

## **Introduction**

The purpose of my lectures is to introduce you to some of the most foremost philosophical issues of quantum mechanics. Since the topic and purpose of this whole course is to understand the relations between science and religion, I think it IS important to say from the outset what, according to me, are the connections—and maybe sometimes, the lack of connections—between these two disciplines. In order to do this, I will begin by commenting on the few historical texts written about the connections between science and religion. The last one is very timely because IT EXPRESSES A RECENT DISCUSSION I HAD WITH A MAJOR CONTEMPORARY PHILOSOPHER OF SCIENCE. The first experience I had recently was to discuss with His Holiness THE DALAI-LAMA one year ago. Another experience I had was with two doctoral students working toward a doctorate in protestant theology so I have some experience of these problems. Let me begin with a few comments. I will state, by means of these texts, my own positions on these connections between science and religion. Of course, you may disagree with me but it will be very interesting as a topic of discussion, a lively way of talking. I strongly recommend you to interrupt if you feel there is something interesting to discuss. Now, the best way to is begin with the texts.

### **The distinction and cooperation between science and religion**

First, here is a sentence I like very much that I found in a French newspaper that I was reading only three days ago by a very well-known biologist IN FRANCE called Etienne BEAULIEU: “Today, humans are **ASSAILED BY DOUBT** This is due both to the feeling of their power over nature and their **IMPOTENCE** with regard to themselves.” If you assume that power over nature is provided by science and technology, which follows from it, and that reflection on ourselves, on our values, on our aims and our beings is the subject matter, even if not the only one, of religion, then you realize two important things. First, science is clearly distinct, not to say divergent with respect to religion. Secondly, the divergence is **HARMFUL** because one without the other can be **DANGEROUS**. So a good attitude is this two-fold **ORIENTATION**; not to try to mix up the two distinct disciplines, nor to fill in the lacunae of one discipline with statements from the other discipline, but to try to find ways of cooperation, of synergy between the two, each one at its level and in its proper field, cooperation rather than mixing. This is, roughly, my view of the relations between science and religion. Let me make this a little more explicit with a few texts by well-known authors.

This double claim of distinction and cooperation has been developed by several philosophers of science whom I will refer to here. The first one is Immanuel Kant, the second is Erwin Schrödinger, developer of the wave equation and one of the fathers of quantum mechanics, and the third is Bas van Fraassen, an American philosopher of science with whom I talked just a few days ago so it is very timely issue. There is an entire chapter in his book devoted to the relation between science and religion and he claims to be Catholic so I think it is very interesting.

### **Immanuel Kant**

Beginning with Kant, we find almost everything in the Preface of the second edition of the *Critique of Pure Reason*, also in many other of his books but here is a good summary. Kant drew a curtain between speculative reason on the one hand and practical reason on the other. The aim of speculative reason is to develop discourse on nature, scientific discourse firstly and metaphysical discourse secondly. Kant's practical reason actually is concerned with things that are usually said to

be in the field of speculative reason.

For Kant, practical reason is concerned with the problem of God, the problem of the soul, and the problem of freedom, three problems that are usually taken to be metaphysical problems. ACCORDING TO HIM they are, PREFERABLY, problems of how to be, of how to have a certain attitude in the world rather than speculating about it. This is a very Kantian way of dividing the issues between speculative reason and practical reason. Kant established limits of speculative reason. He said speculative reason cannot go very far towards speculating about the ultimate laws of the world, the ultimate nature of this or that. It cannot speculate about the existence of God or the immortality of the soul or the reality of freedom because, according to Kant, speculative reason is bound to apply itself only to experience. As soon as it goes beyond experience it is a little too, I wouldn't say speculative, in order not to be redundant, but it becomes a little too daring. There is a sort of excess of pride of speculative reason that thinks it can speculate on things that are not really in its field because its field is limited to experience.

Kant says, in this Preface, that the excess of pride of speculative reason, its attempts to prove the existence of God or the immortality of the soul or the existence of freedom leads to skepticism. Too much metaphysics, especially if metaphysics is too excessive in its pretensions, can only lead to skepticism. The excess of metaphysics, he says, is the enemy of religion, which seems strange because usually they are thought of in common. At this point, he condensed all his remarks saying, "I first have to bind knowledge, constrain knowledge, in order to find room for faith." In some way he found that these two disciplines were, so to speak, complementary, in the sense of Bohr, that they each have their own field of investigation but that it's very important to find the connection between the two.

What are the connections according to Kant? First of all, why are they really different? One is a matter of concepts and efficient insights, the other is a matter of duty, attitudes, ways of being, a field of practical reason. This is why they are different, but why are there, nevertheless, deep connections between the two fields? The first connection is that scientific research must be guided by the right attitudes, the right ways of being. If not, it leads to disasters. Secondly, attitudes and ways of being can be easier, or more difficult, to hold according to the evolution in scientific concepts. For instance you know the story that was told in Bertolt Brecht's play *Galileo*, when Galileo announces his ideas about the world, people said, "oh, our faith is made difficult by that". Whether it is right or wrong to say that, it is clear that different representations of the world can have an influence on how you view your faith, and attitudes of the world and such.

### **Erwin Schrödinger**

Schrödinger also had positions on the relation between science and religion that were quite interesting. He expressed them in his book *Nature and the Greeks*, which was published in 1952 by Cambridge University Press. According to Schrödinger there is "openness", by which he means an incompleteness of the scientific picture of the world. The scientific picture of the world is never closed, it is still open, still lacking something, still in the process of being. Of course, some very prominent people say that in fifty years we will have the ultimate laws of nature, but they said that fifty years ago and also one hundred years ago so you have to be critical about it.

Schrödinger says that there is this openness, that religion is not only an attitude but also an order of metaphysical proposition and even promotes this attitude of ways of being because

metaphysics in religion is not a sort of pretentious thing, it may have theological justification but basically it is aimed at promoting a certain moral attitude. At any rate, these positions of religion try to fill in this openness by trying to explain what science cannot explain at the moment and maybe will never be able to explain.

The first quotation I have is: “One of the aims, if not perhaps the main task of religious movements, has always been to round up the ever unaccomplished understanding of the unsatisfactory and bewildering situation in which man finds himself in the world, to close the disconcerting openness of the outlook gained from experience alone in order to raise his confidence in life and strengthen his natural benevolence and sympathy towards his fellow creations.”

Here, Schrödinger says that religion attempts to close the openness of the picture of the world that is provided by science and it may be criticized but it has positive aims, increasing benevolence and sympathy towards our fellow creations. The reason why science wants to keep the openness of its own view is, according to Schrödinger, to be open to future research. For instance, and here is another quote from Schrödinger, “in the honest search for knowledge you quite often have to abide by ignorance for an indefinite period. Instead of filling a gap with guesswork, genuine science has to put up with it and this is not so much from conscious struggles to avoid telling lies as from the consideration that however irksome the gap may be, its obliteration by a faith removes the urge to seek after alternative answers”.

I think Schrödinger is saying that the ethics of the scientist is to keep wide open this gap, this absence of discourse because maybe future research may fill in the gap with other types of discourse. I think that things would be different, of course, if the openness of the scientific discourse were due not to contingent but to necessary limitations of objective knowledge, a sort of blind spot which can be reduced and circumscribed by science, but not completely abolished. This is precisely what is suspected, first by the history of science in general—we have no reason to think that one day the complete gap will be filled in—and secondly, quantum mechanics offers some very good reasons to think that this gap is a very basic and not just a temporary one. For instance, **A. PERES AND WH ZUREK** in a well-known paper about quantum mechanics said the following—I quote from memory but I’m quite sure to be accurate in the meaning if not in the letter—“in microphysics, one can get information about anything, but not about everything.” For instance, you can get information about the position of a certain microsystem but NOT ABOUT the complete set of variables which we could measure. If you take some information about position you cannot take accurate information about the momentum and so on. ANOTHER, MORE IMPORTANT, CASE, IS WHEN YOU WANT TO GET INFORMATION ON SOME VERY INCLUSIVE SYSTEM: YOU CAN GET INFORMATION ABOUT A LARGE PART OF THE SYSTEM, BUT NOT ON THE ENTIRE UNIVERSE BECAUSE YOU ARE PART OF THIS UNIVERSE (YOU CANNOT KNOW YOURSELF ENTIRELY BUT ONLY *BE* YOURSELF). So, you can have information about anything but not everything. Here there is a sort of very basic gap that is quite difficult to fill even if you think about the remote future. Now I come to van Fraassen, I think it’s very exciting to hear what he has to say about science and religion.

### **Bas van Fraassen**

Van Fraassen recently wrote a book, *The Empirical Stance* from Yale University Press and here is his idea: he says that philosophical positions are not really reducible to statements. philosophical positions have more to do with what he calls “stances”, attitudes, ways of considering

the world not only something that can be put on paper in a few sentences, but a way of producing new sentences that you find relevant to such and such situations. For instance, materialism, as you will see in my next lecture, has a very difficult position nowadays, especially because of quantum mechanics, but people who are very interested by materialism, who call themselves materialists, would say, well, yes, I know that the concept of material body is difficult to hold on to today, especially at the micro-level (because of all sorts of difficulties I will speak about later), but we materialist believe in everything that physics says.

Actually then, they are no longer real materialists because they don't believe in that little cell of space that is impenetrable that we call material bodies but they believe in what physics says, and physics says some very strange things, as you know, about microsystems and such. So, materialism is not a set of sentences because a set of sentences can evolve, but it is a sort of attitude of faith in science and can be only that, an attitude, not really a doctrine. The same way with empiricism, van Frassen is an empiricist and he shows that his own views are not the same as Hume who was called an empiricist a few centuries ago, it has evolved very much with respect to that although his basic attitude is the same. In the same way he says that performing signs and having a religious attitude are not reducible to any sentences but rather are "stances" or attitudes.

For instance, I have a quote from van Frassen's book *The Empirical Stance*: "If I am right, what distinguishes the secular from the religious is not the beliefs about what the world is like, although those two are often found among the differences." The difference is not only about the view of the world. IN Another very interesting quotation that you may appreciate, he says: "An encounter with God does not involve solving the theoretical equation or answering the factual query, its searing question is an **\*\*\*(existence of demand)** with face in fear and trembling. As with a human person, the encounter coincides with a call to decide. Possible stances toward ourselves and to our world come to the fore and ask for choice." So here again, religion is a matter of stance.

So there are two stances as I told you, toward the outcome of scientific enquiry. One of the stances, namely the secular or scientific stance finds satisfactory the answers of science even though there are all these open texts, this incompleteness of the picture of the world, people who hold the secular view think that the scientific picture is ultimately satisfactory even if there are some little loopholes that need to be filled in, it's ok. Whereas in the religious attitude there is an element of dissatisfaction with the scientific picture. Of course, people are quite open to it even if they hold a religious attitude, but they don't think it is the whole of truth.

Again, I quote a few sentences from van Frassen: "The more important contrast will be between two attitudes that one can have towards the scientific form of enquiry. One is to be counted with the scientific form as extremely sufficient, so to speak, the other is discounted, abiding wonder, though, as I see it, the discontent is in possible peaceful coexistence with science and every form of practical cognition. Central examples of secularism display that contentment and central examples of religious life exemplify the discontent. An abiding astonishment not allayed by the fruits of scientific enquiry." The other quotation about that is even more striking, I think, I like it: "A religious person could say that at the same time while this objectified enquiry has brought us untold riches, what does it profit us to gain the whole world and lose our own soul?" So this is the type of thing a religious person could say, and he is a religious man.

So, here are some preliminary reflections about the relations between science and religion.

Now I think I can confront the center of the subject, interpretation and the philosophy of quantum mechanics. The first thing I want to do is to ask what is the main new thing that was brought by quantum mechanics? What was really new to it in respect to other branches of science, previous branches of science besides classical physics? There are four possible answers to that question.

### **The difference between quantum mechanics and other sciences**

First of all we must understand the sense of wonder that people had when they first discovered quantum mechanics. Planck spoke about the “explosive power” of quantum theory in one of his texts, he is actually quoted by Cassirer in *Determinism and Indeterminism in Modern Physics*. Heisenberg pointed out the real break in the structure of science that was induced by quantum mechanics and Schrödinger invoked, with some lyrical undertone, the attitude, very exciting, very new, and very revolutionary that was introduced by quantum mechanics. So you see that even the creators of quantum mechanics were aware that something completely amazing was occurring in their science. But when they had to say what it was exactly that was so amazing in quantum mechanics, they couldn't decide. Each one said a different thing so it was difficult for others to understand what was so extraordinary in quantum mechanics. As I said, I can see at least four or five answers to the reason why quantum mechanics is so revolutionary.

1. The first answer is that, actually, the new thing about quantum mechanics is exactly what is in its own name, quantization, the fact that certain variables do not have continuous but rather discrete values. For instance, you know the discreteness of spectra, of the emission of light, and then you have certain variables such as the frequency of emitted light which are discrete. This is the first possibility and it was strange indeed because in classical philosophy there was a certain law that was considered very important, which had a regulative status even in Kant, and which was the law of continuity. Everything was continuous in nature, nothing could jump, so it was quite new, quite strange, quite interesting.

2. Now, between 1905 and 1911, and then in the twenties with Lewis de Broglie another new feature was introduced that was also very interesting and strange, it was the relativity between wave-like and corpuscular-like aspects of micro-entities. For instance, Einstein considered the photon as corpuscles but at the same time he realized that he couldn't just waive the old considerations about the wave-like behavior of light but he didn't really how to combine the two. De Broglie tried to combine them a little bit more and then they were combined in a sort of non-pictorial but rather very formal image that was the formalism of quantum mechanics. So the second thing was the strange association between waves and corpuscles.

3. The third conception about the most strange thing in quantum mechanics was developed by Heisenberg in 1927, which were his Uncertainty Relations or Relations of Indeterminacy, according to how you conceive them. He concluded his paper by saying that quantum physics meant abandoning the idea of determinism, so determinism was opened. Indeterminism then was the third conception of a new element from quantum mechanics.

4. The fourth conception, which is maybe I think the most important, is the strongest incentive ever not to content oneself with a conception of pre-established objectivity, but rather to go back to the very way an objective world is constituted, in the Kantian conception, almost constructed out of phenomena and out of concepts that are able to link the phenomena in such a way that this link is common to anyone, any scientist anywhere at any time. So the work of objectification has to be

performed once again. You cannot just say, well, things are objective out there, I just have to study them by any means, but I really have to do something much more difficult and much more involved, which is going back to the phenomena, phenomena that, according to Bohr, cannot be, so to speak, divided into the contribution of the apparatus and the contribution of the sort of pre-existing object, but phenomena which are completely, holistically I would say, united. So when you have these phenomena that are holistically united, you then have to do additional work to get back an objective discourse.

This is a very interesting point. Heisenberg spoke of the loss of the Cartesian cut between *res cogitans* and *res extensa*. The very interesting thing, I believe, is that all the other strange features of quantum mechanics, namely indeterminism, discontinuity, and wave aspects of corpuscles can be derived from the last one, which is very fascinating. Not everyone knows this in a clear way, but you can find it scattered in the literature and it is quite easy to gather all the ideas about it. I will speak more of this in a moment.

### **The convergence of ontology and epistemology**

I've come back to the first big change in our view of the world, the change from continuous to discontinuous mathematics, from continuity to discontinuity in the transitions between one state and the other. So first, what is quantization? Is it the theoretical expression of a sort of discontinuous evolution that is going on out there in nature or is it the sort of way of analyzing the process that might be continuous as well? Is discontinuity in nature or in ourselves? This is the first question. Or is there a third possibility? This is the usual dichotomy between subject and object, either it is nature or it is us, but there could be a third possibility which was well expressed by Heisenberg in 1958. He said that discontinuity is neither completely in nature nor completely in us, but it's in the interaction between the two, it's in the interface we have with nature.

Heisenberg said that discontinuity is indiscernibly ontological and epistemological. It's linked to the changes that occur when we dig experimentally into what we want to know in nature. So it is the matter of the relation between us and nature rather than either nature or us. According to how you answer that question, to whether you say that discontinuity is a matter of nature or our way of analyzing nature or if it is something in between, you have a very different view about who really discovered quantization. Who was it? Well, if you think that discontinuity is essentially a subjective matter then you can say it was Planck who discovered discontinuity.

In 1900, Planck hypothesized that the exchanges of energy between matter and radiation must be analyzed according to a discontinuous grid of values of energy. When you analyze his papers at that time, you find that he never said that in true fact, the elementary oscillators of a black body were quantized. He never said that. He was even very much adverse toward atomism and an atomistic view of the world, but he introduced that grid of analysis of energy because it was the only way to get the right formula. Then a few years later, in 1905, Einstein took the formula and said, actually, what could be done in order to derive Planck's formula is to introduce true quantization. First the quantization of the oscillators of the black body and second even the quantization of electromagnetic radiation, namely considering that electromagnetic radiation, which was usually conceived of as completely continuous, was actually made of little quanta of energy, which were later called photons.

Later on, in 1913, Bohr introduced quantization not only for oscillators of black bodies and

electromagnetic energy like Einstein, but also in the possibility of motion of electrons in an atom because it was the only way to assure the atom's stability.

Finally after this work by Planck, by Einstein, by Bohr and such, people were aware that there was something really new, that processes were quantized. They had just discovered, thanks to the work of Einstein in 1906, that there were really good reasons to believe in the existence of atoms. The new view is that existence in nature is discontinuous and that atomism has finally won the battle against its opponents who were very numerous at the time. So, a sort of triumph of atomism, but be careful! In 1924-25 many things happened that were more nuanced.

For instance, in 1924, Bose and Einstein published a paper about the derivation about Planck's law of radiation by considering that electromagnetic radiation was made of a gas of photons, but in order to derive Planck's law from this idea that there is a gas of photons, Einstein and Bose had to make a strange hypothesis. You could describe this hypothesis mathematically but it's not very interesting. I just want to show the reaction that Einstein himself had to this hypothesis. He said that, actually, in order to explain our hypothesis we have to assume that there is a reciprocal dependence, a mutual dependence of quanta between each other. Mainly, the sort of instantaneous inference of quanta on each other. This gas of quanta didn't behave in a usual way; it was not a set of little things separated with links or such. It was a whole because one part interacted instantaneously with another and this special hypothesis couldn't be understood without assuming this. It was Einstein who said this in a letter. Then, in 1925, Schrödinger also theorized the same law of Planck but he did something even more daring. He didn't say that, after all, electromagnetic radiation was made of a gas of photons but was just one, single standing wave in a category. This standing wave was quantized using the fact that as any standing wave it can have one node or two node or three nodes or so on. The number of nodes was connected to what was usually called the number of particles. If there are  $n$  nodes, there are  $n$  particles.

This is an anticipation of the problems of locality and time. It is the first time in history that this strange feature was, I don't want to say discovered, but at least imagined because it came to explain the strange statistical hypothesis.

I think Schrödinger was even more daring. He says, ok, forget about the thesis, it's really a whole, it's not just a few quanta connected instantaneously with each other, it's really a whole, a real standing wave and he actually even said that, according to him, there are no quanta at all, there are only nodes of oscillation of a standing wave. This is the preliminary version of something that is very well-known nowadays, which is quantum field theory in which the number of photons or the number of any particles is actually the value of an observable that has to do with measurements on a certain field, a quantized field. It's no longer a view in which you have a sort of gas of photons, but a view in which you have a certain continuous medium that is quantized and the value of the quanta corresponds exactly to what we usually call the number of particles. So you see that instead of having a sort of ultimate victory of atomism, things changed completely very radically only in 1925 into something completely different, something much less atomistic and much more holistic. It was very exciting.

Other things that are more directly furnished might trigger the feeling that there actually were atoms, that there were little things like particles and that all these considerations by Einstein or Schrödinger were just their anticipation. For instance, in 1923 the Compton effect was discovered. In

sending electromagnetic radiation, without saying whether they were waves or particles, into a gas of electrons you get some scattering of the radiation. The scattering could only be explained by hypothesizing that each photon is a sort of relativistic particle and that electrons are also relativistic particles and then you get the right answer about the angle and so on and so forth. You could use something like wave behavior but it's only in order to calculate the certain variables that the particle possesses like position and momentum.

Almost all of the scattering phenomena can be explained by supposing that electrons and photons are like those special relativistic particles since there is this proof that there is something **\*\*\*(...)** in the microworld. Conceptually, empiricism is holding always that a certain philosophical assumption is always underdetermined by experience, that experience doesn't pick exactly what theory is right and which is wrong, but only which theory or group of theories is viable and what other group of theories is not viable at all in probabilistic experience. So actually there are many more theories that can explain this Compton experience than the theory according to which the microelements of matter are all made up of corpuscles.

For example, Schrödinger himself, in 1927, made a completely wave-like model of Compton scattering. He says that electrons are actually identified to a certain grid of defraction that is made by their own waves and that electromagnetic radiation is also made up of waves. These two waves then interact by means of the usual formalism of defraction. Then you arrive at exactly the same results as by using the relativistic particle formalism. So Schrödinger says that there wasn't proof that they were made of corpuscles because I can explain it just as well as with my own purely wave-like model. Later, there was **VON NEUMANN'S model using THE ABSTRACT** formalism of quantum mechanics that is neither corpuscular nor wave-like but very formal, HILBERT SPACE and so on and which also give the same results. So you see there are many theories that can give the same results so the idea that the Compton effect gave proof of the corpuscular-like nature of matter is not complete.

Does this mean that quantum mechanics has nothing MECHANICAL or nothing quantum in it? It seems strange because it is the very name of the discipline. It's all the more strange that people usually don't think it deserves the name of mechanics because it IS not, or not only about motion of things but rather the probable finding of something here or there. Motion is something important from classical mechanics that has equivalence in the formalism of quantum mechanics but which is not really described by quantum mechanics.

Even Heisenberg was really surprised in 1926 when he discovered that in his matrix mechanics there was nothing equivalent with the motion of well-determined trajectory and that he had to invent indeterminacy relations in order to "fix" the old-fashioned notion of motion on the one hand and the new formalism of quantum mechanics. So motion is not really something that is completely intuited, it has to be arranged. It's not because it's not quantum either. Actually, if you made something from quantum theory, the next quantum is the schema representation of the status **\*\*\*(...)**. In the formalism of quantum mechanics you have something called apparatus of interface that usually has quantized ideas, so there is something quantum but it is metaphysical being that can be applied with success in order to predict phenomena. Schrödinger criticized, and I think he was right, that there were little things present in one state and that they jump from one state to another. Actually what there is, is only the mathematics of quantum mechanics, only apparatus with discrete, not little things that go from one Eigen state to another.

The very interesting point is that the schema of quantization of quantum mechanics, the fact of discrete values, Eigen values can be derived from the hypothesis that phenomena are relative to context, or relative to many contexts that are sometimes incompatible with each other. This work was first done by French philosophers of physics called **\*\*\* (Jean-Louis DESTOUCHES)** and then it can also be derived from the elementary theory of quantum mechanics by seeing that the quantization of apparatus can be derived from what we call the correlation relation, which means that some variables are incompatible with each other, that no variable can be defined independently from the way of measuring it. The image of quantization, therefore, can be derived from computation, from the assumption that phenomena cannot be made independent from certain variable measurements and that the practice of measurements are sometimes incompatible with each other. It's very interesting to see that quantization is a sort of secondary consequence of something more elemental, I would say, quantum physics. For example, you will see exactly the same thing for wave-like as for corpuscular-like behavior of quantum elements.

Turning to the problem of wave-like behavior, this was discovered in 1905 by Einstein just because he was surprised by the contrast between his hypothesis of light quanta and the fact that an old theory worked very well for many other phenomena, namely, the old Maxwell theory of electromagnetic waves instead of particles. So how could this be reconciled? In order to explain the photoelectric effect you need these packets of light and in order to explain the interference effect you need waves, so how is it done? Image the dilemma, Einstein was very annoyed by this so he said that its status was only provisional, he couldn't manage to combine the two, but he imagined that maybe the corpuscle was guided by the wave. He was the first and then de Broglie said that maybe Einstein is right about thinking that the wave guides the corpuscles in the case of light and maybe I could do the same the other way around, applying it not only to light and electromagnetic radiation but also to electrons, protons, and all those little elements of matter. So in that case, they are corpuscular but maybe they are also wave-like. There was thus a sort of unified theory formulated by de Broglie about the relation between wave and particle elements.

Then in 1926 Schrödinger proposed a theory in which, the only element needed was waves, not corpuscles at all. For instance he derived the quantized states of atoms by supposing that there were standing waves that were confined by a certain potential triggered by the nucleus and then he theorized not only the form of quantized relations but new quantized relations that fixed things, for instance interference, which Bohr's theory didn't manage to fix.

With this hypothesis Schrödinger managed to show that the things he predicted were very close to the things that Heisenberg had predicted one year before with his matrix theory. So the whole puzzle was completely ok then. So you see that at time a completely unified and satisfactory mathematical framework was obtained and it was able to account for the whole set of phenomena that were hypothesized in conjunction with quantum concepts. The problem was, what was the status of that wave, that strange wave that was associated with particles and that was proposed by Schrödinger as the only real reality. It is only a sort of guide that the particles ride or is it the only reality, as Schrödinger thought, or is it not a thing at all, only a mathematical tool to calculate probabilities as Max Born proposed only a few months after the presentation of Schrödinger's equation, Schrödinger's way of deriving the quantization of spectral dynamics.

Each one of these solutions was developed by different people. For instance, the first

solution, that there is, so to speak, a wave that guides the particles was developed by David Bohm. The option that reality is made of waves, only waves, and that sometimes there are wave packets that simulate corpuscular aspects was developed by scientists after Schrödinger including Hugh Everett whose interpretation was that the consequence of Schrödinger's views was that only waves and nothing else was real.

The last conception that the waves are not real waves but are "probabilistic" waves, are really very special waves because they involve a series of events which disappear at the macroscopic level but not at the microscopic level, was the standard conception, the one that everyone adopted.

Before I finish these considerations about waves, I first have to ask whether there is a definite, crucial experiment that shows the existence of waves that were proposed by de Broglie and that were developed by Schrödinger.

In 1927, two German experimenters made an experiment of defraction of electrons on a prism and observed a differential figure, something that is very typical of waves. The defracted distribution of electrons on the screen was typical of what would be expected if there were real waves. It was very striking. Most people would say, "oh, this experiment shows that there are waves in nature. It is proof of the existence of waves." But in order to take this point of view seriously you would have to show that existence of waves are the only theoretical way to explain this experiment, but there are other ways of explaining it.

In 1951, Bohr, in his book about standard quantum mechanics, orthodox quantum mechanics, years before he proposed his view of hidden variable theory he mentioned that there was another, alternative way of explaining the (Clinton) Davisson– (Lester) Germer experiment that didn't imply waves at all. This possibility was suggested by the American physicist **DUANE** in 1923 and it was developed later by Alfred Landé in his book published in 1965. This alternative explanation is guided by the assumption that there are only corpuscles, no waves, in nature. When the corpuscles interact with the lattice of the crystals, where they are refracted, they try to evade in a quantum way, with (extension) to quanta of energy. If you assume that electrons are particles and that crystals only exchange quanta of energy, then you get this impression of waves, apparently directed waves.

This means, firstly, that supposing there are real waves in nature is not the only way to explain the diffraction events, secondly, that the explanation of diffraction events can take advantage of **CONTEXT**, which is very close to what I explained before, contextualism, namely that you cannot say that this phenomenon is only due to the properties of electrons, but it is due to a sort of combination of properties of the electron *and* the apparatus with which it interacts. Here it is a crystal that interacts with an electron and it changes completely the behavior typical of electrons. So what you see on the screen is not the proof of the nature of electrons, be it corpuscular or be it wave-like. Essentially, it is proof of the nature of the interactions between the microworld and our apparatus.

### **Indeterminism**

Moving on to another very important topic, indeterminism. I said there was another, a third way of understanding the new feature of quantum mechanics, so I have to explain a bit the status of indeterminism to explain that, after all, this also can be discussed, it's not something that is dogma. Moreover, I will explain that indeterminism, or at least the apparent indetermination of events of phenomena can also be explain by holism, by contextualism. In order to show that after all, and I think this is so, there are many reasons for thinking that holism, contextuality, might be the most important

of the changes that were experienced.

Indeterminism in the 1930's was taken as the most interesting and the most strange feature of quantum mechanics. You remember Einstein saying to Bohr, "I cannot believe that God would play dice with the universe." Maybe you are not as familiar with Bohr's response, which is also very interesting, that "Well, how can you say to God what he should do?" It's a way of saying that this issue is very open. This issue of indeterminism was introduced first, I think, by Max Born in October of 1926 because he said the following: "Schrödinger's quantum mechanics gives a precise answer to the question of the effect of collision of particles and the scattering effect, but it is not the causal operation. In theory one does not the answer 'what is the state after a collision?' but 'what is the probability of obtaining a certain effect after the collision?'" So it's clear that the theory only gives answers about probability not about determinative causes.

Heisenberg's crucial remark in his 1927 paper on uncertainty relations wrote the following: "What has been refuted in the exact law of causality according to which when you know the present with precision you can predict the future is not a conclusion but a hypothesis." Meaning, maybe we could predict with precision the future but the problem is that we cannot know with precision the present. Why? Because there are uncertainty relations, we cannot know both the momentum and the position of a certain electron so obviously we cannot predict with certainty what will occur later with this electron.

With this proposition Heisenberg thought it was correct to state the following: (in the same paper he says) "Quantum mechanics states the final failure of causality." When you think about this, when you think about Heisenberg's first and second statement you see that maybe the conclusion is not completely right. In 1929, a younger German philosopher called **\*\*\*(Hugo BERGMANN)** who was then followed by Ernst Cassirer, who is a much more prominent philosopher, mentioned to Heisenberg that his conclusion could not be derived from his premise. Namely, that his premise about the uncertainty relation did not contain the final failure of causality. Why? **\*\*\*(Hugo BERGMANN)** said: "A logical implication is not refuted if one proves that its premise is not correct." What Heisenberg said, that since you cannot know the present you cannot know the future but he didn't prove that you cannot know the future in any case. Of course it was the problem of limitation why you cannot know the present but the result was not as strong as Heisenberg thought. Of course, immediately people think, "maybe there is a way to rescue causality and some people even managed, especially with some hidden variable theories, to save causality. They succeed partially, not entirely, with Bohr's theory, which is deterministic and reproduces most of the predictions of the standard theory.

In this way perhaps we can say with **\*\*\*(PIAGET)**, a French philosopher who wrote a book about the probability of quantum mechanics, that the true lesson of quantum physics is not that determinism is false but only that the classical idea of causal determinism is neither true nor false but devoid of physical meaning because either you accept standard quantum mechanics and you cannot predict phenomena but only probabilities for phenomena, or you adopt the hidden variable theory and then you fall into the Kantian problem, a sort of background world where things happen but which is impossible to reach experimentally. So it is devoid of meaning or experimental verification.

I would just like to show you how you can philosophically treat the issue of determinism and indeterminism without taking a metaphysical position and yet drawing a very interesting conclusion about it. If you take a metaphysical position you could say, again, that indeterminism is something in

nature or something that has to do with us because, for instance, we are disturbing processes and this disturbance is something we bring in and maybe in the beginning everything is determined and it is only because we disturb processes that we cannot really repeat them experimentally. There is some, I would say, undetermination about the status of indeterminism.

Let's shed some light on this idea that there is an undetermination of indeterminism. One of the best specialists of probability in France **\*\*\* (Jacques HARTHONG)** compared the problem of indeterminism to one of the Kantian antinomies. You know that the antinomies are a sort of dialectical reasoning where reason can contradict itself, where reason can convincingly illustrate a certain thesis and can also demonstrate another thesis, which is exactly the contrary of the previous one, in a very convincing way. There are four antinomies in Kant. **\*\*\* (HARTHONG)**, and myself, formulate what we call the fifth antinomy, the antinomy of probabilistic predictions. The first thesis is that the ultimate law of the world is chance, the real laws of nature are just chance and any partial determination that could be found in nature is the result from the laws of large numbers. For instance you could imagine that everything in the microworld is completely indeterminate, no laws only chance and that only because there are such large numbers of events are there statistical regularities that emerge. So you could explain this way why we believe that there are strict laws in the microworld. This thesis is compatible with everything we know. The antithesis is that the ultimate laws of the world are entirely deterministic and any irregularity we could observe, for instance in the microworld, results from deterministic chaos, namely too many conditions, too many causes that interact in an unpredictable way and moreover they are very sensitive to each interaction so that, a priori, there is complete random nature. So here the real law is deterministic and the apparent law is random.

This second position is very consistent with the hidden variable position. Even Bohr, in his hidden variable position said that actually the laws of nature were completely deterministic yet there is **\*\*\* (...)**.

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## **Introduction**

I'll come back to my previous subject. Today I should be able to finish the topic of indeterminism and then begin a whole new topic about the issue of matter and materialism. It's the one I want to develop more although I also wanted to say something about the measurement problem, I have something to say about that, but I think you have plenty of time to face this central issue of quantum mechanics so today I want to do something more, maybe, exciting, philosophically speaking and more basic also.

## **Indeterminism (cont.)**

So, coming back to the problem of indeterminism, I tried to argue that the issue of indeterminism was not really settled in quantum mechanics, that, metaphysically at least, it was not clear that the ultimate laws of nature were indeterminate just because there is a sort of difficulty going beyond, not difficulty but limit to going beyond the strict level of appearance. The strict level of appearance is clearly indeterministic in quantum mechanics in that in most cases you cannot really predict events in a way other than probabilistically but the problem is that there was this kind of antimony, which I developed earlier, that mostly you can explain the fact that appearances are

indeterministic with laws of deterministic chaos or conversely you can explain why sometimes things appear deterministic with the statistical law of large numbers.

If you accept this, the strongest argument that can be given in favor of indeterminism at the microlevel is that any search for deterministic laws would be sterile because it only concerns things which are beyond any possibility of experience such as the laws of some hidden variable theories. The other close argument is that applying the Leibnizian principle of sufficient reason at any cost would be fruitless in that case, that no experimentally testable consequence would arise from this research. The conclusion to me seems to be mitigated in that you cannot completely preclude a sort of underlying deterministic law but at any rate such a search would be a bit sterile.

What is interesting to me is not the ultimate law of nature but explaining why, at any rate, even if the ultimate laws of nature are deterministic, why phenomena appear to be indeterminate and why do they appear in a completely random way, in such a way that we have to predict them only probabilistically. Why is this? Interestingly, there are some ways of stating that. For instance, Karl Popper, in his book about indeterminism, it is actually part of the logic of discovery, one of the last parts of the logic of discovery, one of the comments. In that book he argued that even in a world ruled by an underlying indeterministic law, an observer could not predict a phenomena if this observer were, him/herself, entangled in the process of its production. That is, if someone is completely involved in the process of producing a phenomenon, then they cannot predict it just because there could be something like self-involvement in the prediction. If they predict that such or such an event will appear than they can take this into account in order to change their own behavior and then, changing their own behavior since they are involved in the production of that event, the event will change. Thus they cannot really predict it because they are too much involved in the production of the event. This was the argument of self-involvement that was given by Karl Popper in his book about indeterminism. In short, as soon as the observer has predicted what they will do, the very content of the prediction can be transferred to future behavior.

This spurious act of predicting on the predicted behavior may make the prediction wrong. Then, due to the entanglement of the predictor and the predicted phenomenon, the logical limitation of said prediction results in the limitation of the prediction of phenomenon. So the possible explanation is that even if the hypothetical ultimate laws of nature were deterministic, maybe we still could not predict some events, namely, those in which we are most involved.

Of course, this is very theoretical, very abstract, but in quantum mechanics it is exactly what happens. We are, with our apparatus, very much involved in the production of the phenomenon. We are contextually indiscernible from our apparatus, so to speak, to the production of phenomena. So there is a sort of self-referential loop here that appears and which may be a reasonable explanation of why phenomena appear to be indeterministic. This is also a hint of how things could happen but there are more specific arguments and even a demonstration of that. A first, more involved argument was formulated by **\*\*\*(GRETE HERMANN)**, a young philosopher of physics who worked with Heisenberg, Carl von Weizsäcker, and Bohr in 1934 and she published an excellent book in German called *The Philosophical Foundations of Quantum Mechanics* in which she tried to save the Kantian category of causality from Heisenberg's original criticism.

### **Causality**

She said that, actually, the category of causality could be saved provided that you accept that

certain phenomena has some causes that are not only previous to it but also simultaneous with it, that some of its causes are the very process of interaction between whatever you can call the physical system and the apparatus. This very moment is part of the causes of the phenomena so the phenomenon is caused not only by former events but also by events that are coextensive to its own production. It's a way of saying that we with our apparatus are too involved with the phenomenon to predict it even though you could still consider it as produced by causes.

What is interesting to me in that is not the attempt of saving the category of causality but just the idea of the production of the phenomenon, that the involvement we have with the production of phenomena can explain why we cannot really predict it. I agree that these arguments of causality are a side argument.

The second point is that Kant himself, when he described the category of causality in the *Critique of Pure Reason*, said that the cause could be previous to its effect on the temporal basis but that it could also be previous to the effect on the logical basis. The example he gives is that when you put a heavy ball of metal on a cushion it deforms the cushion so you say, well, the cause is previous to the effect. But let's imagine that the ball is already on the cushion. In that case you could still say that the ball is the cause of the deformation of the cushion, but it's not really previous. At least you could say that it's logically previous, you can just say that *if* the ball had not been on the cushion, then the cushion would not have been deformed. It's a logical way of defining cause, a counterfactual rather than temporal anteriority.

Rather than insisting on this issue I would mention that the French philosopher of physics in the 1940's, Paulette Destouches-Fevrier demonstrated a theory according to which any predictive theory bearing on phenomena that are defined relative to, possibly incompatible with experimental context—just as in quantum mechanics where we have incompatible experimental devices that give complimentary information about anything you could call the physical system—if these phenomena are defined relative to such experimental contexts, then this predictive theory is “essentially indeterministic”. Phenomena cannot be predicted except by probabilistic tools.

Indetermination in the sense of unpredictability here is the direct consequence of the relativity or context-dependence of phenomena. Each time I am trying to show you that the most important features of the quantum revolution, namely quantization, wave-particle duality, and now indeterminism could all be considered as consequences of the relativity or context-dependence of phenomena with respect to our experimental tools, which I think is very exciting for an epistemologist.

It is true that one could think a classical possibility of self-involvement but with a convergent series. The question is why this is not a possibility in quantum mechanics. Either you say that there is no answer at all because this is a sort of principle of quantum mechanics, and I think this was Bohr's idea at the end of his life especially after the EPR discussion, he said I don't want to inquire too much into the reason why there is this impossibility of separating the contribution of the microworld and the contribution of the apparatus. I take that as a principle of holism of the phenomenon and then I derive the rest, which is my own position. Now, if you want to explain it you could rely on the concept of disturbance as Heisenberg did in the 1927 and a little later saying, whenever you want to measure such and such a variable of a quantum system you have to send a probe, for instance a photon, disturbing it in such a way that the disturbance cannot be smaller than a quantum contraction. Then saying, but I can control the disturbance, and how? by sending another photon on the photon but this

particle will disturb the photon in the exact same minimal amount so the theories don't converge because the quantum is always of the same value...

One could say that the distinction between classical and quantum mechanics is that in classical mechanics you can accumulate experiences so any series of successive measurement is convergent because you accumulate information. In quantum mechanics you cannot accumulate information. You can do both. I must say I prefer both because when you use this view of disturbance and say that disturbance cannot be completely clarified you imagine a quantum world in the shape that it would have in classical mechanics. You say that there are small particles and then I disturb them, while in Bohr's view you are completely agnostic about what is or what is not the quantum world and then you try to reconstitute it by trying to combine the phenomena. I prefer this sort of *tabula rasa* where you know nothing about the microworld, you only have this phenomena that are obtained from our apparatus and then you try to reconstitute something out of it. This is a choice, not a...I'll try to do this with materialism, start with a *tabula rasa*, to try to see what of information we can have and what kind of meaning we can give to the very concept of matter.

You remember that I quoted three interpretations of indeterminism, the one that is ontological, the second that is purely epistemological, and the third that is in between. If you take the picture that there are little things moving here and there and that you disturb them, then, clearly, indeterminism is epistemological whereas the ontology is completely undecided because you don't know what is going on independently of your measurement. That is another reason why I try to stay in line with Bohr's views because his views are not *either* ontological *or* epistemological, it simply says here are the phenomena. The phenomena are neither purely natural nor purely epistemological; they are interactive and out of them you can build the whole world of theory. Here again is a way of saying that you cannot decide between the ontological and the epistemological interpretation of indeterminism. I think it's safer not to decide that but to start so to speak *in medias res*, in the middle, from the interaction.

One could say that in this situation there is nothing very new from the classical point of view because, philosophically, the same can happen with a great, big ball because my measurement is always the interaction between me and the ball observed. So where is the difference between distinguishing epistemological than ontological interpretations from classical to quantum mechanics? What is new.

It is an interesting question. I'll return to Kant because I think Kant guessed a lot about it. He says exactly what you do, namely that in classical mechanics you also only have access to phenomena and not to the thing-in-itself. It is exactly the same apparently, but he also said that you can order the phenomena by means of the a priori forms of our sensibility and the a priori forms of our thoughts, namely the categories, in such a way that everything is as if you had objects that had properties independently of our means of experience. But he also always underlined the idea that it was only an "as if" discourse. Actually, classical mechanics does not deal with the thing-in-itself. It only deals with objects that are, so to speak, syntheses of interactive phenomena, but this order of phenomena is such that nothing precludes that somebody says, oh, perhaps they are exactly the thing are they are in themselves in the world; it is only an "as if" discourse, not a metaphysical complete expression. Whereas in quantum mechanics you generally cannot say that the value of an observable is something already possessed by the object before except for the people who believe in

hidden variables, but that's a little too speculative. That's the idea, I believe, that the "as if" clause cannot be implemented in quantum mechanics whereas it can be in classical mechanics.

### **Materialism**

As an introduction I will give you a definition of matter, or more precisely, one of material bodies that has been widely accepted in the West, from ancient Greece to Newton. The material body according to this definition is a fraction of space endowed with properties. The most characteristic among these properties is impenetrability and mass. From the 17th century onwards, this definition was retained but a turn from epistemology to ontology was taken. Before I move on to the 17th century, perhaps I can give a hint of what was believed about material bodies at the time of Aristotle and a little later.

According to Aristotle, a material body is a compound of matter—in the sense of potentiality, not matter in the usual sense—and of form. This form is what gives matter three-dimensional extension and quantity or volume. Matter plus this extension that is given by form makes a material body. This means that quantity, or volume, or extension in space was taken as a simple determination of matter, a simple property, so it was something rather secondary in Aristotle even though, in the list of categories, quantity has the second rung after substance that means that it was quite important. In later commentators of Aristotle, the tendency was to promote this privilege of special extension by putting it at the first rather than the second rung of categories, that is, at the same level as substance itself.

For instance, **\*\*\*(John PHILOPONUS)**, a commentator of Aristotle of the fourth or fifth century, had two steps in his book. The first he thought exactly the same as Aristotle, that is, pure, non-informed matter and form that gives it quantity and extension. As a second step, he thought that three-dimensional extension should be at the same rung as substance. It's interesting. He thought that three-dimensional extension was called the first subject of any other characteristic. So it was really considered as *the* substance. I think this was inherited by Western thought that actually the substance was *essentially* extended and thus that matter, what we call "matter", became completely synonymous with "material body", bodies that have volume and extension, whereas in the Aristotelian sense matter was something much more non-informed, much more potential and not actually endowed with extension and volume.

Now we come to the 17th century, which is very important because there is a turn from ontology to epistemology with Descartes and Kant especially. The reason why Descartes thought that the very nature of material bodies identified especially as extension, exactly like **\*\*\*(John PHILOPONUS)** but in a very different sense, is that we can still very clearly conceive of the bodies if we make abstraction of their qualities, but not if we make abstraction of their spatial extension. It's because we can clearly conceive of a body that is extended but we cannot conceive of a body that is not even extended. Here it is our capacities, our faculties of knowledge that determine the nature of matter, not the nature of matter that determines which capacities are to be used in order to know it. So I think this is the epistemological turn of the 17th century that is clearly seen.

Things are quite similar but more elaborate with Kant. According to Kant, phenomena can be objectified or detached from particular situations if they are pre-ordered by the concepts of our understanding in such a way that we manage to extract invariant structures out of them, structures that could be exactly identical to themselves if we adopted different standpoints in respect to them, if we

were different subjects, or in different positions in relation to that variant, or even if we were later or earlier than them. So we manage to extract invariant structures by ordering phenomena according to the a priori forms of our sensibility. On the other hand, these phenomena are given to us through the forms of our sensorial intuition that are spatial for reasons that Kant explains in the first part of his critique.

They are bound to be spatial because space is a precondition for there being experience of things external to us and external to each other. If the phenomena were not experienced in a space-like framework, we would not even have the domain of perspective apparatuses and this would make pointless the very thought of extracting invariants. These kind of a priori conceptions that are very typical of Kant's critique. If this is so, the only objects that we can properly constitute in our experience are bound to be extended. In other terms, the only genuine objects of our external knowledge are material bodies.

So it's clear that here you have the very concept of material body that is an extended entity that is a consequence of our use of this compound faculty of knowledge that is made by sensibility, which has space as an a priori form, and our concepts, which order these spatially given phenomena. In some way you could say the fact that our primary objects are material bodies is a consequence of our own epistemic constitution. The connection between material objectivity has been confirmed and strengthened by modern experts of cognitive science. I could talk about very modern cognitive science, but I think I will use an intermediate step between Kant and modern cognitive science, which is still quite recent, the Swiss cognitive scientist Piaget.

According to Piaget, children can objectify things as soon as they are able to extract reversible schemes of actions having a group structure. Reversibility means that one can come back as many times as necessary to a situation wherefrom the phenomena looks exactly similar. It means that one can reproduce and hence find a way to make invariant a certain configuration of phenomena. So it is very important for a child to acquire this group behavior, namely, when they take something they can replace it, or when they see something from a certain angle than they can come back to the previous angle and see it again, or when they see a certain object moving they can see it disappear behind a screen and continuing along with their eyes they can follow, not in thought but at least by motor activity, the hypothetical trajectory then they can recognize it again on the other side of the screen. All these types of behaviors, which are also types of reversible behaviors because they can return to the previous position to find maybe another object making the same trajectory or so on, all these types of behaviors are sort of an embodied group structure. Afterwards then, in the child's development, this type of embodied group structure will be abstracted at the mathematical level, giving rise to many theoretical constructs.

This is the basis for our recognition that there are material bodies because we can follow them, displace them, substitute them, and so on. This takes the place of Kant's categories, Kant's categories supplemented by the schemes of imagination are, so to speak, made very concrete, more concrete by Piaget. The very interesting thing is that space itself can be constructed out of reversible schemes of action having a group structure as was shown by the French mathematician of the late 19th century, Henri Poincaré. Poincaré showed that you can generate the structure of Euclidian space by means of the group of displacements of the body, which is interesting and fits quite well with Piaget's views of the genesis of the concept of permanent material body.

Here again, a very strong link between space and objectivity arises. The way you arrive at the idea of objective elements is the same way you arrive at Euclidian states. Our objects are bound to be spatial, they are bound to be material bodies. The fundamental idea I want to show you is that the scheme that makes elements of phenomena objective according to Piaget are exactly isomorphic to the schemes that make Euclidian space possible in Poincaré's views, namely, there is a complete coincidentalness between objectivity and the constitution of space. Thus, it's no wonder that our basic objects are material objects in that sense, namely, extended objects.

Going back to the issue of materialism, I could summarize saying that the reason why our privileged objects of knowledge have to be material bodies, or spatially extended entities, is that the scheme of motor activity that extracts invariants in space is identical to the schemes that defines the structure of space. It is very interesting that there is this coincidence between the structure of activity that enables us to extract objects and the scheme of activity that allows us to constitute space. By the way, this also provides us with an answer to the puzzle of what Eugene Wigner called the "unreasonable expectedness of mathematics in physics". Why are mathematics that are produced by our minds so efficient to grasp the objects of extended reality? This agreement between mathematics and physics looks quite mysterious but would look much less mysterious I think, and much more reasonable if one construes mathematics as a symbolic abstraction of actual and possible schemes of action, and if accordingly one assumes that objects are constituted out of phenomena which are then embedded into actual schemes of action. For instance, in Piaget, mathematics is an abstraction of our possible schemes of action whereas physics is concerned with acting concretely, in actuality, on phenomena by trying to anticipate them.

So it is clear that here there is something that is much closer to one another. Mathematics and physics are much closer to one another than in the case where you conceive that mathematics is all in our mind and physics is all outside. With action you have an intermediate way. Action is both external, it's on something, and internal because it's by somebody. This interface of action is the place where both physics and mathematics arises. The agreement between the two fields is not as strange as people believe if there are too dualistic.

It is true that physics doesn't like infinity very much whereas the mathematicians do. So not everything is a match. Now, what is infinity? Of course you can conceive of actual infinity as Kantor did and this is a little difficult to assimilate in physics. You can also, as classical mathematicians did, conceive of infinity as just a sort of indefinite possibility of development and this is quite easily assimilated by physics, which is concerned with possibilities of action. It is perfectly acceptable in physics to conceive of possibilities that are indefinitely developed. So it depends on your conceptions.

So, if you accept what they say about matter, you see that material body appears as a relatively anthropocentric notion, a notion that is convenient for people who are able to act, to manipulate, to move, to follow, and so on. It is nothing more and nothing else than a pragmatic notion useful for human purposes in the direct environment of humankind, that is, in the macroscopic world we live in. Given its purely pragmatic status, we should not be surprised if the notion of material body falls apart when we go far from the direct environment of mankind, for instance, when we go the microscopic world. This is precisely the case. At the microscopic scale the notion of material body as an object of knowledge is deprived of the basic cognitive conditions of its actuality. To show this I'll return to Piaget who also wrote about microphysics in a very clever and very interesting way.

According to Piaget, the question is not about knowing how to characterize already existent material bodies nor conversely to find a way to demonstrate the inexistence of such material bodies in a domain of investigation such as the microworld. According to him, the true question is to determine to what extent the conditions that enable us to presuppose the availability of material bodies in action and discourse are still available in this microscopic domain of investigation. So the question is: are the conditions of possibility of our talk of material bodies still available in the microworld? It is very careful way of putting the question. It is not a question of do they exist or not exist, because this is a bit far from ....

This way of thinking was illustrated by Piaget in a discussion in the second volume of his *Introduction to Genetic Epistemology*. In this second volume he wrote very interesting things such as: "The contemporary specialist of microphysics imposes to itself as an idea, a going back to primitive ways of cognition. The baby usually builds the concept of material bodies out of their schemes of action but the microphysicist cannot do that, or at least has to think about the possibility of doing that whereas we, as adults, when we have completely constituted this notion of material body we can forget the conditions and can think that material bodies are intrinsically existent." This is probably the psychological basis for materialism. We just forget that it was a hard task to constitute that notion out of phenomena, touch, sight, sound, and so on. We think that it is really existent because we forget how we constituted the notion.

The microphysicist, however, has to go back to the way that we first constituted the concept of material body. They have to make, what Piaget calls, a "return to the primitive methods" that we had when we were children. So, in a way, the microphysicist is a child in front of this microworld. They have to be innocent, to see the phenomena as they are, and to think about what to do in order to reconstitute something objective out of it. Piaget's "return to the primitive" is tantamount to remobilizing, point by point, the framework of objectivity that is already embodied in our forms of life instead of just being content to apply it in an unconscious, non-reflective way as we usually do when we manipulate objects.

This "going back" could be perceived of as a regression, a going back to the state of a child, but actually, it is only so insofar as it compels us to bracket the refined projection of the forms of these objectification procedures in material bodies. If, however, we conceive it in from non-refined point of view it can be recognized as an important progress because it allows us, on the one hand, to generalize and thus to make much more efficient the reciprocity schemes that first enabled us to constitute the notion of material bodies and, on the other hand, it also enables us to acquire a much more precise reflective consciousness of the way these schemes intervene in the constitution of objects. Of course, we are a little disappointed to have to go back to a child-like state, to have nothing that is already given, to have to redo all the work of reconstituting out of concepts, out of actions, out of coordination of experience, and so on but it is very interesting because it forces us to be conscious of the way it was done the first time when we were children.

For a philosopher, therefore, it is very important because it forces us to come back to a certain process of constitution that was typical of our childhood. Piaget says, "as a young child, the microphysicist doesn't believe in the permanence of the individual object as long as they cannot recover these commandments by coordinated actions." Permanence is not something given. The permanence of the object is something that can be constituted if you can follow it continuously in its

trajectory. If you cannot do that, there is no permanence. Permanence is not something objective, it's something of your action.

The similarity between the young child and the physicist or the microphysicist then is that they do not believe in the permanence of objects from the beginning, they construct it. If they cannot construct it then they do not believe it whereas we usually, when we are adults in the world of macro-objects, believe in the permanence of objects unconsciously. We don't try to follow things all the time but believe that, even if we are not looking at it, we think it's still there and we don't have to care about it. The microphysicist, however, cannot do that. They have to be much more critical.

The difference between the child and the microphysicist is that the microphysicist isn't content to refuse to accept notions that go beyond effective action. They also elaborate a system of intellectual and mathematical operations in view of translating the breakdown of the performative conditions of the constitution of material bodies while continuing to master, from a primitive standpoint, the consequences of their experimental manipulations. That is, if a child did not find the conditions for talking about a certain body, they would just say "ok, I can't do anything with it, maybe it's magical, I don't care, I go to things that make more sense". The physicist doesn't abandon things but tries to make a synthetic mathematical scheme about this phenomena that cannot be synthesized in material bodies and yet predict, at least probabilistically, the future of phenomena out of the past phenomena. So there is a further step with respect to a child.

The interesting thing is that neither the child nor the physicist believe in the permanence of material bodies as long as they don't have a sort of model or a scheme of permanence that they implement by following a body step by step. It's very interesting to see that this idea has been implemented even in modern semantics. For instance, according to Searle and **\*\*\*(KRIPKE)**, it's exactly in this way that we make reference to things. According to Searle, referring to something means implicitly telling yourself that you will be able to identify this thing now or if it occurs again and again in the future. When you name a certain thing, Table A, you say that even if you go out of the room and come back in, you will be able to re-identify it by its position or characteristics, or anything else, and say "this is Table A". The act of reference in language, therefore, is deeply linked to the possibility of re-identification. In the same way, **\*\*\*(KRIPKE)** said that reference was deeply connected to what he called an act of "baptism". You say "this is A" and then you can follow its trajectory or can re-identify it somehow and say "this is still A".

The problem is that in the domain of microphysics, especially the quantum domain, usually no criteria of identification can be used. If you tried to identify something from individual determinations that are specific to some element, then you come short of an element of determinations because if you give a list of determinations that you can ascribe to a certain element, say the mass or charge or absent value of spin, all these characteristics do not define an individual but the spaces. For instance, they define the electron or the proton or the charmed quark in general, and so on. In order to make it more specific you would have to specify that it is the electron that is here, in this point of space. This can be very useful and efficient in some cases, but not all. In some other cases you can have another level of the regions of space where you can find electrons and in that case you don't have any criteria of recognition any longer. You can lose track of electron A that you named before because it was isolated here and electron B that was isolated there when their regions or probably their presence overlap.

So usually there is no identity, no trajectory so no longer this basic criterion of identity that was the trajectory. Then you cannot make reference to electron A or electron B, or if you do, as sometimes in quantum formalism when you say, “this is electron A, this is electron B” then you have to use a certain trick that involves symmetrization or anti-symmetrization, which is tantamount to exchanging the role of the two electrons. It’s a way of saying “this is A and this is B” but it’s completely indifferent and you have to exchange the role in order to get the right answer.

Clearly, the basic criterion that allows you to make reference to something, the criterion of trajectory, is missing in quantum physics. You will see that now there is a sort of slogan of people who are very conscious of this fact: “no entity without identity”. If you cannot re-identify it, there is no entity, no single and individual entity. You can try to make an ontology of SORTS as some Italian philosophers of physics, such as **\*\*\*(Prof. TORALDO DI FRANZIA)** who says that in quantum mechanics you do not have an ontology of individuals that are gathered in sets but an ontology of sorts, kinds that are instantiated by fake individuals. This is a possibility.

At any rate you do not have the pragmatic criteria that enable you to make reference to something and to say that there are little individual material bodies here and there. If you want to follow Piaget’s strategy, going back to child-like behavior, then you should not believe in the intrinsic existence of things if you do not have the scheme of activity that enables you to follow it. This is a principle, a sort of maxim for belief or non-belief in the existence of entities.

This is the basic idea. Now, Schrödinger was, among the creator’s of quantum mechanics, the one who was very insistent on this strange feature of quantum mechanics. He was so insistent that he completely transformed his own views on ontology. I think I will insist on his views here because they are so radical that they are all the more interesting. They are radical yet, I believe, very credible because grounded in the very serious analysis of the way we constitute material objects, the possibilities of following them, of manipulating them, of transposing them, and so on. According to Schrödinger, when you do not have access to good criteria of identity, one should refuse to refer to a particle at all. I quote, “According to me (Schrödinger), abandoning the concept of trajectory means abandoning the concept of particle.” No trajectory means no particle. The fact that a trajectory is completely unavailable—and it’s unavailable in principle because in quantum mechanics you do not have such trajectories, the formalism does not have trajectories or only has approximate trajectories that are subject to uncertainty relations—means that “the particles in the old naive sense do not exist at all”.

So the physicist’s discourse is now completely reverted from this conception. Instead of accepting that when there are **ITEMS** that are related to one another in space, the individual particles have a probability of exchanging one another’s identity. One is at risk of mistaking one for another. Instead of saying that there are particles but sometimes you mistake one for another, Schrödinger says there are no individuals that can be taken for one another. These statements are just senseless, meaningless. Why? Because, in order to say that, at a certain time, there are particles and then to say they are mixed up and so on, you would have to have a means to follow them, not only in part of their trajectory but, essentially, everywhere. If you can completely lose track of them at a certain point then nothing precludes that something new hasn’t arisen and that the old particles that you had haven’t just disappeared in the mixture and has reappearing later. Nothing is sure in that domain and since you don’t want to make assertions that go beyond your possibilities to ascertain them, then you say that

there are no real particles at all, no individuals, and you just have a discrete sequence of phenomena that you can, at times, synthesize as if they were particles and, at other times, cannot. You go very low in the process of constitution, you become very critical of the process of the constitution of objects, trying rather to be completely prudent about it.

According to Schrödinger you should not even use the formalism of quantum mechanics, which is tantamount to giving particles names and then exchanging their names in the process of symmetrization and anti-symmetrization because, he thinks, it is assuming too much. Rather, he promotes the antimony view, according to which, as a matter of fact, there are no particles at all, only fields that are completely ubiquitous. These fields are quantized exactly as in quantum field theory, of which he was a very eager proponent, which states that there are only quanta of excitation of these fields.

As I said in the previous class, when you have a state that is  $n$  times quantized, it is equivalent in the usual language to saying there are  $n$  particles, but, when you use the language of field theory, saying that you have a field that is  $n$  times quantized instead of saying there are  $n$  particles, then you are not prone to believing that there are any little entities because these quanta of excitation are not local. What may be local is the effect that the quanta of excitation of the field have on a certain detector. You can have a local impact on the screen, but a local impact on the screen should not be taken as proof that there was something that was following a trajectory and arriving at the screen. You may explain the facts exactly as well as supposing that there was a field that was extended everywhere, having  $n$  quanta of excitation, and from time to time there is a local excitation by this field of the detector.

Then has Schrödinger translated a problem of an epistemological nature definitely into a problem of an ontological nature? Perhaps for Schrödinger it could be said so, but I think he was not as naive as that because he said that you have to have a certain conception of reality, but he wrote very precisely "reality is only your construct". So, it's ontological, but it's ontological in a certain exception that is certainly not transcendental but only constructed. It's very special. He was very interested by the formalism of quantum field theory and he gave it a lot of importance as you see. There is an argument that can make you prefer the formalism of quantum field theory rather than the formalism of labels and the exchange of labels in the process of symmetrization and anti-symmetrization. This argument was given a little later by people working on quantum field theory, people like Rindler. He noticed that in a state where you have 0 quanta of excitation, in the usual language where you have 0 particles, and then a certain detector should be completely non-excited, should count nothing because there is nothing to count, if you accelerate the detector it should detect lots of impacts or whatever you get. You will detect some impacts if the detector is accelerated in that pure vacuum where you believed that there was nothing because it was a 0 quanta state. It's a little puzzling. If you believe either that there are particles and they are counted or there are no particles and they are not counted you would say that the detector should count nothing.

One would say there is a difference because quantum mechanics is a well-proved theory while Quantum field theory is only a hypothesis. However, here I am discussing philosophical ideas and it's interesting to see that at least one of the quantum theories, here quantum field theory, is able to bear this idea that perhaps there are no particles but rather something that is completely holistic and in the field that appears to be in states of excitation, so it's another view.

At any rate, even in standard quantum mechanics, Schrödinger says that all that can be accounted for is only “a long series of successively occupied states”. Not a trajectory but successively occupied states, discrete states. The only thing which leads many physicists to speak of the trajectory of particles is that “such series of states, for instance in the bubble chamber, give the feeling or impression of a **PERMANENT ENTITY**”. It’s only an impression, or worse, according to Schrödinger, an illusion. Sometimes these events form shapes that give the illusion of being a permanent entity.

I think Schrödinger was doing exactly what Piaget was advising, going back to a primitive state and saying, here we don’t have a trajectory but just a sequence of states, for instance a sequence of bubbles in the chamber. If we only have a sequence of states we should not think that they are intrinsically existent particles that are permanent entities and permanently existent.

To summarize, all these schemes of constitution of objects are only available at the microscopic level. The consequence is that, finally, we could say that the very objects of quantum mechanics or even more generally of quantum theories, is no longer a little material body but something else. The objectified entity is not a material body. Maybe you can reconstitute the phenomena that give the appearance that there are material bodies at the microlevel, but you are reconstituting it out of something that is not itself isomorphic to the concept of material body. So I would say, to summarize in a very strong way, beyond material bodies there are no material bodies, beyond macroscopic material bodies there are no microscopic material bodies. Atoms are called values of observables by some people. This is the idea.