Realization of Maxwell's Hypothesis

A heat-electric conversion in contradiction to Kelvin's statement

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December, 2010

ABSTRACT

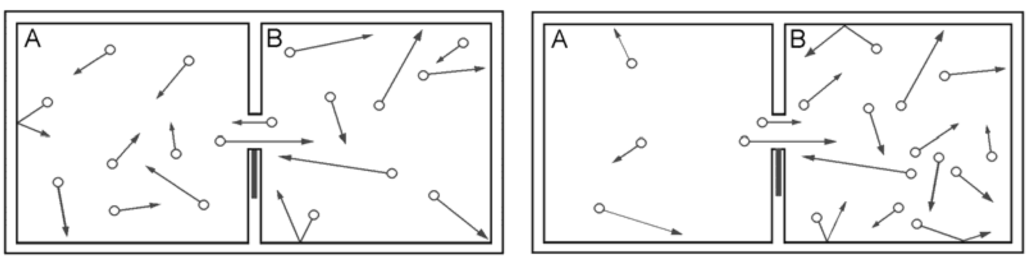
Two similar and parallel Ag-O-Cs surfaces in a vacuum tube eject electrons at room temperature ceaselessly. A static magnetic field applied to the tube plays the role of "Maxwell's demon". The thermal electrons are so controlled by the magnetic field that they can fly only from one Ag-O-Cs surface to the other, resulting in collections of positive and negative charges on the two surfaces, respectively, as well as an electric potential between them. A load, a resistance out the tube for example, is connected by wires to the two surfaces, getting an electric power from the tube continuously. The ambient air is a single heat reservoir in this test, and all of the heat extracted by the tube from the air is converted to electric energy, without producing any other effect. The authors believe that the experiment is in contradiction to Kelvin's statement, and the famous hypothesis proposed by Maxwell about 140 years ago is realized eventually.

1. INTRODUCTION

In 1850 and 1851, Clausius and Kelvin established the second law of thermodynamics. According to this law, all the thermodynamic processes known by mankind so far result in the increase of entropy, and they are all "irreversible". All the energy conversions and transmissions happened within the universe have a common and single direction, changing from useful energy to useless one. For instance, the electric energy that every family spends every day is, as is well known, useful energy. It is also well known that every piece of such electric energy can be used once only. After being used, the electric energy has been converted into waste heat and scatters into the surrounding air. Then it transmits to the farther atmosphere and ground, and eventually ejects to the cosmic space. The vast cosmic space is the terminal of all energy conversions and transmissions, and it is actually the final settlement of energy, the grave of energy.

The second law of thermodynamics, no matter whatever a description it takes, always professes the same idea: energy cannot circulate, it just gets older and older straightly without any backward step until its death, and after the death, never will it revive.

In 1871, to challenge this odd and peculiar law, Clerk Maxwell put forward an ingenious and creative hypothesis, the so-called (by Kelvin) Maxwell's demon [1]. The hypothesis goes directly into the possibility of energy refreshment (i.e., the possibility of energy circulation). It starts with an initially equilibrium gas confined within a vessel, with the temperature and pressure uniform throughout the gas. There is a separator that divides the vessel into two equal parts, portion A and portion B, with a tiny door on the separator, as shown in Fig. 1. The demon's job is, without expenditure of work, to observe the motions of individual molecules of the gas, and according to the situation of the molecules' motion open and close the tiny door at proper times, so as to interfere intentionally with the molecules' random thermal motion. A demon may work in either of the two modes as below.



(a) In the first mode, demon makes an inequality in temperature

(b) In the second mode, demon makes an inequality in pressure

Fig. 1 Maxwell's demon interferes with the random thermal motion of gas molecules*

In the first mode, as shown in Fig. 1(a), the demon lets only swifter molecules pass the door from A to B, and slower ones from B to A, causing eventually a difference in temperature between A and B. This is the reverse process of heat transfer.

In the second mode, as shown in Fig. 1(b), the demon lets the molecules, whether swifter ones or slower ones, pass the door only from A to B, never from B to A, causing eventually a difference in pressure between A and B. This is the reverse process of gas free-expansion.

*Note: Fig. 1 of this paper is quoted from W. Ehrenberg's *Maxwell's Demon, Scientific American*, pp.103 (1967).

Getting a difference in temperature or a difference in pressure without expenditure of work means the renewing of part of the energy of the gas [2], and that is in contradiction to the second law of thermodynamics.

In the past 140 years, there have been many people who endeavored to find a way to realize this attractive hypothesis. They tried with a variety of physical and other methods, nevertheless, all their efforts failed.

The authors hold that Maxwell's hypothesis will be much easier to realize if the demon, instead of dealing with the neutral molecules of a gas, turn to dealing with the thermal electrons ejected by two cathodes in a vacuum tube. Electrons in vacuum tubes were widely used in the 20th century and are very familiar to today's physicists [3].

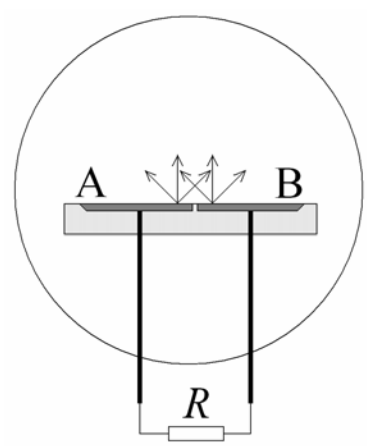
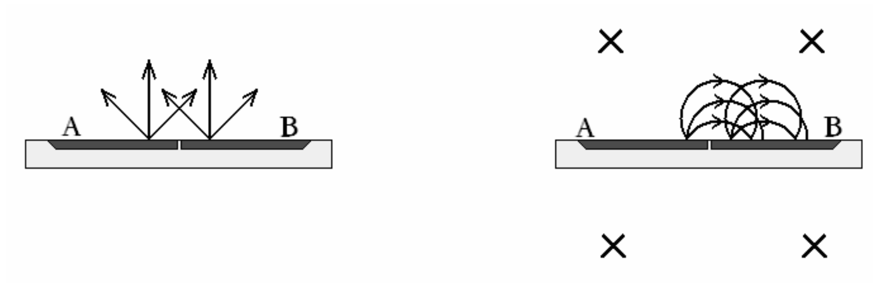


Fig. 2 Replacing Maxwell's neutral molecules with the thermal electrons ejected from two cathode-material surfaces in a vacuum tube.

To illustrate this, let us imagine an electron tube whose essential part is an insulated plate (a quartz plate for example) coated with two identical and parallel thermal electron ejectors on one of its surfaces, as shown in Fig. 2. We refer to the two ejectors after Maxwell as ejectors A and B. There is a narrow interval between A and B, keeping A and B well insulated from each other. The whole tube is immersed in some single heat reservoir whose temperature is such that A and B eject thermal electrons ceaselessly.

Fig. 3(a) illustrates the motion of electrons ejected from two points on A and B near the interval when there is no exterior magnetic field applied to the electron tube. It is easy to see that a part of electrons ejected by A can fly across the interval and fall on B, while an equal part of electrons ejected by B can also fly across the interval and fall on A. The two tendencies cancel each other, resulting in no collections of positive and negative charges on the two surfaces, respectively.



(a) Electrons ejected into a zero-field space (b) Electrons ejected into a magnetic field

Fig. 3 How a magnetic demon deals with the thermal electrons.

Now, if we apply an appropriate static uniform magnetic field to the tube in the direction parallel to the interval between A and B, the tracks of the ejected thermal electrons will change into circles with different radii, swifter electrons moving along bigger circles and slower ones moving along smaller circles. As shown in Fig. 3(b), a part of the electrons ejected by A can still fly easily across the interval and fall on B, but it is now impossible for any electron ejected by B to fly across the interval and fall on A. Such a net transition of electrons from A to B will quickly result in a charge distribution, with A positively charged and B negatively charged. A potential difference between A and B is set up simultaneously. The situation is very similar to the above mentioned second mode of Maxwell's demon, by which the gaseous molecules move only from portion A to portion B, causing a difference in pressure, as shown in Fig. 1(b). Connecting ejectors A and B with two metal wires to an external load, a resistor or a reversible battery for example, the load will obtain a DC voltage and a DC current, both small but macroscopic.

Such a voltage and current means a small but macroscopic electric power, and the electron tube is supplying electric energy for the load continuously. One may ask, where does this electric power come from?

It comes from the heat extracted by the electron tube from the neighboring single heat reservoir. We interpret the energy conversion from the heat extracted from the single heat reservoir into electric energy as follows.

As mentioned above, when a magnetic field is applied to the tube, cathode A quickly gets positively charged while cathode B gets negatively charged. These positive charge and negative charge produce a static electric field in the space above the interval between A and B. The direction of this electric field tends to prevent the succeeding thermal electrons ejected by cathode A from flying towards cathode B. Nevertheless, the thermal electrons have kinetic energy. Relying on their kinetic energy, a certain part of the thermal electrons ejected by A can overcome the prevention of the static electric field and fly across the interval to fall on B. On arriving at B, each electron has obtained a certain amount of electric potential energy, which is of course derived at the cost of losing an equal amount of the electron's kinetic energy. Thus, the electrons are "cooled down" (slightly), and consequently the temperature of the electron tube will also drop down (very slightly). The cool down of the tube can be compensated spontaneously by extracting heat from the neighboring single heat reservoir.

In the above process, the electron tube extracts heat from the single heat reservoir and all of the extracted heat is converted into electric energy, without producing any other effects. We maintain that the process is in contradiction to Kelvin's statement of the second law of thermodynamics.

The magnetic field here is actually a Maxwell's demon.

The following is a description of an actual experiment based on the above idea. We first describe the electron tube used in the test, focus on the cathode material and the structure of the tube, and then the actual experiment.

2. ELECTRON TUBE OF MODEL FX

A. The thermal electron ejectors and working temperature

First of all, we give some words about the cathode material of ejectors A and B. In principle, any of the present known thermal electron cathode material may be used in such an experiment. Nevertheless, most of such materials work at high temperature (≥800°C); if we adopt them, as the load and measurement instrument is mostly at room temperature, there will be some great temperature difference along the closed electric circuit shown in Fig. 2, causing serious disturbance to the test. To deal with these disturbances is complicated and difficult. In order to accomplish a simple but integrated original experiment, we, for the time being, choose Ag-O-Cs cathode material for the two electron ejectors. Ag-O-Cs has the lowest work function among all present thermal electron materials, only about 0.8 eV. It is so far the best one to eject more thermal electrons at room temperature. Adopting this material and let the tube and whole device work at room temperature, the closed electric circuit in the test may easily be kept at a uniform temperature, eliminating thermal electromotive force. In a word, we want the test be well simplified and idealized.

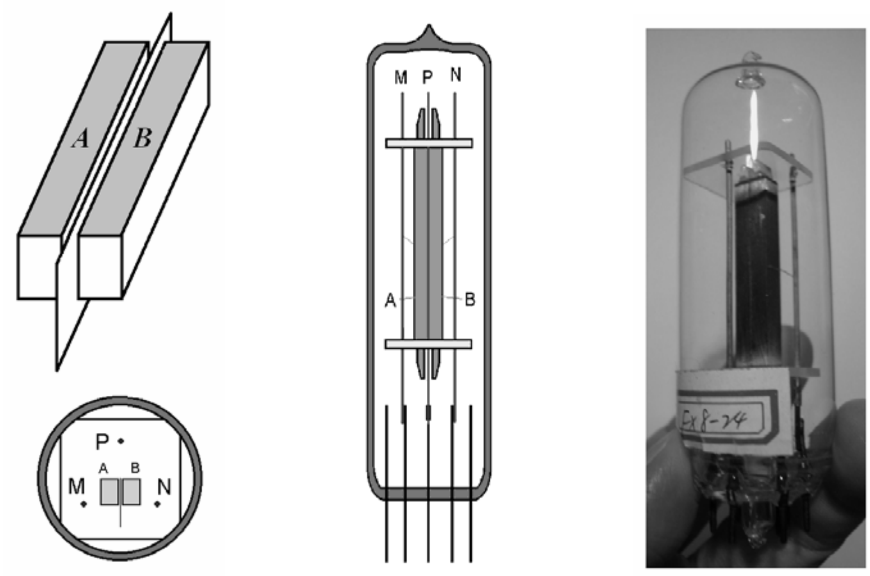
Ag-O-Cs cathodes are widely used today in photoelectric tubes and photo amplifiers. Due to their particularly low work function of 0.7 to 0.9 eV, Ag-O-Cs cathodes are very sensitive to light, even to near-infrared rays. Also due to this low work function, the cathodes can eject the greatest amount of thermal electrons among all existing cathodes at room temperature, which is usually referred to as dark current [4]. In common photoelectric tubes and photo amplifiers, people hope the tubes are of weaker dark current, the weaker the better. Most manufacturers, by making effort in adjusting their manufacture technology, get cathodes with very low dark current ranging from 10^{-11} to 10^{-14} A/cm^2. In our experiment, quite contrary, we prefer greater dark current, the greater the better. The authors, together with the engineers and workers of Yi Zhen Electron Tube Factory at Jiang Su Province, adjusted the technology repeatedly in the past eleven years, and eventually got a rather strong dark thermal current, ranging from 10^{-8} to 10^{-11} A cm^{-2}.

In this experiment, the tube plays the role of an electric power source. The load of the power source may be a resistor or a storage battery. In our present test, we take the input resistor of an electrometer, Keithley Model 6514, as the load. The advantage of choosing the input resistance of Keithley 6514 as the load is that the electrometer can simultaneously be used to measure the current or voltage produced by the electron tube. The whole circuit, i.e. the power source (the tube) and the load (the input resistor), should be kept at a uniform temperature so as to remove Seebeck effect and other similar disturbances. This demand is rather easy to be satisfied for we have chosen the room temperature as the working temperature.

By the way, if instead of adopting Ag-O-Cs ejectors, we adopt Ba-Sr-Ca oxide cathode material as ejectors in the experiment, the output current and power of the tube will certainly increase tremendously (one million or ten million times greater). Nevertheless, in so doing, there will be serious temperature difference in the closed circuit: the cathodes are at about 800°C, but the load or electrometer is usually at room temperature, say, 20°C. The seriously great difference in temperature along the closed circuit will result serious Seebeck effect. In order to simplify the experiment, we discard Ba-Sr-Ca oxide ejectors and adopt Ag-O-Cs ejectors.

Another advantage of adopting Ag-O-Cs ejectors and room temperature is: the experiment attracts the "waste heat" from the ambient air in the laboratory and converts it directly into useful energy again. Such an event is certainly of great significance.

B. The structure of the electron tube used



(a) Ejectors A and B, mica sheet, supports, rods P, M, N. (b) Main structure of FX tube (c) A photo of FX8-24

Fig. 4 Electron tube FX8-24

The electron tube used in the experiment is FX8-24, whose structure is shown in Fig. 4. The outer shell is of glass. In Fig. 4(a), A and B, the upper surfaces of two copper bases, are two similar and parallel Ag-O-Cs thermal electron ejectors, each with an area of 4 x 40 mm^2. Between the two copper bases (also between the ejector surfaces A and B) there is a mica sheet 0.07 ~ 0.09 mm in thickness, which keeps A and B very close (about 0.10 mm) but well insulated from each other. A, B and the top of the mica sheet should be kept approximately at a same plane, as shown in Fig. 4 (a). At the bottom of A and B, the mica sheet should stretch out for about 5 ~ 7 mm, to prevent thermal electrons from rotating back from B to A. M, N and P are three molybdenum supporting rods. M and N are also used as leading wire of A and B to the tube base pins. P is 6mm above the interval between A and B, and it may also be used as a temporary anode when needed. It is used as an anode in the process of manufacturing Ag-O-Cs ejectors (A and B), helping to oxidize the silver films on the upper surfaces of the two copper bases by oxygen-discharge. After the manufacture of the tube is accomplished, P is also used temporarily as an anode to check whether the tube is qualified to be used in the destined experiment: apply a DC voltage of 30V to the P-A circuit or to the P-B circuit, measure the corresponding photoelectric sensitivity and the dark current of ejectors A and B. Our typical photoelectric sensitivity of each ejector is 0.2 ~ 10.0μA/lumn, and the typical dark current of each ejector is 100~2500pA. Besides, the leakage resistance between A and B, $R_{leakage}$, should be higher than 100~200MΩ. Otherwise, according to our experience, the tube is unqualified for the destined experiment. The value of the leakage resistance depends mainly on the input amount of cesium and the final heat activation and exhausting process.

3. MEASUREMENT OF THE MAGNETIC FIELD AND THE OUTPUT CURRENT

A. Magnetic field measurement

The magnetic field to deflect the tracks of thermal electrons is produced by a magnet of 150×100×25 mm^3 (Ceramic 8, MMPA Standard). In Fig. 5 and Table I, B stands for the magnetic induction at a field point O on the axis of the magnet, and d stands for the distance from point O to the magnet. The $B \sim d$ relation is measured in advance with a tesla meter.

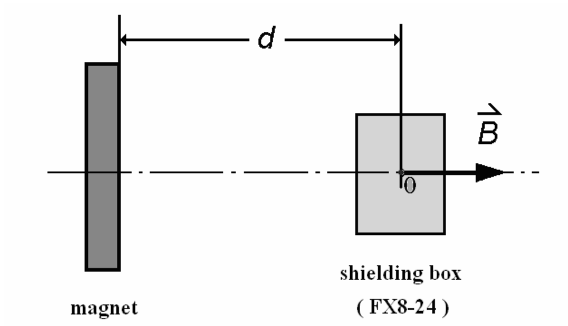


Fig. 5 The magnetic field produced by a single magnet

d_{cm}	70	60	50	40	35	30	25	20	15	10
$B\uparrow_{gaus}$	0.2	0.3	1.1	2.1	2.9	4.4	7.2	13.1	25.5	59.7
$B\downarrow_{gaus}$	-0.6	-0.8	- 0.7	-1.6	- 2.5	- 4.0	- 6.7	- 12.7	- 24.9	- 58.8
$B_{avr,,gaus}$	0.4	0.6	0.9	1.9	2.7	4.2	7.0	13	25	60

Table I $B \sim d$ relation of the magnet used in the experiment

B. Output current

As mentioned above, we use an electrometer Keithley Model 6514 to measure the output current of the electron tube FX8-24. The best current resolution of 6514 is 1×10^{-16}A. The measuring circuit is very simple, as shown in Fig. 6. We mainly measure the output current, but the instrument and circuit may also be used to measure the output voltage.

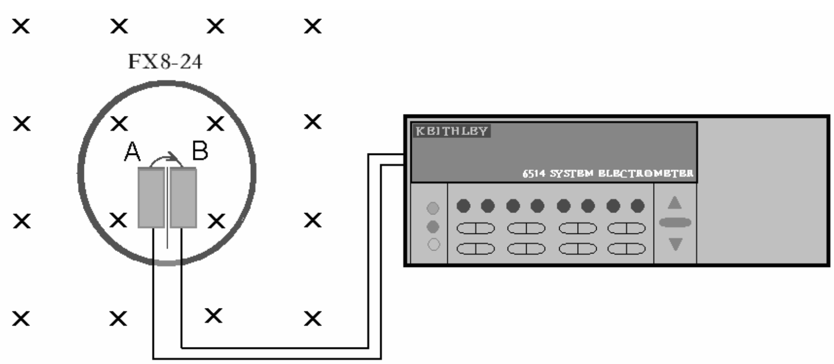
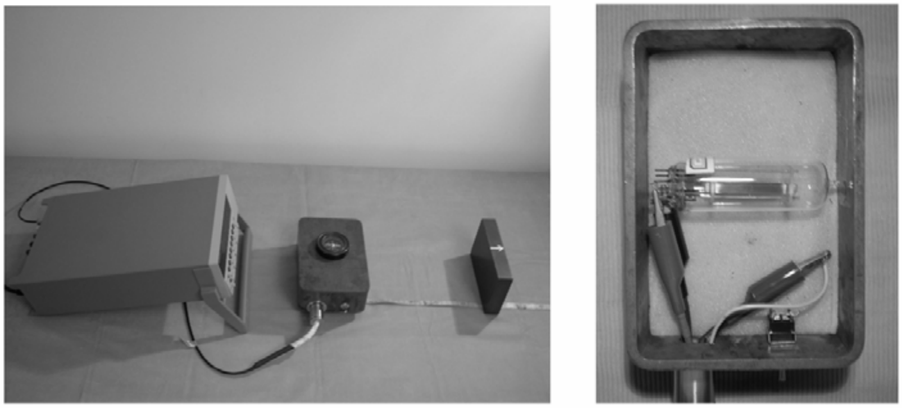


Fig. 6 Current-measuring circuit.
The best current resolution of 6514 is 1×10^{-16} A

4. THE EXPERIMENT AND THE RESULT

Fig. 7 is two photos of the set up of the experiment. For preparation, put electron tube FX8-24 into a copper shielding box. The four walls of the copper shielding box, as well as its cover and bottom, are all 5 mm or more in thickness, so, external visible light and other electromagnetic waves are all well kept away of the box. The expected output current or voltage of tube FX8-24 when a magnetic field is applied is transferred from the box to electrometer 6514 through an accessory concentric cable, as shown in the photos.



(a) (b)

(a) Electrometer Keithley 6514, copper shielding box (containing FX8-24), magnet.

(b) Position and direction of electron tube FX8-24 in the copper shielding box.

Fig. 7 Set up of the experiment

First, we measure the output current of FX8-24 at different magnetic induction.

At the beginning, we do not apply a magnetic field to the electron tube, and there should be no current in the circuit. Then we apply a positive magnetic field (northward) B_+ of a rather weak magnetic induction to the tube (for example, $B_+ = 0.6$ gausses, corresponding to $d \approx 70$cm). The magnetic field should be parallel to the axis of the tube (also parallel to the interval between A and B)), and we use a compass put on the top of the copper shielding box to show the direction of the magnetic field. A positive output current emerges immediately. We strengthen B_+ step by step by reducing d, giving a sufficiently long pause for every step (to eliminate Faraday's motional electric motive force). We obtain at every step a stable value of output current $I_{+,}$ corresponding to a stable magnetic induction B_+. At the beginning, I_+ increases as B_+ increases. There is then a peak of I_+, after which I_+ decreases as B_+ increases further. Such a peak is according to our expectation and it is easy to be interpreted: At the beginning, as B_+ getting stronger, the effect of the magnetic field that forces the electrons go only from A to B is also getting stronger, so the current gets stronger step by step; after the magnetic field have got strong enough, the radii of the electron orbits become so tiny that more and more electrons (the slower ones first) are no longer capable to cross the 0.10 mm interval between A and B, resulting in the drop down of the current.

Move the magnet back to d=70cm and turn it 180° to reverse the direction of the magnetic field in the copper shielding box, which is now southward and is designated as B_-. The electrometer shows that the direction of the output current, as expected, reverses, too. We designate the present current as I_-. As the distance d reduces step by step, B_- gets stronger and stronger, and I_- increases first, then decreases after a negative peak in a similar way just as I_+ changes after B_+.

We refer to the currents I_+ and I_- briefly as Maxwell's current, and designate it as I. For a giving FX tube, Maxwell's current I depends on two factors: the magnetic induction B and the temperature T,

$$\boldsymbol{I = I(B, T)} \tag{1}$$

The detailed results of the experiment are shown in tables and by graphs as follows.

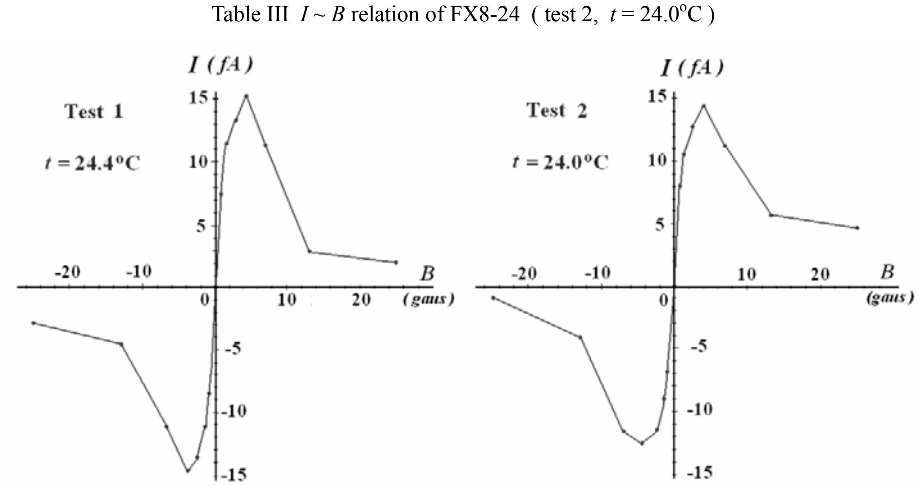
Table II and Table III illustrate the data of $I \sim B$ relation of electron tube FX8-24 measured in two tests. Fig. 8 (a) and (b) are the corresponding $I \sim B$ graphs. In each test, the temperature is regarded as a constant parameter.

d (cm)	∞	50	40	35	30	25	20	15
B (gauss)	0	0.9	1.9	2.7	4.2	7.0	13	25
I_+ (10^{-15}A)	0	7.4	11.4	13.4	15.1	11.3	3.0	2.1
I_- (10^{-15}A)	0	-8.5	-11.2	-13.6	-14.5	-11.0	-4.3	-3.4

Table II $I \sim B$ relation of FX8-24 (test 1, $t = 24.4^{o}$C)

d (cm)	∞	50	40	35	30	25	20	15
B (gauss)	0	0.9	1.9	2.7	4.2	7.0	13	25
I_+ (10^{-15}A)	0	8.0	10.5	12.8	14.3	11.1	5.3	4.6
I_- (10^{-15}A)	0	-6.9	-9.1	-11.4	-12.7	-11.8	-4.2	-1.2

Table III $I \sim B$ relation of FX8-24 (test 2, $t = 24.0^{o}$C)



(a) (b)

Fig. 8 I - B graphs of electron tube FX8-24

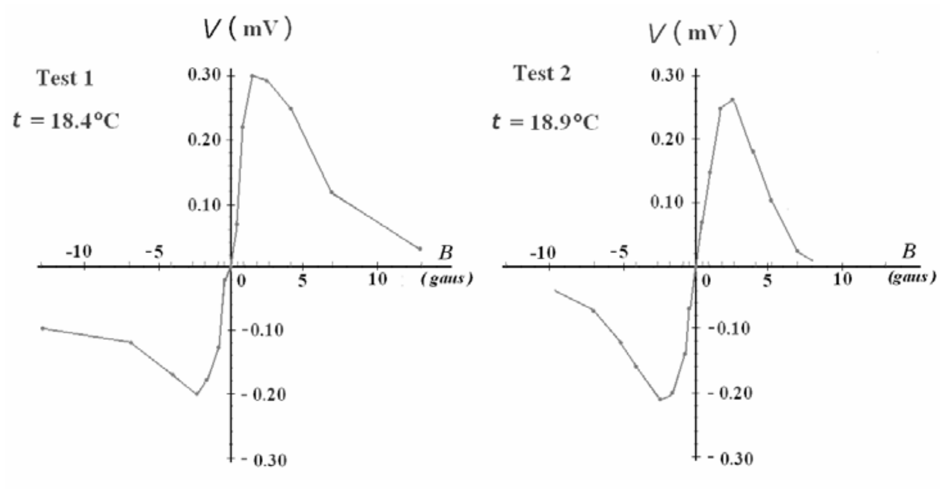
Keithley 6514 may also be used to measure the output voltage of tube FX8-24. Table IV and Table V list the data of voltage ~ magnetic induction relation derived in two tests. The voltage here is the circuit-open voltage of FX8-24. Figure 9 (a) and (b) are the corresponding V ~ B graphs.

d **(cm)**	∞	70	50	40	35	30	25	20
B **(gauss)**	0	0.4	0.9	1.9	2.7	4.2	7.0	13
V_+ **(mV)**	0	0.07	0.22	0.30	0.29	0.25	0.10	0.03
V_- **(mV)**	0	-0.02	-0.13	-0.18	-0.20	-0.17	-0.12	-0.09

Table IV *V ~ B* relation of electron tube FX8-24 (Test 1, $t = 18.4^oC$)

d **(cm)**	∞	70	50	40	35	30	27.5	25
B **(gauss)**	0	0.4	0.9	1.9	2.7	4.2	5.2	7.0
V_+ **(mV)**	0	0.03	0.16	0.25	0.26	0.18	0.10	0.02
V_- **(mV)**	0	-0.07	-0.14	-0.20	-0.21	-0.16	0.12	-0.07

Table V *V ~ B* relation of electron tube FX8-24 (Test 2, $t = 18.9^oC$)



(a) (b)

Fig. 9 *V ~ B* graph*s* of electron tube FX8-24.

The output currents and voltages of the experiment are very weak, but they are macroscopic currents and voltages. For example, the peak value of the output current in Fig. 8(a) is $I_+ = 15.1\times10^{-15}$A, the corresponding number of electrons passed from A to B in each second is N = 15.1×10^{-15}A/1.6×10^{-19} Col = 94,000 electrons/sec. Without any doubt, such a one-direction flow of electrons is a macroscopic direct current (DC). And, in Figure 9 (b), the positive and negative maximum values of the *V ~ B* curve are $V_{+\ max}$ = 0.26 mV and $V_{-\ max}$ = 0.21 mV, respectively, both being explicitly macroscopic voltages.

Such a macroscopic current and macroscopic voltage is totally different from the thermal fluctuation current and voltage (Johnson effect, or thermal noise, similar to Brownian motion) in a metal bar.

A large number of our Maxwell current and voltage elements (Ag-O-C_s pairs) may be connected in parallel to increase the current, and connected in series to increase the voltage, so as to form a much greater electric power. Because of this characteristic, we are more confident that Maxwell's current and voltage are macroscopic ones.

Contrary, Johnson fluctuating currents and voltages are thermal random ones. Their directions alternate ceaselessly and irregularly, without any stable period or frequency. As is well known, they are impossible to be added up to form a greater electric power. They are essentially thermal and random one, microscopic ones.

5. CONCLUSION

In the above experiment, the heat extracted by the electron tube FX8-24 from the ambient air is converted completely into electric energy, without producing any other effect. The event proves clearly that the second law of thermodynamics is not absolutely valid.

The authors maintain: In ordinary thermodynamic processes, as pointed out correctly and profoundly by Clausius, entropy always increases, never deceases; nevertheless, in some extraordinary thermodynamic processes, such as this experiment, entropy does decrease. The two kinds of thermodynamic processes are absolutely different from each other, and they should be referred to as Clausius processes and Non-Clausius processes, respectively.

Thus, after a long, long delay, Maxwell's cherished wish has eventually been realized. Mankind has recognized a rather deeply hidden truth of the nature: Energy is capable of circulating.

Energy is immortal.

ACKNOWLEDGEMENT

The authors are very grateful to Professors Fang Junxin and Hua Zhongyi, Professors Meng Zaoying and Qian Weichang, but for their encouragement and help, we could not have progressed so well. Gu Weijia, an engineer in the Medical Equipment Center of Shanghai Jiao Tong University, and Xu Ping, an engineer of Yi Zheng Electron Tube Factory, both helped much in making the test tubes. We express here our sincere gratefulness to them as well as to all the others who have helped us ardently in this work.

Invited by the prominent American physicist Dr. Marlan O. Scully, one of the authors of this paper went to Salt Lake City in January 2007 to attend the 37^{th} Annual Colloquium on the Physics of Quantum Electronics (37^{th} PQE). He gave a talk in the meeting and discussed the topic with many attendants, including Dr. Scully himself. These discussions are very interesting and beneficial. We express here our respect and gratefulness sincerely to Dr. Scully and his fellows.

REFERENCE

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[2] W. Ehrenberg Maxwell's Demon, *Scientific American*, pp.103-110 (1967)
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APPENDIX

Maxwell's original idea about the being (the demon)

One of the best established facts in thermodynamics is that it is impossible in a system enclosed in an envelope which permit 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 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."

From James Clerk Maxwell *Theory of Heat*, 1871