The Art of Counterfactual Thinking in Physics

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> Some men see things as they are and ask, *Why?* Others dream things that never were and ask, *Why not?*
> — G. B. Shaw

Abstract

Counterfactual thinking involves treating as false a fact of the world. We'll see how Einstein, Heisenberg, and others used counterfactual thinking as a heuristic to create whole new way of looking at the physical world.

1 Introduction

Counterfactual thinking involves treating as false a fact of the world. Now, a "fact" is merely a statement of empirical content that is accepted as true by the majority of a population or by at least a majority of experts in some field, or a personal truth about the world. It may seem at first that counterfactual thinking should have no value in physics, but we will soon see that its value lies in its ability to allow us to see the world with fewer constraints. It serves a heuristic purpose.

Some people have a real problem with the notion of counterfactual thinking, as though it is a sin against reason itself. Well, it depends on what it's used for. What about the person who sets his clock ahead by five minutes so as not to miss appointments. That's counterfactual thinking, and it works for some people. Consider this situation: An opponent of counterfactual thinking is sure she put her house keys on the table in the den, but she can't find it there now. Her friend tells her to imagine where she would have put the keys if she had not put them on the table in the den. She replies that she won't even consider it because to her it is a fact that she put the keys on the table in the den. However, her friend protests that she could be mistaken and asks what harm this subjunctive thinking will be.[1] She replies with the platitude that such counterfactual thinking is a sin against reason. But, sometimes it works.

[1] The subjunctive mood indicates unreality in some sense, such as, What if you didn't leave them on the table?

2 Heisenberg and Einstein

In 1932, Heisenberg pondered why the masses of the proton and the neutron should be so close to each other. He thought up the idea of isospin (short for isotopic spin) by supposing what the world of subatomic particles would be like if there was no electromagnetic force or charge. In particular, if there were no electric field of the proton, would it still be distinguishable from the neutron. In other words, he imagined that the proton and neutron were just two forms of the 'same' particles, called a nucleon. Here's a description of the insight Heisenberg had from an article (Elementary Particles) by Murray Gell-Mann and E. P. Rosenbaum (Appeared in *Scientific American*, Reprinted in "Particles and Fields" (a collection of articles) W. H. Freeman and Company, 1980. p. 33)

Now, in the early days of modern nuclear physics—the strong forces between two protons, two neutrons, or a proton and a neutron are all equal. This phenomenon, called charge independence, means that so far as strong interactions are concerned the neutron and proton look like the same particle. They can be distinguished only by their electromagnetic interaction. Suppose electromagnetism could be "turned off", like turning off a magnetic field in the laboratory. Then the proton and neutron would also degenerate into indistinguishability, right? This behavior strengthens Heisenberg's claim that we should formally treat the nucleon as sort of a "doublet," with one state representing the proton and the other the neutron.

And here's another analogy from Einstein on his counterfactual thinking regarding the "true nature" of the electromagnetic field equations in empty space, arguing against the "factuality" of their linearity:

> What can be attempted with some hope of success in view of the presents situation of physical theory? At this point it is the experiences with the theory of gravitation which determine my expectations. These equations give, from my [formal] point of view, more warrant for the expectation to assert something precise than all other equations of physics. One may, for example, call on Maxwell's equations of empty space by way of comparison. These are formulations which coincide with the experiences of infinitely weak electromagnetic fields. This empirical origin already determines their linear form; it has, however, already been emphasized above that the true laws can not be linear. Such linear laws fulfill the superposition-principle for their solutions, but contain no assertions concerning the interaction of elementary bodies. The true laws can not be linear nor can they be derived from such.
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> Found in: A. Einstein, *Albert Einstein: Philosopher-Scientist*, Vol 1, Autobiographical Notes, p. 89.

Einstein argued in 1905 that space and time do not have an independent reality in physics, as it had been assumed to be true at that time.

Let's play some more *What if?* thinking.

• What if light is not a wave? thought Einstein.

• What if particles are not unwave-like objects? thought de Broglie.

• What if the earth is not the center of the universe? thought Copernicus.

• What if stars are not just the peeking through of light from beyond the celestial sphere?

• What if orbiting electrons in the atom do not continuously radiate energy according to classical electromagnetic theory? thought Bohr.

• What if quantum mechanics is nonlocal? thought Bell.

• What if parity is not conserved by the weak force? thought Chen-Ning Yang and Tsung-Dao Lee.

• What if position and momentum values cannot be simultaneously measured to arbitrary accuracy for subatomic particles? thought Heisenberg.

• What if physical concepts are not uniquely determined by the facts of the world? thought Einstein.

• What if atoms are not permanent? thought Marie and Pierre Curie.

3 Conclusion

I suppose the reader might feel disappointed that so far I have not offered the case of the young Einstein's imagining himself to move at the speed of light while chasing a light beam. He concluded that if he could do that, then he would see a standing light wave, but that is not ever what physicists see in the laboratory. However, though the constancy of the speed of light (locally) is considered to be fact at this time, it wasn't when Einstein engaged in that thought experiment. So, what status can we grant to imagining the same thought experiment for the physics students of today, since it is now considered counterfactual thinking? Very much, I'd say, because it offers the student *insight* into the nature of light and of special relativity and of the ability to free oneself to think counterfactually, though I doubt many physics professors would bother to point that out to his or her pupils.