Chapter 1 Fundamentals of Physics

Learning outcomes

1) familiar with science, scientific method and the scope of science
2) Standard unit systems and international unit systems
3) Unit conversion and scientific notation

Contents

1.1 What is Science?

The “science” is from a Latin word meaning “knowledge”. There are various interpretations of science. For instance: Science is simply common sense at its best that is, rigidly accurate in observation, and merciless to fallacy in logic." - Thomas Henry Huxley (1825-1895), English biologist. "Science is the knowledge of consequences, and dependence of one fact upon another." - Thomas Hobbes (1588-1679), English philosopher, author. "In essence, science is a perpetual search for an intelligent and integrated comprehension of the world we live in." - Cornelius Bernardus Van Niel (1897-1985), U. S. microbiologist. According to the definitions online, "Science is knowledge or a system of knowledge covering general truths or the operation of general laws especially as obtained and tested through scientific method" - Merriam-Webster dictionary. "Science is the intellectual and practical activity encompassing the systematic study of the structure and behavior of the physical and natural world through observation and experiment." - Google dictionary.

All of each definition captures the essence of science. Science is a systematic study of all objects in our surroundings through observation, experimentation, and the testing of theories against the evidence obtained.

Since the birth of modern science, human’s exploration of nature has continued which at the same time, the means and methods of mankind's use of natural resources have been enriched, developing into modern science and technology. In turn, science and technology have become the decisive factors in promoting the development of productivity and the progress of human society. Science has enhanced the depth and breadth of human understanding of nature, changing human lifestyle, and bring human civilization to new heights. The development of quantum theory and the theory of relativity changed humankind's view of time and space, matter and energy, and became the theoretical cornerstone of a series of major scientific discoveries and technological inventions in the twentieth century. The establishment of the DNA double helix structure model marked a landmark for mankind in revealing the genetic secrets of life, laying the foundation for biotechnology which has a profound impact on the development of modern agriculture and medicine. The development of information science and the invention of the Internet have revolutionized human cognition and communication.

Science has nothing to do with faith. Faith belongs to the mind and conscious behavior. Science only studies matter and the laws of its existence. Science has nothing to do with feelings or intuition. Science is about discovery, and discovery is unpredictable. Unlike engineering and technology in plans can be formulated, science cannot plan. Science is unique and objective.

From the perspective of the development of science, modern science emerged more than 400 years ago. In the process of development, new hypotheses and new disciplines are constantly being created, and original theories are constantly being falsified, updated, and eliminated. But its basic assumption has remained unchanged, that is, the nature world is objective and the laws of nature are not affected by human opinions. Science is a beacon for mankind to understand nature, although the areas it illuminates are limited, and the world that is not illuminated by science is still dynamic and changing.

In short, science is seeking truth from facts, and science is the summary of daily practices and scientific experiments, which is the systematic knowledge in which human understanding has reached a mature stage. Science is contradicted with religion and superstition, and is a promoter of the development of social productivity.

1.2 The Scope of Physical Sciences

The saying of “Modern civilization is built on science” is on the ground that science has provided mankind with ideas, answers, and solutions for hundreds of years. Then what is science? **Science** is the systematic study of the physical and natural world through observation, experimentation, and the testing of theories against the evidence obtained to build and organize knowledge of verifiable explanations and prediction about physical and natural world. [1] Therefore, based upon what topic the science looks into, there are 10 main branches of science which include physics; biology; chemistry; zoology; astronomy; medicine; astrophysics and earth science. Biology and Zoology look into things with lives like animals, human beings, plants and bacteria. While Astronomy, astrophysics and earth science investigate the universe, from all objects in the outer space, galaxies, to the core of the Earth. Physics and chemistry are the sciences that commonly focus on the study of non-living matter in which physics is seeking understanding about how the universe functions, through the study of energy and matter in time and space. Chemistry studies the composition of substances, their properties and the ways in which they interact, combine, and change; and the use of these processes to form new substances.

As early as more than 2,000 years ago in ancient Greece, Aristotle and Archipelago Mead, along with other scientists began to explore physical phenomena and laws, and discovered the lever principle, the law of buoyancy and other laws. This was the infancy of physics. In the 16th and 17th centuries, Galileo, Newton and others founded the systematic scientific knowledge based on the work of their predecessors through a series of mechanical experimental observations and theoretical analysis. In 1687, Newton published his famous book "Autonomia" --the Mathematical Principles of Natural Philosophy, which marked the birth of modern physics.

After four centuries of development, physics has become a branch with many branches. It profoundly affects the development of contemporary science and technology and even the foundation of the progress of human social civilization.

Physical science education consists of physical science I and physical science II. The focus of physical science I is on Physics and Astronomy, while Physical science II deals with Chemistry and Geology.

1.3. Scientific Method

In order to investigate the natural world surrounding us, scientists conduct research day in and day out to get better understanding about the world. The method scientists adopt to look into the world is called scientific method, which is the process utilized by scientists to obtain new knowledge or discovery so as to improve our understanding about our surroundings. First of all, observations must be made on the phenomenon being studied, then explanations for the observations will be suggested; next is to test the possible explanations--- so-called hypotheses by conducting new observations. A hypothesis is a proposed explanation of a phenomenon which is still subject to test.

The so-called scientific method is the method used by scientists when engaging in certain scientific discoveries. Steps of the scientific method can be summarized as:

(1) When conducting scientific research, one should first identify a problem in a situation.

For example, when studying the motion of an object, you should first pay attention to why the object moves as it does, that is, why the object moves faster and faster (accelerates) under certain conditions, while under other conditions, why it would run slower and slower (deceleration motion).

(2) It is necessary to figure out the irrelevant aspects of the situation and eliminate them. For example, the smell of an object has no effect on the motion of the object.

(3) Gather all the data you can find about the situation. In various natural phenomena, there are lot of conditions affecting objects to move in a certain way. Various data related to the situation must be collected.

For example, when looking into some balls rolling down along inclined surfaces, you can use balls of various sizes, changing the surface properties of the balls, or changing the inclination of the inclined surfaces, etc.

(4) With these collected data, some preliminary generalizations can be made in order to explain them as concisely as possible, that is, using some concise language or some mathematical relationship to summarize them. This is also a hypothesis or hypothesis.

(5) Once you have a hypothesis, you can conduct experiments. Next, the results of these experiments can attest or disprove your hypothesis.

(6) If the results of experiments support your hypothesis, then the hypothesis would have a strong factual basis and may become a theory or even a "law of nature." If not, repeat the above steps until the results of experiments are consistent with the proposed hypothesis.

Commonly scientists exploit the scientific method to conduct their research, but not necessarily by following the order stated in the figure. Sometimes, hypothesis is proposed before observations are conducted; sometimes observations are done before hypothesis are formulated. In any event, scientists need to go through their procedures thoroughly to ensure that their experimental data and results could be reproduced and verified by others. If a hypothesis could be supported by many experiments, the hypothesis turns into a theory. Theories remain theories forever which are being retested with every experiment and observation over time. Theories can never become fact or law because law describes the fact or what happens. Law will not be altered even after more evidence come up.

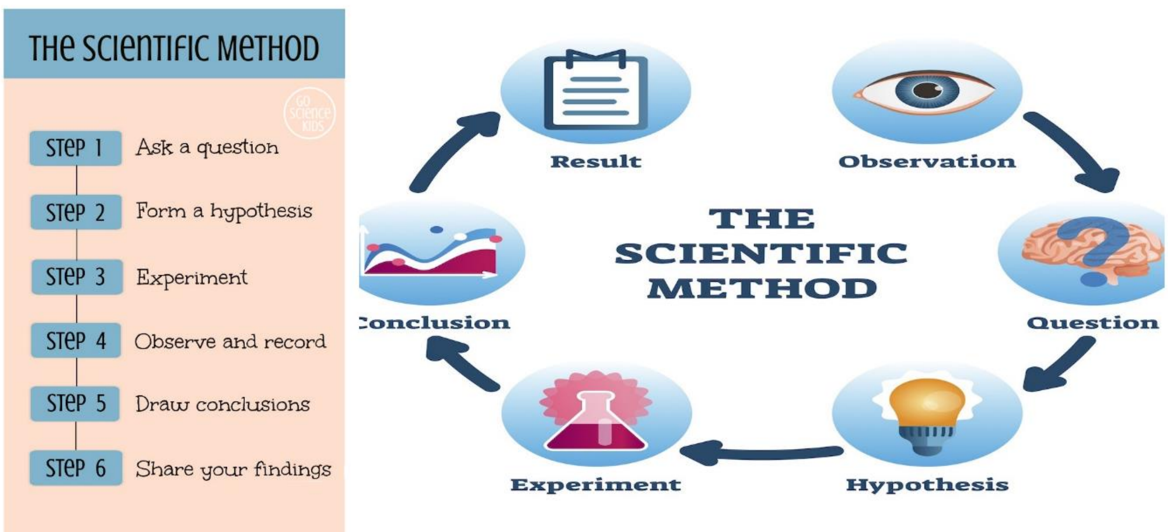

Figure 1. The diagram of the sequence of the scientific method, Ref.1.

The idea that science can be addressed using one method has been misunderstood for years. The scientific method is not so much a series of steps as it is a way of thinking about solving problems in science. We all learned that the steps of the scientific method need to be followed carefully; however, pure scientists solve problems in a systematic manner that reflects and follows those steps rather than follow them one-by-one. Yes, scientific research needs a well-designed experiment, a way of controlling variables, a way of testing predictions, and a careful method for collecting and recording data. The data are used to draw a reasonable conclusion. That methodology has served scientists well for many years.

This process repeats itself again and again. New data, new observations and new experimental results will continue to appear, and the old theories will continue to be replaced by new theories, because these new theories can not only explain various phenomena that the old theories can explain, but also explain some phenomena that cannot be explained by the old theories. In reality, scientists do not need to proceed step by step like a set of calisthenics. Factors like intuition, insight, and even luck often play a greater role than other things. The entire history of science is full of examples that sometimes "experiments just happen" and lead to wonderful discoveries. For instance, in September 1928, Alexander Fleming was studying a kind of bacteria, Staphylococcus aureus, in a simple laboratory. Because the lid of the petri dish was not closed properly, a Penicillium spore fell from the window and landed on the agar used to culture bacteria. Fleming was surprised to find that the staphylococci surrounding the Penicillium spores disappeared. He concluded that Penicillium would produce something harmful to Staphylococcus aureus, so he invented the miraculous antibacterial drug Penicillin. Another example is the discovery of X-rays. On the evening of November 8, in order to avoid the influence of ambient light, Wilhelm Conrad Röntgen wrapped the discharge tube tightly with black paper and conducted experiments in a completely blackout darkroom. He used a piece of cardboard coated with barium cyanogen platinite as a fluorescent screen. He used a higher voltage/vacuum than what Leonard did and tried to see if cathode rays could penetrate farther into the air. When a large voltage was applied to the discharge tube, he found that the fluorescent screen about 1 meter away from the discharge tube emitted a weak flash in the dark. When the power was turned off, the flash disappeared; when the voltage was applied again, the flash reappeared; he moved the paper screen more than two meters away or turned the paper screen over and the fluorescence still appeared. The rays can pass through the aluminum window and produce fluorescence through a fluorescent screen more than one meter away. In fact, the cathode rays that hit the small aluminum window are X-rays. Some people call this ray "Lernard ray", but Lerner De did not study in depth and thus missed the discovery of X-rays. Roentgen continued his research on cathode rays and made new discoveries.

Therefore, allowing your mind to be open to those ideas requires a scientific attitude. According to Isaac Asimov, "The dangers that face the world can, every one of them, be traced back to science. The salvations that may save the world will, every one of them, be traced back to science."

1.4 Facts, Laws, and Theories

Common beliefs are that competent observers can observe scientific facts and those observers agree the facts to be true. Scientific facts are generally believed to be independent of the observer: no matter who performs a scientific experiment, all observers will agree on the outcome. Facts are good data, can answer questions, and are central to the idea that is scientific reasoning. Facts provide a basis for knowledge. Facts can lead to questions and to scientific hypotheses.

As scientific hypotheses are tested many times, which can be supported by the collected data scientists form laws or principles from the conclusions. Scientific laws tend to be concise statements that express a fundamental scientific principle. They always apply under the same set of conditions that suggests a relationship between the cause-and-effect. This makes the law applicable in a defined set of circumstances and not always applicable in a different setting. Generally, the law is a result of the systematically, repeated collection of data.

Scientific theories must be logically sound and be supported by a significant body of scientifically valid observations. Their credibility is derived from their ability to show a relationship among events that previously were thought to be unrelated. Theories should have predictive power. A classic example that the discovery of Neptune, which evidences the predictive power of a theory, resulted from predictions made by mathematicians John Couch Adams and Urbain Le Verrier, based on Newton's theory of gravity.

1.5 Applications of mathematics in physics

Physics and mathematics are closely related, as one mathematician says “Physical science not only gives us (mathematicians) the opportunity to solve problems, but also helps us discover methods to solve them by the ingenious combination of mathematical ideas and physical laws”. In physics, relationships between physical quantities, physical changes; rules; and laws are described, besides in text words, in mathematical equations or systems of equations. Formulas, proportional formulas, trigonometric functions, trigonometric equations, etc. are widely used in upper level physics courses. In mathematical language, all variables will be represented by letters or Greek letters, which is particularly the case in mathematic equation for physics. For instance, the weight of an object equals the product of mass and the gravitational acceleration on the surface of Earth.

$$W=m*g,$$

in which W stands for weight; m represents the mass while g denotes the constant value of 9.81/s^2 --the gravitational acceleration on the surface of Earth. Also, through this equation, the direct proportional math relationship could be examined. The weight is direct proportional to the mass of an object. The more massive an object is, the heavier weight it has. Such a relationship can be generalized as when the quotient of two variables is a constant number, they are directly proportional. While when the product of two variables is a constant number, they are inversely proportional. For instance, in Ohm's law, for any electric device with a fixed resistance, the voltage and current are inversely proportional, which can be expressed as:

$$V*I=R,$$

in V is a voltage across the electric device, while "I" is current passing through it. R is the resistance of the device. It also means, when the V increases, the I decreases, verse versa.

Being able to solve many physical problems and converting physical problems into mathematical problems is a very important way to learn physics. Everyone needs to be consciously cultivated to use mathematical ideas to solve physical problems; provide precise mathematical language and solutions for the expression of physical concepts and laws and the solution of physical problems. It is necessary for students to see through physical phenomena, understanding physical concepts, physical laws, and dealing with physical problems, being able to transform the relationship between physical quantities into functions and equations. For instance, when studying the nature and laws of object motion, it is necessary to establish physical models for relevant analysis and corresponding practice; when exploring new conceptual laws, students are required to use analogy thinking to concepts and models with similar attributes for comparing and analyzing to achieve rational understanding.

1.6 Standard measurement System and Units

When we are looking around our surroundings, there are numerous objects. Objects are physical matter that take up space. In order to describe an object, qualitative language or descriptive language can be adopted like to describe the sky, you can say it is ocean blue; the temperature like spring-like temperature. All of the statements are very vague. In order to precisely and accurately describe certain properties of an object, quantitative measurements must be considered, like the temperature of one summer day is 88 Fahrenheit or 31 degree Celsius. In physics, the quantity must have a numerical value and an appropriate unit. For example, if you tell the class your height is 1.65, which would be meaningless in the US Standard System. However, in the international unit system, your height is 1.65 meters, which is average height for women among some country. There are two Standard units of measurement. In the US Standard System, the mass can be measured in Pound, Ounce and Length can be measured in Yard, miles and inches. In the International System of Units (SI), Kilogram or gram will be used for mass, and Kilometer, meter or millimeter will be utilized for length. For time, in both systems, seconds, minutes, hours, days, weeks, months, years, decade, and century are used to describe the time. Mass, length and time are called fundamental units. All other units can be derived from them. For example, speed is meter/second, which is distance over time. The density is defined as mass per unit volume, mathematically it can be written as $\rho = \frac{m}{v}$, in which ρ represents density; m denotes the mass while V is the volume. Therefore, the unit of density can be, kg/m^3 or gram/cm^3.

1.7 Unit Conversions

As aforementioned, different units could cause some confusion. In order to be consistent, the international unit system is adopted in the scientific world. If there are different units appearing in one problem, unit conversion is a must. There are lots of charts to show unit conversion. For instance, in Asia, the height of a person is in meters. However, in USA, it is in foot or inches. If the height of a person is 1.63 meters, most Americans would have no clue about how tall this person is. However, if you are told that the height of the person is 5"4, told the person is 5'4", you would instantly be able to estimate the height.

In the scientific world, the accepted 3 fundamental units are mass (kg, or grams); length (in meters, or km) and time (in second). All other units are called derived units. For instance, the unit of speed is meter/second. It comes from the mathematical operations of length and time. Another example is the density, indicated by mass/cm^3. It can be expressed as the division of mass over the cube of length. In a scientific world, virtually all variables must have a proper unit to indicate some significance.

1.8 Significant Figures

In the scientific world, some quantities are extremely large or extremely small, which cause trouble in expressing the routine decimal. For example, the speed of light in the air, c=300000000.0m/s. Too many zeros give rise to too much trouble! However, it can be expressed in a scientific notation, and it would be much compacted. For instance, the light speed in vacuum is C=3.0*10^8m/s. The significant figures indicate the accuracy of the quantities in experiments. For instance, 3.0 meters, is mathematically equal to 3.00 meters. However, the difference between these two measurements is the number of significant figures. 3.00 meters represent the more accurate measurement while 3.0 meters is rough as it is estimated to tenth, not hundredth.

Summary

It has been said, "Modern civilization is built on science." Science has provided mankind with ideas, answers, and solutions for hundreds of years. As our children learn science, they will be using it to solve problems that we, as adults, have not even dreamed about. As humankind, we have used science to cure diseases, to design earthquake resistant buildings, to develop faster communication systems. We are leaving a body of knowledge that has been accumulated through the scientific method.

We have also encouraged deeper thinking and educated a youth that questions the idea of absolute truth. We need to be sure that youth understands that science is a body of knowledge that addresses that nature of the world and what can be learned about it.

Exercises:

1) The scientific method is
a. a way to discover truth
b. a way that scientists take to look into things
c. a procedure in lab
d. a way to verify laws and theories

2) A theory is true:
a. always
b. for certain amount of years, then it would be changed
c. As long as a committee of scientists says so
d. if it is still supported by new experimental findings

3) A hypothesis is
a. an idea needs to be verified
b. an idea that needs to be confirmed by further experiment
and observation
c. an idea that needed to be discarded as it is not in consistent with
further experiment and observation
d. scientific ideas shared among scientists

4) The idea of evolution of living things
a. is a law in biology
b. is a theory in biology
c. an intelligent design
d. objected by all religions

5) Which of the following is true except?
a. the Ptolemaic system
b. the Copernican system
c. Kepler's laws of planetary motion
d. Newton's law of gravity

6) A density is an indicator of a substance. It would change if
a. its volume decreases
b. it is chemically reacted with other materials
c. its mass doubles
d. its volume doubles

7) Law is always valid because
a. it describes a fact
b. it describes what happened/happens
c. it is verified
d. all scientists believe so

8. A*B=K, in which K is a constant number. We claim
a. A and B is directly proportional
b. A and B is inversely proportional
c. A and B has no mathematical relationship
d. A and B are in a linear relationship

9) Pound is a unit in English metric system for a variable of
a. Mass
b. distance
c. weight
d. energy

10) there are 3 fundamental units in international metric system
a. mass

b. length
c. time
d. density

Problems

1. There are two blocks on the table. Block A has a mass of 100 gram and 150 Cm^3 while Block B has a mass of 200 grams with 300Cm^3. What are the densities of them and are they the same type of materials?
2. If a person with a mass of 60 kg, what is his weight?
3. An electric heater has a resistance of 10 ohm, if the voltage across is 15 voltage, what is the current passing through it?
4. Mass of earth is 5.97219 × 1024 kilograms, what is it in milligrams?
5. A radius of carbon tube is 1.69 nanometers, what this radius is in kilometers?
6. A cube with sides of 10 cm, has a mass of 100 gram, what is its density?
7. If a person with 490 N weight, what is his mass?
8. How to convert a speed of 66 miles per hour into meter per second?
9. For a given block with a density of 20 kg/m^3, please convert it into grams/cm^3?
10. Find the resistance of a hair dryer if there is 30 Voltage across it with a current of 20 A passing through it.

1.10 Internet Links

https://www.theladders.com/career-advice/the-7-scientific-method-steps.

http://teacher.pas.rochester.edu/phy_labs/appendixe/appendixe.html

http://www.project2061.org/publications/sfaa/online/chap1.htm?txtRef=&txtURIOld=%2Ftools%2Fsfaaol%2Fchap1.htm

https://languages.oup.com/google-dictionary-en/

https://www.unitconverters.net/

https://www.sciencebuddies.org/science-fair-projects/science-fair/steps-of-the-scientific-method