Quantum Mechanics and the Second Law of Thermodynamics: Can a Quantum Heat Engine Break the Law?

Peter D. Keefe

*University of Detroit Mercy, Detroit MI USA**

Website: www.Keefengine.com

While the absolute status of the First Law of Thermodynamics is historically unchallenged, challenges to the absolute status of the Second Law of Thermodynamics are historic, extending back to the fabled "Demon" of Maxwell in 1871 to the present day, notably exemplified by the First International Conference on Quantum Limits to the Second Law held at the University of San Diego in July, 2002. The Carnot engine is universally acknowledged as the most efficient heat engine cycle operating between two temperature heat reservoirs, one hot, the other cold. Indeed, the Carnot heat engine cycle is theoretically 100% efficient if the low temperature heat reservoir is at absolute zero, and this is so independent of choice of working medium, whether classical (as for example a gas in the context of P-V space) or quantum mechanical (as for example a superconductor in the context of H-T space). This paper will investigate what boundary conditions, if any, can be placed on a quantum mechanical working media, as well as its processing heat engine cycle, which could provide, at least in theory, supra-Carnot efficiency.

**Author address: 24405 Gratiot Ave., Eastpointe, MI 48021 USA*

I. Introduction

A. Description of a Classical Heat Engine Processing a Classical Working Media

A classical heat engine[1] processing a classical working media, as schematically represented by Figure 1, comprises a device having a structure and function which provide cyclic processing of a working media, whereby a heat influx is in part converted into a work output. The working media is a thermodynamically processible material which is acted upon by the device, and constitutes any classical substance, as for example a gas or paramagnetic salt. The structure of the device is without limitation, even to the extent of having no moving parts, so long as it is able to process the working media cyclically through a set of thermodynamic coordinates. The heat influx originates from a high temperature heat reservoir and is processed by the device, wherein a portion of the energy of the heat influx is converted into work, and the remainder of the energy of the heat influx is rejected as waste heat delivered to a low temperature heat reservoir.

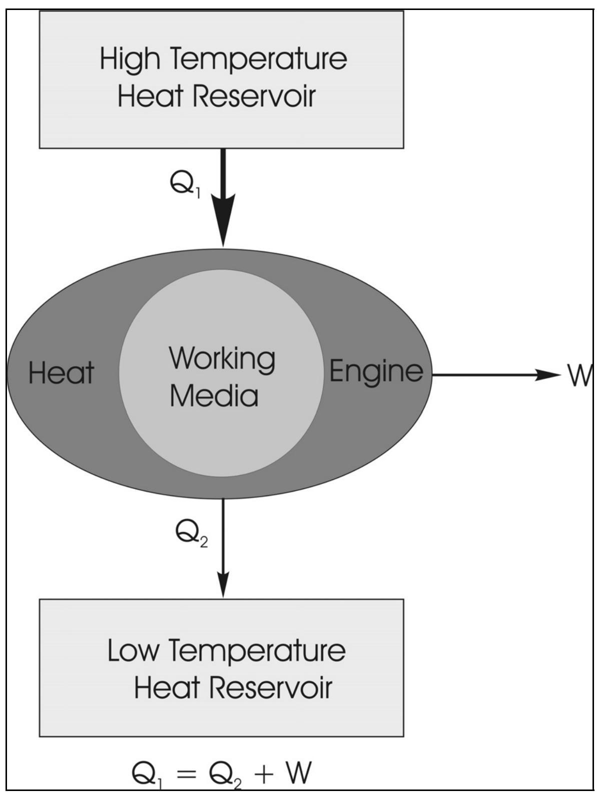

Fig. 1. A classical heat engine takes in a heat influx, Q_1, from a high temperature heat reservoir to thermodynamically process a classical working media, resulting in a work output, W, and a waste heat, Q_2, being rejected to a low temperature heat reservoir.

B. Description of a Classical Heat Engine Processing a Quantum Working Media

A classical heat engine processing a quantum working media, as schematically represented by Figure 2, comprises a device operating as described above, wherein now the working media is a thermodynamically processible material in which a portion thereof undergoes a quantum mechanical condensation while being cyclically processed through a set of thermodynamic coordinates by the device. The quantum working media is any quantum mechanically condensable substance, such as one obeying Bose-Einstein statistics. As in the case of a classical working media, the heat influx originates from a high temperature heat reservoir and is processed by the device, wherein a portion of the energy of the heat influx is converted into work, and the remainder of the energy of the heat influx is rejected as waste heat delivered to a low temperature heat reservoir.

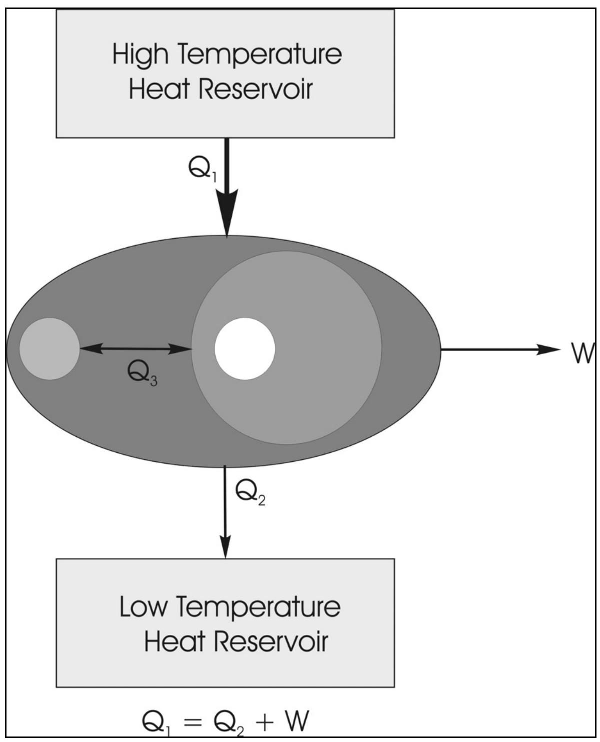

Fig. 2. A classical heat engine takes in a heat influx, Q_1, from a high temperature heat reservoir to thermodynamically process a quantum working media which in part undergoes a quantum mechanical condensation, Q_3, resulting in a work output, W, and a waste heat, Q_2, being rejected to a low temperature heat reservoir.

Any classical heat engine, no matter the nature of the working media, obeys the Second Law of Thermodynamics. The highest theoretical efficiency of any classical heat engine is that of a Carnot engine.

II. Discussion

A. Description of a Quantum Heat Engine

A quantum heat engine is a device which processes a quantum working media in a manner differently from a classical heat engine, in that: 1) the quantum working media is isolated from any external system; and 2) the quantum working media is in a coherent macro-quantum state[2].

As depicted at Figure 3, with the quantum working media adiabatically isolated, the quantum heat engine processes the Bose-Einstein condensation of a portion of the quantum working media to provide a work output at the expense of the internal energy of the quantum working media.

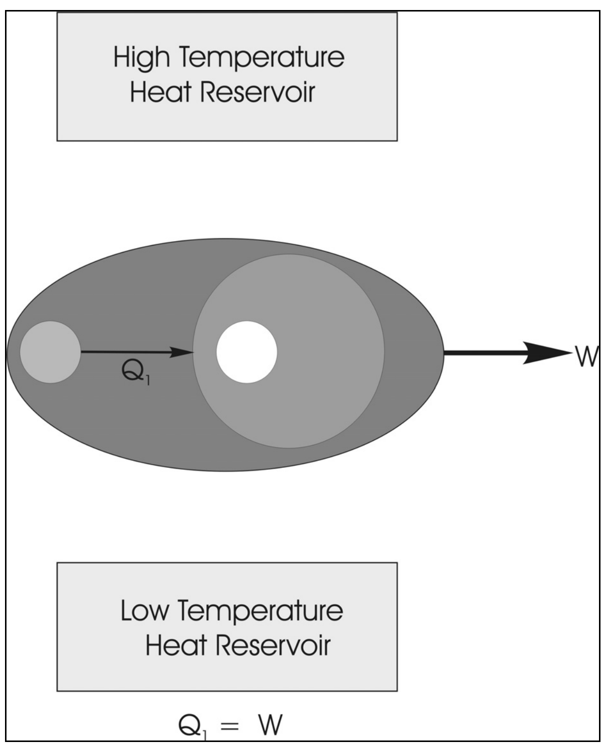

Fig. 3. A quantum heat engine has an adiabatically isolated quantum working media, wherein the Bose-Einstein condensation of a portion of the quantum working media results in a work output, W, at the expense of internal energy, Q_1, of the quantum working media.

Thereupon, as depicted at Figure 4, adiabatic isolation is modified to permit a heat influx from a high temperature heat reservoir to be delivered to the heat engine, whereby the quantum working media is reinitialized to the initial thermodynamic coordinates. Now, with adiabatic isolation re-established, the process cycle is repeated.

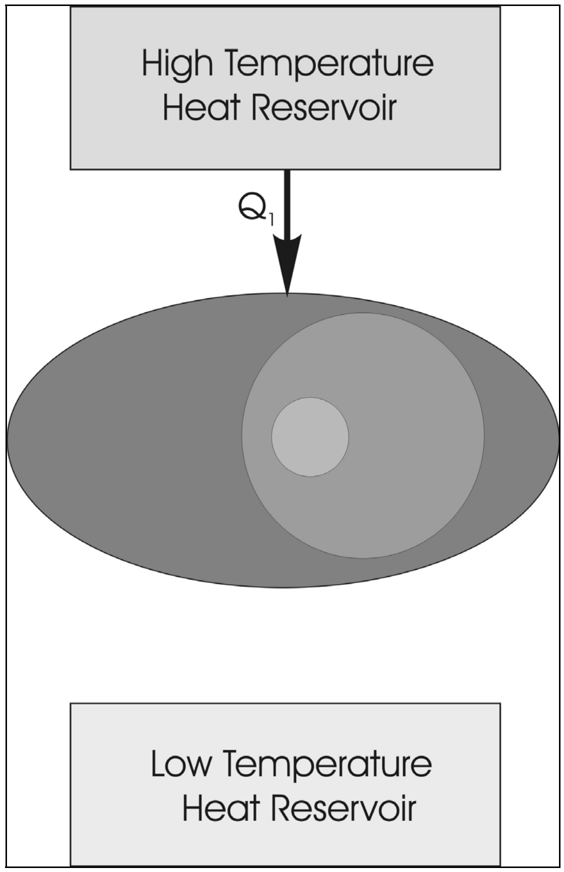

Fig. 4. The quantum heat engine now has delivered an influx of heat, Q_1, from a high temperature heat reservoir which reinitializes the thermodynamic coordinates of the quantum working media.

III. Conclusion

The above discussion has addressed itself to elaborating the nature of a quantum heat engine, wherein the quantum working media thereof is processed involving two crucial steps: 1) the quantum working media is isolated from any external system; and 2) the quantum working media is in a coherent macro-quantum state. A quantum working media comprising isolated particles of Type I superconductor provide a means to realize a quantum heat engine operating with supra-Carnot efficiency[3].

REFERENCES

1. M.W. Zemansky, *Heat and Thermodynamics*, 5th Ed., McGraw-Hill Publishing, New York, 1968.
2. P.D. Keefe, Quantum Limits to the Second Law: First International Conference, AIP Proceedings CP643, 213-218, 2002.
3. P.D. Keefe, Physica E, V. 29, 104-110, 2005.