Heating without Heat

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In this talk, we will show that is is possible to increase (or decrease) simultaneously the temperature of two finite systems without any supply of energy [1]. This effect, in apparent contradiction with our basic thermodynamic intuition, can be achieved if the systems exchange particles in a narrow band of energy.

Such a selective exchange of particles does not need the action of any sort of Maxwell demon and can be carried out by passive filters without compromising the second law of thermodynamics. In fact, there are many examples of passive filters based on resonant tunneling, which are currently used in micro-refrigerators and energy transducers [2].

Here we present a detailed analysis of the thermal properties of passive filters using linear irreversible thermodynamics and kinetic theory [1]. We will prove the existence of two time scales when two systems exchange particles through an energy filter with a narrow, but finite, width. First, the global system relaxes to a pseudo-equilibrium state in a relative short time, followed by the relaxation to full equilibrium in a much longer time scale, as shown in Fig. 1. The ratio between these two time scales is given by the width of the filter.

For very narrow filters the second relaxation is very slow and the pseudo-equilibrium state is almost stationary. We will show that this pseudo-equilibirum state exhibits interesting and unexpected properties. Under certain conditions the fast relaxation to the pseudo-equilibrium state comprises the simultaneous increase of temperature of the two finite systems without any external energy supply. In other words, the possibility of "heating without heat". The opposite, i.e., spontaneous simultaneous cooling, can also occur.

The reason behind these striking behaviors is that temperature is related to the average energy and this average depends both on the total energy and the total number of particles. As in evaporative cooling, temperature can decrease (increase) if particles with high (low) enough energy leave the system [3]. The interplay of this consideration and the selective exchange of particles induces a rich and unexpected phenomenology.

These phenomena could be exploited to design interesting setups with potential applications. For instance, one can use standard infinite thermal reservoirs to set the temperature and density of a finite system and then make them interact through an energy filter. Using this strategy, we have been able to engineer a cycle operating between to reservoirs at temperatures $T_1 < T_2$ that can be converted into an effective reservoir at temperature $T_1' < T_1$ without the need of any mechanical work [1].

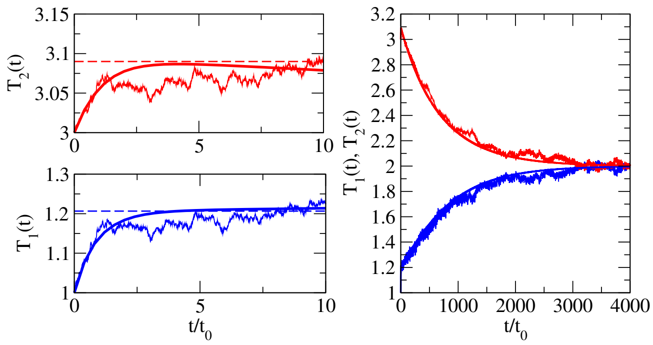

Figure 1: Numerical evolution of the temperatures of the hot $T_1(t)$ (blue) and cold $T_2(t)$ (red) gas as a function of time t, for two-dimensional gases of hard disks. *Left:* Short time evolution, where the system relaxes to the pseudo-equilibrium state (dashed lines indicate the pseudo-equilibrium temperatures). *Right:* Long time evolution, where the system relaxes to full equilibrium.

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