Research Methodology
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Lecture - 06
Causality Part 02

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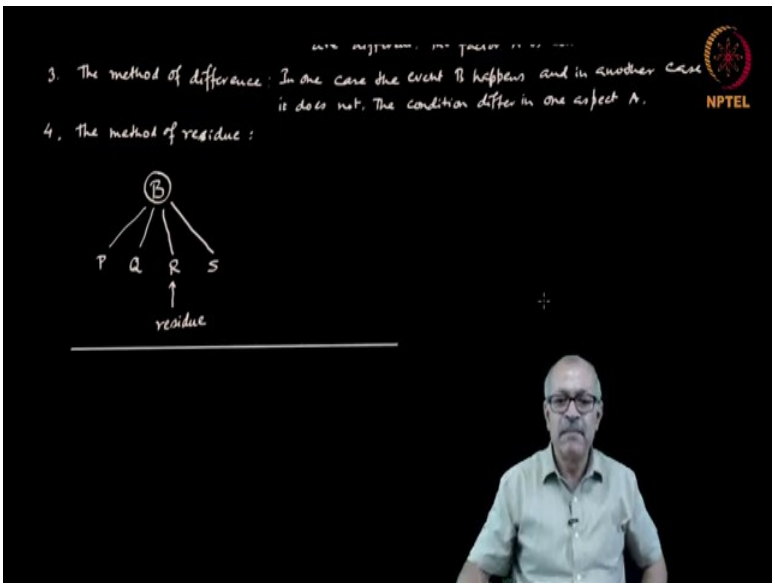

After John Stuart Mill gave these four methods of looking for causes of events, science actually flourished in various directions following his prescription. Many scientists used his prescription to unravel mysteries of nature. Let me give some examples. Some of these actually happened before Mill's prescription, but that can fall into that category. Some happened after.

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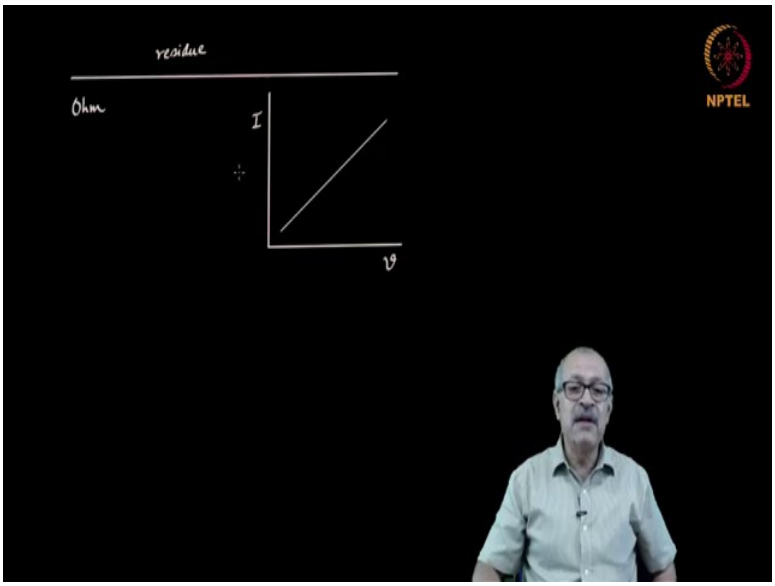

For example, Georg Ohm. Let me draw a line here. Ohm was trying to find out the relationship between the voltage across a piece of wire and the current passing through that piece of wire. So, voltage and the current. He made an arrangement by which the voltage can be varied in steps and for each value of the voltage, he measured the value of the current and he found that when voltage increases the current also increases.

So, it is known as the Ohm's law. Well it can be plotted something like this. The voltage was plotted here, the current was plotted here, and he obtained a line something like this. So, whenever V increases, I also increases. The voltage increases and the current increases, and so he concluded that voltage causes current. But it is not true that causality works one way. If you apply current, i.e., if you make a specific amount of current to pass through that piece of wire, a voltage will appear across the wire and if you measure that, that will also lead to a similar graph. So, current can be a cause and voltage the effect. Both are possible. This is an application of the method of concomitant variation.

At the turn of century, Rontgen, Wilhelm Rontgen, discovered the X-ray and very soon after the discovery it started to be used because he showed that you can see the bones of a hand. So, doctors started using it very soon after the discovery of the X-rays. The discovery of X-ray immediately caught the attention of Henri Becquerel.

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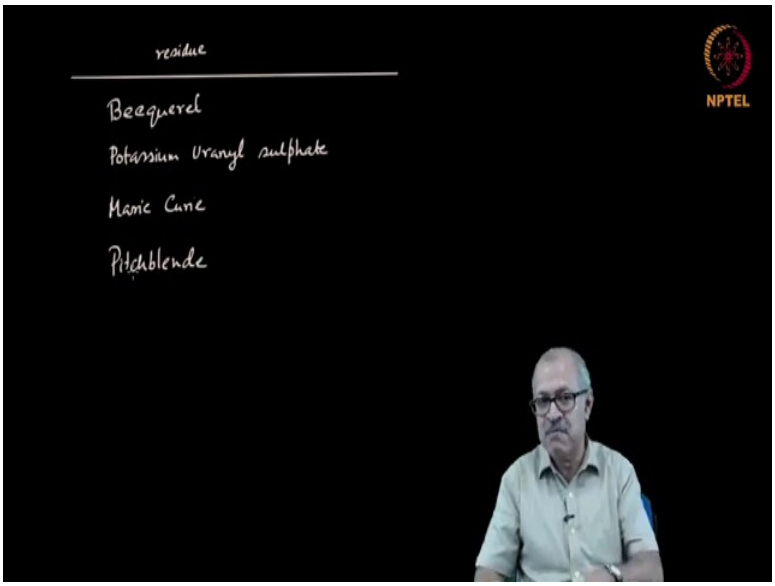

At the time it was not known what causes the X-rays, and Becquerel assumed that the phenomenon of emission of X-rays is similar to what was at the time known as phosphorescence. What is phosphorescence? There are certain materials which, when exposed to the sunlight, absorb energy from the sunlight and later at night they can emit that radiation and they become luminescent.

So, that is called phosphorescence and Becquerel knew that there is a phosphorescent material called potassium uranyl sulphate. This was known to be a phosphorescent material. So, he started experimenting with this material. Since he believed that X-ray was phosphorescence so, naturally he would try to experiment with phosphorescence. So, he kept that material in the sun and brought it back. After exposure to the sunlight for some time, brought it in. And then he exposed a photographic plate using that potassium uranyl sulphate that has been exposed to sunlight and he found that the photographic plate became exposed, which means that when developed, it turn black. If it turns black, it means that the potassium uranyl sulphate has emitted rays and so, he assumed that it was basically a issue of phosphorescence.

The next few days were cloudy. So, he could not continue with his experiment and he simply put that chunk of potassium uranyl sulphate in his drawer, away from the sun. A week later again it became sunny. So, he wanted to resume the experiment. When he wanted to resume the experiment, then obviously the first thing he would do is to put it

back to the sun. But before doing that, he wanted to check whether the thing that has been kept in his drawer has completely sort of ‘discharged’ .

So, he exposed another photographic plate using the potassium uranyl sulphate that has been kept in the drawer for a week and he was surprised. He found that it was again fully exposed. So, what happened? Then he started experimenting very carefully. This time he sometimes would keep it in the sun and would check whether it exposes the photographic plate or not; sometimes he would not put it in the sun and check whether it exposes the photographic plate or not. He found that in all cases it was exposed.

So, he was planning the experiment following method of agreement because in both cases, the end result was that the photographic plate became exposed though the conditions were different. Once he was exposing it to sunlight, another time he was not exposing to the sunlight, and so he ensured that the conditions prevailing before that are different. But they agreed on one point: that is the existence of potassium uranyl sulphate.

He experimented with other materials. It did not happen. But whenever potassium uranyl sulphate is present, then the photographic plate was exposed. So, it was a method of agreement by which he concluded that potassium uranyl sulphate causes the exposure and it is radiating all by itself. It does not need to absorb energy from the sun in order to radiate because the amount of exposure is always the same. So, following the method of agreement he came to that conclusion.

At the time Marie Curie had just finished her master’s and was looking for a problem to take up for PhD work and this issue attracted her attention. She asked: what is causing this radiation? She termed it as radioactivity. So, she asked what is causing radioactivity? It was known at that time that potassium uranyl sulphate causes radioactivity, but she was asking: is it the compound property or is it the element property?

What she did was, since it contains potassium, uranium, and sulphate, she obtained some compounds of potassium that do not contain uranium or sulphate; she obtained some compounds of uranium without potassium and sulphate; and she also obtained some sulphates that do not contain potassium or uranium. She checked the radioactivity of each of them and found that only the uranium compounds have radioactivity.

So, she concluded that the element uranium is responsible for radioactivity. Notice that, in this case she was using one of Mill's criteria. Which one was it? In this case for different compounds, the end result was different. In some cases it happened, in some cases it did not happen. In some cases there was radioactivity, in some cases there was no radioactivity. And the situation was, the difference was caused by whether or not uranium is present and from that she concluded that uranium is a causative agent. So she used the method of difference. Then she wanted to recheck it using another of Mill's criteria.

She obtained some different compounds of uranium each with a different amount of uranium unit per unit mass and then she checked the radioactivity of each one of them. She found that the amount of radioactivity is proportional to the amount of uranium present in that compound. All of them are uranium compounds, but depending on the amount of uranium present in that compound the radioactivity increases or decreases. So, here she used the method of concomitant variation to infer that uranium as a material, as an element, is responsible for it.

Then she asked: Is there any other element that is radioactive? She experimented with many different minerals that are found and checked the radioactivity of each one. She found that in most cases these are not radioactive. But she found some radioactivity in some of them.

She knew uranium was responsible for radioactivity. So, she isolated the uranium in it and if she still found radioactivity, then there must be another element in it and she found that thorium is also radioactive. So, uranium and thorium. These are the two things that are radioactive.

Then she asked, is there any other? Again she started checking all different minerals and she found that most of these are non-radioactive. But there is a mineral called pitchblende that was found in Czechoslovakia. Pitchblende is radioactive. And so, she assumed that pitchblende contains uranium and thorium. She collected a bit of pitchblende and then she isolated the amount of uranium in it and then isolated the amount of thorium in it. She knew this amount of uranium can cause how much radioactivity; she knew this much of thorium can cause how much radioactivity.

So, she was assuming that the total radioactivity of the pitchblende should be the sum of the radio activities created by uranium and thorium. She found that pitchblende has much higher radioactivity than what can be accounted for from the uranium and thorium.

Notice, here she was using the method of residues. She knew the effect of uranium; she knew the effect of thorium; and the resulting effect is much more than what can be accounted for by the radiation due to uranium and thorium. So, she argued that there must be some residual radioactive substance in pitchblende that is causing the residual radioactivity and this pursuit led her to discover two, not one but two, elements: polonium and radium.

So, you can see that science has benefited immensely from Mill's logic. His methods are called the methods of 'operational causality'. Operationally how do you find out the cause of something? It has proved to be immensely beneficial.

Now, after I have illustrated what was done by these philosophers, I can tell you that there have been various philosophers in the modern age, also in the twentieth century, who have contributed to the idea of causality. But more or less the groundwork was laid by these people and we still follow their prescriptions. So, we need not go into further details.

Let me just outline the current status as far as their prescriptions are concerned. I said that in the Renaissance period, out of the four causes outlined by Aristotle, the final cause was dropped and the formal cause was included in the efficient cause, and people talked about material cause and the efficient cause.

After David Hume made his prescriptions I have already illustrated what the objections were. I can tell you that now we say that 'the effect cannot precede the cause'. We do not say 'the cause precedes effect', because they can be almost simultaneous.

The law of contiguity has been abandoned because now we know that something can cause something else from quite a bit of distance. So, they need not be contiguous.

The constant conjunction: we know that is faulty, but the idea of constant conjunction has been replaced by statistical testing of cause and effects. I will come to that in the later lectures, where I will talk about, for example, how do we discover drugs? Here also

there is a causality involved: the drug is causing the cure of a particular disease. How do we find that out? There are statistical techniques which are applicable even when constant conjunction does not apply.

The prescriptions of John Stuart Mill are still very much in use.

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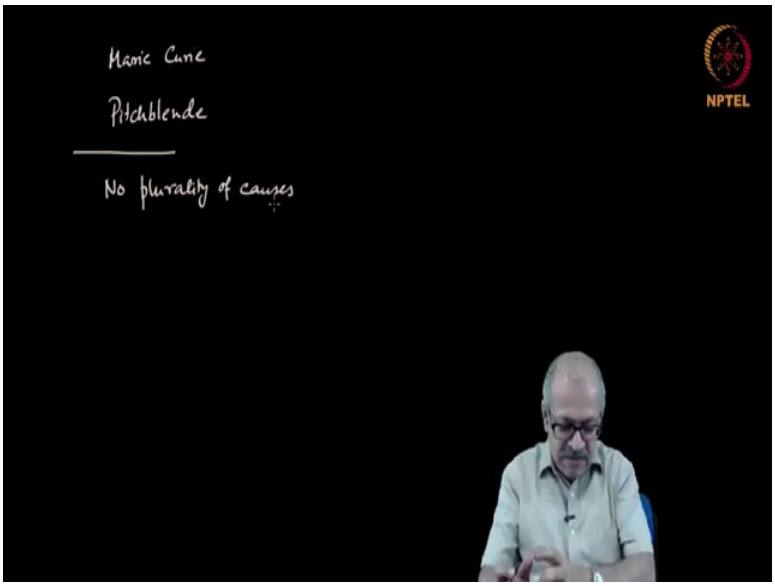

There have been some further developments in the idea of causality. The most important development is that now we understand that there cannot be a plurality of causes. Cause is unique, no plurality. The cause of any effect is one and unique. There cannot be many causes.

Let me give an example. If there is a seed put in soil, it will germinate and grow into a sapling. If I now ask what is the cause of the sapling? You will say that the seed is the cause. And then somebody might come and say that, no no, there was water in the soil, that is why it germinated. So, water is also the cause. Somebody might come and say that because there was oxygen in the air, that was also responsible for this germination. Oxygen is the cause. Somebody might say that appropriate temperature, humidity and other conditions prevailed, and that is why it could germinate. So, the temperature is the cause.

So, all these can be seen as causes. But modern science says, these are not causes. These are ‘factors’ included in the cause. Then what is the cause? The cause is, taking into

account all these factors, the condition prevailing just before germination. That is the cause of the germination. That includes the existence of the seed, that includes the existence of water, air, oxygen, temperature—all that put together is the cause.

So, the cause is the immediate antecedent of the effect. That is how we understand it. And for every effect there is a unique cause. That is why, when scientists try to find out the cause of something, and initially they do not know what is the cause, they may guess and they know that all the guesses, all the different possible guessed causes, which we call hypothesis, should not be true, because there is a unique cause. One of them should be true and they try to figure out which ones are wrong. That is how we proceed.

We have also understood the following. In the last class, I talked about materialism and idealism, and since science bases itself on materialism, we also demand that the cause should be found in material processes and phenomena. So, something happened and you cannot say that that happened because of magic, that happened because somebody willed it, that happened because of some supernatural forces, etc. We cannot say that. For every event, when we look for the cause, we look for the cause in material processes and phenomena.

With this I will end the class on causality. But throughout this course or throughout your scientific carrier you will find causality as the basis of all science. All science practically is built on looking for the cause of something. So, whenever you encounter a situation, you encounter a phenomenon, an event, you should always ask ‘what is the cause?’ and you should always look for the cause in material processes and phenomena. You should always look for the cause following the prescriptions that I have outlined. You should always look for the cause knowing fully well there is one cause for every event.