Introduction to Physics — Scientific Notation, Proportionality and Unit Analysis

See online here

Physics is an important subject that helps us understand the processes that take place in biological systems. Physics helps medical personnel in three major ways. First, it is the foundation for many technological tools used in the medical sciences. Second, it helps explain the physical aspects of systems in the body. Finally, an understanding of physics can be applied in many other fields, providing the framework for solving problems.

Introduction to Physics

Motion

Motion is defined as the **act of changing location or position**. Three types of motion exist: **translational**, **oscillatory**, and **rotational**. Translational motion occurs when a change in location takes place. Oscillatory motion takes place without changing location; an example of such motion is the vibration of strings on a musical instrument. Rotational motion occurs when objects spin.

Force

Force occurs when **two objects interact with each other**. Each object exerts a force on the other: a **push** or a **pull**. When the interaction between the two objects stops, the force also disappears. This force can be separated into two categories: **forces from contact** and **forces from the action at a distance**. The difference between the two classifications is whether the two objects are in direct contact with each other or not. The unit of force is the **newton** (N).

Equilibrium

The definition of equilibrium is defined in the word itself. It deals with **equal parts, implying a balance**. If an object has forces acting on it, the object may undergo motion. However, if the object is in equilibrium, then the object will not move because all the forces balance each other.

One way to look at the motion of an object is to separate the forces acting on the object into **horizontal and vertical forces**. In equilibrium, the horizontal forces will balance themselves and the vertical forces will balance themselves; thus, no motion of the object will occur in either the horizontal or vertical axes.

Momentum

Momentum can be understood by looking at the **mass and velocity of an object**. Mass is a property of an object that measures the amount of matter in an object. Velocity is the distance an object travels over a given time. It is a vector quantity, so **directionality** is also expressed. Momentum, also a vector quantity, is the product of mass and velocity. In practicality, momentum refers to the quantity of motion possessed by an object. The unit of momentum is **kilogram-meter per second** (kg-m/s).

Energy

Energy is the property that is transferred to an object to allow it to generate work. The energy in the universe is fixed, which means that it can be transferred but cannot be created or destroyed. Energy exists in many forms: **kinetic** (moving energy), **potential** (storing energy), **elastic** (stretching energy), **chemical** (reaction energy), **radiant** (light energy), and **thermal** (temperature energy). The energy stays constant overall as it is transferred from one form to another.

Work

Work is the result of **force being applied to an object to move the object**. It can be measured by multiplying the force applied by the distance traveled. Work is closely related to energy. The **work-energy principle** states that an increase in kinetic energy of an object is due to an equal amount of work performed on the object. The unit of work is the **joule** (J), which is equal to a **newton-meter** (N-m).

Fluids

Fluids are one of the **phases of matter** that deform due to the **application of pressure or stress**. This characteristic allows fluids to travel through different channels in the body to carry substances such as oxygen, cells, waste, antibodies, and medicines. Fluids flow according to **Bernoulli's principle**, which states that fluid increases its speed as pressure decreases or the fluid's potential energy decreases.

Gases

Gas is a phase of matter in which the **particles are vastly separated,** unlike solids and liquids, in which particles are closer together. Gases are difficult to observe, so they are classified according to temperature, number of particles, pressure, and volume.

Gases have **lower density and viscosity** than other states of matter. Two laws explain their properties. **Boyle's law** states that at a constant temperature, the pressure of the gas varies inversely with its volume. **Charles's law** states that at constant pressure, the volume of the gas is directly proportional to its temperature. These laws explain the movement of gases in different body compartments

Periodic motion

Periodic motion is the motion that occurs in **equal intervals of time**. It can be seen in a rocking chair, a swing in motion, a planet orbiting the sun, a vibrating tuning fork, and a water wave. The period is the interval of time needed for one complete cycle. It can be explained by the term **frequency**, which refers to the number of periods per time unit.

Electricity

Electricity is associated with the existence of an electrical charge, which depends on the **number of electrons**, the negative particles in an atom. When the electrical charges are not moving, it is called **static electricity**. If the electrons are moving, it is called **dynamic electricity**.

In the human body, different **ions** (positively or negatively charged substances) can move based on electrical differences that exist across membranes. This allows for the transportation of substances and the conduction of impulses needed for nerve and muscle transmission.

Magnetism

Magnetism is the physical action that results from the force caused by magnets (objects that generate fields that attract or repel other objects). The particles that undergo this effect are **electrically charged particles**. The force that is created depends on the charge magnitude, the particle velocity, and the magnetic field strength. **MRI** (magnetic resonance imaging) generates pictures of the anatomy and physiology of the body using magnetic fields.

Circuits

A circuit is a closed loop through which charges can continuously move. For instance, when you flip a light switch, the light turns on. The switch closes the circuit, allowing electrons to move and be transformed into light energy. When the circuit is closed, the electron motion is referred to as the **current** of the circuit. The **human body has many circuits** in which electrical activity generates the physiologic activity associated with nerve transmission and muscle contraction.

Waves

A wave is a **disturbance that travels through a medium** from one place to another. A medium is a substance that carries the wave. In a pond that is undisturbed, the water is quiet in its resting position, with a smooth surface. When a rock is dropped, a disturbance is generated. The change that occurs from the rock causes a fluctuation in the water that is transmitted as a wave that either travels to the shore or disperses over time. In the body, fluid travels in channels with a wave effect.

Light

Light is **electromagnetic radiation** that can be detected by the human eye. Electromagnetic radiation is the flow of energy through space or material in the form of electric and magnetic fields. The elementary particle of light is a **photon**. Visible light reaches the visual layer of the eye, where it is converted to chemical energy and transmitted to the brain via nerve impulses. The brain re-forms the image, allowing us to see.

Sound

Sound is **pressure or mechanical wave that is formed by the back-and-forth vibration of particles**. The wave leaves the source in all directions and can be detected by sensors. In humans, the sound waves are captured by the ear and transmitted into the ear canal, creating the vibratory motion of the middle ear bones. The waves that are generated by vibration are **longitudinal waves**.

Atoms

An atom is the smallest particle into which an element can be divided without losing its chemical identity. An atom is made up of **electrons**, **protons**, and **neutrons**. The **central nucleus** is made up of the neutrally charged neutrons and the positively charged protons. The negatively charged electrons exist as a cloud around the nucleus. The **electron configuration and number** determine the ability of each element to bond, creating chemical reactions.

Electronic structure

The electron structure, or configuration, is the **arrangement of electrons in energy levels** around the central nucleus in an atom. The levels are different orbitals in which the electrons exist. The electrons fill the orbitals closer to the nucleus and, depending on the element, extend the orbitals outward. The ability of elements to form bonds is based on the status of the outer electron shell.

Thermodynamics

The study of thermodynamics involves **heat** and **temperature** and their **association with energy and work**. The laws of thermodynamics define these relationships.

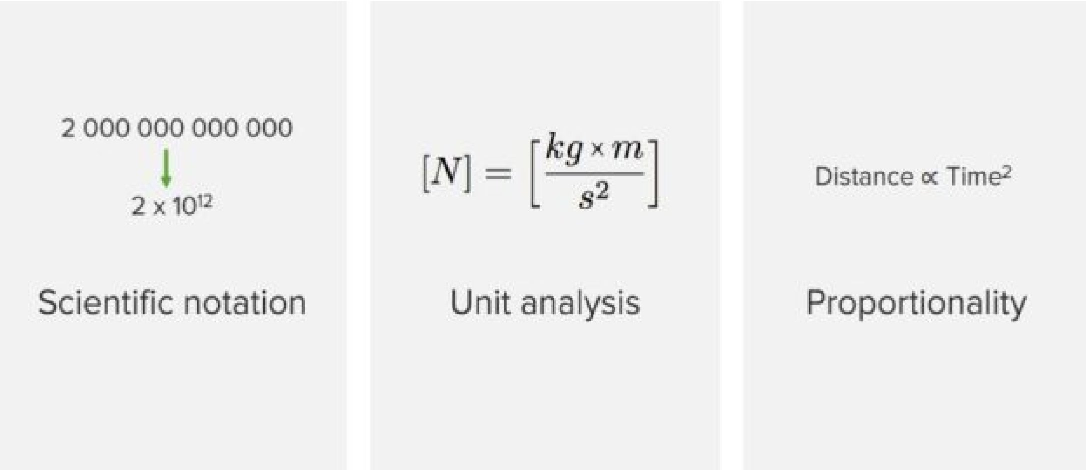
- The first law states that the **internal energy of an isolated system is constant**. An isolated system does not exchange heat, work, or matter with the surroundings.
- The second law states that **heat cannot spontaneously flow from a colder location to a hotter location**.
- The third law states that **all processes cease as a system approaches absolute zero**.

Thermochemistry

Thermochemistry deals with energy and heat and their association with chemical interactions and physical transformations. Reactions can either **absorb or release energy**. It also explains what occurs during **phase changes**, such as melting and boiling. The human body performs chemical reactions, which are classified as endothermic and exothermic. **Endothermic reactions** absorb heat, whereas **exothermic reactions** release heat.

Tools and Skills for Quantitative Thinking

Many tools and skills are used to transform the concepts of physics into numerical data. These tools give us the ability to make proper comparative calculations: to make sure that we are not comparing apples to oranges, but apples to apples. In addition, the tools help us perform calculations more quickly with mathematical techniques. Three methods that allow for this transformation are scientific notation, unit analysis, and proportionality.



"Tools and Skills for Quantitative Thinking" Image created by Lecturio

Scientific notation

Scientific notation is used to handle either very large numbers or very small numbers. It makes calculations much easier by using **exponents**. In any particular number, there are two parts: the actual number itself and the number of places the number is shifted to the right or left of the decimal point.

Scientific notation examples

The first example is a **large number**: 1,200,000,000. The digit term in this number would be 1.2, and then we look at how many places the number is shifted from the decimal point. To get from 1.2 to 1,200,000,000, the decimal point is shifted 9 places to the right. This indicates the need for an exponential term: 109. The number 9 (the exponent of 10) is the number of places the decimal point needs to be shifted. The positive exponent shows that the decimal point is shifted that number of places to the right. Therefore, 1,200,000,000 can be written as 1.2 × 109.

A second example is a **small number**: 0.00000012. The digit term in this number would also be 1.2, and then we need to look at how many places the number is shifted from the decimal point. To get from 1.2 to 0.00000012, the decimal point is shifted 7 places to the left. This indicates the need for an exponential term: 10-7. The number 7 (the exponent of 10) is the number of places the decimal point needs to be shifted. The negative exponent shows that the decimal point is shifted to the left, so 0.00000012 can be written as 1.2 × 10-7.

Prefix	Amount	Symbol
Smaller than 1.0		
Pico	10^{-12}	p
Nano	10^{-9}	n
Micro	10^{-6}	µ
Milli	10^{-3}	m
Centi	10^{-2}	c
Deci	10^{-1}	d
Greater than 1.0		
Kilo	10^{3}	k

Mega	10^6	M
Giga	10^9	G
Tera	10^{12}	T

Unit analysis

Unit analysis is the analysis of the relationship between different physical properties by identifying their **fundamental dimensions** and **units of measure**. These properties are expressed as calculations, and comparisons are performed.

For example, to determine the distance an object moves from rest if it is moving at a constant acceleration, the following relationship is used:

***x* = ½*at*2**,

where *x* = distance, a = acceleration, and *t* = time. When calculating the distance, ½ is multiplied by acceleration and time squared.

If the answer has been calculated correctly, the units will also match. Acceleration is given in (meters/second)/second, time is given in seconds, and distance is given in meters. Therefore,

meters = (meters/second2)/(second2).

The second2 terms can be canceled out, and the equation is reduced to

meters = meters.

If the equation had been written incorrectly, the units would not have matched. This would indicate that the calculation was incorrect because the wrong relationship was used.

Proportionality

Proportionality is the relationship between two quantities that **decrease or increase at the same rate**. Proportionality can exist in many different relationships. In a **direct relationship,** a change in one factor causes the measured factor to change in the same proportion. In an **inverse relationship,** a change in one factor causes the measured factor to change in the opposite direction. Some relationships in physics have multiple proportionalities.

distance fallen ∝ time2

Original falling distance = (constant) × (original falling time)2

New falling distance = (constant) × (2 × original falling time)2

New falling distance = 4 × (constant) × (original falling time)2

New falling distance = 4 × (original falling distance)

References

Giancolli, Physics, 6th edition, 2005.

Physics Central

the Physics Classroom

Notes