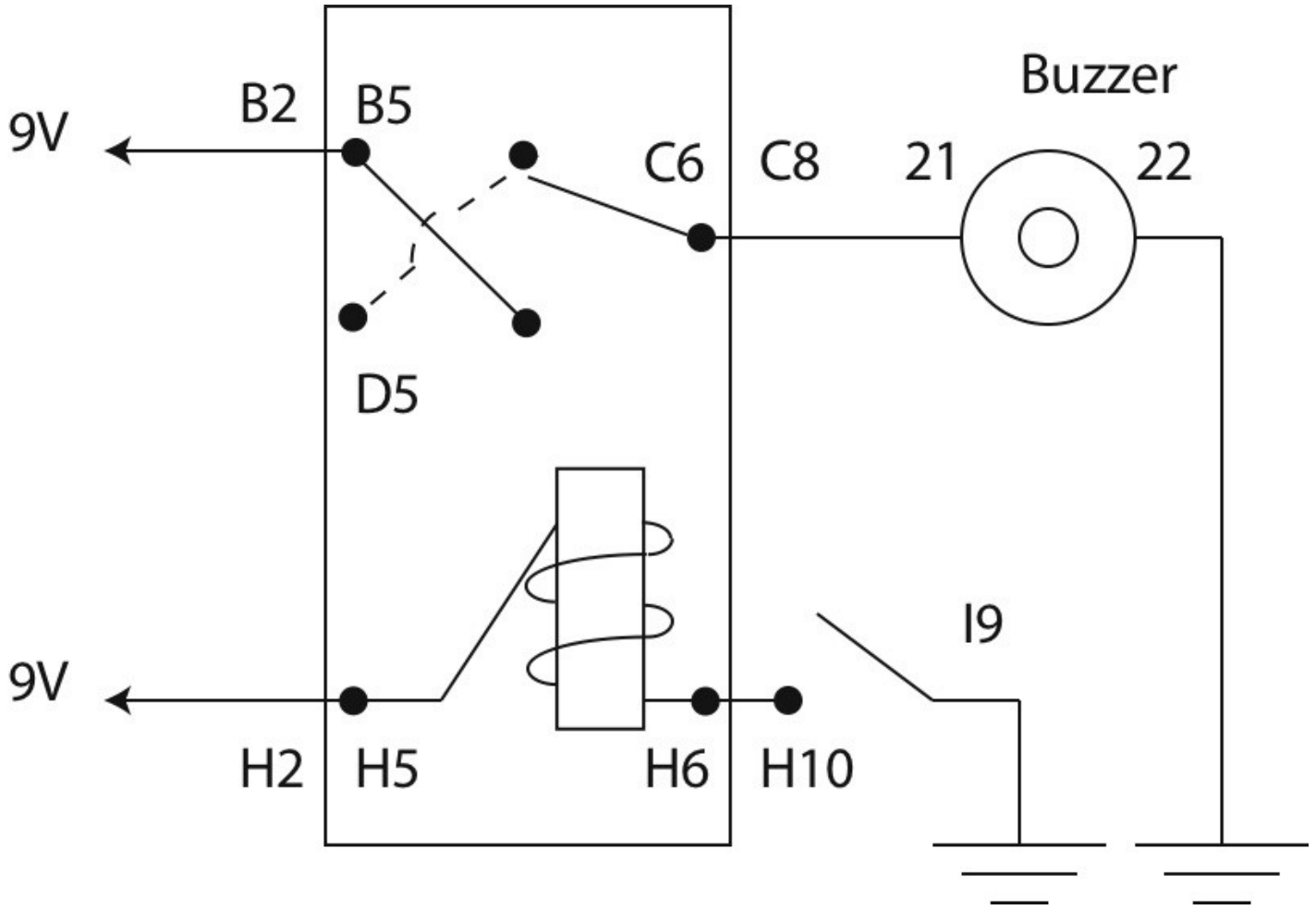
Two Alternating Switches



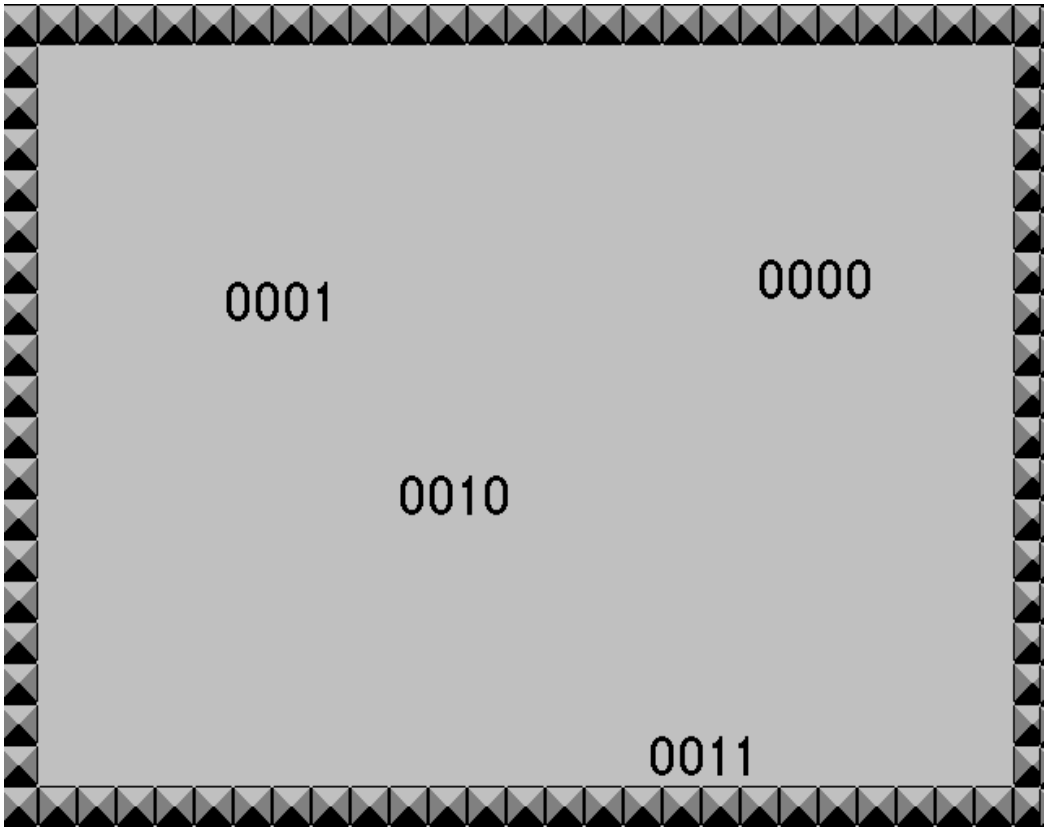
Electromagnetic Relay (Switch)



Use a Relay to Switch Current



Activity 3: Computer Concepts



- Learn how to count with binary numbers
- Play “Game Maker” example game that uses binary numbers
- Learn to program your own game in Game Maker

Computers Use Binary Numbers

0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010

ASCII Code: Character to Binary

0	0011 0000	O	0100 1111	m	0110 1101
1	0011 0001	P	0101 0000	n	0110 1110
2	0011 0010	Q	0101 0001	o	0110 1111
3	0011 0011	R	0101 0010	p	0111 0000
4	0011 0100	S	0101 0011	q	0111 0001
5	0011 0101	T	0101 0100	r	0111 0010
6	0011 0110	U	0101 0101	s	0111 0011
7	0011 0111	V	0101 0110	t	0111 0100
8	0011 1000	W	0101 0111	u	0111 0101
9	0011 1001	X	0101 1000	v	0111 0110
A	0100 0001	Y	0101 1001	w	0111 0111
B	0100 0010	Z	0101 1010	x	0111 1000
C	0100 0011	a	0110 0001	y	0111 1001
D	0100 0100	b	0110 0010	z	0111 1010
E	0100 0101	c	0110 0011	.	0010 1110
F	0100 0110	d	0110 0100	,	0010 0111
G	0100 0111	e	0110 0101	:	0011 1010
H	0100 1000	f	0110 0110	;	0011 1011
I	0100 1001	g	0110 0111	?	0011 1111
J	0100 1010	h	0110 1000	!	0010 0001
K	0100 1011	I	0110 1001	'	0010 1100
L	0100 1100	j	0110 1010	"	0010 0010
M	0100 1101	k	0110 1011	(	0010 1000
N	0100 1110	l	0110 1100	)	0010 1001
				space	0010 0000

American Standard Code for Information Interchange

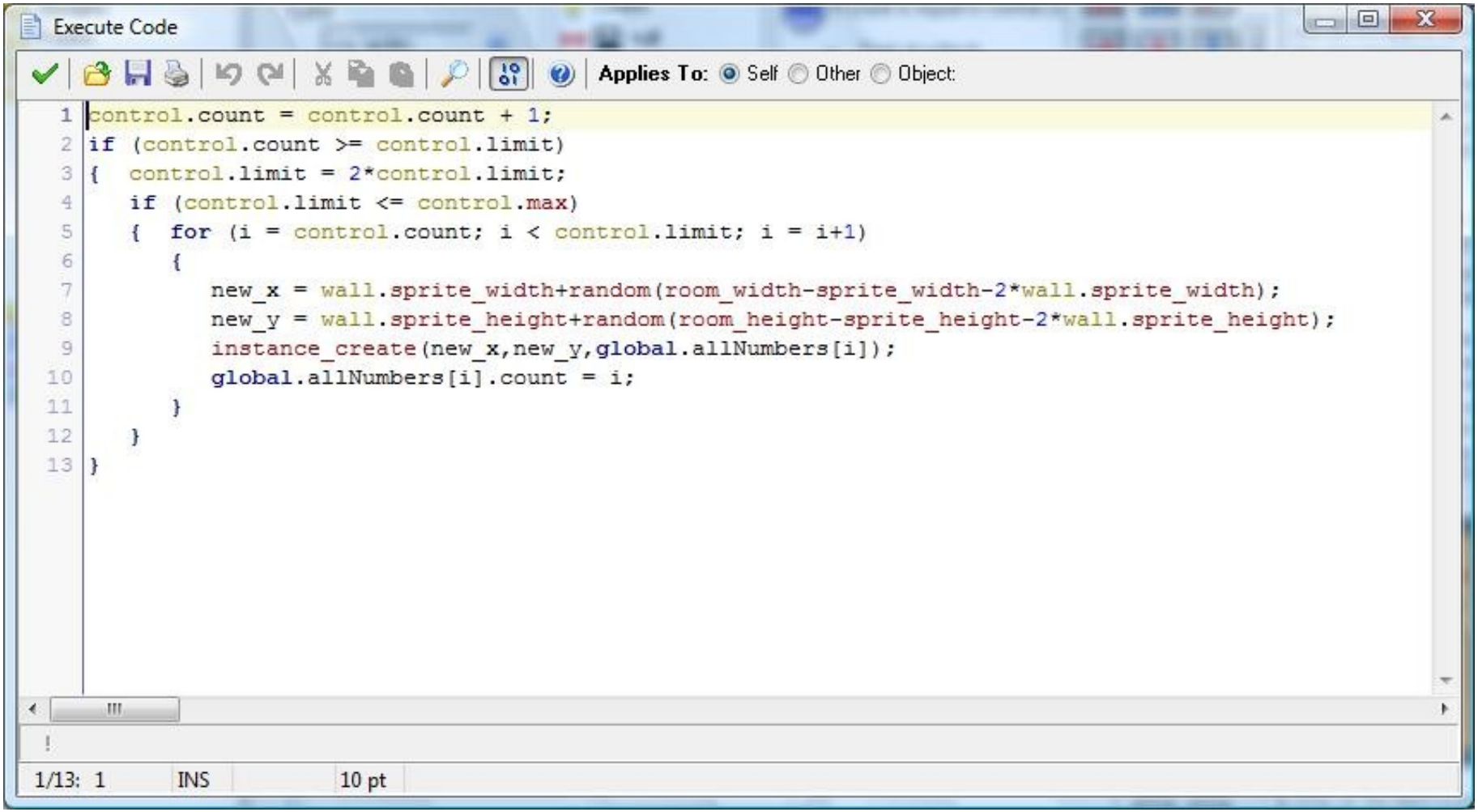
Low-Level Computer Programs

Machine and Assembly Languages:

```
 1  00000400                    ORG      $400    ;Start of the program
 2
 3  00000400 303900000500       MOVE.W   X,D0    ;Put the value of X in D0
 4  00000406 C0C0               MULU     D0,D0   ;Calculate X2
 5  00000408 323900000502       MOVE.W   Y,D1    ;Put the value of Y in D1
 6  0000040E C2C1               MULU     D1,D1   ;Calculate Y2
 7  00000410 D280               ADD.L    D0,D1   ;Add X2 to Y2 and put result in D1
 8  00000412 343900000500       MOVE.W   X,D2    ;Put the value of X in D2
 9  00000418 947900000502       SUB.W    Y,D2    ;Subtract Y from D2 to get X - Y
10  0000041E 82C2               DIVU     D2,D1   ;Divide D1 by D2 to get (X2+Y2)/(X-Y)
11  00000420 33C100000504       MOVE.W   D1,Z    ;Put the result now in D1 into Z
12  00000426 4E722700           STOP     #$2700
13
14  00000500                    ORG      $500    ;Put the data here
15
16  00000500 0032          X:   DC.W     50      ;Initial dummy value for X
17  00000502 000C          Y:   DC.W     12      ;Initial dummy value for Y
18  00000504 00000002      Z:   DS.W     1       ;Reserve space for the result
19
20           00000400           END      $400    ;End of program and address of entry
```

From http://www.alanclements.co.uk/BCSweb/assembly.htm

High-Level Computer Programs



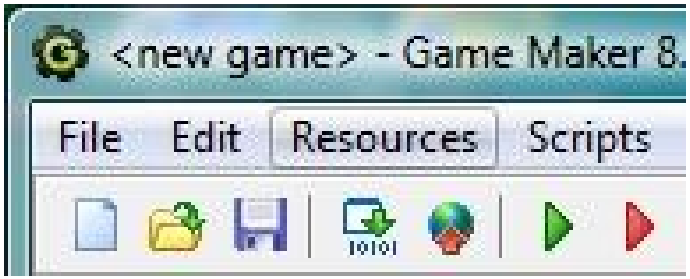
Let's Use Game Maker!

Start the Game Maker Software

Click 

Open the file **`BinaryCounting.gmk`**

Click on the green triangle



Summary

- Electricity and magnetism are connected.
- Physics lays the foundation for computers.
- Magnetic materials enable digital storage of data as binary numbers (101010).
- Computers use binary numbers to perform arithmetic and logical operations.
- Computers (and computer games) are fun!