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Scientific Knowledge: The Scientific Method

Objective

In this lesson we will study the scientific method of inquiry. We will also examine the mathematical tools needed for displaying and communicating experimental data.

The Scientific Method

All scientific investigation is a result of human curiosity's being stimulated by observation of interesting natural and physical phenomena. When such probing and questioning is conducted as a formal process of observation, inference, and experimentation it is called scientific method. The scientific method may be summarized as a series of iterative steps where observations lead to inferences and a testable hypothesis, which in turn leads to experiments. The hypothesis is a chosen inference that the scientist will attempt to confirm or disprove through testing. That is done through experiments. The results of experiments could either prove or disprove the hypothesis. If a hypothesis were disproved, then one would have to go back to the inferences and reformulate the hypothesis and re-test it. On the other hand if the hypothesis were proved to be correct, it would lead to formulation of theories to explain the observations.

Observation, careful experimentation and measurement are one part of scientific inquiry. The other part is composed of postulating theories based on the observations. Theories are explanations of why an observed behavior occurs. Theories are the results of scientific imagination and are used to make further predictions that could be testable through experimentation. However, theories can be proved or disproved and are subject to change. Thus a theory is only an interpretation or a 'why' of an observation, but an observation is a witnessed true event that occurs irrespective of the worthiness of the theory.

Once a theory is proved by several independent sources, a natural law can be formulated. A natural law states 'how' something must happen based on measurable behavior. A law is a concise statement about how nature behaves. Sometimes laws take the form of mathematical relationships between experimentally determinable physical quantities, e.g. Newton's second law of motion, $F = ma$, relating force, mass, and acceleration. The theory, on the other hand, merely attempts to provide an explanation for observed behavior.

Scientific Knowledge: Scientific Method

For a scientific experiment to be plausible, one must define control and variable parameters. Variable parameters are the physical variables being changed from experiment to experiment whereas the control is kept a constant to show the effect a given environment has on certain variables. Thus controlled experiments are sets of identical experiments where only that variable which is being tested is changed. Ideally, the scientific method is utilized to make scientific discoveries. Remember, however, sometimes these steps are not distinctly defined and need not progress in a continuous pattern.

The process of observation, inference and design of a testable hypothesis involves a certain amount of creativity on the part of the scientist. For instance, when Aristotle (384-322 BCE) interpreted motion, he observed that objects when given an initial push always slow down and stop. And thereby inferred and argued that being at rest was a natural state of any object and for an object to be in motion a force is required to move it. However, Galileo Galilei (1564-1642) observed motion and formulated the notion of inertia, i.e. an object in a state of motion or in a state of rest continues to be in the same state of motion or rest unless an external force acts upon it. Galileo is credited by many as being the father of modern science. He observed and validated the presence of frictional forces by conducting several experiments with the inclined plane.

The notion of inertia forms the cornerstone of Newton's laws of motion. In fact Newton, who was born the same year that Galileo died, built on Galilean theories of motion to provide us with the law of universal gravitation. Newton's contributions to physics are innumerable and wide ranged, as we shall see in later chapters on laws of motion and light.

Mathematics and the Scientific Method

Mathematics is an essential tool for science, and particularly so in physics. Physics extensively employs the tools of algebra, trigonometry, calculus and statistics in formulating equations that model physical problems. Trigonometry is used in understanding vector quantities like forces, velocity, and acceleration in motion problems. Statistics is widely employed in studying stochastic (random) processes of Brownian motion and thermodynamics. Calculus forms the basis of electromagnetic theory. Relativistic models use topology, Euclidean, and non-Euclidean geometry. Observing and collecting measurements, as well as hypothesizing and predicting, often require mathematical models and extensive use of mathematics. Graphical analysis of experimental data uses mathematics to derive equations that relate physical quantities. It plays an important role in defining relationships between different variables and in predicting physical models related to the theory.

Graphical Analysis of Experimental Data

In order to successfully complete a scientific investigation, we must be able to communicate the results and conclusions to the scientific community at large. Since experimental data is generally collected in numerical form, tools for displaying mathematical data are important. Graphical analysis is a critical way to present results. Graphs are used extensively to determine relationships between or among variables and to analyze the results from large amounts of numerical data. Extracting meaningful information from numerical data, understanding the trends in numbers, and developing a relevant and

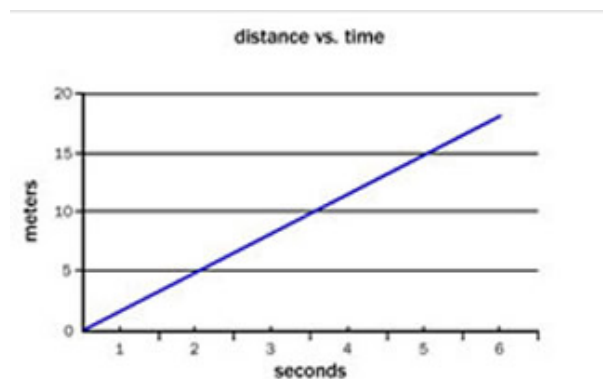
correct analysis in order to come to significant conclusions for the experiment are all crucially dependent on the proper graphic display and presentation of data.

When studying an experimental system of a cause and effect nature, we are usually concerned with two variables, one that can be manipulated by the experimenter and therefore is an independent variable and the other whose behavior may be the consequence of the change in the independent variable. This second quantity is called the dependent variable. The goal of data analysis is to deduce a relationship between the two variables. A graph can reveal relationships between dependent and independent variables and is one of the simpler but vital methods of data interpretation. The independent variable (the cause) is plotted on the **x**-axis or the abscissa, and the dependent variable (the effect) is plotted on the **y**-axis or the ordinate. The range of values for both should be properly evaluated to determine a reasonable scale for the graph so that it is easily readable.

Linear and Non-linear Relationships

In physics we deal with many mathematical relationships between the physical quantities of interest. Variables depend linearly, non-linearly, exponentially and logarithmically on one another. The simplest relationship is the linear one where the graph obtained normally follows a straight line equation of $y = mx + b$, where y is the dependent variable, x is the independent variable, m is the slope of the line, and b is the value of y when x is equal to zero.

The graph below shows the distance from home versus time for a bicyclist traveling at a constant speed. It shows a linear relationship between the dependent variable (distance) and the independent variable (time).



A linear relationship between distance and time

This relationship can be expressed as a linear equation in the form:

$$\text{Distance} = \text{Velocity} \cdot \text{Time}$$

The slope of the line is determined as the change in distance over change in time, which is the definition of velocity. Notice that the slope is positive indicating that the distance from home increases linearly with time as the bicyclist pedals at a