SCIENCE AND THE HUMAN PREDICAMENT*

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Abstract

The centenary of Einstein's Year of Miracles is a good time to review in broad terms the increase in scientific knowledge and conceptual advances in our understanding of the physical universe over a century. Considering developments over a somewhat longer time frame, we appreciate better the evolving nature of human knowledge, and the meaning of understanding in science. The reinterpretation of Kantian ideas as suggested by Lorenz and Delbruck in the light of evolutionary theory, shows us the abilities and limitations with which we function, as well as our singular place in Nature. The predicament of the individual then emerges as a possible source for the important quality of compassion which is as essential for human existence as possession of knowledge.

The past century in science

This year is the centenary of Albert Einstein's "Annus Mirabilis", 1905. It may therefore be worthwhile to remind ourselves very selectively of where we were in physics in particular, and in science in general, a century ago, and what major

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advances have occurred since then. On the experimental side, the previous decade had seen the discoveries of X-rays, the electron and radioactivity. But around 1905 doubts were still expressed about the existence and reality of atoms. At the other end of the scale, even upto 1919, it was believed that the universe consisted of our Milky Way galaxy alone. The processes behind energy production in the sun and other stars were unknown, neither were there concepts and language to talk meaningfully about cosmology. It was still thought that the ether was necessary as a carrier of electromagnetic waves. The origins of spectra and of the laws of spectroscopy were unclear, as also the basic principles of chemistry. The Darwinian theory of evolution had been formulated in 1859 but the underlying mechanisms were unknown. The principles of genetics found by Gregor Mendel in 1865 had been forgotten, awaiting rediscovery by Hugo de Vries and others in 1900.

Today, even school children are aware of the enormous progress that has been made on all these fronts. Limiting oneself to the most major advances, one should mention the special and the general theories of relativity from 1905 and 1915 respectively, followed by quantum mechanics in 1925-26. This was preceded of course by the old quantum theory led by Planck, Einstein and Bohr. With the advent of special relativity, the ether was finally given up and electromagnetic radiation became an irreducible constituent of nature. The secrets behind spectroscopy, the periodic table of the elements, and the theoretical underpinnings of chemistry, were all revealed by quantum theory. As time went on, atomic, molecular, nuclear and elementary particle physics, as well as all processes involving radiation, became amenable to analysis. These led in turn to the whole domain of astrophysics, the understanding of stellar structure and evolution. Experimental discoveries resulted in a reappraisal of the size and content of the universe. Thus our Milky Way is only one of some one hundred billion galaxies, each with as many stars. From general relativity came the conceptual basis and tools for the subject of cosmology.

In the life sciences, the greatest advances have been in the field of genetics at the molecular level, leading to the material and mechanism on which Darwinian evolution works. The crowning achievement was the 1953 discovery of the structure of the genetic material, DNA, by Watson and Crick. Here the astonishing earlier work by Avery, Macleod and McCarty should also be mentioned. The upshot has been the realization of the great unity in all forms of life at the molecular level.

In this very brief listing, let me add Claude Shannon's classical theory of information from 1948 – a really beautiful mathematical analysis showing how to measure information and its transmission quantitatively. This has been the foundation on which the later information revolution has grown.

As far as practical applications of physics are concerned, we can say that in the first half of the 20th century it was mainly the exploitation of classical physics, for example in communication and transport. The fruits of quantum mechanics have come during the second half of the century, through the transistor revolution, the computer age, lasers and many medical applications.

Human knowledge – Kantian philosophy

I would now like to take you a little further back in time – to about two centuries ago – and trace the development of certain ideas in the form of a story. Towards the close of the 18^{th} century, the physical principles and methods established by Galileo and Newton had been repeatedly and remarkably successful in explaining many phenomena. Apart from the initial domain of astronomy, there were successes in fluid dynamics, elasticity, the theory of continuous media; and towards the end of the 1700's the monumental works of Laplace and Lagrange on celestial and analytical mechanics. Then the phenomena of electrostatics and magnetostatics also fell into the same pattern. Against a fixed space-time background, all processes were describable in a causal and deterministic way. All this advance was possible to a great extent by separating natural science from preconceived notions and, so to say, allowing the phenomena to speak for themselves. As Max Born characterized Galileo and Newton: "The distinctive quality of these great thinkers was their ability to free themselves from the metaphysical traditions of their time and to express the results of observations and experiments in a new mathematical language regardless of any philosophical preconceptions".

Nevertheless the great philosopher Immanuel Kant made a deep attempt to explain these successes of Galilean-Newtonian principles. He combined the rationalist and the empiricist ways of thinking to arrive at a synthesis, a new point of view towards the nature of human knowledge. Rationalism is the view that, in Plato's words,

"…. Knowledge of nature does not require observation and is attainable through reason alone",

while empiricism holds that the laws of nature can be found only through experience. In Kant's approach there is a subtle combination of the two: there are both internal and external components to the way we understand Nature through science. These are called respectively the `a priori' and the `a posteriori' elements of thought. `A priori' means `in advance of experience', `a posteriori' means `as a result of experience'. The a priori in turn consists of two parts: the analytic, which are statements of pure logic or definitions; and the synthetic, which have nontrivial content and are assertions about properties of the actual world. Kant's idea was that the synthetic a priori principles exist in our minds even before we have any experience of the world, they provide a framework within which alone experience can be handled. Here are some examples: the concepts of separate and absolute space and time in the sense of Newton; Euclidean geometry of space; ideas of causality and the permanence of matter; and in later forms, also Newton's 3rd Law of Motion and the Law of Conservation of Matter.

Kant thus made some of the important elements of Galilean-Newtonian science into inevitable features of the world. They became preconditions for science, not results of experience, hence their automatic and necessary validity.

During the succeeding decades and centuries, physics moved into new realms where some of the Galilean-Newtonian ideas had to be modified. These changes came about successively through the development in the 1800's of Faraday-Maxwell electrodynamics, the discovery of non-Euclidean geometry within mathematics, and then the developments of relativity and quantum mechanics. In contrast to the action-at-a-distance concept which was accepted in the 18th century, the concept of the field and action by contact came to centre stage. This happened first for electromagnetism in the 19th century, and later for gravitation in the 20th. The separate absoluteness of space and of time has been replaced by a unified space-time, with a new meaning for distant simultaneity. In the microscopic domain there is a single conservation law subsuming the earlier separate laws for mass and for energy. Geometry has become a dynamical entity within physics, and gravitation is described in a non-Euclidean framework. From the strict determinism and causality of classical physics, we have moved to an irreducible probabilistic element, a statistical form of causality in quantum mechanics. So in an understandable way exploration into new domains of nature have shown the limitations of the earlier framework and of the Kantian picture.

Nevertheless, the profound combination of rationalism and empiricism, the a priori and the a posteriori, in the Kantian approach remains fascinating. And one is led to wonder: how could it happen that the synthetic a priori principles, assumed to be present in our minds before we meet the world, fit so much of later experience so well? If not from experience, then where do they come from?

Lorenz, Delbruck and the World of Middle Dimensions

A very interesting, in fact captivating, explanation came in the 1940's through the work of Konrad Lorenz based on the ideas of Darwinian evolution. For a physicist this is sure to be fascinating, and I will describe it briefly in a moment. However, maintaining the chronological sequence, let me first present the views expressed by the mathematician David Hilbert, and then by the physicist Carl von Weiszacker, on these questions. These were in the 1930's, about a decade before Lorenz's work. At his retirement in 1930 Hilbert had this to say:

"I…… believe that mathematical knowledge depends ultimately on some kind of such intuitive insights….. Thus the most general basic thought of Kant's theory of knowledge retains its importance… But the line between that which we possess a priori and that for which experience is necessary must be drawn differently by us than by Kant…. Kant's a priori theory contains anthropomorphic dross from which it must be freed. After we remove that, only that a priori will remain which also is the foundation of pure mathematical knowledge".

This was a mathematician's perspective. In the case of physics, here is an interesting episode again from around 1930. The philosopher Grete Hermann visited Heisenberg and his colleagues to discuss the role of Kantian ideas in the new situation created by the discovery of quantum mechanics. Her argument was that according to Kant, the law of causality is a synthetic a priori, it is a precondition for scientific work; in today's language it is not negotiable. In that case how can quantum mechanics deny strict causality and yet be a part of science? Here is Weiszacker's summing up after intense discussions between the philosopher and the physicists:

"……Kant gave a correct account of the state of scientific knowledge in his time …. I believe that Kant's analysis of human understanding represents true knowledge, not some vague expression of opinion, and that it will apply whenever thinking beings enter into the kind of contact with their environment to which we refer as `experience'….. We should nevertheless remember that the very structure of human thought changes in the course of historical development. Science progresses not only because it helps to explain newly discovered facts, but also because it teaches us over and over again what the word `understanding' may mean".

I will return later particularly to the last part of this statement on the meaning of understanding Nature. Since this year is full of Einstein, you may wonder what he had to say on Kant. Unfortunately he is rather non-committal, as he said in 1922:

"Arbitrary concepts are necessary in order to construct science; as to whether these concepts are given a priori or are arbitrary conventions, I can say nothing".

However, on another occasion at about the same time he was quite categorical:

"I am convinced that the philosophers have had a harmful effect upon the progress of scientific thinking in removing certain fundamental concepts from the domain of empiricism, where they are under our control, to the intangible heights of the a priori.

Now to Lorenz's analysis from the 1940's and its later eloquent presentation by Max Delbruck in the 1970's. According to Darwinian ideas, as a species develops over many generations and immense periods of time, new abilities continually arise essentially at random. Of these, those beneficial to dealing with the external world and surviving in it are retained and passed on to succeeding generations, while the others are weeded out or discarded. Here we appreciate that this very slow process of evolution by natural selection takes place through interaction with a narrow range of natural phenomena, a limited range of scales of length, time and energy. These collectively define what is called the `World of Middle Dimensions' – it is in contact with this limited part of Nature that life and the abilities of species evolve. As we would expect, through this slow process of `phylogenetic evolution', living organisms retain and refine just those capacities that are `tuned to' the most important features of this part of the world, because only this is relevant to biological survival. Thus each species goes through a slow learning process involving countless generations. Ultimately our intuitive concepts of space, time, geometry, causality, nature and permanence of matter, all arise from the experience of the species with a limited part of nature.

This phylogenetic development over millions of years is now to be contrasted with `ontogenetic development' – what happens to an individual organism between birth and death, a much shorter span of time. Each individual comes into the world so to say with all these evolved capabilities given ready made at birth. What the species has learnt slowly through experience of the World of Middle Dimensions over millennia seems given to the individual as a set of finely tuned abilities in advance of experience. No wonder they are so well adapted to dealing with this limited part of Nature. But in ontogeny too there is a process of learning. The phylogenetic inheritance of each individual is the capacity, not the content, for knowledge adapted to the World of Middle Dimensions. The actual acquisition of such knowledge is largely completed during infancy and early childhood. Let me at this point quote from Delbruck:

"Lorenz pointed out that the empiricist argument that knowledge about the world can enter the mind only through experience is valid if we consider only the ontogenetic development of man…. But once we also take into account the phylogenetic development of the human brain through evolutionary history, it becomes clear that persons can know something of the world innately, prior to and independent of their own experience….. These ideas are indeed a priori for the individual, but they did not fall from heaven; they are matters of evolutionary adaptation, designed for survival in the real world…. What is a priori for individuals is a posteriori for the species…. Thus we see the world through multiple pairs of glasses: some of them are inherited as part of our physiological apparatus, others acquired from direct experiences as we proceed through life".

There are thus two forms or sources of knowledge from experience – of the species, and of the individual – so each is a posteriori. But species experience effectively becomes a priori from the individual's view point, as indicated in this table:

Knowledge from experience

	Nature of knowledge for species	Nature of knowledge for individual
Phylogenetic development, experience of species	a posteriori	a priori (capacity, not content)
Ontogenetic development, experience of individual	-	a posteriori

It is interesting that the philosopher of science Hans Reichenbach had made the following categorical statement in 1944 in a discussion of the philosophic foundations of quantum mechanics:

"We cannot admit that there is any synthetic a priori principle, ie., a principle which is not logically empty and which physical theory is bound to satisfy".

While this is undoubtedly true, we now see that such synthetic a priori can subtly reenter the scene in the manner outlined by Lorenz and Delbruck. The origins and roles of the a priori and the a posteriori are placed in perspective by the idea of Darwinian evolution guided by natural selection, in a way not available in Kant's time, but we can see better the depth of his thinking. These are relative terms intertwined with phylogenetic and ontogenetic development. We have this immense saga of species evolution and learning built up out of so many individual organisms, their births and learning experiences and deaths, so many links in a vast chain of life, so much like a play within a play!

Let me return briefly to Einstein's remark of 1922. We now see that the capacity of the human mind to create new concepts is a result of evolution guided by natural selection, but it has gone far beyond immediate biological need. What is however amazing is that this capacity seems essential to discover the way Nature works. In that sense it is not wasted. Our desire to understand Nature needs this capacity for its fulfillment. Thus ultimately Einstein's somewhat noncommittal view about Kant has this link to the Lorenz-Delbruck analysis. The situation is beautifully captured in Julian Schwinger's words:

"It is remarkable how Nature aids mankind's groping towards an understanding of the universe. As we raise the level of our scientific skills and sharpen our artificial senses, fascinating new phenomena continue to appear, testing and challenging our growing comprehension of Nature's grand design".

The meaning of understanding Nature

With this background we can see why when we explore Nature in the microscopic and macroscopic domains far from our own scale, we find strange features clashing so strongly with our intuition. But then, how could we expect Nature to appear the same at all scales of length, mass and time? It becomes extremely difficult, especially in the quantum domain, to picture what is going on – because our abilities to make mental pictures were fashioned for a very different domain! So in these extreme reaches of Nature we have to rely increasingly on mathematical structures as our principal guides.

It is in this context that I go back to von Weiszacker's remarks on the changing meaning of the phrase `understanding Nature'. We can see the truth of this in many instances. When Newton found an action-at-a-distance description of gravity, he privately expressed difficulty in accepting it, but it worked. Then as a result of a century of successes it became the universal paradigm, readily extended to electric and magnetic forces. But at the next stage the field concept came in, and with it a return to notions of continuity and action by contact, only to be challenged later by the photon picture of light. The ether was presumed to be the carrier of electromagnetic waves for a long time, only to be given up after relativity. In quantum mechanics the subtle notions of states and physical quantities are far removed from our intuitive Middle World ideas, it is impossible to make any reliable mental pictures at all. Each success in mathematical description has been at the cost of concrete visualization of the kind one had become accustomed to. Step by step, questions earlier considered meaningful and answerable have turned into grammatically admissible but physically meaningless sentences. No wonder that Heisenberg admitted:

"Almost every progress in science has been paid for by a sacrifice, for almost every new intellectual achievement previous positions and conceptions had to be given up. Thus, in a way, the increase of knowledge and insight diminishes continually the scientist's claim on `understanding' Nature".

<u>Our place in the universe</u>

May be now you see why my title has the phrase `the Human Predicament'. Here we are, the results of biological evolution occupying an incredibly tiny niche in an immense universe, with elementary particles at one end and clusters of galaxies at the other, a range of about forty four orders of magnitude. Even within the four billion year old saga of life, we have been around for an incredibly short period of time – the hominid line is only about five million years old, and within that homo sapiens is a mere two hundred thousand years old. These may seem like long stretches of time in terms of one individual life span, but they are no more than like the twinkling of an eye in the billion year scale of life. And as far as we can tell, even our own appearance on the scene seems to have been a result of chance, not of necessity. We inherit the abilities as well as the limitations fashioned by phylogenetic evolution, and then seek to understand something far grander than ourselves in every sense. And yet we seem – at least to ourselves – to be succeeding surprisingly well.

This way of viewing ourselves in relation to Nature shows us how lonely we are as a species, how small a part of an immensity outside. Judged against the vastness of Nature, it is difficult to believe that we are central to it.

In spite of this realization, we may try to find a basis for moral and ethical principles – so important to govern our collective existence – in our scientific understanding of the universe. This is a swing from an external to an internal view of the situation, of our predicament. But here we find no solace. In Erwin Schrodinger's eloquent words:

"…..the scientific world view contains of itself no ethical values, no aesthetical values, not a word about our ultimate scope or destination, and no God…"

Einstein was even more categorical:

"…..every attempt to reduce ethics to scientific formulae must fail".

At this point we become aware of an amazing parallel between the profound loneliness of humankind as a component of the universe, and the sense of loneliness surrounding each individual human being, which is equally profound. There are deep uncrossable limits to communication between individuals. We believe we all `see' the same colours, `hear' the same sounds, and think similar thoughts; but never can we ever know that this is so. To put across this point as forcefully as possible I turn to the writings of others because they say so much better what I too feel. In C.P.Snow's essay on `The Two Cultures' there is this passage:

“Most of the scientists I have known well have felt-just as deeply as the nonscientists I have known well – that the individual condition of each of us is tragic. Each of us is alone: sometimes we escape from solitariness, through love or affection or perhaps creative moments, but these triumphs of life are pools of light we make for ourselves while the edge of the road is black: each of us dies alone…. Each of us is solitary”

Against this background he nevertheless sees value in trying to do something for the collective good. This solitariness is even more poignantly expressed by Schrodinger in his book `My View of the World’. Here are several passages that do so:

“….. each person’s sense world is strictly private and not directly accessible to anyone else…..”

“……that inexorable, absolute division between spheres of consciousness….”

“….breaking through that privacy and separateness on which we have touched so often….. that is impossible”.

“…..the inexorable separateness of spheres of consciousness, and their total and impenetrable exclusion of each other…..”

And yet, as social beings created by evolution, we crave contact and companionship. Einstein put it this way:

“Man is, at one and the same time, a solitary and a social being”.

In spite of this loneliness, there is the possibility of some degree of communication between individuals, and a surprising degree of apparent commonality in the pictures of the world they separately create.

This whole situation seems so paradoxical – so much apparently shared collective knowledge, and yet an unbridgeable gulf, a separateness between individuals. I am inclined to conclude that, though science itself as an intellectual effort is unable to lead to feelings of a moral or ethical nature, these can arise from a feeling of compassion that each of us should have towards every other, since we are each in the same predicament. That word again! One of Einstein’s frequently quoted lines is:

“Science without religion is lame, religion without science is blind”.

However I feel a sense of starkness in these words. Expand `science’ to the more inclusive word `knowledge’, and replace `religion’ by the more gentle word `compassion’. You are then led to this statement from Victor Weisskopf which is more deeply meaningful, humane and wise:

"Human existence is based upon two pillars: compassion and knowledge. Compassion without knowledge is ineffective; knowledge without compassion is inhuman".

That is our predicament. Both components are essential to our functioning, and possibly the scientist has the greater chance of grasping this truth and therefore the greater responsibility.