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Quantum Thermodynamics

An introduction to the thermodynamics of quantum information

Sebastian Deffner and Steve Campbell

Epilogue

In this book we have attempted to, concisely, explore several facets of modern thermodynamics—from its axiomatic origins through to the development of *Stochastic Thermodynamics* and right up to the most recent advances in its quantum formulation. Indeed, as a physical theory, thermodynamics is imposing in both its range of applicability and the deep insights into the workings of the Universe it provides. For instance, as we have seen in chapter 1, the role of entanglement in providing a unique means of deriving canonical concepts in statistical mechanics enhances the special place that the seemingly counterintuitive notions of quantum mechanics play in dictating how the world around us emerges. Naturally, we have seen that a consistent quantum formulation of the core tenets of thermodynamics—quantum work and heat—is a delicate issue. Nevertheless, as established throughout chapters 2 and 3, as technological progress marches (and miniaturizes) on, understanding the thermodynamics in this regime is crucial. It is, therefore, our hope that the material in this book has provided the necessary tools to handle the exciting challenges ahead.

Of course there is a whole host of interesting topics that we simply could not cover in the limited space available, one particular field being so-called resource theories. As the field of quantum information reached maturity, a greater focus was given to understanding the manipulation of quantum systems from a resource theoretic viewpoint. Indeed, it is clear that quantum features, in particular entanglement and other quantum correlations, are quantifiable resources for information processing and other tasks. Such an approach is fruitful when applied to understanding *Quantum Thermodynamics*. The resource theory of quantum thermodynamics has shed light into what constitutes thermally free states and operations, thus providing insight into the thermodynamic cost of quantum information. Other exciting work has gone into exploring thermodynamic principles in cold atomic systems, where theoretical and experimental tools in this arena are progressing in tandem, and quantum biology, which studies the impact of genuine quantum effects on biological processes.

We close with some aspirations for the future. As new quantum technologies develop, the understanding of their thermodynamic working principles is key to ensuring practical, energy efficient devices. The topics covered in chapter 3 gave a snap-shot of some of the more recent developments in this regard, however, as mentioned, a great deal of work still needs done before the full promise of quantum technologies can be realized. Nevertheless, the great pace at which the young community continues to drive the field leaves us with no doubt that, as with the incredible advances that classical thermodynamics provided a little over a century and a half ago, quantum thermodynamics has many more remarkable insights yet to come.

If one cannot enjoy reading a book over and over again, there is no use in reading it at all.

(Oscar Wilde)