

Maxwell's demon with no energy consumption

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Abstract:

In this study, we design two devices that can achieve the function of Maxwell's demon without consuming energy by making use of upconversion materials (β -NaYF₄:Yb³⁺,Er³⁺).

1. Introduction

Maxwell's demon, as one intelligent device assumed by James Clerk Maxwell, was proposed to indicate the possibility of violating the Second Law of Thermodynamics. But up until now, existing physical experiments have shown that the operation of Maxwell's demon needs the consumption of energy or the increase of corresponding entropy.

Therefore, it's worth exploring whether there is one device that could play the role of Maxwell's demon without energy consumption.

2. Methods and Discussion

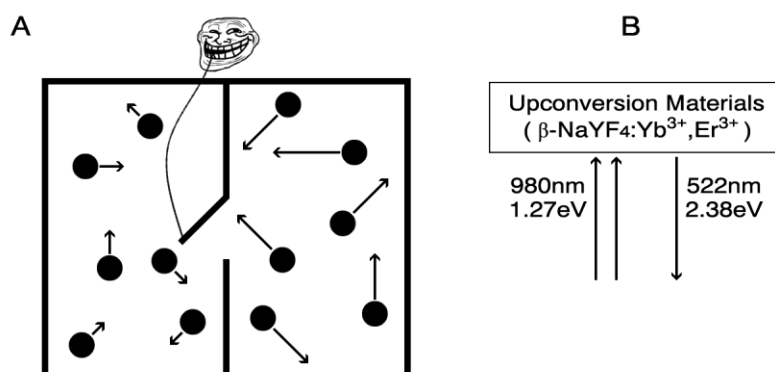


Fig. 1 (A) Schematic operation diagram of Maxwell's demon. (B) Schematic diagram of upconversion materials (β -NaYF₄:Yb³⁺,Er³⁺).

The operation procedure of Maxwell's demon could be mainly divided into two steps:

Step 1: Detect the energy (or velocity) of each particle, during which certain energy is consumed.

Step 2: Designate one valve at first, and then place particles into opposite sides of the box depending on their energy. In this way, temperature differences would appear gradually. It should be noted that energy consumption is involved during the process of opening and closing valves.

Due to the differences in matrix materials, doped rare earth elements, and doping ratios, there are various categories of upconversion materials doped with rare-earth ions. Accordingly, the absorption and emission spectra are also different [1, 2]. To simplify the model, one series of upconversion materials $\beta\text{-NaYF}_4\text{:Yb}^{3+},\text{Er}^{3+}$ was chosen as an example [3]. Simultaneously, photons with absorption wavelengths at 980 nm (corresponding to an energy of 1.27eV) and emission wavelengths at 522 nm (corresponding to an energy of 2.38eV) were considered as research objects. Hereinafter, photons with wavelengths at 980 nm and 522 nm will be referred to as low- and high-energy photons, respectively.

There are two steps during the working processes of up-conversion materials:

Step 1: Absorb two or more low-energy photons selectively.

This step is equivalent to the detection of each photon's energy by Maxwell's demon. In fact, the energy of photons for upconversion materials was unessential to be known. In this process, upconversion materials could keep running spontaneously without extra energy, merely absorbing low-energy photons selectively.

Step 2: Emit one high-energy photon.

The step was equivalent to the process of operation by Maxwell's demon, which merged two or more low-energy photons firstly and then ejected one photon with higher energy. More importantly, upconversion materials could spontaneously work without external energy supply during the conversion process.

So, the remaining question is: how should we use these high-energy photons? Two devices are designed in this paper.

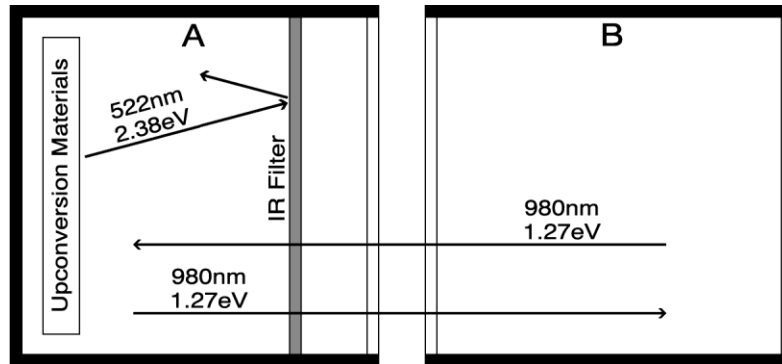


Fig. 2. The up-conversion materials can absorb two or more low-energy photons and then emit a high-energy photon. Subsequently, the high-energy photon is absorbed or reflected by the infrared filter. Low-energy photons can freely move between Boxes A and B.

As for Device 1 shown in Fig. 2, upconversion materials and an infrared filter are placed inside Box A, and this infrared filter is used to absorb or reflect visible light and transmit infrared light. Box B is empty, without placing objects. In the initial state, Boxes A and B have the same temperature.

Upconversion materials inside Box A can emit a high-energy photon after absorbing two or more low-energy photons. After reaching the infrared filter, the high-energy photons will be absorbed by the infrared filter or reflected back to Box A. In this context, it is equivalent to state that high-energy photons are imprisoned inside Box A and cannot escape. The efficiency of the infrared filter is not required to reach 100%, and this does not affect the final result.

The low-energy photons emitted by Box A itself can reach box B freely, while those emitted by Box B can also reach Box A freely. After a period of time, as more and more high-energy photons are absorbed or reflected back into Box A, the temperature of Box A will increase, whereas the temperature of Box B will decrease.

In this device, the infrared filter is equivalent to the valve of Maxwell's demon, which prevents high-energy photons from passing through while permitting low-energy

photons to get through. Moreover, during this process, the infrared filter that acts as a valve works spontaneously, and we do not need to provide additional energy for it.

It should be noted that the temperature in Boxes A and B should be high enough in the actual verification experiment to radiate enough intensity of photons with a wavelength of 980 nm, but it should not be too high that it can destroy the upconversion materials and infrared filter. If necessary, some upconversion materials with better performances should be used [4-6]. The selection of upconversion materials should give priority to satisfying these conditions: the excitation power density should be as low as possible, the excitation wavelength should be as long as possible, the emission wavelength should be as short as possible, the high-temperature resistance should be as good as possible, and the upconversion efficiency should be as high as possible.

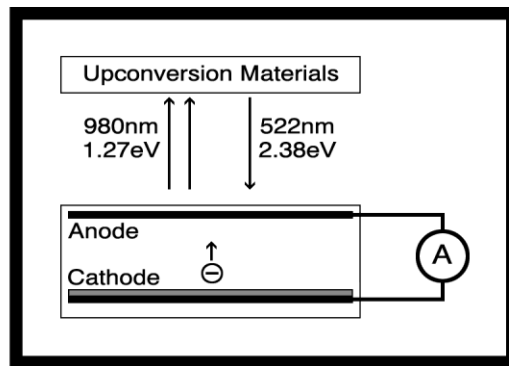


Fig. 3. Current detection device in the single heat source environment.

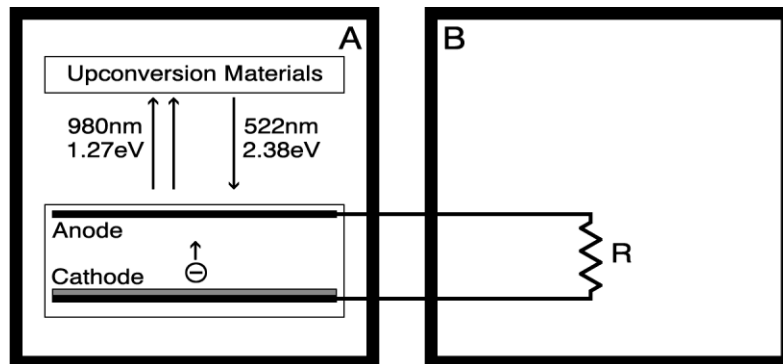


Fig. 4. Current generated by Box A will work through resistor R to heat Box B.

As for Device 2 shown in Fig. 3, upconversion materials, photocells, and ammeters are placed in a single heat source environment. The cathode material of the phototube is a compound of cesium, while the anode material is copper metal with a mesh structure. An ammeter is connected to the anode and cathode of the phototube through a conductor.

After the upconversion materials absorb two or more low-energy photons, they emit a high-energy photon. When the high-energy photon irradiates the cathode of the phototube, electrons will first escape from the surface of the cathode and then be absorbed by the anode. Subsequently, these absorbed electrons will return to the cathode through the wire loop. This process is cyclic, and thus the ammeter will detect the current. This current can be used to work. As shown in Fig. 4, the low-temperature environment can spontaneously transfer heat to the high-temperature environment after replacing the ammeter with a resistor.

In Device 2, the cathode of the phototube is equivalent to the valve of Maxwell's demon (absorbing high-energy photons and ignoring low-energy photons). In this process, the cathode, which acts as a valve, works spontaneously, and we do not need to provide additional energy for it.

It should be noted that the temperature of this single heat source must be high enough in the actual verification experiment to radiate sufficient photons with a wavelength of 980 nm, but the temperature must not be too high that it can destroy the upconversion materials and photoelectric cells (the cathode material of the photoelectric tube should not be decomposed nor evaporated as gas to get attached to the anode). Other suitable cathode materials can be used if necessary. The resolution of the ammeter should reach 10^{-15} A.

According to the above analysis of the simplified model, we manage to achieve the function of Maxwell's demon without consuming energy by combining upconversion materials and an infrared filter (Device 1) and combining upconversion materials and a photoelectric tube (Device 2). However, these two devices have different working ways than the traditional Maxwell's demon.

3. Conclusion

In this study, we analyze the workflow of upconversion materials (β -NaYF₄:Yb³⁺,Er³⁺) and design two devices that can achieve the function of Maxwell's demon without consuming energy based on logical analysis. In the actual experiment, if the temperature difference is measured in Device 1 or current is detected in Device 2, it means that the Second Law of Thermodynamics is violated.

References

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