A Brief History of Science
Part 12: The Rise and Fall of Positivism

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The Advent of Positivism

We have seen earlier that post-Renaissance development of science relied, to a large extent, on empirical evidence in order to dispel common misconceptions held since antiquity. Francis Bacon advised scientists to gather empirical data on a large scale. In order to build a more complex body of knowledge from these direct observations, he recommended the use of inductive reasoning (making generalizations based on individual instances). This approach saw quite a bit of success in the following century. Thus, the mood of the time was to rely on empirical evidence in judging truth.

This line of thinking was formalized by John Locke and David Hume in England, by theorizing that all knowledge derives from sense experience. This point of view, called empiricism, says that all concepts are about or applicable to things that can be experienced. All rationally acceptable beliefs or propositions are justifiable or knowable only through experience, also called *a posteriori* knowledge.

But what is amenable to sense experience? In Germany, Immanuel Kant (1724-1804) considered this question. His opinion was that corporeally existing things, by themselves, are not amenable to sense experience; only parts or aspects of it are. For example, we can experience the taste, smell, colour, and other aspects of an apple. But the apple is not a sum-total of these sense experiences about it. It is something else. This, he said, is the 'thing-in-itself', and the aspects that we have access to through our sense experience constitute, in his language, the 'thing-for-us'. He proposed this as a general concept: in everything that are subjects of scientific investigation, there are 'things-in-themselves' and 'things-for-us', the former being unknowable while we try to make sense of the world through the latter.

We have seen that in the early part of the 19th century there was great advancement in different branches of science. With that, scientists faced the question of epistemology: how do we come to know? What is the correct way of knowing, or of investigating phenomena? At that time a viewpoint developed in continuation of the empiricist tradition that was to exert enormous influence on the scientific community in the latter part of the 19th century. It was called positivism.

The initial proponent of positivism was the French philosopher and social scientist Auguste Comte (1798-1857) who described his ideas in his books 'The Course in Positive Philosophy' and 'A General View of Positivism'. The term 'positivism', coined by Comte, derives from the emphasis on the positive sciences—that is, on tested and systematized experience rather than on undisciplined metaphysical speculation.

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August Comte (1798-1857)

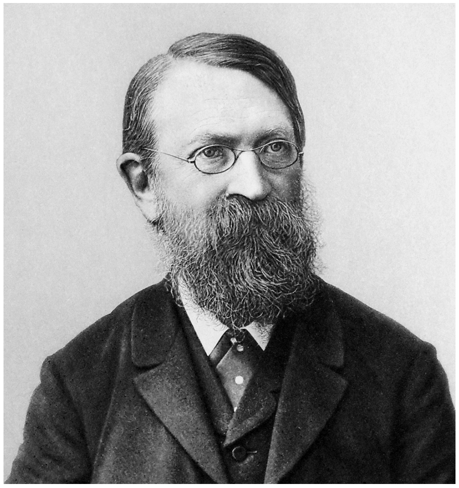
According to him, techniques for investigating phenomena should be based on gathering observable, empirical, and measurable evidence, subject to specific principles of reasoning. In the study of social sciences, he stressed the adoption of a 'value-free' or objective approach to the study of humanity that shares much in common with methods employed in the natural sciences, as contrasted with speculation of how things should or ought to be.

In the later part of the 19th century, the doctrine of positivism was further developed by Richard Avenarius (1843-1896) in Switzerland, and especially by the famous scientist Ernst Mach (1838-1916) in Austria. Their viewpoint is also known as empirio-criticism. For them, the answer to the question "How do we know?" was: we know with the help of our sense perceptions. Our knowledge about anything is nothing but a combination of sensations received from that thing. The nerves carry these sensations to the brain, and the brain forms perception about that object using these signals. That is why, they said, sense experience is the only reliable source material for forming knowledge.

They insisted on a strict adherence to empirical data. According to them, the goal of knowledge is to describe the phenomena that we experience. The purpose of science is simply to stick to what we can observe and measure. Knowledge of anything beyond that, a positivist would hold, is impossible. Kant had divided the physical world into things-in-themselves and things-for-us, but believed in existence of the things-in-themselves. Mach went a step further and renounced even formal recognition of real material objects. According to Mach, taking any step beyond what is given by sensory data would tantamount to metaphysical speculation. "The materialists, we are told, recognise something unthinkable and unknowable—'things-in-themselves'—matter 'outside of experience' and outside of our knowledge. They lapse into genuine mysticism by admitting the existence of something beyond, something transcending the bounds of experience and knowledge."

The essence of positivism is to say that our knowledge of the world, which starts from our sensations and sense-impressions, can never extend to anything beyond those sense-impressions, and that the job of science is simply to correlate observational data. The famous physicist Arthur Eddington said that the data of physics consisted in "pointer-readings and similar indications"; the physicist could never say what lay behind those observations; all he could do, or needed to do, was to state their correlations. The real world could never be known to science. The positivists opined that science should concern itself only with the 'observables,' for, in their opinion, what cannot be observed is not real.

As a result, positivists could not accept the idea of causality. According to positivists, causality is nothing but a useful word to use when correlating observations. But since all we can observe are the repeated occurrence of events in a definite sequence (for example, cloud and rain),



Ernst Mach (1838-1916)

science can only document the sequential occurrence of events and cannot infer the existence of any real, objective causal connection.

On the face of it, the strict adherence to empirical data obtained from sense perceptions (enhanced with the aid of instruments) seems to be a correct scientific standpoint. After all, this can be used to dispel many unscientific beliefs. To the question "do ghosts exist?", a scientist would say "no, because we do not perceive a ghost through our sense perception." That is why, most scientists in the later part of the 19th century were swayed by the positivist argument, and this approach became the de-facto 'scientific method'.

Even though this line of thinking sounds materialistic, in actuality it stands in sharp contrast to materialism. Materialists hold that the universe is composed of matter, the material world exists independently of our consciousness, and there is nothing supra-matter in this material world. The multitude of phenomena which science investigates is nothing but different forms of matter in motion. That is why they hold that all truths are to be found in the properties of matter and the interactions between its different forms. The sharp line of difference between the positivists and materialists was that the first group refused to treat anything as real unless it is observable, while the second group argued that since matter exists independently of our consciousness, the reality of any concept does not depend on our ability to observe it. The way to reach the underlying reality of phenomena is through theory-building, and by testing the theories objectively.

The Development of Science, 1870-1900

What was the intellectual climate in the later part of the 19th century? Idealism was still very strongly entrenched in common peoples' minds. Materialism had overcome the shortcomings of mechanical materialism and metaphysics, and was spreading among the rationally minded people and among the scientists. But at the same time the positivist philosophy emerged, received wide publicity, and was gaining prominence as the guiding principle of science.

The materialists' emphasis on objectivity helped dispel many unfounded beliefs. The positivist approach gave impetus to experimental research and data collection. This resulted in many important discoveries and technological inventions in the period from 1870 to 1900. Here we list some of the important advancements that occurred in this period.

There was a speculative idea prevalent at that time, that the development of an individual embryo repeated the same evolutionary stages of its ancestors. Wilhelm His (1831-1904) rejected this idea and sought to discover the physical and chemical causes for embryonic development. His new experimental approach gained many followers, who studied the internal responses of an egg to an altered physical environment. Thus, over the period 1875-1900, embryology became an experimental science.

It was a prevalent belief at that time that epidemic diseases were caused by something called *miasma*, a noxious form of 'bad air' emanating from rotting organic matter. Louis Pasteur (1822-1895) experimentally showed that this belief was false, and that most infectious diseases are carried by micro-organisms or germs. He showed that germs do not grow spontaneously; these can originate only from other germs. Thereby he established the germ theory of diseases and revolutionized medical science. Following his lead, Robert Koch (1843-1910) studied the bacteria that cause diseases like tuberculosis, cholera and anthrax, and established the experimental techniques of bacteriology. By 1880, the miasma theory was abandoned. Viruses were discovered in the 1890s.

The cathode ray was first observed in 1869 by German physicist Johann Hittorf, and was named in 1876 by Eugen Goldstein. The study of cathode rays revealed many new aspects including the eventual discovery of the electron in 1897 by Joseph John Thomson (1856-1940). Thomson's novel experiments on the properties of cathode rays passing through gases led him to conclude that these were minute particles carrying negative charges. Photoelectric effect was first observed in 1887 by Heinrich Hertz (1857-1894). The German physicist Philip Lenard conducted detailed experiments on the photoelectric effect. But the results remained unexplained for a long time.

At that time it was believed that there was a substance called 'ether' that pervades all of space, and light and other electromagnetic waves are waves in this ether medium. If that be so, the velocity of light as seen from bodies moving with different velocities, i.e., the relative velocities, should be different. In 1887 the American scientists Albert Michelson and Edward Morley tried to detect the relative velocity of light using the motion of the Earth in its orbit employing a very precise spectrometer. They found that the velocity of light through vacuum is the same irrespective of the motion of the observer. This result also remained a mystery for a long time.

In 1896 Henri Becquerel of France was using naturally fluorescent minerals to study the properties of x-rays, which had been discovered in 1895 by Wilhelm Roentgen. He exposed a uranium compound—potassium uranyl sulfate—to sunlight and then placed it on photographic plates wrapped in black paper, believing that the uranium absorbed the sun's energy and then emitted it as x-rays. He found that even when the compound was not exposed to sunlight, it darkened the photographic plates. Thus he serendipitously discovered radioactivity. Subsequently he carefully analyzed the nature of the radiation and showed that it contains charged particles; hence could not be x-rays. Ernst Rutherford conducted further experiments on these rays, and named them alpha, beta, and gamma rays.

Quite a few technological inventions were made in this period that dramatically changed the life-style of people. The electrical generator was invented by Werner von Siemens in 1866. In 1878 Thomas Edison improved the design of the incandescent lamp and made it commercially usable. In 1882, Edison introduced the 110V direct current electrical power supply system in the United States. The Serbian engineer Nicola Tesla immigrated to the United States in 1884. He invented the transformer and the AC induction motor, and using these, the Westinghouse Electric Company introduced the alternating current power supply system in 1888. From the 1890s, electrical power was introduced in most of the industrialized countries. The telephone was invented in the 1870s by Alexander Graham Bell and Elisha Gray. Motor vehicles using internal combustion engines were invented by Gottlieb Daimler in 1885-86. The German engineer Carl von Linde invented a continuous process of liquefying gases in large quantities, which formed a basis for the modern technology of refrigeration. He developed refrigerators employing methyl ether (1874) and ammonia (1876) as refrigerant.

The Impact of Positivism on the Development of Science

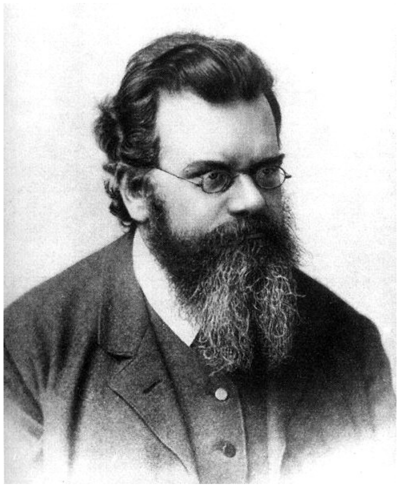
In spite of these advancements in experimental science and technology, it is noticeable that not much theoretical development occurred in the last three decades of the 19th century. The last major theoretical development in biology was Darwin's theory of evolution (1859), that in physics was Maxwell's theory of electromagnetism (1862), and that in chemistry was Mendeleev's periodic table (1869). What was blocking the development of theoretical sciences?

To probe this issue, let us take the case of statistical mechanics in general and kinetic theory of gases in particular. We know that the English scientist John Dalton proposed the atomic theory—which was a major theoretical breakthrough in the first decade of the 19th century. Dalton said that if we continue breaking up any piece of matter into smaller and smaller pieces, in the end we will get tiny particles called atoms, and there are only a few "species" of atoms. All atoms of a given element are identical in mass and properties. Compounds are formed by a combination of two or more different kinds of atoms, and a chemical reaction is nothing but a rearrangement of atoms. This theory helped chemists understand chemical reactions. That is why the chemists started using the theory out of practical necessity.

But most physicists did not recognize the existence of atoms and molecules. From the positivist viewpoint they asked: Have you ever seen a molecule or an atom? Has anybody ever experienced it through sense perceptions? If not, there is no reason to believe that atoms and molecules actually exist. True, that concept helps chemists in their calculation of proportions. But it should not be taken as anything more than a convenient tool of imagination.

Still, a few physicists started using these ideas to develop the kinetic theory of gases. They assumed that gases were made of innumerable small molecules moving randomly at high speed, and then argued that the behaviour of the gas in terms of the relationships between pressure, temperature and volume could be explained on the basis of the average motion of molecules. In 1856 August Kronig (1822-1879) of Germany created a simple model, by considering the translational motion of the particles. The next year, Rudolf Clausius developed a more sophisticated version of the theory by including rotational and vibrational molecular motions as well. In 1859, after reading a paper by Clausius, James Clerk Maxwell formulated the famous Maxwell distribution of molecular velocities, which gave the proportion of molecules having a certain velocity in a specific range. This was the first-ever statistical law in physics. In 1871, Ludwig Boltzmann generalized Maxwell's achievement and formulated the Maxwell-Boltzmann distribution. He also formulated the concept of entropy in mathematical terms, based on probability theory.

These were works of path-breaking importance, as shown by the later developments in physics. But Maxwell and Boltz-



Ludwig Boltzmann (1844-1906)

mann were severely criticized by positivists. The physicist Mach and the chemist Ostwald were particularly unsparing in their criticism of Boltzmann. In 1895 Wilhelm Ostwald gave a talk under the title "The Overcoming of Scientific Materialism" in the city of Lubeck (and later published a book with that title) in which he identified the belief in atoms and molecules with the philosophy of scientific materialism, and attacked both. During Boltzmann's lifetime the physics community did not accept his theory. Why? Because molecules were treated only as figments of imagination. Maxwell and Boltzmann had committed the 'error' of basing their theory on something that were not observable. Boltzmann appealed to the famous scientist Max Planck for support, but did not get it, because at that time Planck was also influenced by the positivist philosophy. Boltzmann was so heartbroken at this rejection of the work of his lifetime that he committed suicide. Such was the influence of the positivist doctrine on physicists.

The Nobel Prize winning scientist Steven Weinberg commented on this episode in his book 'Dreams of a Final Theory' : "Positivism was at the heart of the opposition to the atomic theory at the turn of the twentieth century. The nineteenth century had seen a wonderful refinement of the old ideas of Democritus and Leucippus that all matter is composed of atoms, and the atomic theory had been used by John Dalton and Amadeo Avogadro and their successors to make sense of the rules of chemistry, the properties of gases and the nature of heat. Atomic theory had become part of the ordinary language of physics and chemistry. Yet the positivist followers of Mach regarded this as a departure from the proper procedure of science because these atoms could not be observed with any technique that was then imaginable. The positivists decreed that scientists should concern themselves with reporting the result of observation, as for instance that it takes 2 volumes of hydrogen to combine with 1 volume of oxygen to make water vapour, but they should not concern themselves with speculations about metaphysical ideas that this is because the water molecule consists of two atoms of hydrogen and one atom of oxygen, because they could not observe these atoms or molecules. Mach himself never made peace with the existence of atoms."

The discovery of the electron reveals an even stranger impact of positivism. The year Thomson performed his famous experiment that resulted in the discovery of the electron, the same year a German physicist named Walter Kaufmann (1871-1947) performed practically the same experiment in Berlin. Yet we know the name of Thomson as the discoverer of electron and not of Kaufmann. Why? That was because Kaufmann, who adhered to the positivist doctrine, reported his observation (from which we know that he had obtained a better charge-to-mass ratio of the electron), but believed that it is not his business to say anything beyond the pointer readings of instruments. So he did not realize that he had discovered a new kind of particle!

These are well documented cases. But there may have been many other instances where scientific advancements were nipped in the bud or where scientists were led astray by the belief in positivism before the work reached a stage of maturity where the attempts would be publicly known.

Einstein stands against Positivism

In the formative phase of his life, Einstein was also influenced by the positivist argument. But during his post-college days, when he was actively seeking a correct philosophy to guide his scientific pursuits, he became disillusioned about positivism and embraced the materialist philosophy. All his scientific work carries the mark of his conviction about the existence of matter independent of human consciousness and sense-perception.

Very few know that his first scientific work was to prove the existence of molecules. He argued that if molecules and atoms really exist, their existence would not depend on our consciousness, and on our ability to observe them. But if they exist, and if our theory about them is correct, we should be able to deduce certain manifestations which can be tested. He wrote some half a dozen papers to prove the reality of molecules from different angles, out of which let us mention two important ones.

One is his Ph.D. thesis, entitled "A new determination of molecular dimensions," submitted to the University of Zurich on 20 July, 1905. He forwarded a new line of reasoning to prove the reality of molecules. He argued that if molecules exist, they must have some dimension—however small. The question is, can we measure the dimension? By assuming a molecular picture of a sugar solution, Einstein showed that the viscosity and coefficient of diffusion of the liquid will change due to the mixing of sugar, and the extent of change is dependent on the radius of the solute molecules. Since viscosity and the coefficient of diffusion are measurable, the radius of the sugar molecule can be obtained by measuring these quantities before and after mixing with sugar.

The second research paper proving the existence of molecules was published in the same year in the German journal 'Annalen der Physik', with the title "On the motion of small particles suspended in liquids at rest required by the molecular-kinetic theory of heat." It concerned Brownian motion: pollen particles placed in a drop of water can be seen as moving about in a random fashion in small straight line segments when observed with a microscope. The cause behind this peculiar type of motion was not known at that time. Einstein showed that this particular zigzag motion of the pollen was an important evidence of the existence of molecules. If the apparently stagnant drop of water was composed of millions of molecules, the kinetic theory of heat would require that the molecules should move about at high speeds due to thermal motion. If a pollen particle with size and mass much larger than those of water molecules was placed in the drop, it would be subjected to innumerable collisions with the water molecules. Since the water molecules would strike from all directions, the resultant effect would be a random motion of the pollen particle. It would traverse in a straight path as a result of one collision, and successive collisions would change the direction of motion. If molecules are real, this is what is naturally expected to happen. Since the motion of the pollen particle had been observed, Einstein argued that we had in effect observed molecules in motion.

But this is a qualitative argument. In order to establish a theory—a controversial one at that—it is necessary to talk in terms of quantities on the basis of which it can be objectively tested. So Einstein asked: If the motion of the pollen is completely random, is it possible to say what distance the particle will traverse from the starting position after, say, a thousand impacts? Einstein showed that even though the motion is random, it is possible to work out a probabilistic estimate of the distance traversed, and that it would be proportional to the square root of the time elapsed. This means that if one measured the distance traversed, then the average distance over a number of trials will be approximately equal to that obtained from Einstein's theory. This is something that can be objectively tested. People did the test, and found that the motion of the pollen did indeed follow Einstein's equation.

After such objective proof, it was impossible to question the existence of molecules.

Next, he took up another issue to fight the positivists' position from a materialist standpoint. The nature of heat radiation from a body had intrigued scientists for a long time. After Maxwell's discovery it was known that heat radiation is also electromagnetic wave, which means it is defined by frequency and wavelength, which are measurable quantities. It was found that the radiation emitted by a heated body does not have a single wavelength, rather, it is a mixture of waves of many wavelengths. The natural question was: Is there any law that tells us which frequency component will be emitted in what proportion?

Experimental results obtained from a close approximation to the ideal black body (something that can absorb all the radiation falling on it and whose thermal radiation

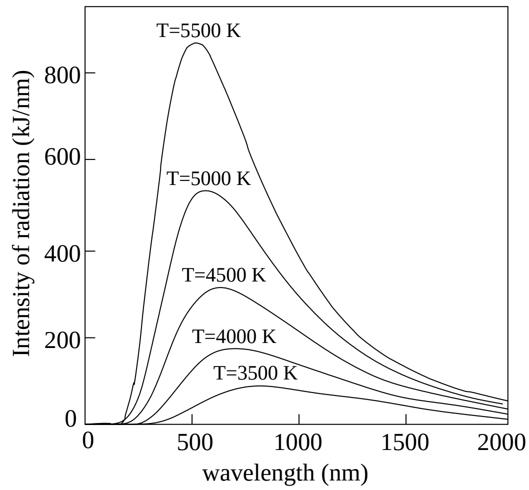


Figure 1: The experimentally observed nature of black-body radiation at different temperatures.

depends only on its temperature) showed a definite relationship between the intensity of radiation and the frequency. For any given temperature of the radiating body, the radiation has a maximum value at a specific frequency, which falls off following well defined curves for higher and lower frequencies (see Fig. 1).

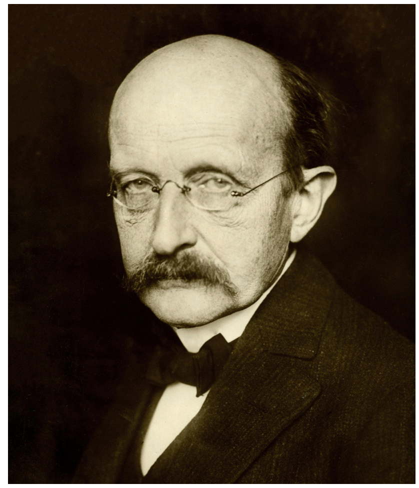
Then scientists faced the problem of explaining why black body radiation follows this specific curve. This is where the crucial problem occurred. Physicists found that if the existing theory is followed, that is, if one assumes that energy is emitted in continuous stream in a wavelike fashion, the predicted graph does not match that obtained from experiment.

When physicists were groping in dark for an answer to the problem, Max Planck showed that if we assume, ad hoc, that energy is not radiated continuously, rather it is emitted in distinct 'packets,' then one obtains exactly the same curve from theory as is obtained from experiment. People were not happy at all: What is this ad hoc assumption that has no basis? Has anybody observed the packets of energy? Has anybody measured? If one assumes for the time being that Planck is right, the quantity of energy in each packet is very small — so small that they would never be observable individually. According to positivist philosophy, what is not observable is not real. The opposition was so intense that Planck's calculation was not accepted by the main body of scientists. Planck also could not forcefully defend his own theory.

In this situation Einstein looked at the problem from a materialist standpoint. If the quanta of radiation exist, their reality would not depend on our consciousness, that is, on our ability to observe them individually. But the fact that Planck's calculation did tally with experimental observation was, to Einstein, an indirect evidence of their reality.

But more direct evidence is needed. He did not have to look very far. Many experimental observations had accumulated over the years that were yet unexplained. The phenomenon of fluorescence and Stoke's rule relating the incident and emitted radiations were not properly understood. It had been observed that gases ionise if radiated with ultraviolet light, and this also was not properly explained. Then there was the photoelectric effect. Einstein solved all these apparent mysteries in another paper published in the same year in 'Annalen der Physik', and showed that all these were evidences that quanta of radiation were not just convenient assumption; they were real.

The case of photoelectric effect has earned some fame, as the Nobel Committee cited this as *the* contribution for which the Nobel Prize was awarded to him (even though it was a small part, Section 8, of his original paper where his main contention was to prove that quanta are real). So let us explain it in some detail.



Max Planck (1858-1947)

It had been observed some years earlier that when light falls on plates made of some metals, electrons are emitted. At first nothing seemed unusual about it, because light has energy, and when light is absorbed by an electron, the energy goes into it. If the energy is sufficient to overcome the electrical attraction of the nucleus, it is natural that electrons will be ejected. Only, it should take some time to accumulate sufficient amount of energy to overcome the electrical attraction, and so it was expected that the electrons would be emitted after some delay. But the experiments showed that the electron flow starts from the moment light falls on the metal plate.

Scientists now looked at the situation carefully. If the incident light is monochromatic, it has a specific frequency (or colour), which can be varied. It can also have a specific intensity which can be varied. In the output side also there are two measurable quantities: the number of electrons emitted and the average kinetic energy of the electrons. It was found that no electrons are emitted below a certain frequency (not intensity). If we choose the frequency above this minimum value and vary the intensity, the number of emitted electrons varies but the energy of each electron remains fixed. If we keep the amplitude constant and vary the frequency, the number of emitted electrons remains fixed but the kinetic energy of the electrons varies.

Einstein showed that these characteristics of the photoelectric effect actually proved the reality of the quantum. If radiation is emitted in packets, it must also be absorbed in packets. Therefore if electrons absorb radiation, the increase in energy will be exactly the same as that contained in one packet. It is not possible to absorb radiation slowly, with continuous increase of energy. If the energy of the electron is to increase, it must happen in one jolt, and if that is sufficient to overcome the attraction, the electron will be emitted. That is why electrons start flowing the moment light falls on the metal plate.

Moreover, as per Planck's assumption, the energy in the packet is proportional to the frequency. Therefore if the frequency is increased keeping the intensity fixed, the number of packets remains fixed but the energy in each packet goes up. On the other hand, if the frequency is kept fixed and the intensity is increased, the energy in each packet remains fixed and the number of emitted electrons goes up. It is clear that if one assumes the quantum nature of light, the whole picture fits in like a jig-saw puzzle. Einstein presented this natural explanation of the photoelectric effect, and thus proved that light quanta are not just figments of imagination. The concept actually reflects the underlying reality, irrespective of our ability to observe individual quanta.

In his special theory of relativity also, he reflected a staunch anti-positivist position. He showed that space and time are relative, in the sense that distances and time-durations between two events would be different as seen by different observers moving at different velocities. When he proposed this, did he have any indication coming from sense perceptions? No. It was based on pure logic. But then, he demanded experimental physicists to check if the predictions of his theory were indeed correct. The predictions of the theory of relativity were found to be true in all experiments conducted so far. It is interesting to note that the same Walter Kaufmann conducted the key experiment that confirmed Einstein's prediction of the change in an electron's mass moving at high velocity.

Similarly, in his General Theory of Relativity proposed in 1916, he showed that space-time itself becomes curved in the neighbourhood of a heavy mass, and other bodies (including light) moves in the shortest path available in that curved space-time. Did he have any inkling of that coming from sense perceptions? No. He just noticed that Newton's theory of gravity was not compatible with the Special Theory of Relativity, and he developed the GTR to resolve the conflict. Thus, it was a product of pure logic. At the same time, he demanded scientists to check the predictions of the theory objectively. The prediction that light would bend when it goes past a heavy body was observationally confirmed during a total solar eclipse in 1919. The prediction on gravitational waves has been observationally confirmed only in 2016, a century after Einstein made the prediction. If we adhered to the prescriptions of positivism, such development of human understanding of nature would not have been possible.

Thus, we see that the cornerstone of Einstein's thought process was the belief in existence of objective reality independent of observer. He believed that sensory experiences provide information about reality, but empirical data do not automatically lead to conceptualization. He underscored the necessity of scientific speculation constrained by empirical facts, and insisted that the emerging picture of reality has to be tested through targeted experiments.

Positivism loses its hold

One of the staunchest proponents of positivism, the Nobel Laureate chemist Wilhelm Ostwald accepted the existence of atoms and molecules in 1908, following Einstein's argument on Brownian motion. Max Planck, who adhered to the doctrine of positivism up to his forties, became its bitter critic. He nominated Boltzmann to the Nobel Prize, but before any decision was made, Boltzmann committed suicide in 1906. Planck later regretted not having defended Boltzmann when he needed it the most.

In the book "Where is science going?" written in 1933, Planck forwarded powerful arguments against positivism. According to him, if positivist ideas are followed, all conclusions of science will turn into 'as-if' statements. For example, if a stick is dipped into a glass of water, it looks bent. That is the observation, and the positivist would state that and only that. He cannot say whether the stick is really straight or bent, because his source of knowledge is his sense-perception. He can at most say that the stick looks as if it were bent.

Einstein, as we have seen, was all along rooted in materialist philosophy. In 1931, on the occasion of the hundredth birth anniversary of Maxwell, he wrote "The belief in an external world independent of the perceiving subject is the basis of all natural science. Since, however, sense perception only gives information of this external world or of "physical reality" indirectly, one can only grasp the latter by speculative means." That is, the scientist has to imagine beyond the immediate sense perceptions, has to formulate hypotheses and postulates, and has to test these against objective reality—in order to unravel the working of nature. "If you want to find out anything from the theoretical physicists about the methods they use, I advise you to closely stick to one principle: Don't listen to their words, fix your attention on their deeds." (Herbert Spencer lecture, Oxford, June 10, 1933).

Werner Heisenberg, one of the originators of quantum theory, was a staunch positivist. Along with Niels Bohr, he was responsible for formulating the positivist interpretaion of quantum mechanics, known as the Copenhagen interpretation. Yet, he, too, was disillusioned towards the end of his life. In an essay titled 'Positivism, Metaphysics and Religion' (1969), He wrote: "The positivists have a simple solution: the world must be divided into that which we can say clearly and the rest, which we had better pass over in silence. But can any one conceive of a more pointless philosophy, seeing that what we can say clearly amounts to next to nothing? If we omitted all that is unclear we would probably be left with completely uninteresting and trivial tautologies."

What was really the problem with Positivism?

What needed to be done was to show, in philosophical terms, why the positivist prescription is not the right way of reaching truth about nature. This was done by the Marxist philosopher and the leader of the Russian revolution, V I Lenin. In 1908 he wrote a book titled 'Materialism and Empirio-Criticism', in which he clearly pointed out the differences of viewpoints of scientific materialism and positivism, and showed that positivism, in effect, comes very close to the idealist position—which is directly opposed to science.

The positivists viewed matter as metaphysical abstraction. Mach wrote, "To us investigators, the concept 'soul' is irrelevant and a matter for laughter. But matter is an abstraction of the same kind, just as good or as bad as it is. We know as much about the soul as we do of matter."

Lenin clarified that the concept of matter is concrete as it comes from abstraction and generalization from the objects existing in the external world. The words "fruit" or "mammal" are also products of generalization. There is no palpably existing thing called fruit. There are mangoes, cherries, bananas, and we get the concept of "fruit" through a process of abstraction and generalization. Similarly, there are tigers, monkeys, deer, etc., from which we form the idea of mammals through a process of abstraction and generalization. That is why the words like "fruit" or "mammals" convey concrete ideas; these are not metaphysical abstractions. The concept of matter is also a product of abstraction and generalization in the same way. "Matter is a philosophical category denoting the objective reality which is given to man by his sensations, and which is copied, photographed, and reflected by our sensations, while existing independently of them."

Next, he asked, are the sense perceptions really the *source* of knowledge, or are they the *means* of knowledge? What is the source of our sensations? What exactly causes excitement at the nerve-ends, which are conveyed to the brain by the nerves, thus giving rise to the sensations? He pointed out that matter, existing independently of our consciousness, act on our sense-organs. Through the sense organs we perceive matter. Thus, matter is the source of sensations, and thence of perceptions. The positivists erred by considering sensations as the source of knowledge, thus eliminating matter from the purview of scientific discussions. The correct approach should be to view matter as the source of knowledge, and sensations and sense-perceptions as the means of knowledge.

Third, he pointed out that knowledge and experience are not the same thing. Experience is personal, and the ideas born out of individual experience are subjective. But knowledge is born out of collective experience; that is why its nature is impersonal. Moreover, knowledge is not the result of 'pure' experience; it is the result of a mixture of experience and logic. Only the application of logical reasoning can filter out unnecessary and irrelevant things from human experience, and can give birth to impersonal knowledge. We see the sun rising from the East, setting in the West, and appearing to go round the Earth. That is our experience. It is only by the application of logic we realize that the sense perception was deceptive, that in reality the Earth is going round the sun while spinning around its own axis. "Knowledge is the reflection of nature by man. But this is not simple, not an immediate, not a complete reflection, but the process of a series of abstractions, the formation and development of concepts, laws, etc., and these concepts, laws, etc., embrace conditionally, approximately, the universal, law-governed character of eternally moving and developing nature."

Then he points out that, in order to obtain correct knowledge about nature, any theory should be tested. And the test of correctness of any idea comes from practice, not from mere sense perceptions. One has to apply that idea to formulate deliberate experiments. One has to try to use that idea to make something that works. Only through practice we can test the correctness of a theory.

And finally, quoting the idealist Bishop Berkeley, Lenin showed that the positivist position is not close to materialism. In fact it is veiled idealism which is directly opposed to science. While materialism says that matter exists independently of our consciousness, idealism holds that matter exists only in our consciousness. By demanding to build science only on the basis of sense perceptions, the positivists effectively said the same thing as idealists did, because sense perceptions are part of our consciousness.

The hangover of Positivism

As the limitations of positivism became clearer, it came to be recognized that science should try to understand the character of the real world existing independent of our consciousness, and for that it should make theoretical constructs about the nature of physical reality—things that are observable as well as the ones that are not observable at a given time. This view came to be known as scientific realism, which says that we can reasonably construe scientific theories as providing knowledge about unobservable entities, forces, and processes, and that understanding the progress of science requires that we do so. It recognizes the objective existence of reality, empirical observations and on their basis theoretical constructs which reflects the truth or approximate truth about reality.

Even though most leading scientists came out of the influence of positivism in the first half of the 20th century, its hangover remained in different fields. Then came a time when exposure to different lines of philosophy was dropped from the education of a scientist. Scientists became indifferent to and unconscious about their own philosophical positions. Most scientists today do not have any exposure to the lines of philosophical thoughts that have accelerated or retarded the march of science in the past, and unconsciously subscribe to idealistic and positivist trends of thought. This is an aspect that is blocking the unrestricted growth of science, because, in the language of Planck, "You cannot be a scientist if you did not know that the external world existed in reality."

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On a lighter note