

A Challenge to the Second Law of Thermodynamics

An Experiment of Heat-Electric Conversion in Conflict with the Kelvin Statement



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Useful energy and useless energy

We now use electric energy everyday.

1 joule electric energy, as we use it, changes to **1 joule waste heat** and scatters to the ambient air.

Electric energy is **useful energy**, that means, it can be used to do work.

Waste heat is **useless energy**, that means, it cannot be used to do work.

The second law of thermodynamics

The ubiquitous second law of thermodynamics implies:

All the processes from useful energy to useless energy are irreversible.

Most physicists are well convinced that the second law is correct, without any doubt. **They believe that it will never be overthrown.**

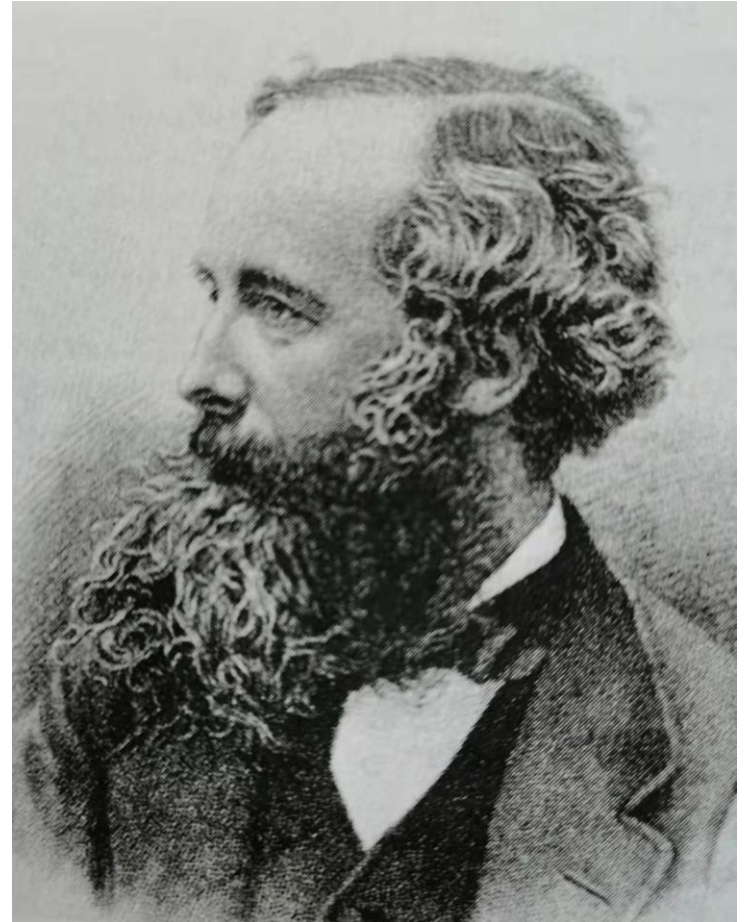
However, in the history of physics, there were a few people, who felt that **the second law was a strange and peculiar theory** in physics. **They doubted that it was absolutely valid.**

Among them, the most famous one was Maxwell.

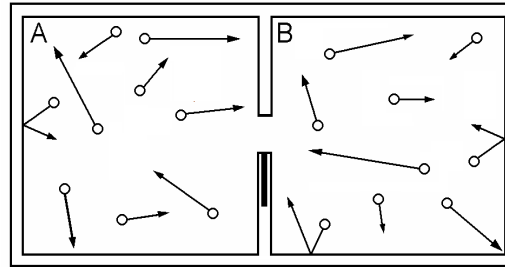
From 1867 to 1871, Maxwell investigated the problem continuously. He conceived **an intellectual being (Maxwell's demon)** who may be able to make use of the waste heat to do work again.

James Clerk Maxwell

1831 – 1879

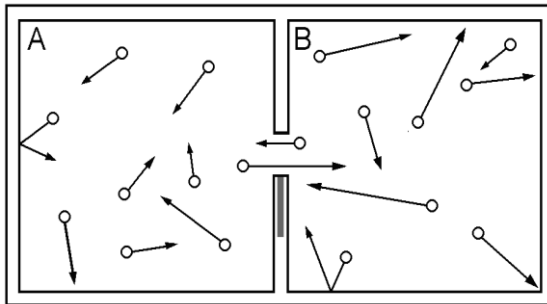


How Maxwell's demon works

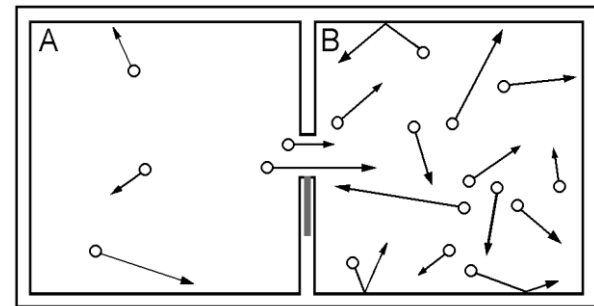


A vessel of air of two portions, A and B: Initially, the air in the vessel is **in a thermal equilibrium state**.

The demon has two work modes.



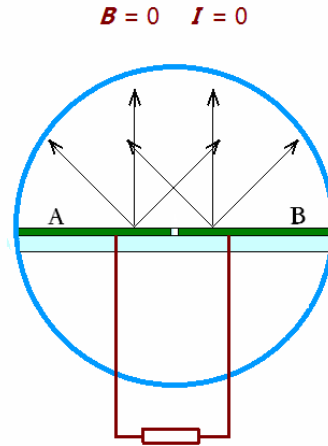
a temperature demon



a pressure demon

In the past 151 years, many people have tried to find such and such a demon. However, so far, they all failed.

We think, we have found a real demon.
— It is a magnetic demon.



The above figure shows a vacuum tube containing two identical and parallel **Ag-O-Cs (silver-oxygen-caesium) electron emitters, A and B.**

Ag-O-Cs is a **photoelectric cathode material** widely used in some photoelectric tubes, photomultipliers, and various night vision devices.

Its work function is only 0.8eV, the least one. **It can eject thermal electrons at room temperature**, usually referred to as **dark current**.

The users of photoelectric tubes etc. are fond of Ag-O-Cs emitters of high **photoelectric sensitivity**.

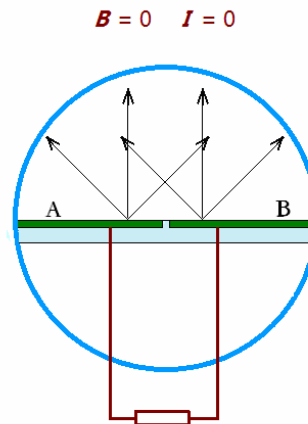
Meanwhile, they prefer to use Ag-O-Cs emitters of **weak dark current**, usually being kept in a range of current density **from 10^{-11} to 10^{-14} A/cm⁻²**.

We, on the contrary, prefer to use Ag-O-Cs emitters of **strong dark current**.

After years of efforts, we have built Ag-O-Cs emitters (by adding a little more cesium) with a dark current density ranging **from 10^{-7} to 10^{-11} A/cm⁻²**.

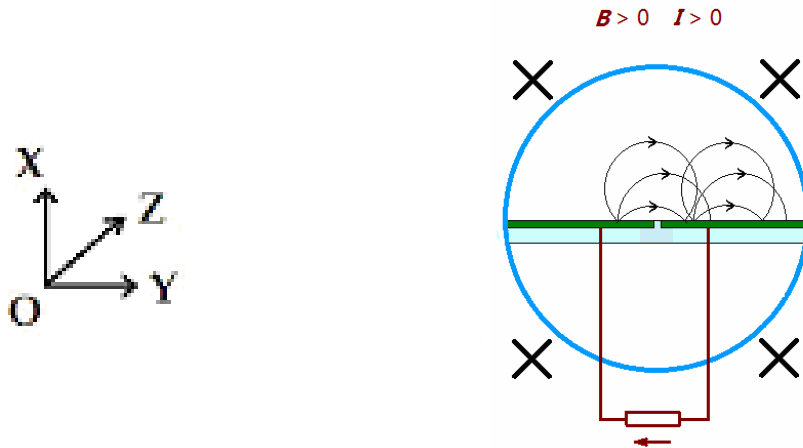
How the magnetic demon works

First, when there is no magnetic field applied to the tube, the thermal electrons eject from A or B, fly straight forward, hit the glass tube wall, bounce back, and fall into A or B. **They move ceaselessly and randomly. Their motions are isotropic.**



There are some electron exchanges between A and B. However, as the motions are isotropic, **the number of electron migrations from A to B is equal to the one from B to A.** The two tendencies cancel each other.

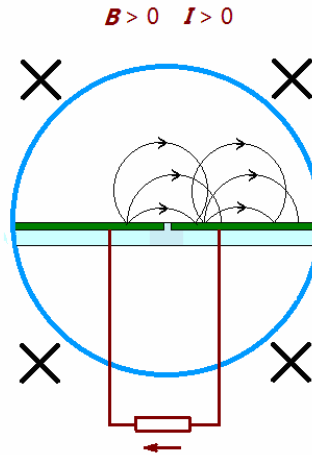
Now, if a static uniform magnetic field entering the drawing is applied to the tube, all the electrons fly clockwise along circles with different radii r according to their component speed u .



$$u = \sqrt{v_x^2 + v_y^2}$$

$$r = \frac{m}{eB} u$$

The left-right symmetry of the electrons' motion is now partly destroyed by the magnetic field, **the number of electrons move from A to B exceeds the one from B to A**. That means, **there is a slight net electron migration from A to B** due to asymmetry.



Thus, emitter A, losing electrons, becomes charged positively. Emitter B, receiving electrons, becomes charged negatively.

A potential difference between A and B emerges, producing a current in the closed circuit. (**The magnetic demon is a potential demon.**)

The current can do work on an external load, e.g., a resistor, or a storage battery.

We use a permanent magnet to provide the static uniform magnetic field. A permanent magnet used this way entails no work.

In our tests, the output current can remain persistent for a long duration, **provided the magnet keeps stationary.**

In our real experiments, the output current have been persistent for 30 seconds, 3 minutes, 3 hours, and so on, **as long as we wish.**

The ceaseless output of electric energy reduces the internal energy of the tube.

Hence, the electron tube cools down, slightly.

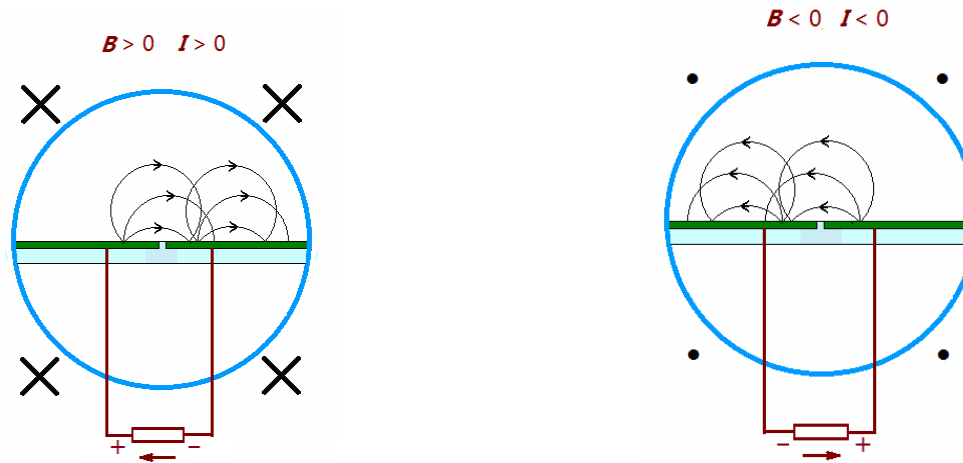
The slightly cooled tube spontaneously extracts heat from ambient air to compensate its output of electric energy.

Thus, we see:

1 joule waste heat is possible to convert back to 1 joule electric energy again!

This is an explicit challenge to the Kelvin-Planck statement of the second law of thermodynamics.

If the magnetic field is in the opposite direction, leaving out the drawing, the direction of the current reverses.

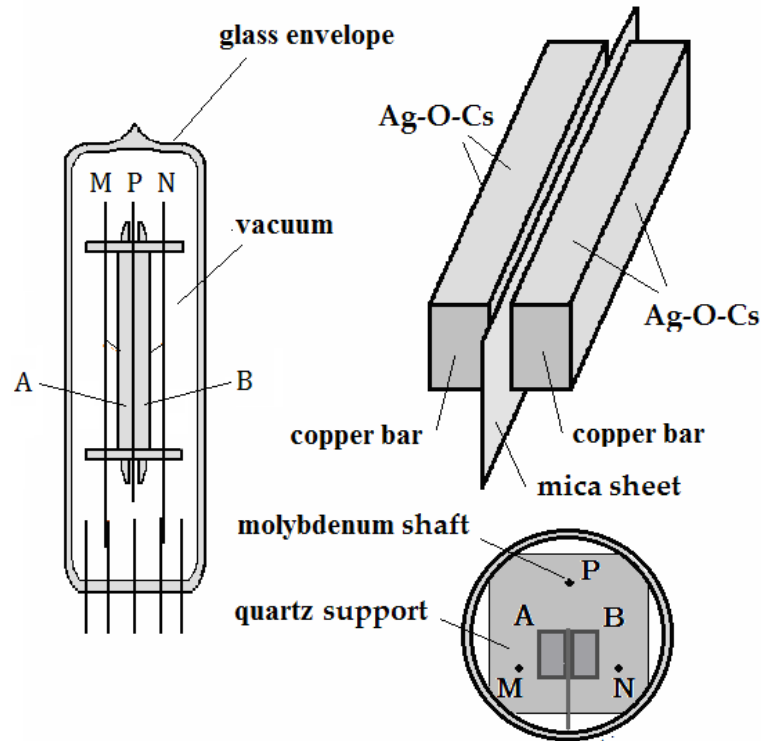


An actual electron tube — the FX type tube



The envelope of the vacuum tube is made of glass. Two identical and parallel Ag-O-Cs thermal electron emitters are settled in.

Structure of the FX type electron tube



The geometry of the FX type tube is similar to the ideal tube in our preceding discussion.

The FX type electron tube lying in a copper shielding box



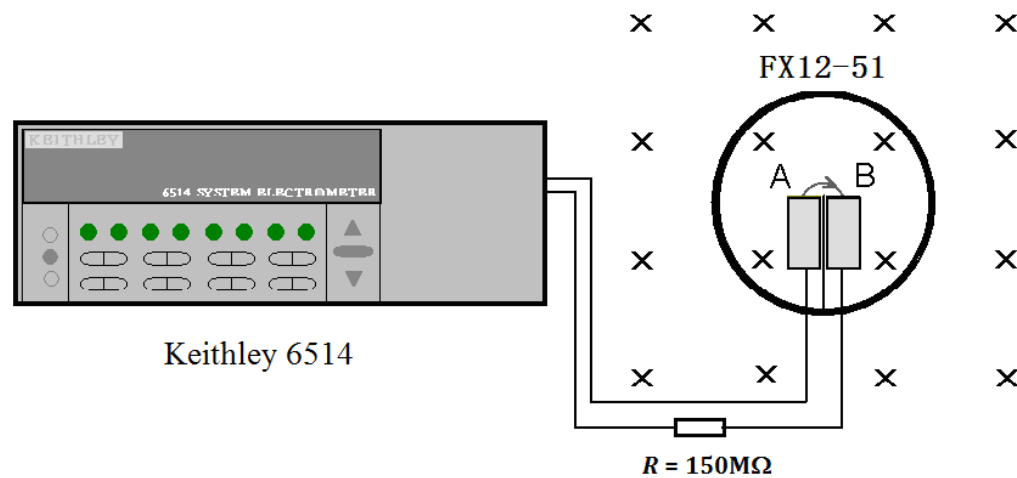
Within the copper box, there are an FX type tube, a $150\text{M}\Omega$ resistor (as a load), two alligator clips leading the circuit to the Keithley 6514, an electrometer (measuring the current in the circuit).

The set up of the experiment



From left to right: An electrometer Keithley 6514 (measuring the current), a copper shielding box containing the FX type electron tube, and a magnet.

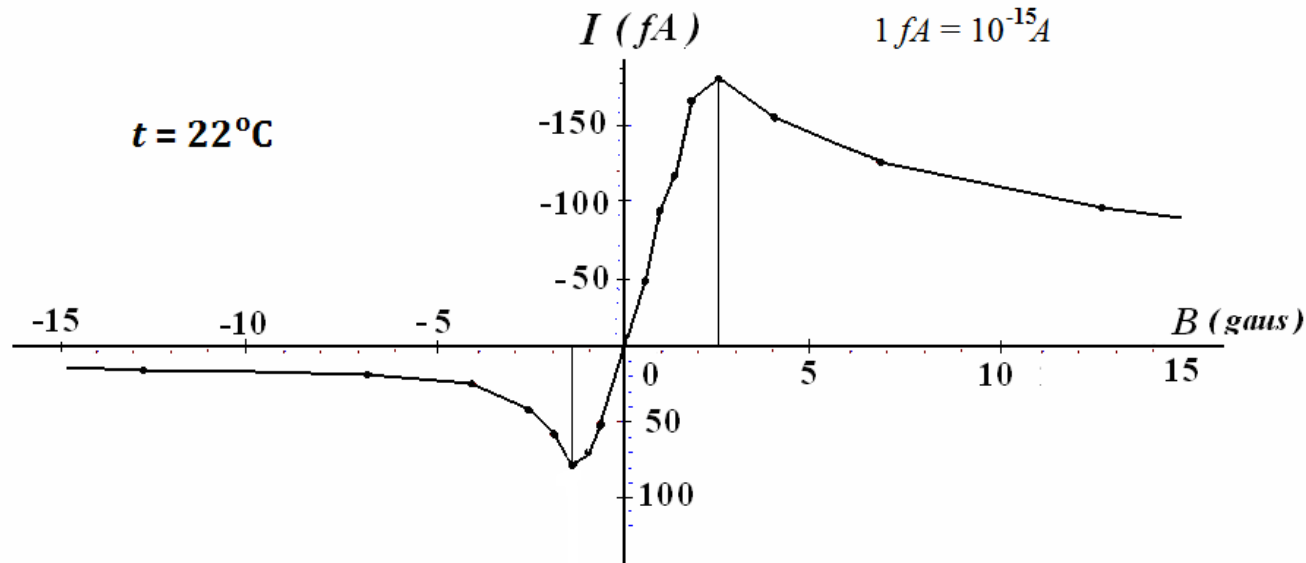
Circuit diagram of the experiment



The whole circuit is at a uniform room temperature, e.g., 20°C.

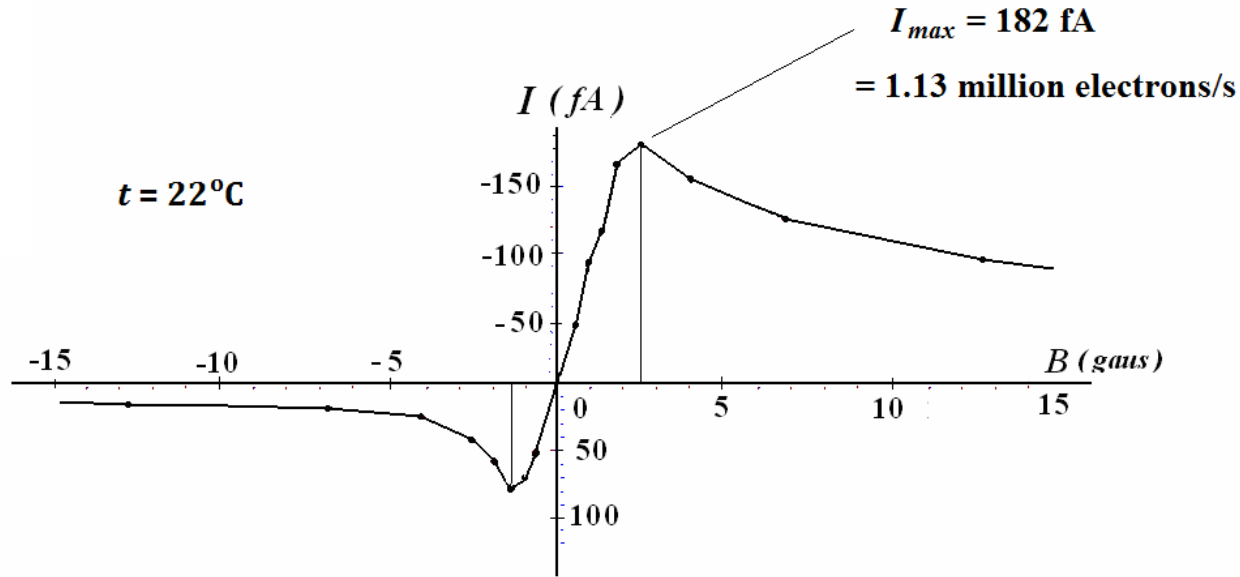
I vs. B graph

The I vs. B graph of one of our experiments with electron tube FX12-51



The graph should be central symmetric. However, the actually graph is not perfectly symmetric. The deviation is mainly because of the work functions of the two emitters are slightly different, which is formed during the manufacture process.

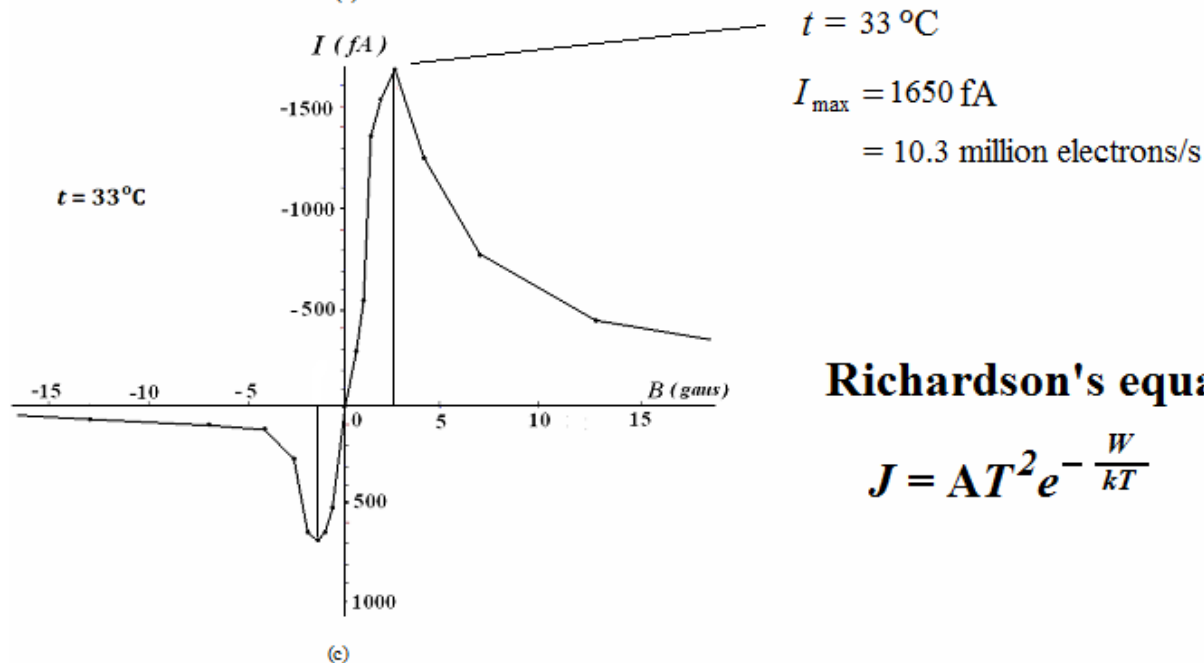
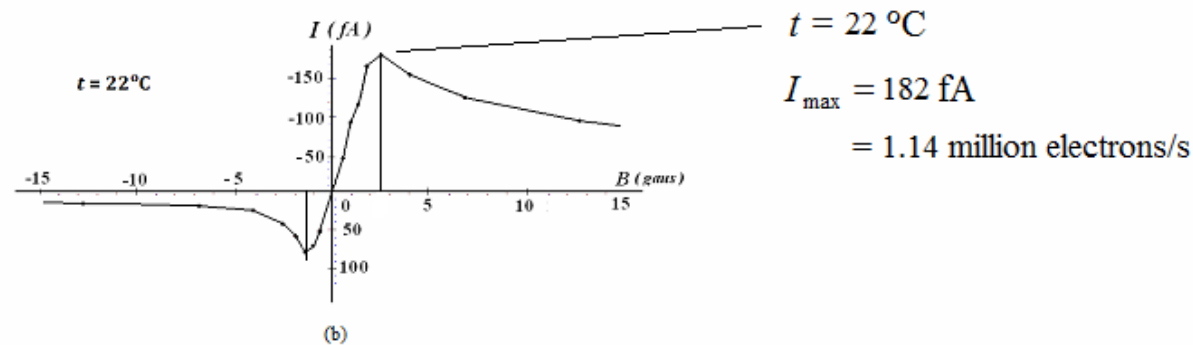
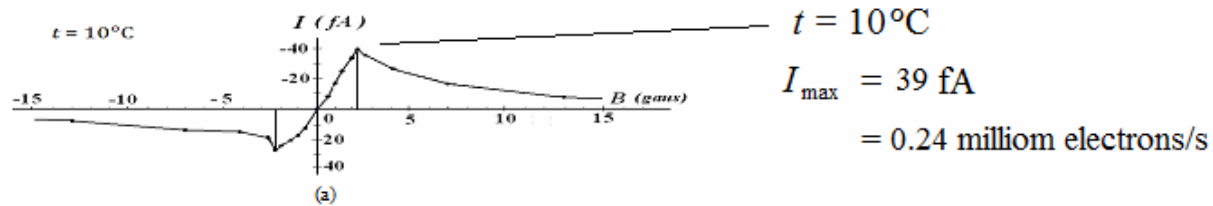
The maximum current in the above I vs. B graph



In each second, 1.13 million electrons migrate from emitter A to emitter B.

Oh, our magnetic demon is really an excellent demon!

Experiments at three different temperatures



Richardson's equation

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

Conclusion

In the above experiments, the heat extracted by the electron tube from a single temperature reservoir (the ambient air) converted completely into work (electric energy) without producing other effect.

The experiments were a sharp challenge to the Kelvin-Planck statement of the second law of thermodynamics.

(Post Script)

The Natural Philosophy for Thermodynamics

Energy is **the vital force of the Nature**.

It has two major attributes.

The first attribute of energy is its quantity.

The quantity of energy keeps constant in any physical process, it can neither increase nor decrease.

It can neither be generated from empty, nor be eliminated into nothing at all.

The first attribute exists within energy itself, never leave, for ever.

So, beyond doubt, the first attribute of energy is an intrinsic attribute.

The second attribute of energy is its capability to do work.

Traditionally, **according to the second law of thermodynamics**, once some useful energy is used to do work, it changes to useless energy. The corresponding second attribute, i.e., the capability to do work, is destroyed, and soon eliminated into nothing at all (when it reaches the vast cosmic space in the form of thermal radiation.)

The second attribute no longer exists.

And, it can never be restored.

So, the second attribute of energy seems not an intrinsic one.

Nevertheless, in Maxwell's idea, the second attribute of energy is also intrinsic.

Energy is **the vital force** of the Nature. It should neither be destroyed, nor be eliminated, in quantity, and in quality as well.

Maxwell conceived, when some useful energy changes to waste heat, **its second attribute still exists, albeit, in some latent state.**

The second attribute **falls asleep.**

Under some proper condition, **it can wake up.**

Our two experiment videos demonstrate **two such waking up processes, intuitively and vividly!**

Like the mass of matter, energy is immortal, both in quantity and in quality.

Energy should be possible to be used to do work repeatedly.

This is the core of Maxwell's thought about the demon.