Research Methodology
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Lecture - 22
Historical Perspective: The Rise and Fall of Positivism Part 02

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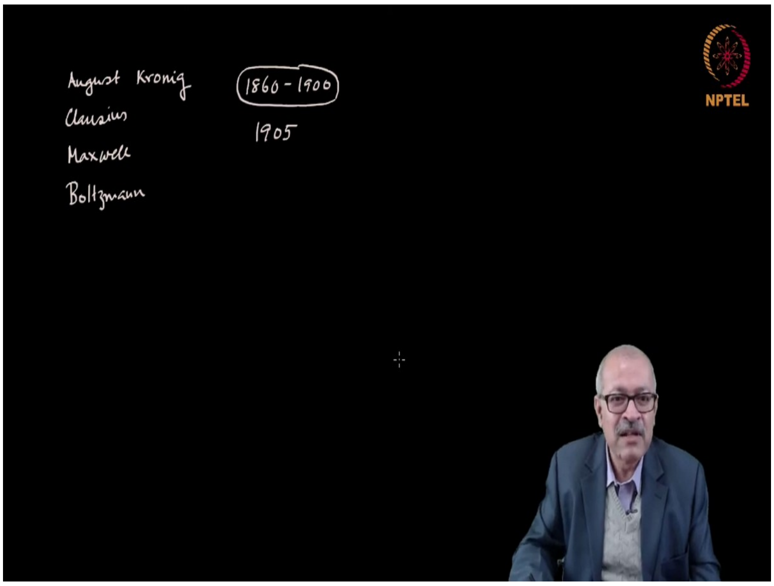

Then in 1905, a young 26 year old patent office clerk, you know who is, Einstein, he took up this particular problem. Very few know that his initial investigation was on proving the existence of molecules. His PhD thesis was on that.

Let me clarify the point he was making. Essentially, he realized that the position of positivism and position of scientific materialism were completely different. Even though both appear to be materialistic, scientific, but their positions are entirely different.

Positivism said that matter does not exist unless you observe it; nothing exists unless you observe it; what is not observable are not real. The materialist position would say that the existence of matter does not depend on our consciousness, and therefore, does not depend on our ability to observe it. At some point of time our ability to observe something may be limited by the status of technological development, but that does not mean that does not exist. So, how then, should we prove the existence of something?

Einstein’s logic was that, in that case we have to build theories. The theory need not be based on what you actually observe, the theory should have some experimentally or observationally testable prediction, and then go on ahead and test it. If the test comes to be correct then you have some confidence in believing that the initial assumption was right.

And from that point of view, Einstein started to argue that, if molecules exist, I may not be able to see it, but then it must have some experimentally testable prediction; some kind of ramification that can be experimentally tested. So, he proceeded with a very simple thought experiment. He said that, suppose I take a little bit of water and then if I believe in the molecular theory, then I would assume that that is comprising a large number of small water molecules going around in that droplet.

And then suppose, I have mixed little bit of sugar in it. As we mixed a bit a sugar in it, the mental picture would be that relatively bigger sugar molecules are going around among a large number of smaller water molecules. So, bigger molecules going around in a sea of smaller molecules. Then he argued that, that will result in two changes, A, the viscosity will change, and B, the coefficient of diffusion will change.

And then he proceeded to analytically obtain how much will those changes be.

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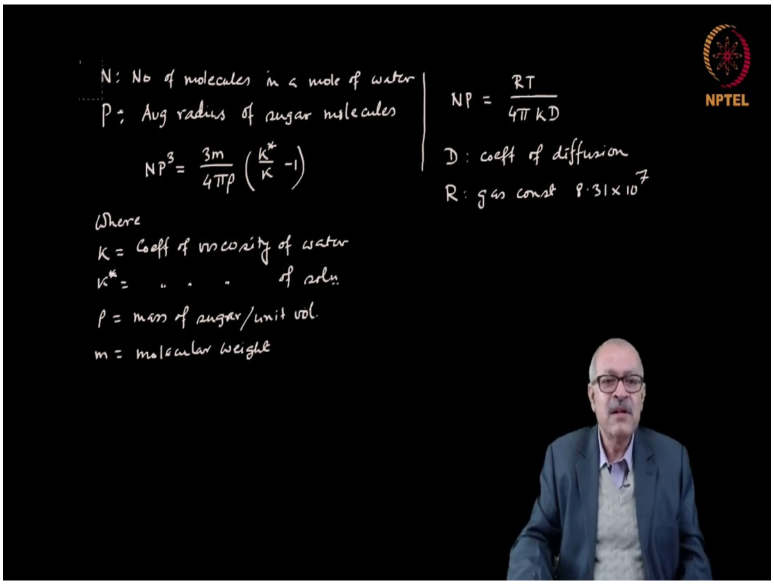

For example, he said that, let N be the number of molecules in a mole of water, P the average radius of sugar molecules; sugar or any such mixable substance. Then he he derived an equation NP cube is equal to thrice m by 4 pi rho, K star by K minus 1 [$\mathbf{NP^3=(3m/4\Pi\rho)\{(K^*/K)-1\}}$] (see the equation in the picture), where K is the coefficient of viscosity of water and K star: coefficient of viscosity of a solution.

And K star and rho are necessary. Rho is the mass of sugar per unit volume, so density of sugar. And m is necessary; m is its molecular weight. So, all the terms in the right hand side can be measured.

And therefore, you have an expression for NP cube, but this comprises two things N and P and unless you have another equation, you cannot really measure them individually. Here we are basing on the idea that viscosity will change. So, without sugar the viscosity is K, with sugar the viscosity is K star.

But another thing will change. That is the coefficient of diffusion. So, he then derived another equation NP is equal to RT, T is the absolute temperature R is the gas constant and by 4ΠKD [$\mathbf{NP=(RT)/(4\Pi KD)}$]. So, here we have the D is the coefficient diffusion and this is the absolute temperature, this is the gas constant R. These are already known and its value is 8.31×10^7.

So, he then argued that if you have both these then with the already existing experimental results, we can find out the value of N and value of P and notice that both depend on the existence of molecules. The number of molecules, the radius of molecules, and therefore, these actually talk about the physical existence of molecules. We can observe this. If we assume the existence of molecules and the molecular picture of the whole thing, then we can theoretically predict how much will be the change and we do see that much is the change.

And therefore, from there we can find out the values of N and P. So, that is essentially a sort of evidence of the existence of molecules. His point was that. He submitted that as his PhD thesis. Time was not proper for him to put that as a PhD thesis because everybody at the time, most physicists at the time, believed in positivism and naturally the thesis was immediately rejected. Einstein’s PhD thesis was actually rejected.

Well, he made some cosmetic changes on the PhD thesis, but did not really change his main contention. But the next time when it went to the examiner; the examiner accepted it grudgingly. The same examiner, who had once rejected his PhD thesis, a few years later recommended him for the Noble prize.

So, this was one line of work where he was actually making the point that molecules exist. In the same year he wrote another very seminal paper explaining the Brownian motion.

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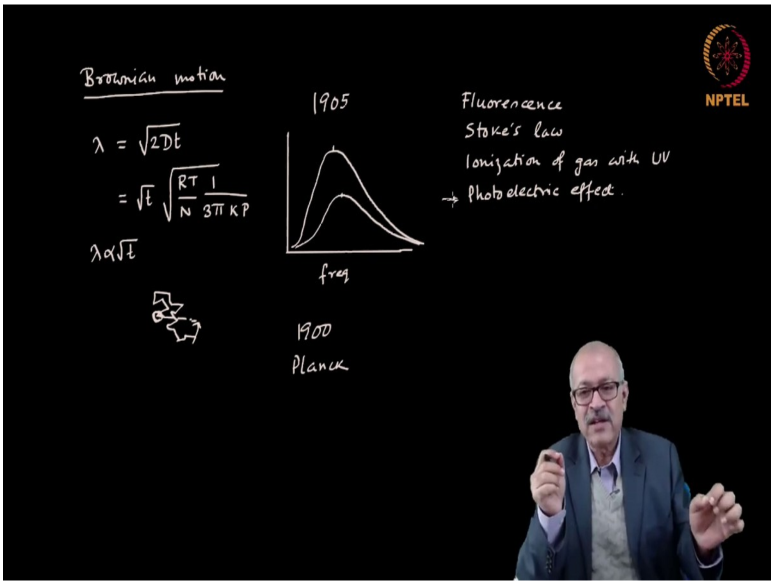

Brownian motion is a random motion of pollen particles suspended in a drop of water and this was observed by Brown some time in the middle of the 19th century. And nobody understood why it happens, because initially people thought that the pollen particles are alive and they are actually swimming around.

But later when the motion was observed somewhat minutely, they found that it does not really satisfy the requirements of a swimming motion, because these are straight line segments: short small straight line segments. Einstein picked up on that point, and showed that the fact that the Brownian motion is short straight-line segments comprising that proves the existence of molecules.

Because what would the molecular picture be? It will be a large pollen particle suspended in a drop of water, which comprises a huge number of millions of water molecules, each moving at high velocity. And therefore, each one will impinge with, hit the pollen particle, will make it move in some direction, another will hit and will make it move make in another direction, and a third one will hit and will make it move in another direction.

So, if this picture is correct, it is supposed to be a collection of straight line segments. Just a hand-waving argument does not work. It does not convince scientists. So, he had to derive something that can be experimentally tested and so he developed the theory and showed that the distance travelled by the particle from an initial point, the lambda, will depend on the swuare root of D t. D is the same coefficient of diffusion and t is time. And therefore, it is actually dependent on the square root of time. A few minutes back I wrote here the expression from which D can be extracted.

And therefore, if you put D there, you get the expression [$\boldsymbol{\lambda = \sqrt{t} \times \sqrt{(RT/N)} \times (1/3\Pi KP)^2}$] square root of t times square root of RT by N 1 by 3 pi KP. All these are known constants and therefore, it will depend on the square root of time. So, he said that, suppose a pollen particle starts one point and then it goes in short straight line segments. And ultimately after some time it will move some distance from here to here. There will be a distance and that distance will be, on an average, proportional to the square root of time. And he said that go forth and test it. People tested and found that that is true.

As a result, after these papers appeared in 1905, by about 1908-09, most people had accepted the existence of molecules and atoms. And after that the theory of molecules and atoms was accepted and you knew with the confidence that atoms react to form molecules and molecules react with each other and that developed chemistry. And physicists started worrying about what happens inside the atoms.

So, sub-atomic particles: people then investigated. All that happened after people started having some kind of a confidence in the atomic and molecular theories. And that was Einstein’s one of the major contributions.

Notice the philosophical grounding there. His point was that, the existence of matter does not depend on our ability to observe it, because it does not depend on our consciousness. But if atoms and molecules exist, they must have some kind of a experimentally or observationally testable ramification. One of them was Brownian motion.

That things move from their initial position only by the extent of root over t, that is the result of continuous bombardment from all sides by molecules, and therefore, molecules exist. And then he said that if your experimental observation comes out right, that means, you find that lambda is truly proportional to the square root of t, then unless you have some other explanation of this being true, you have to assume my initial assumption, which is that molecules exist.

In the same year, 1905, he proposed the light photon hypothesis. You know its background, I am not going into the details. But in the period from 1860 to 1900 people did experiments on black body radiation and found that the blackbody radiation follows a characteristic something like this. And at different temperatures you would have different characteristic something like this. At higher temperature it will be like that. So, the peak will be at different. So, the frequency here and the amount of radiation here, which means that a black body radiates various frequencies, but that is distributed in a very specific way. At that time nobody was able to explain that characteristic by the existing theory of radiation which is that it is radiated in a continuous stream.

In the year 1900, Planck, out of desperation, assumed that radiation is not emitted in a continuous stream, but it is actually emitted as packets of energy. And those packets of energy, or quantum of energy, he assumed that and then he derived the expression. He found that it is exactly following what is actually observed.

He being a positivist, could not defend his theory, because the energy quanta are not observed. These are not something that we have observed and therefore, he could not defend his position.

Einstein took it up from there. His argument was that, if energy quanta exist, their existence will not depend on our being able to observe them. But if they exist, they must have some experimentally testable ramification. So, he looked around in literature: has there been any observation, any experiment, whose results indicate such experimentally testable ramification? He found many.

He wrote another paper in the same year, in which he explained, for example, fluorescence. He explained Stokes law. He explained ionization of gas with ultraviolet light. And he explained photoelectric effect. Well, the Nobel committee chose to give him the Nobel prize for having explained the photoelectric effect.

But that paper actually explained many of the observations. Some of them I have mentioned here, photoelectric effect was the the section 8 of that paper, a small section in which he explained photoelectric effect using the idea of light quanta.

So, what was wrong with positivism then? Well, following Einstein's effort, people realized that positivism assumes that sense perception is our source of knowledge, but it was realized that sense perceptions are *means* of knowledge. Source of knowledge are the actual existing material objects. They are the sources of knowledge. A new methodology of probing nature developed, in which our starting point need not always be experience. The starting point can be logical derivation. But that should have an experimentally testable prediction and when that is experimentally tested, then only we say that we have reason to believe that that theory is correct.

So, it is not completely devoid of experimental test. The assertion of positivists was that experiment or observation is the only reliable yardstick, and you do not build any theory, just do the observation and stop there. That is something that was more or less abandoned after that. Many theoretical developments have happened after that by following the prescription of scientific materialism.

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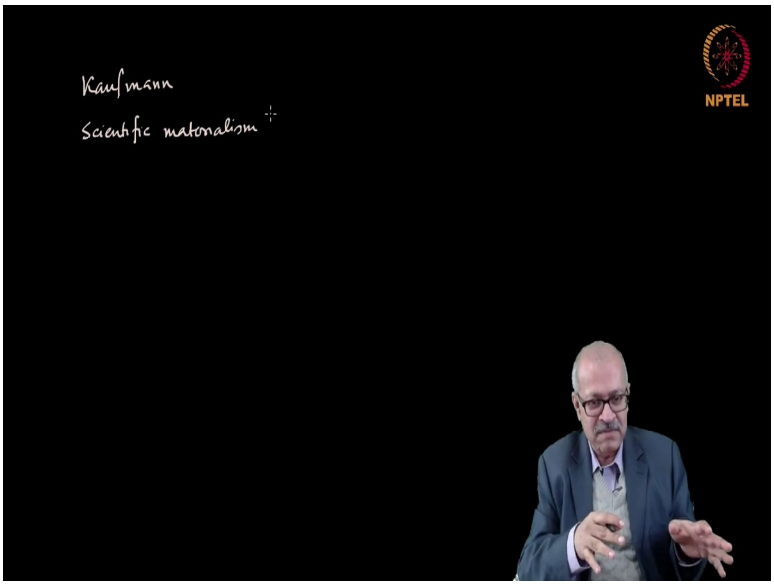

The most glaring example of where a scientist can be led astray comes from a person called Kauffman. Kauffman did the same experiment at J J Thompson which led to the discovery of electron. He did exactly the same experiment, but he only reported that I have observed that the pointer moved by this much. He, being a positivist, stated what his observation was: that the pointer moved by this much. He did not speculate on what is giving rise to that observation. As a result, he missed being named as the discoverer of the electron or even a co-discoverer of electron.

So, that was one problem with positivism. So, matter is the source of knowledge. Knowledge and experience are not exactly the same thing. Experience is the starting point, all right, but knowledge is not just individual experience. Knowledge comes from collective experience. Many people experiencing the same thing, the way to test any idea. So, the idea developed that now we have to develop theories, build theories.

And then, ultimately the test of the theory should be from practice. Test of a theory should be from practice. The positivists believed that, what ultimately we get are the sensations through our five sense organs and that is what is true for me. The thing is not true. People pointed out that, suppose you see a snake. You definitely run or at least do something, so that you are not bitten. You have seen it, so, it has come to your senses, but you do believe that the snake exists. That is why you actually run or do something so that you are not bitten. That act, that practice, proves the existence of the snake.

So, scientific materialism in which Einstein subscribed, it recognizes theory as an approximate copy of objective reality. You have to develop theories to try to be as close as possible, to be able to express or represent objective reality. And the theory needs to be tested through practice or experiment. That is the methodology that developed in the following years.

Well, after 1908 most people abandoned the position of positivism, though its hangover still continues. But most people abandoned the position of positivism. For example, Ostwald, the chemist Ostwald. He was a positivist and was a strong opponent of Boltzmann. He criticized Boltzmann like anything. He even wrote a book whose name was 'The Overcoming of Scientific Materialism'.

But after 1908, he jettisoned the idea of positivism and embraced scientific materialism. That happen with many other scientists. So, today we are doing science basically following the prescription of scientific materialism.

Before we end the set of lectures on the history of development of science, I need to mention that the history of development of science has not been a smooth ascent.

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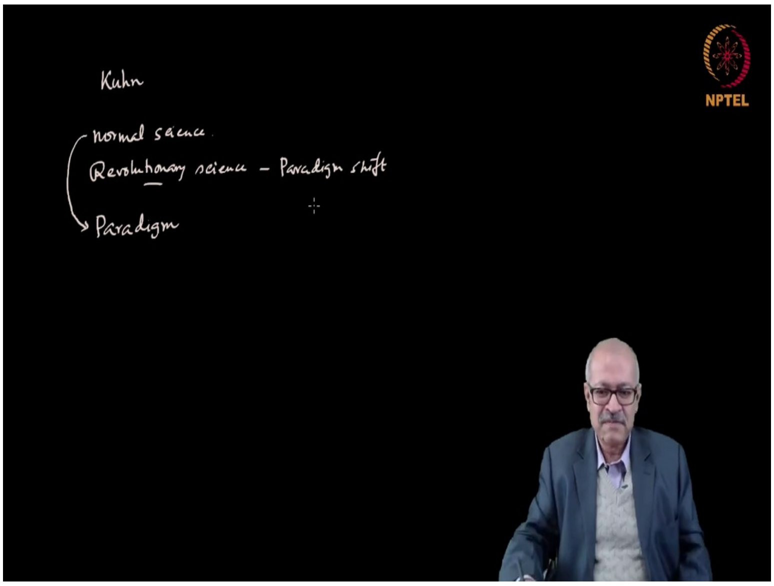

Rather it has been, as Professor Kuhn showed, that there have been the periods of 'normal science' and the periods of 'revolutionary science'.

During the period of normal science we make incremental progress. We make incremental addition to human knowledge by basing ourselves on the existing knowledge. In these periods of development of normal science, certain techniques, tools, methodologies develop. Students absorb those tools, techniques, methodologies, way of thinking, and on that basis they make incremental contribution.

But through the process of development of normal science, sometimes we see that certain problems build up. These problems are not solved using normal science. And therefore, unsolved problems build up and at some point of time some scientist thinks out of the box.

And when a scientist is able to think outside the box, then comes the period of a revolutionary science and when that happens, many of the earlier beliefs, earlier methodologies, earlier techniques are questioned, changed, and a completely new set of beliefs, techniques and methodologies develop.

That collection of tools, techniques, beliefs, understandings, put together Kuhn termed as 'paradigm'. So, normal science is characterized by a paradigm that one follows in doing science and when there is a revolutionary change, then there is a 'paradigm shift'.

For example, earlier it was believed that the solar system has the Earth at the center and things going around that as per the Ptolemaic picture of the epicycles. That idea stayed for 2000 years, and when it was broken by the efforts of Copernicus and Galileo, a completely new paradigm developed.

Similarly, the fixity of species was a paradigm for a long time. And then, when the evolution theory developed through the efforts of Lamarck and Darwin, the paradigm completely changed. The whole idea completely changed; methodologies changed. Similarly the classical physics that was developed in the 19th century—the theory of electromagnetism, Newton's theory, thermodynamics, all put together the classical physics—that underwent a paradigm shift when quantum mechanics developed.

Similarly, there have been such periods of normal science and periods of revolutionary science. A student of science has to realize that: what he or she is learning in school, college, university, through the process of doing PhD, are basically the tools, techniques, beliefs, and methodologies of normal science.

It is possible that, within your lifetime, the normal science will undergo a radical change, a revolutionary science will appear. Then a scientist's mind has to be open enough to welcome that change. That is a very important point I would like to make before I end this class.