Physics

for Utah SEEd Standards

2020-2021

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Utah State Board of Education OER
2020-2021

AUTHOR

USBE OER

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We especially wish to thank the amazing Utah science teachers whose collaborative efforts made the book possible. Thank you for your commitment to science education and Utah students!

Students as Scientists

What does science look and feel like?

If you’re reading this book, either as a student or a teacher, you’re going to be digging into the “practice” of science. Probably, someone, somewhere, has made you think about this before, and so you’ve probably already had a chance to imagine the possibilities. Who do you picture doing science? What do they look like? What are they doing?

Often when we ask people to imagine this, they draw or describe people with lab coats, people with crazy hair, beakers and flasks of weird looking liquids that are bubbling and frothing. Maybe there’s even an explosion. Let’s be honest: Some scientists do look like this, or they look like other stereotypes: people readied with their pocket protectors and calculators, figuring out how to launch a rocket into orbit. Or maybe what comes to mind is a list of steps that you might have to check off for your science fair project to be judged; or, maybe a graph or data table with lots of numbers comes to mind.

So let’s start over. When you imagine graphs and tables, lab coats and calculators, is that what you love? If this describes you, that’s great. But if it doesn’t, and that’s probably true for many of us, then go ahead and dump that image of science. It’s useless because it isn’t you. Instead, picture yourself as a maker and doer of science. The fact is, we need scientists and citizens like you, whoever you are, because we need all of the ideas, perspectives, and creative thinkers. This includes you.

Scientists wander in the woods. They dig in the dirt and chip at rocks. They peer through microscopes. They read. They play with tubes and pipes in the aisles of a hardware store to see what kinds of sounds they can make with them. They daydream and imagine. They count and measure and predict. They stare at the rock faces in the mountains and imagine how those came to be. They dance. They draw and write and write and write some more.

Scientists — and this includes all of us who do, use, apply, or think about science — don’t fit a certain stereotype. What really sets us apart as humans is not just that we know and do things, but that we wonder and make sense of our world. We do this in many ways, through painting, religion, music, culture, poetry, and, most especially, science. Science isn’t just a method or a collection of things we know. It’s a uniquely human practice of wondering about and creating explanations for the natural world around us. This ranges from the most fundamental building blocks of all matter to the widest expanse of space that contains it all. If you’ve ever wondered “When did time start?”, or “What is the smallest thing?”, or even just “What is color?”, or so many other endless questions then you’re already thinking with a scientific mind. Of course you are; you’re human, after all.

But here is where we really have to be clear. Science isn't just questions and explanations. Science is about a sense of wondering and the sense-making itself. We have to wonder and then really dig into the details of our surroundings. We have to get our hands dirty. Here's a good example: two young scientists under the presence of the Courthouse Towers in Arches National Park. We can be sure that they spent some amount of time in awe of the giant sandstone walls, but here in this photo they're enthralled with the sand that's just been re-washed by recent rain. There's this giant formation of sandstone looming above these kids in the desert, and they're happily playing in the sand. This is ridiculous. Or is it?

How did that sand get there? Where did it come from? Did the sand come from the rock or does the rock come from sand? And how would you know? How do you tell this story?

Look. There's a puddle. How often is there a puddle in the desert? The sand is wet and fine; and it makes swirling, layered patterns on the solid stone. There are pits and pockets in the rock, like the one that these two scientists are sitting in, and the gritty sand and the cold water accumulate there. And then you might start to wonder: Does the sand fill in the hole to form more rock, or is the hole worn away because it became sand? And then you might wonder more about the giant formation in the background: It has the same colors as the sand, so has this been built up or is it being worn down? And if it's being built up by sand, how does it all get put together; and if it's being worn away then why does it make the patterns that we see in the rock? Why? How long? What next?

Just as there is science to be found in a puddle or a pit or a simple rock formation, there's science in a soap bubble, in a worm, in the spin of a dancer and in the structure of a bridge. But this thing we call "science" is only there if you're paying attention, asking questions, and imagining possibilities. You have to make the science by being the person who gathers information and evidence, who organizes and reasons with this, and who communicates it to others. Most of all, you get to wonder. Throughout all of the rest of this book and all of the rest of the science that you will ever do, wonder should be at the heart of it all. Whether you're a student or a teacher, this wonder is what will bring the sense-making of science to life and make it your own.

Adam Johnston
Weber State University

Science and Engineering Practices

Science and Engineering Practices are what scientists do to investigate and explore natural phenomena

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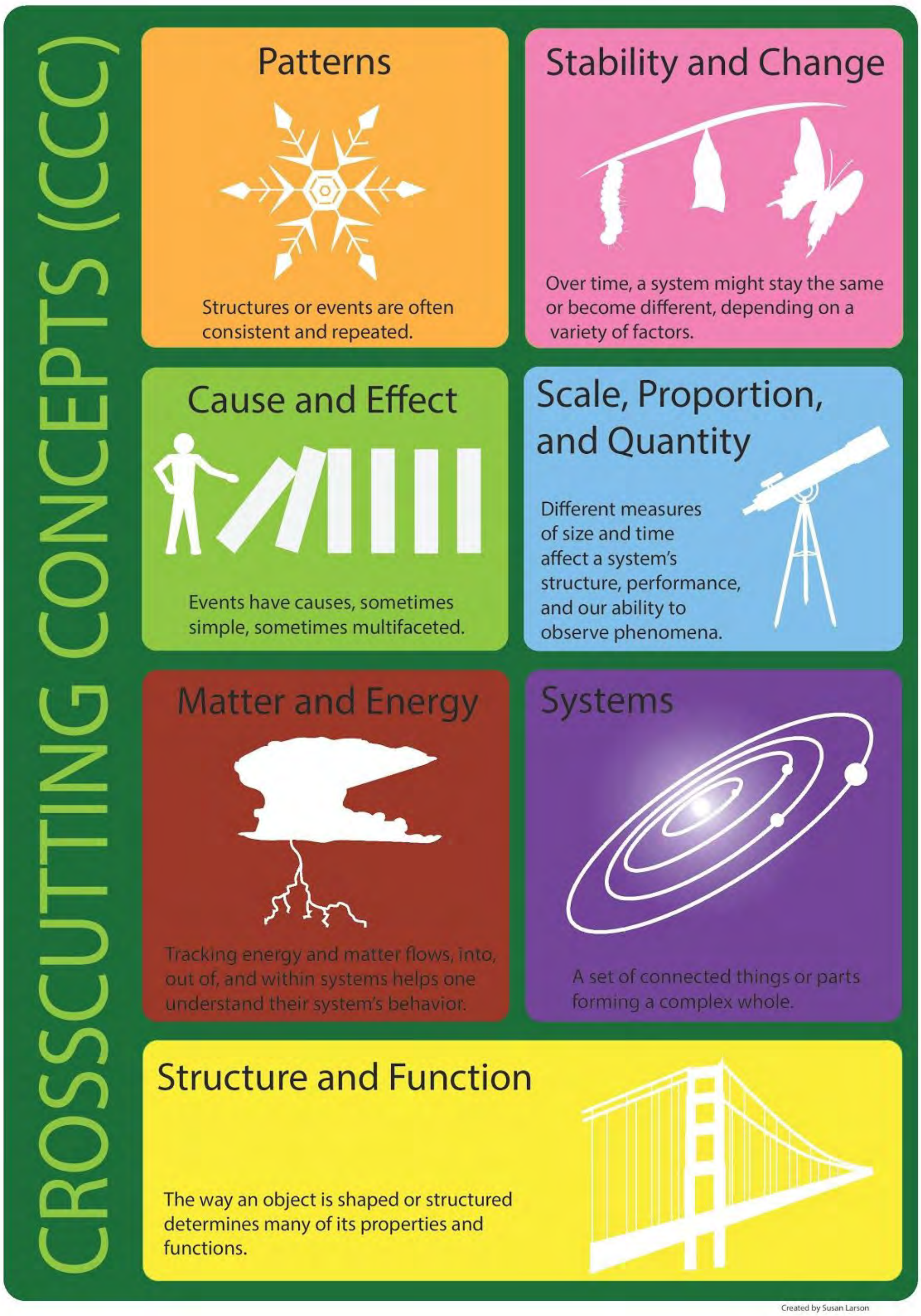
Cross Cutting Concepts

Crosscutting Concepts are the tools that scientists use to make sense of natural phenomena.



A Note to Teachers

This Open Educational Resource (OER) textbook has been written specifically for students as a reputable source for them to obtain information aligned to the Physics Standards. The hope is that as teachers use this resource with their students, they keep a record of their suggestions on how to improve the book. Every year, the book will be revised using teacher feedback and with new objectives to improve the book.

If there is feedback you would like to provide to support future writing teams please use the following online survey: http://go.uen.org/bFi

Table of Contents

CHAPTER 1

Strand 1: Forces and Interactions

Chapter Outline

Image by WikiImages, Pixabay.com, CC0

Uniform motion of an object is natural. Changes in motion are caused by a nonzero sum of forces. A “net force” causes an acceleration as predicted by Newton’s 2nd Law. Qualitative and quantitative analysis of position, velocity, and acceleration provide evidence of the effects of forces. Momentum is defined for a particular frame of reference; it is the product of the mass and the velocity of the object. In any system, the total momentum is always conserved. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system. The time over which these paired forces are exerted determines the impact force.

1.1 Force and Motion (PHYS.1.1)

Explore this Phenomenon

Image by Keith Johnston, pixabay.com, CC0

In the photo above, a baseball is sliding against the ground and coming to a stop.

1. What factors do you think are causing the baseball player to come to a stop?

As you read the following section, try to determine what causes the change in the baseball player's slide.

PHYS.1.1 Force and Motion

Analyze and interpret data to determine the cause and effect relationship between the net force on an object and its change in motion as summarized by Newton's Second Law of Motion. Emphasize one-dimensional motion and macroscopic objects moving at non-relativistic speeds. Examples could include objects subject to a net unbalanced force, such as a falling object, an object sliding down a ramp, or a moving object being pulled by a constant force. (PS2.A)

In this chapter, see if you can identify the causes and effect of the acceleration of an object.

Forces

Force can be simply defined as a push or pull. There are four fundamental forces in the universe, including the force of gravity, electromagnetic force, and weak and strong nuclear forces. These fundamental forces combine in different ways to make other common forces. The table below describes these common forces and the symbols used to identify them.

Force Types	Description	Symbols
Weight	The force of gravity between an object at or near the surface of the Earth. Pointed towards the center of the Earth (or other planetary/celestial objects). Directly proportional to the mass of the object.	w F_g
Tension	The force exerted by a string, wire, or rope pulling between two objects. Direction of tension is always parallel to the string, wire, or rope.	T F_T
Spring	The force exerted by a spring that is either compressed or stretched. Direction of spring force is always parallel to the spring	F_{sp}

Normal	The force exerted by a surface against any object pressing against it. The direction of the normal is always perpendicular to the surface. Also known as the support force.	N F_N
Friction	The force which resists motion when two solid objects are in contact with one another. The direction is always opposite the direction of motion and parallel to the surfaces involved. Two Types: • Static - when the objects are at rest • Kinetic - When the objects are moving relative to one another	F_f f_s f_k

Drag	The force which resists motion when an object moves through a fluid - liquid or gas. Also known as air resistance. The direction is always opposite the direction of motion. The object has to be moving at a substantial speed for air drag to be significant	D F_D F_{AD}, F_{air}
Thrust	Caused when a rocket or jet expels gas at a high speed. The direction of thrust is in the opposite direction in which the exhaust gas is expelled.	T F_T
Electric & Magnetic Forces	Forces caused between stationary and moving charges.	F_E F_B, B

All changes in motion are caused by forces. Every time the motion of an object changes, it's because a force has been applied to it. Force can cause a stationary object to start moving or a moving object to change its speed or direction or both. A change in the speed or direction of an object is called acceleration. Remember that acceleration happens when there is a change in the velocity. Since velocity includes speed and direction, changing either speed or direction changes the velocity of an object.

Look at the child in the Figure below. He’s getting his skateboard started by pushing off with his foot. The force he applies to the ground with his foot causes the skateboard to move in the opposite direction. The harder he pushes against the ground, the faster the skateboard will go.

Image by WebDonut, pixabay.com, CC0

Mass

Inertia is the property of an object that resists a change in its state of motion. An object’s inertia is related to the mass of the object. The more massive an object is, the more difficult it is to start it moving or to change its speed or direction once it is moving.

Mass and weight are two different things. Mass (typically in units of kg or grams) is a measure of the amount of matter in an object. Mass is related to the weight of an object, but mass and weight are not the same thing. Weight is a measure of how much the force of gravity is accelerating the object’s mass. When an astronaut travels to space, their mass is the same as when the astronaut was on Earth, but their weight is less because the force of gravity from the earth has decreased.

Force, Mass, and Acceleration

Whenever an object speeds up, slows down, or changes direction, it accelerates. Acceleration occurs whenever an unbalanced force acts on an object. Two factors affect the acceleration of an object: the net force acting on the object and the object’s mass. Newton’s second law of motion describes how force and mass affect acceleration. The law states that the acceleration of an object equals the net force acting on the object divided by the object’s mass. This can be represented by the equation:

$$\text{acceleration} = \frac{\text{Net Force}}{\text{mass}} \quad \text{or} \quad a = \frac{F_{Net}}{m}$$

Felicia exerts a backward force against the ground, as you can see in the Figure below, first with one skate and then with the other. This force pushes her forward. Although friction partly counters the forward motion of the skates, it is weaker than the force she exerts. Therefore, there is a forward net force on the skates.

Image by angelinawongm15, pixabay.com

Newton's second law shows that there is a direct relationship between force and acceleration. The greater the force that is applied to an object of a given mass, the more the object will accelerate. For example, doubling the force on the object doubles its acceleration.

The relationship between mass and acceleration is different. It is an inverse relationship. In an inverse relationship, when one variable increases, the other variable decreases. The greater the mass of an object, the less it will accelerate when a constant force is applied. For example, doubling the mass of an object results in only half as much acceleration for the same amount of force.

Putting It Together

Image by Keith Johnston, pixabay.com, CC0

Let us revisit this phenomenon:

1) Using your knowledge of Newton's Second Law of Motion, explain what causes the baseball player to come to a stop.

2) What do you think would happen if the baseball player's mass was doubled? Use Newton's Second Law to justify your answer.

3) Determine what would happen if the baseball game was occuring on an ice skating rink. Use Newton's Second Law to justify your answer.

1.2 Conservation of Momentum (PHYS.1.2)

Explore this Phenomenon

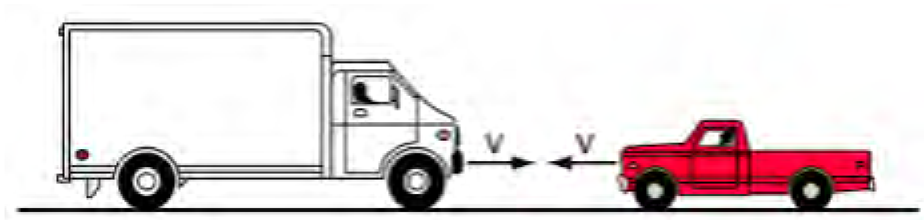


Image from ck12.org

To explore some other similar phenomenon, look at these links:
[Weight distribution]
[Launching ships]

You are looking out of the window and see a white moving truck heading straight towards the red truck.

1. What do you predict will happen when these two objects collide?

2. Which direction will the crash move and wny?

As you read the following section, think of ways that you could use math and computational thinking to support your claim. Be prepared to provide quantitative evidence that shows how total momentum is conserved. You will also use this evidence to qualitatively describe this principle.

PHYS.1.2 Conservation of Momentum

Use mathematics and computational thinking to support the claim that the total momentum of a system is conserved when there is no net force acting on the system. Emphasize the quantitative conservation of momentum in interactions and the qualitative meaning of this principle. Examples could include one-dimensional elastic or inelastic collisions between objects within the system. (PS2.A)

In this chapter, you will identify the way in which systems interact with other systems. While you observe these interactions, pay attention to the momentum of each system (before, during, and after the interaction).

What is momentum?

Momentum is a vector that points in the direction of the velocity vector. The magnitude of this vector is the product of mass and velocity. The total momentum of the universe is always the same and is equal to zero. The total momentum of an isolated system never changes. Momentum can be transferred from one body to another. In an isolated system in which momentum is transferred internally, the total initial momentum is the same as the total final momentum. Momentum conservation is especially important in collisions, where the total momentum before the collision is the same as the total momentum after the collision.

Key Equations

$p=mv$ Momentum is equal to the object's mass multiplied by its velocity

Conservation of Momentum

These skaters are racing each other at Newton's Skate Park. The first skater in line, the one on the left, is distracted by something he sees. He starts to slow down without realizing it. The skater behind him isn't paying attention and keeps skating at the same speed.

Q: Provide a detailed description for what happens next with a reason WHY.

A: Skater 2 runs into skater 1. When skater 2 runs into skater 1, he's going faster than skater 1 so he has more momentum. Momentum is a property of a moving object that makes it hard to stop. It's a product of the object's mass and velocity. At the moment of the collision, skater 2 transfers some of his momentum to skater 1, who shoots forward when skater 2 runs into him. Whenever an action and reaction such as this occur, momentum is transferred from one object to the other. However, the combined momentum of the objects remains the same. In other words, momentum is conserved. This is the law of conservation of momentum.

Momentum is another way of looking at how objects affect each others' motion. Rather than looking at how forces change over the time of the interaction, we can look at how objects are moving before they interact and then after they interact.

Momentum and Impulse

If a bowling ball and a ping-pong ball are each moving with a velocity of 5 mph, you intuitively understand that it will require more effort to stop the bowling ball than the ping pong ball because of the greater mass of the bowling ball. Similarly, if you have two bowling balls, one moving at 5 mph and the other moving at 10 mph, you know it will take more effort to stop the ball with the greater speed. It is clear that both the mass and the velocity of a moving object contribute to what is necessary to change the motion of the moving object. The product of the mass and velocity of an object is called its momentum. Momentum is a vector quantity that has the same direction as the velocity of the object and is represented by a lowercase letter *p*.

$$\mathbf{p=mv}$$

The momentum of a 0.500 kg ball moving with a velocity of 15.0 m/s will be

$$p=mv=(0.500\ kg)(15.0\ m/s)=7.50\ kg\cdot m/s$$

You should note that the units for momentum are kg·m/s.

For more information, watch this video describe momentum: Momentum-Bozeman Science https://www.youtube.com/watch?v=uQ1UMHXyFrM&feature=youtu.be

According to Newton's first law, the velocity of an object cannot change unless a force is applied. If we wish to change the momentum of a body, we must apply a force. The longer the force is applied, the greater the change in momentum. A common misconception is that when two objects collide, the smaller object is hit harder or experiences more force than the larger object.

The impulse is the quantity defined as the force multiplied by the time it is applied. It is a vector quantity that has the same direction as the force. The units for impulse are N·s but we know that Newtons are also $kg\cdot m/s^2$ and so $N\cdot s = (kg\cdot m/s^2)(s) = kg\cdot m/s$. Impulse and momentum have the same units; when an impulse is applied to an object, the momentum of the object changes and the change of momentum is equal to the impulse.

$Ft=\Delta mv$

Example 1

A 0.15 kg ball is moving with a velocity of 35 m/s. Find the momentum of the ball.

$$p=mv=(0.15\ \text{kg})(35\ \text{m/s})=5.25\ \text{kg}\cdot\text{m/s}$$

Example 2

If a ball with mass 5.00 kg has a momentum of 5.25 kg·m/s, what is its velocity?

$$v=pm=5.25\ \text{kg}\cdot\text{m/s}5.00\ \text{kg}=1.05\ \text{m/s}$$

It should be clear from the equation relating impulse to change in momentum, **$Ft=\Delta mv$**, that any amount of force would (eventually) bring a moving object to rest. If the force is very small, it must be applied for a long time, but a greater force can bring the object to rest in a shorter period of time.

If you jump off a porch and land on your feet with your knees locked in the straight position, your motion will be brought to rest in a very short period of time and thus the force would need to be very large – large enough, perhaps, to damage your joints or bones.

Suppose that when you hit the ground, your velocity was 7.0 m/s and that velocity was brought to rest in 0.05 seconds. If your mass is 100. kg, what force was required to bring you to rest?

$$F=\Delta mvt=(100.\ \text{kg})(7.0\ \text{m/s})0.050\ \text{s}=14{,}000\ \text{N}$$

If, on the other hand, when your feet first touched the ground, you allowed your knees to flex so that the period of time over which your body was brought to rest is increased, then the force on your body would be smaller and it would be less likely that you would damage your legs.

Suppose that when you first touch the ground, you allow your knees to bend and extend the stopping time to 0.50 seconds. What force would be required to bring you to rest this time?

$$F=\Delta mvt=(100.\ \text{kg})(7.0\ \text{m/s})0.50\ \text{s}=1400\ \text{N}$$

With the longer period of time for the force to act, the necessary force is reduced to one-tenth of what was needed before.

Extending the period of time over which a force acts in order to lessen the force is a common practice in design. Padding in shoes and seats allows the time to increase. The front of automobiles are designed to crumple in an accident; this increases the time the car takes to stop. Similarly, barrels of water or sand in front of abutments on the highway and airbags serve to slow down the stoppage time. These changes all serve to decrease the amount of force it takes to stop the momentum in a car crash, which consequently saves lives.

Elastic and Inelastic Collisions

Newton's cradle is an example of nearly elastic collisions.

Pendule en mouement - Newton's Cradle by hellolapomme, https://flic.kr/p/4ugPZm, CC-BY

This device is known as Newton's cradle. As the balls collide with each other, nearly all the momentum and kinetic energy is conserved. If one ball swings down, exactly one ball will swing up; if three balls swing down, exactly three will swing back up. The collisions between the balls are very nearly elastic.

For all collisions in a closed system, momentum is conserved. In some collisions in a closed system, kinetic energy is conserved. When both momentum and kinetic energy are conserved, the collision is called an elastic collision. Most collisions are inelastic because some amount of kinetic energy is converted to potential energy, usually by raising one of the objects higher (increasing gravitation PE) or by flexing the object. Any denting or other changing of shape by one of the objects will also be accompanied by a loss of kinetic energy. The only commonly seen elastic collisions are those between billiard balls or ball bearings, because these balls do not compress. And, of course, collisions between molecules are elastic if no damage is done to the molecules.

Much more common are inelastic collisions. These collisions occur whenever kinetic energy is not conserved, primarily when an object's height is increased after the collision or when one of the objects is compressed.

Example

A 12.0 kg toy train car moving at 2.40 m/s on a straight, level train track, collides head-on with a second train car whose mass is 36.0 kg and was at rest on the track. If the collision is perfectly elastic and all motion is frictionless, calculate the velocities of the two cars after the collision.

Since the collision is elastic, both momentum and KE are conserved. We use the conservation of momentum and conservation of KE equations.

Equation #1 Conservation of momentum:

$$m_1 v_1 + m_2 v_2 = m_1 v_1^{`} + m_2 v_2^{`}$$

Since m_1,m_2,v_1, and v_2 are known, only v_1' and v_2' are unknown. When the known values are plugged into these two equations, we will have two equations with two unknowns. Such systems can be solved with algebra.

Conservation of momentum:

(12.0 kg)(2.40 m/s)+(36.0 kg)(0 m/s)=(12.0 kg)(v_1')+(36.0 kg)(v_2')

28.8 kg* m/s=12.0 kg(v_1')+36.0 kg (v_2')

Solving this equation for v_1' yields v_1'=2.4 m/s−3 v_2'

Equation #2 Conservation of KE:

$$\tfrac{1}{2} m_1 v_1{}^2 + \tfrac{1}{2} m_2 v_2{}^2 = \tfrac{1}{2} m_1 v_1{}^{2`} + \tfrac{1}{2} m_2 v_2{}^{2`}$$

½ (12 kg) (2.4 m/s)^2+½ (36.0kg)(0 m/s)^2=1/2(12.0 kg)(v_1')^2+1/2(36.0 kg)(v_2')^2

34.56 kg* m^2/s^2= 6.0 kg(v_1')^2+18.0 kg (v_2)$'^2$

34.56 kg* m^2/s^2= 6.0 kg (1 (v_1')^2+3.0 (v_2)$'^2$)- divide both sides by 6.0 kg

5.76 m^2/s^2=$v_1'^2$+3 $v_2'^2$

Substituting the equation for v_1' into this equation yields

5.76 m^2/s^2 =(2.4 m/s−3 v_2')^2+3 $v_2'^2$

5.76m^2/s^2=5.76m^2/s^2−14.4 m/s v_2'+9 ($v_2'^2$)+3($v_2'^2$)

12($v_2'^2$)−14.4 m/s (v_2')=0

12(v_2')=14.4 m/s

(v_2')=1.2 m/s

Substituting this result back into v1′=2.4 m/s−3 v_2' , we get v_1'=−1.2 m/s.

So, the heavier car is moving in the original direction at 1.2 m/s and the lighter car is moving backward at 1.2 m/s.

Explore: Using the PhET simulation link below, explore the differences between elastic and inelastic collisions, objects with varying masses and velocities. Observe the momentum of each object.

PhET Collision lab https://phet.colorado.edu/en/simulation/legacy/collision-lab

1. Create a simulation scenario that replicates our phenomenon (two objects headed towards each other; one with a mass that is greater than the other)
2. Document the following for each object
    a. mass
    b. velocity
    c. momentum
    d. other observations
3. Write a summary that describes what you observed. Use this information to help you explain “Putting It Together” in the section below.

Putting It Together

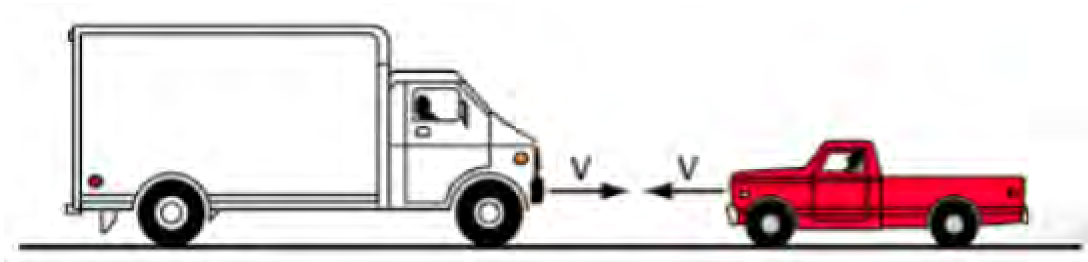


Image from ck12.org

Let’s revisit the phenomenon depicted above:

Using your newly acquired knowledge of conservation of momentum, explain the following image above.
In a head-on collision:

1. Which truck will experience the greatest change in velocity? *Use quantitative observations to support your claim.*

2. Which truck will experience the greatest change in momentum? *Use quantitative observations to support your claim.*

3. Which truck would you rather be in during the collision and why?

4. Would this scenario be classified as an elastic or inelastic collision and why?

5. How might this scenario differ, in terms of ***conservation of momentum***, if both trucks had the same mass (they are still traveling towards each other with the same velocity)? Make a claim that is supported by quantitative and qualitative evidence.

1.3 Collisions (PHYS.1.3)

Explore this Phenomenon

Image by cfarnswroth, pixabay.com, CC0

It is state law for you to wear your seatbelt in your car.

1. What is the purpose of the seatbelt in a car?

As you read this section, think about how a seatbelt is designed to be able to fulfil its function.

PHYS.1.3 Collisions

Design a solution that has the function of minimizing the impact force on an object during a collision. *Define the problem, identify criteria and constraints, develop possible solutions using models, analyze data to make improvements from iteratively testing solutions, and optimize a solution*. Emphasize problems that require application of Newton's Second Law of Motion or conservation of momentum. (PS2.A, ETS1.A, ETS1.B, ETS1.C)

In this section, we will look at how we can safely come to a stop during a collision and how devices are able to serve their function of minimizing devastating impact forces.

What is involved in Engineering Design?

Engineering is a creative process where each new version of a design is tested and then modified, based on what has been learned up to that point. This process includes a number of stems:

1. Identifying the problem and defining criteria and constraints.
2. Generating ideas for how to solve the problem. Engineers can use research, brainstorming and collaboration with others to come up with ideas for solutions and designs.
3. Build and then test the prototypes. Using data collected, the engineer can analyze how well the various prototypes meet the given criteria and constraints.
4. Evaluate what is needed to improve the leading design or devise a better one.

To design a solution to the problem, you will need to start by identifying the criteria and constraints. Then develop several possible solutions. Once you have several possible solutions, use the criteria and constraints to evaluate each. You should test the solution that will best meet the criteria and constraints, and then determine how to improve the solution, based on test results. Testing the solution may include modeling, working with materials, using mathematical relationships, etc.

In the Science with Engineering Education (SEEd) Standards, specific engineering standards generally involve two types of tasks:

1. If the standard includes the idea of designing, then the design process will contain components of defining the problem (along with identifying the criteria and constraints), developing many possible solutions, and optimizing a solution (e.g., determining a best solution for the situation based on the criteria and constraints, testing the solution, refining the solution).
2. If the standard includes the idea of evaluating, then the design process will contain components of defining the problem (along with identifying the criteria and constraints) and optimizing a solution. The idea of developing many possible solutions is not included because various solutions will be provided. The idea of evaluating then means determining a best solution from the provided solutions for the situation based on meeting the criteria and constraints requirements.

Which type of engineering task is utilized in this SEEd Standard?

Conservation of Momentum
As you learned in the previous section, momentum is conserved in a collision if we include both vehicles. If we look at a single vehicle system, however, we see that the momentum changes based on the following model where the external force is provided, primarily, by the other vehicle.

$$\vec{F} = m\vec{a}$$

$$\vec{F} = m\frac{\Delta\vec{v}}{\Delta t}$$

$$m\Delta\vec{v} = \vec{F}\Delta t$$

$$\Delta\vec{p} = \vec{F}\Delta t$$

Since the amount of time in a collision is very small, the amount of force exerted must be very large in order to change the momentum in accordance with the model. A passenger must experience this same change in momentum, but without the damaging impact force. Based on this model, what could we do to minimize force? We could increase the amount of time for the change in momentum since $F \propto 1/\Delta t$. Would this be a valid solution to the seat belt problem?

Pressure
When we apply a force to an object, we can either apply that force to a small area or a large area. The ratio of the amount of force applied to an area is called pressure

$$P = \frac{F}{A}$$

Having a lot of force distributed across a large area may result in a small pressure. Essentially, every part of that area experiences just a small amount of the total force. How can we combine Newton's second law and the concept of pressure? Based on this model how can we minimize the impact force?

Putting It Together

Image by cfarnswroth, pixabay.com, CC0

Let's revisit the phenomena:

1. With references to Newton's second law, pressure, and conservation of momentum. How is a seat belt able to reduce the impact force from a collision?

2. How could an egg survive a fall from a second story window? Design a solution.

CHAPTER 2

Strand 2: Energy

Chapter Outline

2.1 Conservation of Energy (PHYS.2.1)
2.2 Thermal Energy (PHYS.2.2)
2.3 Types of Mechanical Energy (PHYS.2.3)
2.4 Energy Conversion (PHYS.2.4)
2.5 Renewable Energy (PHYS.2.5)

Image by Skeeze, pixabay.com, CC0

Energy describes the motion and interactions of matter and radiation within a system. Energy is a quantifiable property that is conserved in isolated systems and in the universe as a whole. At the macroscopic scale, energy manifests itself in multiple ways such as in motion, sound, light, and thermal energy. Uncontrolled systems always evolve toward more stable states— that is, toward more uniform energy distribution. Examining the world through an energy lens allows us to model and predict complex interactions of multiple objects within a system and address societal needs.

2.1 Conservation of Energy (PHYS.2.1)

Explore this Phenomenon

Bouncing ball strobe edit.jpg by Michael Maggs, edited by Richard Bartz, https://en.wikipedia.org/wiki/File:Bouncing_ball_strobe_edit.jpg, CC-BY-SA

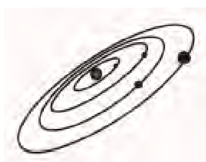
The picture above was taken using a strobe light as a basketball bounced by.

1. What energies were present in the system as it bounced?

As you read the following section, think about the different energies of the system and how they changed during the bounce.

PHYS.2.1 Conservation of Energy

Analyze and interpret data to track and calculate the transfer of energy within a system. Emphasize the identification of the components of the system, along with their initial and final energies, and mathematical descriptions to depict energy transfer in the system. Examples of energy transfer could include the transfer of energy during a collision or heat transfer. (PS3.A, PS3.B)



In this chapter, identify different systems, the energies contained within the system, and track the energy going into and out of the system.

Conservation of Energy

Energy is conserved in a closed system. That is, if you add up all the energy of an object(s) at one time it will equal all the energy of the same object(s) at a later time. A closed system is a system where no energy is transferred in or out. The total energy of the universe is a constant (i.e. it does not change). Mathematically, this is represented by the equation

$$\Sigma E_{\text{intitial}} = \Sigma E_{\text{final}}$$

where Σ is the Greek letter "Sigma". It is sometimes referred to as "summation" and means the total amount or the net amount. If we use K for kinetic energy and U for potential energies, (see section 2.3) the above equation becomes:

$$K_{\text{initial}} + U_{\text{initial}} = K_{\text{final}} + U_{\text{final}}$$

Let's look at an example where energies are conserved.

Image by Jessica Lewis (thepaintedsquare), pixabay.com, CC0

Suppose a 10 kg plant is sitting on a shelf that is 5 m above the ground. While it is on the top of the shelf, the plant has a gravitational potential energy of 490 J and 0 J of kinetic energy (because it is not moving). The total mechanical energy of the plant is 490 J. Mechanical energy is the sum of potential and kinetic energies that an object has. If the plant falls, the potential energy that the plant had while it was on the shelf will be transferred into kinetic energy. When the plant is halfway between the floor and the shelf (at a height of 2.5 m), it will have only 245 J of potential energy. Where did the rest of the energy go? Since energy cannot be created or destroyed, it didn't just disappear. The remaining potential energy is now kinetic energy. When the plant is half way down to the floor, it has 245 J of potential energy and 245 J of kinetic energy. It still has a total energy of 490 J.

When the plant has fallen 4 meters (so it is only 1 meter above the ground), the potential energy is only 50 J. How much kinetic energy does it have? It now has 440 J of kinetic energy and is moving with a speed of about 9.4 m/s. When it hits the ground, it will have no more potential energy and 490 J of kinetic energy.
At any given point, the total energy must be the same.


Thursday Morning Waterslide by Camp ASCCA, https://flic.kr/p/Whxwog, CC-BY-NC

Now consider a person sliding to rest on a horizontal part of a waterslide. They start out with 500 J of kinetic energy and 0 J of potential energy. They end with 0 J of both kinetic and potential energy.

Clearly the ending energy (0 J) and the beginning energy (500 J) are not the same. Where did the energy go? This is an example of where the system is not closed. A closed system in terms of energy is a system where energy doesn't leave or enter the system. In real life, rarely is a system closed. Energy can be transferred into or out of the system via work or heat. Additionally, there are other forms that energy can change into. Sometimes the energy changes into sound, electrical energy, light, or other types of energy. The energy can change form or type, but all energy must be accounted for. When using the law of conservation of energy it's important to identify all the types of energy that exist in the system. Additionally, if it appears that energy is disappearing, it is important to know where that energy went. Let's talk about the main methods that the energy of a system changes: heat and work.

What is work?
For some, the exciting part of a roller coaster is speeding down; for others it is the anticipation of climbing up. While the coaster is being towed up, it is having work done on it. The work done towing it to the top of the hill becomes potential energy stored in the coaster and that potential energy is converted to kinetic energy as the coaster runs down from the top of the hill to the bottom.

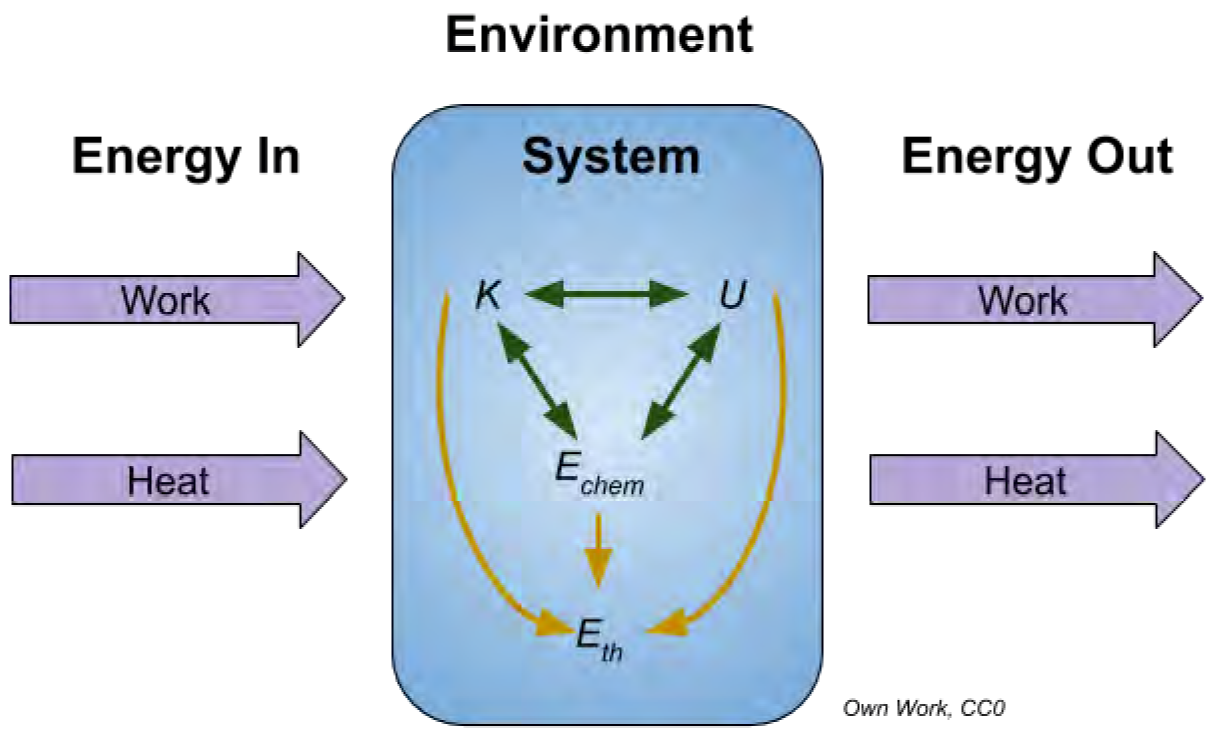
Image by Paul Brennan (paulbr75), pixabay.com, CC0

The word work has both an everyday meaning and a specific scientific meaning. In the everyday use of the word, work would refer to anything which required a person to make an effort. In physics, however, work is defined as the force exerted on an object multiplied by the distance the object moves due to that force.

W=Fd

In the scientific definition of the word, if you push against an automobile with a force of 200 N for 3 minutes but the automobile does not move, then you have done no work. Multiplying 200 N times 0 meters yields zero work. If you are holding an object in your arms, the upward force you are exerting is equal to the object's weight. If you hold the object until your arms become very tired, you have still done no work because you did not move the object in the direction of the force. When you lift an object, you exert a force equal to the object's weight and the object moves due to that lifting force. If an object weighs 200. N and you lift it 1.50 meters, then your work is W=Fd=(200. N)(1.50 m)=300. N m.

Work is done only if a force is exerted in the direction of motion. If the motion is perpendicular to the force, no work has been done. If the force is at an angle to themotion, then the component of the force in the direction of the motion is used to determine the work done.



In conclusion, in order to properly use the Law of Conservation of Energy, one should consider all types of energy, and account for the energies transferring into and out of a given system. The diagram above illustrates the energy transfers that could occur for a given system.

Putting It Together

Bouncing ball strobe edit.jpg by Michael Maggs, edited by Richard Bartz, https://en.wikipedia.org/wiki/File:Bouncing_ball_strobe_edit.jpg, CC-BY-SA

Let's revisit this phenomenon:

1. Using your knowledge about the Law of Conservation of Energy, explain what is happening to the basketball

2. Is Energy being conserved in this system? If so, Explain how you know it is. If not, identify where the energy is going.

2.2 Thermal Energy (PHYS.2.2)

Explore this Phenomenon

Image by insightzaoya, pixabay.com, CC0

In order to keep water cold we have to add ice.

1. Why would we add ice to already cold water?

As you read this section, think about the direction energy transfers and how this relates to the perception of hot and cold.

PHYS.2.2 Thermal Energy

Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system. Emphasize that uniform distribution of energy is a natural tendency. Examples could include the measurement of the reduction of temperature of a hot object or the increase in temperature of a cold object. (PS3.B)

In this section, build connections between the ideas of energy transfer, temperature, and the motion of particles. All three are needed to fully understand our phenomenon.

What is Thermal Energy?

Thermal energy is the average kinetic energy of moving particles of matter, measured by their temperature. For a gas this can be modelled as:

$$E_k = \frac{3}{2}kT$$

Where E_k is the average kinetic energy in Joules and T is the temperature in Kelvin (k is a constant and not important for this discussion). The key point is the more particles move, the greater the temperature will be; regardless of its state of matter. Why do you think that more motion results in a greater temperature?

Heat

Heat is the transfer of thermal energy between substances. Note that heat is not the energy itself, it is the transfer of energy. A transfer of energy can only occur when two systems of different temperatures can interact with each other. What will happen to the system with the greater temperature? What will happen to the system with the lower temperature?

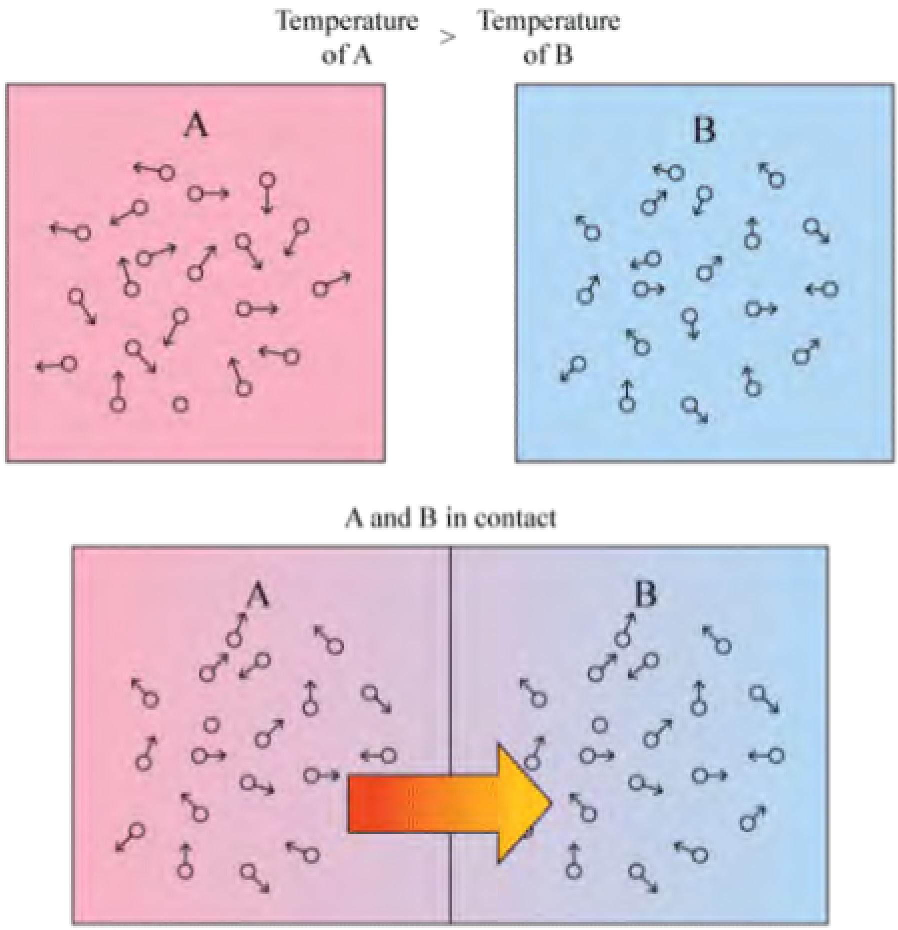


Image from ck12.org

We can visualize the energy “flowing” from the higher temperature to the lower temperature. Eventually, how will the temperature of system A compare to the temperature of system B? How would their temperatures compare if they had never interacted? What interactions are occuring with the phenomenon?

Specific Heat

When heat flows into an object, its thermal energy increases and so does its temperature. The amount of temperature increase depends on three things:

1) how much heat was added,
2) the size of the object, and
3) the material of which the object is made.

When you add the same amount of heat to the same mass of different substances, the amount of temperature increase is different. Each substance has a specific heat, which is the amount of heat necessary to raise one mass unit of that substance by one temperature unit.

In the SI system, specific heat is measured in J/g•°C. (Occasionally, you may also see specific heat expressed sometimes in J/kg•°C). The specific heat of aluminum is 0.903 J/g•°C. Therefore, it requires 0.903 J to raise 1.00 g of aluminum by 1.00 °C.

The amount of heat gained or lost by an object when its temperature changes can be calculated by the formula $Q = mC\Delta T$ where Q is the heat gained or lost, m is the mass of the object, c is its specific heat, and ΔT is the change in temperature. You should note that the size of a Celsius degree and a Kelvin degree are exactly the same, and therefore ΔT is the same whether measured in Celsius or Kelvin.

When an interaction occurs, we can equate the energy transfers and develop the following model for the final temperature.

$$T = \frac{m_A C_A T_A - m_B C_B T_B}{m_A C_A - m_B C_B}$$

Is there a way of preventing this energy transfer?

A Change in Matter

Just like we can use thermal energy to change the temperature of matter, we can also use it to change the state of matter. For example, it takes thermal energy to melt ice into liquid water. What direction do you think the heat flows in this example into the ice or into the water?

Investigate

Boil a sample of water and place the same size sample of water in a refrigerator. Once the water is boiling combine both systems and give them time for energy to transfer. Does the final temperature match the model? Is a section of the water boiling? Is a section still cold?

Let the combination sit until the next day. What is the temperature now? Why do you think it is the same or different?

Putting It Together

Image by insightzaoya, pixabay.com, CC0

Let's revisit this phenomenon:

1. For the ice water in the glass, what transfers of energy are occurring?

2. Even if the water was already cold, why would we want to add ice to it?

2.3 Types of Mechanical Energy (PHYS.2.3)

Explore this Phenomenon

Image from MaxPixel, CC0

Jack pulls back on his new slingshot and lets the rock fly.

1. What are the energies that are contained within the rock/slingshot system?

As you read the following section, think about how you could model the different energies present as the rock is pulled back in the slingshot and flies through the air.

PHYS.2.3 Types of Mechanical Energy

Develop and use models on the macroscopic scale to illustrate that energy can be accounted for as a combination of energies associated with the motion of objects and energy associated with the relative positions of objects. Emphasize relationships between components of the model to show that energy is conserved. Examples could include mechanical systems where kinetic energy is transformed to potential energy or vice versa. (PS3.A)

In this chapter, see if you can identify the different types of energy that exist for an object, based on its motion and position.

Forms of Mechanical Energy

Energy or the ability to do work can exist in many different forms. The two main types of energy that we study are kinetic and potential energies. These two types of energy are grouped together under the term Mechanical Energy. Kinetic energy is the energy of motion; any moving object possesses kinetic energy.

Potential energy is the energy of position. There are many other subcategories of both kinetic and potential energy. The next infographic identifies each of these subcategories.

FORMS OF ENERGY

All forms of energy fall under two categories

POTENTIAL

Potential energy is stored energy and the energy of position (gravitational)

CHEMICAL ENERGY

Chemical energy is the energy stored in the bonds of atoms and molecules. Biomass, petroleum, natural gas, propane and coal are examples of stored chemical energy.

NUCLEAR ENERGY

Nuclear energy is the energy stored in the nucleus of an atom. It is the energy that holds the nucleus together. The nucleus of a uranium atom is an example of nuclear energy.

STORED MECHANICAL ENERGY

Stored mechanical energy is energy stored in objects by the application of a force. Compressed springs and stretched rubber bands are examples of stored mechanical energy.

GRAVITATIONAL ENERGY

Gravitational energy is the energy of place or position. Water in a reservoir behind a hydropower dam is an example of gravitational potential energy. When the water is released to spin the turbines, it becomes kinetic energy.

KINETIC

Kinetic energy is energy in motion. It is the motion of waves, electrons, atoms, molecules and substances

RADIANT ENERGY

Radiant energy is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays and radio waves. Solar energy is an example of radiant energy.

THERMAL ENERGY

Thermal energy (or heat) is the internal energy in substances; it is the vibration and movement of atoms and molecules within substances. Geothermal energy is an example of thermal energy.

MOTION

The movement of objects or substances from one place to another is motion. Wind and hydropower are examples of motion.

SOUND

Sound is the movement of energy through substances in longitudinal (compression/rarefaction) waves.

ELECTRICAL ENERGY

Electrical energy is the movement of electrons. Lightning and electricity are examples of electrical energy.

Used with permission from "Secondary Science of energy" by the NEED (National Energy Education Development) project. Go to www.need.org for other great resources for teachers and students.

As discussed in section 3.1, the energy of a closed system is constant. In order for this to occur, energy will transfer between these types of energy as the position and motion of an object changes.

Common Energy Calculations

In order to properly model the different types of energy, equations have been developed to calculate and track the energy of a system. The ones that we are most concerned with are Kinetic Energy of Motion, Thermal Energy, Gravitational Potential Energy, and Elastic Energy (Stored Mechanical Energy). Thermal energy was addressed in section 2.2. How to calculate the other energies will be described below.

Kinetic energy of motion, involves a mass moving at a specific velocity. The amount of kinetic energy in a moving object depends directly on its mass and velocity. An object with greater mass or greater velocity has more kinetic energy. You can calculate the kinetic energy of a moving object with this equation:

$$\text{Kinetic Energy} = \tfrac{1}{2}\ \text{mass x velocity}^2$$

$$KE = \frac{1}{2}\ mv^2$$

This equation shows that an increase in velocity increases kinetic energy more than an increase in mass. If mass doubles, kinetic energy doubles as well, but if velocity doubles, kinetic energy increases by a factor of four. That’s because velocity is squared in the equation.

IMG_8455 by OkiGator, https://flic.kr/p/a5AFzf, CC-BY-NC-ND

Let’s consider an example. The picture shows Juan running on the beach with his dad. Juan has a mass of 40 kg and is running at a velocity of 1 m/s. How much kinetic energy does he have? Substitute these values for mass and velocity into the equation for kinetic energy:

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}\ 40\ kg \times (1\ m/s)^2$$
$$= 20\ kg\ m^2/s^2$$
$$= 20\ J$$

Notice that the answer is given in joules (J), or Nm, which is the SI unit for energy. One joule is the amount of energy needed to apply a force of 1 Newton over a distance of 1 meter.

What about Juan's dad? His mass is 80 kg, and he's running at the same velocity as Juan (1 m/s). Because his mass is twice as great as Juan's, his kinetic energy is twice as great, so 40 J.

Q: What is Juan's kinetic energy if he is now traveling 2 m/s?

A: 80 J


Diving Board 2 by Claire Gillman, https://flic.kr/p/7BbfbV, CC-BY

Potential energy due to the position of an object above Earth's surface is called gravitational potential energy. Like the diver on the diving board, any mass that is raised up above Earth's surface has the potential to fall because of gravity.

Gravitational potential energy depends on an object's weight and its height above the ground. It can be calculated with the equation:

Gravitational Potential Energy (PE) = weight × height

Remember that weight is calculated by multiplying the mass of an object by the acceleration due to gravity, so the equation may also be written:

$$\text{Potential Energy} \begin{aligned} &= \text{weight x height} \\ &= \text{mass x gravitational acceleration x height} \end{aligned}$$

$$PE = wh = mgh$$

Note: sometimes the letter U is used to represent gravitational potential energy, since there are so many different types of potential energy.

Image by Ben Kerckx, pixabay.com, CC0

Consider the little girl on the sled. She weighs 140 Newtons (remember

that weight=mg), and the top of the hill is 4 meters higher than the bottom of the hill. As she sits at the top of the hill, the child's gravitational potential energy is:

PE = 140 N × 4 m = 560 N m

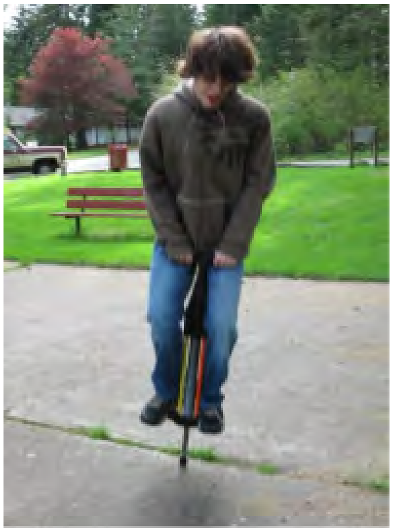
Notice that the answer is given in Newton meters (Nm), which is the SI unit for energy. A Newton meter is the energy needed to move a weight of 1 Newton over a distance of 1 meter. A Newton meter is also called a Joule (J).

Q: The gymnast on the balance beam in the picture weighs 360 Newtons. If the balance beam is 1.2 meters above the ground, what is the gymnast's gravitational potential energy?

A: 432 N

Potential energy due to an object's shape is called elastic potential energy. This energy results when an elastic object is stretched or compressed. The farther the object is stretched or compressed, the greater its potential energy is. A point will be reached when the object can't be stretched or compressed any more. Then it will forcefully return to its original shape.

Image by Skeeze, pixabay.com, CC0



Fwoosh! by Shavon Ni, https://flic.kr/p/6mGEFv, CC-BY-NC

Look at the pogo stick in the picture. Its spring has elastic potential energy when it is pressed down by the girl's weight. When it can't be compressed anymore, it will spring back to its original shape. The energy it releases will push the pogo stick—and the girl—off the ground.

The Elastic potential energy stored by a spring will depend on what the spring is made of and how much the spring is stretched or compressed. You can calculate the elastic potential of a spring by using the following equation:

Elastic Potential Energy = ½ x spring constant x $(\text{displacement})^2$

$$EPE = \frac{1}{2} k x^2$$

This equation shows that an increase in displacement increases elastic energy more than an increase in the spring constant. If the spring constant doubles, elastic energy doubles as well, but if displacement, elastic energy increases by a factor of four. That's because displacement is squared in the equation.

Let's work an example. Suppose that the spring in the pogo stick has a spring constant 250,000 N/m. When the girl bounces on the stick she compresses the spring by 0.25 m. How much elastic potential energy does the girl have?

$EPE = \frac{1}{2} k x^2 = \frac{1}{2} \times 250{,}000 \text{ N/m} \times (0.25 \text{ m})^2$

= 7,812.5 N m

= 7,812 J

Notice that the answer is given in joules (J), or Nm, which is the SI unit for energy. One joule is the amount of energy needed to apply a force of 1 Newton over a distance of 1 meter.

Q: How much energy is stored in the pogo stick if it is compressed 0.15 m?

A: 2,812.5 J

In conclusion, there are many different types of energies that can exist in a system. Knowing the motion and position of an object can help us to determine the amount of energy in our system.

Putting It Together

Image from MaxPixel, CC0

Let us revisit this phenomenon:

Jack pulls back on his new slingshot and lets the rock fly.

1. What are the energies that are contained within the rock/slingshot system?

2. Create a model to help illustrate your explanation.

2.4 Energy Conversion (PHYS.2.4)

Explore this Phenomenon

Image by enriquelopezgarre, *pixabay.com, CC0*

While you are on a trip, you notice a field of turbines. Some are moving while others are stationary.

1. Why are some of the turbines moving while others are not moving?

As you read the following section, be able to differentiate between the different forms of energy prior to the construction of your device. The device you construct will convert one form of energy to another. You will use both qualitative and quantitative observations in the evaluation of your device.

PHYS.2.4 Energy Conversion

Design a solution by constructing a device that converts one form of energy into another form of energy to solve a complex real-life problem. *Define the problem, identify criteria and constraints, develop possible solutions using models, analyze data to make improvements from iteratively testing solutions, and optimize a solution*. Examples of energy transformation could include electrical energy to mechanical energy, mechanical energy to electrical energy, or electromagnetic radiation to thermal energy. (PS3.A, PS3.B, ETS1.A, ETS1.B, ETS1.C)

In this section, use the information provided to help you construct a device that converts energy from one form to another.

Image from NASA, public domain

This giant six-limbed robot is NASA's Tri-ATHLETE. As the robot's name suggests, it is very "athletic." It was designed to do the heavy lifting in explorations of other planets and moons in the universe. The *Tri* ("three") part of its name refers to the fact that the robot can split into two separate three-limbed robots. These smaller robots can do things that the larger, six-limbed robot can't.

What is involved in Engineering Design?

Engineering is a creative process where each new version of a design is tested and then modified, based on what has been learned up to that point. This process includes a number of stems:

1. Identifying the problem and defining criteria and constraints.

2. Generating ideas for how to solve the problem. Engineers can use research, brainstorming and collaboration with others to come up with ideas for solutions and designs.
3. Build and then test the prototypes. Using data collected, the engineer can analyze how well the various prototypes meet the given criteria and constraints.
4. Evaluate what is needed to improve the leading design or devise a better one.

To design a solution to the problem, you will need to start by identifying the criteria and constraints. Then develop several possible solutions. Once you have several possible solutions, use the criteria and constraints to evaluate each. You should test the solution that will best meet the criteria and constraints, and then determine how to improve the solution, based on test results. Testing the solution may include modeling, working with materials, using mathematical relationships, etc.

In the Science with Engineering Education (SEEd) Standards, specific engineering standards generally involve two types of tasks:

1. If the standard includes the idea of designing, then the design process will contain components of defining the problem (along with identifying the criteria and constraints), developing many possible solutions, and optimizing a solution (e.g., determining a best solution for the situation based on the criteria and constraints, testing the solution, refining the solution).
2. If the standard includes the idea of evaluating, then the design process will contain components of defining the problem (along with identifying the criteria and constraints) and optimizing a solution. The idea of developing many possible solutions is not included because various solutions will be provided. The idea of evaluating then means determining a best solution from the provided solutions for the situation based on meeting the criteria and constraints requirements.

Which type of engineering task is utilized in this SEEd Standard?

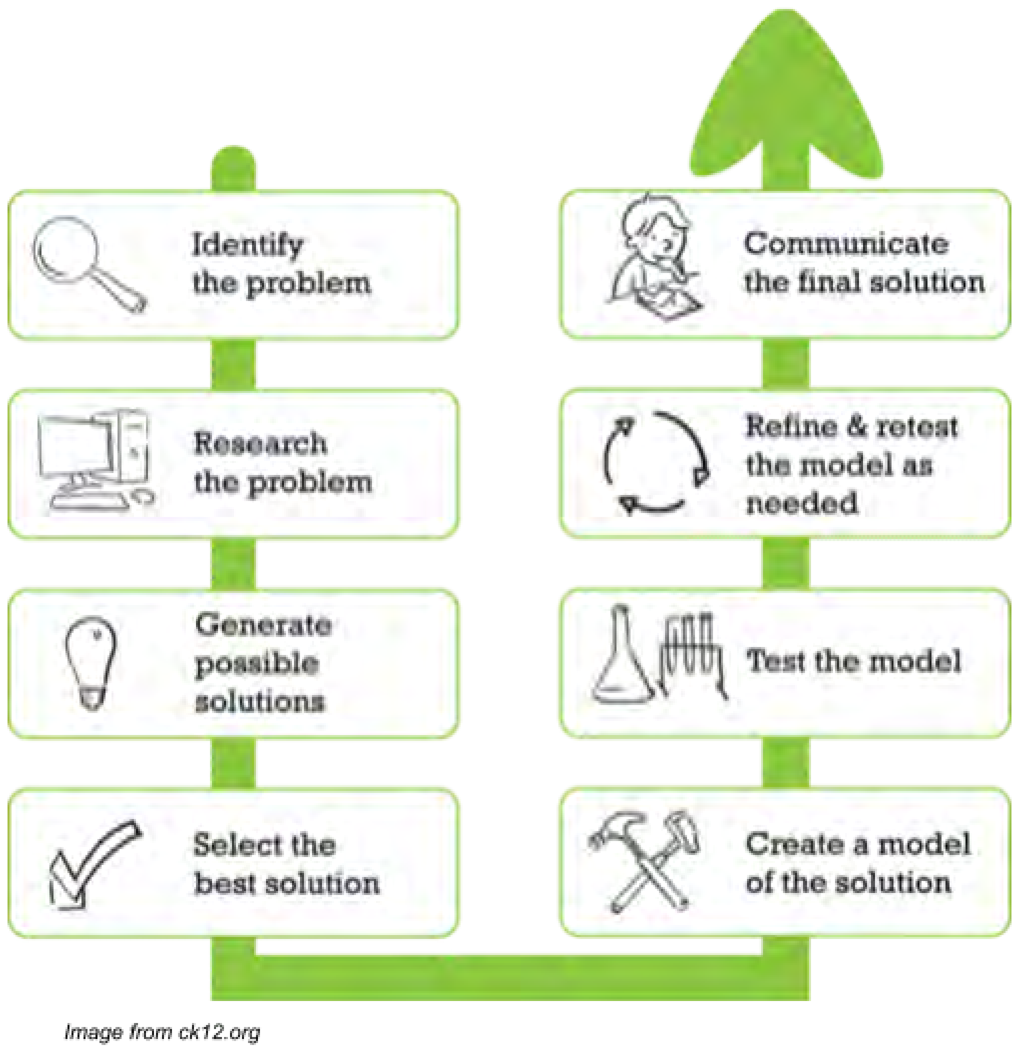
What Is Technological Design?

The process in which tri-ATHLETE was created and perfected is called technological design. This is the process in which most new technologies are developed. Technological design is similar to scientific investigation. Both processes rely on evidence and reason, and follow a logical sequence of steps to solve problems or answer questions.

The process of designing a new technology includes much more than just coming up with a good idea. Possible limitations, or constraints, on the design must be taken into account. These might include factors such as the cost or safety of the new product or process. Making and testing a model of the design are also important. These steps ensure that the design actually works to solve the problem. This process also gives the designer a chance to find problems and modify the design if necessary. No solution is perfect, but testing and refining a design assures that the technology will provide a workable solution to the problem it is intended to solve.

Steps of the Technological Design Process

The technological design process can be broken down into a series of steps shown in the flowchart in Figure below. Typically, some of the steps have to be repeated, and the steps may not always be done in the sequence shown.



This flowchart illustrates the steps of the technological design process.

Consider the problem of developing a solar-powered car. Many questions would have to be researched in the design process. For example, what is the best shape for gathering the sun's rays? How will sunlight be converted to usable energy to run the car? Will a back-up energy source be needed? After researching the answers, possible designs are developed. This generally takes imagination as well as sound reasoning. Then a model must be designed and tested. This allows any problems with the design to be worked out before a final design is selected and produced.

Q: Assume you want to design a product that lets a person in a wheelchair carry around small personal items so they are easy to access. What questions might you research first?

A: You might research questions such as: What personal items are people likely to need to carry with them? What types of carriers or holders are there that might be modified for use by people in a wheelchair? Where might a carrier be attached to a wheelchair or person in a wheelchair without interfering with the operation of the chair or hindering the person?

Q: Suppose you have come up with a possible solution to the problem described in the previous question. How might you make a model of your idea? How could you test your model?

A: First, you might make a sketch of your idea. Then you could make an inexpensive model using simple materials such as cardboard, newspaper, tape, or string. You could test your model by trying to carry several personal items in it while maneuvering around a room in a wheelchair. You would also want to make sure that you could do things like open doors, turn on light switches, and get in and out of the chair without the carrier getting in the way.

Summary

- Technological design is the process in which new technology is developed.
- Steps of the technological design process include: identify a problem, research the problem, generate possible solutions, select the best solution, create a model, test the model, refine and retest the model as needed, and communicate the final solution.

Review

1. What is technological design?
2. How is technological design similar to scientific investigation?
3. List the steps of the technological design process.

Conversion of Energy

Sari and Daniel are spending a stormy Saturday afternoon with cartons of hot popcorn and a spellbinding movie. They are obviously too focused on the movie to wonder where all the energy comes from to power their weekend entertainment. They'll give it some thought halfway through the movie when the storm causes the power to go out!

Image from ck12.org

Changing Energy

Watching movies, eating hot popcorn, and many other activities depend on electrical energy. Most electrical energy comes from the burning of fossil fuels, which contain stored chemical energy. When fossil fuels are burned, the chemical energy changes to thermal energy and the thermal energy is then used to generate electrical energy. These are all examples of energy conversion. Energy conversion is a process in which one kind of energy changes into another kind. When energy changes in this way, the energy isn't used up or lost. The same amount of energy exists after the conversion as before. Energy conversion obeys the law of conservation of energy, which states that energy cannot be created or destroyed.

How Energy Changes Form

Besides electrical, chemical, and thermal energy, some other forms of energy include mechanical and sound energy. Any of these forms of energy can change into any other form. Often, one form of energy changes into two or more different forms. For example, the popcorn machine below changes electrical energy to thermal energy. The thermal energy, in turn, changes to both mechanical energy and sound energy. You can read the Figure below how these changes happen.

Image by Jill Wellington, pixabay.com, CC0

1. The popcorn machine changes electrical to thermal energy, which heats the popcorn.

2. The heat causes the popcorn to pop. You can see that the popping corn has mechanical energy (energy of movement). It overflows the pot and falls into the pile of popcorn at the bottom of the machine.

3. The popping corn also has energy. That's why it makes popping sounds.

Kinetic-Potential Energy Changes

Mechanical energy commonly changes between kinetic and potential energy. Kinetic energy is the energy of moving objects. Potential energy is energy that is stored in objects, typically because of their position or shape. Kinetic energy can be used to change the position or shape of an object, giving it potential energy. Potential energy gives the object the potential to move. If it does, the potential energy changes back to kinetic energy.

That's what happened to Sari. After she and Daniel left the theater, the storm cleared and they went for a swim. That's Sari in the Figure below coming down the water slide. When she was at the top of the slide, she had potential energy. Why? She had the potential to slide into the water because of the pull of gravity. As she moved down the slide, her potential energy changed to kinetic energy. By the time she reached the water, all the potential energy changed to kinetic energy.

Q: How could Sari regain her potential energy?

A: Sari could climb up the steps to the top of the slide. It takes kinetic energy to climb the steps, and this energy would be stored in Sari as she climbed. By the time she got to the top of the slide, she would have the same amount of potential energy as before.

Q: Can you think of other fun examples of energy changing between kinetic and potential energy?

A: Playground equipment such as swings, slides, and trampolines involves these changes.

Summary

- Energy conversion is a process in which energy changes from one form or type to another. Energy is always conserved in energy conversions.
- Different forms of energy—such as electrical, chemical, and thermal energy—often change to other forms of energy.
- Mechanical energy commonly changes back and forth between kinetic and potential energy.

Review

1. Define energy conversion.
2. Relate energy conversion to the law of conservation of energy.
3. Describe an original example of energy changing from one form to two other forms.
4. Explain how energy changes back and forth between kinetic and potential energy when you jump on a trampoline. Include a sketch to help explain the energy conversions.

What does "NIMBY" stand for?

Not in my backyard. As much as any type of power source, wind power pits people who are concerned about the environment against, well, people who are concerned about the environment. Some people want the benefits of clean wind power but don't want the turbines in their vicinity.

Image by enriquelopezgarre, pixabay.com, CC0

Wind Energy

Energy from the Sun also creates wind, which can be used as wind power. The Sun heats different locations on Earth by different amounts. Air that becomes warm rises and then sucks cooler air into that spot. The movement of air from one spot to another along the ground creates wind. Since the wind is moving, it has kinetic energy.

Wind power is the fastest growing renewable energy source in the world. Windmills are now seen in many locations, either individually or, more commonly, in large fields.

Wind Power Use

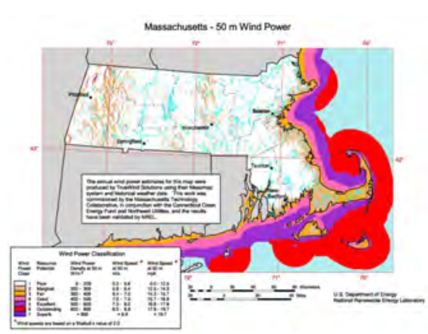
Wind is the source of energy for wind power. Wind has been used for power for centuries. For example, windmills were used to grind grain and pump water. Sailing ships traveled by wind power long before ships were powered by fossil fuels. Wind can be used to generate electricity, as the moving air spins a turbine to create electricity.

Wind Turbine video
https://www.youtube.com/watch?v=tsZITSeQFR0&feature=youtu.be

Consequences of Wind Power

Wind power has many advantages. It does not burn, so it does not release pollution or carbon dioxide. Also, wind is plentiful in many places. Wind, however, does not blow all of the time, even though power is needed all of the time. Just as with solar power, engineers are working on technologies that can store wind power for later use.

Windmills are expensive and wear out quickly. A lot of windmills are needed to power a region, so nearby residents may complain about the loss of a nice view if a wind farm is built. Coastlines typically receive a lot of wind, but wind farms built near beaches may cause unhappiness for local residents and tourists.



The Cape Wind project off of Cape Cod, Massachusetts has been approved but is generating much controversy. Opponents are in favor of green power but not at that location. Proponents say that clean energy is needed and the project would supply 75% of the electricity needed for Cape Cod and nearby islands.

Summary

- Wind contains energy, which can move a turbine and generate electricity.
- Wind power is clean and does not release greenhouse gases, but some people complain about the spread of windmills across certain locations.
- Wind has been used as a local energy source for centuries and is now being scaled up for use regionally.

Review

1. Describe what causes wind and how wind energy can be harnessed.
2. What are some of the downsides of using wind power?
3. Why do you think that wind is the fastest growing non-renewable energy source?

Explore: Wind Turbine CK12 simulation
https://www.ck12.org/auth/signin?returnTo=https%3A%2F%2Finteractives.ck12.org%2Fsimulations%2Fphysics%2Fwind-turbine%2Fapp%2Findex.html

1. Where does the turbine get its energy from?
2. Which form of energy does the turbine convert the energy to?
3. Describe the process of energy conversion in a turbine.
4. Use the simulation to explore how a change in wind speed, efficiency, and propeller diameter.

If you need further information on how a wind turbine works, see section 3.2 on Electromagnetic induction.

Putting It Together

Image by enriquelopezgarre, *pixabay.com, CC0*

Let's revisit this phenomenon:

1. What is causing these turbines to move?

2. What are these turbines used for?

3. Which type(s) or energy are involved? What are these forms of energy being converted to?

4. What are the advantages and disadvantages of turbines?

5. Use the Technological Design process to construct a device that solves a problem on how to convert energy from one form to another.
   a. define the problem
   b. Identify criteria and constraints
   c. develop possible solutions using models
   d. analyze data
   e. evaluate device quantitatively and qualitatively
   f. optimize a solution

2.5 Renewable Energy (PHYS.2.5)

Explore this Phenomenon

Highland under the inversion by jpstanley, https://flic.kr/p/dKcqWA, CC-BY-NC-SA

In Utah, In the winter, an inversion occurs, trapping bad polluted air in the valleys.

1. What causes Utah's winter air inversion?

2. Why is this a problem?

As we work through this phenomenon try to propose a practical solution to Utah's mountain valley inversion problems.

PHYS.2.5 Renewable Energy

Design a solution to a major global problem that accounts for societal energy needs and wants. *Define the problem, identify criteria and constraints, develop possible solutions using models, analyze data to make improvements from iteratively testing solutions, and optimize a solution*. Emphasize problems that require the application of conservation of energy principles through energy transfers and transformations. Examples of devices could include one that uses renewable energy resources to perform functions currently performed by nonrenewable fuels or ones that are more energy efficient to conserve energy. (PS3.A, PS3.B, PS3.D, ETS1.A, ETS1.B, ETS1.C)

In this section, identify how we are able to produce usable energy and what are the consequences of that particular form of energy production. For each type of energy production, consider where it could be implemented. Don't just look at Utah, think globally.

What is involved in Engineering Design?

Engineering is a creative process where each new version of a design is tested and then modified, based on what has been learned up to that point. This process includes a number of stems:

1. Identifying the problem and defining criteria and constraints.
2. Generating ideas for how to solve the problem. Engineers can use research, brainstorming and collaboration with others to come up with ideas for solutions and designs.
3. Build and then test the prototypes. Using data collected, the engineer can analyze how well the various prototypes meet the given criteria and constraints.
4. Evaluate what is needed to improve the leading design or devise a better one.

To design a solution to the problem, you will need to start by identifying the criteria and constraints. Then develop several possible solutions. Once you have several possible solutions, use the criteria and constraints to evaluate each. You should test the solution that will best meet the criteria and constraints, and then determine how to improve the solution, based on test results. Testing the solution may include modeling, working with materials, using mathematical relationships, etc.

In the Science with Engineering Education (SEEd) Standards, specific engineering standards generally involve two types of tasks:

1. If the standard includes the idea of designing, then the design process will contain components of defining the problem (along with identifying the criteria and constraints), developing many possible solutions, and optimizing a solution (e.g., determining a best solution for the situation based on the criteria and constraints, testing the solution, refining the solution).
2. If the standard includes the idea of evaluating, then the design process will contain components of defining the problem (along with identifying the criteria and constraints) and optimizing a solution. The idea of developing many possible solutions is not included because various solutions will be provided. The idea of evaluating then means determining a best solution from the provided solutions for the situation based on meeting the criteria and constraints requirements.

Which type of engineering task is utilized in this SEEd Standard?

The Ongoing Demand

We need usable energy. As technology continues to advance and the population grows the amount of usable energy we need will continue to increase. This demand is currently being met by nonrenewable sources, such as fossil fuels. As noted in the previous section, the use of fossil fuels to power our society is not clean energy and releases tons of pollutants into our environment. What do you think will happen to the amount of pollutants in our environment if we continue this trend?

Our Part

Image by Blomst, pixabay.com, CC0

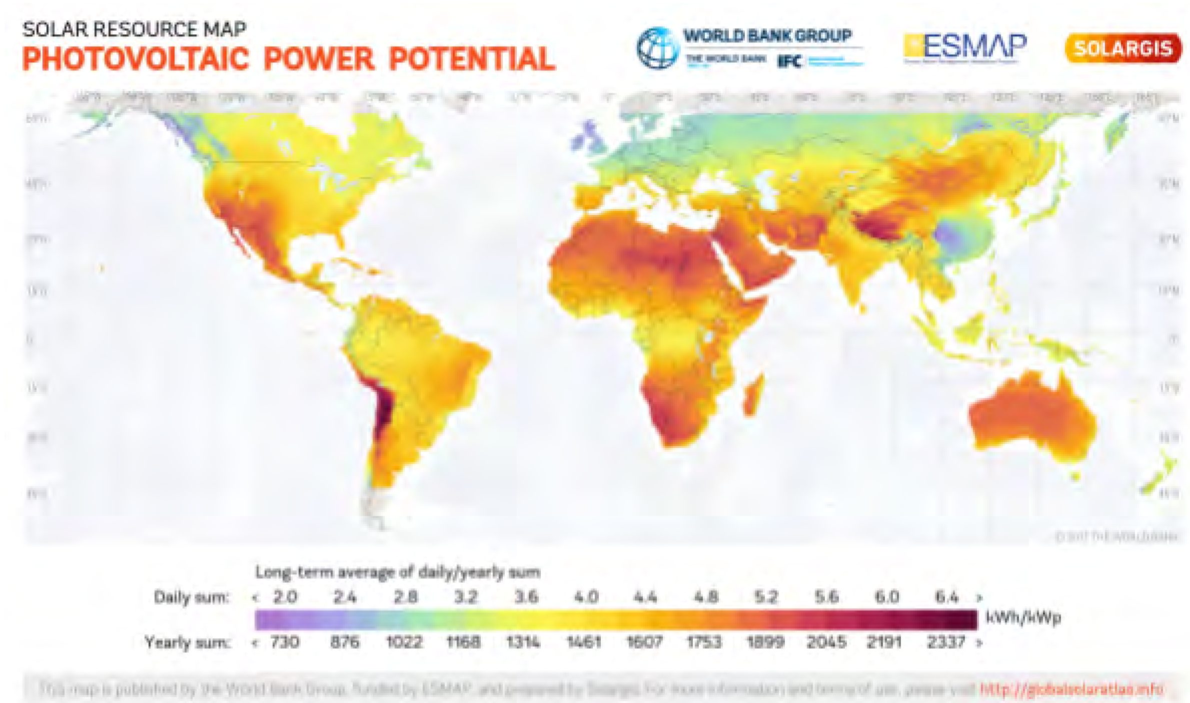
Transportation: In very recent history, we have seen enormous growth in the viability of the electric car; most notably in the form of the Tesla.

Problem solved right? If we can eliminate the estimated 1 billion combustion engine cars and replace them with clean electric cars, is that a step in the right direction? Something needs to provide the electric car with electricity and that is our current mass energy production system. Is there another way to power the vehicle?

Housing: In Utah, there has been a rise in solar panels placed on housing to meet energy demands. What are some of the issues with solar energy? Are they efficient? Are they cheap? Are they clean to produce?

Large Scale Energy Production

Thinking about large scale energy production, the one that has received arguably the most attention is solar energy. While the sun sends energy to the entire planet, some areas of the earth receive more than others. Looking at a map for the photovoltaic potential shows the estimated amount of energy that can be produced by crystalline silicon photovoltaic cells in regions across the globe.

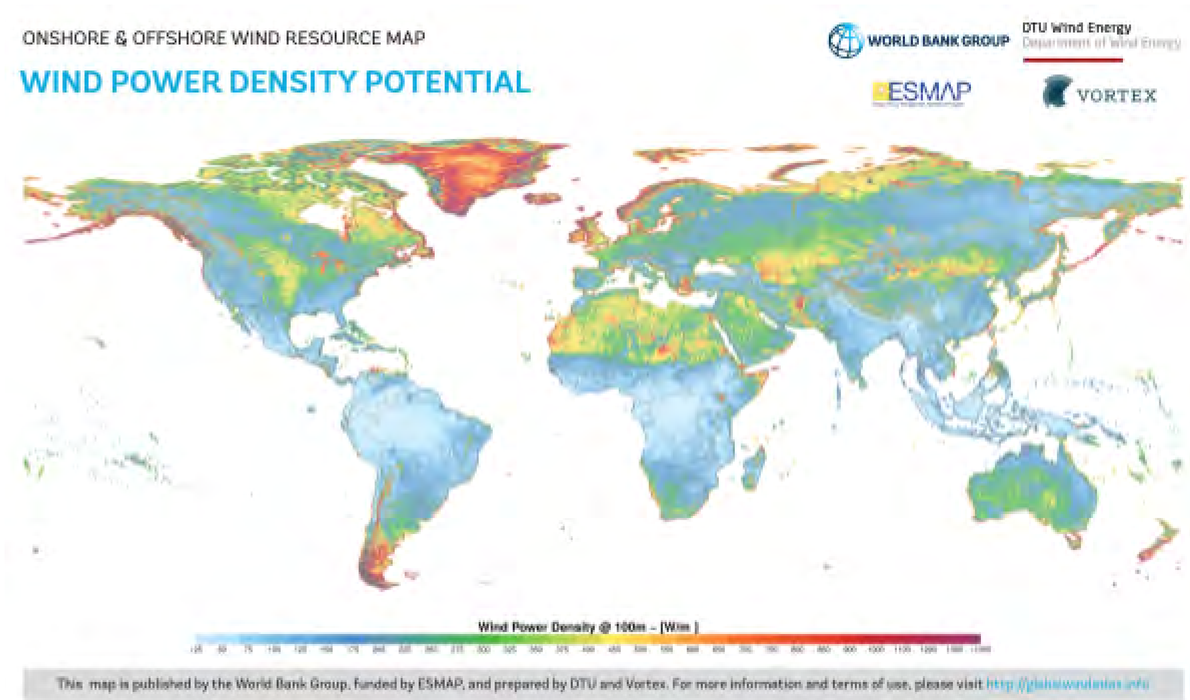


Global Map of Photovoltaic Power Potential by World Bank Group, https://globalsolaratlas.info, CC-BY

What are some patterns you notice about the potential? What are some of the factors affecting the amount of solar energy received by an area of the world? Is there an area that surprises you? Investigate

The issues that exist with small scale solar energy still exist with large scale solar energy. Is it clean to implement? Is it expensive? Is it efficient?

Wind Energy: How we convert the wind into usable energy was explained in the previous section, but it only works if there is wind. Just like solar energy, there is a wind potential that maps across the globe.



Global Map of Wind Power Density Potential by Technical University of Denmark, https://commons.wikimedia.org/wiki/File:Global_Map_of_Wind_Power_Density_Potential.png, CC-BY

What are some patterns you notice about the potential? What are some of the factors affecting the amount of wind energy received by an area of the world? Is there an area that surprises you? Investigate

There are other forms of renewable energy, such as hydroelectric power, but being clean is not enough. It must be viable to the region and affordable.

The End Goal

The goal is to produce a sufficient amount of energy to cover an ever increasing demand for that energy. We must realize that a solution for one part of the world may not work in another part of the world for various reasons.

Putting It Together

Highland under the inversion by jpstanley, https://flic.kr/p/dKcqWA, CC-BY-NC-SA

Let's revisit this phenomenon:

1. Propose a solution to either eliminate or reduce Utah's inversion problem.

2. Would this solution work in Germany? Why or why not?

3. Would this solution work in the Angola? Why or why not?

CHAPTER 3

Strand 3: Fields

Chapter Outline

Magnetic Fields - 14 by Windell Oskay, https://flic.kr/p/7YPPbb, CC-BY

Fields describe how forces act through space and how potential energy is stored in systems. These take on different forms of electric, magnetic, or gravitational fields, but similarly provide a mechanism for how matter interacts. When two objects interacting through a field change relative position, the energy stored in the field is changed. These fields are important at a wide variety of scales, ranging from the subatomic to the astronomic.

3.1 Gravitational and Electric Fields (PHYS.3.1)

Explore this Phenomenon

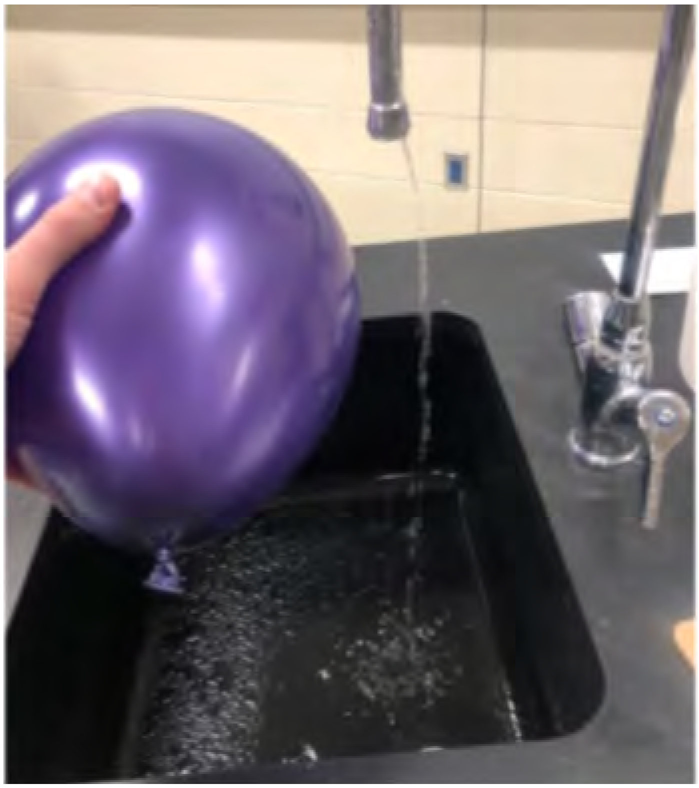


Image by Milo Maughan, CC0

You are playing around with a balloon at a party and decide to hold it next to a running faucet (as depicted in the image above).

1. What is causing this to happen?

As you read the sections below, think about how the size of the balloon and distance from the running water of the faucet (scale and proportion) might affect situations like the one above.

PHYS.3.1 Gravitational and Electric Fields

Use mathematics and computational thinking to compare the scale and proportion of gravitational and electric fields using Newton's Law of Gravitation and Coulomb's Law. Emphasize the comparative strength of these two field forces, the effect of distance between interacting objects on the magnitudes of these forces, and the use of models to understand field forces. (PS2.B)

In this chapter, pay close attention to how the size of each object and their distances from each other affect the forces that exist between them. As you observe changes in size and/or distance, note any trends in changes to scale or proportion in gravitational and electric field calculations. We can use models to compare the strengths of field forces.

Gravitational and Electric Fields

Image by Jonny Linder, pixabay.com, CC0

Long, long ago, when the universe was still young, an incredible force caused dust and gas particles to pull together to form the objects in our solar system. From the smallest moon to our enormous sun, this force created not only our solar system, but all the solar systems in all the galaxies of the universe. The force is gravity.

Defining Gravity

Gravity has traditionally been defined as a force of attraction between things that have mass. According to this conception of gravity, anything that has mass, no matter how small, exerts gravity on other matter. Gravity can act between objects that are not even touching. In fact, gravity can act over very long distances. However, the farther two objects are from each other, the weaker is the force of gravity between them. Less massive objects also have less gravity than more massive objects. Gravity is an example where there is a force field that results when forces act on bodies, at various positions or distances in space, without touching each other (non-contact force).

Earth's Gravity

You are already very familiar with Earth's gravity. It constantly pulls you toward the center of the planet. It prevents you and everything else on Earth from floating away or being flung out into space as the planet spins on its axis. It also pulls objects that are above the surface—from meteors to skydivers—down to the surface. Gravity between Earth and the moon and between Earth and artificial satellites keeps all these objects circling around Earth. Gravity also keeps Earth and the other planets moving around the much more massive sun.

Q: There is a force of gravity between Earth and you and also between you and all the objects around you. When you drop a paperclip, why doesn't it fall toward you instead of toward Earth?

A: Earth is so much more massive than you that its gravitational pull on the paper clip is immensely greater.

Image by S. Hermann & F. Richter (pixel2013), pixabay.com, CC0

You may have heard a story about Isaac Newton coming up with the idea of gravity when an apple fell out of a tree and hit him in the head. The story isn't true, but seeing how things like apples fall to Earth helped Newton form his ideas about gravity, the force of attraction between things that have mass. Of course, people had known about the effects of gravity for thousands of years before Newton came along. After all, they constantly experienced gravity in their daily lives. They observed over and over again that things always fall toward the ground. However, it wasn't until Newton developed his law of gravity in the late 1600s that people knew gravity applies to everything in the universe that has mass.

What affects the gravitational pull between two objects?
Newton is widely recognized as being the first person to suggest that gravity is universal and affects all objects in the universe. That's why Newton's law of gravity is called the law of universal gravitation. Universal gravitation means that the force that causes an apple to fall from a tree to the ground is the same force that causes the moon to keep moving around Earth. Universal gravitation also means that while Earth exerts a pull on you, you exert a pull on Earth (remember Newton's 3rd Law). In fact, there is gravity between you and every mass around you—your desk, your book, your pen. Even tiny molecules of gas are attracted to one another by the force of gravity.

Newton's law of universal gravitation had a huge impact on how people thought about the universe. A field force that acts across a distance without touching (non-contact) was unheard of while contact forces that push or pull on an object are easy to observe. Newton's law was the first scientific law that applied to the entire universe. It explains the motion of objects not only on Earth but in outer space as well.

Key Equations

$$F_G = G\frac{m_1m_2}{d^2}$$

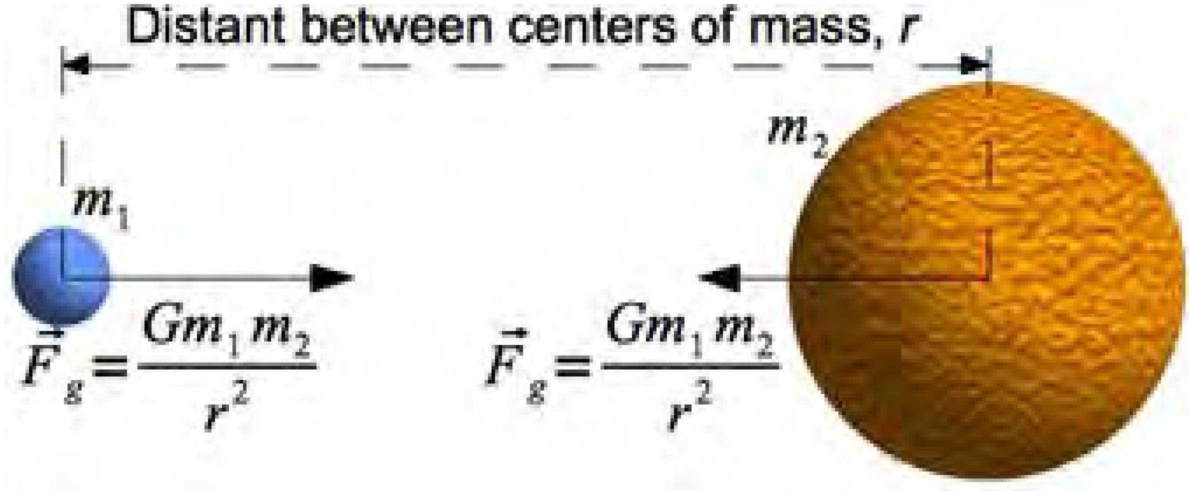
F is the force of gravity between an object with mass m1 and another object of mass m2 that have a distance between them of d. Sometimes the symbol r is used, rather than d, to show this distance. When r is used, it represents the "orbital radius", or how far the centers of the two objects are from each other.

$$G = 6.67\text{x}10^{-11}\frac{Nm^2}{kg^2}$$

This is called the universal constant of gravitation. This was determined by measuring the force between two 1.0 kg objects whose center of masses were exactly 1.0 m apart.

Look at the equation of Universal Gravitation and see what happens when you plug in masses of 1.0 kg and a distance of 1.0 m. Why would using these quantities result in a force that equals the gravitational constant?

Using astronomical data, Newton was able to formulate his ideas into an equation. This equation tells us the strength of the force of gravity between any two objects anywhere in the universe. Newton discovered that any two objects in the universe, with masses m1 and m2 with their centers of mass at a distance r apart will experience a force of mutual attraction along the line joining their centers of mass equal to: Here is an illustration of this law for two objects, for instance the earth and the sun:



Factors that Influence the Strength of Gravity

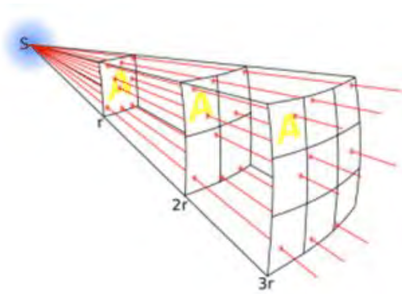
Newton's law also states that the strength of gravity between any two objects depends on two factors: the masses of the objects and the distance between them. According to this equation, the force of gravity is directly proportional to the masses of the two objects and inversely proportional to the square of the distance between them. This means that objects with greater mass have a stronger force of gravity between them. For example, because Earth is so massive, it attracts you and your desk more strongly that you and your desk attract each other. That's why you and the desk remain in place on the floor rather than moving toward one another. For example:

• If you double the mass of one of the objects, the force will also double.
• If you triple the mass of one of the objects, the force will triple.
• If you double the mass of one object and triple the mass of the other, the force will become six times (2×3=6) stronger.

Objects that are closer together have a stronger force of gravity between them. For example, the International Space Station is closer to Earth than it is to the more massive sun, so the force of gravity is greater between the Space Station and the Earth than between the Space Station and the Sun. That's why the Space Station circles around Earth rather than the Sun. You can see this in the figure below.

Inverse Square Law

In physics, an inverse-square law is any physical law stating that a specified physical quantity or intensity is inversely proportional to the square of the distance from the source of that physical quantity. As an example, let's look at an image which shows how the intensity of light decreases according to the inverse square law.



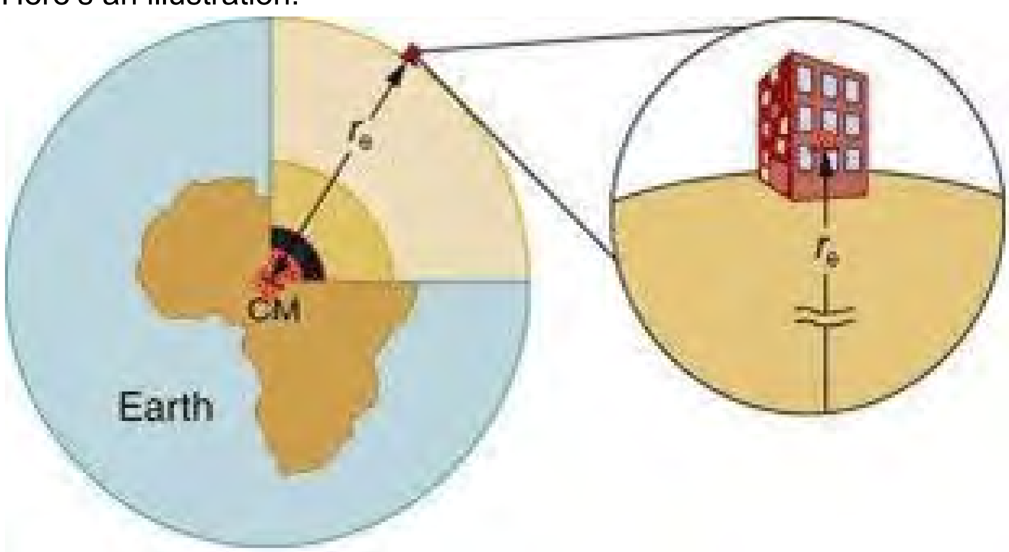
Because the light spreads out over an area, every time we double the distance, the light intensity decreases by 1/4. If we triple the distance, the light intensity will decrease by 1/9. Both the law of Universal Gravitation and Coulomb's Law (discussed in the next section) obey the inverse square law for distance. See if you can fill in the missing values in the next table.

Distance	Inverse	Inverse Square
1(D)	1/1	1(F)
2(D)	½	¼(F)
½(D)	2	4(F)
3(D)		___(F)
¼(D)		____(F)
___(D)	5/6	____(F)
___(D)	8/7	____(F)
___(D)	9/10	____(F)
___(D)		4/9(F)
___(D)		49/16(F)
___(D)		0.36(F)

Gravity on the Earth's Surface

On the surface of a planet—such as Earth—the r in the formula is very close to the radius of the planet, since a planet's center of mass is (usually) at its center. It also does not vary by much: for instance, the Earth's radius is about 6,000,000 m. Even the height of Mt. Everest is only 8,800 m, so we can say that for objects near the surface of the Earth, the r in formula is constant and equal to the Earth's radius. This allows us to say that gravity is more or less constant on the surface of the Earth. The value on (or near) the surface of Earth for the gravitational acceleration is about 9.8 m/s2.

Here's an illustration:



For any object near the surface of the earth, the force of gravity may be expressed as:

$$F_G = G \frac{mass_{Earth} mass_{object}}{r^2_{radius\ of\ the\ earth}}$$

In fact, an object's weight is the magnitude of the gravitational force on it. To find the weight of an object on another planet, star, or moon, use the appropriate values in the formula for the force of gravity.

Some data needed for the problems:
• The radius of the Earth is 6.4 x 106 m.
• The mass of the Earth is about 6.0 x 1024 kg.
• The mass of the Sun is about 2.0 x1030 kg.
• The Earth-Sun distance is about 1.5 x 1011 m.
• The Earth-Moon distance is about 3.8 x 108 m.

G= Gravitational Constant= $6.67300\times10^{-11} m^3 kg^{-1} s^{-2}$ or G = 6.673×10^{-11} N m^2 kg^{-2}

Guidance

When using the Universal Law of Gravity formula and the constant G above, make sure to use SI units of meters and kilograms. The direction of the force of gravity is in a straight line between two objects. It is always attractive. Newton relied on calculus in order to prove that for a spherical object (like Earth) one can assume all of its mass is at the center of the sphere (thus in his formula, one can use the radius of Earth for the distance between a falling rock and Earth).

Newton's Laws apply to all forces; but when he developed them only one was known: gravity. Newton's major insight—and one of the greatest in the history of science—was that the same force that causes objects to fall when released is also responsible for keeping the planets in orbit.

Example 1

Determine the force of attraction between a 15.0 kg box and a 63.0 kg person if they are 3.45 m apart. Assume that the distance given is the distance between the two centers of the objects.

$$F_g = \frac{Gm_1m_2}{d^2} = \frac{(6.67\ x\ 10^{-11}\ \frac{Nm^2}{kg^2})(15.0\ kg)(63.0\ kg)}{(3.45\ m)^2} = 5.30\ x\ 10^{-9} N$$

Example 2

Determine the force of attraction between the sun and the Earth.

$$F_g = \frac{Gm_1m_2}{d^2} = \frac{(6.67\,x\,10^{-11}\,\frac{Nm^2}{kg^2})(2.0x\,10^{30}\,kg)(6.0\,x\,10^{24}\,kg)}{(1.5\,x\,10^{11}\,m)^2} = 3.6\,x\,10^{22}N$$

Image from sethink, pixabay.com, CC0

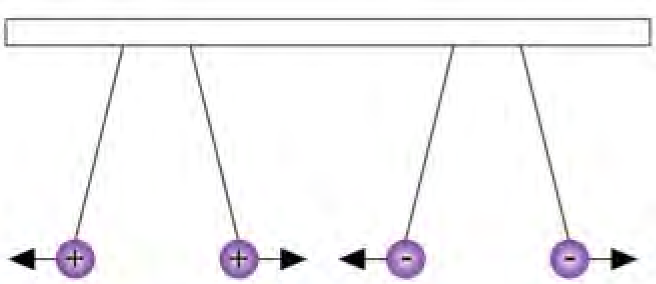
A lightning bolt is like the spark that gives you a shock when you touch a metal doorknob. Of course, the lightning bolt is on a much larger scale. But both the lightning bolt and spark are a sudden transfer of electric charge.

Introducing Electric Charge

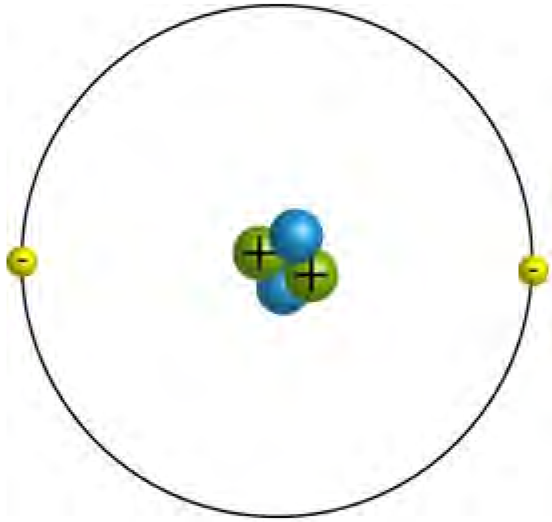
Electric charge is a physical property of particles or objects that causes them to attract or repel each other without touching. All electric charge is based on the protons and electrons in atoms. A proton has a positive electric charge, and an electron has a negative electric charge. In the figure below, you can see that positively charged protons (+) are located in the nucleus of the atom, while negatively charged electrons (-) move around the nucleus.

Electric Force

When it comes to electric charges, opposites attract, so positive and negative particles attract each other. You can see this in the diagram below. This attraction explains why negative electrons keep moving around the positive nucleus of the atom. Like charges, on the other hand, repel each other, so two positive or two negative charges push apart. This is also shown in the diagram. The attraction or repulsion between charged particles is called electric force. The strength of electric force depends on the amount of electric charge on the particles and the distance between them. Larger charges or shorter distances result in greater force.



Q: How do positive protons stay close together inside the nucleus of the atom if like charges repel each other?



A: There are other stronger forces in the nucleus hold the protons together.

Key Equation

q=Ne: Any object's charge is an integer multiple of an electron's charge.

- q represents the total charge on an object, measured in units of Coulombs (which is abbreviated as C).
- N represents the number of extra or missing electrons.
- e represents the fundamental charge unit, 1.6 Å~ 10-19 C.

Opposite charges attract and like charges repel.

The charge (q) of an electron (e) and proton is 1.6Å~10-19 C. An electron has a negative charge and a proton has a positive charge. This is called the fundamental charge unit. If an object has a net negative charge, it means that the object has gained electrons. If the object has a net positive charge, it means that the object has lost electrons. One can determine the number of excess electrons (or protons if positive charge) by dividing the object's charge by the fundamental charge. Most objects are electrically neutral (equal numbers of electrons and protons). This enables gravitational force to dominate on a macro scale.

Example 1

Question:

If an object has +0.003 C of charge, how many electrons did the object lose?

Solution:

q=Ne

0.003 C = N (-1.6 x 10-19 C)

N = -1.875 x 1016 electrons

Answer:
1.875 x 1016 electrons fewer than protons.

What is Coulomb's Law?

Charles-Augustin de Coulomb
(1736-1806)

All objects have positive and negative charges inside them. If the number of positive and negative charges are equal, as they most often are, then the object is neutral. Charged objects are objects with more positive charges than negative ones, or vice versa. Opposite charges attract, and similar charges repel. Electric fields are created by a net charge and point away from positive charges and towards negative charges. Many macroscopic forces can be attributed to the electrostatic forces between molecules and atoms.

Charles-Augustin de Coulomb noticed that a force existed between charged particles. He called this force electrical force. This force was different than the gravitational force between objects with mass. The force between charged particles varied directly with the magnitude of the charges and inversely squared to the distance between the particles. For example, particles with a larger charge (either more negatively charged or positively charged) would have a greater force between them. He also noticed that this force between the charges could be either attractive (between opposite charges) or repulsive (between like charges). This is different from gravitational forces, because gravitational force can only be attractive.
Similar to the gravitational force, the electrical force follows the inverse-square law with distance. As the distance between the objects increases, the electrical force between the objects decreases. The relationship between charge, distance, and force is called Coulomb's Law.

The Coulomb Force Law states that any two charged particles (q1 and q2) with charge measured in units of Coulombs at a distance r (with distance measured in units of meters) from each other will experience a force of repulsion or attraction along the line joining them equal to:

$$F_e = k\frac{q_1 q_2}{d^2}$$

This looks a lot like the Law of Universal Gravitation, which deals with the attraction between objects with mass. It depends on the product of the two charges and obeys the inverse square law for distance.

For example, if you double the charge on one of the objects, the force will also double. If you triple the charge on one of the objects, the force will triple.

If you double the charge on one object and triple the charge on the other, the force will become six times (2 × 3 = 6) stronger. This is because the charge and the force are directly proportional.

If we double the distance, the force decreases by 1/4. If we triple the distance, the force will decrease by 1/9. This is because the distance and the force are inverse-squared proportional.

Coulomb's Law Summarized

There are two types of charge: positive and negative.

• Electrons have a negative charge.
• Protons have a positive charge.
• Magnitude of the charge is the same for electrons and protons: e=1.6×10-19

Coulomb's law is used to calculate the force between two charged particles, where k is a constant, q is the charge, and d (or r) is the distance between the charged particles.

• k has a value of approximately 8.99 Å~ 109 N·m2 / C2
The force can be attractive or repulsive depending on the charges:
• Like charges (charges with the same sign) repel.
• Charges with opposite signs attract.

Q: What do you think would happen if the distance between the charges was cut in half?

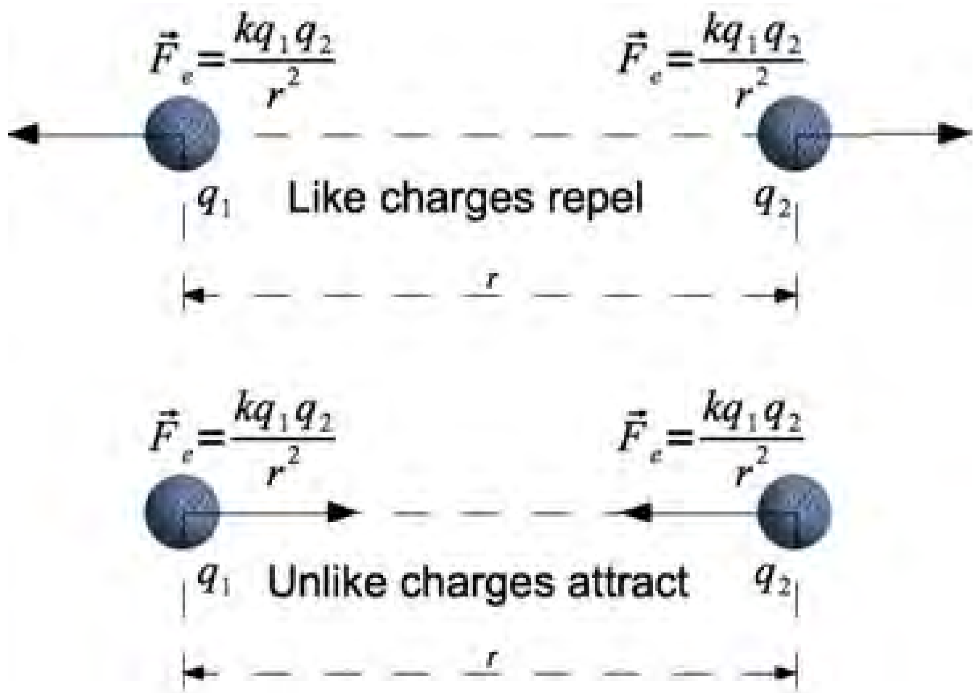
A: The inverse of 1/2 is 2/1=2. The inverse SQUARE is 22 = 4. The force would become four times stronger.

What's the difference?

The big difference is that while any two masses experience mutual attraction, two charges can either attract or repel each other, depending on whether the signs of their charges are alike:

• The sign of the force can tell you whether the two particles attract or repel.
• If the force between two charged particles is positive, then we can say the force is repulsive.
• For example, if the two charges are both positive, say +2 C and +3 C, the product of the charges will be positive.
• If the two charges are both negative, say -2 C and -3 C, the product of the charges will also be positive.

• If the force between two charged particles is negative, then we can say the force is attractive.
• For example, if one charge is positive and the other is negative, say +2 C and -3 C, the product of the charges will be negative.

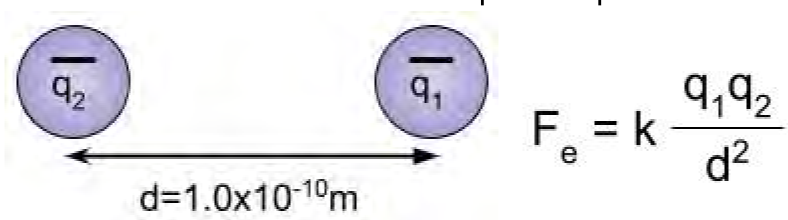


Like gravitational (and all other) forces, Coulomb forces add as vectors. Thus to find the force on a charge from an arrangement of charges, one needs to find the vector sum of the force from each charge in the arrangement.

Example 1

An electron is located 1.00Å~10-10 m to the right of another electron. What is the force on the first electron from the second electron, Fe1? What is the force on the second electron from the first electron, Fe2? What if these are protons instead?

It is useful to draw a picture just to visualize the problem. The first electron is 1.00Å~10−10 m to the right of the second electron, so the appropriate drawing is:
We want to first find the force on q1 from q2.



To solve this problem, we need to use Coulomb's Law and merely substitute in the appropriate values. The magnitude of Coulomb's law is:

We know that $k = 8.99x10^9 \frac{Nm^2}{C^2}$ and d (or r) is given in the problem as 1.00x10-10m.

The charge of an electron is e= - 1.6x10-19C. So, plugging these into the equation, we get:

$$F_e = k\frac{q_1q_2}{d^2}$$

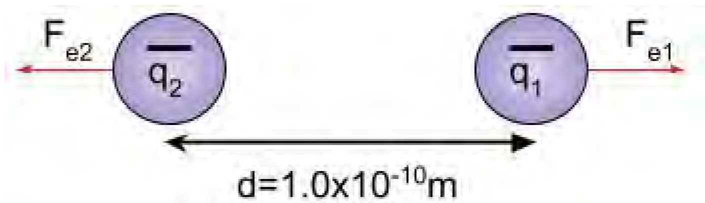
$$= 8.99x10^9 \frac{Nm^2}{C^2} \frac{(1.6x10^{-19}C)(1.6x10^{-19}C)}{(1.0x10^{-10}m)^2}$$

$$= 2.31x10^{-8} N$$

This gives us the magnitude of the force. The sign of our answer, positive, tells us that the force is repulsive. So, the force on q1 is directed away from q2, or to the right.

Finally, our answer is:

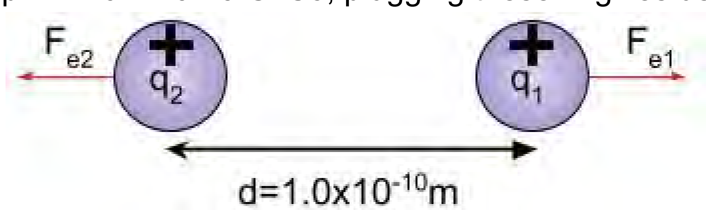
Fe1=2.31x10-8 N to the right



The force on q2 is equal and opposite (remember Newton's third law?). Therefore Fe2 = 2.31 × 10-8 N to the left.

Now consider the question, "What if these are protons instead?"

Most of the numbers are the same. The only difference is that the charge of a proton is p+ = 1.6 × 10-19 C. So, plugging these in gives us



$$F_e = k\frac{q_1 q_2}{d^2}$$

$$= 8.99\times10^9 \frac{Nm^2}{C^2}\ \frac{(1.6\times10^{-19}C)(1.6\times10^{-19}C)}{(1.0\times10^{-10}m)^2}$$

$$= 2.31\times10^{-8}\ N$$

Which is again a positive number. So the force is repulsive, and will be directed away from the other proton.

Fe1=2.31 x 10-8 N to the right
Fe2=2.31 x 10-8 N to the left

Notice that the answer is the same, although the charges are different. What are some examples of electrostatics in life?

The Van de Graaff Generator

Van de Graff Generator by Ricardo Mendonça Ferreira, https://flic.kr/p/4Ltz6v. CC-BY-NC-SA

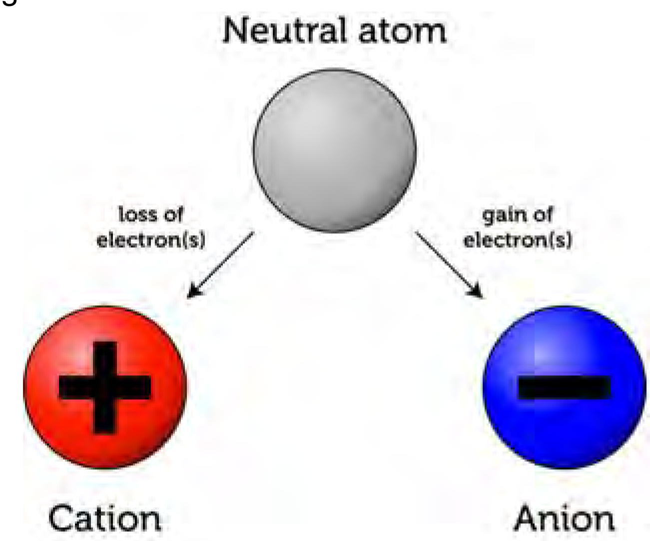
What explains this shocking photo? The man in the picture is touching a device called a Van de Graaff generator. The dome on top of the device has a negative electric charge. When the man places his hand on the dome, he becomes negatively charged as well—right down to the tip of each hair!

Q: Why is the man's hair standing on end?
A: All of the hairs have all become negatively charged, and like charges repel each other. Therefore, the hairs are pushing away from each other, causing them to stand on end.

Transferring Electrons

The man pictured above became negatively charged because electrons flowed from the Van de Graaff generator to him. Whenever electrons are transferred between objects, neutral matter becomes charged. This occurs even with individual atoms. Atoms are neutral in electric charge because they have the same number of negative electrons as positive protons. However, if atoms lose or gain electrons, they become charged particles called ions. You can see how this happens in the figure below. When an atom loses electrons, it becomes a positively charged ion. When an atom gains electrons, it becomes a negatively charged ion.

Conservation of Charge
Like the formation of ions, the formation of charged matter in general depends on the transfer of electrons, either between two materials or within a material. Three ways this can occur are referred to as conduction, polarization, and friction. All three ways are described below. However, regardless of how electrons are transferred, the total charge always remains the same. Electrons move, but they aren't destroyed. This is the law of conservation of charge.

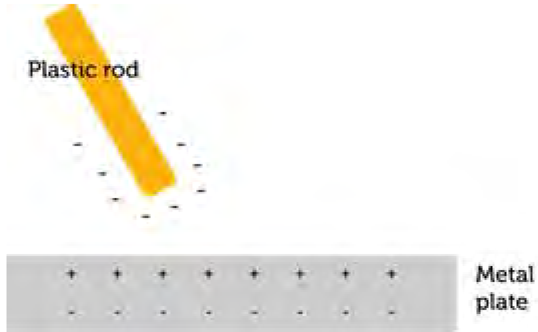


Conduction
The transfer of electrons from the Van de Graaff generator to the man is an example of conduction. Conduction occurs when there is direct contact between materials that differ in their ability to give up or accept electrons. A Van de Graaff generator produces a negative charge on its dome, so it tends to give up electrons. Human hands are 90 positively charged, so they tend to accept electrons. Therefore, electrons flow from the dome to the man's hand when they are in contact.

You don't need a Van de Graaff generator for conduction to take place. It may occur when you walk across a wool carpet in rubber-soled shoes. Wool tends to give up electrons and rubber tends to accept them. Therefore, the carpet transfers electrons to your shoes each time you put down your foot. The transfer of electrons results in you becoming negatively charged and the carpet becoming positively charged.

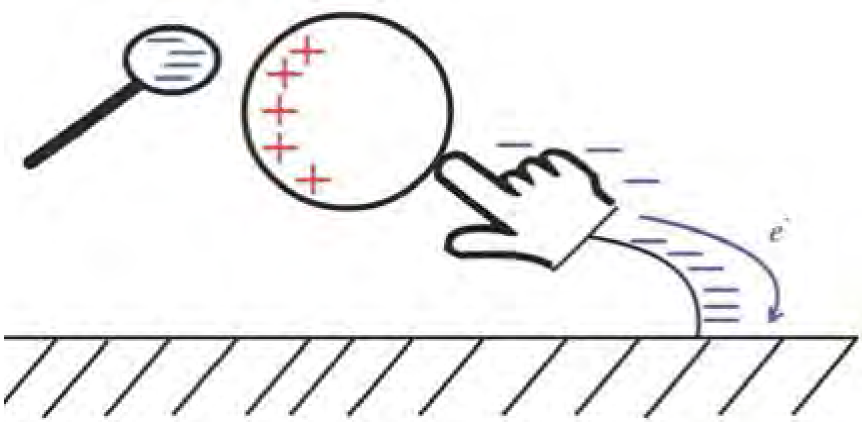
Polarization
Assume that you have walked across a wool carpet in rubber-soled shoes and become negatively charged. If you then reach out to touch a metal doorknob, electrons in the neutral metal will be repelled and move away from your hand before you even touch the knob. In this way, one end of the doorknob becomes positively charged and the other end becomes negatively charged. This is called polarization. Polarization occurs whenever electrons within a neutral object move because of the electric field of a

nearby charged object. It occurs without direct contact between the two objects. The figure models how polarization occurs.



When the negatively charged plastic rod is placed close to the neutral metal plate (above), the electrons in the plate are repelled by the positive charges in the rod. The electrons move away from the rod, causing one side of the plate to become positively charged and the other side to become negatively charged. Charging by induction is when we charge an object without touching it. There are many methods for charging objects by induction, but here is one process for charging a single object by induction.

1. First touch one finger to the neutral object to ground the object.
2. Then, bring a charged object (we'll assume it's negatively charged, but it can be either) close to the neutral object. This causes negative charges in the neutral object to be repelled through your body to the ground.
3. When the finger is removed, the neutral object will be positively charged.
When charging by induction, the originally neutral object will always end up with the opposite charge.



When charge moves, electrons are always the ones that move. Protons cannot move between atoms.

Friction

Did you ever rub an inflated balloon against your hair? Friction between the balloon an hair cause electrons from the hair to "rub off" on the balloon. That's because a balloon attracts electrons more strongly than hair does. After the transfer of electrons, the balloon becomes negatively charged and the hair becomes positively charged. The individual hairs push away from each other and stand on end because like charges repel each other. The balloon and the hair attract each other because opposite charges attract.

Electrons are transferred in this way whenever there is friction between materials that differ in their ability to give up or accept electrons.

Watch the animation “Balloons and Static Electricity” at the following URL to see how electrons are transferred by friction between a sweater and a balloon.

• http://go.uen.org/b3C

Q: If you rub a balloon against a wall, it may stick to the wall. Explain why.
A: Electrons are transferred from the wall to the balloon, making the balloon negatively charged and the wall positively charged. The balloon sticks to the wall because opposite charges attract. You’re a thoughtful visitor, so you wipe your feet on the welcome mat before you reach out to touch the brass knocker on the door. Ouch! A spark suddenly jumps between your hand and the metal, and you feel an electric shock.

Image by Zachary Wilson, CK-12 Foundation, CC BY-NC 3.0

Q: Why does electric shock occur?

A: An electric shock occurs when there is a sudden discharge of static electricity.

What Is Static Electricity?

Static electricity is a buildup of electric charges on objects. Charges build up when negative electrons are transferred from one object to another. The object that gives up electrons becomes positively charged, and the object that accepts the electrons becomes negatively charged. This can happen in several ways. One way electric charges can build up is through friction between materials that differ in their ability to give up or accept electrons. When you wipe your rubber-soled shoes on the wool mat, for example, electrons rub off the mat onto your shoes. As a result of this transfer of electrons, positive charges build up on the mat and negative charges build up on you.

Once an object becomes electrically charged, it is likely to remain charged until it touches another object or at least comes very close to another object. That’s because electric charges cannot travel easily through the air, especially if the air is dry.

Q: You’re more likely to get a shock in the winter when the air is very dry. Can you explain why?
A: When the air is very dry, electric charges are more likely to build up objects because they cannot travel easily through the dry air. This makes a shock more likely when you touch another object.

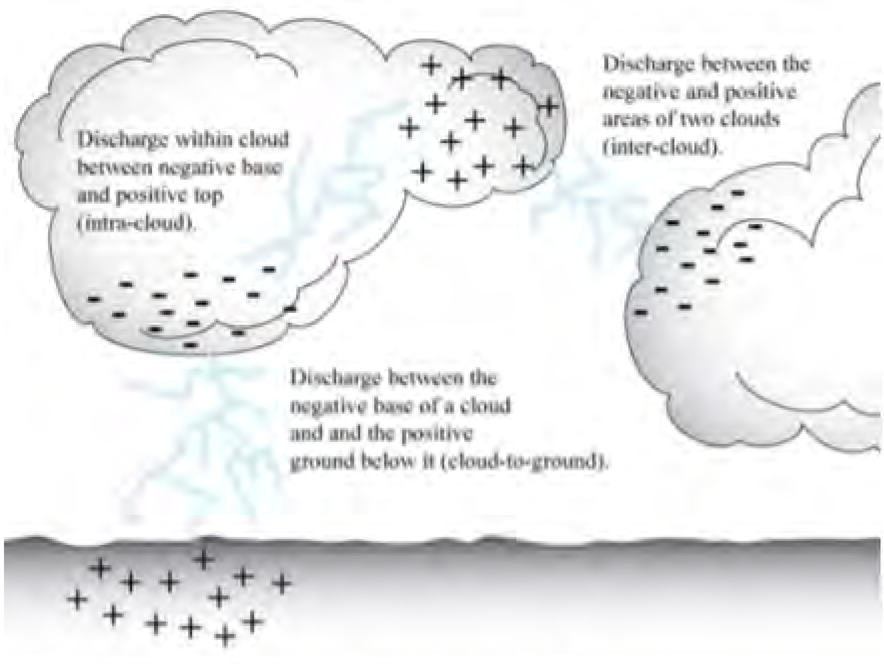
Static Discharge

What happens when you have become negatively charged and your hand approaches the metal door-knocker? Your negatively charged hand repels electrons in the metal, so the electrons move to the other side of the knocker. This makes the side of the knocker closest to your hand positively charged. As your negatively charged hand gets very close to the positively charged side of the metal, the air between your hand and the knocker also becomes electrically charged. This allows electrons to suddenly flow from your hand to the knocker. The sudden flow of electrons is static discharge. The discharge of electrons is the spark you see and the shock you feel.

Watch the animation “John Travoltage” at the following URL to see an example of static electricity and static discharge. • http://go.uen.org/b3D

How Lightning Occurs

Another example of static discharge, but on a much larger scale, is lightning. You can see how it occurs in the following diagram and animation as you read about it below.



Credit: Zachary Wilson, CK-12 Foundation, CC BY-NC 3.0

During a rainstorm, clouds develop regions of positive and negative charge due to the movement of air molecules, water drops, and ice particles. The negative charges are concentrated at the base of the clouds, and the positive charges are concentrated at the top. The negative charges repel electrons on the ground beneath them, so the ground below the clouds becomes positively charged. At first, the atmosphere prevents electrons from flowing away from areas of negative charge and toward areas of positive charge. As more charges build up, however, the air between the oppositely charged areas also becomes charged. When this happens, static electricity is discharged as bolts of lightning.

Glass Plasma Globe by Slimsdizz,
https://commons.wikimedia.org/wiki/File:Glass_plasma_globe.jpg, CC0

A plasma globe, such as the one pictured above, is filled with a mixture of noble gases and has a high-voltage electrode at the center. The swirling lines are electric discharge lines that connect from the inner electrode to the outer glass insulator. When a hand is placed on the surface of the globe, all the electric discharge travels directly to that hand.

The Electric Field

Coulomb's Law gives us the formula to calculate the force exerted on a charge by another charge. On some occasions, however, a test charge suffers an electrical force with no apparent cause. That is, as observers, we cannot see or detect the original charge creating the electrical force. Michael Faraday dealt with this problem by developing the concept of an electric field. According to Faraday, a charge creates an electric field about it in all directions. If a second charge is placed at some point in the field, the second charge interacts with the field and experiences an electrical force. Thus, the interaction we observe is between the test charge and the field and a second particle at some distance is no longer necessary.

The strength of the electric field is determined point by point and can only be identified by the presence of test charge. When a positive test charge, *qt,* is placed in an electric field, the field exerts a force on the charge. The field strength can be measured by dividing the force by the charge of the test charge. Electric field strength is given the symbol E and its unit is Newtons/coulomb. Where $E = F/q$ or Force per unit charge.

The test charge can be moved from location to location within the electric field until the entire electric field has been mapped in terms of electric field intensity.

Electric Field Strength

Example

A positive test charge of $2.0 \times 10^{-5} C$ is placed in an electric field. The force on the test charge is 0.60 N. What is the electric field intensity at the location of the test charge?

$E = F/q = 0.60 N / 2.0 \times 10^{-5} C = 3.0 \times 10^{4} N/C$

Launch the Hockey simulation below and try to use the electric field to help you score a goal: Hockey simulation

Further Reading

- Millikan Oil Drop Experiment

Summary

- An electric field surrounds every charge and acts on other charges in the vicinity.
- The strength of the electric field is given by the symbol *E*, and has the unit of Newtons/coulomb.
- The equation for electric field intensity is $E=F/q$

Review

1. The weight of a proton is $1.64 \times 10^{-26} N$.
2. The charge on a proton is $+1.60 \times 10^{-19} C$.
3. If a proton is placed in a uniform electric field so that the electric force on the proton just balances its weight, what is the magnitude and direction of the field?
4. A negative charge of $2.0 \times 10-8$ C experiences a force of 0.060 N to the right in an electric field. What is the magnitude and direction of the field?
5. A positive charge of $5.0 \times 10-4$C is in an electric field that exerts a force of $2.5 \times 10-4$N on it. What is the magnitude of the electric field at the location of the charge?
6. If you determined the electric field intensity in a field using a test charge of $1.0 \times 10-6$C and then repeated the process with a test charge of $2.0 \times 10-6$C, would the forces on the charges be the same? Would you find the value for E?
7. A 0.16 C charge and a 0.04 C charge are separated by a distance of 3.0 m. At what position between the two charges would a test charge experience an electric field intensity of zero?

Explore More

Use this resource to answer the questions that follow.

1. What does it mean when a force is called a non-contact force?
2. What symbol is used to represent electric field strength?
3. What is the relationship between the direction of the electric field and the direction of the electric force?

Putting It Together

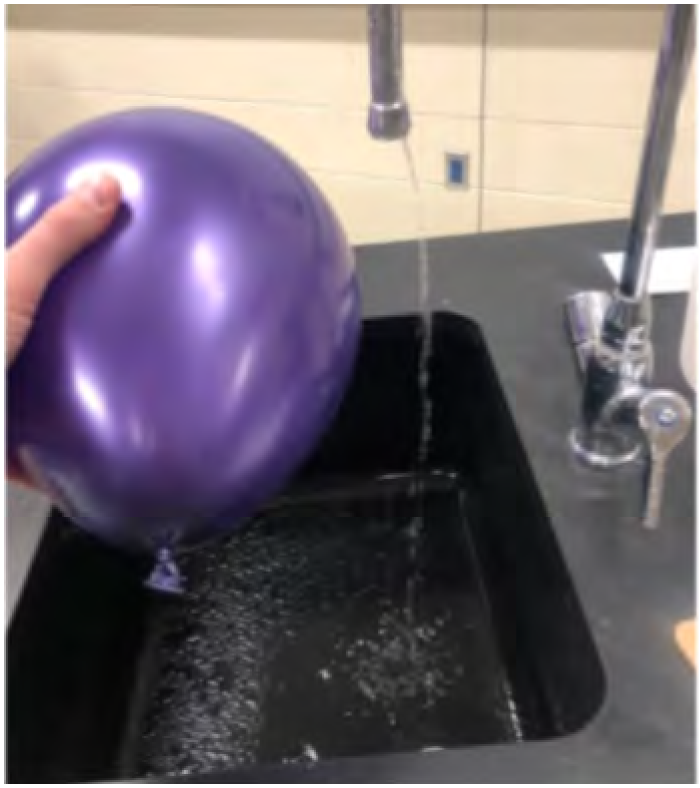


Image by Milo Maughan, CC0

Let's revisit this phenomenon:

1. Using your knowledge of gravity and electric fields, explain what causes the water to curve towards the balloon in the image above.
2. Create, draw, or find a model to help illustrate your explanation.
3. Provide an explanation for what would happen if the amount of charge of the balloon were to increase or decrease.
4. Provide an explanation for what would happen if the mass of the balloon were to increase or decrease.
5. Provide an explanation for what would happen if the distance of the balloon from the water were to increase or decrease.
6. Which fields are present in the phenomena above and what is your evidence to support your claim?

3.2 Electromagnetic Induction (PHYS.3.2)

Explore this Phenomenon

Stripped Down Motor by Exploratorium, https://www.exploratorium.edu/snacks/stripped-down-motor,

When the device is connected to a battery the copper ring (on the right above the cup) starts to spin.

1. Why does the wire ring spin when the battery is connected?

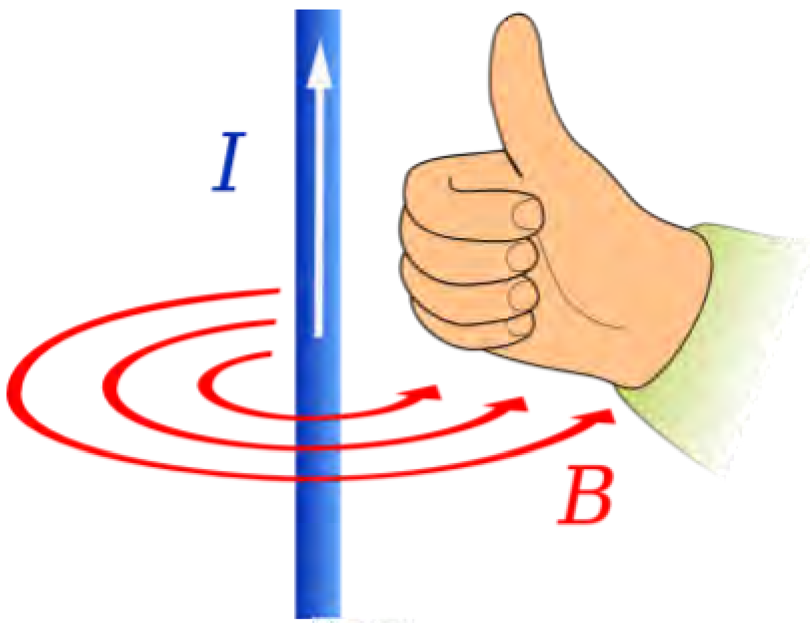
PHYS.3.2 Electromagnetic Induction

Plan and conduct an investigation to provide evidence that an electric current causes a magnetic field and that a changing magnetic field causes an electric current. Emphasize the qualitative relationship between electricity and magnetism without necessarily conducting quantitative analysis. Examples could include electromagnets or generators. (PS2.B)

In this section, see if you can identify when a magnetic field causes an electric current and when an electric current causes a magnetic field.

What Is Electromagnetism?

Electromagnetism is magnetism produced by an electric current. When electric current flows through a wire, it creates a magnetic field that surrounds the wire in circles. You can see this in the diagram below. Note that electric current is conventionally shown moving from positive to negative electric potential and the direction of the magnetic field is given by the right hand rule



Right Hand Grip Rule by Jfmelero, https://en.wikipedia.org/wiki/Magnetic_field#/media/File:Manoderecha.svg, CC-BY-SA 4.0

If more current flows through a wire, how might this affect the magnetic field surrounding the wire?

Electromagnetic Induction

Electricity and magnetism are two sides of the same coin, you cannot have one without the other as seen above. A change in one will produce a change in the other.

This is summed up nicely in Faraday's Law of Induction:

$$\varepsilon = -\frac{dB}{dt}$$

This says that the electromotive force (e.g. the voltage of a battery) produced in a wire is equal to the rate at which the magnetic field through the wire changes. How is this different from our phenomenon?

Force in a Current Carrying Wire

If we let a wire carrying a current pass through a magnetic field, a force must be experienced since we have two magnetic fields. Depending on the direction of the current, the force can either be attractive or repulsive. Since our motor has a wire ring, current flows in both directions so both attractive and repulsive forces are felt. How can you diagram these attractive and repulsive forces?

Putting It Together

Stripped Down Motor by Exploratorium,
https://www.exploratorium.edu/snacks/stripped-down-motor,

Let's revisit this phenomena:

1. Why does the wire ring spin when the battery is connected? Design simpler investigations to help support your claim

2. Is this process reversible? Provide evidence

3.3 Interacting Objects and Fields (PHYS.3.3)

Explore this Phenomenon

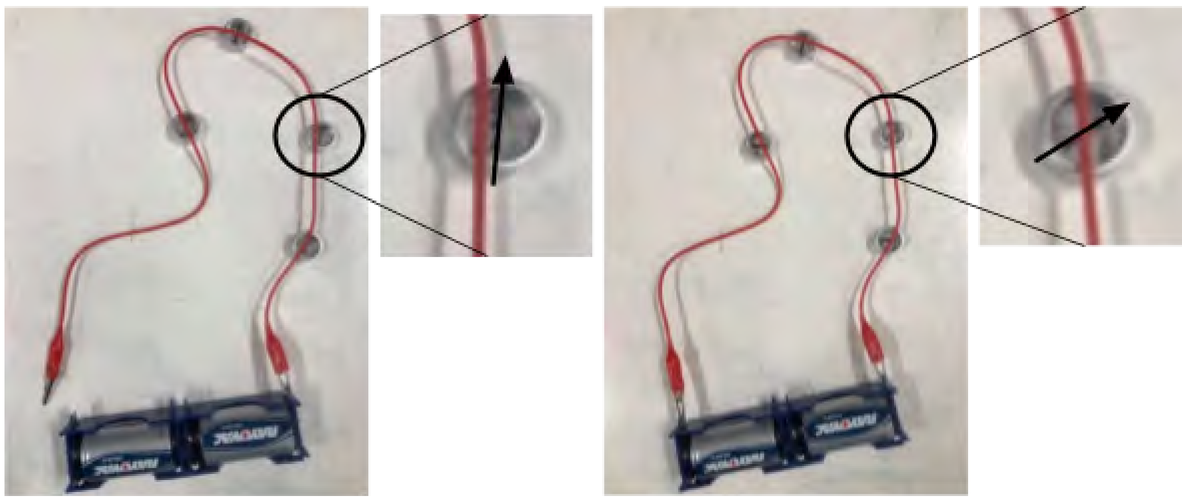


Image by Milo Maughan, CC0

When a compass is put near a wire and no current is flowing through the wire, nothing happens (picture on left). However, when a current is put through the wire, the points in a direction perpendicular to the wire (picture on right).

1. What is causing this to happen?

As you read the following section, try to identify why the needle changes when a current flows through the wire.

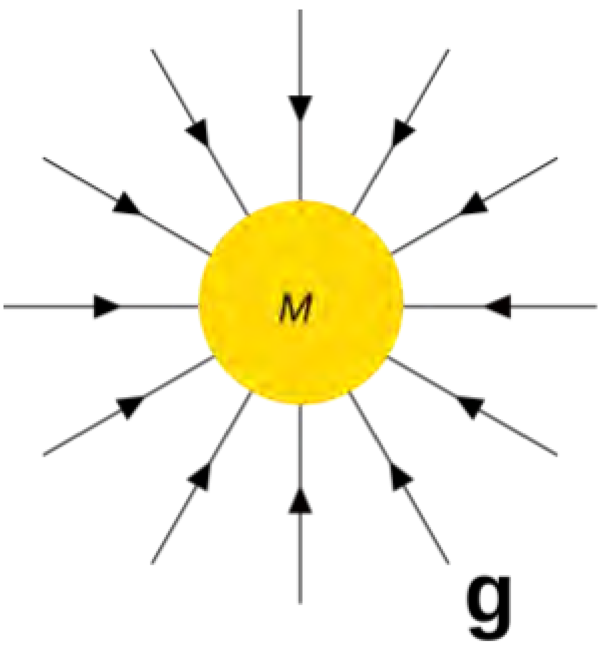
PHYS.3.3 Interacting Objects and Fields

Analyze and interpret data to compare the effect of changes in position of interacting objects on electric and gravitational forces and energy. Emphasize the similarities and differences between charged particles in electric fields and masses in gravitational fields. Examples could include models, simulations, or experiments that produce data or illustrate field lines between objects. (PS3.C)

In this chapter, see if you can identify how a change in an object's motion is caused by the presence of a field.

Interacting Objects and Fields

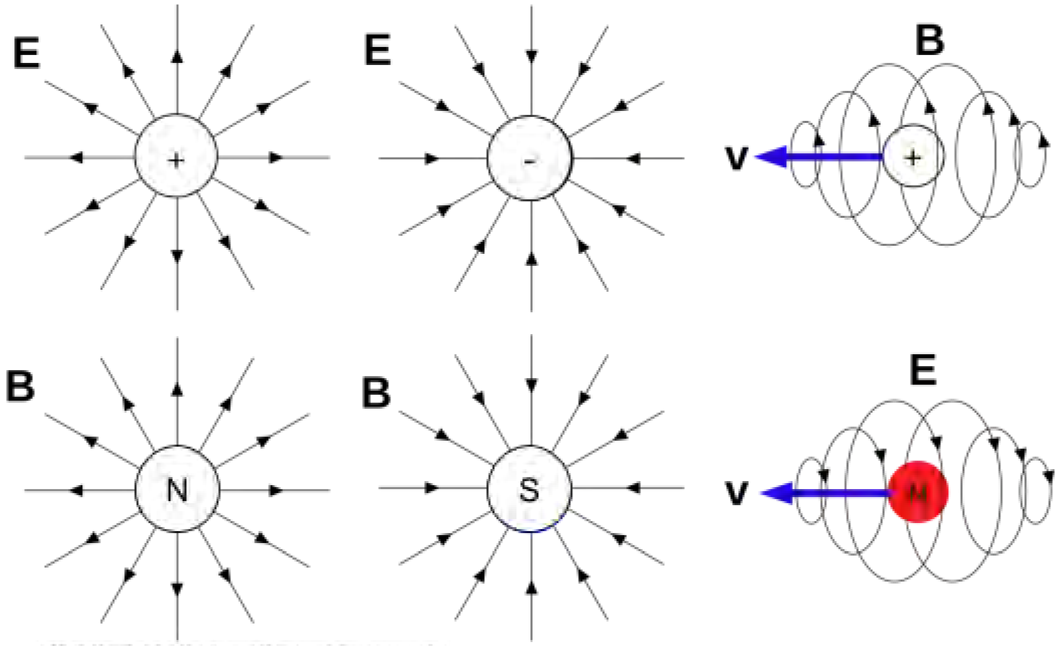
As discussed in section 3.1, two objects with mass will be attracted to each other and two objects with charge will be attracted or repelled from each other. These are interacting objects. These interactions and changes in an object's motion cause fields to emanate from an object.



Gravitation in Newton's theory by Maschen, CC0

Field, In physics, is a region in which each point is affected by a force. Objects fall to the ground because they are affected by the force of earth's gravitational field. A paperclip placed in the magnetic field surrounding a magnet, is pulled toward the magnet, and two like magnetic poles repel each other when one is placed in the other's magnetic field. An electric field surrounds an electric charge; when another charged particle is placed in that region, it experiences an electric force which either attracts or repels it.

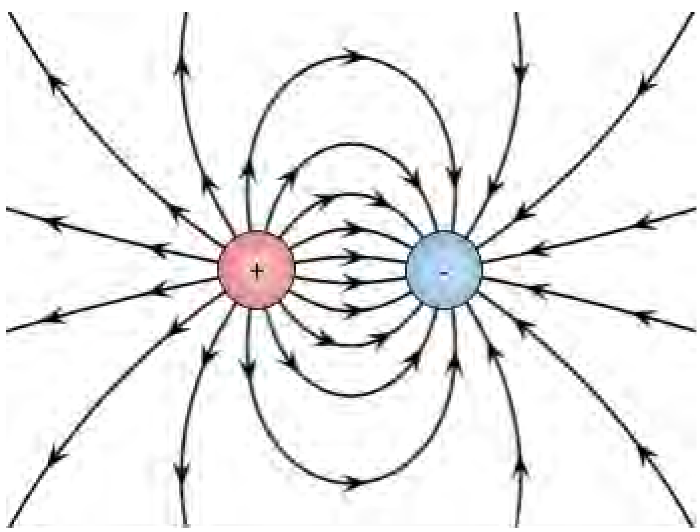
We can represent a field around an object with a series of vector lines. The diagram above represents a gravitational field around an object of mass, for example, the Earth. The strength of a field, or the forces in a particular region, can be represented by field lines; the closer the lines, the stronger the forces in that part of the field.



EM fields due to electric and magnetic monopoles by Maschen, CC0

The fields around a charged object or a magnetic object will look similar to that around an object with mass. The diagram illustrates the fields around a charged object (white/positive, black/negative) and a magnetic object (Red/North, Blue, south). However, notice that the field lines can go towards (negative, south) or away (positive, north) from our object.

Additionally, as discussed in Section 3.2, a moving charge creates a magnetic field, and a moving magnet creates an electric field. This is also illustrated on the diagram.



Adapted from "Field of a Positive and Negative Charge Point" by Geek3, https://en.wikipedia.org/wiki/Field_(physics)#/media/File:VFPt_charges_plus_minus_thumb.svg, *CC-BY-SA 3.0*

When two objects with similar fields are put in proximity to each other, the fields will interact. This interaction is illustrated in the diagram of positive and negative point charges. This interaction of fields is what produces the changes in motion. See section 3.4 for more information about field characteristics.

Putting It Together

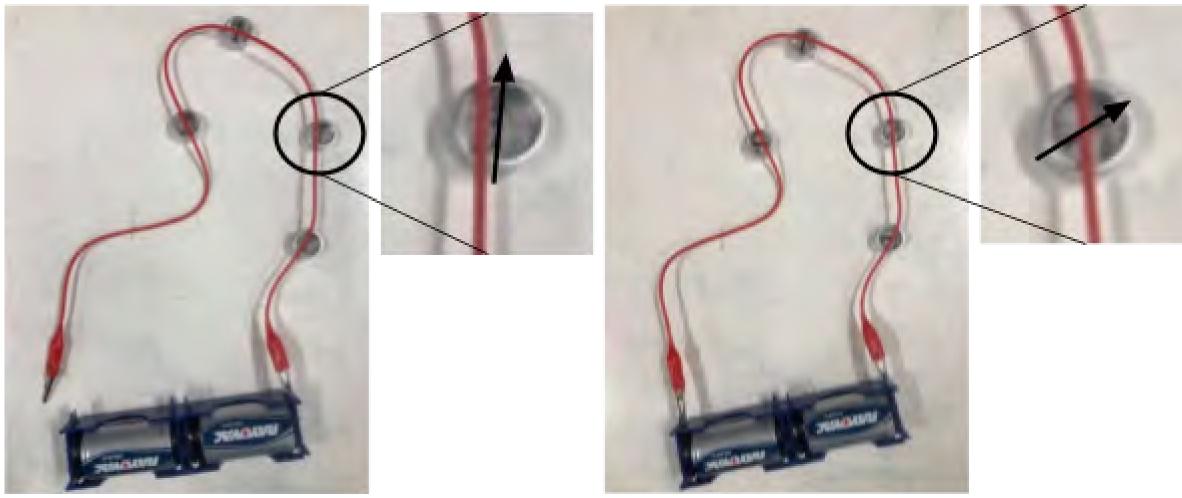


Image by Milo Maughan, CC0

Let’s revisit this phenomena

1. Using your knowledge of fields, what causes the magnetic compass to point in the direction of the wire when a current passes through the wire?

2. Create, draw, or find a model to help illustrate your explanation

3.4 Field Characteristics (PHYS.3.4)

Explore this Phenomenon

Static Electricity by Spencer Garness, https://flic.kr/p/79bDFN,

When a charged balloon is brought near pieces of paper, pieces that are close to the balloon attract and stick to the balloon. However, pieces of paper that are farther away only slightly wiggle or don't move at all.

1. What is causing this to happen?

2. As you read the following section, think of possible models you could use to show why the close pieces of paper stick to the balloon.

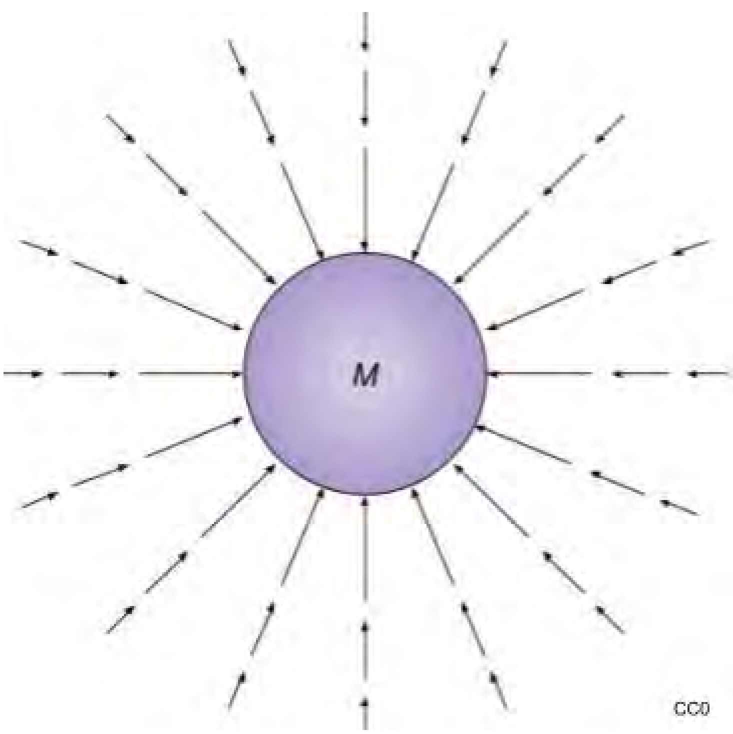
PHYS.3.4 Field Characteristics

Develop and use a model to evaluate the effects on a field as characteristics of its source and surrounding space are varied. Emphasize how a field changes with distance from its source. Examples of electric fields could include those resulting from point charges. Examples of magnetic fields could include those resulting from dipole magnets or current-bearing wires. (PS3.C)

In this chapter, see if you can identify the causes and effects in motion as the position inside of a field is changed.

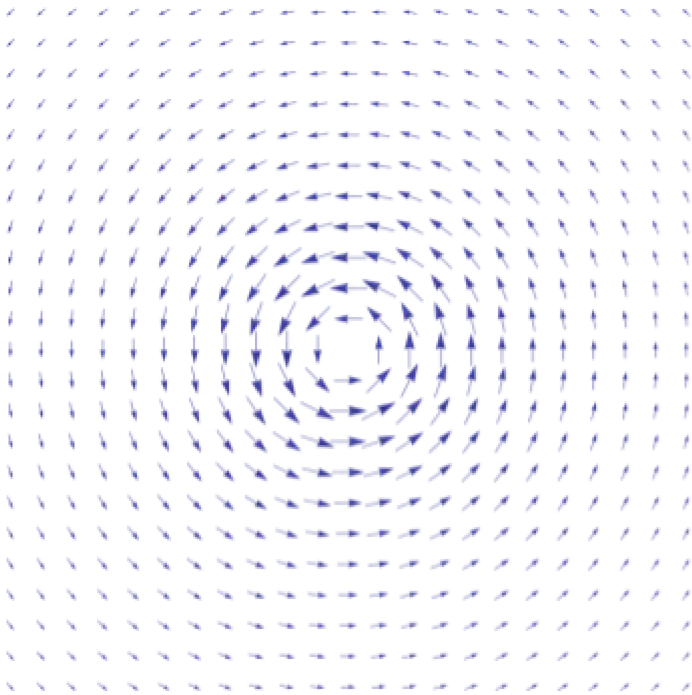
Field Characteristics

Section 3.3 introduced you to fields, this section will describe the characteristics of fields. Section 3.3 illustrated a field using continuous field lines. Alternatively, a field can be represented using a series of vectors. The diagram shows a vector field around the Earth.



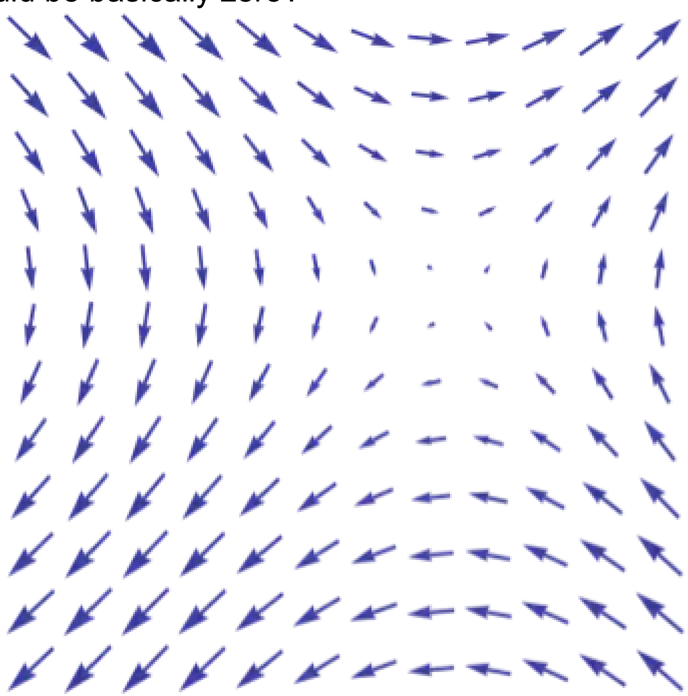
This model of a field is helpful because it shows the strength of the field at different positions. This is represented by the length of the vectors. The longer the vector, the stronger the gravitational force on the object. When looking at the diaphragm, the farther away an object is from the Earth, the weaker the gravitational force is (as indicated by shorter vectors farther away from the earth).

Any field can be represented by this type of vector diagram. The picture below illustrates a magnetic vector field around a wire carrying current.



Irrotational Field by AllenMcC, https://en.wikipedia.org/wiki/Vector_field#/media/File:Irrotationalfield.svg,

Vector fields can also be useful to show what would happen to the force in the presence of multiple interacting fields. The next diagram illustrates this idea. Can you identify where the force would be basically zero?



Vector Fields by Jim.belk,

Putting It Together

Static Electricity by Spencer Garness, https://flic.kr/p/79bDFN, CC-BY-NC-SA

Let's Revisit this phenomenon:

1. Using your knowledge about vector fields, explain why some pieces of paper attract and stick to the balloon, while others only wiggle or don't move at all.

2. Create, draw, or find a model to help illustrate your explanation.

CHAPTER 4

Strand 4: Waves

Chapter Outline

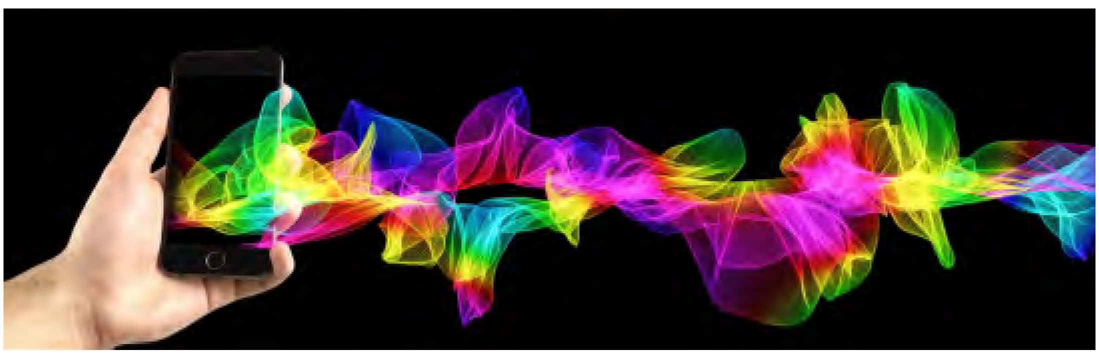


Image by Gerd Altmann (geralt), pixabay.com, CC0

Waves transfer energy through oscillations of fields or matter. The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it passes. Waves produce interference as they overlap but they emerge unaffected by each other. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. Electromagnetic radiation can be modeled as a wave of changing electric and magnetic fields or as particles called photons. When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy. Because waves depend upon the properties of fields and the predictable transformation of energy, they can be used to interpret the nature of matter and its energy. Waves are utilized to transmit information both in analog and digital forms.

4.1 Wave Speed Relationship (PHYS.4.1)

Explore this Phenomenon

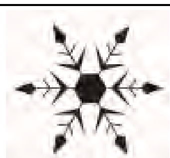
Image by sethink, pixabay.com, CC0

When lightning strikes, there is time in-between when we see the lightning and when we hear the thunder.

1. Why do we hear thunder after we see lightning?

PHYS.4.1 Wave Speed Relationship

Analyze and interpret data to derive both qualitative and quantitative relationships based on patterns observed in frequency, wavelength, and speed of waves traveling in various media. Emphasize mathematical relationships and qualitative descriptions. Examples of data could include electromagnetic radiation traveling in a vacuum or glass, sound waves traveling through air or water, or seismic waves traveling through Earth. (PS4.A)



Usually when looking for patterns we are looking at tangible objects and comparing and contrasting. For this section, look for these relationships in the mathematical models that are developed.

Image by Arek Socha (qimono), pixabay.com, CC0

No doubt you've seen this happen. Droplets of water fall into a body of water, and concentric circles spread out through the water around the droplets. The concentric circles are waves moving through the water.

What is a Mechanical Wave?

The waves in the picture above are examples of mechanical waves. A mechanical wave is a disturbance that transfers energy through matter. A mechanical wave starts when matter is disturbed. A source of energy is needed to disturb matter and start a mechanical wave. Where does the energy come from in the water wave pictured above?

The Medium

The energy of a mechanical wave can travel only through matter. The matter through which the wave travels is called the medium (plural, media). The medium in the water wave pictured above is water, a liquid. But the medium of a mechanical wave can be any state of matter, even a solid. How do the particles of the medium move when a wave passes through them?

Types of Mechanical Waves

There are three types of mechanical waves: transverse, longitudinal, and surface waves. They differ in how particles of the medium move. You can see this in the figure and in the animation at the following URL.

• http://go.uen.org/b4o

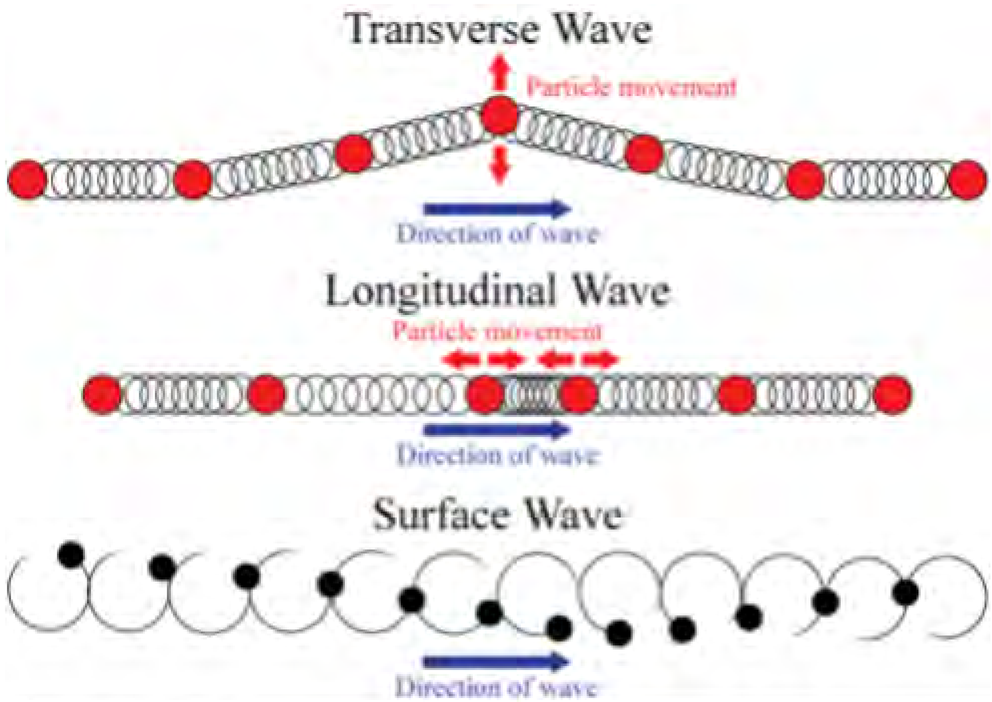


Image by CK-12 Foundation, CC-BY-NC-SA 3.0

In a transverse wave, particles of the medium vibrate up and down perpendicular to the direction of the wave.

- In a longitudinal wave, particles of the medium vibrate back and forth parallel to the direction of the wave.
- In a surface wave, particles of the medium vibrate both up and down and back and forth, so they end up moving in a circle. Think of this as a combination of transverse and longitudinal wave

What Is a Transverse Wave?

A transverse wave is a wave in which particles of the medium move at right angles, or perpendicular, to the direction that the wave travels. Another example of a transverse wave is the wave that passes through a rope with you shake it up and down, as in the figure. The direction of the wave is down the length of the rope away from the hand.

The rope itself moves up and down as the wave passes through it.

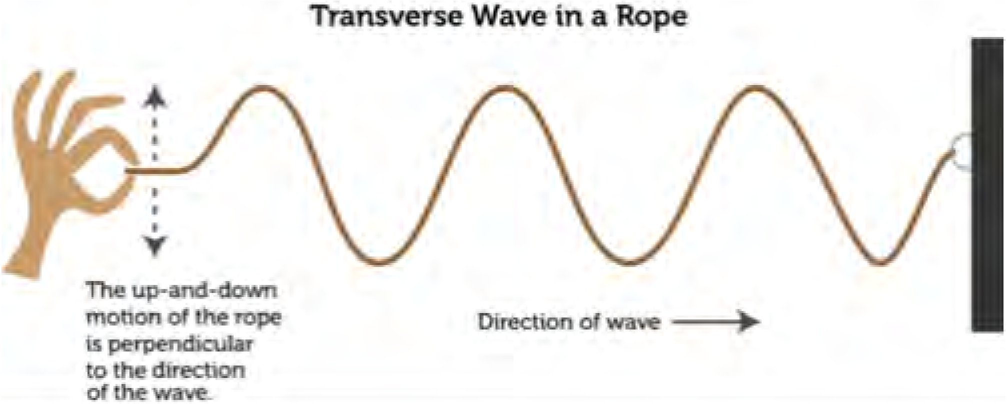


Image by Christopher Auyeung;Zachary Wilson, CK-12 Foundation, CC BY-NC 3.0

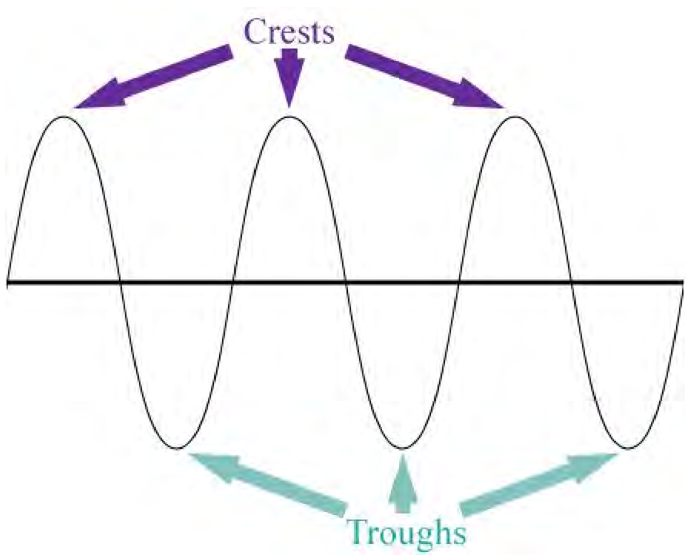
You can watch a video of a transverse wave in a rope at this URL:http://go.uen.org/b3T

To see a transverse wave in slow motion, go to this URL:http://go.uen.org/b3U

When a guitar string is plucked, in what direction does the wave travel? In what direction does the string vibrate?

Crests and Troughs

A transverse wave is characterized by the high and low points reached by particles of the medium as the wave passes through. The high points are called crests, and the low points are called troughs. You can see both in the figure.



What Is a Longitudinal Wave?

A longitudinal wave is a type of mechanical wave. A mechanical wave is a wave that travels through matter, (referred to as a medium, such as air or water). In a longitudinal wave, particles of the medium transfer kinetic energy through collisions in a direction that is parallel to the direction that the wave travels. You can see this in the figure. The person's hand pushes and pulls on one end of the spring. The energy of this disturbance passes through the coils of the spring to the other end.

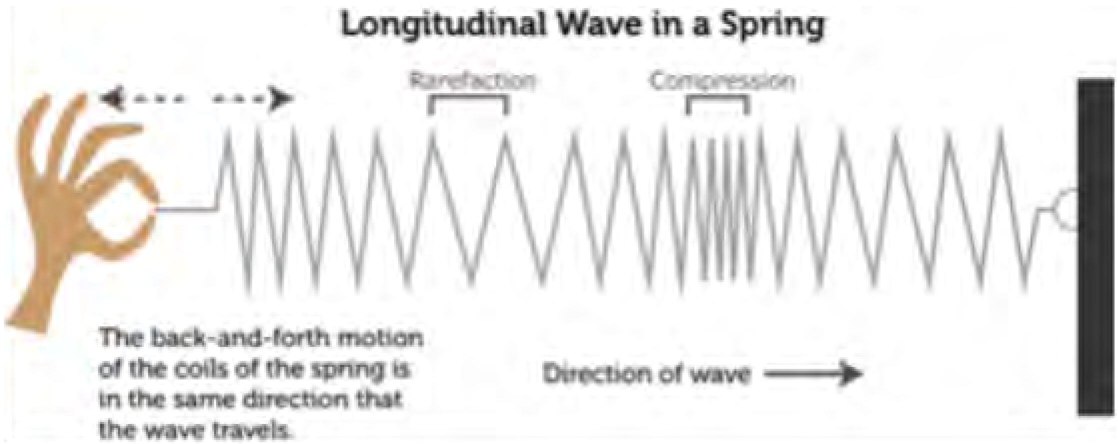


Image by Christopher Auyeung;Zachary Wilson, CK-12 Foundation, CC BY-NC 3.0

You can see a video of a longitudinal wave in a spring at this URL:
https://youtu.be/ubRlaCCQfDk

Wavelength

Wavelength is one way of measuring the size of waves. It is the distance between two corresponding points on adjacent waves, and it is usually measured in meters. How it is measured is a little different for transverse and longitudinal waves. In a transverse wave, particles of the medium move up and down at right angles to the direction that the wave travels. The wavelength of a transverse wave can be measured as the distance between two adjacent crests, or high points, as shown in the diagram.

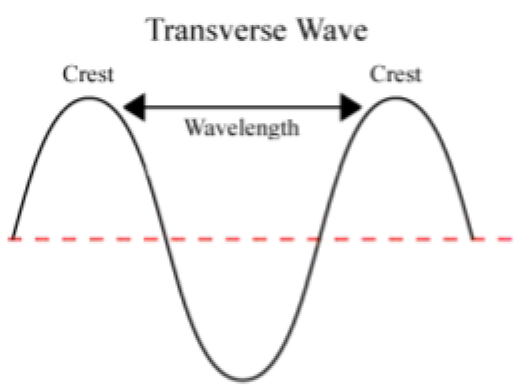
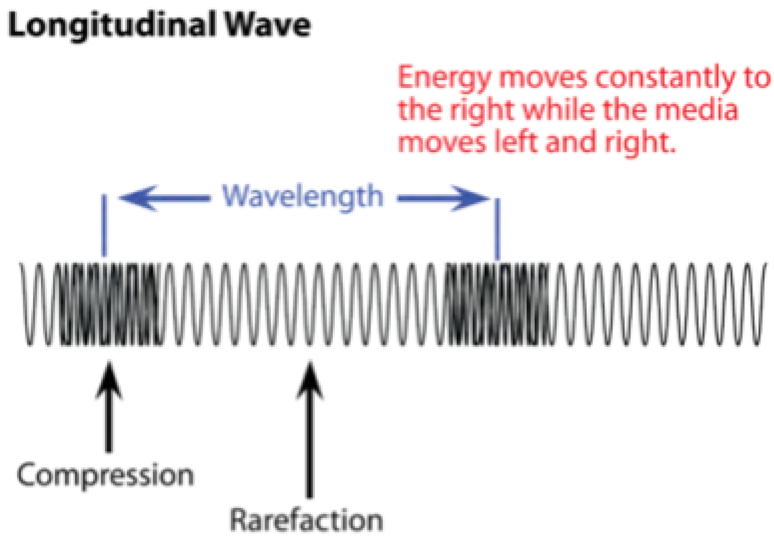
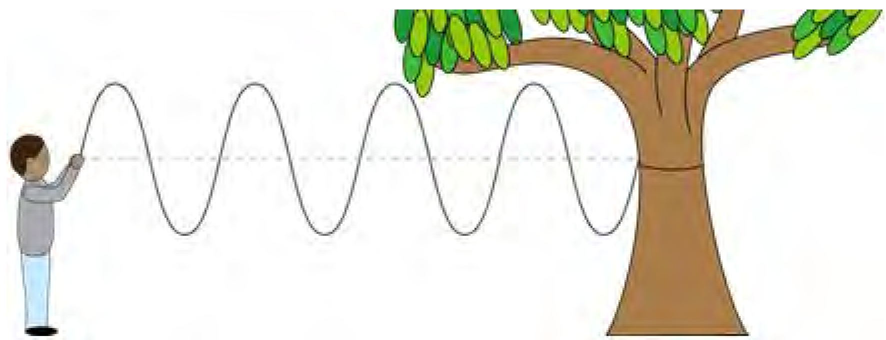


Image by Christopher Auyeung;Zachary Wilson, CK-12 Foundation, CC BY-NC 3.0

In a longitudinal wave, particles of matter move back and forth in the same direction that the wave travels. The wavelength of a longitudinal wave can be measured as the distance between two adjacent compressions, as shown in the diagram. Compressions are the places where particles of the medium crowd close together as the energy of the wave passes through.



At the following URL, watch the animation to see examples of wavelength. Also, get a feel for wavelength by playing with the wave generator. http://go.uen.org/b4p



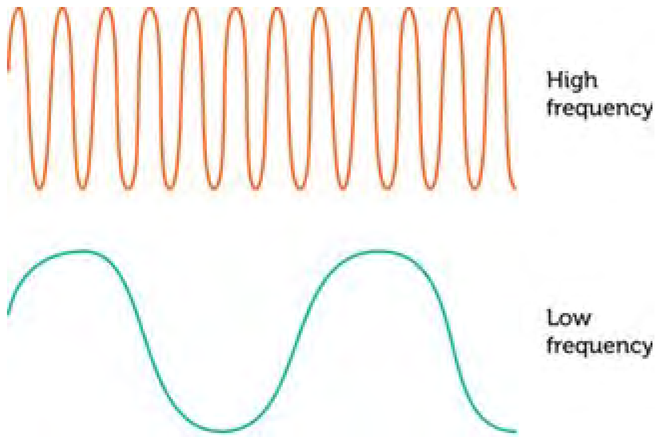
Imagine making transverse waves in a rope, like the person in the sketch above. You tie one end of the rope to a tree or other fixed point, and then you shake the other end of the rope up and down with your hand. You can move the rope up and down slowly or quickly. How quickly you move the rope determines the frequency of the waves. You can make a longitudinal wave by moving a slinky back and forth in the same direction as illustrated in the previous diagram.

Period

The period, commonly represented by the symbol T, is the amount of time for the harmonic motion to repeat itself, or for the object to go one full cycle. The period of a wave is the time it takes the object to return to its exact starting point and starting direction. The period of a wave depends on the period of oscillation of the object creating the wave.

Frequency

The number of waves that pass a fixed point in a given amount of time is wave frequency. Wave frequency can be measured by counting the number of wavelengths of waves that pass a fixed point in 1 second or some other time period. The higher the number is, the greater the frequency of the waves. The SI unit for wave frequency is the hertz (Hz), where 1 hertz equals 1 wave cycle passing a fixed point in 1 second. The figure below shows high-frequency and low-frequency transverse waves.



The higher frequency also has the shortest wavelength.

You can simulate transverse waves with different frequencies at this URL:

- http://go.uen.org/b3V

How are speed, wavelength, and frequency related?

Assume that you move one end of a rope up and down just once to generate a wave in the rope. How long will it take the wave to travel down the rope to the other end? It depends on the length of the rope and the speed of the wave.

The Speed of a Wave

To mathematically model the speed of a wave we make the assumption that the wave speed will remain constant. This allows us to use the simple relationship between distance travelled, speed, and time

$$v = \frac{d}{t}$$

We want to express the wave speed in terms of wave measurements, specifically wavelength and frequency.

First we should set a time limit for the motion to occur, let's allow one period of time to pass. How far will the wave travel in one period of time?

$$v = \frac{\lambda}{T}$$

where λ represents the wavelength measured in meters

By using the reciprocal relationship between period and frequency, we arrive at the wave speed equation

$$v = \lambda f$$

At the following URL, you can see what happens to the wavelength when the frequency of a wave increases. http://go.uen.org/b3X.

How are wavelength and frequency related? What would have to happen to the wavelength of a wave if it travels at the same speed, but has a decrease in frequency?

How are electromagnetic waves made?

Electromagnetic waves are waves that are created by vibrating charges in an electromagnetic field. Like other waves, electromagnetic waves transfer energy from one place to another. The transfer of energy by electromagnetic waves is called electromagnetic radiation. Electromagnetic waves can transfer energy through matter or across empty space.

You can see animations of electromagnetic waves at these URLs:

- http://go.uen.org/b46

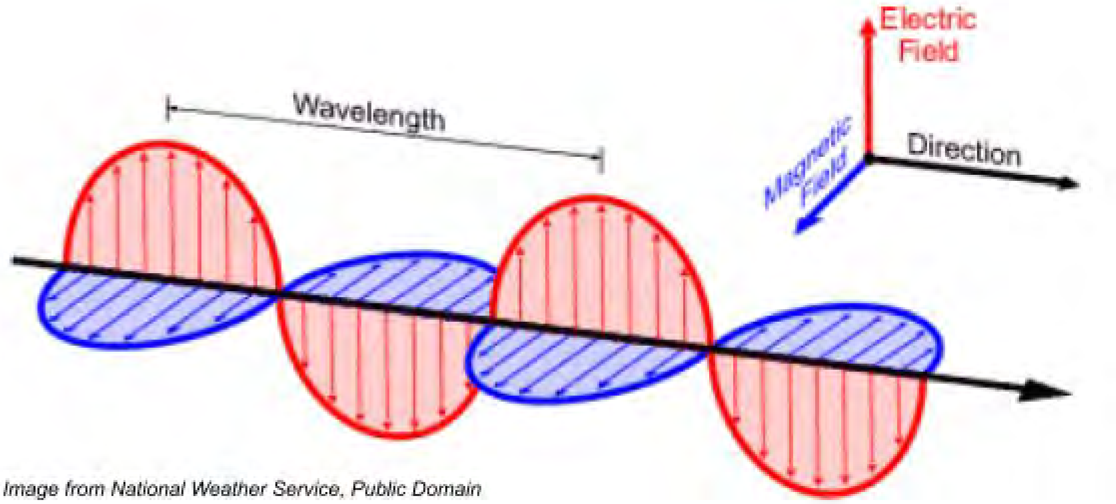


Image from National Weather Service, Public Domain

How an Electromagnetic Wave Travels

As you can see in the diagram, the electric and magnetic fields that make up an electromagnetic wave are perpendicular (at right angles) to each other. Both fields are also perpendicular to the direction that the wave travels. Therefore, an electromagnetic wave is a transverse wave. However, unlike a mechanical transverse wave, which can only travel through matter, an electromagnetic transverse wave can travel through empty space since it travels through this EM field. When waves travel through matter, they lose some energy to the matter as they pass through it. But when electromagnetic waves travel through space, no energy is lost. Therefore, electromagnetic waves don't get weaker as they travel. However, the energy is "diluted" as it travels farther from its source because it spreads

out over an ever-larger area.

How fast do EM waves travel?

The term "electromagnetic radiation" is a fancy term for light. What we know as light is only a small portion of all possible light. Birds, for example, can see in the ultraviolet region and humans glow in infrared. Older TV remotes that have the light bulb on the end transmit information through a blinking IR bulb. You can see this through your smart phone, provided it is not Apple. Why wouldn't an Apple device show this?

Speed of Electromagnetic Waves

All electromagnetic waves travel at the same speed through empty space. That speed, called the speed of light, is about 300 million meters per second (3.0x108 m/s) and is denoted with the letter c. No matter what frame of reference you select, this is the speed you measure. It is the main idea behind the special theory of relativity. Our wave speed model can then be specified for light as

$$c = \lambda f$$

Putting It Together

Image by sethink, pixabay.com, CC0

Let’s revisit this phenomena:

1. How can you use a lightning strike and the wave speed model to determine how far away it occurred?

2. What data would you need to collect to help refine your result?

4.2 Particle-Wave Duality (PHYS.4.2

Explore this Phenomenon

Image by author, CC0

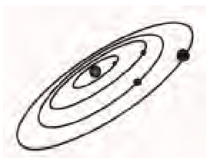
Underneath trees, there are lots of circular light spots, even though the gaps in the tree above is not circular. Some spots are brighter than others.

1. What is causing this to happen?

As you read the following section, think of possible reasons why the light spots under a tree are all circular.

PHYS.4.2 Particle-Wave Duality

Engage in argument based on evidence that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model better explains interactions within a system than the other. Emphasize how the experimental evidence supports the claim and how models and explanations are modified in light of new evidence. Examples could include resonance, interference, diffraction, or the photoelectric effect. (PS4.A, PS4.B)

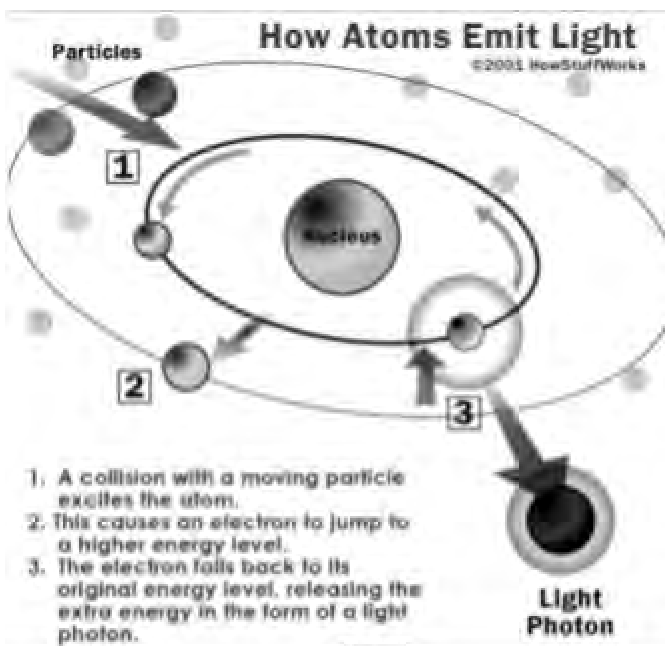


In this chapter, see if you can identify if the characteristics of light discussed supports whether the system of a light behaves like a wave or like a particle.

What is Light?

Have you ever wondered what light is? What is it made of? As mentioned in section 4.1, visible light is only a small portion of a much larger spectrum, the electromagnetic spectrum.

Electromagnetic waves are waves that consist of vibrating electric and magnetic fields. Like other waves, electromagnetic waves transfer energy from one place to another. The transfer of energy by electromagnetic waves is called electromagnetic radiation. Electromagnetic waves can transfer energy through matter or across empty space.



Adapted from *Fluorescent-lamp-atom* by NFejza, https://commons.wikimedia.org/wiki/File:Fluorescent-lamp-atom.gif, CC-BY-SA

How an Electromagnetic Wave Begins

An electromagnetic wave begins when an electrically charged particle vibrates (see diagram). A vibrating charged particle causes the electric field surrounding it to vibrate as well. A vibrating electric field, in turn, creates a vibrating magnetic field. The two types of vibrating fields combine to create an electromagnetic wave.

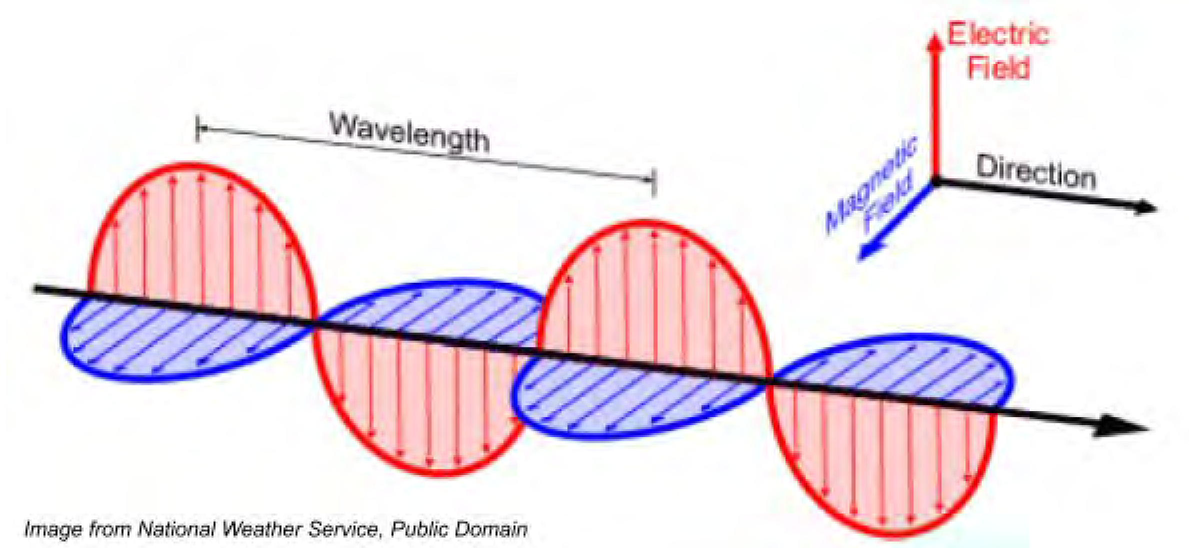


Image from National Weather Service, Public Domain

How an Electromagnetic Wave Travels

As you can see in the diagram, the electric and magnetic fields that make up an electromagnetic wave are perpendicular (at right angles) to each other. Both fields are also perpendicular to the direction that the wave travels. Therefore, an electromagnetic wave is a transverse wave. However, unlike a mechanical transverse wave, which can only travel through matter, an electromagnetic transverse wave can travel through empty space. When waves travel through matter, they lose some energy to the matter as they pass through it. But when electromagnetic waves travel through space, no energy is lost. Therefore, electromagnetic waves don't get weaker as they travel. However, the energy is "diluted" as it travels farther from its source because it spreads out over an ever-larger area.

How fast do EM waves travel?

Image by Thomas Tangelder, pixabay.com, CC0

Image by rawpixel, pixabay.com, CC0

What do these two photos have in common? They both represent electromagnetic waves. These are waves that consist of vibrating electric and magnetic fields. They transmit energy through matter or across space. Some electromagnetic waves are generally harmless. The light we use to see is a good example. Other electromagnetic waves can be very harmful and care must be taken to avoid too much exposure to them. X rays are a familiar example. Why do electromagnetic waves vary in these ways? It depends on their properties. Like other waves, electromagnetic waves have properties of speed, wavelength, and frequency.

Speed of Electromagnetic Waves

All electromagnetic waves travel at the same speed through empty space. That speed, called the speed of light, is about 300 million meters per second (3.0×10^8 m/s). Nothing else in the universe is known to travel this fast. The sun is about 150 million kilometers (93 million miles) from Earth, but it takes electromagnetic radiation only 8 minutes to reach Earth from the sun. If you could move that fast, you would be able to travel around Earth 7.5 times in just 1 second!

Section 4.1 discussed the wave speed equation where, $|v| = \lambda f$. Therefore, if either wavelength or frequency is known, the missing value can be calculated since we always know the speed of the wave. Consider an electromagnetic wave that has a wavelength of 3 meters. Its speed, like the speed of all electromagnetic waves, is 3.0×10^8 meters per second. Its frequency can be found by substituting these values into the frequency equation:

$$f = \frac{|v|}{\lambda}$$

$$f = \frac{3 \times 10^8 \text{ m/s}}{3\text{m}} = 1 \times 10^8 \text{ Hz}$$

Sometimes the speed of electromagnetic waves is represented by c.

$c = \lambda f$ wave equation for light

$c = 3 \times 10^8 \ m/s$ the speed of light in a vacuum

What is the EM spectrum?

Electromagnetic (EM) waves are classified by their frequency and wavelength. EM waves with a high frequency also have a short wavelength. EM waves with a low frequency have a long wavelength. Energy is directly related to the frequency of a wave. The higher the frequency, the more energy the wave has. Radio waves have a very low frequency and therefore a low energy. Gamma rays have a high frequency and high energy.

Visible light (the part of the EM spectrum that we see) is a very small portion of the EM spectrum. Red has the lowest frequency and the longest wavelength of the light that humans can see. Violet light has the highest frequency of visible light. EM waves that have a slightly lower frequency than red are called infrared waves. EM waves with a slightly higher frequency than violet light are called ultraviolet waves.

The spectrum of electromagnetic radiation can be roughly broken into the following ranges:

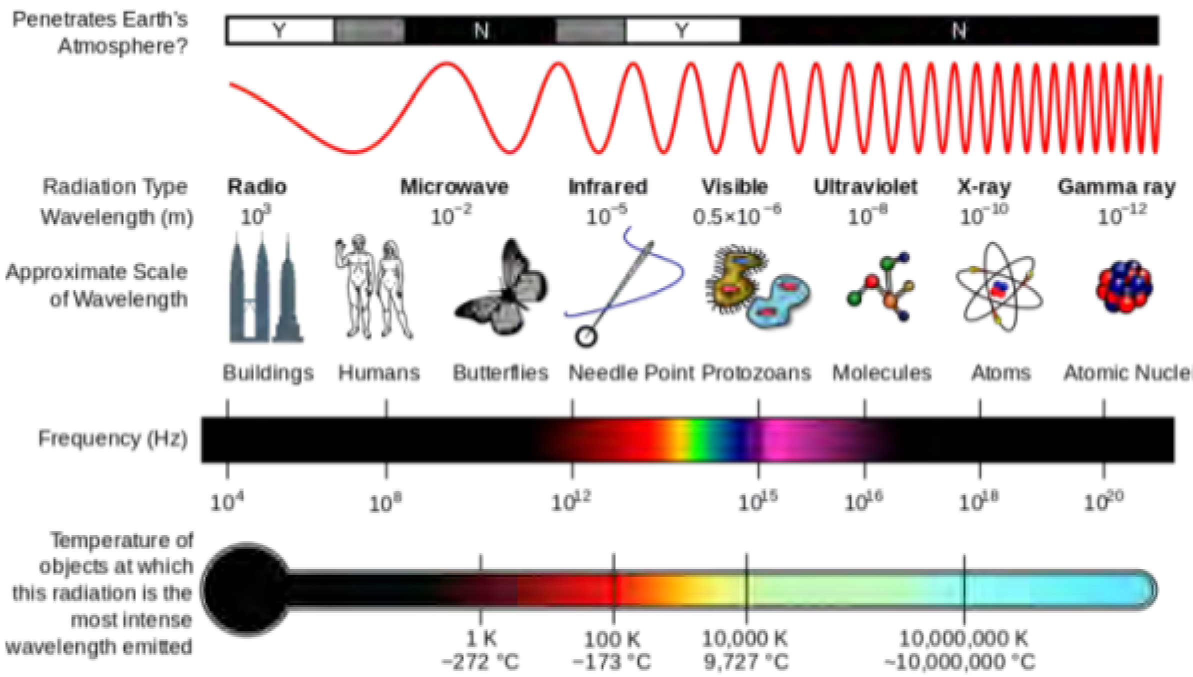


Photo: By Inductiveload, NASA – self-made, information by NASABased off of File:EM Spectrum3-new.jpg by NASAThe butterfly icon is from the P icon set, File:P biology.svgThe humans are from the Pioneer plaque, File:Human.svgThe buildings are the Petronas towers and the Empire State Buildings, both from File:Skyscrapercompare.svg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2974242

In the table below, the parts of the EM spectrum are classified by their wavelengths.

EM wave	Wavelength range	Comparison size
gamma-ray (γ - ray)	10^{-11} m and shorter	atomic nucleus
x – ray	10^{-11} m−10^{-8} m	hydrogen atom
ultraviolet (UV)	10^{-8} m−10^{-7} m	small molecule
violet (visible)	~4×10^{-7} m(400 nm)	typical molecule
blue (visible)	~450 nm	typical molecule
green (visible)	~500 nm	typical molecule
red (visible)	~650 nm	typical molecule
infrared (IR)	10^{-6} m−1 mm	human hair
Microwave	1 mm−10 cm	human finger
Radio	Larger than 10 cm	car antenna

Electromagnetic Wave Interactions

When electromagnetic waves strike matter, they may interact with it in the same ways that mechanical waves interact with matter. Electromagnetic waves may:

- Reflect - bounce back from a surface;
- Refract - bend when entering a new medium;
- Diffract - spread out around obstacles or through openings.

Electromagnetic waves may also be absorbed by matter and converted to other forms of energy. Microwaves are a familiar example. When microwaves strike food in a microwave oven, they are absorbed and converted to thermal energy, which heats the food.

Image by macmao, pixabay.com, CC0

Reflection

An echo is an example of wave reflection. Reflection occurs when waves bounce back from a boundary that separates two different mediums. Reflection can happen with any type of waves, not just sound waves. For example, light waves can also be reflected. In fact, that's how we see most objects. Light from a light source, such as the sun or a light bulb, shines on the object and some of the light is reflected. When the reflected light enters our eyes, we can see the object.

Reflected waves have the same speed and frequency as the original waves before they were reflected because they do not change the medium. However, the direction of the reflected waves is different. When waves strike an obstacle head on, the reflected waves bounce straight back in the direction they came from. When waves strike an obstacle at any other angle, they bounce back at the same angle but in a different direction. This is illustrated in the diagram. In this diagram, waves strike a wall at an angle, called the angle of incidence. The waves are reflected at the same angle, called the angle of reflection, but in a different direction. Notice that both angles are measured relative to a line that is perpendicular to the wall. This line is called the normal line.

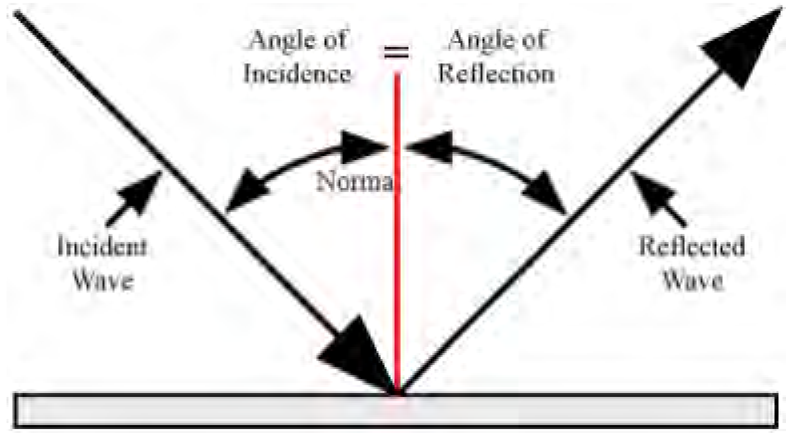


Image by CK-12 Foundation CC-BY-NC-SA 3.0

Refraction

Refraction is another way that waves interact with matter. Refraction occurs when waves bend as they enter a new medium at an angle. You can see an example of refraction in the picture. Light bends when it passes from air to water or from water to air. The bending of the light traveling from the fish to the man's eyes causes the fish to appear to be in a different place from where it actually is.

Waves bend as they enter a new medium because they start traveling at a different speed in the new medium. For example, light travels more slowly in water than in air. This causes it to refract when it passes from air to water or from water to air.

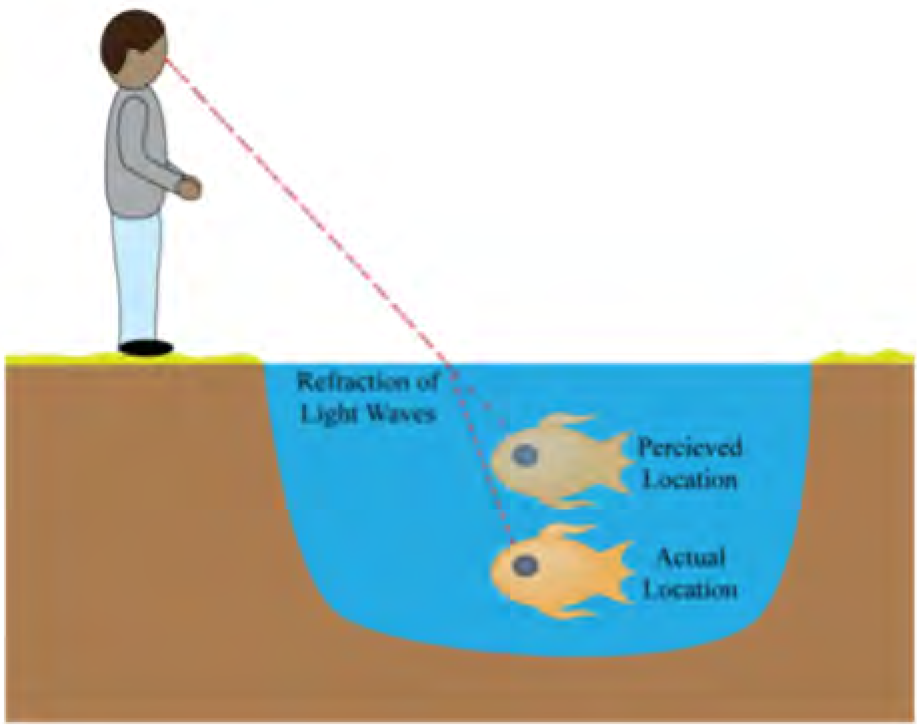


Image by CK-12 Foundation CC-BY-NC-SA 3.0

Q: Where would the fish appear to be if the man looked down at it from straight above its actual location?

A: The fish would appear to be where it actually is because refraction occurs only when waves (in this case light waves from the fish) enter a new medium at an angle other than the normal.

Diffraction

Did you ever notice that you can hear sounds around the corners of buildings even though you can't see around them? The figure shows why this happens. As you can see from the figure, sound waves spread out and travel around obstacles. This is called diffraction. It also occurs when waves pass through an opening in an obstacle. All waves may be diffracted, but it is more pronounced in some types of waves than others. For example, sound waves bend around corners much more than light does. That's why you can hear but not see around corners.

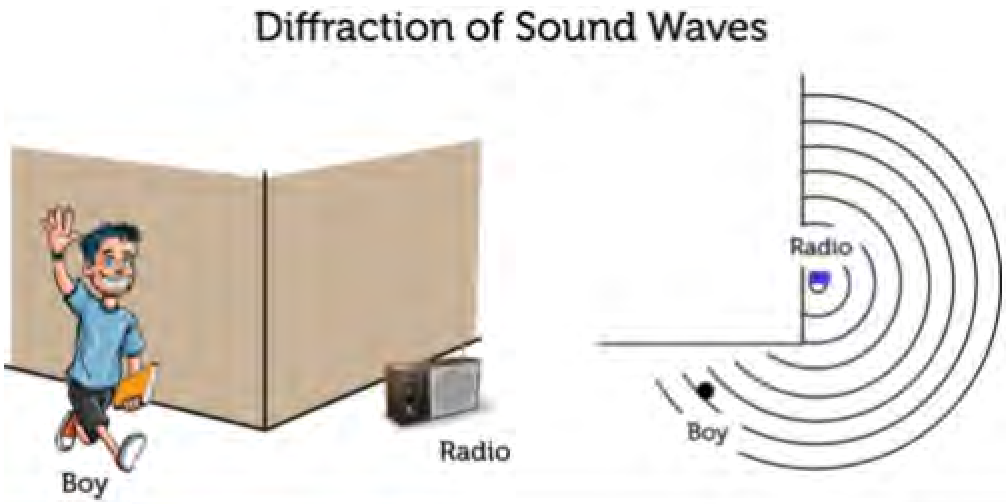
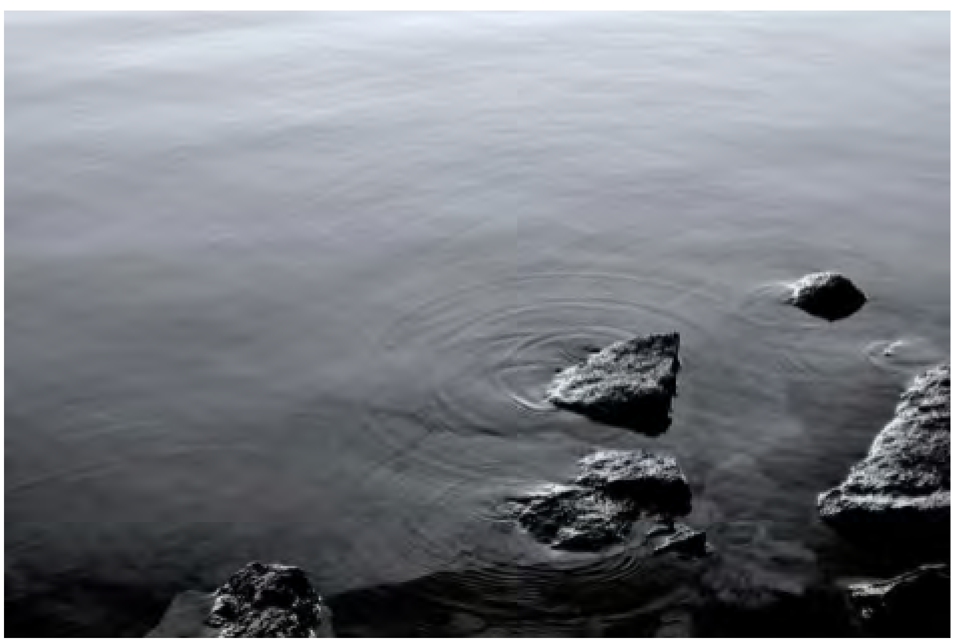


Image by ck12 Foundation, CC-BY-SA

For a given type of wave, such as sound waves, how much the waves diffract depends on the size of the obstacle (or opening in the obstacle) and the wavelength of the waves. In the figure, there is a small opening for the sound waves coming from the radio. This small opening allows a small amount of diffraction to happen and the sound can now be heard around the corner by the boy. Note that the wavelength of the wave is the distance between the vertical lines.

Diffraction and Interference



Zen Ripples by kansasphoto;Samantha Bacic, https://flic.kr/p/665E3r, CC-BY

When waves strike a small slit in a wall, they create circular wave patterns on the other side of the barrier. This is seen in the image above, where ocean waves create precise circular waves. The circular waves undergo constructive and destructive interference, which generates a regular interference pattern.

When a series of straight waves strike an impenetrable barrier, the waves stop at the barrier. However, the last particle of the medium at the back corner of the barrier will create circular waves from that point, called the point source. This can be seen in the image below. This phenomenon is called diffraction, and it occurs in liquid, sound, and light waves. While the waves become circular waves at the point source, they continue as straight waves where the barrier does not interfere with the waves.

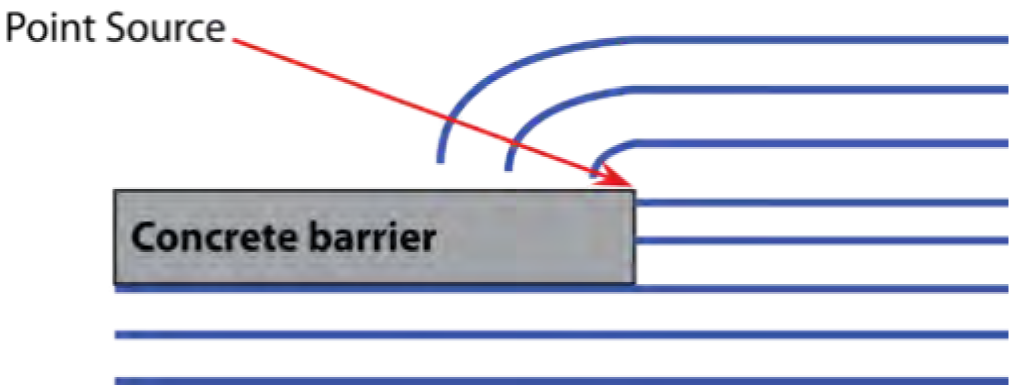


Image by CK-12 Foundation CC-BY-NC-SA 3.0

Any two waves in the same medium undergo wave interference as they pass each other. At the location where the two waves collide, the result is essentially a summation of the two waves. In some places, a wave crest from one source will overlap a wave crest from the other source. Since both waves are lifting the medium, the combined wave crest will be twice as high as the original crests. Nearby, a wave trough will overlap another wave trough and the new trough will be twice as deep as the original. This is called constructive interference because the resulting wave is larger than the original waves. Within the interference pattern, the amplitude will be twice the original amplitude. Once the waves pass through each other and are alone again, their amplitudes return to their original values.

In other parts of the wave pattern, crests from one wave will overlap troughs from another wave. When the two waves have the same amplitude, this interaction causes them to cancel each other out. Instead of a crest or trough, there is nothing. When this cancellation occurs, it is called destructive interference.

Image by Kathy Shield, CK-12 Foundation, CC BY-NC-SA

It is easy to see how waves emanating from multiple sources, such as drops of rainwater in still water, create interference patterns. But a single source of waves can create interference patterns with itself as a result of diffraction.

The Double Slit Experiment

A similar situation to the raindrops above occurs when straight waves strike a barrier containing two slits. These waves are cut off everywhere except for where the waves that pass through the two slits. The medium in the slits again acts as a point source to produce circular waves on the far side of the barrier.

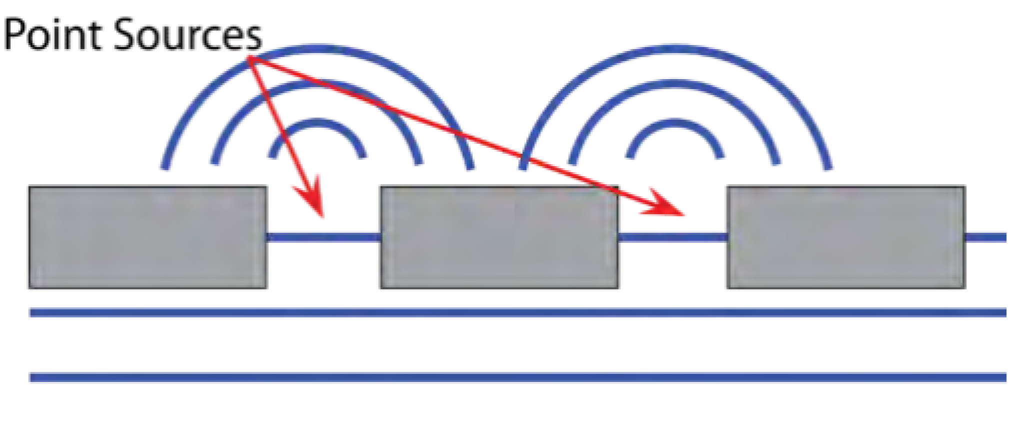


Image by CK-12 Foundation CC-BY-NC-SA 3.0

As long as these two circular waves have the same wavelength, they interfere constructively and destructively in a specific pattern. This pattern is called the wave interference pattern. The same thing is observed when using light and is characterized by light and dark bands. The light bands are a result of constructive interference, and the dark bands occur because of destructive interference.

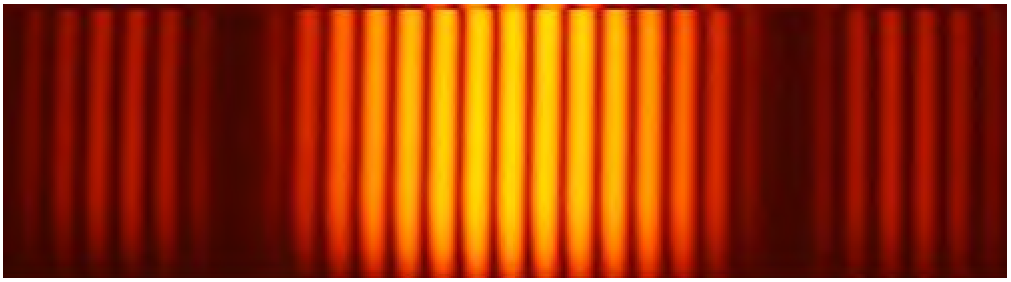


Image by Pieter Kuiper, Public Domain

In the early 1800s, light was assumed to be a particle. There was a significant amount of evidence to point to that conclusion, and famous scientist Isaac Newton's calculations all support the particle theory. In 1803, however, Thomas Young performed his famous Double Slit Experiment to prove that light was a wave. Young shined a light onto the side of a sealed box with two slits in it, creating an interference pattern on the inside of the box opposite the slits. As seen above, interference patterns are characterized by alternating bright and dark lines. The bright lines are a result of constructive interference, while the dark lines are a result of destructive interference. By creating this interference pattern, Young proved that light is a wave and changed the course of physics.

Doppler Effect

Image by Military_Material, pixabay.com, CC0

Has this ever happened to you? You hear a siren from a few blocks away. The source is a police car that is racing in your direction. As the car approaches, zooms past you, and then speeds off into the distance, the sound of its siren keeps changing in pitch. First the siren gets higher in pitch, and then it suddenly gets lower. Do you know why this happens? The answer is the Doppler Effect.

The Doppler Effect is a change in the frequency of waves that occurs when the source of the wave is moving relative to a stationary observer. (It can also occur when the source is stationary and the observer is moving.) The diagram shows how the Doppler Effect occurs.

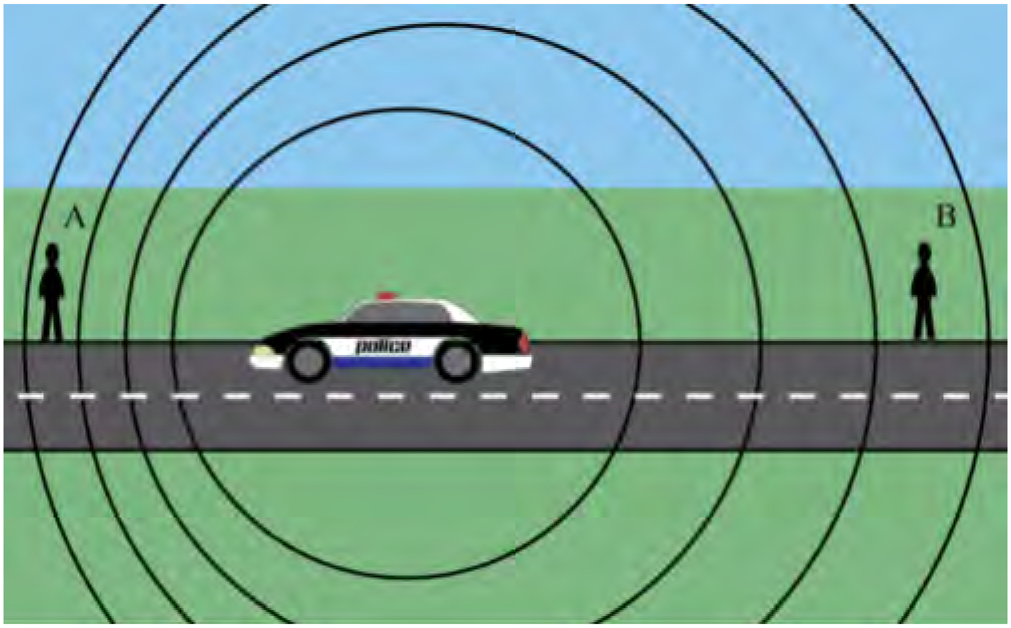


Image by CK-12 Foundation CC-BY-NC-SA 3.0

The sound waves from the police car siren travel outward in all directions. Because the car is racing forward (to the left), the sound waves get bunched up in front of the car and spread out behind it. As they propagate outward they retain their circular shape. Sound waves that are closer together have a higher frequency, and sound waves that are farther apart have a lower frequency. The frequency of sound waves, in turn, determines the pitch of the sound. Sound waves with a higher frequency produce sound with a higher pitch, and sound waves with a lower frequency produce sound with a lower pitch.

Doppler Effect and Light - Blueshift and Redshift

Blueshift and redshift is simply another way to word the Doppler Effect for EM waves. Remember that the Doppler Effect is the observed change in the frequency of a wave when objects are in relative motion. Red-shift can occur when either the Earth is moving away from a distant star (or other object) or when the star is moving away from the Earth. Using equations for the Doppler Effect, scientists can determine the relative speeds of planets, stars, galaxies, and other celestial bodies in our universe.

A blue-shift is any decrease in wavelength (increase in frequency); the opposite effect is referred to as redshift. In visible light, this shifts the color from the red end of the spectrum to the blue end. The term also applies when photons outside the visible spectrum (e.g. x-rays and radio waves) are shifted toward shorter wavelengths. In physics (especially astrophysics), red-shift happens when the original wavelength of light seen coming from an object that has a relative velocity away from us is shifted towards the red end of the spectrum.

Photoelectric Effect

In 1905, Albert Einstein (1879-1955) proposed that light be described as quanta of energy that behave as particles. A photon is a particle of electromagnetic radiation that has zero mass and carries a quantum of energy. The energy of photons of light is quantized according to the E=hv equation. For many years, light had been described using only wave concepts, and scientists trained in classical physics found this wave-particle duality of light to be a difficult idea to accept. A key experiment that was explained by Einstein using light's particle nature was called the photoelectric effect.

The photoelectric effect is a phenomenon that occurs when light shines onto a metal surface causes the ejection of electrons from that metal. It was observed that only certain frequencies of light are able to cause the ejection of electrons. If the frequency of the incident light is too low (red light, for example), then no electrons were ejected even if the intensity of the light was very high or it was shone onto the surface for a long time. If the frequency of the light was higher (green light, for example), then electrons were able to be ejected from the metal surface even if the intensity of the light was very low or it was shone for only a short time. This minimum frequency needed to cause electron ejection is referred to as the threshold frequency.

Classical physics was unable to explain the photoelectric effect. If classical physics applied to this situation, the electron in the metal could eventually collect enough energy to be ejected from the surface even if the incoming light was of low frequency. Einstein used the particle theory of light to explain the photoelectric effect as shown in Figure below.

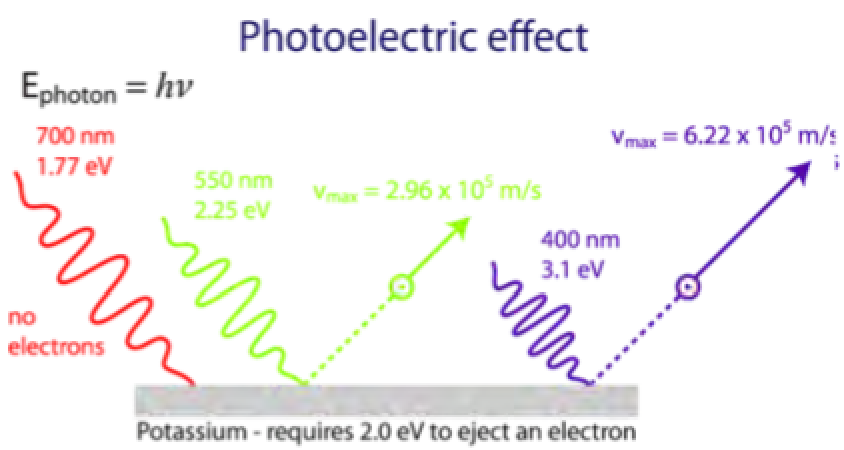


Image by CK-12 Foundation - Christopher Auyeung;Raymond Chou, CC-BY-NC-SA 3.0

Consider the E=hv equation. The E is the minimum energy that is required in order for the metal's electrons to be ejected. If the incoming light's frequency, v, is below the threshold frequency, there will never be enough energy to cause electrons to be ejected. If the frequency is equal to or higher than the threshold frequency, electrons will be ejected. As the frequency increases beyond the threshold, the ejected electrons simply move faster. An increase in the intensity of incoming light that is above the threshold frequency causes the number of electrons that are ejected to increase, but they do not travel any faster. The photoelectric effect is applied in devices called photoelectric cells, which are commonly found in everyday items such as a calculator which uses the energy of light to generate electricity.

Putting It Together

Image by author, CC0

Let’s revisit this phenomenon:

1. Using your knowledge about the characteristics of light, describe why circular light spots appear underneath trees.

2. Is this evidence to show that light behaves like a wave or that it behaves like a particle?

4.3 Biological Effects of Electromagnetic Radiation (PHYS.4.3)

Explore this Phenomenon

Image by US Department of Agriculture, public domain

The symbol above is the international Radura logo, used to show a food has been treated with ionizing radiation. Imagine you saw this logo on food at your local grocery store.

1. Would seeing this logo worry you at all?
2. Would you think that it is safe to eat the food?

As you read the following section, think about electromagnetic radiation and its effects on biological tissue.

PHYS.4.3 Biological Effects of Electromagnetic Radiation

Evaluate information about the effects that different frequencies of electromagnetic radiation have when absorbed by biological materials. Emphasize that the energy of electromagnetic radiation is directly proportional to frequency and that the potential damage to living tissue from electromagnetic radiation depends on the energy of the radiation. (PS4.B)

In this chapter, identify the causes and effects of different frequencies of electromagnetic (EM) radiation when absorbed by biological materials. As you observe the different frequencies of the EM spectrum identify the relationship between frequency and energy of the radiation. We can use cause and effect to help us predict what might happen when living organisms are exposed to electromagnetic radiation.

Effects of Radiation on living things

Image by De Wood, Pooley, USDA, ARS, EMU, Public Domain

That's in our food?

Bacterial contamination in our food often makes the news. There are many bacteria present on raw food, especially raw meat. Campylobacter (pictured above), salmonella, and other microorganisms can be found, even after cooking if the meat has not been sufficiently exposed to the heat. Ionizing radiation can be used to disrupt the DNA-RNA-protein synthesis cycle that allows the bacteria to reproduce. Cobalt-60 is a common radiation source, as is cesium-137. But, just to be safe, order that burger well-done.

Effects of Radiation

In order to better understand how cellular radiation damage occurs, we need to take a quick review of how the cell functions. DNA in the nucleus is responsible for protein synthesis and for regulation of many cellular functions. In the process of protein synthesis, DNA partially unfolds to produce messenger RNA (mRNA). The mRNA leaves the nucleus and interacts with ribosomes, transfer RNA, amino acids, and other cellular constituents in the cytoplasm. Through a complex series of reactions, proteins are produced to carry out a number of specialized processes within the organism. Anything that disturbs this flow of reactions can produce damage to the cell.

The Effects of Radiation on Living Things

Image by Clker-Free-Vector-Images, pixabay.com, CC0

You may have seen this sign before—maybe in a hospital. The sign means there is danger of radiation in the area. Radiation consists of particles and energy that are given off by radioactive isotopes, which have unstable nuclei. But you don't have to go to a hospital to be exposed to radiation. There is radiation in the world all around you.

Radiation in the Environment

A low level of radiation occurs naturally in the environment. This is called background radiation. One source of background radiation is rocks, which may contain small amounts of radioactive elements such as uranium. Another source is cosmic rays.

These are charged particles that arrive on Earth from outer space. Background radiation is generally considered to be safe for living things. You can learn more about background radiation with the animation at this URL:

- http://go.uen.org/b7u

Dangers of Radiation

Long-term or high-dose exposure to radiation can harm both living and nonliving things.

Radiation knocks electrons out of atoms and changes them to ions. It also breaks bonds in DNA and other compounds in living things. One source of radiation that is especially dangerous to people is radon. Radon is a radioactive gas that forms in rocks underground. It can seep into basements and get trapped inside buildings. Then it may build up and become harmful to people who breathe it. Long-term exposure to radon can cause lung cancer.

Exposure to higher levels of radiation can be very dangerous, even if the exposure is short-term. A single large dose of radiation can burn the skin and cause radiation sickness. Symptoms of this illness include extreme fatigue, destruction of blood cells, and loss of hair. To learn more about the harmful health effects of radiation, go to this

URL:

● http://go.uen.org/b7v

Nonliving things can also be damaged by radiation. For example, high levels of radiation can weaken metals by removing electrons. This is a problem in nuclear power plants and space vehicles because they are exposed to very high levels of radiation.

Q: Can you tell when you are being exposed to radiation? For example, can you sense radon in the air?

A: Radiation can't be detected with the senses. This adds to its danger. However, there are other ways to detect it.

Using Radiation

Despite its dangers, radioactivity has several uses. For example, it can be used to determine the ages of ancient rocks and fossils. It can also be used as a source of power to generate electricity. Radioactivity can even be used to diagnose and treat diseases, including cancer. Cancer cells grow rapidly and take up a lot of glucose for energy. Glucose containing radioactive elements can be given to patients. Cancer cells take up more glucose than normal cells do and give off radiation. The radiation can be detected with special machines like the one in the figure below. The radiation may also kill cancer cells. You can learn more about medical uses of radiation at this URL:

● http://go.uen.org/b6F

MRI by Florey Institute, https://flic.kr/p/H5msHB, CC-BY-NC-ND

This machine scans a patient's body and detects radiation.

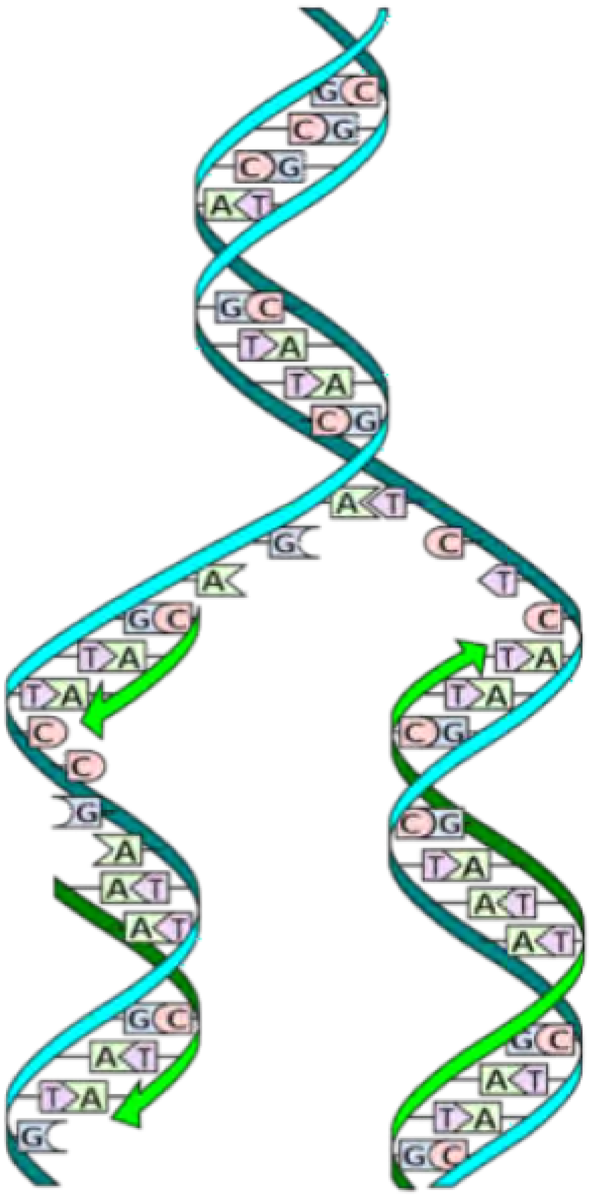
Summary

● A low level of radiation occurs naturally in the environment. This background radiation is generally assumed to be safe for living things.

● Long-term or high-dose exposure to radiation can harm living things and damage nonliving materials such as metals.

● One reason radiation is dangerous is that it generally can't be detected with the senses. It can be detected only with devices such as Geiger counters.

- Radiation has several important uses, including diagnosing and treating cancer.



DNA Replication by Madprime, https://en.wikipedia.org/wiki/DNA_replication#/media/File:DNA_replication_split.svg, CC-BY-SA

The major effect of ionizing radiation on the cell is the disruption of the DNA strand. With the DNA structure damaged, the cell cannot reproduce in its normal fashion. Protein synthesis is affected, as are a number of processes necessary for proper cell function. One common effect is the generation of cancer cells. These cells have an abnormal structure due to the damaged DNA. In addition, they usually grow rapidly since the normal control processes regulating cell growth have been changed by the altered composition of the DNA. Tissue damage is also common in people with severe exposure to radiation.

Effects of Radiation on Humans

We can see two general types of effects when humans are exposed to radiation. Low-level exposure can lead to the development of cancer. The regulatory processes regulating cell growth are disrupted, leading to uncontrolled growth of abnormal cells. Acute exposure can produce nausea, weakness, skin burns, and internal tissue damage. Cancer patients receiving radiation therapy experience these symptoms, but the radiation is targeted to a specific site in the body so that the damage is primarily to the cancer cells and the patient is able to recover from the exposure.

Effect of Radiation on Humans- video https://www.youtube.com/watch?v=ZZPZfDnJaGM&feature=youtu.be

Review

1. What is the major effect of ionizing radiation on the cell?

2. What are the acute effects of radiation damage?

3. What are long-term effects of radiation damage?

Radiation in your home calculators:
EPA calculator; EPA 2
American Nuclear Society

Putting It Together

Image by US Department of Agriculture, public domain

Let us revisit this phenomenon:

1. Using your knowledge of the electromagnetic spectrum, describe how and why radiation was used on the food it's labeling.

2. Does the irradiated food pose any danger to those who eat it? Justify your answer.

4.4 Digital Waves (PHYS.4.4)

Explore this Phenomenon

Image by Jan Vašek , pixabay.com, CC0

1. How is a cell phone able to transmit information securely?
2. How is a cell phone able to transmit information reliably?
3. How can information on a cell phone be stored securely and permanently?

PHYS.4.4 Digital Waves

Ask questions and construct an explanation about the stability of digital transmission and storage of information and their impacts on society. Emphasize the stability of digital signals and the discrete nature of information transmission. Examples of stability and instability could include that digital information can be stored in computer memory, is transferred easily, copied and shared rapidly can be easily deleted, has limited fidelity based on sampling rates, or is vulnerable to security breaches and theft. (PS4.A)

In this section, think about how we are able to take a digital signal and retain the information it contains. The stability of information is crucial in the information age.

Why go Digital?

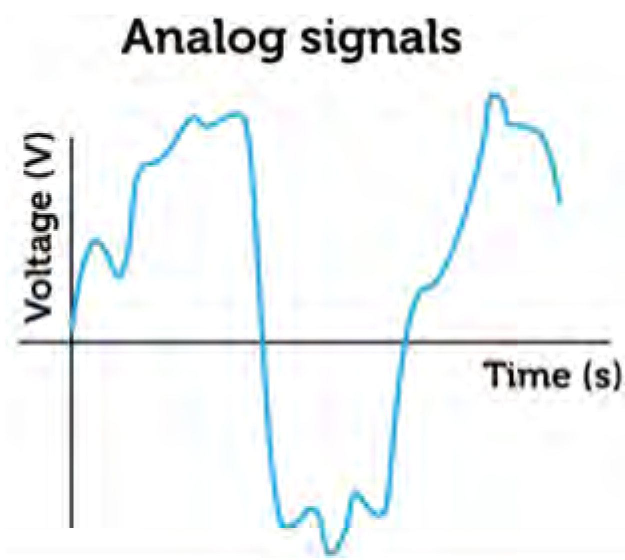


Image by Christopher Auyeung, CK-12 Foundation, CC-BY-NC 3.0

Every raw signal is called an analog signal. Just like your voice can smoothly increase and decrease in volume, an analog signal can go up and down smoothly; an analog signal is curvy. While this signal completely describes the information it is, however, susceptible to distortion. Any deformation of the signal reduces the quality of the signal and the longer the signal travels, the weaker the signal becomes.

analog TV by David Beach, https://flic.kr/p/66nezz, CC-BY

A digital signal can be completely described using nothin but a binary base (1s for voltage and 0s for no voltage). With a digital signal, the only goal is to get the signal to the end point. It will weaken as it travels, but as long as it exists the information is preserved; if it's not a 0 then it is a 1.

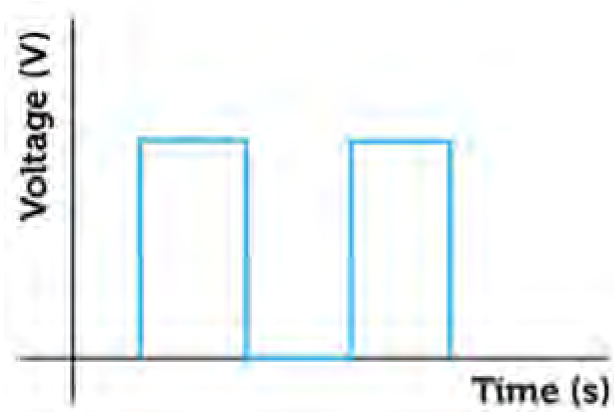
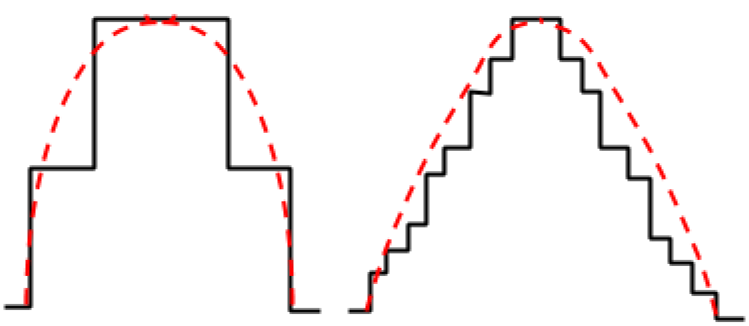


Image by Christopher Auyeung, CK-12 Foundation, CC-BY-NC 3.0

It is also more resilient to interference since 1 that has been deformed will still be interpreted as a 1. The only way a digital signal can be disrupted if the 0s and 1s get flipped or if the signal gets shut down completely. For these reasons, information that used to be transmitted by analog has switched to digital. It is a far more reliable and stable form of information transmission. Can you think of a case where analog is still preferred to digital?

How do we switch from Digital to Analog



If the bit depth is low, the signal will be inaccurately converted because it's sampled in large increments. If the bit depth is increased, you get finer increments for a more accurate representation of the signal. (Image by Author, CC0)

In order to convert an analog signal to a digital signal, we sample the signal. What you see is that the more steps we include, the closer to the true signal we get. The closer we get to this signal the higher the quality becomes. With more samples comes an increase in the number of 0s and 1s needed to describe each section. If we increase the number of 0s and 1s what property of a digital file will tend to increase as well?

Storing and Transmitting

To store this data we have developed technologies to meet ever improved quality

CD - 700 MB
DVD - 4.7 GB
Blu-Ray - 25 GB

The most recent example of this is a remake of Final Fantasy 7 which on its initial release in 1997 took 3 CDs to store its information. The remake which is scheduled to be released in 2020 will need 2 Blu-Ray discs.

Transmitting this digital information is incredibly fast over a wired connection and currently we are able to stream digital video in real time over wireless connections. Even though this is incredibly fast, it is vulnerable to interception and theft. For a YouTube video this is not an issue; it is an issue though when it comes to secure numbers such as credit cards, social security, and other sensitive information. Before a digital signal is sent, it must be encrypted. The goal is that the sender and the receiver know what the message is, but anyone in the middle will not. How can we encrypt messages before transmission? How can we protect information that is stored?

Putting It Together

Image by Jan Vašek , pixabay.com, CC0

Let's revisit the phenomena

1. How can we protect our information whether it is stored or transmitted?

2. Do we need to have the absolute highest sampling rate for our devices?

4.5 Capture and Transmission of Waves (PHYS.4.5)

Explore this Phenomenon

Public Domain

Communication towers, like what is pictured above, are found throughout our cities and on mountaintops. Radio, TV stations, and cell phones use these.

1. How are these towers used?

As you read the following section, think about how these towers are used to transmit and receive transmissions.

PHYS.4.5 Capture and Transmission of Waves

Obtain, evaluate, and communicate information about how devices use the principles of electromagnetic radiation and their interactions with matter to transmit and capture information and energy. Emphasize the ways in which devices leverage the wave-particle duality of electromagnetic radiation. Examples could include solar cells, medical imaging devices, or communication technologies. (PS4.A, PS4.B, PS4.C)

In this chapter, see if you can identify how matter is interacting with energy to allow communication between electronic devices.

Communication

Electromagnetic waves are a major way that communication occurs with today's technology. The link below is an online article describing specifically how cell phones work.

"How Do Cell Phones Work?" - Pong Pulse, Dr. Rong Wong, 20 Dec 2014
http://pongcase.com/blog/cell-phones-work/

What other articles can you find online which describes how electromagnetic waves are used in communication? During your search, be sure to find relevant academic sources and evaluate them for scientific relevance.

Putting It Together

Public Domain

Let's revisit this phenomena:

1. Using the information given in the referenced article and in your own search, describe the purpose of a communication tower.

2. Create, draw, or find a model to help illustrate your explanation.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