College Guild
PO Box 6448, Brunswick ME 04011

SCIENCE SAMPLER
~ Physics ~
Unit 2 of 5

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Part 1: Important Concepts in Physics

Before diving deeper into more sophisticated ideas in physics, it is important to understand some of the basic definitions. Sometimes, we misuse them in our everyday language, but in physics, velocity, speed, acceleration, force, and momentum have very specific meanings.

1. Pick two of these words. Assuming you are not a physicist, how would you define them? Pick another two and use each in a sentence.

Here are some basic definitions of physics terms:

Velocity is the rate at which one object changes its position with respect to time and frame of reference. Velocity is a "vector quantity", meaning that it includes direction and magnitude. Speed, on the other hand is a "scalar quantity", indicating magnitude only. In other words, speed is just the magnitude of velocity. The international System of Unit (SI) for velocity is meter per second (m/s).
Here is the formula for velocity: V = $\frac{\Delta x}{\Delta t}$ where V stands for velocity, Δx stands for change in position and Δt stands for change in time. [Note: Δ (or delta) is the Greek symbol for change.]

2. A car travels east a distance of 100 meters in 5 seconds. What is the car's velocity? What is the car's speed?

In physics, **acceleration** is the rate at which one object changes its velocity—how quickly or slowly it is changing its velocity. The formula for acceleration is: a = $\Delta v/\Delta t$ where "a" stands for acceleration, Δv stands for change in velocity and Δt stands for change in time. The SI unit for acceleration is meter per second squared (m/s^2).

3. If a car is traveling at a constant velocity (meaning no change in velocity), what is the car's acceleration?

4. A car is traveling at a constant speed, but then it changes just its direction. It moves from east to southeast with the same speed it had moving forward. Did the car accelerate? Why or why not?

5. Give an example in our everyday language where we misuse any of the above terms.

Force is an interaction that can change the motion of an object. It is a vector quantity, including magnitude and direction. Force is expressed in Newtons (N). In nature, there are four types of forces (based on their strength, from strongest to weakest):

- *Strong force*, holding protons and neutrons together in an atom's nucleus
- *Electromagnetic force*, occurring between electrically charged objects or particles such as protons and electrons
- *Weak Force*, responsible for radioactive decay
- *Gravitational force*, responsible for sea tides, motion of the planets, and even keeping you on Earth's surface

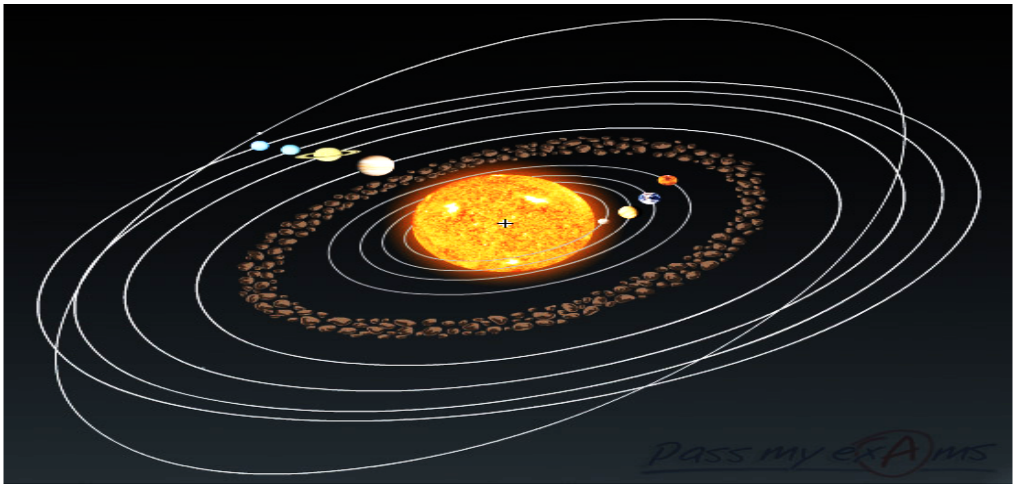
6. When a child is "forced" to do his homework, which physics force would represent his parents? Why did you pick that one?

Momentum is equal to mass times velocity. It is represented by the letter "p" and measured in kilograms times meters per second (kg x m/s). It is a vector quantity, including both direction and magnitude.

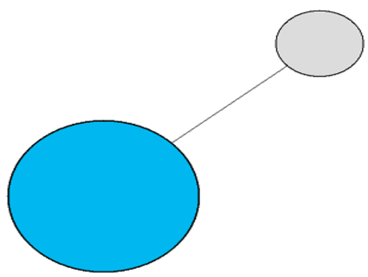
7. Imagine a truck and a bike moving with the same velocity. Which one has the largest momentum? Why?

Part 2: Gravitational Force

In Unit 1, we talked about the origin of the universe: how particles got together to form stars and planets. Now, the question is: What is keeping a planet in its orbit around a star? Look at the picture below [1] :



Each planet goes around the Sun. It looks like there is an "invisible rope" (like the picture below [2]) that is connecting the sun to the planets.



There is a legend that the great physicist Sir Isaac Newton (1643-1727) was sitting under an apple tree, and suddenly an apple fell down. Newton started asking himself what caused the apple to fall [3].

8. Give another example of a legend. Do you believe it or not? Explain why.

Newton realized that the same force that causes an apple to fall down is the same force that causes a planet to orbit the Sun. Newton called this force **Gravity**. Traditionally, we think of gravity as the force that holds us down on Earth and causes objects to fall down.

More specifically, gravity is the attraction between objects, or "gravitational force." Gravitational force is related to the mass of the objects and the distance between them. Below is the formula for Newton's universal law of gravity.

$$F = G\left(\frac{m_1 m_2}{r^2}\right)$$

$$F = gravitational\ force\ between\ two\ objects$$
$$m_1 = mass\ of\ first\ object\ in\ kilograms$$
$$m_2 = mass\ of\ second\ object\ in\ kilograms$$
$$r = distance\ between\ objects$$
$$G = Gravitational\ constant$$

Note: G is an empirical constant sometimes referred to as the "Big G." Its value is: 6.674×10^{-11} N × m^2/kg^2 (so small!). Mathematically speaking, it is a constant of proportionality.

Newton's equation tells us that the heavier an object is, the stronger the gravitational force. Also, the gravitational attraction between two objects decreases as the distance between the two objects increases. Take yourself as an example. You are standing on top of the Earth's surface. Because both you and the planet Earth have mass, you are both pulling each other. But because Earth is more massive than you, Earth's gravitational pull on you is much stronger than your gravitational pull on the earth.

9. Give three examples of how someone might feel the gravitational pull of Earth.

It is amazing that the same force that keeps you on Earth is also the force that keeps the planets in their orbits, and the same force that allowed matter to get together to form stars in the early universe!

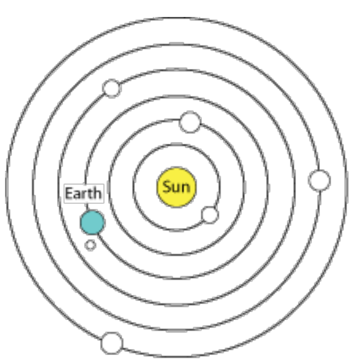
There is more to the theory of gravity, which was later explained by another great physicist, Albert Einstein. Newton's theory of gravity is incomplete because it does not explain how and why gravity works the way it does. As of today, Einstein's theory of gravity, General Relativity, is the most complete version or explanation for the gravitational force between masses.

Part 3: Kepler's Laws

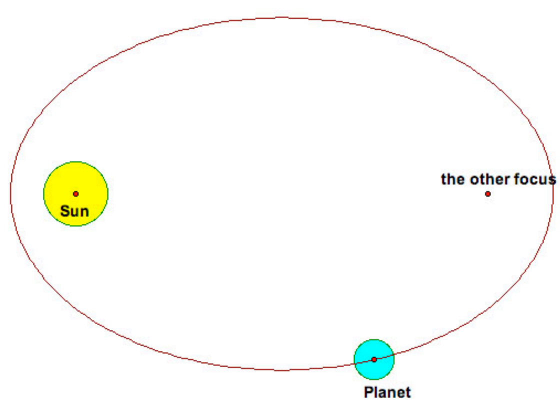
So far, we have seen how gravity keeps the planets in their orbits, but now we will look at the laws that describe the motions of the planets. There are three laws describing the planets' motion, which were discovered by an astronomer named Johannes Kepler (1571-1630).

Kepler's First Law

Before Kepler, a great astronomer named Nicolaus Copernicus (1473-1543) thought that the planets orbited the Sun in a circle. But after studying Copernicus's ideas and his observations, Kepler realized that the planets' orbits are not circular, but elliptical. So, Kepler's first law of planetary motion states: "*The orbit of each planet is an ellipse with the Sun located at one focus and nothing but empty space at the other focus.*"



Copernicas' model [4]



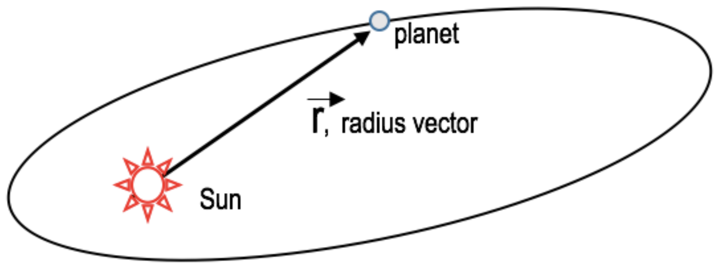
Kepler's model [5]

The picture on the left shows a circular orbit, while that on the right an elliptical orbit.

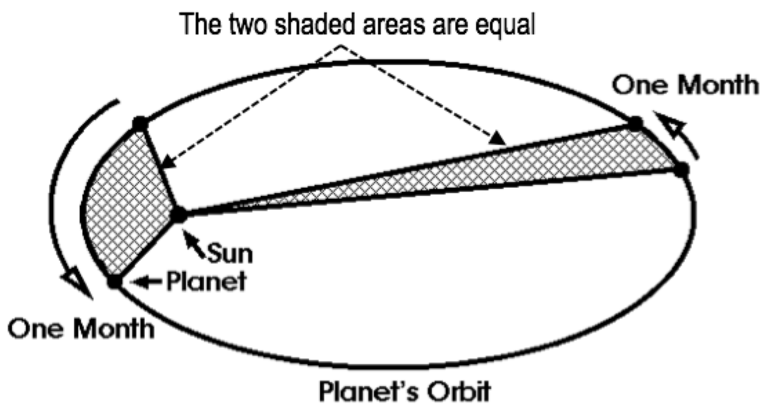
10. Looking at these orbits, how would you define an ellipse?

Kepler's Second Law

The second law deals with how fast the planets move in their orbits. It is noticeable that when Earth (or any other planet) is closest to the Sun, it moves faster than when it is farthest from the Sun. Kepler's second law requires us to imagine a line connecting the planet with the Sun. Look at the picture below:



Now, imagine you are a photographer tracking the movement of the Earth in respect to the Sun. Take a picture when the Earth is farthest from the sun, wait for one month, and then take another. Now do the same thing when Earth is closest to the sun. Your pictures would prove that the following drawing is accurate [6].



The second law states, "*The area swept out by a planet in the same amount of time is always the same, regardless of the location of the planet in its orbit.*" (In other words, the two shaded areas in the previous diagram are the same.)

11. Going back to the formula for gravitational law, explain why the planets move faster when they are close to the Sun.

Kepler's Third Law

Kepler's third law, sometime referred to as the law of harmonies, describes the time that it takes a planet to orbit the Sun. It takes longer for a planet that is farther away from the Sun to complete its orbit than for a planet that is closer to the Sun. For instance, it takes Mercury less time to complete its orbit in comparison to our planet Earth. The law states the following: "*The ratio of the squares of the periods of any two planets is equal to the ratio of the cubes of their average distances from the sun.*" Below is the formula:

$$P^2 = a^3$$

P stands for the period (time) it takes the planet to complete an orbit around the Sun; *a* stands for the average distance from the planet to the Sun.

12. The usual definition of "harmony" has nothing to do with equations! Think of the reason (or make up a reason) why Kepler's Third Law is referred to as the law of harmonies.

Part 4: Newton's Three Laws of Motion

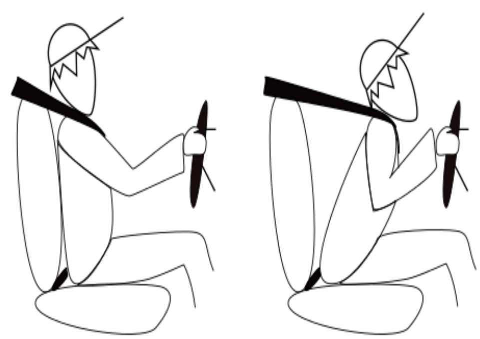
Sir Isaac Newton also studied three fundamental laws of nature – the three laws of motion. You can see Newton's laws of motion in everyday life.

Newton's First Law

Newton's first law of motion states: "*In the absence of external interactions, an object's center of mass moves at a constant velocity*." In other words, Newton concluded that an object at rest stays at rest, and an object in motion stays in motion until an external force acts on the object.

Take an example: When you kick a ball, that ball will keep rolling, but eventually it will stop. But didn't Newton say that when an object is in motion it should stay in motion? Based on Newton's first law, the ball should never stop, right? Remember, though, that Newton also said "…*unless an external force acts on the object*." Here, there is an external force acting on the ball. The ball stops due to **friction** (or frictional force) between the ball and the ground. A frictional force is a contact force between two objects. For instance, when you rub your hands together for a few seconds, your hands become warm. There is a frictional force caused by the contact between your hands. So, when that ball is rolling on the ground, the frictional force "*causes*" the ball's velocity to decrease, eventually causing the ball to stop. If there were no friction or any other external force, then the ball would keep moving forever.

Another example of Newton's first law can be seen when driving a car. When the brake is suddenly pressed to stop the car, the person in the car moves forward [7].



The body will keep moving forward in a straight line because the car and body were in motion, but when the car stops, the body continues in motion because that was its initial state.

13. Using Newton's first law of motion, explain to a child why he should wear a seatbelt.

Newton's Second Law

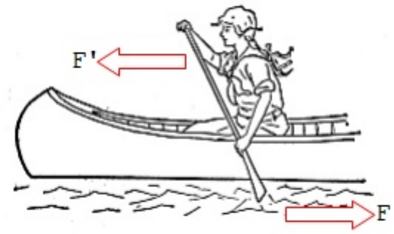
Newton's second law of motion states that the acceleration of an object caused by an <u>external force</u> is equal to the force divided by the object's mass. Here is the equation: **F = m × a**, where "F" is equal to force, "m" is equal to mass, and "a" is equal to the acceleration.

Imagine two situations, one in which you are pushing a car, and other in which you are pushing a bike. Imagine you push both the bike and the car with the same amount of force.

14. Which will move faster, the car or the bike? Explain based on Newton's Second Law.

Newton's Third Law

Newton's third law of motion is sometime referred to as the "action-reaction" law. It states the following: "*When two objects interact, the force of interaction between the two objects is equal in magnitude and opposite in direction*." In general, for every action, there is an equal and opposite reaction. One of the classical examples can be seen when paddling a canoe [8].



15. When you push backwards with the paddle, what happens to the canoe? Explain using Newton's Third Law.

16. Think of another example that explains this action-reaction law.

Part 5: Energy

We have been mentioning energy throughout this entire course, but we haven't really discussed what energy means. As mentioned in Unit 1, energy and matter can be converted into one another. A classic example of energy-matter conversion is when stars die. A star begins with a given mass, but when it dies, it explodes. During that time, some of its mass will be converted into energy.

In most physics textbooks, you find that "energy is the ability to do work," but that is not totally true. The international unit for energy is the joule (J). There are many forms of energy, starting with Kinetic and Potential:

- **Kinetic Energy** is related to motion. It is what you would need to make an object move through space. It depends on the mass of a body and also its initial speed. The formula to calculate kinetic energy is **K =** $\frac{1}{2}mv^2$, where *K* stands for kinetic energy, *m* stands for an object's mass, and *v* stands for the object's speed.

- **Potential Energy** is related to objects' position relative to something else. There are many types of potential energy, such as gravitational potential energy, electrical potential energy, and elastic potential energy, among others.

Here is an example that illustrates the conversion of gravitational potential energy into kinetic energy: hold a pen, pencil or book up in the air. Relative to the earth (the floor), that object has a given gravitational potential energy, which depends in part on the height of your hand above the floor and the object's mass. If you drop the object, its height is decreasing as it falls; therefore, so is its gravitational potential energy. So where is the gravitational potential energy going? That gravitational energy is being converted to kinetic energy as the object moves. In other words, it moves faster as it falls.

17. Give another example in which potential energy is being transferred into kinetic energy.

18. When a skydiver jumps from an airplane, what would prevent him from moving faster and faster as he falls?

Other forms of energy are thermal, nuclear, magnetic, electric, elastic, mechanical, and chemical.

19. Pick three of these and give examples in everyday life.

Conservation of Energy: the first law of thermodynamics states that in a closed system, energy is never destroyed or created. Your initial energy must be equal to your final energy; energy can only be transformed. From dropping an object, potential energy was decreasing over time, but was being converted into kinetic energy as the object fell. Just as energy is conserved, so is mass.

20. Give an example of a situation where one form of mass is converted to another.

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