**Response of Joel Lebowitz to the presentation of the Grand Medaille, October 24, 2014**

Thank you, Monsieur le President, for your kind words.

It is a great honor and pleasure for me to receive this medal from the French Academy of Sciences. I have spent much time in France and collaborated scientifically with many French colleagues, some of whom are here today. I am most grateful to all of them, as well as to my other collaborators, for the science they taught me and for their friendship.  I would also like to thank all other friends and particularly my family for all their support leading to this occasion.

I call myself a mathematical physicist which, according to Freeman Dyson, a very distinguished member of the community, “is the discipline of people who try to reach a deep understanding of physical phenomena by following the rigorous style and method of mathematics. It is a discipline that lies at the border between physics and mathematics. The purpose of mathematical physicists is not so much to calculate phenomena quantitatively but to understand them qualitatively. They work with theorems and proofs. Their aim is to qualify with mathematical precision the concepts upon which physical theories are built.”

It is not at all obvious why this enterprise should be viable. Why should the laws of nature be expressible, at the deepest level, in mathematical form? This is what Eugene Wigner, one of the great mathematical physicists, called “The unreasonable effectiveness of mathematics in the natural sciences”. He went even further, saying, “It is not at all natural that ‘laws of nature’ exist much less that man is able to discover them”. But this is getting into philosophy: As far as science goes we take these facts as given and then go on searching for the laws and for the consequences of these laws.

My own research efforts within mathematical physics are primarily in the field of statistical mechanics, whose aim is to explain how the cooperative behavior of many individual entities, forming an aggregate system, can give rise to new collective phenomena having no counterpart in the properties or dynamics of the separate elements. The nature of these entities and of the system they form can vary widely: in traditional studies they are atoms in a fluid, spins in a magnet, electrons in a metal, etc. In more recent applications they can also be birds in a flock, or people in a soccer stadium or at a demonstration. The emergent phenomena can be the boiling/ freezing of water, people clapping rhythmically at a performance, etc.

The modern search for a quantitative microscopic theory of macroscopic phenomena, like boiling and freezing, heat conduction, diffusion, etc. dates to the middle of the nineteenth century. At that time the experiments of Joule and others made it clear that such thermal phenomena have their origins in the dynamics of the atoms and molecules which are the constituents of matter.

It was also soon recognized that the large disparity in the spatial and temporal scales between the world of atoms and the world of macroscopic experience not only necessitates a statistical theory but also assures, in analogy to the law of large numbers in probability theory, that such a theory will give predictions precise enough to have the force of “law” as in Fourier’s law of heat conduction or in the second law of thermodynamics, formulated by Clausius on the basis of the work of Carnot and others.

The twentieth century saw the development of the subject into a physically very successful and mathematically very beautiful theory of statistical mechanics of systems in thermal equilibrium.

The development of a comparable theory for the more complex world of nonequilibrium phenomena, including in particular those occurring in biological systems, remains a challenge for physicists, mathematicians, biologists, etc.

As an example of the difference between equilibrium and nonequilibrium phenomena, let me now describe very briefly some joint work with Bernard Derrida, who is present here. This work was done partly in Paris.

Consider a piece of metal, like this medal, in an equilibrium state, which means roughly that its temperature is uniform. In that case it will also have a uniform density so the number of atoms in a small piece of this medal, say 1/3 of the whole volume, will be “roughly” one third of all the atoms in the whole piece. However, if you wait for a long time, there will be not only small fluctuations around this average number of one third but also times when there will be very large deviations from the average of 1/3, say ½ or only 1/4 of all the atoms will be in 1/3 of the volume. (Think of a very large crowd, say 60,000 people milling around in a big square more or less uniformly. Then focus on the number of people in a given section, say the middle third of the big square; here there will usually be only small fluctuations above or below the average number of 20,000, say a few hundred people more or less. But occasionally it will happen that there are only 16,000 people in this area, we call that a large deviation.)

The question now is what is the typical size of the fluctuations? And what is the probability of large deviations in a given size? Simple arguments show that the larger the average number is, the less likely you are to get a given percentage deviation. Now remember that the number of atoms in a small piece of matter is billions and trillion times larger than the number we have been talking about, even larger than the number of grains of sand in all the beaches of France.

Statistical mechanics provides a method for computing these probabilities precisely when the system is in equilibrium, that is, at a uniform temperature. This is, in fact, something I have been recently computing in some work with David Ruelle, who is also here. We do not know, however, how to compute such probabilities when the system is not in equilibrium, such as if I kept one end of this medal in boiling water and the other end in iced champagne. In work I did with Bernard Derrida some years ago we were able to do this computation for a very simple model non-equilibrium system.

Some of the areas where rare events in non-equilibrium systems may be of great relevance include the global climate system, the development of cancer, and indeed the origin of life itself. These systems are all very far from equilibrium. The development of a better theory of non-equilibrium systems should lead to a better understanding and control of these phenomena.