

Scientific Discovery: an Encounter of the “I” with Reality

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1. Introduction

Which common characteristics can be identified for all kinds of discoveries, and thus for the generation of novelty in human knowledge? This is a very provocative question for anyone, as it aims at individuating and describing the specific aspects that determine the onset of something “new” in the personal and general experience connected to any human enterprise. In the attempt to answer this question, I take a personal perspective, distilling some elements that, while emerging from my own experience as an experimental physicist, can be considered of a somehow more general relevance, and can therefore be offered as a useful contribution to a discussion. The paper is therefore organized using few “keywords” that correspond to what in my opinion are characteristic elements of scientific discovery. I describe these keywords by means of personal stories and examples, in order to highlight the human path that led me to identify these keywords. From time to time I will also quote words taken from famous scientists, but only as much as they express in a clearer way what my experience was.

2. Curiosity

At the origin of the road that eventually leads to scientific discovery there is an original attitude that any human being, in whatsoever situation and context, experiences: the attitude of being curious, i.e. interested in the surrounding reality, for no specific reason. It is a desire to know that normally manifests itself in the form of questions, which are asked not primarily because there is something to gain from the answers, but simply because there is an internal spring that urges to do so.

This attitude is definitely “built in” in our operating system, as becomes immediately obvious by considering how children deal with the world. Children are curious, they look around and every detail of reality that enters their horizon triggers their vivid interest, which immediately generates questions.

If I look back into my own experience, I can very well remember this human position in me as a kid. Actually, I have no memory of a time in which I was not curious. I was indeed



a very curious child, I used to ask thousands of questions on very different subjects, to such an extent that adults were somehow fearing me, because I could be very insistent and, moreover, very often they did not know the answers, and adults hate revealing that they do not know the answers (which turns out to be a big mistake). Questions usually originated from my own experience, the every day life of a young child part of a large family, having a lot of free time and a large yard around the house. For example, with my brother we used to challenge each other on who could dangle from a swing for a longer time with his head down. This is tough, because very soon the blood fills your head, until your eyes become red and you can hardly breath, so that at some point you have to quit. Mulling over this fact (why the hell can't we stay with the head down?), it suddenly popped into my mind that for the people from the other side of the world (I knew that the earth was spherical, we had a globe at home, with a light inside) that was a permanent status, so they had to be condemned to a miserable life with the head “full of blood” all the time. I perfectly remember the split second when I established this link from my simple, specific experience and a more general, relevant issue. I also remember that I asked my father this question, and that one evening he tried to answer, using the steering wheel of his old car as a model of the earth section. He tried hard to provide a reasonable answer, but my feeling, as a kid, was that he did not really have one. Since I loved my father and did not want to embarrass him, I did not push on that. The question though lasted in my head, and it took few years to get the real answer, based on the Newtonian idea of gravitation, which was perfectly adequate and satisfying. So I learned that there was a method, a way, through which I could get specific, exact answers to precise questions. This was one of the reasons why I decided to become a scientist: many of the questions that I had could find a convincing answer this way.

In one way or another, at the origin of every scientific discovery there is this human position that is very similar to that of a child in front of reality, full of curiosity and capable of establishing these sudden links between “local” and “general” questions. This consideration is by no means original, but was shared by many famous scientists, such as Isaac Newton:

“I don't know what I may seem to the world, but, as to myself, I seem to have been only like a boy playing on the sea shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.”^[1]

3. Attraction

It is important to go deeper into what is the origin of the human position described above. Curiosity in itself can express just a generic and shallow interest in everything, an instinctive position with no specific depth or real meaning. After all, it is curiosity that keeps million of people in front of their televisions watching reality shows.

So where does this curiosity towards reality come from? Where did it originate in me and in every other kid on earth? It is the sign of a deeper feeling, an elementary experience of every human being. It is the attraction that every one feels in front of reality. There is



something imprinted deep inside every human being that resonates with the rest of nature, and is strongly fascinated by it. This is an experience that every one has lived, so I do not need to explain it. It could happen at the top of mountain, reached after a long walk, when all of a sudden a great view of the surrounding valleys and mountain tops opens up. Or on a clear night, when it is possible to distinguish the Milky Way crossing the sky above. It is a repercussion of the beauty of reality, which attracts every bit of your being, provokes your reason and sets it in motion. The quest for knowledge, the desire to understand more about nature is just a natural consequence of this elementary experience. It is perfectly reasonable, even though not so easy to explain. Again, I have to resort to an example. On August 11, 1999, there was a total solar eclipse. Over 350 million people moved in Europe and Asia to watch it. There were colossal traffic jams in the eclipse region. I drove most of the night - over 500 Km - with my family and some friends, to reach a good spot close to Munich, just in time to watch the eclipse. Few moments and it was over, and then we had to start our return journey. What sense did it make? The phenomenon is well understood and described, is perfectly predictable and, indeed, very simple: the moon gets in between the earth and the sun, and there are few minutes of night during the day. It is as simple as that. But this description is not adequate to explain what we experienced. It was indeed an unbelievable event, with a mysterious, underlying beauty that was offered to us and filled us with wonder and gratitude. I cannot express it in a better way, but this is what really happened, and was a common experience: none of the people I know that travelled that night to watch the eclipse later regretted the effort. It was definitively worth it.

4. Correspondence

Science is an extraordinary method of acquiring knowledge that humanity has developed in response to this attraction towards nature. The object of our interest, reality, that attracts us in such a deep way is understandable, can be penetrated by our reason, which can unveil to some extent the order, the rules, the links that govern it at a deeper level.

This is a totally astonishing and unpredictable fact, as Einstein himself recognized:

"The very fact that the totality of our sense experiences is such that by means of thinking (operations with concepts, and the creation and use of definite functional relations between them, and the coordination of sense experiences to these concepts) it can be put in order, this fact is one which leaves us in awe, but which we shall never understand. One may say "the eternal mystery of the world is its comprehensibility."^[2]

Any scientific discovery involves the encounter of an "I" with reality, and the dynamics is similar to a situation when a very sharp tip is placed at some distance in front of a plane of unlimited dimensions. If an increasing voltage (the attraction) is set between the tip and the plane, at some point a spark shoots, filling for an instant the gap between them. The specific shape and the exact instant are unique and unpredictable (depending on a large number of parameters); moreover, both the plane and the tip are needed for the spark to exist. Similarly, scientific discovery is that specific moment in time and space when the gap



between the “I” and reality is filled, and a portion of reality gets disclosed to the reason of the researcher. The consequence of this “spark” is what I called “correspondence”, which is a word that needs explanation. Correspondence means “responding together”, and in this context is used to express the experience that the researcher feels when he/she realizes that nature “responds”: the quest for knowledge has an answer, a small or large part of the laws of nature is suddenly disclosed. Note that, at least qualitatively, this experience does not depend on the relevance of the specific scientific discovery, it comes before that. It has really to do with the wonder generated by the evidence that nature is comprehensible by us, somehow “corresponds” to our desire of knowledge, and slowly accepts to be unveiled by us. In an interview he gave some time ago, Andrew Wiles, the British mathematician who proved Fermat’s Last Theorem – a mathematical problem that awaited a solution for over 300 years - gives a precise description of this experience in his own life:

“I was sitting here at this desk. It was a Monday morning, September 19, and I was trying, convincing myself that it didn’t work, just seeing exactly what the problem was, when suddenly, totally unexpectedly, I had this incredible revelation...It was the most—the most important moment of my working life. Nothing I ever do again will. . . I’m sorry... It was so indescribably beautiful; it was so simple and so elegant, and I just stared in disbelief for twenty minutes. Then, during the day, I walked around the department. I’d keep coming back to my desk and looking to see if it was still there. It was still there.”

Andrew Wiles dedicated most of his scientific life to prove that no three positive integers a , b , and c can satisfy the equation $a^n + b^n = c^n$ for any integer value of n greater than two. It might seem exaggerated that he is almost moved to tears when he recalls the moment when the solution to this problem became clear to him, but any scientist knows that he is right. If I refer to my own scientific work, I have similar feelings when I think of the problem that I studied most, i.e. the reactivity of oxygen adsorbed on Rhodium, which we could describe in great detail, unravelling the underlying atomic mechanism, as shown in fig. 1^[3]. I do not want to emphasize the scientific relevance of that result – others should decide on that. But when I think of it, I have similar feelings to the ones Andrew Wiles expresses. It is a small portion of reality that revealed its secrets for the first time to me and my coworkers, and

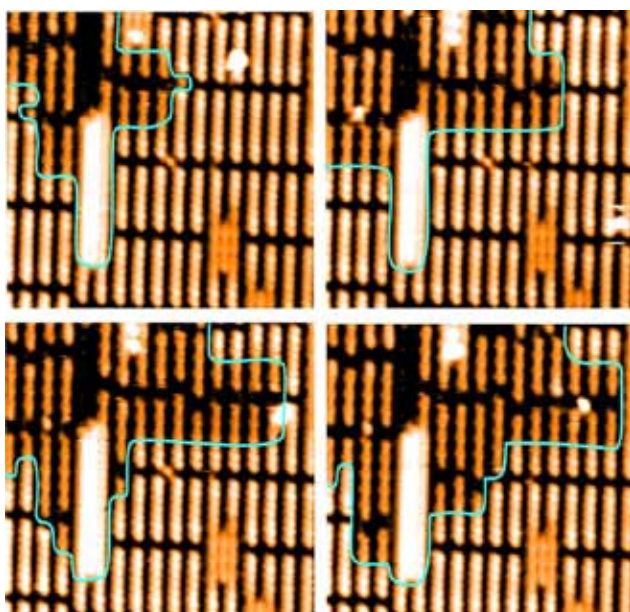


Fig. 1
Sequence of Scanning Tunneling Microscopy images recorded during a water formation reaction between oxygen and hydrogen atoms taking place on a $O-(10 \times 2)$ Rh [110] surface. The image size is $10 \times 10 \text{ nm}^2$. Individual atoms are visible; the reaction front is highlighted.



this fact generates a sense of correspondence that is pure and original, and precedes any consideration about the absolute value of the scientific discovery.

5. Fruitfulness

The final keyword I want to touch is the word “fruitfulness”. As I said, any scientific discovery is an event - something new that happens - and, as such, determines a small or big change of reality afterwards. Any scientific discovery therefore affects the world, beyond the intentions of the researcher. In that sense the experience of scientific discovery is similar to the experience of parenthood: parents are crucial for sons and daughters begin to life but, afterwards, the latter are by no means “theirs” or under their complete control, they grow and can (re)produce on their own. Every scientific discovery sheds light on a portion (small



Fig. 2

Top: View of the Elettra Laboratory in Basovizza (Trieste). FERMI@Elettra, the new Free Electron Laser presently under construction, is the long building to the right, imaged as an artist's impression. Bottom: The FERMI@Elettra team.

or big) of reality, and this fact is irreversible, offering the possibility of further progress to others, in a continuous process where light can generate further light, always passing through this mysterious and extraordinary encounter of an “I” with reality. Let me give an example of this fact, again related to my professional experience. In 1895 a German physicist, Wilhelm Conrad Röntgen, discovered a new kind of radiation, which he termed “X-Rays” and used to acquire the first radiographic images. About fifty years later, Charles H. Townes at Columbia University carried over a research program that eventually led to the invention of the Maser and Laser. We have had the unique opportunity to hear directly from him a live report of those days, and the human experience behind that discovery^[4]. In particular, he said that his research was always motivated by the attempt to generate radiation at shorter wavelengths, i.e. towards the X-rays region, a limit that seemed impossible to achieve for a laser. Remarkably, after about fifty years again, it is today possible to build accelerators, called Free Electron Lasers, that can generate laser radiation in the X-rays region, coupling in a single



device what Röntgen and Townes had been able to obtain. At present we are building at the Elettra Laboratory in Trieste one of the first new facilities of this kind, FERMI@Elettra, which should start commissioning at the end of 2010^[5]. A picture of the Elettra Laboratory with the new Free Electron Laser is reported in Fig. 2, together with the team (more than 100 people!) that is working at the FERMI@Elettra project. The discoveries of Röntgen and Townes are therefore generating today possibilities that they could not even have imagined, showing a “fruitfulness” that goes well beyond their original intentions.

6. Conclusions

Scientific discoveries are among the highest achievements of mankind. Despite the fact that specific discoveries can take place under very different conditions, there are elements that are common and appear therefore to be characteristics of this unique human adventure. Among these elements, Curiosity, Attraction, Correspondence, and Fruitfulness have been presented and described, as factors that can be found in the personal experience of any researcher, regardless of his/her importance and fame. A final example of this is the following citation from Max Planck, one of the most important physicists of the twentieth century, in which the reader can find a trace of some of the concepts presented in the paper.

<<But why all this enormous labor, demanding the best efforts of countless soldiers of science during their entire lives? Is the ultimate result—which, as we have seen, in its individual details always drifts away from the immediately given facts of life—truly worth this costly effort? These questions would indeed be justified if the meaning of exact science were limited to a certain gratification of man’s instinctive yearning for knowledge and insight. But its significance goes considerably deeper. The roots of exact science feed in the soil of human life...And he whom good fortune has permitted to co-operate in the erection of the edifice of exact science, will find his satisfaction and inner happiness, with our great poet Goethe, in the knowledge that he has explored the explorable and quietly venerates the inexplorable.”

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