The Absurd Idea of the Young Heisenberg: Observables

> It was around three o'clock in the morning when the final results of my calculations were before me. I felt profoundly shaken. I was so agitated that I could not sleep. I left the house and began walking slowly in the dark. I climbed on a rock overlooking the sea at the tip of the island, and waited for the sun to come up . . .[1]

I have often wondered what the thoughts and emotions of the young Heisenberg must have been as he clambered over that rock overlooking the sea, on the barren and wind-battered North Sea island of Helgoland, facing the vastness of the waves and awaiting the sunrise, after having been the first to glimpse one of the most vertiginous of Nature's secrets ever looked upon by humankind. He was twenty-three.

He was there seeking relief from the allergy that afflicted him. Helgoland – the name means Sacred Island – has virtually no trees, and very little pollen. ('Heligoland with its one tree,' as Joyce has it in *Ulysses*.) Perhaps the legends of the dreadful pirate Störtebeker hiding on the island, which he loved as a boy, were in his mind as well. But Heisenberg's main reason for being there was to immerse himself in the problem with which he was obsessed, the burning issue handed to him by Niels Bohr. He slept little and spent his time in solitude, trying to calculate something that would justify Bohr's incomprehensible rules. Every so often, he would take a break to climb over the island's rocks or learn by heart poetry from Goethe's *West–Eastern Divan*, the collection in which Germany's greatest poet sings his love for Islam.

Niels Bohr was already a renowned scientist. He had written formulas, simple but strange, that predicted the properties of chemical elements even before measuring them. They predicted, for instance, the frequency of light emitted by elements when heated: the colour they assume. This was a remarkable achievement. The formulas, however, were incomplete: they did not give, for instance, the intensity of the emitted light.

But above all, these formulas had about them something that was truly absurd. They assumed, for no good reason, that the electrons in atoms orbited around the nucleus only on *certain* precise orbits, at *certain* precise distances from the nucleus, with *certain* precise energies – before magically 'leaping' from one orbit to another. The first quantum leaps. Why only these orbits? Why these incongruous 'leaps' from one orbit to another? What force could possibly cause such bizarre behaviour as this?

The atom is the building block of everything. How does it work? How do the electrons move inside it? Scientists at the beginning of the century had been pondering these questions for more than a decade, without getting anywhere.

Like a Renaissance master painter in his studio, Bohr had gathered around him in Copenhagen the very best young physicists he could find, to work together on the mysteries of the atom. Among them was the brilliant Wolfgang Pauli – Heisenberg's extremely intelligent, pretty arrogant friend and former classmate. But Pauli had recommended Heisenberg to the great Bohr, saying that to make any real progress, he was needed. Bohr had taken his advice, and in the autumn of 1924 had brought Heisenberg to Copenhagen from Göttingen, where he was working as an assistant to the physicist Max Born. Heisenberg had spent a few months in Copenhagen, discussing with Bohr in front of blackboards covered with formulas. The young apprentice and the master had taken long walks together in the mountains, talking about the enigmas of the atom; about physics and philosophy.[2]

Heisenberg had steeped himself in the problem. It had become his obsession. Like the others, he had tried everything. Nothing worked. There seemed to be no reasonable force capable of guiding the electrons on Bohr's strange orbits, and in his peculiar leaps. And yet those orbits and those leaps really did lead to good predictions of atomic phenomena. Confusion.

Desperation pushes us to look for extreme solutions. On that island in the North Sea, in complete solitude, Heisenberg resolved to explore radical ideas.

It was with radical ideas, after all, that twenty years earlier Einstein had astonished the world. Einstein's radicalism had worked. Pauli and Heisenberg were enamoured of his physics. Einstein for them was a legend. Had the time perhaps come, they asked themselves, to hazard as radical a step, to escape from the impasse regarding electrons in atoms? Could they be the ones to take it? In your twenties, you can dream freely.

Einstein had shown that even our most rooted convictions can be wrong. What seems most obvious to us now might turn out not to be correct. Abandoning assumptions that seem self-evident can lead to greater understanding. He had taught that everything should be based on what we see, not on what we assume to be the case.

Pauli repeated these ideas to Heisenberg. The two young men had drunk deep of this poisoned honey. They had been following the discussions on the relation between reality and experience that ran through Austrian and German philosophy at the beginning of the century. Ernst Mach, who had exerted a decisive influence on Einstein, insisted that knowledge had to be based solely on observations, freed of any implicit 'metaphysical' assumption. These were the ingredients coming together in the young Heisenberg's thinking, like the chemical components of an explosive, as he isolated himself on Helgoland in the summer of 1925.

And here he had the idea. An idea that could only be had with the unfettered radicalism of the young. The idea that would transform physics in its entirety – together with the whole of science and our very conception of the world. An idea, I believe, that humanity has not yet fully absorbed.

ħħ

Heisenberg's leap is as daring as it is simple. No one has been able to find the force capable of causing the bizarre behaviour of electrons? Fine, let's stop searching for this new force. Let's use instead the force we are familiar with: the electric force that binds the electron to the nucleus. We cannot find new laws of motion to account for Bohr's orbits and his 'leaps'? Fine, let's stick with the laws of motion that we're familiar with, without altering them.

Let's change, instead, our way of thinking about the electron. Let's give up describing its movement. Let's describe *only what we can observe*: the light it emits. Let's base everything on quantities that are *observable*. This is the idea.

Heisenberg attempts to recalculate the behaviour of the