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On Energy Circulation

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Key words

Energy circulation, Energy regeneration, Entropy reducing, Maxwell's demon

Abstract

Maxwell and Planck, two outstanding masters in the history of thermal theory, maintained that energy circulation is not an absurd dream, but a scientific idea. That is a sharp and brave challenge to the second law of thermodynamics. The author approves of the two giants opinion and presents the information of a recent experiment supporting their brave challenge.

Introduction

The Kelvin Statement of the second law of thermodynamics is: **It is impossible to extract heat from a reservoir and convert it totally to work without producing any other effects.**

Conventionally, a device that can extract heat from a reservoir and convert the heat totally to work without producing any other effects is called a perpetual motion machine of the second kind. According to the Kelvin statement, **perpetual motion machine of the second kind is impossible**.

Actually, what the Kelvin statement describes or discusses is the so called **irreversible phenomena**: Work converts totally to heat through friction or collision without producing other effects, such processes are very easy to occur, and are usually called spontaneous processes; nevertheless, conversions in the opposite direction are absolutely impossible, that is, after a process of friction or collision, it is impossible to convert the heat produced in the friction or collision totally to work again without producing other effects, whether by a direct way or an indirect and complicated way.

The Kelvin statement is based on numerous experiments of an extremely wide range. So far as we know, it seems that all the experiments and explorations known today support the statement. After its establishment in 1851, most physicists thought that the statement was valid, beyond any doubt.

Nevertheless, there were also a part of physicists who hold different opinion, doubting the absoluteness of the statement. Among those people, the most famous representatives were Maxwell and Planck.

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Directly opposed to the Kelvin statement, Maxwell and Planck maintained that perpetual motion machine of the second kind was a scientific idea, and it should be possible to be realized in some future days.

The author of this paper approves of Maxwell and Planck's brave idea.

What is his reason of the approval?

As is well believed, **energy has two fundamental attributes: conservation and conversion. Both the attributes are intrinsic, and will never destroyed or disappear.** If one really believes that like conservation, conversion is also an ever lasting attribute of energy, he is obliged to accept such a deduction: **energy must be possible to be used repeatedly.**

This is the justification of the perpetual motion machine of the second kind.

The question of whether the perpetual motion machine of the second kind is possible is actually a question of whether energy circulation is possible.

2. History

Look back to the history of physics of the latter half of the nineteenth century, there were four prominent physicists who contributed tremendously to the establishment and development of the second law of thermodynamics: Clausius and Kelvin, Maxwell and Planck.

Clausius and Kelvin gave preference from a macroscopic point of view to the research on various thermal phenomena known in their time, making efforts to clarify the most profound and fundamental macroscopic physical rules governing all these phenomena. They were the establishers (1850, 1851) and guardians of the second law of thermodynamics. Their contributions in this field will go down in the history of science forever.

Maxwell and Planck were excellent inheritors of the second law of thermodynamics and they carried forward brilliantly its development.

Let us first make a review on Maxwell's contributions to thermal theory and his opinion on the second law of thermodynamics.

In 1860, at his age of 29, Maxwell derived theoretically the famous **speed distribution law of gas molecules**, the first time in history described vividly and accurately the motion of the enormous molecules of a gas under an equilibrium state. The discovery was far in advance of the era (it was verified by Auto Stern's molecule beam experiment in 1920, 60 years later.) It deepened tremendously mankind's knowledge about thermal motion, and was an important milestone in the history of thermal theory. .

In 1865, Clausius came up with his great concept of **entropy** and the **principle of entropy increasing**. Following Clausius closely, Maxwell (at his age of 35) soon came up with the famous **Maxwell's thermodynamic relations**, revealing the intrinsic relations between the entropy of a system and the other state parameters of the system (such as volume, temperature and pressure). The relations were expressed in equations of various partial derivatives composed of the state parameters. It deepened mankind's knowledge about entropy, and was an important useful guide both in theory and practice.

And so on (Maxwell's mean free path of gas molecules, viscosity friction in a gas, ⋯). .

As is well known, Maxwell's most outstanding contribution to physics was his theory of electric and magnetic fields. Maxwell's four fundamental equations of electric and magnetic fields were well matched with Newton's three laws of mechanics and the law of gravitation. Nevertheless, as mentioned above, his contributions to the theory of heat were also outstanding. He was no doubt one of the greatest masters of thermal theory in history.

In 1871, Maxwell published his famous textbook ***Theory of Heat***, about 300 pages. Even according to today's standard, this book is also an integrated and high level treatise on thermodynamics. By the end of this book, Maxwell proposed a hypothesis challenged the second law of thermodynamics bravely:

"One of the best established facts in thermodynamics is that it is impossible in a system enclosed in an envelope which permits neither change of volume nor passage of heat, and in which both the temperature and the pressure are everywhere the same, to produce any inequality of temperature or of pressure without the expenditure of work. This is the second law of thermodynamics, and

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it is undoubtedly true as long as we can deal with bodies only in mass, and have no power of perceiving or handling the separate molecules of which they are made up. If we conceive a being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are still as essentially finite as our own, would be able to do what is at present impossible to us. For we have seen that the 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 number 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 ones to pass from A to B, and only the slower ones 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 (see Fig.1 left)." [1]

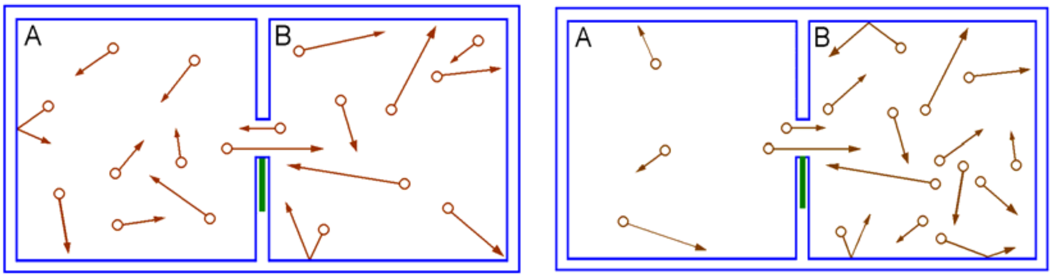

Fig.1 Maxwell's demon makes a difference in temperature or in pressure

Fig.1 right shows an explanation about Maxwell's demon by Ehrenburg et al. The being may adopt another working mode to control the small hole: it allows molecules to pass through the hole only from A to B, never from B to A. He will thus without expenditure of work, raise the pressure of B and lower that of A, in contradiction to the second law of thermodynamics." [2]

In 1867, in a letter to his friend Peter Guthrie Tait, Maxwell described this hypothesis. In 1870, in a letter to another friend John William Strutt, Maxwell discussed further this hypothesis. In 1871, he published the hypothesis in the above mentioned textbook ***Theory of Heat***. We can see that his attitude to this hypothesis is ardent and serious. It is apparent that he had made great effort trying to break out the

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second law of thermodynamics by such a way. Restricted to the level of science and technology of his time, he did not succeed. Nevertheless, he thought that this hypothesis was enlightening, so he published it for the coming generations, hoping that they will achieve real success in some future days.

Now let us make a review on Planck's contributions to thermal theory and his opinion on the second law of thermodynamics.

Molecules, atoms, ions, electrons and so on are so called real particles, and they are the first kind of the micro-objects of thermal motion. The second kind of the micro-objects of thermal motion is random electromagnetic radiation, i.e., thermal radiation. The research on thermal radiation is focused on equilibrium thermal radiation, viz., black body radiation. The history of the research on black body radiation, including experiment and theory, lasted for about half a century, mainly in Europe. More than 10 prominent masters of physics, including Kirchhoff, Stefan, Boltzmann, Wien, Rayleigh, Jeans, Planck etc, worked like a relay team, conquered a series of difficult and knotty problems. Among these masters Planck was the last one, and he gathered all of the previous achievements and gave a final good touching in 1900: his quantum hypothesis to the energies of the electromagnetic harmonic oscillators at various frequencies of the equilibrium thermal radiation in a cavity at a constant temperature resulted to a spectrum of blackbody radiation coincides with the experiment to an astonishing perfection (**as is well known, this hypothesis also opened a new era of physics, the quantum physics!**) In the half-a-century long explorations by these prominent masters, almost every step forward was connected closely and deeply to the second law of thermodynamics. The masters were all proficient at the second law of thermodynamics, and among them, Planck was the most outstanding one.

In 1897, Planck published his ***Treatise on Thermodynamics***, also about 300 pages (Note: it was only three years earlier than 1900, the year he put forward his quantum hypothesis!) In the later 25 years, he ceaselessly made revisions to the book, re-edited it again and again, and finally published the seventh edit in 1922 (a strict German!) No doubt, Planck's most time and effort of life was devoted to thermodynamics. The

Kelvin statement of the second law of thermodynamics, in many textbook of university physics, is referred to as **the Kelvin-Planck statement**[4]. It is apparent that Planck's study and exploration on the second law of thermodynamics was well respected widely. Nevertheless, we can find that there was some divergence between Planck's opinion and the one of Clausius and Kelvin. Let's quote here some paragraphs from sections 116 and 136 of the above mentioned Planck's book:

***It is impossible to construct an engine which will work in a complete cycle, and produce no other effect except the raising of a weight and the cooling of a heat reservoir*. Such an engine could be used simultaneously as a motor and a refrigerator without any waste of energy and material, and would in any case be the most profitable engine ever made. ··· For this reason we take the above proposition as our starting point. Since we are to deduce the second law from it, we expect, at the same time, to make a most serviceable application of any natural phenomenon which may be discovered to deviate from the second law. As soon as a phenomenon is found to contradict any legitimate conclusion from the second law, this contradiction must arise from an inaccuracy in our first assumption, and the phenomenon could be used for the construction of the above described engine.(§ 116)**

In conclusion we shall briefly discuss the question of the possible limitations to the second law. If there exists any such limitations — a view still held by many scientists and philosophers — this much may be asserted, that there existence presupposes an error in our starting point, viz. the impossibility of perpetual motion machine of the second kind, or a fault in our method of proof. From the beginning we have recognized the legitimacy of the first of these objections, and it cannot be removed by any line of argument. The second objection ··· proves untenable. (§ 136)

In the mean time, no more effective weapon can be used by both champions and opponents of the second law than indefatigable endeavor to follow the real purport of this law to the utmost consequences, taking the latter one by one to

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the highest court of the appeal — experience. Whatever the decision may be, lasting gain will accrue to us from such a proceeding, since thereby we serve the chief end of natural science — the enlargement of our stock of knowledge. (§ 136)

In Planck's opinion, the perpetual motion machine of the second kind is neither ignorant nor stupid, but a profound and reasonable scientific idea. He encouraged the new generations to make further explorations on the problem, seeking experiments that would break out the second law..

Maxwell and Planck were two of the greatest geniuses in the history of physics (the other two greatest geniuses were, of course, Newton and Einstein). They sharply and resolutely challenged a universally accepted fundamental law of physics, such an event was very rare in the history of science. Then, what was the start point in their mind to make this brave challenge? What was the central pillar in their beliefs that contradicted to the whole academic orthodoxy?

Very simple, this starting point or central pillar is: **Energy should be possible to cycle**. What Planck said straightly "**The legitimacy of the perpetual machine of the second kind**" is actually "**The legitimacy of energy circulation**".

What's the meaning by **energy circulation?**

According to Clausius and Kelvin, work changes totally to heat through friction or collision without producing other effects, and then the heat scatters to the surroundings, and aii these processes are "absolutely irreversible." That is to say, conversions in opposite direction are impossible.

According to Maxwell and Planck, conversions in opposite direction should be possible. That is to say, the heat produced in friction or collision may be gathered together and changes back totally to work without producing any other effects (i.e., "both the system and the environment restore to their original states"), and then, the work may be used once again.

The two processes, one positive and the other negative, form a cycle.

If energy is really possible to cycle, we may use it repeatedly for one thousand times, ten thousand times, and so on, and it will neither reduce in quantity, nor get exhausted or died. Energy may be used by us repeatedly, just as the oxygen in the earth's atmosphere, by the cycle of its mutual change with carbon dioxide, may be used by us repeatedly without an end.

Maxwell and Planck took a broad and long view over the whole thermal science of their time with their keen eyes, and believed that energy should be possible to cycle. They of course knew that there was no any experimental evidence at their time supporting the idea. Nevertheless, they were confident that such experimental evidences "**not exist now, but will appear in future.**"

In the past 55 years the author of this paper made ceaseless efforts to find such experimental evidences. He had found a way to realize Maxwell's hypothesis about thirty years ago, and accomplished finely the corresponding experiment in recent years (see the introduction of the experiment at the final part of this paper.)

3. The second law and its position in thermodynamics

Clausius and Kelvin's second law of thermodynamics was established on an extremely large quantity of observations and experiments over an extremely wide range. Hence, it is almost always valid. Based on this, Clausius maintained further that all of the thermodynamic processes in the universe are irreversible, and every such process causes the increase of entropy, and the final fate of the universe is its entropy reaches a maximum value and everything in the universe falls into the **Heat Death**.

The author maintains that, just as Maxwell and Planck insisted on, the general unidirectional changes of all thermodynamic processes declared by Clausius and Kelvin was impossible to be absolutely valid. Entropy increases in ordinary and spontaneous thermodynamic processes, it should also be possible to decrease in some extraordinary and non-spontaneous thermodynamic processes.

Only after mankind has discovered some entropy-reducing processes, verifying that energy is truly possible to cycle, then could thermodynamics be a really integrated theory.

4. An Experiment Realizing Maxwell's Hypothesis

Here is a brief introduction of a new experiment, whose design is inspired by the

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famous Maxwell's hypothesis.

First, the author hold that Maxwell's hypothesis will be easier to be realized if the demon, instead of dealing with the neutral molecules of a gas, turn to deal with the thermal electrons emitted by two cathodes in a vacuum tube.

As shown in Fig. 2, in an electron tube, there is a quartz plate, whose upper surface is coated with two identical and parallel thermal electron emitters, A and B. A narrow gap between A and B keeps A and B insulated from each other. The whole tube is immersed in some single-temperature heat reservoir whose temperature is such that A and B ceaselessly emit thermal electrons.

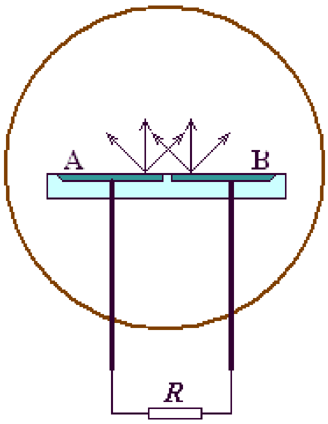

Fig. 2 In a vacuum tube, there are two identical thermal electron emitters on an insulation plate.

Fig. 3 illustrates the motion of the thermal electrons emitted from two points located separately on A and B when there is no magnetic field applied to the tube. A part of the electrons emitted by A can travel across the gap and fall on B, while an approximately equal part of electrons emitted by B can also travel across the gap and fall on A. The two tendencies cancel each other, resulting in no net charges (positive or negative) on A or B.

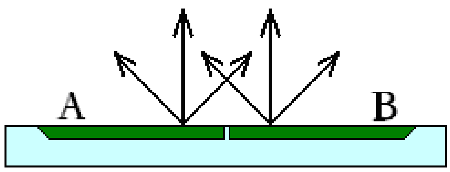

Fig. 3 Thermal electrons eject into a zero-field,

Now, if a static uniform magnetic field is applied to the tube in the direction parallel to the gap between A and B, the paths of the electrons will change into circles with different radii, with swifter electrons moving along larger circles and slower ones along smaller circles. If the direction of the magnetic field enters the paper, as shown in Fig. 4 left, a certain part of the electrons emitted by A can travel across the gap and fall on B, but it is now impossible for any electron emitted by B to travel across the gap and fall on A. (If the direction of the magnetic field leaves the paper, as shown in Fig.4 right, thermal electrons will fly from B to A).

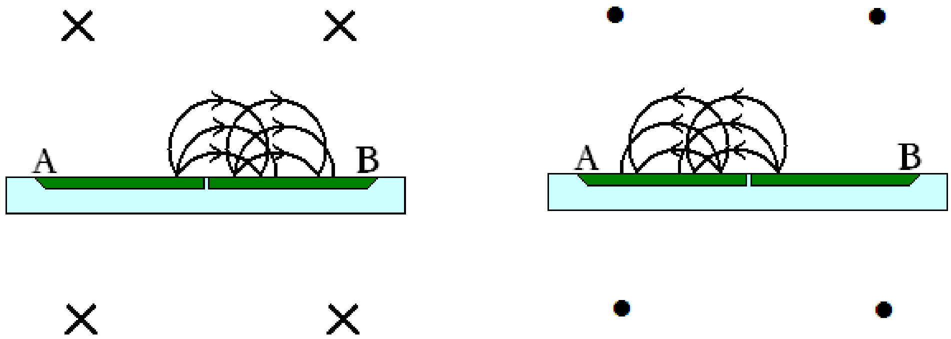

Fig. 4 Left: magnetic field enters the paper; Right: magnetic field leaves the paper

Such a net transition of electrons from A to B will rapidly result in a charge distribution, with A charged positively and B charged negatively. A potential difference between A and B is simultaneously established, and a DC current as well as an electric power is transferred to a load, a resistor or a reversible battery outside the tube.

Where does the electric power come from?

It comes from the heat extracted by the electron tube from the heat reservoir in which the tube is immersed. We analyze this heat-electric conversion process as follows.

As A is charged positively and B is charged negatively, a static electric field between them (especially in the region above the gap between A and B) emerges. The direction of the electric field is to prevent the succeeding thermal electrons to fly from A to B. In the upper part of figure 5, above the gap, a flying electron is shown: The direction of its speed is to the right, and the force the static electric field exerted on it is to the left, so the electron is decelerated by the force. Nevertheless, all the thermal

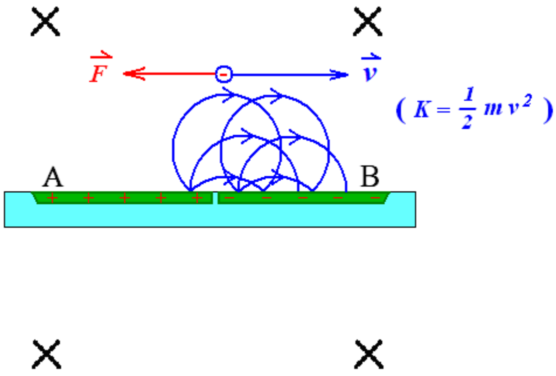

Fig.5, ***v*,** rightward, is the speed of an electron above the gap between A and B**.**

F, leftward, is the force exerted on the electron by the electric field between A and B

electrons emitted by A have kinetic energy, and relying on their kinetic energy, a part of the electrons (mainly the faster ones) can overcome the prevention of the static electric field and travel across the gap to fall on B. On arriving at B, each electron has obtained an amount of electric potential energy at the cost of losing of an equal amount of the electron's kinetic energy. Thus, these electrons "cool down". Consequently the two emitters and then the whole electron tube will also cool down (may be slightly). As electric energy is continuously transferred to the resistance outside the tube, the tube loses continuously its internal energy, which is compensated by the heat that the tube extracts from the surrounding heat reservoir. [4] [5]

In the above process, the electron tube continuously extracts heat from a heat reservoir and all the heat converts to electric energy without producing other effect. We maintain that the process is in contradiction to the Kelvin's statement of the second law of thermodynamics.

The magnetic field here is actually a Maxwell's demon, and it might be referred to as a **magnetic demon**.

It will be interesting to adopt Ag-O-Cs cathode material as the thermal electron emitters in such an experiment. Ag-O-Cs cathode is used widely today in photoelectric tubes and photomultipliers. Its work function is only 0.8 eV, and it can emit thermal electrons apparently at room temperature (the so called **dark current**.) We have performed an experiment using a tube with two Ag-O-Cs cathodes and with the whole closed circuit at a uniform room temperature. The tube extracted heat from the ambient air (within the laboratory) and converted it totally to electric energy. [6] [7]

We believed that the experiment realized Maxwell's hypothesis, verified Planck's argument of "the legitimacy of the perpetual motion machine of the second kind cannot be removed out by any line of argument."

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