

Theory, Model, Law, Hypothesis, and all that Jazz

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Abstract

This essay attempts to define theory, model, law, and hypothesis along what I would call “philosophical lines.” They will be defined rather differently than is presented in most science references — at least from what I’ve seen. When using concrete examples, I will prefer the domain of physics to the other sciences.

In a good mystery story the most obvious clues
often lead to the wrong suspects. In our
attempts to understand the laws of nature
we find, similarly, that the obvious intuitive
explanation is often the wrong one.
— *The Evolution of Physics*¹

1 Presentation of Terms

A **law** is an invariable relationship on the objective variables of science. The objective variables are those that can be directly measured in the lab, so to speak. (My definition is derived from a definition I got from Campbell, N. 1921. [Reprinted 1953]. *What is Science?* New York: Dover Publication, Inc.)

A **metalaw** is an invariable relationship/constraint on the formal variables of science. The *formal variables of science* are those that can be invented that are not directly measurable, but are in some way theoretical precursors to objective variables. Some good examples of a formal variable are 1) the wave function of quantum mechanics, 2) the action variable of Lagrangian formalism, 3) the gravitational potential function, and 4) the partition function of statistical mechanics. These things are not themselves directly measurable things, but they influence the set of measurable things.

¹*The Evolution of Physics*, Einstein & Infeld, Touchstone, 1938, p. 9.

And now, my definition of science:

Science – an investigative division within Natural Philosophy – is the search for a patchwork of theoretical explanations for and mathematical descriptions of the behavior of natural phenomena founded on intersubjective “reality,” and supported by covariant physical laws (according to the current paradigm) with semi-freely created formalisms and models.

Now, I know that there are those who are offended that I should place science under the auspices of anything ‘higher’, and certainly not natural philosophy. First, if not natural philosophy, then under what? Second, I suppose that most scientists today hold to the philosophical view of *scientism*, which is the dogma that science is a completely self-contained source of true knowledge about the natural world and needs no help from any outside source.

And now, my definition of natural philosophy:

Natural Philosophy is the set of all possible beliefs about the natural realm.

So, under natural philosophy is science, and under science is physics:

Physics is the search for the so-called “laws of Nature,” which are more properly to be called the “laws of physics.” This is done by instituting research programs that define what a “law of physics” is and also set down modeling biases that must be adhered to. These would include possibly some absolute restrictions for certain modeling allowances, and also some strongly preferred modeling methods. For example, in the Newtonian research program, one must model matter as a collection of particles which interact via forces. In Lorentz’s ether theory, one models light propagation in terms of some undetectable absolute rest space. In special relativity one is, by the adoption of a formal point of view, strictly forbidden from using any concept of any absolute “rest space.” Instead, one is admonished to formulate all such theories on the Principle of Lorentz covariance as a heuristic to “discover” local “laws of physics.” Every research program must come to grips with the question of the relationship between reference frame and “law of physics”! The current favored research program in physics for a given collection of related phenomena is called the “paradigm” for that phenomena. With respect to particle physics, the current paradigm is referred to as the *Standard Model*.

Phenomena is defined as either the direct sensations that humans experience as a result of interacting with the so-called “external world” (i.e., the world “external” to a human’s mind) or is the immediate external cause of the

sensation. When we hold a stick in our hand, we experience the stick through our senses. From this viewpoint, whatever we can know about the stick is constrained to whatever superficial meaning our minds can possibly assign to the stick as a result of using our senses to gain information about the stick. Add to that that we allow ourselves to know properties of the stick which can be obtained by the use of technology. This technology is a derivative of human thought processes and is also constrained by what humans value as worthy of being measured, such as length, hardness, compressibility, etc. Neither the human nor the measuring instrument can ever capture the essence of the stick “as it really is.” Instead, both human and measuring instruments experience the stick according to their limited and prejudiced manner of ‘knowing’ through the operations they perform on the stick. We are even more remote from direct truth about the real when we posit a theoretical model of the stick. Not that there is anything in principle wrong with using theoretical models. It’s just that we shouldn’t think more highly of them than is warranted.

A **model** is a representation of a thing, structure, or relationship. The point particle is a model for a very small (maybe vanishingly small) particle or for a body whose center of mass is the focus of investigation. The luminiferous ether is a model of the embodiment of an absolute rest space, and also as a supposed real elastic medium in which light propagates. The spacetime of special relativity is a model which serves as an instrument of mental organization and simplification. It does this by representing relationships among events in a graphical manner. The continuous model of macroscopic matter (CMMM) is used to represent the gross properties of matter for certain approximations in calculations. Yet, our best theories to date — such as the theory of the molecular structure of macroscopic matter — tell us that macroscopic matter is never continuous.

So why do we use a model that is generally accepted as ‘false’? Because theoretical models need not be about truth, simply because theories themselves are not about truth. Theories are about success in matching predictions against experiment. The CMMM is a model which gives very good approximate predictions in many situations which are useful for analysis. This alone justifies their use in theories. In the ordinary sense, a model serves as a tool of thought for the modeler. Einstein referred to continuum mechanics as sort of a useful fiction:

This mechanics [of continuous media] is characterized by the fiction that the density and the velocity of matter depends continuously upon coordinates and time, and that the part of the interactions not explicitly given can be considered as surface forces (pressure forces) which again are continuous functions of position. Herein we find the hydrodynamic theory, and the theory of elasticity of solid bodies. These theories avoid the explicit introduction of material points by fictions which, in the light of classical mechanics, can only have approximate significance.

— Found in: “Physics and Reality,” A. Einstein, *Ideas and Opinions*, Three Rivers Press, p. 302.

A **hypothesis** is a simple proposition or claim. A common misconception is that by virtue of scientific vetting, a hypothesis can be promoted to a theory! Logically speaking, a **theory** is a collection of two or more self-consistent hypotheses (axioms or postulates) which, combined with logical deductions, can arrive at logical conclusions, also known as *theorems* of the theory. It is usually by these theorems that a theory has its empirical tests. Logically speaking, the theorems are the “predictions” of the theory. Now, I know that there are folks out there who would insist that the notion of experimental “prediction” should, by rights, be about something novel. But this is no more than a legitimate equivocation on how the term is used in the two contexts. Please try to understand the context in which it is used to avoid confusion.

Let’s look at a few examples of hypotheses: 1) *What goes up, must come down*. This is a generally accepted hypothesis. If you believe it, you may refer to it as a **principle**, which is the assertion of a **proposition** (a true-or-false statement). Thus, the formal distinction between *hypothesis* and *principle* is just the degree of one’s confidence in it. When Einstein referred to the hypothesis that *the speed of light as measured in an inertial reference frame in a vacuum is a constant* as the *Light Principle*, he was conferring to it the status of inviolate ‘fact’ for the purpose of his special theory of relativity. Future experimental evidence may tend to strengthen or weaken that hypothesis, but that’s where he was on the issue in 1905.

A principle that is universally taken as true or reliable can be called a “law.”

My last example of a hypothesis is this: *Because of the horizon effect, there exists no viewpoint by which the entire surface of the earth can be seen at a single moment*. I take this to be a principle. The reader must decide for him or herself — but choose wisely.

From the standpoint of practicality, the central objects of science are its laws. But from the standpoint of understanding, simplicity, and concinnity, the central objects of science are its *theories*. A sound or validated theory has two criteria: It is logically consistent and it is in good correspondence with measurement. (Meaning that the logical predictions made from a theory are found to hold by the experimentalists to a high degree of accuracy on the domain of applicability of the theory.) The correspondence with measurement means that whenever a statement of the theory has physical content (i.e., makes a “prediction” of the value of some measurement of the physical realm) then that measurement is in close agreement with the prediction.

To be useful in science, a scientific theory must make at least one prediction that is testable by experiment (or any act of measurement). If the purpose of a new theory is merely to find a new foundation to existing data or phenomena, it may not even produce novel predictions.

The human appeal to theories generally is that they explain how things happen, usually in terms of cause-and-effect. But from the logical point of view, how do they ‘explain’? They explain phenomena in terms of the theory’s formal point of view (its prefoundational biases/constraints) and the axioms at its foundation. Thus, the Lorentz ether theory ‘explains’ Lorentz-Fitzgerald contraction of a moving rod as the closing of the intermolecular distances be-

tween molecules of the rod. Whereas, in special relativity, the contraction of the moving rod relative to its measured length in the rest frame of the rod is a consequence of the fact that observers in the two frames of reference do not agree on the simultaneity of events during the measuring process.

Embedded in the very notion of a ‘measurable variable’ is recognition of exactly how the measurement is to be made. It is naive to think that how a variable gets measured can be taken for granted. This form of definition of variables in terms of their procedures of making a measurement of the variable is called an *operational definition*. Thus, time is what a clock measures it to be, and space is what a ruler says it is, according to some operational definition. If there is more than one way to make a measurement of a given variable, one must ensure consistency between them.

Question: Is the term ‘Standard Model’ an appropriate name for today’s fundamental theory of particle physics?

Answer: Yes. As I have defined the terms above, *model* and *theory* are not mutually exclusive. The notion of a model is so broad that it easily covers the notion of a theory. In other words, a theory can be considered a representation of a collection of phenomena. Alternatively, every scientific theory contains at least one model, if only to describe the measuring instruments required for testing the theory.

2 The Formal Point of View

Ironic as it is, science cannot get by on just objective “truth” (in the form of empirical facts and laws induced on them, such as the Ideal Gas Law), which does not by itself provide a sufficiently focused platform for inventing a testable theory. We need to add to our objective “truth” certain subjective elements: biases, beliefs, rationalizations, dogmas, intuitions, etc. Einstein said:

In order to construct a theory, it is not enough to have a clear conception of the goal. One must also have a formal point of view which will sufficiently restrict the unlimited variety of possibilities.

— Found in: *Ideas and Opinions*, “The fundamentals of theoretical physics,” p. 328.

The first observation is that the principle of general relativity imposes exceedingly strong restrictions on the theoretical possibilities. Without this restrictive principle it would be practically impossible for anybody to hit upon the gravitational equations, not even by using the principle of special relativity, even though one knows that the field has to be described by a symmetric tensor. No amount of collection of facts could lead to these equations unless the principle of general relativity were used. This is the reason why all attempts

to obtain a deeper knowledge of the foundations of physics seem doomed to me unless the basic concepts are in accord with general relativity from the beginning. The situation makes it difficult to use our empirical knowledge, however comprehensive, in looking for the fundamental concepts and relations of physics, and it forces us to apply free speculation to a much greater extent than is presently assumed by most physicists. I do not see any reason to assume that the heuristic significance of the principle of general relativity is restricted to gravitation and that the rest of physics can be dealt with separately on the basis of special relativity, with the hope that later on the whole may be fitted consistently into the general relativistic scheme.

— Found in: “On the Generalized Theory of Gravitation,” A. Einstein, *Ideas and Opinions*, Three Rivers Press, p. 352.

3 Types of Theories

All theories are not constituted in the same manner. Einstein clarified what to him are the two major ways to found scientific theories, particularly in physics. The oldest way, started by Newton, is to start off by declaring the precise models or modeling strategies of a theories and then add to it whatever constraints one likes. The second, and more modern way to found a theory, is to present first the empirically established rules that the models of matter must adhere to, allowing, in principle, a larger scope of models and modeling strategies. As Einstein put it:

We can distinguish various kinds of theories in physics. Most of them are constructive. They attempt to build up a picture of the more complex phenomena out of the materials of a relatively simple formal scheme from which they start out. Thus the kinetic theory of gases seeks to reduce mechanical, thermal, and diffusional processes to movements of molecules – i.e., to build them up out of the hypothesis of molecular motion. When we say that we have succeeded in understanding a group of natural processes, we invariably mean that a constructive theory has been found which covers the processes in question.

Along with this most important class of theories there exists a second, which I will call “principle-theories.” These employ the analytic, not the synthetic, method. The elements which form their bases and starting-point are not hypothetically constructed but empirically discovered ones, general characteristics of natural processes, principles that give rise to mathematically formulated criteria which the separate processes or the theoretical representations of them have to satisfy. Thus the science of thermodynamics seeks by analytical means to deduce necessary conditions, which separate events have to

satisfy, from the universally experienced fact that perpetual motion is impossible.

The advantages of the constructive theory are completeness, adaptability, and clearness, those of the principle theory are logical perfection and security of the foundations.

— Found in: “What is the Theory of Relativity?”, Einstein, *Ideas and Opinions*, Three Rivers Press, pp. 228–9.

4 That’s Only a Theory!

Who is allowed to make a theory? Of course, scientists make theories. Mathematicians make theories. Criminologists and prosecuting attorneys make theories. In fact, anyone can make a theory.

When Columbo tells his prime suspect his current theory on how and why the suspect killed the deceased, the suspect can claim, “Oh, that’s only a theory. You can’t prove any of it.”

When a physicist claims that special relativity is true, someone out there is going to counterclaim, “Oh, that’s only a theory. You can’t prove any of it.”

When a mathematician claims that the Axiom of Infinity is a valid starting point to build a theory of mathematics, someone out there who is skittish about actual infinity is going to complain that, “That’s only a theory. You can’t prove actual infinity exists and therefore the theory is bogus.”

The problem here is that the term ‘theory’ is used in different ways. Above, I tried to define the term quite technically as an ‘explanation based on axioms and their implied conclusions (necessary inferences)’. But, the term ‘theory’ can also mean, quite nebulously, ‘a cohesive body of knowledge.’

Einstein has claimed that there is no unique theory that can account for a set of experimental facts. If that is true, how can anyone claim that a given theory is true? What would such a claim mean? Would it mean that the predictions of the theory are true? Or, would it mean that both the predictions and the assumptions of the theory are true?”

If we’re going to talk about truth in science, we need a philosophical theory of truth, and that’s referred to as *epistemology*. I think it is arrogant for a scientist to declare that “theory X is an established fact, no longer allowed any forum of dissent or re-evaluation.” Replace the X with whatever theory you want. So, when a biologist, geologist, or physicist declares that Darwinian evolution (in whatever form you like) is a **fact**, no wonder creationists rebel and counter with, “That’s only a theory.” But both sides are wrong. Both sides don’t understand the difference between a scientific theory and a scientific fact.

A scientific fact can come in either of two forms: 1) A datum collected by experimentation or by direct human observation (and then vetted by scientific authorities), and 2) empirical principles, which I have already defined above.

So, data and novel hypotheses can, by vetting, be promoted to *factual* status; whereas, novel theories can, by vetting, be promoted to *validated theories*. If

scientists are going to conflate theories and facts, they ought to quit claiming to be nondogmatic.

5 Conclusion

The reader has, no doubt, already encountered definitions of Theory, Model, Law, and Hypothesis, and they are probably very different from what I've presented here. If you implicitly use the definitions I've presented here in your writings, you may confuse your readers. Therefore, I suggest that you explicitly define these terms so as not to frustrate your readers.