Science Olympiad
2020
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Exploring the World of Science
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Basics of Electricity

What is a Circuit?

- A circuit is a loop with wire and a power source.
- There must be a conducting material to connect the positive terminal to the negative terminal.
- Electricity is electrons jumping from 1 atom to another.

A model of an Atom.
DC Circuit Theory

What is Current?

- **Current** is the rate of flow of charge past a particular point or region.
- In circuits, an **electrical charge** is normally carried by electrons.
- In electrical conductors, the atoms are bonded in a way where the electrons are able to move around the material without sticking to a particular atom.
- This allows the electrons to "flow."
- the movement of individual electrons within a conductor, known as the electron’s **drift velocity** is quite slow (around several micrometers/second for 1 A in a 2mm diameter copper wire.)
- Current is like the flow in water.
- Current is measured in amperes.
- Amperes are also known as amps.
- High current can heat things up.
- Negative(-) to Positive(+) is known as electron flow.
- Positive(+) to Negative(-) is known as conventional flow.

Direct Current

- Direct current has constant direction.
- All batteries have direct current.
- Direct current is also known as DC.
- Most electronics use direct current.
- DC currents are much less hazardous than AC currents. But, if you get in contact with a wet surface, and then touch a DC current, it can be very hazardous.

Alternating Current

- Alternating current regularly reverses direction.
- An alternating current is also known as AC.
- Alternating current is more dangerous than direct current.
- Alternating current has less power loss to heat during transmission.
- Alternating current is used for generation and transmission.
- House electricity and power lines use alternating current.
- Alternating Current is transmitted at very high voltages and stepped down using a transformer for home usage (normally around 220V AC in the US).
What is Voltage?
- Voltage is the force behind electrons.
- Batteries range from 1.5 volts to 24 volts.
- Home electricity ranges from 110 volts to 220 volts.
- Lightning can be millions of volts.
- Voltage is also known as a potential difference.
- Voltage is similar to pressure in water.
- Voltage is measured in volts.
- The symbol/abbreviation for a volt is V.

What is Resistance?
- Resistance is the opposition against the free transfer of electrons in a conductor.
- Copper, Silver, and other conductors have low resistance.
- Glass, wood, rubber, plastic, and other insulators have high resistance.
- Transfer (or current) is usually due to some force like the EMF (Electromotive Force) from the voltage of a battery.
- The wider the wire is the less resistance it has.
- Resistance is like how difficult it is for water to flow.
- Resistance is measured in ohms (Ω).
- Always have tables of resistivity, ρ units are Ω•m
- Superconductors = 0 Ω•m
- Metals/Conductors ~10^-8 Ω•m
- Semiconductors (variable upon doping)
- Insulators ~10^16 Ω•m
- Superinsulators ~∞ Ω•m
- Top Common Conductors
  - Silver ρ = 1.59x10^-8 Ω•m
  - Copper ρ = 1.68x10^-8 Ω•m
  - Gold ρ = 2.44x10^-8 Ω•m
  - Aluminum ρ = 2.65x10^-8 Ω•m
- Top Common Semiconductors
  - GaAs ρ = 1x10^-3 to 1x10^8 Ω•m
  - Germanium ρ = 4.6x10^-1 Ω•m
  - Silicon ρ = 6.4x10^2 Ω•m
- Top Common Insulators
  - Deionized water, Glass, Diamond, Hard Rubber, Air, and Dry Wood
  - Fused Quartz ρ = 7.5x10^17 Ω•m
  - PET ρ = 1x10^21 Ω•m
  - Teflon ρ = 1x10^23 to 1x10^25 Ω•m
Ohm’s Law

The Big Three ---Volta, Ampere, and Ohm, together make Ohm’s Law, shown above.

Relationship to Water
Electrostatic Force - Coulomb’s Law

\[ F = k \frac{q_1 q_2}{r^2} \]

- **F** = electrostatic force
- **q** = electric charge
- **r** = distance between charge centers
- **k** = Coulomb constant
  \[ 9.0 \times 10^9 \text{N} \cdot \text{m}^2/\text{C}^2 \]

Unlike charges attract.

Like charges repel.

**Right-Hand Rule**

The current enters from the arm and is induced to go right. The force is motion, like a motor, and the magnetic field is a magnetic field.
Kirchhoff's Voltage Law

The sum of all voltages must be equal to 0.

Kirchhoff's Current Law

The current entering any junction is equal to the current leaving that junction. $i_2 + i_3 = i_1 + i_4$.

A charge is conserved. Therefore, the current that flows into a resistor equals the current that flows out of the resistor. Similarly, the current that flows into a junction must equal the sum of the currents leaving the junction.
Analyzing Circuits With Kirchhoff’s Laws

Step 1: Give an arbitrary node a value of 0.

Step 2: Follow the Circuit and add a value based on the changes in a circuit such as a battery.

Step 3: Calculate the “rise” that is given.
Step 4: Calculate the “drop” and repeat from step 3 until you reach where you started. You should have a value of 0.

Step 5: Drop can also be a negative rise.

Step 6: Double-check your work with the equation below.
Magnets

Electromagnets

**Magnetism** - the force exerted by magnets

What causes magnetism: There are 2 main ways that magnetism can arise:

Moving Charges / Electron magnetic moments and electric current:

- **Electric current**: The movement of electric charges creates a magnetic field surrounding the moving current because of the following
  1. Electron's property of spin (which are electron magnetic dipole moments)
  2. And, The electron's motion around the proton that's known as the electromagnetic field.

- **Electron magnetic dipole moment**: This occurs when an electron has a magnetic moment (or creates magnetism) because of its intrinsic property of spin. Yet, this normally cancels out with other electrons, but sometimes—either spontaneously, or owing to an applied external magnetic field, each of the electron's magnetic moments can be added together and produce a net total magnetic field.

**Nuclear magnetic moment** (of atomic nuclei):

Because of how these moments are thousands of times smaller than electrons magnetic moments, they are negligible in the magnetization of materials. Electric field flows from positive to negative.

**Magnets**:

- Magnets always have 2 poles and are considered to be dipoles.
- They will always be magnetic fields.
- Always comes in the form of dipoles.
- Theoretically, a magnetic monopole is possible but has never physically worked.
- If a dipole magnet were cut in half it would have 2 dipole magnets.
- Electrostatic forces and magnetic forces are the same thing. Yet, they are typically treated as 2 different things.
- Poles will always find the shortest path.
- Magnetic poles always flow from North to South
Similarities between magnetic fields and electric fields:
- Electric fields are produced by two kinds of charges, positive and negative. Magnetic fields are associated with two magnetic poles, north and south, although they are also produced by charges (but moving charges).
- Like poles or charges repel; unlike poles or charges attract
- Electric field points in the direction of the force experienced by a positive charge.

Differences between magnetic fields and electric fields:
- Positive and negative charges can exist separately. North and south poles always come together. Single magnetic poles, known as magnetic monopoles, have been proposed theoretically, but a magnetic monopole has never been observed.
- Electric field lines have definite starting and ending points. Magnetic field lines are continuous loops. Outside a magnet the field is directed from the north pole to the south pole. Inside a magnet, the field runs from south to north.

<table>
<thead>
<tr>
<th>Nature</th>
<th>Electric Field</th>
<th>Magnetic Field</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Created around an electric charge (voltage)</td>
<td>Created around moving electric charge and magnets (current)</td>
</tr>
<tr>
<td>Units</td>
<td>Newtons per Coulomb (N/C), Volts per meter (V/m)</td>
<td>Gauss, Tesla</td>
</tr>
<tr>
<td>Force</td>
<td>Proportional to electric charge</td>
<td>Proportional to speed and charge of electric charge</td>
</tr>
<tr>
<td>Movement in EM Field</td>
<td>Perpendicular to the magnetic field</td>
<td>Perpendicular to the electric field</td>
</tr>
<tr>
<td>Pole</td>
<td>1 or 2 Poles</td>
<td>2 Poles</td>
</tr>
</tbody>
</table>
If you break a permanent magnet into 2, you will have 2 magnets.

**Geomagnetism/ Earth’s magnetic field:**
The Earth is surrounded by an immensely large magnetic field called the magnetosphere.

**Geomagnetism Definitions:**

**Solar Winds:** A stream of charged particles from the sun.
**Van Allen Belts:** Magnetic region above Earth; in the atmosphere.
**Magnetic Declination:** Angle between geographic north/south and magnetic north/south.
**Compasses:** A device that shows where one is based off how the magnetic needle points north.

**Different Magnets**
**Ferromagnets** - magnetize readily
**Paramagnets** - slightly magnetic
**Diamagnets** - do not magnetize readily
**Ferromagnetism definition:** A Mechanism by which certain materials form magnetic domains.

**Paramagnets:** Magnets that are attracted to externally applied magnetic fields.
Not permanent magnets. Repelled by magnetic fields
**Diamagnets:** Magnetic materials that are repelled to an externally applied magnetic field.
Not permanent magnets. Repelled by magnetic fields

**Diamagnetism:** When an applied magnetic field creates an induced magnetic field within the Diamagnetic materials in the opposite direction, causing a repulsive force.
**Paramagnetism:** When an applied magnetic field creates an induced magnetic field within the paramagnetic and ferromagnetic materials in the same direction causing them to be attracted by the magnetic field.

**Magnetic flux density:** The amount of how compact the magnetic field is.
**Units:** Tesla or Gauss (not gausses).
The Earth’s ‘north’ pole is actually a south pole! This is why the north side of the compass needle points north.

**Electromagnets:**
Are temporary magnets, operated by electric current, and can change their magnetic
field strength/ magnetic flux density (they both show increases in magnetic field intensity).
Due to how current has the property of magnetism; when current is passed through a solenoid, it is able to induce a polarized magnetic field.
These are used for generators and motors because of how they can induce polarized magnetic fields (and thus a force as according to Fleming’s right hand rule) and EMF.
How to make an electromagnet stronger:
1. Increase the amount of coils in solenoid.
2. Greater diameter of ferromagnetic core (typically iron)
3. The increase voltage traveling through circuit/ electromagnet

Solenoid:
A cylindrical coil of wire acting as a magnet when carrying electric current.

Fleming’s Left and Right Hand Rule
Fleming’s Right Hand Rule: Fleming’s Right hand rule is a hand sign that is used for figuring out which direction the current is flowing towards within an electric generator. 
Note: Fleming’s Right Hand Rule can only be used when you are using electric generators.
Fleming’s Left Hand Rule: Fleming’s Left Hand Rule is a hand sign that is used for figuring out which direction the current is flowing towards within an electric motor.
Note: Fleming’s Left hand Rule can only be used when you are using electric motors.

Magnetic Monopoles - magnets that only have 1 pole

Gauss’s Law of Magnetism
In physics, Gauss's law for magnetism is one of the four Maxwell's equations that underlie classical electrodynamics. It states that the magnetic field B has divergence equal to zero, in other words, that it is a solenoidal vector field. It is equivalent to the statement that magnetic monopoles do not exist. Rather than "magnetic charges", the basic entity for magnetism is the magnetic dipole. (If monopoles were ever found, the law would have to be modified, as elaborated below.)
Transformers and Motors

Transformers

- There are 2 types of transformers, step up and step down.
- Only works with AC.
- There are 2 coils in a single phase transformer.
- If the second coil has more turns than the first coil the voltage will be stepped up, as a result if the second coil has less turns than the first coil the voltage will be stepped down.
- If you step up voltage the current will decrease and if you step down voltage the current will increase.
- Coils are used as electromagnets to push electrons in the secondary coil.
Motors

- Can be brushed or brushless.
- It has an electromagnet repel against another magnet.
- Uses the right hand rule.
- Coils are used as electromagnets.
- Brushed motors use brushes to change contact in the commutator ring.
- Brushless motors are used for heavy duty tasks because brushes can wear out.
- Universal motors use 2 electromagnets on the same power source.
- Motors can be used as generators in reverse.

![Brushed Motor Diagram](image1)

Brushed Motor Diagram

![How Brushless Motor and ESC Work](image2)

Brushless Motor Diagram
Diodes

Standard Diodes

- Two types of doping, N, and P.
- It only allows current one way.
- Doping is added to a semiconductor such as silicon.
- N-doping has added electrons that try to run away.
- P-doping has slots for electrons that cause electrons to go in empty slots.
- The border between the N and P doping is slightly positively charged with another border slightly negatively charged. This border is called ‘the depletion region.
- The depletion region will only allow flow 1 way when connected to the charge.

Light Emitting Diodes

- Three important factors are the polarity, forward voltage, and max current.
- There is an anode and cathode these are the 2 leads.
- Light is created by positive charges colliding with negative charges.
- Longer side is anode and the shorter side is cathode.
- If you exceed max current then the LED can burn.
- Some approximate ratings are below.

<table>
<thead>
<tr>
<th>Color</th>
<th>Forward Voltage</th>
<th>Forward Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>3.1V</td>
<td>20ma</td>
</tr>
<tr>
<td>Red</td>
<td>2.1V</td>
<td>20ma</td>
</tr>
<tr>
<td>Blue</td>
<td>3.4V</td>
<td>20ma</td>
</tr>
<tr>
<td>Green</td>
<td>3.4V</td>
<td>20ma</td>
</tr>
<tr>
<td>Yellow</td>
<td>2.1V</td>
<td>20ma</td>
</tr>
</tbody>
</table>
3-Way Switch

Toggling the switch disconnects one "traveler" terminal and connects the other. Electrically, a typical "3-way" switch is a single-pole, double-throw (SPDT) switch. By correctly connecting two of these switches together, toggling either switch changes the state of the load from off to on, or vice versa. A light or lights can be controlled by more than one switch. The usual practice in home construction is to use 3-way switches. "3-way" is the electrician's designation for a single pole double throw (SPDT) switch. The three-way switch is a variation of the standard single-pole switch, which controls a light only from one location. In summary, a 3-way switch is like 2 overlapping circuits with 2 switches.

Multiple ways to turn on and off.
Static Electricity

Static Energy:

This is electricity that doesn't flow. It has a voltage but no current. Caused by over/underpopulated electrons in an object. We learned that atoms are made up of tiny particles called neutrons, protons, and electrons. The neutrons and protons make up the nucleus. The electrons spin around the outside of the nucleus. A static charge is formed when two surfaces touch each other and the electrons move from one object to another. One object will have a positive charge and the other a negative charge. Rubbing the items quickly, like when you rub a balloon fast over something or your feet on the carpet, will build up a large charge. Items with different charges (positive and negative) will attract, while items with similar charges (positive and positive) will push away from each other. Sort of like a magnet. One example of this is when you slide down a slide and all of your hair stands up straight. This is because the friction of sliding has caused a positive charge to be built up on each hair. Since each hair has the same charge, they all try to push away from each other and end up standing up straight.

Dangers of Static:

- Static electricity builds up in clouds which cause a huge spark to form between the ground and the cloud. This is called lightning - a flow of charge through the atmosphere.
- It is dangerous when there are flammable gases or a high concentration of oxygen. A spark could ignite the gases and cause an explosion.
- Touching an object with a large electric charge will allow the charge to flow through your body, causing an electric shock. This could cause burns and heart stoppage.
- Refuelling aircrafts/tanker can be dangerous. When fuel passes through the hose, this could build up static charge, cause a spark, and ignite the fuel.
Popular Circuits

Wheatstone Bridge

![Wheatstone Bridge Diagram](image)
Famous Scientists

Nikola Tesla

Information

Nikola Tesla was a Serbian-American inventor, electrical engineer, mechanical engineer, and futurist who is best known for his contributions to the design of the modern alternating current electricity supply system. Nikola Tesla often had a lack of sleep.

Born: July 10, 1856

Died: January 7, 1943

Accomplishments

- He patented the polyphase alternating current induction motor in 1887-88.
- His alternating current emerged winner in the battle of currents.
- He developed the tesla turbine as an alternative engine for mechanical machines.
- He was instrumental in building one of the first hydroelectric plants.
- He invented the tesla coil leading to the possibility of wireless transmission.
- He invented an electro-mechanical oscillator.
- He made important contributions to radio technology.
- Nikola Tesla created one of the world’s first wireless remote controls.
- He played a key role in the development of x-rays.
- Nikola Tesla had close to 300 patents.
Alessandro Volta

Information
Alessandro Giuseppe Antonio Anastasio Volta was an Italian physicist, chemist, and pioneer of electricity and power who is credited as the inventor of the electric battery and the discoverer of methane.

Born: February 18, 1745

Died: March 5, 1827

Full name: Alessandro Giuseppe Antonio Anastasio Volta

Accomplishments
- He invented the voltaic pile (first battery) in 1800.
- He was the first person to isolate methane.
- Discovered methane mixed with air could be exploded using an electric spark: this is the basis of the internal combustion engine.
- Discovered “contact electricity” resulting from contact between different metals.
- Recognized two types of electric conduction.
- Wrote the first electromotive series. This showed, from highest to lowest, the voltages that different metals can produce in a battery.
- Discovered that electric potential in a capacitor is directly proportional to electric charge.
Heinrich Hertz

Information

Heinrich Rudolf Hertz was a German physicist who first conclusively proved the existence of the electromagnetic waves predicted by James Clerk Maxwell's equations of electromagnetism. The unit of frequency, cycle per second, was named the "Hertz" in his honor.

Born: February 22, 1857

Died: January 1, 1894

Accomplishments

- He proved that electric current has negligible mass.
- He compared Maxwell's theory with other competing theories in a famous paper.
- Heinrich Hertz discovered radio waves.
- He conclusively proved Maxwell's electromagnetic theory of light.
- Hertz laid the foundation for modern communications technology.
- He was the first to discover the photoelectric effect.
- He produced pioneering work in the field of contact mechanics.
- He invented the dipole antenna.
Georg Simon Ohm

Information
Georg Simon Ohm was a German physicist and mathematician. As a school teacher, Ohm began his research with the new electrochemical cell, invented by Italian scientist Alessandro Volta. He believed in contagious particles and theorized that sound is perceived as a number of harmonic tones.

Born: March 16, 1789
Died: July 6, 1854

Accomplishments
- Georg Ohm discovered some laws relating to the strength of a current in a wire. Ohm found that electricity acts like water in a pipe.
- George Ohm created Ohm’s Law.
- Ohm discovered that the current in a circuit is directly proportional to the electric pressure and inversely to the resistance of the conductors.
Michael Faraday

Information

Michael Faraday FRS was an English scientist who contributed to the study of electromagnetism and electrochemistry. His main discoveries include the principles underlying electromagnetic induction, diamagnetism, and electrolysis. Faraday rejected a knighthood, twice declined the presidency of the Royal Society and refused to cooperate with the government in producing chemical weapons for use in the Crimean war.

Born: September 22, 1791

Died: August 25, 1867

Accomplishments

- Michael Faraday invented the first electric motor.
- He discovered benzene.
- He was the first to liquefy chlorine and ammonia.
- Michael Faraday discovered the phenomenon of electromagnetic induction.
- His work laid the basis for future developments in the field of electromagnetism.
- Michael Faraday invented the first electromagnetic generator (dynamo).
- He formulated Faraday’s laws of electrolysis.
- He discovered the principle of electrostatic shielding to invent the Faraday Cage.
- He provided the first experimental evidence that linked electromagnetism and light.
- Faraday demonstrated diamagnetism as a property of all matter.
André-Marie Ampère

Information
André-Marie Ampère was a French physicist and mathematician who was one of the founders of the science of classical electromagnetism, which he referred to as "electrodynamics". He is also the inventor of numerous applications, such as the solenoid and the electrical telegraph.

Born: January 20, 1775

Died: June 10, 1836

Accomplishments

- He recognized the existence of the element fluorine and coined the term for it.
- He correctly identified that chemical elements should be organized according to their properties.
- He devised a popular rule in electromagnetism known as the right-hand grip rule.
- Ampere was the first to discover that magnetism could be produced without magnets.
- He formulated the Ampère's Force Law in 1823.
- He proposed an advanced theory explaining the Earth’s magnetism.
- André-Marie Ampère wrote the foundational test of electrodynamics.
- He theorized the existence of a particle similar to an electron.
- He played a key role in the development of the galvanometer.
- Ampere is regarded as one of the founders of the field of electromagnetism.
Charles-Augustin de Coulomb

Information
Charles-Augustin de Coulomb was a French military engineer and physicist. He is best known as the eponymous discoverer of what is now called Coulomb's law, the description of the electrostatic force of attraction and repulsion, though he also did important work on friction.

Born: June 14, 1736
Died: August 23, 1806

Accomplishments
- Charles-Augustin de Coulomb formulated Coulomb's Law.
- He devised a sensitive apparatus to evaluate the electrical forces related to Priestley’s law.
- He developed the inverse square law of attraction and repulsion of unlike and like magnetic poles.
- Coulomb extensively worked on the friction of machinery, the elasticity of metal and silk fibers and windmills. This is called torsional force.
Gustav Robert Kirchhoff

Information

Gustav Robert Kirchhoff was a German physicist who contributed to the fundamental understanding of electrical circuits, spectroscopy, and the emission of black-body radiation by heated objects. He coined the term black-body radiation in 1862.

Born: March 12, 1824

Died: October 17, 1887

Accomplishments

- Kirchhoff formulated his Kirchhoff's Circuit Laws.
- In 1857 he calculated that an electric signal in a resistance-less wire travels along the wire at the speed of light.
- He contributed greatly to the field of spectroscopy by formalizing three laws that describe the spectral composition of light emitted by incandescent objects.
- He also contributed to optics, carefully solving Maxwell's equations to provide a solid foundation for Huygen's principle (and correct it in the process).
### Resistor Color Chart

<table>
<thead>
<tr>
<th>COLOR</th>
<th>1ST BAND</th>
<th>2ND BAND</th>
<th>3RD BAND</th>
<th>MULTIPLIER</th>
<th>TOLERANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1Ω</td>
<td>±1% (F)</td>
</tr>
<tr>
<td>Brown</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>10Ω</td>
<td>±2% (G)</td>
</tr>
<tr>
<td>Red</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>100Ω</td>
<td>±0.5% (D)</td>
</tr>
<tr>
<td>Orange</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1KΩ</td>
<td>±0.25% (C)</td>
</tr>
<tr>
<td>Yellow</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>10KΩ</td>
<td>±0.10% (B)</td>
</tr>
<tr>
<td>Green</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>100KΩ</td>
<td>±0.05%</td>
</tr>
<tr>
<td>Blue</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>1MΩ</td>
<td>±0.05%</td>
</tr>
<tr>
<td>Violet</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>10MΩ</td>
<td>±0.05%</td>
</tr>
<tr>
<td>Grey</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>100MΩ</td>
<td>±0.05%</td>
</tr>
<tr>
<td>White</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>1GΩ</td>
<td>±0.05%</td>
</tr>
<tr>
<td>Gold</td>
<td></td>
<td></td>
<td></td>
<td>0.1Ω</td>
<td>±5% (J)</td>
</tr>
<tr>
<td>Silver</td>
<td></td>
<td></td>
<td></td>
<td>0.01Ω</td>
<td>±10% (K)</td>
</tr>
</tbody>
</table>

### 5-Band-Code

- 0.1%, 0.25%, 0.5%, 1%
- 237 Ω ±1%