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Einstein's Veil
Science and a New Global Vision

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Any sufficiently advanced technology is indistinguishable from magic.
Arthur C. Clarke

Quantum physics is a child of the 20th century. It began in the year 1900, when Max Planck, in order to explain the color of glowing bodies, the so-called black-body spectrum, had to make the bold assumption that light consists of indivisible entities which he called quanta. Quantum physics has become the basis of many branches of modern high technology. For example, the understanding of semiconductors and therefore computers would be completely impossible without quantum physics. Other manifestations include the laser, the all-understanding of chemistry and magnetism. Nevertheless, a problem persists even now in the 21st century, which has been formulated nicely by Richard P. Feynman in a quote from the Seventies: "I think I can safely say that nobody today understands quantum mechanics." Feynman certainly had a right to make such a statement, as he himself received the Nobel Prize for one of the most successful formulations of quantum theory. The problem is not whether or not the theory is correct, which is certainly true to a high degree, but the problem is to understand what it means for our world view, for our Weltanschauung. Starting from intellectual curiosity to see whether quantum mechanics is really as strange as it predicts, in the 1970s philosophically motivated experiments started, investigating the behavior of individual quantum systems and, completely to not only my own surprise, since the 1990s ideas for a new information technology based on just these phenomena emerged.

A basic phenomenon criticized already by Albert Einstein is the new role of randomness, of chance ("Zufall") in quantum physics. Einstein noticed already that randomness is of a different nature in quantum phenomena than in everyday life or in classical physics. In the latter case, randomness is only a subjective phenomenon in the sense that while we don't know the reason for a certain event to happen and therefore, it appears random to us, a causal chain can still be constructed which explains the individual event. This is not true any more in the case of quantum physics. There, we know that the individual event has no cause in the sense that it is

impossible to explain why it happens precisely the way it happens. For example, a radioactive atom might decay at some time, but no one can predict when this will appear, not even the atom itself carries enough information. Einstein formulated this in his famous quote "Gott würfelt nicht" ("God does not play dice"), to which Niels Bohr answered that he should stop telling the Lord how to run the world.

Today, randomness of quantum physics has been completely accepted and leads to new technologies. For example, the best existing random number generators are based on quantum physics.

Another fundamental notion of quantum physics which has already worried Einstein is entanglement. Entanglement occurs when two systems interacted in the past. It means that after that interaction, observation of one system determines the quantum state of the other one, no matter how far the two systems are separated. Albert Einstein called this "spukhafte Fernwirkung" ("spooky action at a distance"), and he wanted to find a way around it. Today, we know from numerous experiments that entanglement is just a basic feature of the world, and this corroborates Erwin Schrödinger's position that entanglement is *the* essential characteristic of quantum physics. Some of these experiments confirming entanglement have been performed outdoors. For example, just last year in Vienna, we were able to send these entangled particles across the river Danube over a distance of 500 meters. At present new experiments are going on, with the eventual goal to establish a world-wide quantum communication network exploiting the correlations of entangled systems.

Among the specific applications the most advanced one is quantum cryptography. There, entanglement allows us to establish a secret key between two parties, Alice and Bob, in such a way that no eavesdropper has any chance to learn about the key without being detected. The status of quantum cryptography is advanced: very recently in Vienna, we succeeded in performing the first real bank transfer, where all banking information was secured by the new technology. One of the most interesting applications in the future is quantum teleportation, where it is possible to teleport the information one system carries over to another one, no matter how far the other system is away. This has been demonstrated thus far with photons and most recently with atoms. It works over distances of a few hundred meters, and future experiments including satellites will allow teleportation over much larger barriers. Quantum teleportation will be important in future communication networks using quantum computers. The quantum computer will actually be the ultimate application of all these strange features of quantum physics.

Coming back to the philosophical issues, we now know that it is wrong to think in quantum physics that the objects, the things, exist completely independent of us. In fact, there are situations where the act of observation is essential for creating reality. Ultimately, we have to conclude that it does not make sense to make any distinction between reality and information, as it is impossible to make any statements about reality without referring to information. Therefore, we have to search for a new notion which embodies information and reality as a common concept, or, in another sense, one may very well say that information is the most basic concept of the Universe.

It should be mentioned at the end that all this research, which most certainly will lead to new communication and information technologies within the next twenty years, has been started by philosophical curiosity. This is a pattern which happened many times in the history of science, when curiosity-driven research opened new doors for applications and new doors for industry. One might quote Werner von Siemens, who in 1883 said about technical progress: "Die naturwissenschaftliche Forschung bildet immer den sicheren Boden des technischen Fortschritts, und die Industrie eines Landes wird niemals eine internationale, leitende Stellung erwerben und sich halten können, wenn das Land nicht gleichzeitig an der Spitze des naturwissenschaftlichen Fortschritts steht. Dieses herbeizuführen, ist das wirksamste Mittel zur Hebung der Industrie." This statement by Werner von Siemens, who created the largest technology company in Germany, should lead us into the future if followed and read properly.

We might finally conclude with a famous quote by Albert Einstein about his motivation: "Ich möchte wissen, wie Gott diese Welt erschaffen hat. Ich bin nicht an dem einen oder anderen Phänomen interessiert … alles Übrige sind nur Einzelheiten."