QSS46 - Alexia Auffèves - Questions & Answers

Alexia Auffèves

At a fundamental level, where is the randomness in stochastic thermodynamics coming from? The randomness must arise from not knowing something which you then declare as a "bath", right?

ALEXIA: Absolutely. Historically, randomness in stochastic thermodynamics was due to the coupling to a bath with many degrees of freedom that we would not want to describe. It was epistemic randomness, due to our ignorance. In the quantum realm, randomness is deeper, fundamental, ontologic you may say – due to quantum measurements ultimately. This brings a new flavor to the thermodynamic concepts.

We normally associate the increase of entropy with an "arrow of time". In a quantum system, do we then need decoherence to give a well-defined "arrow of time", and also is this "arrow of time" in some sense better defined in a larger system than in a small microscopic system?

ALEXIA: As far as time arrow is concerned, I am currently happy with an operational approach, that can be phrased that way: “Am I able to apply a protocol on a quantum system, then rewind the protocol and bring back the system to its initial state?” If I am, it means I have access to all degrees of freedom of my system, I have full control on it, there is no randomness in its evolution, which is thus reversible. Reaching this ideal regime of reversibility looks easier if there are few particles. However, in the quantum realm, we have an irreducible cut, i.e. the final projective measurement. This comes with quantum randomness, hence irreversibility. So yes, I think that at the fundamental level, it is measurement (or decoherence, which is uncontrolled measurement) that gives rise to irreversibility. There is therefore an arrow of time at the quantum level, which does not need many particles to show up.

It seems that as the randomness is associated with the measurement, you are more defining entropy associated to the quantum measurement than entropy of the quantum state. When do we cross the border?

ALEXIA: There is actually no “border” since these are two different notions. The entropy of a system is a state function, and in the quantum realm, we usually use the Von Neumann entropy. The “entropy of the measurement” usually refers to the Shannon entropy of the probability distribution for the measurement outcomes. The two entropies are equal when we consider the system’s entropy after the measurement. What we did (and we were probably not the first) was to exploit the framework of stochastic thermodynamics (which is agnostic with respect to the source of randomness) to compute the amount of “entropy production” induced by quantum measurement. Entropy production is a different concept that measures the irreversibility of a thermodynamic process: It is not a state function at all. And it appears that in the case of projective measurement, the entropy production simply corresponds to the change of VN entropy of the measured system.

Miguel: Here you are considering the various measurements as an ensemble, and looking at energy averages. In practice, you only have one specific outcome. Does this mean that in a single trial you can have-energy imbalances? even though on average everything checks out

ALEXIA: Yep. These are quantum fluctuations that appear at the scale of quantum trajectories. When they are thermal, this looks less shoking □

Bill Philipps: Concerning the issue of projective measurement and irreversibility: if an atom emits a photon into free space, that is effectively an irreversible measurement whether we detect the photon or not (although we lose some information if we dont detect). If the atom is coupled to a cavity that does not leak, then emission is not a measurement at all–I just have a bigger quantum system. In between these extremes is something else–possibly an excitation shared among many degrees of freedom. Or, we can consider weak measurement instead of projective measurement. How do these alternatives for quantum measurement affect the understanding of irreversibility and the thermodynamic perspective on quantum mechanics.

ALEXIA: This question brings many others, for instance, what do we call a measurement? To oversimplify what would require long discussions, there are two options:

- Measurement = the unitary creation of correlations between two systems= entanglement generation. In this case "measurement" is reversible, facts are relative, and we welcome Wigner's friends in the party
- Measurement = The revelation at the classical level of an objective fact. This is a non-unitary process, captured by Heisenberg's cut and the measurement postulate. Here "measurement" is by essence irreversible.

I belong to the second team since I believe QM entirely relies on the measurement postulate, defined as the revelation of objective facts – without which science is impossible. This is an approach we have been defending with Philippe Grangier and Nayla Farouki for a few years now, the corresponding ontology for QM being dubbed CSM like Contexts, Systems, Modalities.

Bill Philipps Concerning reversibility of a quantum computation: if you extract the result at the end of the quantum computation, doesn't that mean that if you then reverse all the operations that you do not in fact recover all the energy, having done something irreversible in measuring at the end of the computation.

ALEXIA: Absolutely. Reversing the quantum computation is only possible in the absence of noise, otherwise there is entropy production. And this noise can indeed be brought by the final measurement, if the register's final state does not pertain to the computational basis.

Ruichen Zhao: many qubit platform do not support direct plus state measurement. instead, we need to rotate the bloch sphere by pi/2 first then project qubit on the e/g basis and use this result to infer the plus state population. Is this measurement scheme compatible with the experiment here?

ALEXIA: Yes, in the article we actually modeled our measurement exactly the way you suggest.

Continuous measurement (at the Zeno limit) wouldn't actually yield anything though, right? Because at that point you have essentially a frozen classical system. Also is there a natural transition to Carnot's theorem?

ALEXIA: I don't understand what you mean by classical system. The qubit is "frozen" but the cycle time is also infinitely small. And it appears that the work extracted per cycle scales like the time cycle, i.e., the engine delivers a constant, finite power. I invite you to read the article for details.

What do you think that nano quantum machines are going to be good for?

ALEXIA: Not to save the planet, that is for sure. They are proof of concepts, to study the flows of energy, entropy and information at the quantum scale. This knowledge will be essential to assess the energetic sustainability of quantum technologies, which is for me the killing application at the present time.

Is there any change to the details or interpretation of the measurement-based engine if we use continuous weak measurement and feedback, rather than projective measurements?

ALEXIA: Weak measurements can always be analyzed as the result of entanglement with ancillae and projective measurement of these ancillae (which is the cut). The basic concept of quantum heat remains valid at the cut, as a fundamental, unavoidable energy transfer. But the energy flows inside the entangled systems remain to be computed and studied.

Miguel: is this definition of the quantum heat applicable also in quantum field theory? For example, in the interaction between and atom and the non-empty vaccum of virtual particles around it? QFT would be necessary for these fluctuations at the Zeno limit, no?

ALEXIA: I am not an expert in QFT. But since to my knowledge, the measurement postulate is everywhere, its energetic counterpart is also.

Sandro Huber: Does the measurement process always cost you as much energy as you can extract from the system, so that energy conservation is not violated?

ALEXIA: Energy conservation is not violated. What the quantum heat captures, is that measuring can transfer energy to the measured system. This energy is not necessarily easy to extract though, since quantum measurement also brings entropy – hence the design of dedicated quantum engines.