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Thermo-charged capacitors and the Second Law of Thermodynamics

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ABSTRACT

In this Letter we describe a vacuum spherical capacitor that generates a macroscopic voltage between its spheres harnessing the heat from a single thermal reservoir at room temperature. The basic idea is trivial and it makes use of two concentric spherical electrodes with different work functions. We provide a mathematical analysis of the underlying physical process and discuss its connections with the Second Law of Thermodynamics.

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1. Introduction

The Second Law of Thermodynamics, explicitly in the form of Kelvin–Planck postulate, puts a fundamental limit to the way in which usable work can be extracted from heat reservoirs, and to the maximum amount of work extractable (Carnot's principle). In particular, Kelvin–Planck postulate states that it is not possible to *cyclically* extract work from a *single* heat reservoir. Clausius postulate of the Second Law, which is notoriously equivalent to the Kelvin–Planck one, makes the impossibility more striking and understandable: heat cannot spontaneously flow from sources at absolute temperature T_1 to sources at absolute temperature T_2 when $T_2 \geqslant T_1$.

Although in the macroscopic physical world the Second Law seems authoritatively to make the difference between what is allowed and what is forbidden (to date, no experimental violation of the Second Law has been claimed), in the microscopic realm it seems to be continuously violated: let us take into account the Brownian motion or every fluctuation phenomena, for example.

About Brownian motion, Poincaré wrote [1]:

> "[...] we see under our eyes now motion transformed into heat by friction, now heat changed inversely into motion, and that without loss since the movement lasts forever. This is contrary to the principle of Carnot."

Almost every past attempt to understand and exploit such microscopic violation relies on the approach of *fluctuations rectification*. Even the famous thought experiment of *Maxwell's Demon* is actually an idealized version of fluctuations rectification. The main difficulties which seem to afflict all these past approaches (sentient and non-sentient) are that every macroscopic/microscopic rectifier device seems either to suffer fluctuations itself, which neutralize every usable net effect, or its functioning seems to increase the total entropy of the system (at least of the same amount of the alleged reduction) mainly because of energy dissipation and/or entropy cost in the acquisition of information needed to run the device (for sentient devices).

For an interesting historical account of Second Law classical challenges (starting from Maxwell, and passing through Smoluchowski, Szilard, Brillouin, till Landauer) and their attempted resolutions, see Earman and Norton [2].

Nonetheless, over the last 10–15 years an unparalleled number of challenges has been proposed against the status of the Second Law of Thermodynamics. During this period, more than 50 papers have appeared in the refereed scientific literature (see, for example, Refs. [3–21]), together with a monograph entirely devoted to this subject [22]. Moreover, during the same period of time two international conferences on the limit of the Second Law were also held [23,24].

The general class of recent challenges [22,18,21] spans from plasma [17], chemical [20], gravitational [10] and solid-state [19,25,21]. Currently, all these approaches appear immune to standard Second Law defenses (for a compendium of classical defenses, see [2] again) and several of them account laboratory corroboration of their underlying physical processes.

The present Letter aims to describe another approach to microscopic rectification that poses interesting theoretical questions along the aforementioned recent line of research: we are referring to an equivalent of the photo-electric effect with materials

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