# Maxwell's demon does not violate the second law but violates the first law of thermodynamics

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**Abstract**

Maxwell's Demon is believed to violate the second law of thermodynamics. Maxwell, who conceived of this being in 1867, did not believe that it violated the second law, but rather that it only highlighted the statistical validity of the law - with less than 100 percent certainty for its results - in contrast to the general view that thermodynamics gave results with 100 percent certainty. From then on, many other forms of challenges appeared. Some try to exorcise the demon by proposing new theories to prove that the second law is not violated by the demon, while others argue that the demon violated the second law. The debate has been continuing for the past nearly 150 years.

We show in this article that Maxwell's Demon does not violate the second law but violates the first law. This we show by demonstrating that the Maxwell's Demon Process (MDP) can be incorporated as a step into a reversible cycle. Through this cycle, the system subjected to MDP can be restored to its original state without leaving any changes in the surroundings. Therefore, the cycle must be reversible. If such a reversible cycle involving MDP as one of its steps were to be impossible, then it must violate the first law. Violation of the first law by this reversible cycle can arise only if MDP violated the first law, as no other process in the cycle violates either the first law or the second law of thermodynamics.

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**Keywords**: Maxwell's Demon process, Second law violation, Reversal of Maxwell's Demon process, First law violation, Thermodynamics.

## 1. Introduction

Maxwell's Demon (MD) is an important and controversial being in thermodynamics. It is a one and a half century old being defying death. It was born in 1867 in the writings of Maxwell and was christened in 1874 by Lord Kelvin – who did not envisage the creature as malicious. Its significance arises from the fact that it is believed to violate the famous second law of thermodynamics - a law that was considered inviolable, absolute and beyond question [1]. Since birth, the demon created controversies tossing thermodynamicists – both who favor it and those who oppose it alike – like ping pong balls. Many other demons came on scene making the issue of inviolability of the second law debate a never ending challenge. Its *running history* is well documented [1-5]. Since our interest here is to examine its challenge to the second law, we do not delve more into the historical aspects but rather refer the interested reader to the literature in the references. Again, since our approach is purely thermodynamics based, we do not concern ourselves in this article, with the works that discuss the issue from statistical and quantum mechanical points of view.

MD was born thus: We quote from Maxwell [6]: "…… if we consider of a being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are essentially finite as our own, would be able to do what is impossible to us. For we have seen that molecules in a vessel full of air at uniform temperature are moving with velocities by no means uniform, though the mean velocity of any great many of them, arbitrarily selected, is almost exactly uniform. Now let us suppose that such a vessel is divided into two portions, A and B, by a division in which there is a small hole, and that a being, who can see the individual molecules, opens and closes this hole, so as to allow only the swifter molecules to pass from A to B, and only the slower molecules to pass from B to A. He will thus, without expenditure of work, raise the temperature of B and lower that of A, in contradiction to the second law of thermodynamics."

Maxwell's did not intend to deliberately challenge the second law but wanted to high light the fact that the second law's predictions had only statistical certainty (< 100%), in contrast to the belief that the second law gave predictions with 100% certainty. Statistical certainty implies that it is possible that in a particular case a very different event might occur than that expected from the regularity of the averages. However, MD became an issue of debate since its inception.

## 2. Maxwell's Demon Process (MDP)

What MD does is depicted in Fig.1. A rigid walled vessel filled with an ideal gas is divided into two compartments by a rigid partition having a trap door. The vessel and the trap door ate thermally insulated. MD operates the trap door allowing swifter molecules from left to right and the slower molecules from right to left compartments. This operation leads to a temperature difference between the two compartments. Neither MD nor the surroundings suffer any change. This spontaneous generation of temperature difference in a system initially at a uniform temperature throughout violates the second law of thermodynamics (more details in section 4). Therefore, MD is believed to violate the second law.

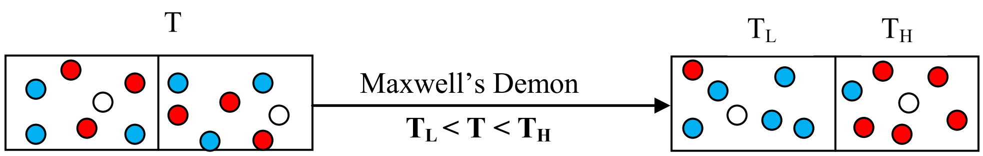


Fig.1. MDP is depicted in this figure. Unfilled circles in Fig. 1denote molecules with average speed. The red color filled circles denote molecules with above average speed (higher energy/temperature). The blue color filled circles denote molecules with below average speed (lower energy/temperature). For the sake of simplicity, we showed all molecules with high speeds in one color (red) and all molecules with low speeds in a different color (blue). T denotes absolute temperature.

## 3. Simple reversal of MDP

In Fig. 2 we show that MDP could be reversed and the system brought back to its original state without leaving any changes in the surroundings. As stated above, MD suffers no change. Hence the cycle is a reversible cycle[1].

[1] We use here, the fundamental definition of reversibility given by Max Planck [7]: "A process which in no way can be reversed is termed *irreversible*, all other processes *reversible.* That a process may be irreversible, it is not sufficient that it cannot be directly reversed. The full requirement is that it be impossible, even with the assistance of all agents in nature, to restore everywhere the exact initial state when the process has once taken place."

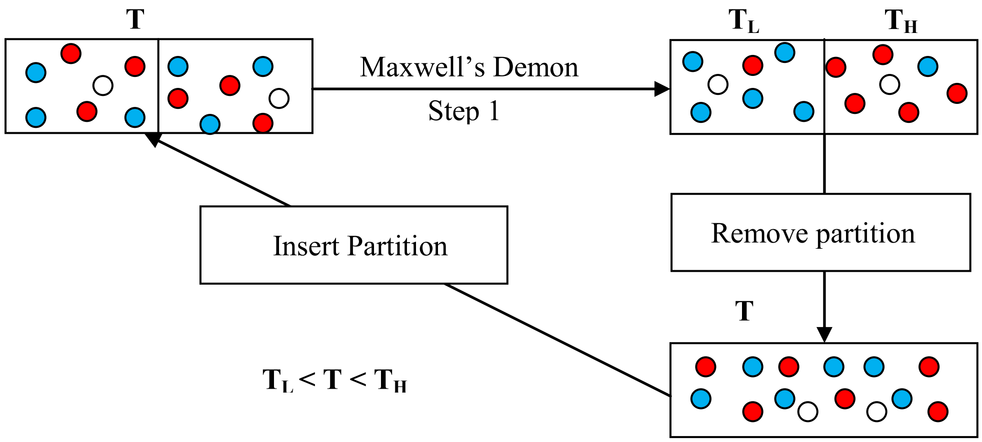


Fig. 2 depicts a cyclic process in which MDP is reversed with no changes left in the surroundings.

If MDP violated the second law, the above cyclic process would have been impossible. The cycle, however, *is possible and is reversible* at that, Therefore, if the cycle were to be an impossible cycle, the only possibility is that it must violate the first law - the change in the internal energy of the system, $\Delta U$, is not zero for the cycle. However, since the removal or insertion of partition does not involve any changes of internal energy of the system, for those steps $\Delta U = 0$. Therefore, it follows that $\Delta U \neq 0$ for step 1. (We note that during step 1 the surroundings suffer no change). Consequently, MD violates the first law of thermodynamics. The implications of this result have bearings on the dynamical theory of heat.

## 4. Conventional argument that shows MD violates the second law

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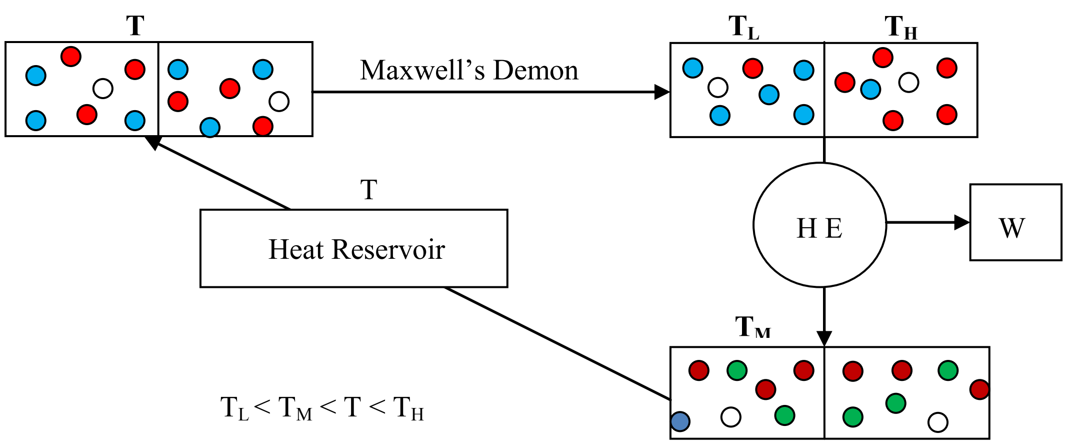


Fig. 3. A cyclic process conventionally employed to show that MD violated Kelvin's statement of the second law of thermodynamics. H E denotes a reversible heat engine and W, the work produced by H E.

In Fig, 3 we show a cyclic process involving MDP, that transforms heat absorbed from a heat reservoir at temperature T, into work with no other change elsewhere. This cycle violates the second law, formulated by Kelvin [8]. However, this cyclic process can be reversed and the system and surroundings brought back to their initial state, by combining it with Joule's heating process (see Fig. 4).

## 5. Reversal of MDP generalized

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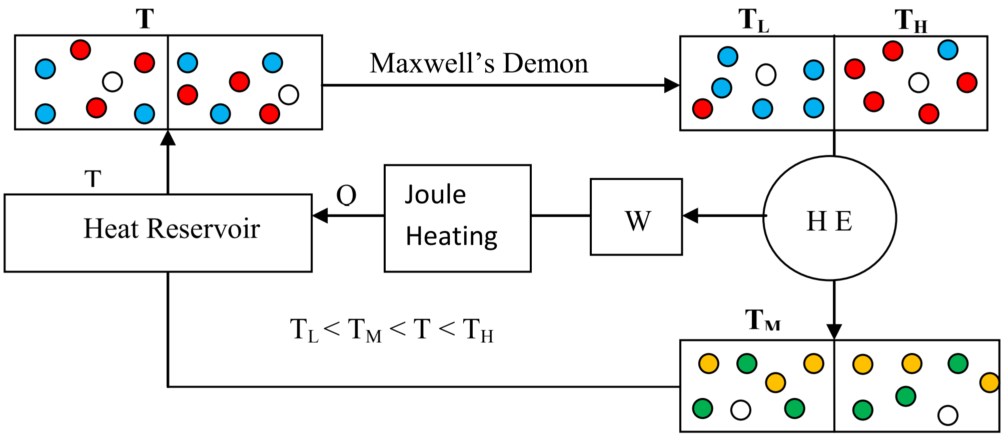


Fig. 4. A cyclic process that shows reversal of MDP. Note, Q may even be directly transferred to the system at temperature $T_{M,}$ without heat reservoir in the cycle.

The cyclic process, involving Maxwell's Demon, heat engine H E and Joule's heating, shown in Fig. 4 is a compound cyclic process. It brings the system to its original state, leaving no changes in the surroundings. The compound cyclic process neither violates the first law nor the second law of thermodynamics. Moreover, it is a reversible process, since the system reaches its original state and the surroundings suffer no change whatever. The only way that this cycle becomes impossible would be that MDP violate the first law, since the other processes do not violate either the first law or the second law. The cycle as a whole would then violate the first law and become an impossible cycle.

## 6. Conclusion

From the above analysis, we conclude that Maxwell's Demon violates the first law of thermodynamics. This result calls for a fresh look at the kinetic molecular theory of heat.

Note: Using similar procedure as that shown in Fig. 4, we can combine, the impossible cyclic process whose only final result is transformation into work, heat absorbed from a body at a uniform temperature throughout (Kelvin's process) with Joule's heating process to construct a cycle that restores the system and surrounding to their original state. So no entropy change of the universe occurs. Such a cycle is a reversible cycle. Similarly, we can also combine the impossible cyclic process whose only final result is transfer of heat from a lower temperature body to a higher temperature body (Clausius process) with Joule's heating process to construct a cycle that brings no entropy change of the universe. This cycle too, is then reversible [9].

## 7. References

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