

Notes: Scientific Method and Scientific Notation

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Scientific Method

The scientific method is a means of uncovering and explaining physical phenomena. It relies on observation and logical reasoning to achieve insight into the actions and relations of the phenomena, and a means of relating it to similar items. The method starts with observations and measurements. Based on these and background knowledge such as mathematics, physics, the behavior of similar phenomena, and so on, a tentative explanation, or *hypothesis*, is derived. The hypothesis is then tested using experimental or field data. The precise nature of the tests depend on the area of study, but the idea will always be the same: namely to see if the predictions of the hypothesis are borne out under alternate applicable conditions or data sets. A proper hypothesis must be *testable* and *falsifiable*. That is, the hypothesis must be able to be proven wrong by subsequent observation. If it is not, then the hypothesis is better classified as *philosophy*. For example, Newtonian gravitation could be proven false by letting go of a suspended hammer and watching it remain motionless or fall upwards, rather than fall down toward the Earth. Similarly, Evolution could be proven false by the discovery of “fossil rabbits in the Precambrian”, to quote famous biologist J. B. S. Haldane (Haldane was being somewhat snippy, but in general, he meant anything that would be clearly out of the expected time-line, in this case a small mammal predating even the most simple creatures with backbones).

A hypothesis is tested by repeated cycles of prediction, observation and measurement, and also subject to *peer review*, that is, the critique of others in the field of study who may point out inconsistencies in the explanations or logic, errors in experimental design, and so on. This cycle continues until the weight of data and scientific opinion elevates the hypothesis to a *theory*. One might say that a theory is a hypothesis that has withstood the rigors of the scientific method. This cycle was well expressed by the Marquise du Châtelet¹. She explained hypotheses as “probable propositions”. While it would only take one observation to falsify a hypothesis, several would be required to vindicate it: “each non-contradictory result would add to the probability of the hypothesis and ultimately... we would arrive at a point where its ‘certitude’ and even its ‘truth’, was so probable that we could not refuse our assent”.

It is important to note that the scientific usage of the word theory is entirely different from its popular usage, which is perhaps closer to “hunch” or “seat-of-the-pants guess”. Also, a scientific theory is not *true* in the same sense as a *fact*. Facts come in three main varieties: direct and indirect observations; and those that may be logically deduced. A direct observation is something that you have measured yourself, such as noting the time

¹ Du Châtelet was that most rare of 18th century women: a mathematician and physicist. She translated Newton’s *Principia Mathematica* into French and was also the lover of Voltaire. Unfortunately, after an affair with the poet Jean François de Saint-Lambert in her early 40’s, she became pregnant and died six days after giving birth.

it takes for a ball to reach the ground when released from a given height. An indirect observation is something that may be inferred from other known quantities or proper historical data, such as “George Washington was the first president of the United States of America”. An example of the third variety would be “If x is an even integer larger than four and smaller than eight, then x must be six”. At first glance, it may seem that facts are highest on the pecking order, but scientific theories are much more useful than facts because isolated facts have very little predictive capacity. It is the predictive and explanatory ability of theories that make them so powerful.

So a theory is a “best estimate so far”, a model to explain some observable aspect of the universe. It is understood that as our view of what is observable widens and our knowledge extends, so too a given theory may be refined. A good example is Newtonian Gravitation. This model was sufficient to describe the movements of the planets around the sun and is still used to plan the flight of space craft. In the early 1900’s, however, Einstein’s Theory of Relativity refined Newtonian Gravitation to include more extreme (relativistic) effects. It is important to note that we did not “throw out” Newton’s equations; rather, we now have a better understanding of the set of conditions under which they apply. While this trek towards more and more refinement is not truth in and of itself, to paraphrase the late Harvard paleontologist, Stephen Jay Gould, to ignore the weight of scientific data behind an established theory would be perverse.

Scientific Notation

In any effort to reduce the cumbersome nature of very large and very small numbers, scientists and engineers use *scientific notation*. This removes the problem of excessive leading and trailing zeroes. For example, consider the value 17,000,000,000,000. It might take you a moment to note that this is commonly referred to as “17 trillion”. Similarly, it takes more than a few seconds to see that .0000000032 is “3.2 billionths” or even “32 ten-billionths”. As scientists and engineers use very large and very small numbers frequently, keeping track of all of those zeroes can be a pain and a source of error. With scientific notation, a number is expressed as two parts: first a *mantissa*, or “precision part”, and secondly an *exponent* which tells you the magnitude or “scale of largeness”. The exponent is basically a power to which the number 10 is raised. You can also think of it as the number of zeroes trailing. The first example, 17,000,000,000,000 would be written as 17 times 10 to the 12th power, or 17 times 10^{12} . Note that there are 12 trailing zeroes. The value 5,600,000,000 could be written as 56 times 10^8 , noting the 8 trailing zeroes. It could also be written as 5.6 times 10^9 . (If the power of 10 is a multiple of 3, that is, it corresponds to one of those place-holding commas; we call it *engineering notation*—more on this in a moment.) Continuing, if you imagine moving the decimal point of .0000000032 to the right, you’d move it 9 times to get between the 3 and 2. This would be 3.2 times 10^{-9} , the negative power indicating a shift right rather than left (i.e., smaller than 1). This value may be written as 32 times 10^{-10} as well. On a normal scientific calculator, there is a further shortcut: The *exponent button*, which is typically labeled *E*, *EXP* or *EE*. So, to enter the last example, you’d type in 3.2*E*-9 or 3.2*EE*-9 or 3.2*EXP*-9. (For consistency, we will always use a single *E* for descriptions from here on.)

Certainly, it is much more compact and less prone to transcription error to write 4.32 times 10^{-9} than .00000000432 (and better still to use 4.32E-9); but, there is an even better reason to use this form, and that's when multiplying or dividing values.

1. When multiplying two values in scientific notation, multiply the two mantissas (the precision parts) and then add the exponents. For example, 3.2E9 times 2E-3 is 6.4E6. You can probably do that in your head whereas 3,200,000,000 times .002 may not be so obvious.

2. When dividing two values in scientific notation, divide the two mantissas and then subtract the exponents. For example, 3.2E9 divided by 2E-3 is 1.6E12 (remember, subtracting a negative three is the same as adding a positive three).

To further simplify, we give names to powers that are multiples of three:

10^9 Giga (billions)	Use the letter G as a shortcut
10^6 Mega (millions)	Use the letter M as a shortcut
10^3 Kilo (thousands)	Use the letter K as a shortcut
10^{-3} milli (thousandths)	Use the letter m as a shortcut
10^{-6} micro (millionths)	Use the letter μ (the Greek letter mu) as a shortcut
10^{-9} nano (billionths)	Use the letter n as a shortcut

So, for our earlier example of .0000000032, we can say 3.2n (3.2 nano, or 3.2E-9 or 3.2 times to 10^{-9}). We then apply these prefixes to whatever it is we are measuring. If we are measuring distance, we'd use meters (1 meter is approximately 39.37 inches). If it's sort of far, like the Boilermaker Road Race, we'd use *kilometers*. The Boilermaker is 15k, or 15,000 meters (about 9.3 miles). If the distance is fairly small, like the parameters of an integrated circuit chip, we might use *micrometers* (millionths of a meter). If you want to impress your friends, run the Boilermaker and tell them that you just ran 15 times 10^9 micrometers!

Science!

