Heisenberg’s Failed Prophecy for Particle Physics

James D. Wells

Scholardox E6 / February 15, 2002

Prominent politicians and writers have opined recently that the era of fundamental discoveries in the physical sciences has ended. It is especially troublesome to hear related views expressed by some of our distinguished colleagues. Usually the attacks are toward one particular subfield by a member from another subfield. Particle physics has been just one of the targets of this confused thinking.

Extreme pessimistic views about science progress have been with us since the very beginning of science. Distinguished scientists in their later years are not uncommon proponents. One example is Werner Heisenberg's view of particle physics in the late 1950's and early 1960's. It is instructive to see how little the arguments have changed against particle physics over more than four decades despite the staggering accomplishments the field has made since then. Heisenberg's fully developed views are summarized most succinctly in his 1963 talk, ``The Present Situation in the Theory of Elementary Particles'' delivered in Copenhagen.

Although Heisenberg did not have significant direct impact on particle physics progress in the post-war years, he was still an active researcher well into his sixties. His amazing pre-war discoveries in quantum mechanics put him permanently in the club of scientific genius and Nobel laureates who deserved to be taken seriously. Heisenberg's talk covered many interesting topics including the role of local field operators in any sensible axiomatic theory, the usefulness of symmetry classifications (isospin, parity, etc.), and the ubiquity of broken symmetries of the ground state. He clearly had an expert overview of the field.

Heisenberg was less impressive when he tried to extrapolate the current knowledge into a vision for the future of the field. A major theme in his talk was that the era of high-energy physics was over. Although he hedged slightly here and there on making this claim too strongly, he said it with as much force as an esteemed scientist can say anything speculative and still sound reasonable.

He began the talk by asking the rhetorical question, What is an elementary particle? The old answer to this question says that elementary particles are the smallest indivisible units of matter. The past brought the successes of watching bulk material reduced to atoms, atoms reduced to electrons and nuclei, and nuclei to protons and neutrons. The trend must continue indefinitely, it would seem to the naive observer.

But the reductionist trend has ended, according to Heisenberg. The “big accelerators" at Berkeley, Dubna, Geneva, and Brookhaven were only seeing more of the same stuff. The particles they were seeing were “not smaller units of matter", but rather “the same kinds of elementary particles." He admonished his fellow scientists to not think of elementary particles as a collection of fundamental building blocks. Instead, they are “just different forms of the same ‘substance'." He further claimed that all the elementary particles were likely to be merely stationary states of a “system matter" analogous to energy levels of an atom. “No distinction can be made in principle between an elementary particle and a compound system," he claimed.

These perspectives, which he was quick to emphasize derive from experimental results, lead to an almost inescapable conclusion in Heisenberg's view:

> *If these results will be confirmed, it would mean that at the elementary particles we have actually come to an end in dividing matter. Any further ‘division' or ‘splitting' of elementary particles would not lead to new or smaller particles; it would be pointless to use higher and higher energies in collisions, because nothing new will happen.*
>
> *This final result is not yet certain, but it looks rather probable. If it turns out to be correct, it would not mean that physics has been closed. Physics would be closed only at the limit of highest energies or smallest spatial dimensions. It would still be open in the limit of very large spatial dimensions (cosmology) or very large particle numbers (biology).*

Comments were recorded at the end of the talk, and Victor Weisskopf strongly objected to the view that high-energy physics was over. Weisskopf emphasized that “the universe presents us with possibilities that we just don't know of.'' Of course, we know now that Weisskopf was right.

Since that conference, quarks and asymptotic freedom have been discovered. The Fermi model of weak interactions has been pulled apart and explained by a spontaneously broken SU(2) gauge symmetry. More exotic quarks have been discovered, including the top quark whose mass is well into the energy realm where Heisenberg thought things would be uninteresting. Only very recently did we have well-posed questions about the origin of mass and gauge symmetry breaking, and it is widely agreed that present and future experimental pursuits will further enlighten us to answer these questions. We also believe we are making progress understanding how quantum mechanics and gravity coexist. The insights in particle theory have transferred over to cosmology, and vice versa, in completely unanticipatable ways from Heisenberg's day.

In most ways our current situation in particle physics is much more interesting than the state of particle physics those many years ago. We have readily identifiable big-question holes in our knowledge that we are confident experiment can fill. It did not seem so promising in that era, where the elementary particles looked like an endless herd of cattle kept in line by a limping sheepdog named Regge Theory, yet only a decade after Heisenberg's talk the Standard Model of particle physics was established.

Although Heisenberg was somewhat isolated by his own idiosynchratic theories, he was not alone in the general pessimistic view that future experiments were not likely to change the basics of our understanding. I see some parallels today. The overly confident optimist might be a little humorous, but the overly confident pessimist ``runs a danger'' as Weisskopf said after Heisenberg's talk those many years ago. The tremendous knowledge we have attained regarding the high-energy domain in the last few decades came at least in part because Heisenberg's bleak views in the 1950's and 1960's did not stop experiment.

For physicists like me, educated in the 1990's, it is not much of an exaggeration to say that modern high-energy physics starts becoming recognizable around the early 1970's. In Heisenberg's era it was difficult to even recognize the questions that would become relevant for the later discoveries, much less be able to figure out the correct answers. Experiment was critical for progress, and future experiments at the frontiers of energy, intensity and precision will continue to stimulate deeper knowledge about the underlying laws of nature.