 doi:10.20944/preprints201607.0028.v5

Realization of Maxwell's Hypothesis

A Heat-Electric Conversion in Contradiction to the Kelvin Statement

Xinyong Fu & Zitao Fu Shanghai Jiao Tong University xyfu@sjtu.edu.cn
February 1, 2019

Key Words
Maxwell's demon magnetic demon entropy decreasing energy circulation

Abstract

In a vacuum tube, two identical and parallel Ag-O-Cs surfaces, A and B, with a work function 0.8eV, ceaselessly emit thermal electrons at room temperature. The thermal electrons are controlled by a static uniform magnetic field (a magnetic demon), and the number of electrons migrate from A to B exceeds the one from B to A (or vice versa). The net migration from A to B quickly results in a charge distribution, with A charged positively and B negatively. A potential difference between A and B emerges, and the tube outputs an electric current and a power to a load (a resistance, e.g.). The ambient air is a single heat reservoir in the experiment, and all the heat extracted by the tube from the air is converted into electric energy without producing other effects. We believe the experiment is in contradiction to the Kelvin statement of the second law.

Experiment Video

We have a video on YouTube showing the main measuring process of the experiment, about 30 minutes: https://www.youtube.com/watch?v=PyrtC2nQ_UU.

1. Fundamental Concept

Let us first imagine an ideal vacuum tube containing a quartz plate, as shown in Fig.1. The upper surface of the quartz plate is coated with two identical and parallel Ag-O-Cs electron emitters, A and B. The work function of Ag-O-Cs is only 0.8eV, hence A and B eject thermal electrons ceaselessly at room temperature (the so called "dark current" in a phototube or a photomultiplier.)

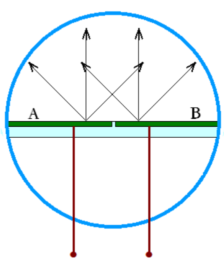

Fig.1 Two identical and parallel thermal electron emitters, A and B, are coated on the surface of a quartz plate in a vacuum tube (a cross section).

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Fig.2 (a) illustrates the motion of the thermal electrons emitted from two symmetric points on A and B when no magnetic field is applied to the tube. The thermal electrons exit from A or B, fly straight forward, hit the glass wall and bounce back, and finally fall into either of the two emitters. There are electrons migrate from A to B and from B to A (A and B like two islands). Because of symmetry, the tendencies of electron migration from A to B and from B to A cancel each other, there is no net electron migration between A and B. Hence, no current outputs to the exterior resistor. [(1)] [(2)]

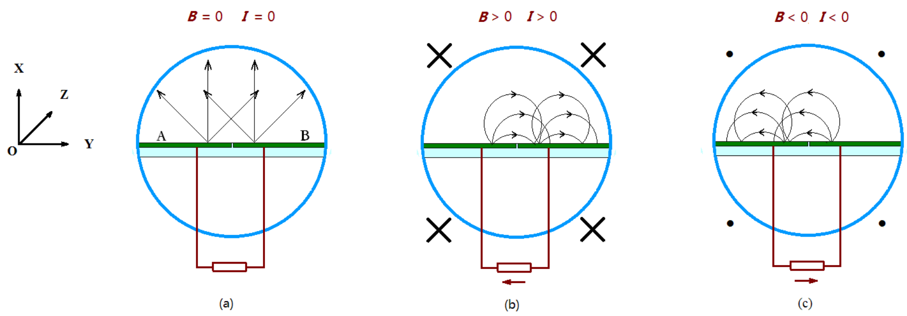

Fig. 2 Thermal electrons' motion with or without a magnetic field

Now, if a static uniform magnetic field is applied to the electron tube in the direction parallel to the tube axis, i.e., the Z-axis, and, firstly, directed into the plane of the figure, as shown in Fig 6(b), all the thermal electrons will fly clockwise along circles of different radii according to their speeds (we omit the description of the thermal electron's Z-component motion),

$$R = \frac{m}{eB} v \qquad (v \text{ is the velocity component perpendicular to the Z-axis})$$

There are numerous various electron trajectories, of different exiting angles, different speeds, and different exiting spots.

Thermal electrons emitted from A may fall back to A, or migrate to B. Thermal electrons emitted from B may fall back to B, or migrate to A. All the trajectories may thus be divided into four groups, and briefly illustrated by the examples in Fig 3.

(1) The first group: A-A A-glass-A

A-A Due to the magnetic field, part of the electrons emitted from A directly(i.e., no collision with the glass wall) fall back to A. Examples, the left part of Fig 3(a) (from E

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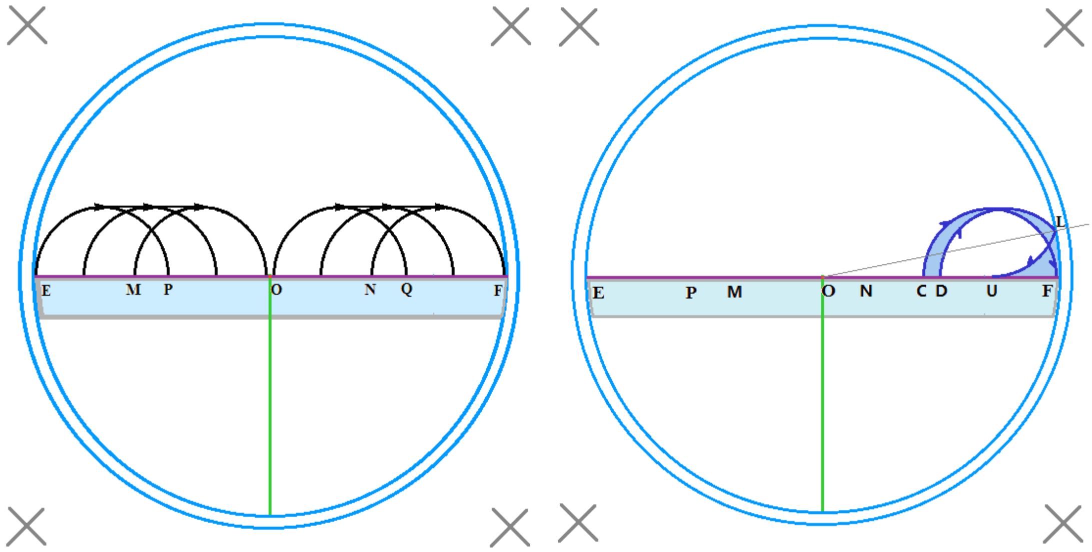
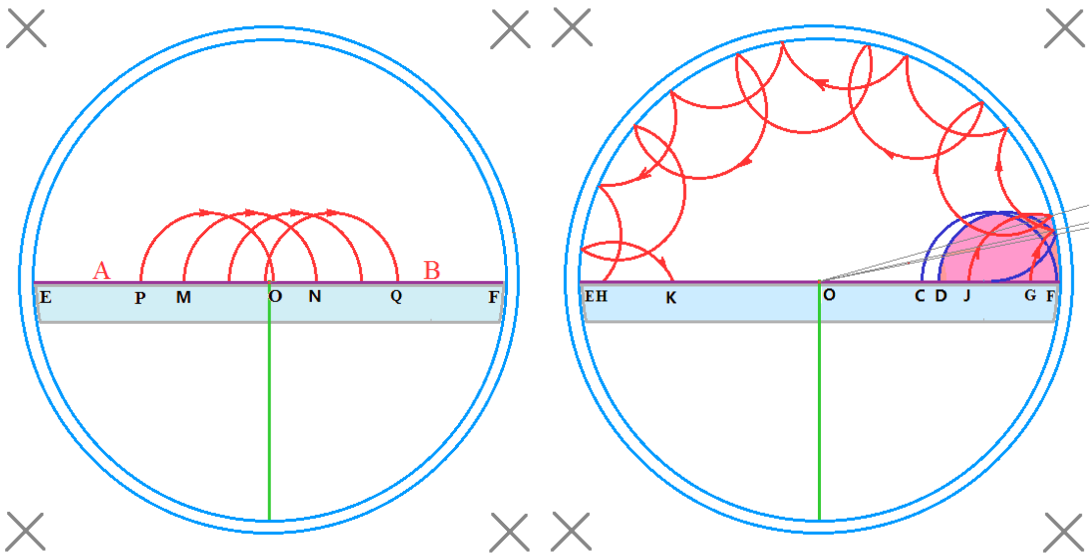
to P, M to O, etc.)



(a) A-A & B-B (b) B-Glass-B

No electron migration between A and B due to the above trajectories.



(c) A-B directly

PO/EO = 40/70 = 0.57

57% of the electrons of (0^o, v_p)

emitted from A migrate to B.

(d) B-Glass-A

DF/OF = 35/70 = 0.50

50% of the electrons of (0^o, v_p)

emitted from B migrate to A.

The contribution of all the electrons of (0^o, v_p) to the output current is

$D_{0^o}(v_p) = \{(\text{A-B directly}) - (\text{B-Glass-A})\}_{\theta=0^o\ v=1v_p} = 0.57 - 0.50 = 0.07.$

Fig 3 Four figures showing all the electron trajectories of $\theta = 0^o$, $v = v_p$, R = 4mm.

A-glass-A Part of the electrons emitted from A hit the glass wall and bounce back to A. Examples, absent in Fig.3 (refer to *The Right Most Problem*[(3)], Fig.4-3-1, page 102).

The trajectories of the first group result in no electron migration between A and B, contribute nothing to the output current.

(2) The second group: B-B B-glass-B

B-B Part of the electrons emitted from B directly fall back to B. Examples, the right part of Fig 3(a) (from O to Q, N to F, etc.)

B-glass-B Part of the electrons emitted from B hit the glass wall and bounce back to B. Examples, Fig 3(b) (from C to F, D to U, etc.)

The trajectories of the second group also result in no electron migration between A and B, also contribute nothing to the output current.

(3) The third group: A-B A-glass-B

A-B Part of the electrons emitted from A directly fall into B. Examples, Fig 3(c) (from P to O, M to N, O to Q, etc.).

A-glass-B Part of the electrons emitted from A hit the glass wall and bounce back into B (migrate from A to B indirectly.) Examples, absent in Fig 3 (refer to *The Right Most Problem*, Fig. 5-6-2, page 136.))

The electrons of the third group migrate from A to B, directly or indirectly, both contribute positively to the output current.

(4) The fourth group: B-glass-A

B-glass-A Part of the electrons emitted from B hit the glass wall and bounce back once or several times, and finally fall into A. Examples, Fig 3 (d) (from G to H, J to K, etc.)

The electrons of the fourth group migrate from B to A, and contribute negatively to the output current.

A strange thing happens here: a part of the electrons emitted from A may directly fall into B, but none of the electrons emitted from B may directly fall into A.

Obviously, in the above discussion, the ways of electron migrations from A to B are of totally different geometrical patterns from the ones from B to A, that leads to a net electron migration from A to B.

Similarly, for the whole tube, according to an overall survey of ours on the various trajectories of electrons of different exiting angles, different speeds and exiting spots[(3)], the over all general electron migration from A to B exceeds the one from B to A, as intuitively showed in Fig.2(a).

The net electron migration from A to B rapidly results in a charge distribution on A and B, with A charged positively and B charged negatively. A potential difference between A and B emerges, and a stable direct current (and a power) is transferred to the exterior resistor (or a reversible battery).

If the intensity of the magnetic field is different, all the trajectories and hence the output current will also be different. By adjusting the intensity of the magnetic field, we may find a maximum output current from the tube at a given temperature.

If the direction of the magnetic field is opposite, as shown in Fig 6(c), all the electron trajectories will be changed symmetrically (mirror reflection symmetry, left-right symmetry), and the direction of the output current will be reversed. This is a simple and easy operation, but very significant in our experiment.

A problem rises here: Where does the output electric power come from? Or, what is the origin of the obtained electric energy?

It is the heat extracted by the electron tube from the ambient air. We explain this heat-electric conversion process as follows.

In Fig. 2(b), as A is charged positively and B charged negatively, a static electric field between them (mainly in the region above the border between A and B) is established immediately. The direction of the static electric field is to resist the succeeding thermal electrons to fly from A to B.

As shown in Fig.4, at the middle of the upper part in the tube, there is an electron with a velocity ***v*** flying rightward, and the force exerted on it by the static electric field, ***F***, is left-ward, so the electron is decelerated by the force. Nevertheless, a certain part of the electrons emitted from A (especially the faster ones), relying on their kinetic

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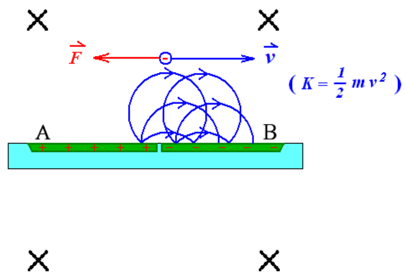


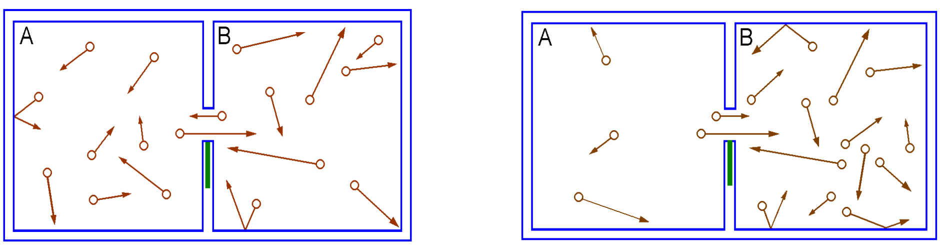
Fig.4, $\vec{v}$ **is** rightward, $\vec{F}$ is leftward; $\vec{F}$ resists the electron's flight from A to B. The kinetic energy of the faster electrons emitted by A enables them to overcome the prevention of $\vec{F}$ and fly across the gap to fall on B.

energy, can overcome the resistance of the static electric field and travel across the border to fall into B. On arriving at B, each electron has obtained an amount of electric potential energy, in exchange with the loss 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 cool down (maybe very slightly), witch is compensated automatically by the heat the tube extracts from the ambient air.

In practical experiment, we can see clearly and vividly (with an electrometer) an electric current and power continuously flow out from the tube to the resistor. Beyond any doubt, the tube is losing its internal energy. So, it must cool down (maybe very slightly), and hence automatically extracts heat from the ambient air to compensate the loss of its internal energy.

In the above process, the electron tube extracts heat from a single-temperature heat reservoir (the ambient air) and all the heat is converted into electric energy without producing other effect. We maintain that the process is in contradiction to the Kelvin statement of the second law of thermodynamics.

As is well known, in 1871, to challenge **the absoluteness of the second law of thermodynamics**, James Clerk Maxwell came up with a famous hypothesis — Maxwell's demon. According to Maxwell[4], Ehrenburg [5], et al, a demon may work in either of the two following modes.



(a) In the first mode, the demon produces an inequality in temperature between A and B.

(b) In the second mode, the demon produces an inequality in pressure between A and B.

Fig. 5 Maxwell's demon interferes with the random thermal motion of gas molecules*

 doi:10.20944/preprints201607.0028.v5

In the first mode, as shown in Fig.5 (a), the demon allows only the swifter molecules to pass through a small doorway and move from A to B, and the slower ones to pass through the doorway from B to A, causing eventually a difference in temperature between A and B.

In the second mode, as shown in Fig.5 (b), the demon only allows the molecules to pass through the doorway from A to B (no electrons from B to A), causing eventually a difference in pressure between A and B.

In our present design, the **magnetic field** functions as a **demon**, working in the second mode: It allows thermal electrons to flight from A to B (actually, there is just a net flight from A to B: the number of electrons migrate from A to B exceeds the one from B to A), causing a difference in electric potential between A and B, and an output current.

As is well known, **applying a static magnetic field in such a way does not need expenditure of work**.

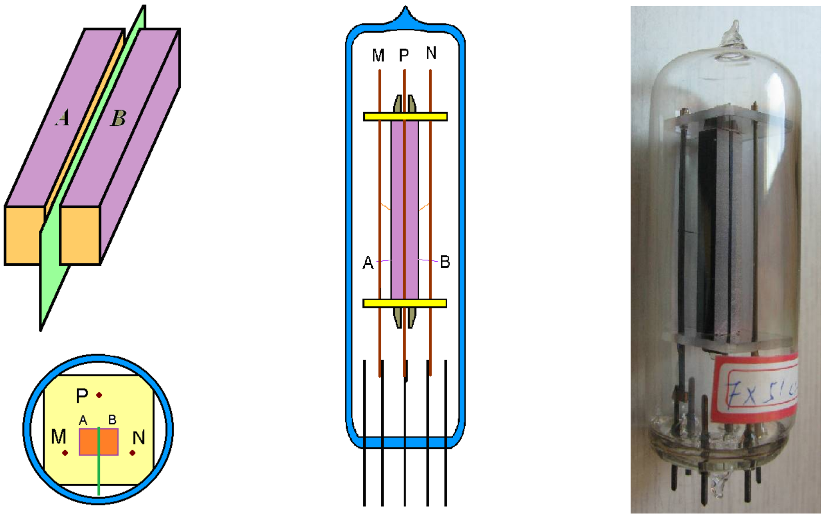
The following is an actual experiment we performed in recent years (1998 ~ 2018), showing how thermal electrons in a vacuum tube move in a magnetic field, causing an electric potential difference, a current, and an output power.

2. The Electron Tube Used in our Experiment

We choose Ag-O-Cs as the thermal electron emitters. Ag-O-Cs has the lowest work function among all the known thermal electron materials, about 0.8 eV, and is currently optimum in maximizing **thermal electron emission at room temperature**[6]. We adopted this material and let the tube and the closed circuit shown in Fig.2 to operate under a uniform room temperature, so as to avoid disturbance of Seebeck effect, etc.

Ag-O-Cs cathodes are in nowadays widely used in photoelectric tubes and photomultipliers, and their emission of thermal electrons is usually referred to as **dark current**. Ordinary users certainly prefer to Ag-O-Cs cathodes of weak-dark-current. Manufacturers adjust technology and craft to produce Ag-O-Cs cathodes with lower-dark-current, usually kept in the range of 10^{-11} to 10^{-14} A/cm^2. In our experiment, on the contrary, we hope to adopt Ag-O-Cs emitters of strong-dark-current. We adjusted the manufacturing technology and craft repeatedly over the past 20 years and succeeded in producing Ag-O-Cs emitters with a dark current in the range of 10^{-7} to 10^{-10} A/cm^2 [7].

The electron tube used in our experiment was a FX type tube (FX12-51), whose structure is shown in Fig.6. It is similar to but has some difference with the above



(a) Emitters A and B, a mica sheet, rods P, M, N, supports.

(b) Sketch of the structure of electron tube FX12-51

(c) A photograph of FX12-51

Fig. 6 Electron tube FX12-51 (i.e., FX51 (12))

discussed ideal tube of Fig.1. The envelope was of glass. A and B were two identical and parallel Ag-O-Cs thermal electron emitters on the surfaces of two copper bars. Between the copper bars there was a mica sheet, keeping A and B mutually insulated. Under the copper bars, the mica sheet stretched out to reach the bottom of the glass wall, so as to prevent electrons cycling back from B to A in the space of the lower part of the tube. M, N and P were three molybdenum supporting rods. M and N were also used as electrical leads connecting A or B to a resistor outside the tube. P was 6mm above the gap, and was used as a temporary anode in the tube manufacture process to oxidize the silver films on A and B by oxygen-discharge. After the manufacture of the tube, P was again used as a temporary anode to measure the dark current of the two emitters to check the quality of the tube. The typical dark current of each emitter of the FX12 type tubes was 300 ~ 300,000 pA.

Finally, the leakage resistance between A and B should be at least greater than 100MΩ. The value of the leakage resistance depends chiefly on the amount of cesium input during the manufacture.

3. The Magnetic Field

The magnetic field used to deflect the flights of the thermal electrons was produced by a 150 mm × 100 mm × 25 mm magnet (Ceramic 8, MMPA Standard). Fig. 7 shows the magnetic induction intensity B at point O on the axis of the magnet, a distance d apart. The $B \sim d$ relation was measured in advance by a tesla-meter, and the results are

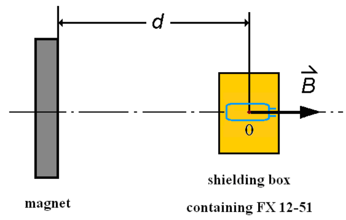


Fig. 7 The magnetic field at point O produced by the magnet used in the experiment

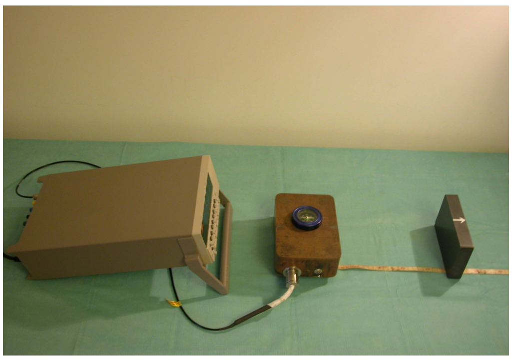
d (cm)	60	50	40	35	30	25	20	15	10
$\boldsymbol{B}_\uparrow$ (N) (gaus)	0.3	1.1	2.1	2.9	4.4	7.2	13.1	25.5	59.7
$\boldsymbol{B}_\downarrow$ (S) (gaus)	-0.8	-0.7	-1.6	-2.5	-4.0	-6.7	-12.7	-24.9	-58.8
$\boldsymbol{B}_{(abs,\ mean)}$	0.6	0.9	1.9	2.7	4.2	7.0	13	25	60

Table 1 $B \sim d$ relation of the magnet.

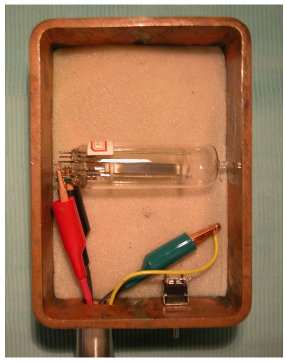
listed in Table 1. In our experiment of thermo-electric conversion, the electron tube was put at point O, within a copper shielding box, with the tube axis parallel to the magnetic field.

4. The Experiment

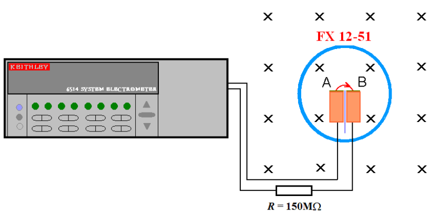
Fig.8(a) is a photograph of the set up of the experiment, from left to right: a Keithley 6514 electrometer (highest current sensitivity 1×10^{-16}A = 0.1fA), a copper shielding box (containing electron tube FX12-51), and a magnet. Fig.8(b) shows how the electron tube lay within the copper shielding box. The anticipated output current caused by a



(a) a Keithley 6514, a shielding box and a magnet



(b) How the tube lay within the copper box



(c) The current measuring circuit

Fig. 8 Set up of the experiment

static magnetic field was transferred to the electrometer through a special accessory cable. Fig.8(c) is the circuit diagram.

First, chose a room temperature, which should be finely uniform and stable. Switch on the electrometer and wait a period. Now, the magnet was far away from the tube, $d \approx \infty$, $B \approx 0$, the tube should produce no output current, $I \approx 0$. However, actually, there was usually a background current. The closed measuring circuit was under the same room temperature, e.g. 20ºC, nevertheless, small differences in temperature along the closed circuit still exist, e.g., 0.1ºC ~ 1.0ºC (at least, 0.01ºC ~ 0.10ºC). Hence there was a current chiefly caused by Seeback effect in the circuit. This background current changed from day to day (even from hour to hour). However, if it was changing, the change was usually slow. Sometimes, it might keep stable for an hour, even longer. Fortunately, in most cases, the background current and its change were much smaller than the output current produced by the magnetic field. The signal to noise ratio is fine.

Of course, the weaker the background current, the better it was for our experiment.

The influence of the earth magnetic field to this experiment was small, we just neglected it.

We then applied a weak positive magnetic field to the tube (as shown in Fig.2(b), and denoted it by $B_{\uparrow}$, for example, d = 60cm, and $B_{\uparrow}$ = 0.6 gauss. The compass placed on the top of the copper box demonstrated the direction of the magnetic field, which should be adjusted (easily) to be parallel to the axis of the tube in all the steps of the whole measuring process.

We observed that the tube put out at that time a weak but stable current.

The magnetic induction intensity of the field was then increased in steps by reducing the distance d of the tube from the magnet. **For each step, we let the magnet remain stationary for a period of at least one or two minutes, so as to exclude disturbance of Faraday's electromagnetic induction, etc**. We found that for each step, the output currents first changed quickly as the magnet arrived at a new place, and soon, it gradually reached **a stable value**. We might keep the stable value unchanged as long as we wish, just by keeping the magnet stationary. As the experiment going on in steps, we found, from the beginning of $B_{\uparrow} \approx 0$ and $I \approx 0$, as $B_{\uparrow}$ increased step by step, the output current I (I **represented the stable values of each step**) followed, until I reached a

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maximum value. After that, I decreased as the magnetic field increased further. This drop down of the output current accorded with our expectation: after the maximum, as the magnetic field became stronger and stronger, the radii of thermal electrons became smaller and smaller, causing the output current to progressively reduce.

(See the experiment video, https://www.youtube.com/watch?v=PyrtC2nQ_UU).

The magnet was then returned to the position of d = 60cm and then rotated through 180°. The direction of the magnetic field in the copper shielding box consequently reversed. The magnetic field was now negative and denoted by $B_{\downarrow}$. As we expected, the direction of the output current also reversed. We then again reduced the distance d in steps to increase the intensity of the magnetic field $B_{\downarrow}$. The stable negative output current I for each step first increased, and then decreased after reaching a maximum value. The situation was similar in pattern to that with the positive magnetic field.

Further experiment showed that, in each step, provided the magnetic field remained stable (i.e., the magnet kept stationary), the output current I would remain stable, with a period of stability possible for as long as we wished, several minutes, several hours, even several days.

We call the output current Maxwell's current. In general, the Maxwell's current for a given FX tube depends on two factors, the temperature T and the magnetic induction intensity B.

d (cm)	∞	60	50	45	40	37.5	35	30	25	20	15
B (gauss)	0	0.6	1.0	1.4	2.0	2.3	2.7	4.2	7.0	13	25
$I(fA)$ ($B\uparrow$)	4.1	9	17	25	34	39	36	26	17	8	2.7
$I(fA)$ ($B\downarrow$)	4.1	-13	-17	-20	-24	-27	-19	-15	-14	-13	-12

Table 2 $I \sim B$ relation of FX12-51 at t = 10°C. Background current I_o = 4.1fA.

d (cm)	∞	60	50	45	40	35	30	25	20	15
B (gauss)	0	0.6	1.0	1.4	2.0	2.7	4.2	7.0	13	25
$I(fA)$ ($B\uparrow$)	3.0	45	85	117	165	182	152	127	104	94
$I(fA)$ ($B\downarrow$)	3.0	-53	-72	-78	-59	-43	-26	-22	-20	-17

Table 3 $I \sim B$ relation of FX12-51 at t = 22°C. Background current I_o = 3.0fA.

d (cm)	∞	60	50	45	40	35	30	25	20	15
B (gauss)	0	0.6	1.0	1.4	2.0	2.7	4.2	7.0	13	25
$I(fA)$ ($B\uparrow$)	7.7	290	560	1360	1530	1650	1270	790	440	250
$I(fA)$ ($B\downarrow$)	7.7	-520	-670	-690	-670	-270	-130	-122	-117	-115

Table 4 $I \sim B$ relation of FX12-51at t = 32°C. Background current I_o = 7.7fA.

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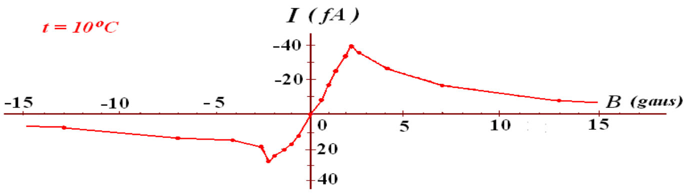
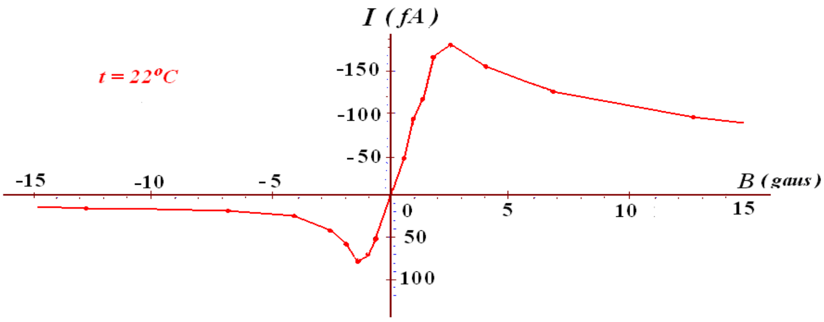
$$I = I(B, T).$$

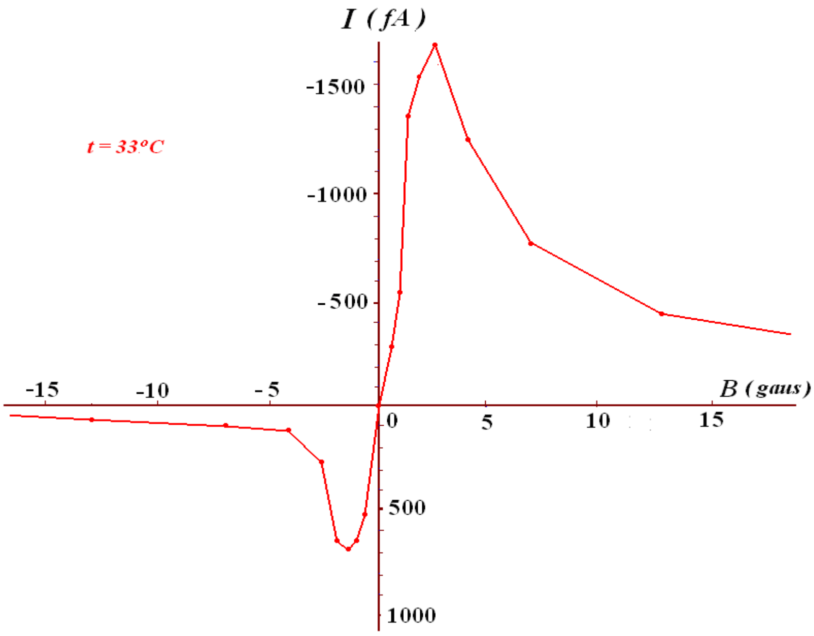
Tables 2, 3 and 4 list the data from three tests at three different temperatures, 10ºC, 22ºC and 33ºC. Fig.9 (a)(b)(c) are the correspondent $I \sim B$ graphs.



(a)



(b)



(c)

Fig 9 The $I \sim B$ graphs of electron tube FX12-51 at three different temperatures.

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From t = 10ºC to t = 33ºC (i.e., from 283K to 310K)，the temperature rose only 23ºC, nevertheless, the output current changed from 40fA to 1600fA, 40 times! This can be finely explained by Richardson's formula: thermal electron emission rises very rapidly as the temperature rises,

$$J = AT^2 e^{-\frac{W}{kT}}.$$

In addition to the output current, the electrometer together with the circuit was also used to measure the output voltage of the electron tube, as shown in Fig.10. The highest voltage sensitivity of Keithley 6514 is 1×10^{-5}V = 0.01mV. The voltage here is actually the open-circuit voltage of the tube, or the electric motive force (EMF) of the tube. This output voltage chiefly depends on the average kinetic energy of the thermal electrons of the emitters, in other words, depends on the temperature.

We noted that the value of the output voltage might be affected by the current leakage between the two emitters.

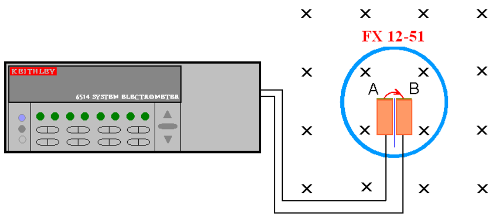

Fig.10 The voltage or e.m.f. measuring circuit.

The following were the output voltages we measured with electron tube FX12-51 in a test at room temperature of T = 25ºC (298K):

Background voltage $B\approx 0$, V_o = 5.6 mV.

The maximum of the output voltage when a magnetic field was applied to the tube was also stable provided the magnet kept stationary. Each output voltage was measured for four times,

$B\uparrow \approx$ 3.5 gauss V = 20 21 20 21 mV,

$B\downarrow \approx$ 3.5 gauss V = -16 -18 -16 -17 mV。

According to Boltzmann's law of equi-partition of energy, the average kinetic energy of thermal electrons at 25ºC (298K) is

$$\bar{\varepsilon} = \frac{3}{2}kT = \frac{3}{2} \times 1.38 \times 10^{-23} \times 298\,\mathrm{J} = 0.0385\mathrm{eV} = 38.5\mathrm{emV}.$$

In expression $38.5emV$, the factor 38.5mV is of the same magnitude order with the output voltage we have derived in our experiment（≈ 20mV). Therefore, we thought, the output voltages were surely resulted from the conversion of part of the kinetic energy of the thermal electrons.

Both the output current and output voltage of our experiment were very weak, nevertheless, they were no doubt DC current and DC voltage, both being macroscopic physical quantities. A large number of such Ag-O-C_s pairs could be connected in parallel to increase the output current, and connected in series to increase the output voltage, so as to build up a much greater electric power output.

5. Conclusions

In the above experiment, the heat extracted by electron tube FX12-51 from the ambient air converted completely into electric energy without producing other effect. The process proves that the second law of thermodynamics is **not absolutely valid**, just as Maxwell and Planck predicted more than 100 years ago[4] [8].

The authors maintain: in ordinary thermodynamic processes, just as Clausius and Kelvin pointed out correctly, entropy always increases, never decreases. Nevertheless, in some specific or extraordinary thermodynamic processes, such as our thermal electron experiment, entropy does decrease.

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