**Electricity and Magnetism**

**On the Relationship Between Electric Charge and Magnetic Charge, and the Behavior of Monopoles and Dipoles**

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-Origins of electromagnetic waves, strange fluctuations of electromagnetic field, produce light

-wave function: frequency, period, wavelength, amplitude

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**Magnetic Monopoles in the Universe**

1. Mechanics
2. Electricity and Magnetism
3. Heat
4. Light
5. Sound
6. Nuclear Physics
7. Topological Argument
8. Newton’s Laws of Motion
9. Theory of Universal Gravitation
10. Momentum Principle
11. Simple Harmonic Motion
12. Laws of Thermodynamics
13. Kinetic Theory
14. Principles of Optics
15. Coulomb’s Law
16. Faraday’s Law
17. Hall Effect
18. Conservative and Nonconservative Forces
19. Contact and Noncontact Forces
20. AC/DC and Ohm’s Law
21. Circuits, Series and Parallel
22. Gravitational Field
23. Maxwell’s Equations, unifying electricity and magnetism
24. Electromagnetic Field
25. Electrostatic Fields
26. Electric Displacement Field
27. Electromagnetic Force
28. Electrochemical Force
29. Electromagnetic Radiation- due to accelerating particles
30. Electromagnetic Induction
31. Electric Charge and Magnetic Charge
32. Electric and Magnetic Flux
33. Dipoles and Monopoles
34. Max Planck and Quantum Theory
35. Einstein and the Special Theory of Relativity
36. Quantum Physics, Atomic and Molecular Physics
37. Solid-State Physics
38. Nuclear Physics
39. Particle Physics
40. Cosmology

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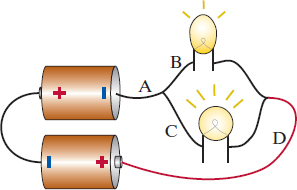
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**Informative Speech, Electricity and Capacity Markets**



**Introduction**

1. Welcome to this speech on electricity and power plants. Imagine you are an ancient Egyptian, and the Pyramid power plant has just been finished to provide electricity to your house on the Nile. How do you celebrate?
2. In this speech, we will discuss how electricity is produced at power plants and distributed to our homes and businesses, and how power plants finance power plant additions to produce electricity, called capacity markets.
3. Electricity powers our homes, businesses, and even cars now. Power plants produce electricity through using various forms of energy as inputs, including natural gas, nuclear power, and renewable energy sources such as wind, solar, and hydro.

**Ancient Electricity**

1. Our first topic is Ancient Electricity. We all know the story in the U.S. about Benjamin Franklin proving that lightning contained electricity, though older cultures around the world have also experimented with electricity in various forms.
2. Electricity is an aspect of our everyday life that has been around since ancient times.
3. For example, according to the Smith College Museum in 2024, the Baghdad Battery, around 2000 years old, was found in Iraq that contained a cylinder of copper and an iron rod suspended in the center.
4. Replicas of the battery were made that could produce a charge of about one volt when used with vinegar or lemon.
5. The Baghdad Batteries may have been used to electroplate items, such as putting a layer of one metal (gold) onto the surface of another (silver), a method still practiced in Iraq today.
6. Bret’s Electric (2023) describes how the ancient Egyptians recorded electric shocks from fish, and the ancient Greeks recorded experiments in static electricity.
7. Some people have even argued that the Egyptian pyramids were giant power plants designed to harvest electricity from the Nile River.

**Ohm’s Law**

1. Next, we will discuss Ohm’s Law, which considers the relationship between voltage, current, and resistance.
2. Although many ancient civilizations discovered forms of electricity, they all did not have a firm understanding of Ohm’s Law.
3. One facet of electricity that impacts our understanding of the phenomenon is that you cannot see electricity.
4. True, you can see lightning, but lightning is actually a reaction in the air to the energy passing through it, and not the energy exchange happening from the clouds to the earth itself.
5. *Study.com in 2024 describes the relationships between current, voltage, and resistance.*
6. Current: The amount of charge that flows through a conductor in a given time interval, or the rate at which charge is flowing. Measured in Amps.
7. Voltage: The potential difference between two points, measured across a wire or component, or the difference in charge between two points. Measured in Volts.
8. Resistance: The opposition to current in a circuit, or a material's tendency to resist the flow of charge (current). Measured in Ohms.
9. These values, current, voltage, and resistance, describe the movement of charge, and thus, the behavior of electrons.
10. To study these values, we use circuits, which are closed loops that allow charge to move from one place to another.
11. Components in the circuit allow us to control this charge and use it to do work Spark Fun Learn (2024).
12. Ohm's Law states that the current flowing through a circuit is directly proportional to the voltage applied, and inversely proportional to the resistance of the circuit.
13. This relationship is expressed mathematically as V = I \* R, where V is voltage, I is current, and R is resistance.
14. One method for calculating these electricity values is to use linear algebra to construct a matrix and solve for the unknowns.
15. Isaac Physics (2024) describes Kirchhoff’s Laws, which describe rules for current and voltage in a circuit.
16. Kirchhoff's current law (1st Law) states that the current flowing into a node (or a junction) must be equal to the current flowing out of it. This is a consequence of charge conservation.
17. Kirchhoff's voltage law (2nd Law) states that in any complete loop within a circuit, the sum of all voltages across components which supply electrical energy (such as cells or generators) must equal the sum of all voltages across the other components in the same loop. This law is a consequence of both charge conservation and the conservation of energy.

**Capacity Markets**

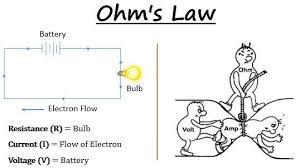
1. Our third topic today is how power plants are funded. Power plants make money from energy markets, selling electricity in the present, and capacity markets, selling reserves to produce electricity in the future.
2. Capacity markets are a reserve market construct used in electricity markets to provide revenue to plant operators in response to price caps and plant additions.
3. Capacity markets became more widespread after deregulation of electricity markets in the 1990s; some regions use capacity markets to generate income and some do not.
4. Also, the emergence of renewable energy sources which have zero marginal cost, that is, they don’t require fuel, have pushed down electricity costs and remuneration for plant operators, thus opening the argument that capacity markets are needed because of the increased emergence of renewable energy sources and deregulation, which cut rates.
5. Capacity Markets for providing remuneration to power plants is relevant because they directly impact our electricity bills, and the argument is that capacity markets for electricity remuneration result in overall lower electricity bills for customers.
6. Capacity markets help ensure that there is enough electricity to meet future demand and provide long-term stability to the power system by allowing investment for infrastructure (NRG Editorial Voices, 2023).

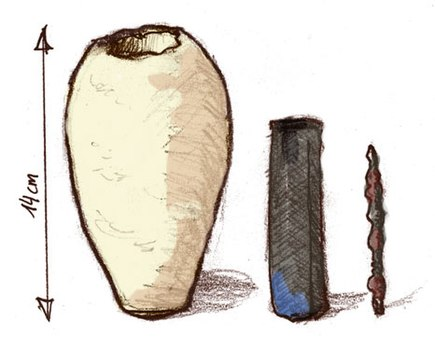
**Conclusion**

1. Without electricity, our modern society would cease to function as we know it. Electricity powers the air conditioners in our homes and lights in our businesses, and also even powers up automobiles now.
2. I want to pose a question to the audience about electricity. How would you light your house without electricity? Would you use candles? Would you use a kerosene lamp? Or would you wake up earlier when the sun rises and go to sleep when the sun sets in the evening.
3. These are questions that people had to face before electricity became commonplace in our homes and businesses. The power plants that produce electricity keep us up and running in our lives.

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**Persuasive Speech, Go Green**

**Kevin Sleem, COM 231**

**Introduction**

1. Recycling and energy conservation is a good way to preserve our planet. Let me ask the audience a question. Do you recycle? If not, would you recycle more if there was a community program in place?
2. The biggest obstacle in convincing people to conserve energy and recycle is relevancy, in that we have to convince people that recycling is an important part of their lives.
3. The strongest argument against recycling is that some people think that it doesn’t matter, that the landfills and incinerators can handle any amount of garbage just fine.
4. The strongest argument against energy conservation, electric vehicles, and renewable energy is that society is not ready yet for a full scale transition.
5. My interest in this topic is driven primarily by a fascination with the transition to electric vehicles and renewable energy sources. Electric vehicles are becoming cheaper with longer range, and renewable energy sources such as solar and wind are also becoming cheaper and more powerful, capable of harnessing more energy from the sun and wind. Recycling and energy conservation is something small that we all can strive to do to at home to make an impact.

My main points for this speech are:

1. Recycling, communities should have programs in place to encourage recycling.
2. Water Conservation is something that everyone can do at home.
3. Electric vehicles, we need to build more charging stations for electric vehicles.
4. Renewable energy, we need to build more solar farms and wind farms.

***Recycle***

1. Everyone should strive to recycle when available, because it is easy to do and healthy for the planet, even when it is not required by law.
2. It is common for communities to offer recycling waste pick up services along with trash pick up.
3. Some areas in the country might not offer curbside recycling, and the impact of recycling may be minimal, but there are also recycling drop off canisters at grocery stores sometimes such as Food Lion.
4. Sanborn (2023) argues for a national recycling refund.
5. A national recycling refund would increase recycling rates by providing monetary compensation and introduce recycling systems to rural areas and recycling deserts, increase jobs in areas such as recycling collection, processing, and transportation, and reduce litter thereby saving the taxpayers money.
6. Josephson (2023) notes how recycling reduces the energy needed to manufacture goods by the need for growing, mining or extracting raw materials.
7. However, recycling can also lead to some pollution, such as for electronics recycling which is outsourced to less developed nations than the U.S., whereby some chemicals can leach into the ground.

***Water Conservation***

1. Related to recycling is energy and water conservation. The groundwater that makes up the underground water table is a finite resource.
2. Yes, groundwater is replenished naturally through rainwater seeping into the ground, but in some desert communities that do not get a lot of rain they are at risk of running out of ground water.
3. These desert communities may have to transport seawater in pipes to their communities and then desalinate the seawater.
4. On their website the EPA, Environmental Protection Agency, discusses ways to conserve water.
5. For example, you can fix a leak in the kitchen, bathroom, or laundry room, and outdoors you can use a broom instead of a hose.
6. Everyone can do their part to conserve water, and this is important to ensure a reliable water supply for future generations.
7. The Wildlife Trusts in their article on water conservation notes that the average person uses 140 liters of water per day, and at current usage rates, we might see water shortages in some cities in the U.S. by 2080.

***Electric Vehicles***

1. Recycling and water conservation are things we can all do at home, but electric vehicles are a bigger decision for households. We are slowly but surely transitioning to an electric vehicle future.
2. We need to build out more charging station infrastructure, and get mileage better on EVs, but we are making progress.
3. There is also the option of hydrogen fuel cell powered cars, though hydrogen is likely more feasible for long distance trucking and shipping.
4. Wheels for Wishes (2021) notes that one aspect of buying an electric car over a gas car is cost.
5. While gas cars are presently cheaper to buy, electric vehicles are cheaper to maintain, such as no oil changes.
6. As for mileage, gas cars can go further, but there are advancements being made to increase range for electric vehicles.
7. If you make city to city trips and need to refuel on the highway, gas cars are for you, but if you don’t travel in your car, you could make an electric car work.
8. As for energy security, the Department of Energy writes that the transportation sector accounts for approximately 30% of total U.S. energy needs and 70% of U.S. petroleum consumption.
9. The electricity that charges electric cars comes from power plants which burn a mix of nuclear, natural gas, and renewable energy sources.
10. So buying an electric car helps move our country towards energy security by diversifying our energy consumption away from oil.

***Renewable Energy***

1. Like electric vehicles, renewable energy is an important part of the carbon neutral future.
2. We need to reduce power plant emissions from sources such as natural gas and coal, and build more nuclear and solar and wind and hydro power plants.
3. The National Grid in an article on their website writes that the greenhouse gasses produced by burning carbon fuels are contributing to global warming.
4. We can utilize more renewable energy sources which have 0 carbon output, or 0 marginal cost. Renewable energy sources (RES) have a bigger supply than fossil fuels, which have to be mined from the Earth.
5. Solar works on energy from the sun, wind works on the wind blowing, and hydro works on the power of water.
6. In 2022 NRDC wrote that costs are coming down through innovation for renewable energy sources, and RES are thus becoming more attractive.
7. However, there are also drawbacks to RES, such as burning biomass which creates carbon, and hydroelectric dams that redirect the natural flow of water and change migration patterns for fish.

**Conclusion**

1. We are slowly moving towards a greener future, and this green future includes electric vehicles and renewable energy sources.
2. In the meantime, and after, individuals can do their part at home by recycling and conserving water.
3. I challenge the youngest generation, children, to recycle at home
4. I challenge the middle generation, young adults, to research new innovations to renewable energy sources
5. I challenge the oldest generation to spearhead the transition to electric vehicles

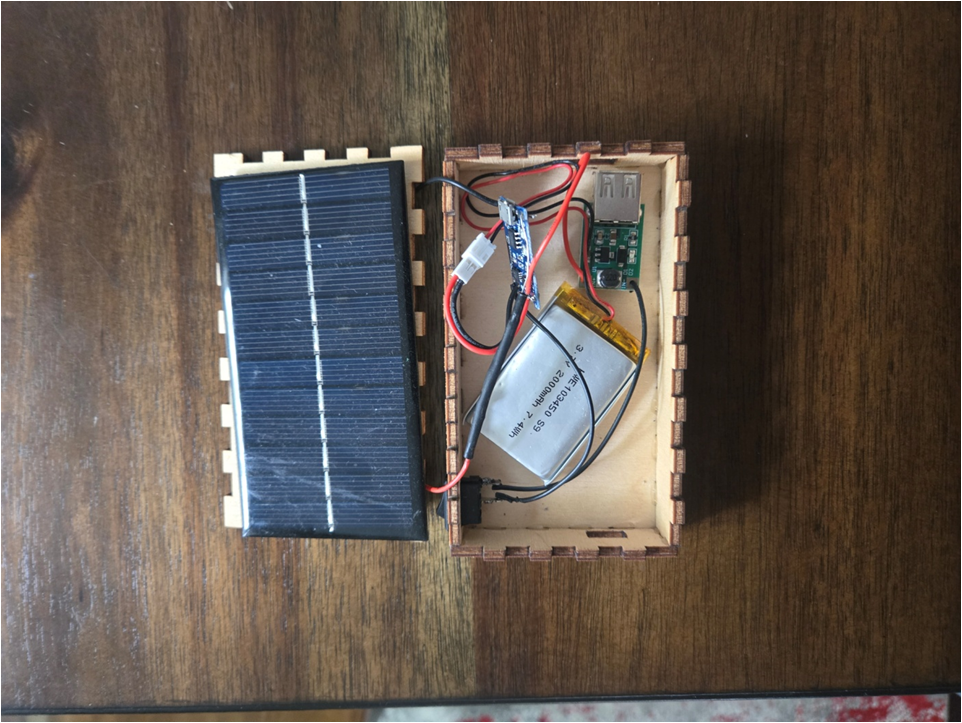
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**What Represents Me**  
**Solar Powered Phone Charger**

**Kevin Sleem, COM 231**

**Solar Cell Phone Charger**



**Introduction**

I. The object which represents me best is the solar powered cell phone charger I made for my electrician class final project.

II. I am like a cell phone charger because I am reliable and challenging.

III. Reliability is a critical success factor in life, and people expect you to show up for work. Also, it is important to challenge yourself in life so you can grow as a person.

**Reliable**

I. I am reliable, like a cell phone charger. Cell phone chargers need to be reliable. They need to work every time.

II. I am reliable because I rarely take sick days from work or school, and strive to complete my work on time.

III. I am an electrician student here at FTCC, and you have to be reliable and dependable to complete the wiring labs and then gain a job as an apprentice.

IV. Reliable is a key attribute of working as an electrician, as customers depend on you to show up on time, and to be competent enough to finish the job.

**Challenging**

I. I am challenging, like a cell phone charger. This cell phone charger I soldered for my final project was challenging to complete, another characteristic of myself.

II. Challenging yourself to reach new heights is a positive way to build character and improve your standing in life. III. Attempting challenging projects and career paths is something I have done in the past, from the US Navy to electrician work.

IV. I also enjoy challenging sports, like basketball and tennis. I enjoy challenging myself to read new books, and to learn Spanish.

**Conclusion**

I. For these reasons, I am reliable and challenging, I am like a cell phone charger.

II. A cell phone charger must reliably work every time, and like that, I expect myself to show up for work when I am not sick and complete my assignments on time.

III. Being challenged in life is key to developing as a person and reaching new heights, both at work and at home.

**Ceremonial Speech**

**Introduction**

I would like to welcome everyone to this graduation ceremony for FTCC. Today we will recognize the achievements of our students for the past year in a graduation ceremony.

Tom Brokaw said, “You are educated. Your certification is in your degree. You may think of it as the ticket to the good life. Let me ask you to think of an alternative. Think of it as your ticket to change the world.”

Today is the beginning of the rest of your life. As graduates, you will have the ability to change the world for the better, and use your newfound knowledge to improve society. As you go out as new graduates, think about what you want to do with your degree. Do you want to work in government? Do you want to work in industry? Or do you want to use your degree to continue your education in the field you choose?

**Government Jobs**

The government is always looking for new graduates. Working for the government can be a fulfilling life knowing that you are a public servant. As a public servant, you will be tasked with not only completing your job but also to respond to the needs of citizens in society. The government seeks to hire people who are knowledgeable in their fields and also have a desire to work to improve the problems in society.

**Industry Jobs**

Maybe you want to work in industry. America is a capitalist country, and our robust private sector is the engine of our economy. Some industries operate with more government influence than others, such as the medical industry, while other sectors have limited red tape, such as manufacturing. I want to appeal to the graduates who are considering going into industry by speaking about a burgeoning industry in America, space exploration. America has now contracted with private companies to deliver astronauts to space. Do you want to work for one of these companies, which are working to transport people to the Moon and Mars?

**Continuing Education**

Some of you will continue in your studies at another institution. Maybe it will be in North Carolina, or maybe you will travel across the United States to enroll in a program in another state. One way to get ahead in life is going to college, and you all have already accomplished this by getting your degree at FTCC. Maybe you are going to transfer to a 4 year university and complete your bachelor’s degree, and then continue on to graduate school. The opportunities for continuing education are limitless in America, and I want to remind the graduates that continuing education is a thing, you always have to be learning new knowledge.

**Conclusion**

In closing, I challenge you graduates to go forward and make a change in the world. Small changes add up to big change, so start small, and make a contribution to society such as volunteering at the homeless shelter or food pantry, or cleaning up garbage on the side of the road. William Bennett said, “All real education is the architecture of the soul.”

**References**

<https://www.countryliving.com/life/g32201893/graduation-quotes/?utm_source=google&utm_medium=cpc&utm_campaign=mgu_ga_clv_md_pmx_hybd_mix_us_18709966696&gad_source=1&gclid=Cj0KCQiA_qG5BhDTARIsAA0UHSLHOHRMOadfFax0mIuQAlPi51VYepHanpNdyvzHY6DzEv35vRCwmUMaArzKEALw_wcB>

**Topological Argument**

<https://chicagoquantum.org/research-areas>

Topological arguments in physics are used to explain phenomena by describing how the mathematical properties of connectivity patterns in complex networks determine the dynamics of the systems. Topology has been used in physics for decades, but has recently become more prominent due to the discovery of topological insulators.

Here are some examples of topological arguments in physics:

* Quantum Hall effect
* In 1980, Thouless and colleagues used topological arguments to explain the quantum Hall effect (QHE). The QHE is an induced voltage in a conductor exposed to a magnetic field. Topological arguments were used to explain the robustness of the QHE, which is independent of the type of material or whether it contains defects or impurities.
* Coherent states
* A topological argument for the robustness of coherent states in quantum optics was developed using two mappings of the driven Jaynes-Cummings model.
* Topological quantum computers
* The properties of topological materials could be used to create a topological quantum computer.

Topological physics is the study of the microscopic geometries and symmetries that lead to particular phenomena.

## [**Topological Physics**](https://chicagoquantum.org/research-areas/topological-physics)

Topological physics is the study of the microscopic geometries and symmetries that lead to particular phenomena. The properties of topological materials emerge from patterns of long-range quantum entanglement and could theoretically be employed to create a topological quantum computer.

## [**Quantum Sensing**](https://chicagoquantum.org/research-areas/quantum-sensing)

Chicago Quantum Exchange researchers are currently working to develop quantum sensors with applications in a wide range of areas, from biology to high energy physics.

## [**Quantum Communications**](https://chicagoquantum.org/research-areas/quantum-communication)

Quantum communication research applies the laws of quantum physics to protecting and transmitting data in a secure and effectively unhackable manner.

## [**Quantum Computing**](https://chicagoquantum.org/research-areas/quantum-computing)

Quantum computing’s distinct power exploits properties unavailable to classical computers. Once fully developed, quantum computers will be able to leverage those properties to efficiently solve scientific and technological problems that are impossible even for today’s most powerful supercomputers.

## 

## [**Condensed Matter Physics**](https://chicagoquantum.org/research-areas/condensed-matter-physics)

Condensed matter physics explores the exotic behaviors that emerge in a material or fluid when quantum particles within it interact.

## [**Atomic, Molecular, and Optical Physics**](https://chicagoquantum.org/research-areas/atomic-molecular-and-optical-physics)

Atomic, molecular and optical physics is the study of how light and matter interact. The field has produced an extremely exciting set of tools for creating and probing many of today’s most exotic quantum systems.

## [**Quantum Chemistry**](https://chicagoquantum.org/research-areas/quantum-chemistry)

Quantum chemistry studies how the laws of quantum mechanics can be applied to chemical models and experiments on chemical systems. It encompasses quantum phenomena at all levels, such as the electronic structure of matter and its interaction with light, energy and charge flow, the collective behavior of complex ensembles, and the quantum chemical dynamics of time-evolving systems.

## [**Quantum Materials**](https://chicagoquantum.org/research-areas/quantum-materials)

Quantum materials research links together a wide spectrum of areas, allowing theory, experiments, and fabrication to come together to both understand and employ these unique properties for scientific applications, such as aircraft development and scientific optical tools.

## [**Quantum Optics**](https://chicagoquantum.org/research-areas/quantum-optics)

Quantum optics harnesses interacting photons (individual particles of light) and atoms to explore the fundamental limits of the physical world and understand how light and matter can interact with one another on a multitude of levels.

## [**Nanomechanics**](https://chicagoquantum.org/research-areas/nanomechanics)

Nanomechanics has emerged at the crossroads of classical mechanics, solid-state physics, statistical mechanics, materials science, and quantum chemistry and employs these fundamental principles in the development of nanodevices.

## [**Device Physics**](https://chicagoquantum.org/research-areas/device-physics)

Researchers in device physics work to design and construct devices that can control electrons and photons for use in sensing and detection, information processing, and studying the fundamental properties of matter.

## [**High Energy & Particle Physics**](https://chicagoquantum.org/research-areas/high-energy-and-particle-physics)

In high-energy and particle physics, researchers study nature at its most fundamental level, investigating particles that make up both ordinary and exotic forms of matter as well as cosmological phenomena such as dark matter.

**Newton’s Laws of Motion**

1. Translational Motion
2. Rotational Motion
3. Torque

## **Newton’s first law: the law of inertia**

Newton’s first law states that if a body is at rest or moving at a constant speed in a straight line, it will remain at rest or keep moving in a straight line at constant speed unless it is acted upon by a [force](https://www.britannica.com/science/force-physics). In fact, in classical Newtonian mechanics, there is no important distinction between rest and [uniform motion](https://www.britannica.com/science/linear-motion) in a straight line; they may be regarded as the same state of motion seen by different observers, one moving at the same [velocity](https://www.britannica.com/science/velocity) as the particle and the other moving at constant velocity with respect to the particle. This [postulate](https://www.britannica.com/dictionary/postulate) is known as the law of [inertia](https://www.britannica.com/science/inertia).

The [law of inertia](https://www.britannica.com/science/law-of-inertia) was first formulated by [Galileo Galilei](https://www.britannica.com/biography/Galileo-Galilei) for horizontal motion on Earth and was later generalized by [René Descartes](https://www.britannica.com/biography/Rene-Descartes). Although the principle of inertia is the starting point and the fundamental assumption of classical mechanics, it is less than intuitively obvious to the untrained eye. In Aristotelian mechanics and in ordinary experience, objects that are not being pushed tend to come to rest. The law of inertia was deduced by Galileo from his experiments with balls rolling down inclined planes.

For Galileo, the principle of inertia was fundamental to his central scientific task: he had to explain how is it possible that if Earth is really spinning on its axis and orbiting the Sun, we do not sense that motion. The principle of inertia helps to provide the answer: since we are in motion together with Earth and our natural tendency is to retain that motion, Earth appears to us to be at rest. Thus, the principle of inertia, far from being a statement of the obvious, was once a central issue of scientific [contention](https://www.merriam-webster.com/dictionary/contention). By the time Newton had sorted out all the details, it was possible to accurately account for the small deviations from this picture caused by the fact that the motion of Earth’s surface is not uniform motion in a straight line (the effects of rotational motion are discussed below). In the Newtonian formulation, the common observation that bodies that are not pushed tend to come to rest is attributed to the fact that they have unbalanced forces acting on them, such as [friction](https://www.britannica.com/science/friction) and air resistance.

# **Newton’s second law: *F* = *ma***

N[ewton’s second law](https://www.britannica.com/science/law-of-force) is a quantitative description of the changes that a [force](https://www.britannica.com/science/force-physics) can produce on the [motion](https://www.britannica.com/science/motion-mechanics) of a body. It states that the time rate of change of the [momentum](https://www.britannica.com/science/momentum) of a body is equal in both magnitude and direction to the force [imposed](https://www.britannica.com/dictionary/imposed) on it. The momentum of a body is equal to the product of its [mass](https://www.britannica.com/science/mass-physics) and its velocity. Momentum, like [velocity](https://www.britannica.com/science/velocity), is a [vector](https://www.britannica.com/science/vector-physics) quantity, having both magnitude and direction. A force applied to a body can change the magnitude of the momentum or its direction or both. Newton’s second law is one of the most important in all of [physics](https://www.britannica.com/science/physics-science). For a body whose mass *m* is constant, it can be written in the form *F* = *ma*, where *F* (force) and *a* ([acceleration](https://www.britannica.com/science/acceleration)) are both vector quantities. If a body has a net force acting on it, it is [accelerated](https://www.britannica.com/dictionary/accelerated) in accordance with the equation. Conversely, if a body is not accelerated, there is no net force acting on it.

## **Newton’s third law: the law of action and reaction**

[Newton’s third law](https://www.britannica.com/science/law-of-action-and-reaction) states that when two bodies interact, they apply forces to one another that are equal in magnitude and opposite in direction. The third law is also known as the law of action and reaction. This law is important in analyzing problems of [static equilibrium](https://www.britannica.com/science/equilibrium-physics), where all forces are balanced, but it also applies to bodies in uniform or accelerated motion. The forces it describes are real ones, not mere bookkeeping devices. For example, a book resting on a table applies a downward force equal to its weight on the table. According to the third law, the table applies an equal and opposite force to the book. This force occurs because the weight of the book causes the table to deform slightly so that it pushes back on the book like a coiled spring.

If a body has a net force acting on it, it undergoes accelerated motion in accordance with the second law. If there is no net force acting on a body, either because there are no forces at all or because all forces are precisely balanced by contrary forces, the body does not accelerate and may be said to be in [equilibrium](https://www.merriam-webster.com/dictionary/equilibrium). Conversely, a body that is observed not to be accelerated may be deduced to have no net force acting on it.

## **Influence of Newton’s laws**

Newton’s laws first appeared in his masterpiece, [*Philosophiae Naturalis Principia Mathematica*](https://www.britannica.com/topic/Principia) (1687), commonly known as the *Principia*. In 1543 [Nicolaus Copernicus](https://www.britannica.com/biography/Nicolaus-Copernicus) suggested that the Sun, rather than Earth, might be at the centre of the [universe](https://www.britannica.com/science/universe). In the intervening years [Galileo](https://www.britannica.com/biography/Galileo-Galilei), [Johannes Kepler](https://www.britannica.com/biography/Johannes-Kepler), and Descartes laid the foundations of a new [science](https://www.britannica.com/science/science) that would both replace the Aristotelian worldview, inherited from the ancient Greeks, and explain the workings of a heliocentric universe. In the *Principia* Newton created that new science. He developed his three laws in order to explain why the orbits of the [planets](https://www.britannica.com/science/planet) are ellipses rather than circles, at which he succeeded, but it turned out that he explained much more. The series of events from Copernicus to Newton is known collectively as the [Scientific Revolution](https://www.britannica.com/science/Scientific-Revolution).

In the 20th century Newton’s laws were replaced by [quantum mechanics](https://www.britannica.com/science/quantum-mechanics-physics) and [relativity](https://www.britannica.com/science/relativity) as the most fundamental laws of physics. Nevertheless, Newton’s laws continue to give an accurate account of nature, except for very small bodies such as electrons or for bodies moving close to the [speed of light](https://www.britannica.com/science/speed-of-light). [Quantum](https://www.merriam-webster.com/dictionary/Quantum) [mechanics](https://www.britannica.com/science/mechanics) and relativity reduce to Newton’s laws for larger bodies or for bodies moving more slowly.

**Laws of Thermodynamics**

laws of thermodynamics, four relations [underlying](https://www.britannica.com/dictionary/underlying) [thermodynamics](https://www.britannica.com/science/thermodynamics), the branch of [physics](https://www.britannica.com/science/physics-science) concerning [heat](https://www.britannica.com/science/heat), [work](https://www.britannica.com/science/work-physics), [temperature](https://www.britannica.com/science/temperature), and [energy](https://www.britannica.com/science/energy) and the [transfer](https://www.britannica.com/science/energy-transfer) of such energy.

## **The zeroth law of thermodynamics**

The first and second laws were formally stated in works by German physicist [Rudolf Clausius](https://www.britannica.com/biography/Rudolf-Clausius) and Scottish physicist [William Thomson](https://www.britannica.com/biography/William-Thomson-Baron-Kelvin) about 1860. The third law was developed by German chemist [Walther Nernst](https://www.britannica.com/biography/Walther-Nernst) from 1906 to 1912. However, scientists realized that one additional law was needed to fully describe energy changes in systems. This “law” was a basic understanding that was always considered to be true but needed to be formally stated. Because the other three laws were already numbered and the additional law is the foundation for the other three, it was dubbed the zeroth law of thermodynamics by Ralph Fowler in the 1930s.

The law states that if two bodies are each in [thermal equilibrium](https://www.britannica.com/science/thermodynamic-equilibrium) with a third body, they must also be in [equilibrium](https://www.merriam-webster.com/dictionary/equilibrium) with each other. This means that if two objects are at the same temperature and they are in thermal equilibrium with another object, then this third object is also at the same temperature as the other two objects. This property makes it meaningful to use [thermometers](https://www.britannica.com/technology/thermometer) as the “third body” and to define a temperature scale.

T[**he first law of thermodynamics**](https://www.britannica.com/science/first-law-of-thermodynamics)

Within an isolated system, the total energy of the system is constant, even if energy has been converted from one form to another. (This is another way of stating the [law of conservation of energy](https://www.britannica.com/science/conservation-of-energy): that energy can not be created or destroyed but merely [converted](https://www.britannica.com/dictionary/converted) from one form to another.) If the system is not isolated, the change in a system’s [internal energy](https://www.britannica.com/science/internal-energy) Δ*U* is equal to the difference between the heat *Q* added to the system from its surroundings and the work *W* done by the system on its surroundings; that is, Δ*U* = *Q* − *W*

## [**The second law of thermodynamics**](https://www.britannica.com/science/second-law-of-thermodynamics)

Heat does not flow spontaneously from a colder region to a hotter region; or, equivalently, heat at a given temperature cannot be converted entirely into work. Consequently, the [entropy](https://www.britannica.com/science/entropy-physics) (measure of the disorder of the material) of a closed system, or heat energy per unit temperature, increases over time toward some maximum value. Thus, all closed systems tend toward an equilibrium state in which [entropy](https://www.merriam-webster.com/dictionary/entropy) is at a maximum and no energy is available to do useful work.

## [**The third law of thermodynamics**](https://www.britannica.com/biography/Walther-Nernst#ref102911)

The entropy of an isolated system approaches a constant value as the temperature of the system approaches [absolute zero](https://www.britannica.com/science/absolute-zero) (−273.15 °C, or −459.67 °F). In practical terms, this theorem implies the impossibility of attaining absolute zero, since as a system approaches absolute zero, the further extraction of energy from that system becomes more and more difficult.

**Electrochemical Force**

An "electrochemical force" refers to the combined force acting on a charged particle due to both its concentration gradient (chemical force) and the electrical potential difference across a membrane (electrical force), essentially driving the movement of ions across a membrane in a specific direction; it is a key concept in fields like biology and electrochemistry, particularly when studying cellular processes like nerve impulses and muscle contractions.

Key points about electrochemical force:

* **Components:**It consists of two parts: a chemical force based on the concentration difference of ions across a membrane and an electrical force arising from the membrane potential.
* **Direction of movement:**The direction of ion movement is determined by the electrochemical gradient, which tells whether the ion will move towards a region of higher or lower concentration depending on its charge and the membrane potential.
* **Application in biology:**In biological systems, the electrochemical force is crucial for the transport of ions like sodium (Na+) and potassium (K+) across cell membranes, which is essential for maintaining proper cell function and electrical signaling.

**Electromagnetic Force**

The **electromagnetic force**, also called the **Lorentz force**, explains how both moving and stationary [charged](https://energyeducation.ca/encyclopedia/Charge) particles interact. It's called the electromagnetic force because it includes the formerly distinct [electric force](https://energyeducation.ca/encyclopedia/Electric_force) and the [magnetic force](https://energyeducation.ca/encyclopedia/Magnetic_force); magnetic forces and electric forces are really the same fundamental force.[[1]](https://energyeducation.ca/encyclopedia/Electromagnetic_force#cite_note-Knight-1) The electromagnetic force is one of the four [fundamental forces](https://energyeducation.ca/encyclopedia/Fundamental_force).

The electric force acts between all charged particles, whether or not they're moving.[[1]](https://energyeducation.ca/encyclopedia/Electromagnetic_force#cite_note-Knight-1) The magnetic force acts between moving charged particles. This means that every charged particle gives off an [electric field](https://energyeducation.ca/encyclopedia/Electric_field), whether or not it's moving. Moving charged particles (like those in [electric current](https://energyeducation.ca/encyclopedia/Electric_current)) give off [magnetic fields](https://energyeducation.ca/encyclopedia/Magnetic_field). Einstein developed his theory of [relativity](http://hyperphysics.phy-astr.gsu.edu/hbase/relativ/relcon.html) from the idea that if the observer moves with the charged particles, magnetic fields transform into electric fields and vice versa! One special case of the electromagnetic force, when all the charges are point charges (or can be broken up into point charges), is [Coulomb's law](https://energyeducation.ca/encyclopedia/Coulomb%27s_law).

Because calculating the force from every single individual charge on every other individual charge is ridiculously complicated, physicists have developed tools to simplify these calculations. These simplified calculations turn into the macroscopic, everyday phenomena listed below:

* [everyday forces](https://energyeducation.ca/encyclopedia/Everyday_force) like
  + [tension](https://energyeducation.ca/encyclopedia/Tension) and [elasticity](https://energyeducation.ca/encyclopedia/Elasticity)
  + [friction](https://energyeducation.ca/encyclopedia/Friction) (how a shoe moves a person forward)
  + [normal force](https://energyeducation.ca/encyclopedia/Normal_force) (how the shoe doesn't fall through the road that it's sitting on)
  + [air drag](https://energyeducation.ca/encyclopedia/Air_drag)
* most of chemistry
  + keeping [atoms](https://energyeducation.ca/encyclopedia/Atom) together
  + chemical bonds between atoms to form [molecules](https://energyeducation.ca/encyclopedia/Molecule), like in [combustion](https://energyeducation.ca/encyclopedia/Combustion)
  + keeping solids a particular shape
* Sticky things like tape or tar sticking to surfaces
* Magnets sticking artwork to a refrigerator
* The force felt on [electrons](https://energyeducation.ca/encyclopedia/Electron) in a loop of [wire](https://energyeducation.ca/encyclopedia/Wire) when near a changing [magnetic field](https://energyeducation.ca/encyclopedia/Magnetic_field). The electromagnetic force is very closely related to the [electromotive force](https://energyeducation.ca/encyclopedia/Electromotive_force), which is what causes electric current to flow.

Modern physics has unified the electromagnetic and weak forces into the [electroweak force](http://hyperphysics.phy-astr.gsu.edu/hbase/forces/unify.html). A full understanding of the electromagnetic force and the full implications of electromagnetism takes many years of study. Some good places to go for more information on electromagnetism include [hyperphysics](http://hyperphysics.phy-astr.gsu.edu/hbase/forces/funfor.html#c3).

**Electromagnetic Field**

A magnetic field is a field explaining the magnetic influence on an object in space

An electric field is a field defined by the magnitude of the electric force at any given point in space

Electric field is created by stationary charges, meaning it surrounds any charged particle at rest

Magnetic field is created by moving charges (current), meaning it only exists around a wire with electricity flowing through it

Electric field due to the presence of charge

Magnetic field due to the motion of charge

Field Lines

1. Electric field lines originate from positive charges and terminate on negative charges
2. Magnetic field lines always form closed loops, from north pole to south pole

Force on a Charge

An electric field exerts a force on any charged particle placed within it, regardless of its motion

A magnetic field only exerts a force on a moving charge

A changing electric field can create a magnetic field and vice versa.

Electric Field: V/m, volts per meter

Magnetic Field: T, Teslas

Magnetic fields due to electric currents, moving electric charges can make magnetic fields.

Magnetic fields can be illustrated by magnetic flux lines.

Magnetic fields are produced by moving electric charges and the intrinsic magnetic moments of elementary particles associated with a fundamental quantum property, their spin

A magnetic field describes a volume of space where there is a change in energy. The spinning and orbiting of the nucleus of an atom produces a magnetic field as does electric current flowing through a wire

There is no shield or substance that will effectively block magnetic fields. You can redirect the magnetic field lines, called magnetic shielding

A static electric field does not create a magnetic field

A dynamic electric field such as current in a wire does create a magnetic field

A magnetic field cannot exist without an electric field, it is changes in the electric field which generates a magnetic field

Earth’s magnetic field is strongest at the poles and weakest at the equator

Neutron stars generate the strongest magnetic fields in the universe, measured by observing the cyclotron absorption lines in their x-ray energy spectra

Magnetic fields do exist around supermassive black holes, but their source is the accretion disk, not the black hole itself

Billions of years ago the Earth and the Moon had a connected magnetic field, but the Moon no longer has a magnetic field

Milky Way contains an ordered, large-scale magnetic field

Earth’s Magnetosphere- generated by the motion of molten iron in the Earth’s core, the magnetic field protects the planet from cosmic radiation and from the charged particles emitted by the sun

***Magnetic Effects***

1. Paramagnetism
2. Diamagnetism
3. Antiferromagnetism

**Electromagnetic Force**

Electromagnetic force is comprised of electric power and magnetic force, when we touch things and electrical appliances

Electromagnetic field contains electric field and magnetic field, and they are thus interconnected and can influence each other

Magnetic force is stronger than gravity, magnet does not fall, magnetic force is electromagnetic force

1. Electromagnetic Force- transmitted by photons (light)
2. Strong Nuclear Force- gluons; makes up matter, stronger than the electromagnetic force
3. Weak Nuclear Force- W bosons and Z bosons; changes particles, weaker than the electromagnetic force, Beta decay of atomic nuclei
4. Gravitational Force

3 forces other than gravity were once unified

A magnetic force is a force that arises between moving charged particles, while an electric force is a force that acts between any charged particles, regardless of their motion; both forces are considered part of the electromagnetic force and are fundamentally related, with the key difference being that magnetic force requires movement of charges to generate a field, whereas electric force only needs the presence of charge.

Key points about electric force:

* **Origin:** Occurs between stationary charged particles.
* **Interaction:** Like charges repel, opposite charges attract.
* **Example:** The attraction between a positively charged proton and a negatively charged electron in an atom.

Key points about magnetic force:

* **Origin:** Occurs between moving charged particles, creating a magnetic field.
* **Interaction:** Depends on the direction of the moving charge and the magnetic field, resulting in a force perpendicular to both.
* **Example:** The force on a current-carrying wire placed within a magnetic field.

**Conservative and Nonconservative Forces**

<https://byjus.com/physics/a-comparative-study-between-non-conservative-and-conservative-force/#:~:text=system%20remains%20conserved.-,Conservative%20force%20abides%20by%20the%20law%20of%20conservation%20of%20energy,is%20the%20non%2Dconservative%20force>.

### **State true or false: A force is said to be conservative if the work done over any closed path is zero.**

True.

Q2

### **State law of conservation of energy.**

The law of conservation of energy states that “In a closed system, i.e., a system that is isolated from its surroundings, the total energy of the system is conserved.”

Q3

### **Give two examples to explain the law of conservation of energy.**

Examples of conservation of energy are:

* In a generator, mechanical energy is converted into electrical energy.
* In a loudspeaker, electrical energy is converted into sound energy.

Q4

### **What is a non-conservative force?**

A non-conservative force is one for which work depends on the path. Hence it is essential to know where the object starts and stops.

Q5

### **Give some examples for non-conservative forces?**

Examples of non-conservative forces are air drag, friction, and tension in the cord.

In physics, conservative forces are forces that depend on the starting and ending positions of an object, while non-conservative forces depend on the path the object takes:

* Conservative forces
* The work done by a conservative force is independent of the path the object takes. Examples of conservative forces include gravitational force, the restoring force of an elastic spring, electrostatic force, and buoyancy force.
* Non-conservative forces
* Also called dissipative forces, non-conservative forces depend on the path the object takes. Examples of non-conservative forces include friction, air resistance, water drag, non-elastic material stress, and viscosity.

You can determine if a force field is conservative by calculating its curl. If the curl is zero, the force field is conservative.

Conservative force abides by the law of conservation of energy. Examples of conservative force: Gravitational force, spring force etc. On the other hand, non-conservative forces are those forces which cause a loss of mechanical energy from the system. In the above case friction is the non-conservative force.

**Contact and Noncontact Forces**

***Contact Forces***

1. Friction Force
2. Tension Force
3. Normal Force

***Noncontact Forces***

1. Electric Force
2. Magnetic Force
3. Gravitational Force

**AC/DC and Ohm’s Law**

Electricity is flow of electrons

AC, electrical current changes direction many times per second

DC, electricity flowing same direction

-electricity from power station is transferred to homes via AC

-AC is stepped up to hundreds of thousands of volts to help prevent power loss over long distances

110 V North AMerica

220 Europe

-AC creates changing magnetic field in transformer that induces a current and induces the transformer to work, simple inexpensive transformers for AC wont work with DC

-high voltage DC energy transmission systems do exist, for connecting AC lines

-primary function of power supply is not convert AC power from wall to DC current for your devices

-devices in your electronics, transistors, are designed to work with specific polarity, electric current that flows in one direction, so logic gates can function

-AC power gets interrupted briefly every time it changes direction, 60 times North America, 50 times Europe, AC lamp

-sensitive electronics need a constant supply of power, cant have interruptions because their -internal logic depends on maintaining very specific voltages; AC/DC adapter for electronics, guitar amps

**Ohm’s Law**

1. Next, we will discuss Ohm’s Law, which considers the relationship between voltage, current, and resistance.
2. Although many ancient civilizations discovered forms of electricity, they all did not have a firm understanding of Ohm’s Law.
3. One facet of electricity that impacts our understanding of the phenomenon is that you cannot see electricity.
4. True, you can see lightning, but lightning is actually a reaction in the air to the energy passing through it, and not the energy exchange happening from the clouds to the earth itself.
5. *Study.com in 2024 describes the relationships between current, voltage, and resistance.*
6. Current: The amount of charge that flows through a conductor in a given time interval, or the rate at which charge is flowing. Measured in Amps.
7. Voltage: The potential difference between two points, measured across a wire or component, or the difference in charge between two points. Measured in Volts.
8. Resistance: The opposition to current in a circuit, or a material's tendency to resist the flow of charge (current). Measured in Ohms.
9. These values, current, voltage, and resistance, describe the movement of charge, and thus, the behavior of electrons.
10. To study these values, we use circuits, which are closed loops that allow charge to move from one place to another.
11. Components in the circuit allow us to control this charge and use it to do work Spark Fun Learn (2024).
12. Ohm's Law states that the current flowing through a circuit is directly proportional to the voltage applied, and inversely proportional to the resistance of the circuit.
13. This relationship is expressed mathematically as V = I \* R, where V is voltage, I is current, and R is resistance.
14. One method for calculating these electricity values is to use linear algebra to construct a matrix and solve for the unknowns.
15. Isaac Physics (2024) describes Kirchhoff’s Laws, which describe rules for current and voltage in a circuit.
16. Kirchhoff's current law (1st Law) states that the current flowing into a node (or a junction) must be equal to the current flowing out of it. This is a consequence of charge conservation.
17. Kirchhoff's voltage law (2nd Law) states that in any complete loop within a circuit, the sum of all voltages across components which supply electrical energy (such as cells or generators) must equal the sum of all voltages across the other components in the same loop. This law is a consequence of both charge conservation and the conservation of energy.

**Circuits, Series and Parallel**

The main difference between series and parallel circuits is how the components are arranged and how the current flows through them:

Series, controls voltage

Parallel, controls current

**Series circuits**

Components are connected in a single line, with the current flowing through all components in the same direction. The total resistance in the circuit is the sum of all the individual resistances of each component. If one part of the circuit fails, the entire circuit fails. Series circuits are useful for indicating when a component has failed.

**Parallel circuits**

Components are connected across each other in different branches of the circuit, with each component having its own branch. The same voltage is applied to each component, but the current can flow through each component differently. If one device fails, the other devices in the circuit are not affected. In a parallel circuit, the battery drains faster because more current is sent through each branch.

When two or more capacitors are connected in series across a potential difference:

1. The equivalent capacitance of the combination is less than the capacitance of any of the capacitors
2. The potential difference across the combination is the algebraic sum of the potential differences across the individual capacitors
3. Each capacitor carries the same amount of charge

When two or more capacitors are connected in parallel across a potential difference:

1. The potential difference across each capacitor is the same

**Rectifier**

-turns alternating current into direct current

**LED**

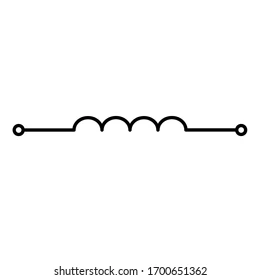
-light emitting diode, made of positive lead, negative lead, and semiconductor die; light bulbs lose 90% of electricity as heat, and LEDs convert 90% of electricity, with no heat, and last 40 times longer than light bulbs

**Inductors**

-device that temporarily stores energy in the form of an electric field, coils of wire, when current flows through a wire, you get a magnetic field; when current stops flowing, the magnetic field collapses, and changes into electrical energy

-the current in an inductor cannot instantly change, it lags, it takes time to store and release the energy in an inductor

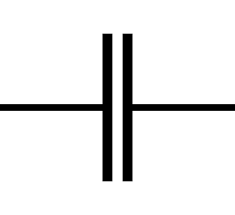
-inductors have no effect on DC, the are wires with a resistance of a few milliohms

****

**Capacitors**

-component to store electrical charge; the difference between batteries and capacitors is capacitors can charge and discharge very quickly; however, capacitors have lower energy density than batteries, and thus can store less energy

-smoothing- capacitor fills in interruptions or flickers in circuit



**Resistors**

-passive electrical component with the primary function to limit the flow of electrical current

-Resistors are electrical components that resist current and expends voltage within a circuit.

-resistor has higher resistance than connecting gates and causes a reduced electrical current, pressure drop in a water pipe, voltage drop

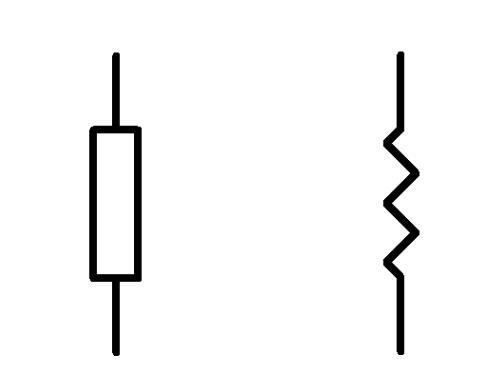
-many types of resistors: 1) Fixed 2) Variable, adjusted by mechanical movement 3) Varying Resistance Dependent on Physical Quantity

***Variable***

1. Potentiometer- used as a variable voltage divider
2. Rheostat- used a variable resistance to control the current in a circuit
3. Digital potential meters- controlled electronically instead of by mechanical action

***Varying Resistance Dependent on Physical Quantity***

1. Light
2. Temperature
3. Voltage
4. Used as measuring devices
5. Wirewound resistors- oldest type, constructed by winding a resisting wire around a nonconducting core; very low resistance values, can be manufactured very accurately, very durable; disadvantage is parasitic reactants for higher frequencies
6. Carbon composition resistors- constructed from a mixture of a nonconducting ceramic and fine carbon particles; tolerance is worse than other resistors, not used as much, can withstand high energy pulses
7. Carbon film- made of nonconducting core with thin carbon film around it, have higher accuracy than carbon composition, but worse than metal film or metal oxide film
8. Metal film- metal layer instead of carbon film, better accuracy, lower temperature coefficient, and good stability
9. Metal oxide film- more durable and higher temperature resistance and reliability than metal film
10. Foil- resistive element of thin metallic foil of several micrometers thick, best today
11. First significant digit
12. Second significant digit
13. Multiplication factor
14. Tolerance

****

**Transistor**

-conjunction, disjunction, negation, True False

-early electronic computers used vacuum tubes, cathode and anode

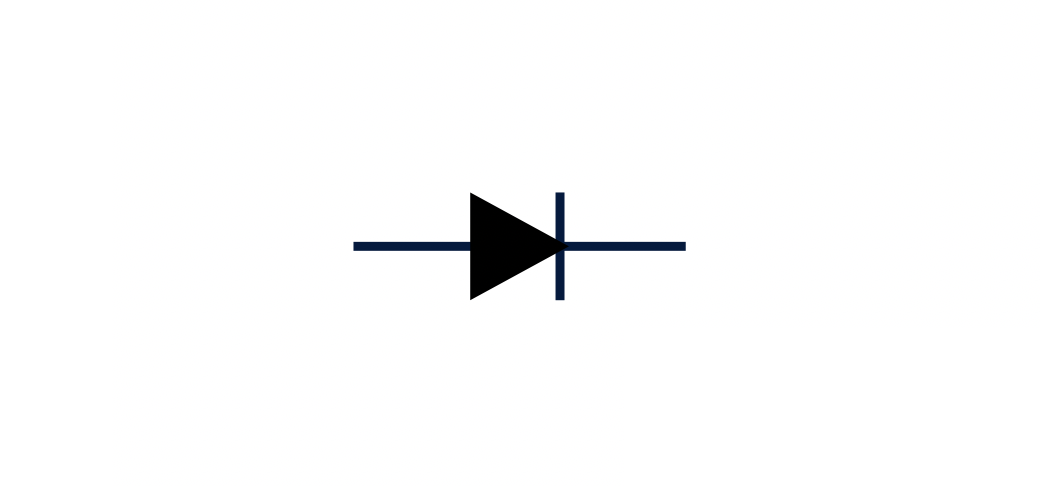
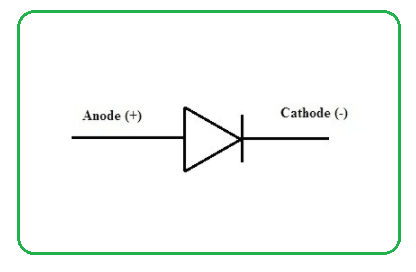
-triode, uses third electrode called grid, ability to amplify signals

-transistor- instead of electrodes, uses semiconductor made of silicon; treated with different elements to create electron emitting n-type, and electron collecting p-type; p-n junctions between emitter and base; efficiency and compactness, do not require heating, more durable and require less power

**Diode**

-device or component that allows current to flow in only one direction

-semiconductor material, have the ability to both block and allow current flow



**Batteries**

Batteries are electrical components that provide electrical energy.



The short end is the negative terminal and the long end is the positive terminal. Batteries have positive and negative terminals. The negative terminal is drawn with a short line, and the positive terminal is shown as a long line.

**Switches**

Switches turn the flow of current through a circuit pathway on and off. When the switch is open, no current flows because there is a gap in the circuit (Figure 3).



Figure 3. Symbol for open switch. No current flows through this location because the conductive pathway has a gap.

When the switch is closed, current can flow because the circuit is continuous (Figure 4).



Figure 4. Symbol for closed switch. Current can pass through this location because the circuit pathway is continuous.

**Node**

A node (or junction) is a place where two or more circuit elements join together. Figure 5 below shows a single node (the black dot) formed by the junction of five electrical components (abstractly represented by orange rectangles).

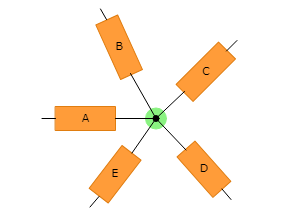


Figure 5. A junction (highlighted in green) between 5 different electrical components.

Are there other components for circuits?

Voltmeter

Ammeter

## DC circuit types

### Simple circuit

A simple circuit contains the minimum amount of components that allow it to be a functional electric circuit: a voltage source

\[ε\]

(battery), a resistor

\[R\]

, and a loop of wires for current

\[I\]

to flow around (see Figure 6 below). We usually ignore any resistance from the wires.

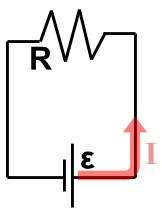


Figure 6. Simple circuit diagram.

In a simple circuit, the voltage supplied by the battery

\[ε\]

is the voltage expended by the resistor

\[R\]

, and there is only one current

\[I\]

in the circuit.

### Closed circuit

A closed circuit has a continuous pathway for current to flow through. In other words, there are no gaps in the circuit.

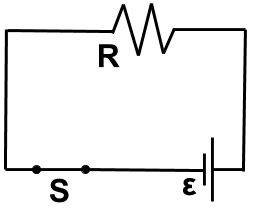


Figure 7. Diagram of a closed circuit.

### Open circuit

An open circuit has a gap in the circuit that does not allow current to flow through. The gap can be caused by an open switch, a broken component, or broken wire.

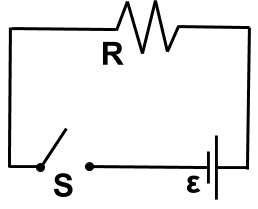


Figure 8. Diagram of a open circuit.

### Short circuit

A short is a pathway of zero resistance within a circuit (see the blue wire in Figure 9). When there is a short circuit, all the current flows across the short because the current prefers the path of least resistance.

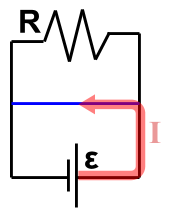


Figure 9. The blue wire has no resistance and is a short in this circuit. Since there is no resistance, all the current

\[I\]

flows across the blue wire instead of going through the resistor

\[R\]

.

Figure 10 below shows how closing a switch

\[S\]

can divert all the current from resistor

\[R\_2\]

. When switch

\[S\]

is open (see Figure 10A), the current

\[I\]

flows out of the positive terminal of the battery towards node

\[N\]

. Since the switch is open, no current flows through the switch and all the current flows through resistor

\[R\_2\]

. When the switch is closed (see Figure 10B), it forms a short around resistor

\[R\_2\]

. Now, once the current

\[I\]

reaches

\[N\]

, the current bypasses

\[R\_2\]

and flows through the switch.

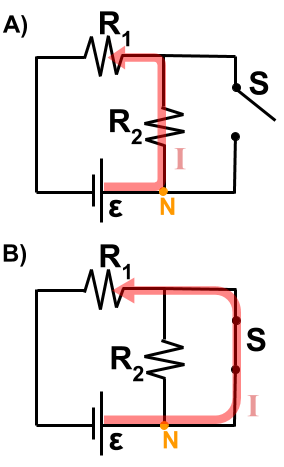


Figure 10. When the switch

\[S\]

changes from open (diagram

\[A\]

) to closed (diagram

\[B\]

), resistor

\[R\_2\]

is shorted out and the current

\[I\]

bypasses it to go through the switch.

**Maxwell’s Equations, Unifying Electricity and Magnetism**

Maxwell showed that the speed of light in free space is c = 3.00 x m/s.

**Classical Electromagnetism and Maxwell’s Equations**

Introduce the idea of a magnetic monopole as a hypothetical isolated magnetic charge, and discuss why it is not allowed in classical electromagnetism based on Maxwell's equations.

Classical electromagnetism refers to the study of interactions between electric charges and currents using classical physics principles, and Maxwell's equations are a set of fundamental equations within this framework that describe the relationship between electric and magnetic fields, essentially unifying electricity and magnetism into a single theory, allowing for the prediction of electromagnetic waves like light. Maxwell's theory of electromagnetism also related electromagnetic waves to charges. He explained that an oscillating charge will produce a changing electric field, which in turn produces a changing magnetic field. These two changing fields will continue to mutually produce each other. Maxwell’s equations describe the properties of radiant energy.

These equations mathematically relate electric fields, magnetic fields, electric charges, and currents, explaining how changing electric fields create magnetic fields and vice versa, leading to the concept of electromagnetic waves. By incorporating the concept of displacement current, Maxwell predicted the existence of electromagnetic waves and calculated their speed, which turned out to be the speed of light, unifying electricity, magnetism, and optics.

As is well known, Equation (1.1) is equivalent to Coulomb’s law (for the electric fields generated by point charges), Equation (1.2) is equivalent to the statement that magnetic monopoles do not exist (which implies that magnetic field-lines can never begin or end), Equation (1.3) is equivalent to Faraday’s law of electromagnetic induction, and Equation (1.4) is equivalent to the Biot-Savart law (for the magnetic fields generated by line currents) augmented by the induction of magnetic fields by changing electric fields.

∇ · E = Gauss's law for electricity (1.1)

∇ · B = 0 Gauss's law for magnetism (1.2)

∇ × E = - Faraday's law of induction (1.3)

∇ × B = + Ampere-Maxwell law (1.4)

E(r, t) = electric field-strength

B(r, t) = electric field-strength

ρ(r, t) = electric charge density

j(r, t) = electric current density

= 8.8542 × = electric permittivity of free space

= 4π × = magnetic permeability of free space.

**Components of Maxwell's equations**

1. Gauss's law for electricity: Relates the electric field through a closed surface to the enclosed charge.
2. Gauss's law for magnetism: States that the magnetic field flux through any closed surface is zero, meaning magnetic monopoles don't exist.
3. Faraday's law of induction: Describes how a changing magnetic field induces an electric field.
4. Ampere-Maxwell law: Connects magnetic fields to both electric currents and changing electric fields (the "displacement current").

**Max Planck and Quantum Theory**

A new theory called quantum mechanics was highly successful in explaining the behavior of particles of microscopic size. Like the special theory of relativity, the quantum theory requires a modification of our ideas concerning the physical world. The first explanation of a phenomenon using quantum theory was introduced by Max Planck. Many subsequent mathematical developments and interpretations were made by a number of distinguished physicists, including Einstein, Bohr, de Broglie, Schrödinger, and Heisenberg. Despite the great success of the quantum theory, Einstein frequently played the role of its critic, especially with regard to the manner in which the theory was interpreted.

An object at any temperature emits electromagnetic waves in the form of thermal

radiation from its surface as discussed in Section 20.7. The characteristics of this

radiation depend on the temperature and properties of the object’s surface. Careful

study shows that the radiation consists of a continuous distribution of wavelengths

from all portions of the electromagnetic spectrum. If the object is at room temperature,

the wavelengths of thermal radiation are mainly in the infrared region and

hence the radiation is not detected by the human eye. As the surface temperature

of the object increases, the object eventually begins to glow visibly red, like the coils

of a toaster. At sufficiently high temperatures, the glowing object appears white, as

in the hot tungsten filament of an incandescent lightbulb.

From a classical viewpoint, thermal radiation originates from accelerated

charged particles in the atoms near the surface of the object; those charged particles

emit radiation much as small antennas do. The thermally agitated particles

can have a distribution of energies, which accounts for the continuous spectrum of

radiation emitted by the object. By the end of the 19th century, however, it became

apparent that the classical theory of thermal radiation was inadequate. The basic

problem was in understanding the observed distribution of wavelengths in the

radiation emitted by a black body. As defined in Section 20.7, a black body is an

ideal system that absorbs all radiation incident on it. The electromagnetic radiation

emitted by the black body is called blackbody radiation.

A good approximation of a black body is a small hole leading to the inside of

a hollow object as shown in Figure 40.1. Any radiation incident on the hole from

outside the cavity enters the hole and is reflected a number of times on the interior

walls of the cavity; hence, the hole acts as a perfect absorber. The nature of the

radiation leaving the cavity through the hole depends only on the temperature of

the cavity walls and not on the material of which the walls are made. The spaces

between lumps of hot charcoal (Fig. 40.2) emit light that is very much like blackbody

radiation.

The radiation emitted by oscillators in the cavity walls experiences boundary

conditions. As the radiation reflects from the cavity’s walls, standing electromagnetic

waves are established within the three-dimensional interior of the cavity.

Many standing-wave modes are possible, and the distribution of the energy in the

cavity among these modes determines the wavelength distribution of the radiation

leaving the cavity through the hole.

The wavelength distribution of radiation from cavities was studied experimentally

in the late 19th century. Active Figure 40.3 shows how the intensity of blackbody

radiation varies with temperature and wavelength. The following two consistent

experimental findings were seen as especially significant:

1. The total power of the emitted radiation increases with temperature. We

discussed this behavior briefly in Chapter 20, where we introduced Stefan’s Law:

where P is the power in watts radiated at all wavelengths from the surface

of an object, = 5.670 x ? is the Stefan–Boltzmann constant,

A is the surface area of the object in square meters, e is the emissivity of the

surface, and T is the surface temperature in kelvins. For a black body, the

emissivity is e = 1 exactly.

2. The peak of the wavelength distribution shifts to shorter wavelengths as

the temperature increases. This behavior is described by the following relationship,

called Wien’s displacement law:

where is the wavelength at which the curve peaks and T is the absolute

temperature of the surface of the object emitting the radiation. The wavelength

at the curve’s peak is inversely proportional to the absolute temperature;

that is, as the temperature increases, the peak is “displaced” to shorter

wavelengths (Active Fig. 40.3).

Wien’s displacement law is consistent with the behavior of the object mentioned

at the beginning of this section. At room temperature, the object does not appear

to glow because the peak is in the infrared region of the electromagnetic spectrum.

At higher temperatures, it glows red because the peak is in the near infrared with

some radiation at the red end of the visible spectrum, and at still higher temperatures,

it glows white because the peak is in the visible so that all colors are emitted.

A successful theory for blackbody radiation must predict the shape of the curves

in Active Figure 40.3, the temperature dependence expressed in Stefan’s law, and

the shift of the peak with temperature described by Wien’s displacement law. Early

attempts to use classical ideas to explain the shapes of the curves in Active Figure

40.3 failed.

Let’s consider one of these early attempts. To describe the distribution of energy

from a black body, we define dl to be the intensity, or power per unit area, emitted in the wavelength interval dl. The result of a calculation based on a classical

theory of blackbody radiation known as the Rayleigh–Jeans law is

=

**Einstein and the Special Theory of Relativity**

Newton’s Laws of Mechanics describe motion in our everyday lives, such as walking or driving, but we need Einstein’s Law of Special Relativity to describe particles moving at near light speed. Newtonian mechanics places no upper limit on speed, and we can test Newton’s Laws at high speed by accelerating electrons or other charged particles through a large electric potential difference. In this scenario, the electron is accelerated to a speed of 0.99c (where c is the speed of light) by using a potential difference, or voltage, of several million volts. According to Newtonian mechanics, if the potential difference is increased by a factor of 4, the electron’s kinetic energy is four times greater and its speed should double to 1.98c. Experiments show, however, that the speed of the electron—as well as the speed of any other object in the Universe—always remains less than the speed of light, regardless of the size of the accelerating voltage.

With Einstein’s theory, experimental observations can be correctly predicted over the range of speeds from v = 0 to speeds approaching the speed of light. At low speeds, Einstein’s theory reduces to Newtonian mechanics as a limiting situation. Einstein was working on electromagnetism when he developed the special theory of relativity. He was convinced that Maxwell’s equations were correct, and to reconcile them with one of his postulates, he was forced into the revolutionary notion of assuming that space and time are not absolute. The special theory of relativity has practical applications, including the design of nuclear power plants and modern global positioning system (GPS) units. These devices depend on relativistic principles for proper design and operation.

**Principle of Galilean Relativity**

The laws of mechanics must be the same in all inertial frames of reference.

When you throw a ball up in the air in the back of a truck, it falls back into your hands whether the truck is moving or not, because when the truck is moving the ball has the same horizontal velocity as the truck, its frame of reference.

***Galilean space–time transformation equations***

x’ = x - vt y’ = y z’ = z t’ = t

(x, y, z, t) (x’, y’, z’, t’)

Note that time is assumed to be the same in both inertial frames. That is, within the framework of classical mechanics, all clocks run at the same rate, regardless of their velocity, so the time at which an event occurs for an observer in S is the same as the time for the same event in S’. Consequently, the time interval between two successive events should be the same for both observers. Although this assumption may seem obvious, it turns out to be incorrect in situations where v is comparable to the speed of light.

***Galilean velocity transformation equation***

= - v = - v

***The Speed of Light***

**Ether Hypothesis-** Physicists of the late 1800s thought light waves move through a medium called the ether and the speed of light is c only in a special, absolute frame at rest with respect to the ether. The Galilean velocity transformation equation was expected to hold for observations of light made by an observer in any frame moving at speed v relative to the absolute ether frame. That is, if light travels along the x axis and an observer moves with velocity  along the x axis, the observer measures the light to have speed c ± v, depending on the directions of travel of the observer and the light. Because the existence of a preferred, absolute ether frame would show that light is similar to other classical waves and that Newtonian ideas of an absolute frame are true, considerable importance was attached to establishing the existence of the ether frame. Prior to the late 1800s, experiments involving light traveling in media moving at the highest laboratory speeds attainable at that time were not capable of detecting differences as small as that between c and c ± v. Starting in about 1880, scientists decided to use the Earth as the moving frame in an attempt to improve their chances of detecting these small changes in the speed of light. Observers fixed on the Earth can take the view that they are stationary and that the absolute ether frame containing the medium for light propagation moves past them with speed v. Determining the speed of light under these circumstances is similar to determining the speed of an aircraft traveling in a moving air current, or wind; consequently, we speak of an “ether wind” blowing through our apparatus fixed to the Earth.

Galilean Relativity Principle does not apply to electricity, magnetism, or optics

A direct method for detecting an ether wind would use an apparatus fixed to the Earth to measure the ether wind’s influence on the speed of light. If v is the speed of the ether relative to the Earth, light should have its maximum speed c + v when propagating downwind. Likewise, the speed of light should have its minimum value c - v when the light is propagating upwind and an intermediate value ( - when the light is directed such that it travels perpendicular to the ether wind. In this latter case, the vector  must be aimed upstream so that the resultant velocity is perpendicular to the wind. If the Sun is assumed to be at rest in the ether, the velocity of the ether wind would be equal to the orbital velocity of the Earth around the Sun, which has a magnitude of approximately 30 km/s or 3 x m/s. Because c = 3 x m/s, it is necessary to detect a change in speed of approximately 1 part in for measurements in the upwind or downwind directions. Although such a change is experimentally measurable, all attempts to detect such changes and establish the existence of the ether wind (and hence the absolute frame) proved futile!

The principle of Galilean relativity refers only to the laws of mechanics. If it is assumed the laws of electricity and magnetism are the same in all inertial frames, a paradox concerning the speed of light immediately arises. That can be understood by recognizing that Maxwell’s equations imply that the speed of light always has the fixed value 3.00 3 108 m/s in all inertial frames, a result in direct contradiction to what is expected based on the Galilean velocity transformation equation. According to Galilean relativity, the speed of light should not be the same in all inertial frames. To resolve this contradiction in theories, we must conclude that either (1) the laws of electricity and magnetism are not the same in all inertial frames or (2) the Galilean velocity transformation equation is incorrect. If we assume the first alternative, a preferred reference frame in which the speed of light has the value c must exist and the measured speed must be greater or less than this value in any other reference frame, in accordance with the Galilean velocity transformation equation. If we assume the second alternative, we must abandon the notions of absolute time and absolute length that form the basis of the Galilean space–time transformation equations.

**Einstein’s Principle of Relativity**

1. The principle of relativity: The laws of physics must be the same in all inertial reference frames.

2. The constancy of the speed of light: The speed of light in vacuum has the same value, c = 3.00 x m/s, in all inertial frames, regardless of the velocity of the observer or the velocity of the source emitting the light.

The first postulate asserts that all the laws of physics—those dealing with mechanics, electricity and magnetism, optics, thermodynamics, and so on—are the same in all reference frames moving with constant velocity relative to one another. This postulate is a generalization of the principle of Galilean relativity, which refers only to the laws of mechanics. From an experimental point of view, Einstein’s principle of relativity means that any kind of experiment (measuring the speed of light, for example) performed in a laboratory at rest must give the same result when performed in a laboratory moving at a constant velocity with respect to the first one. Hence, no preferred inertial reference frame exists, and it is impossible to detect absolute motion.

Note that postulate 2 is required by postulate 1: if the speed of light were not the same in all inertial frames, measurements of different speeds would make it possible to distinguish between inertial frames. As a result, a preferred, absolute frame could be identified, in contradiction to postulate 1.

In relativity, concepts of simultaneity, time intervals, and lengths, all three of which are quite different in relativistic mechanics from what they are in Newtonian mechanics. In relativistic mechanics, for example, the distance between two points and the time interval between two events depend on the frame of reference in which they are measured.

***Simultaneity and the Relativity of Time***

A basic premise of Newtonian mechanics is that a universal time scale exists that is

the same for all observers. Newton and his followers took simultaneity for granted. In his special theory of relativity, Einstein abandoned this assumption. This thought experiment clearly demonstrates that the two events that appear to be simultaneous to observer O do not appear to be simultaneous to observer O’. Simultaneity is not an absolute concept but rather one that depends on the state of motion of the observer. Einstein’s thought experiment demonstrates that two observers can disagree on the simultaneity of two events. This disagreement, however, depends on the transit time of light to the observers and therefore does not demonstrate the deeper meaning of relativity. In relativistic analyses of high-speed situations, simultaneity is relative even when the transit time is subtracted out. In fact, in all the relativistic effects we discuss, we ignore differences caused by the transit time of light to the observers.

***Time Dilation***

Because is always greater than unity, Equation 39.7 shows that the time interval measured by an observer moving with respect to a clock is longer than the time interval measured by an observer at rest with respect to the clock. This effect is known as time dilation.

= = Time Dilation, 39.7

=

= = , 39.5

Time dilation is not observed in our everyday lives, which can be understood by considering the factor . This factor deviates significantly from a value of 1 only for very high speeds. For example, for a speed of 0.1c, the value of g is 1.005. Therefore, there is a time dilation of only 0.5% at one-tenth the speed of light. Speeds encountered on an everyday basis are far slower than 0.1c, so we do not experience time dilation in normal situations.

The time interval in Equations 39.5 and 39.7 is called the proper time interval. (Einstein used the German term Eigenzeit, which means “own-time.”) In general, the proper time interval is the time interval between two events measured by an observer who sees the events occur at the same point in space.

If a clock is moving with respect to you, the time interval between ticks of the moving clock is observed to be longer than the time interval between ticks of an identical clock in your reference frame. Therefore, it is often said that a moving clock is measured to run more slowly than a clock in your reference frame by a factor g. We can generalize this result by stating that all physical processes, including mechanical, chemical, and biological ones, are measured to slow down when those processes occur in a frame moving with respect to the observer. For example, the heartbeat of an astronaut moving through space keeps time with a clock inside the spacecraft. Both the astronaut’s clock and heartbeat are measured to slow down relative to a clock back on the Earth (although the astronaut would have no sensation of life slowing down in the spacecraft).

***The Twin Paradox***

The paradox is not that the twins have aged at different rates. Here is the apparent paradox. From Goslo’s frame of reference, he was at rest while his brother traveled at a high speed away from him and then came back. According to Speedo, however, he himself remained stationary while Goslo and the Earth raced away from him and then headed back. Therefore, we might expect Speedo to claim that Goslo ages more slowly than himself. The situation appears to be symmetrical from either twin’s point of view. Which twin actually ages more slowly?

***Length Contraction***

The measured distance between two points in space also depends on the frame of reference of the observer. The proper length of an object is the length measured by an observer at rest relative to the object. The length of an object measured by someone in a reference frame that is moving with respect to the object is always less than the proper length. This effect is known as length contraction.

L = =

***Space Time Graphs***

It is sometimes helpful to represent a physical situation with a space–time graph, in which ct is the ordinate and position x is the abscissa. The twin paradox is displayed in such a graph in Figure 39.11 from Goslo’s point of view. A path through space– time is called a world-line.

***The Relativistic Doppler Effect***

Another important consequence of time dilation is the shift in frequency observed for light emitted by atoms in motion as opposed to light emitted by atoms at rest. This phenomenon, known as the Doppler effect, was introduced in Chapter 17 as it pertains to sound waves. In the case of sound, the motion of the source with respect to the medium of propagation can be distinguished from the motion of the observer with respect to the medium. Light waves must be analyzed differently, however, because they require no medium of propagation, and no method exists for distinguishing the motion of a light source from the motion of the observer. If a light source and an observer approach each other with a relative speed v, the frequency f’ measured by the observer is

f’ =

where f is the frequency of the source measured in its rest frame. This relativistic Doppler shift equation, unlike the Doppler shift equation for sound, depends only on the relative speed v of the source and observer and holds for relative speeds as great as c. As you might expect, the equation predicts that f9 . f when the source and observer approach each other. We obtain the expression for the case in which the source and observer recede from each other by substituting negative values for v in Equation 39.10. The most spectacular and dramatic use of the relativistic Doppler effect is the measurement of shifts in the frequency of light emitted by a moving astronomical object such as a galaxy. Light emitted by atoms and normally found in the extreme violet region of the spectrum is shifted toward the red end of the spectrum for atoms in other galaxies, indicating that these galaxies are receding from us. American astronomer Edwin Hubble (1889–1953) performed extensive measurements of this red shift to confirm that most galaxies are moving away from us, indicating that the Universe is expanding.

***Lorentz Equations***

The equations that are valid for all speeds and that enable us to transform coordinates from S to S’ are the Lorentz transformation equations:

x’ = (x - vt) y’ = y z’ = z t’ = (t - x)

These transformation equations were developed by Hendrik A. Lorentz (1853– 1928) in 1890 in connection with electromagnetism. It was Einstein, however, who recognized their physical significance and took the bold step of interpreting them within the framework of the special theory of relativity. Notice the difference between the Galilean and Lorentz time equations. In the Galilean case, t = t’. In the Lorentz case, however, the value for t’ assigned to an event by an observer O’ in the S’ frame in Figure 39.13 depends both on the time t and on the coordinate x as measured by an observer O in the S frame, which is consistent with the notion that an event is characterized by four space–time coordinates (x, y, z, t). In other words, in relativity, space and time are not separate concepts but rather are closely interwoven with each other.

***Lorentz Velocity Transformation Equations***

=

***Relativistic Linear Momentum***

To describe the motion of particles within the framework of the special theory of relativity properly, you must replace the Galilean transformation equations by the Lorentz transformation equations. Because the laws of physics must remain unchanged under the Lorentz transformation, we must generalize Newton’s laws and the definitions of linear momentum and energy to conform to the Lorentz transformation equations and the principle of relativity. These generalized definitions should reduce to the classical (nonrelativistic) definitions for v ≪ c.

 = = 

where m is the mass of the particle and  is the velocity of the particle.

The relativistic force  acting on a particle whose linear momentum is  is defined as

 =

***Relativistic Kinetic Energy***

K = - = - = (

The constant term , which is independent of the speed of the particle, is called the rest energy of the particle:

=

The term , which depends on the particle speed, is the sum of the kinetic and rest energies. It is called the total energy E:

Total energy = kinetic energy + rest energy

E = =

**Mass and Energy**

Equation 39.26, E = , represents the total energy of a particle. This important equation suggests that even when a particle is at rest ( = 1), it still possesses enormous energy through its mass. The clearest experimental proof of the equivalence of mass and energy occurs in nuclear and elementary-particle interactions in which the conversion of mass into kinetic energy takes place. Consequently, we cannot use the principle of conservation of energy in relativistic situations as it was outlined in Chapter 8. We must modify the principle by including rest energy as another form of energy storage. This concept is important in atomic and nuclear processes, in which the change in mass is a relatively large fraction of the initial mass. In a conventional nuclear reactor, for example, the uranium nucleus undergoes fission, a reaction that results in several lighter fragments having considerable kinetic energy. In the case of 235U, which is used as fuel in nuclear power plants, the fragments are two lighter nuclei and a few neutrons. The total mass of the fragments is less than that of the 235U by an amount . The corresponding energy associated with this mass difference is exactly equal to the sum of the kinetic energies of the fragments. The kinetic energy is absorbed as the fragments move through water, raising the internal energy of the water. This internal energy is used to produce steam for the generation of electricity. Next, consider a basic fusion reaction in which two deuterium atoms combine to form one helium atom. The decrease in mass that results from the creation of one helium atom from two deuterium atoms is = 4.25 x kg. Hence, the corresponding energy that results from one fusion reaction is = 3.83 x J = 23.9 MeV. To appreciate the magnitude of this result, consider that if only 1 g of deuterium were converted to helium, the energy released would be on the order of J! In 2010’s cost of electrical energy, this energy would be worth approximately $30 000.

***The General Theory of Relativity***

Up to this point, we have sidestepped a curious puzzle. Mass has two seemingly different properties: a gravitational attraction for other masses and an inertial property that represents a resistance to acceleration. To designate these two attributes, we use the subscripts g and i and write

Gravitational Property =

Inertial Property

Einstein’s general theory of relativity has two postulates:

1. All the laws of nature have the same form for observers in any frame of reference, whether accelerated or not
2. In the vicinity of any point, a gravitational field is equivalent to an accelerated frame of reference in gravity-free space (the principle of equivalence)