PHYSICS OF THE IMPOSSIBLE:
The Bold Ones in the Land of Strange

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A new scientific center has just opened at Singapore's Science Drive 2: its efforts are focused on revealing nature's uttermost secrets. The place attracts many young, talented and eccentric physicists, among them some Poles.

This summer night is as hot as any other night in the equatorial Singapore (December ones included). Five men, seated at a table in one of the city's countless bars, are about to finish another pitcher of local beer. They are Artur Ekert, a Polish-born cryptologist and a Research Fellow at Merton College at the University of Oxford (profiled in issue 27 of POLITYKA); Leong Chuan Kwek, a Singapore native; Briton Hugo Cable; Brazilian Marcelo Franca Santos; and Björn Hessmo of Sweden. While enjoying their drinks, they are also trying to find a trace of comprehensive tactics in the chaotic mess of ball-kicking they are watching on a plasma screen above: a soccer game played somewhere halfway across the world.

"My father always wanted me to become a soccer player. And I have failed him so miserably," says Hessmo. His words are met with a nod of understanding. So far, the game has provided the men with no excitement. Their faces finally light up with joy only when the score table is displayed with the results of Round One of the ongoing tournament. Zeros and ones – that's exciting! All of them are quantum information physicists: zeroes and ones is what they do.

As Hessmo's story illustrates, one's passion for physics is a condition not easily uprooted, not even by the strictest of upbringings. Thankfully, there are a few places in the world where those affected by this peculiar condition are welcomed with open arms, and where their strange fixations are put to good use for the benefit of science. One such place is the newly opened Centre for Quantum Technologies (CQT), where the focus is on basic research. The center is truly a singularity by Singapore's standards: its philosophy challenges the local principle of taking a technology-driven, practical approach. CQT is also a symbol of the new vision of development that is gaining ground in this vast city of 4.6 million people.

Audacity Sets the Tone

The beginning of CQT's history goes back to a series of informal meetings, initiated by a group of scientists who used to meet after hours to discuss correlations between quantum effects and computational processes. Among the group's "founding fathers" was the aforementioned Kwek, who was soon joined by a brilliant young Polish physicist Dagomir Kaszlikowski (who ventured abroad shortly after completing his PhD thesis at the University of Gdansk). At these meetings, questions were posed that for a long time have been pushed outside the collective psyche of the mainstream scientific community: Why is quantum physics so bizarre? What does it actually mean that micro-objects can be located in many different places at the same time up to the point when measurements are taken? What is quantum entanglement, which binds particles with a force so powerful that they appear as one, regardless of the distance between them? These phenomena have been studied with methods borrowed straight from information science. The idea is that understanding nature can be made easier by an assumption that natural phenomena are in fact computational processes of sorts – ones in which photons, electrons, atoms and particles simply exchange bits of information. In other words, an audacious effort of reinventing quantum mechanics has been initiated.

The group grew bigger and bigger up to the point when, two years ago, its activities were formally recognized by the establishment of CQT, with its hefty initial budget and Artur Ekert at the helm. Asked why he agreed to accept the challenge of leading the new center, Ekert explains: "Doing science in established places like Oxford, the Massachusetts Institute of Technology, or the California Institute of Technology is easy; here, on the other hand, where everything has to be built from scratch, one gets a chance to really make a difference."

In his search for the right people to run the center, Ekert faced a dilemma: Should he bank on established scientists – or pursue the young, the bold, the ambitious ones? "I got the best doctoral candidates in the business, the people who still think of proving things rather than just patenting them," he explains. Today, the staff of the Singapore center consists of 90 scientists from 24 different countries; it also retains dozens of research fellows and a wide network of consultants and advisers. Ekert was able to assemble one of the most unique scientific teams in this field: "I don't shy away from hiring people who are deemed eccentric or difficult. A scientist does not have to be nice and cuddly; it's the creativity that counts," he says.

Hitting the Nail on the Head

Dagomir Kaszlikowski did not have to be persuaded to join CQT: he was already on site, and he fully met Ekert's requirements described above. He has coauthored (along with Valerio Scarani, Andreas Winter, Marcin Pawłowski, Tomasz Paterek, and Marek Żukowski) a famous article in "Nature" magazine – one of the very few theoretical papers accepted by this prestigious journal, which usually deals only with experimental research. Despite having defiantly declared himself a "cognitive nihilist," Kaszlikowski, along with his collaborators, has proposed an organizing principle for dealing with the counterintuitive world of quantum mechanics. "It would have been perfect if a simple standard could be devised for quantum mechanics, something as fundamental as the insurmountable speed of light in the theory of relativity – a basic principle that implies all other rules," explain CQT's research fellows Tomasz Paterek and Paweł Kurzyński. – "Newton's physics and Einstein's physics are things of beauty. Quantum mechanics, however, is not, and dealing with it is a constant source of esthetic discontent," declares Kurzyński.

This disagreeable state of affairs may soon be challenged by the so-called informational causality principle, formulated by Kaszlikowski, Paterek and others; the principle sets simple limits for the bit flow in the universe. The hope is that the team has hit the nail on the head with this idea, and that it could be instrumental in mapping the borders between quantum and classical worlds – and explaining why these distinctions exist in the first place.

Developing new theories is very much like shooting in the dark, because, all its peculiarities notwithstanding, quantum mechanics does not seem to have any major, theory-shattering flaws. The scientific community is therefore waiting for a breakthrough – and those can only be achieved in a lab. "Eventually, someone will come up with an experiment that will contradict the entire body of existing knowledge," says Kaszlikowski. And Paterek adds: "This is the beauty of our times – I anticipate a revolution every single day!"

Valerio Scarani subscribes to this point of view. He is described by his CQT colleagues (to his own delight and considerable satisfaction) as a man who enjoys destroying well-ordered theorems. And he has his hands full doing just that. Nowadays, as the science of physics is undergoing a fundamental change, neat hypotheses are a dime a dozen – and this applies to quantum information theory as well. “You can’t call it a crisis, but our field has certainly come of age,” proclaims Scarani. “My own old papers, seemingly so groundbreaking at the time they were published, can be summed up today in just two lines. Things are getting increasingly complicated.”

They certainly are. Consider the idea of a quantum computer – a concept so useful from the standpoint of promotion and outreach: This hypothetical machine of ultimate computational abilities was to employ all of quantum mechanics’ peculiarities to crack into problems unsolvable by traditional computers. The concept of such a contraption proves more and more enigmatic: it is difficult to say what kinds of problems it would be able to confront once it is finally built, or even if it is going to be built at all. “This is, indeed, an open question,” admits Scarani. It is also a subject of intense study in Singapore.

When meeting New Zealander Murray Barrett and his American associate Kyle Arnold, one can’t beat the impression that these loquacious, effervescent folks must have just abandoned their skateboards at the door right before entering their lab. Their area of expertise is the arcane art of catching ions and atoms in super-tiny traps made of electromagnetic field and collimated laser beams. For a year, they have been able to produce a so-called BEC – Bose–Einstein condensate (this skill has only been mastered by a few of the world’s leading laboratories): it is a peculiar (what else!) state of matter in which atoms’ individual properties vanish as they are cooled to temperatures extremely close to absolute zero (barely above −273.15 °C). The duo plans to pursue the issue further by studying BECs' other properties in the context of quantum information theory.

Room for Creativity

In the lab next door Kai Dieckmann is setting up his props. This ambitious German go-getter came to Singapore from Munich, attracted by the prospect of guaranteed creative freedom; he was also, by his own admission, discouraged by the Bavarian mentality. Dieckmann’s methods may be different, but he strives for the same goal as his colleagues – he wants to exercise full control over matter. He mixes various gases (fermionic and bosonic ones), catches them in optical traps (gas particles fall into them like eggs into a carton), and soon he will be stimulating them to interact. Using simple systems he tries to simulate more complex natural ones that cannot be studied either analytically or numerically, due to the high level of their complexity. In other words, Dieckmann is building a multi-purpose quantum simulator.

Kwek Leong Chuan – one of the Center’s most experienced theoreticians and an avid teddy bear collector (the biggest toy in his collection was a gift from Ekert who saved it from a dumpster) – explains that similar simulators are supposed to enable discovery, among other things, of such half-mythic and long sought-after entities as magnetic monopoles (particles with only one magnetic pole). The German still has some preparation ahead of him. And then? “Technical limitations set boundary conditions, but there is room for amazing creative freedom within them,” says Dieckmann.

Dieckmann expresses his exuberance verbally; Christian Kurtsiefer, head of the quantum optics group, simply radiates his own excitement. Kurtsiefer, Valerio Scarani and Spaniard Antia Lamas-Linares are founding fathers (well, Anita is a founding *mother*) of the experimental faction of CQT. In the world of cryptology (see issue 27 of POLITYKA) Kurtsiefer is known as an outstanding designer of quantum key distribution systems. “It may sound funny, but believe me, this is so much more complicated than building a CD player,” he says. What he is most recognized for is proving experimentally that, contrary to popular belief, quantum cryptographic systems do not provide one hundred percent security. “Due to innate and inevitable imperfections of the equipment used, the information processed by it is, figuratively speaking, leaking out,” explains the German scientist. And the key to the cipher leaks out with it.

One has to be brave

How to inspire originality in people, which seems to be the key to understanding the bizarre world of quantum mechanics? How to provoke them so they question the opinions of their teachers? In Asia, where the common mentality bears a strong imprint of Confucianism, this challenge is particularly daunting (they say the younger generation tends to be more independent-minded), but it is almost as difficult in the hedonistic and statist West. “I often ask people what would they want to do if they only had five years to live,” Ekert tells me, “And you know what? They get scared.” In Singapore, the team seems less frightened. Perhaps the reason for this is CQT's unwritten rules; they are: No micromanagement. No job titles. “Here there is no reason to feel embarrassed when nine out of ten of your ideas turn out to be crap – it’s sort of a given things will turn out this way,” says Elisabeth Rieper, a PhD student from Germany. “And then there is this one that may turn out to be dynamite.”

Under Vlatko Vedral’s supervision, Rieper dabbles with the budding discipline of quantum biology (more on this subject soon) which supposes that the amazing effectiveness of some biological processes is stimulated by underlying subtle quantum phenomena. This may be the reason why DNA molecules are stable, why photosynthesis is so energy-efficient, and why the natural avian compass in some birds is perceptive enough to sense variations in the Earth’s magnetic field as subtle as a thousandth of a degree. Rieper is studying the last of these phenomenon: “When I was little I read books both on quantum mechanics and biology, and I thought: Wouldn’t it be great to combine the two? Now my dreams are coming true. What more can one ask for?”

The skeptics (Scarani among them, to be sure) warn that this amazingly smart girl may ruin her career by getting involved with a field that, as of now, lacks precise definition, but she seems adamant: “One has to take risks. One has to be brave!” she says.