A POSSIBLE FLAW
IN THE SECOND LAW OF THERMODYNAMICS

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A B S T R A C T

The general theory supported by various computer simulations predicts the spontaneous generation of an electric current whenever a stationary, but strongly inhomogeneous magnetic field is applied to low-density equilibrium plasma. An experiment has been performed with equilibrium plasma consisting of quasi-free electrons at a uniform temperature of 460 K, influenced by a stationary torsic magnetic field. The measured current closely accords with the theoretically predicted current. The following paper demonstrates that the very existence of this current may violate the Second Law of Thermodynamics.

1. I N T R O D U C T I O N

Detailed computer simulations of a model of a real physical system have predicted the spontaneous generation of an electric current in low-density equilibrium plasma whenever charged particles in plasma are influenced by the magnetic field of a stationary straight-line current [ref. 1]. It is interesting that this effect takes place even when plasma is kept in a strict thermodynamic equilibrium with its surroundings. The value of the newly created current is negligible unless several conditions (discussed later) are fulfilled. General theory (which is also presented in the discussion) hints that any inhomogeneous magnetic field can produce this current. Another interesting example presented here has been examined by three different methods of approach : (A) mathematical analysis, (B) computer simulation, and (C) laboratory experimentation.

The essential parts of the physical system are shown in Fig.1. Plasma is enclosed in a tube of the same temperature and is in thermodynamic equilibrium (TE), to avoid temperature gradients or any other "forces" in the Onsager sense. The inner surface of the container is divided into two mutually symmetric parts made of an electrically conductive material completely separated by an insulating gap. These are electrodes which lead the current generated in plasma to a measuring instrument or some other consumer. The magnetic field is established by a stationary electric current I curculating along a coil shaped in the form of a double helix with pitch p. The electrodes are also helically shaped. The insulating gap between the two electrodes is placed for its entire length exactly under the coil line. Thus, the magnetic field density vector $\boldsymbol{B}$ travels from H to G everywhere inside the tube.

The plasma consists of a low-density, non-degenerate electron gas produced by thermionic emission from both electrodes. The electron density is very low ($n = 3\cdot10^5 \ldots 5\cdot10^7$ particles/cm^3). Accordingly, the interactions among individual electrons are practically absent within the length of the vacuum tube (approx. 10 cm). But, because plasma consists of negative particles only, electrons still sense the charge of the whole plasma cloud.

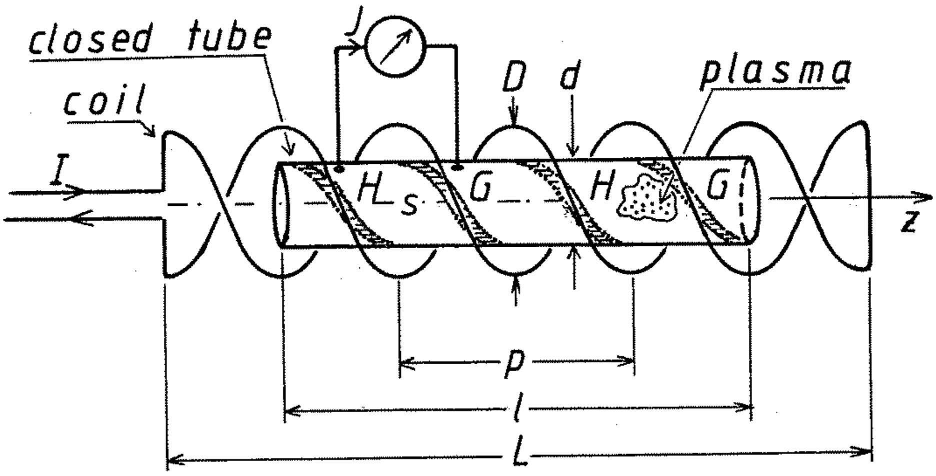

Fig. 1. Geometry of arrangement. Negative and positive electrodes are marked by G and H, respectively.

2. THEORY

The following model has been assumed : Electrons evaporate uniformly from the inner surface of the container, with initial velocities corresponding with the isotropic Boltzmann distribution. (Because of low plasma density and weak magnetic fields, the classical, non-quantum approach is a good approximation.) From then on, only the Lorentz force acts upon a chosen electron, with mass *m* and charge *e*, bending its trajectory, until the electron collides with the wall again:

$$\boldsymbol{r}'' = \frac{e}{m} \cdot (\boldsymbol{E} + \boldsymbol{r}' \times \boldsymbol{B}) \qquad (1)$$

Here, $\boldsymbol{r}$ is the position vector, $\boldsymbol{B}$ is the magnetic flux density, $\boldsymbol{E}$ is the electric field strength, all in the IS system of units. The apostrophe signs mark temporal derivation of the first (') or the second ('') order.

This collision point may be either in region G or region H. If the number of electrons approaching G differs greatly from the number approaching H (so that this difference lies outside normal thermal fluctations), a small current *J* is produced to balance this difference, because in TE the two outgoing fluxes (evaporating from G and H) are equal.

Although the value of the electric field inside plasma is not zero (negative potential of the plasma cloud), calculations were done only for zero-electric field. This simplification will bring about some apparent disagreement between theoretical and experimental results. An additional estimate of electric field influence will adequately explain these experimental results.

(A) ANALYTICAL APPROXIMATIONS

If the plasma container (Fig.1) is narrow enough, only the magnetic field close to the geometrical axis *s* acts upon the particles. This field, called the "torsic magnetic field", can be roughly determined by the formula

$$\boldsymbol{B} = \boldsymbol{B} \cdot [\cos(g\,z), \sin(g\,z), 0], \quad \text{where } g = \frac{2\,\pi}{p} \tag{2}$$

Field ***B*** in (1) is substituted by (2) and the following differential equation is obtained :

$$u'' - (u')^2 + \tfrac{1}{2}\,g^2\,u^3 + \tfrac{1}{2}\,\mathrm{C}\,u = 0 \tag{3}$$

where $u = (z')^2$ and C is a constant. Equation (3) has a solution [ref. 2], which describes a particle trajectory between two succesive collisions with the wall

$$\int_0^t \frac{du}{u \cdot (\mathrm{C} + 2\,\mathrm{B}\,u - g^2\,u^2)} = \mathrm{A} + t \tag{4}$$

(A, B, C are constants depending upon the initial location and velocity, and *t* denotes time). In general, the integral above does not yield a synoptic solution for the inverse function $u = u(t)$. But it is easy to show that the electron is tied up to a single magnetic line of force if C > 0 (strong magnetic field) and that it can move also in the *z*-direction if C < 0 (weak magnetic field).

In the first example, the electron follows a periodic, helical-like pattern (Fig.2). The amplitude of oscillation *a* depends upon the sign of the velocity component $\boldsymbol{v}_B$ which runs parallel to the torsic field :

$$a = \frac{m\,v_{z\,max}}{e\,B}\left(1 + \frac{m\,g\,v_B}{2\,e\,B}\right) \tag{5}$$

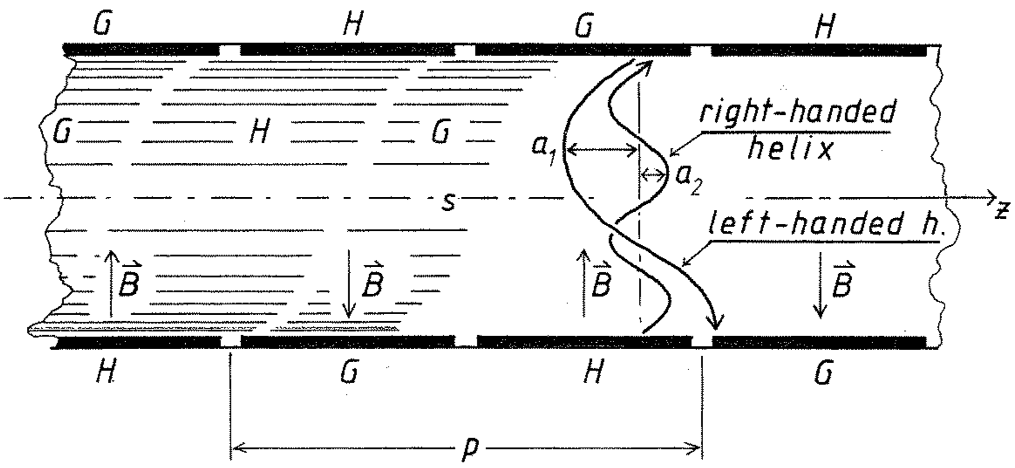

Fig. 2. Longitudinal section of the vacuum tube. Electrons may evaporate either from electrode H or G ; those emitted from H exhibit a smaller amplitude of oscillation so a smaller percentage misses the opposite electrode. The result is a net current gain of electrons from H to G.

Fig.2 shows that, by using helically shaped electrodes, it is possible to measure some net electric current J. After taking into consideration tube geometry and evaluating averages in TE, we can obtain the final result for strong field dependence :

$$J \approx 10\, J_0 \cdot \frac{m\, k\, T}{(p\, e\, B)^2} \qquad (6)$$

J_0 is the electric current evaporating from a single electrode, k is the Boltzmann constant and T is the thermodynamic temperature. On the other hand, the form of weak-field dependence (C < 0) is linear :

$$J \approx J_0 \cdot \frac{e\, B\, d^3}{p^2 \sqrt{m\, k\, T}} \qquad (7)$$

and can be obtained by expanding the position vector $\boldsymbol{r}$ in (1) into a time-dependent series, because in the weak field the radius of an electron trajectory curvature exceeds the value of approx. $\frac{p}{2}$.

Analytical predictions for the dependence of J upon $\boldsymbol{B}$ are plotted in Fig.4 (curve a).

(B) COMPUTER SIMULATIONS

Several conditions have been assumed :

1) short-circuited electrodes and zero-electric field inside the tube,
2) low-density plasma without interactions between electrons in a vacuum,
3) uniform electron evaporation from the entire surface,
4) non-elastic scattering between electrons and walls.

Therefore the starting points s_i (Fig.3) were uniformly distributed. The classification of initial velocities followed the isotropic Boltzmann distribution at a certain temperature T. By this method, 16000 electrons with different starting points and initial velocities were chosen for further calculations. After an electron has evaporated into the vacuum, it obeys equation (1) and follows trajectory T_i. Separate trajectories have been calculated by the Bobkov method [ref. 1], but the magnetic field is more complicated here : The double helix of the coil was constructed from 26 sections of straight wire. Its magnetic field was then calculated.

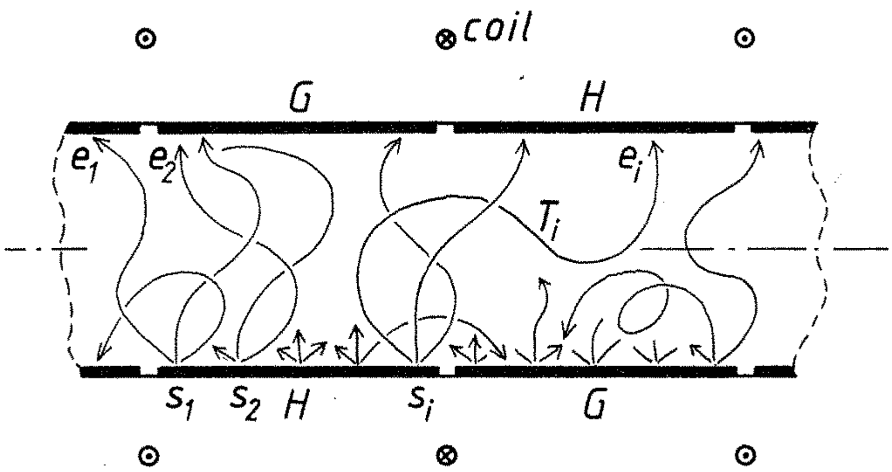

Fig. 3. Set of electron trajectories with different initial velocities. The ending points e_i may be either in region G or H.

The difference between the number of electrons reaching the first or second electrode ($N_1 - N_2$) could not be explained in terms of statistical fluctuations. Again, the "directioning factor" can be defined as

$$\eta = \frac{J}{J_o} = \frac{N_1 - N_2}{N_1 + N_2} \tag{8}$$

which always falls between the parameters of – 1 and + 1, but is usually much smaller.

In computations, the linear dimensions and other specifications close to those used in the experiment were taken into account : $l = 2\,p$, $L = 3\,p$, $d = 0.3\,p$, $D = 0.6\,p$, $T = 453$ K. The factor η was calculated for various values of magnetic field $\boldsymbol{B}$. The results are plotted in Fig.4 (curve *b*). Several theoretical predictions were confirmed :

(a) η is an odd function of magnetic field $\boldsymbol{B}$ (or of field-generating current I),

(b) the function η ($\boldsymbol{B}$) tends to zero with either very strong or weak magnetic fields.

η reaches its extreme value with such a field when the average radius of trajectory curvature is comparable to the linear dimension *d* or *p*, i.e. an average electron can gather the maximum amount of information about the inhomogeneous magnetic field.

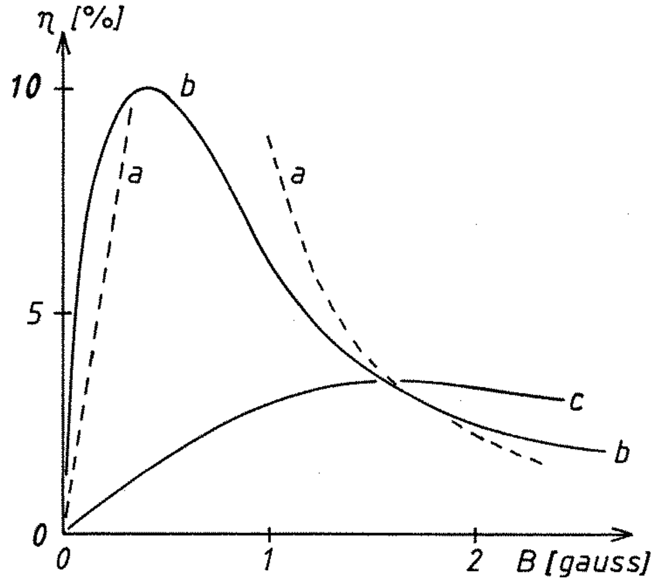

Fig. 4. Dependence of η upon magnetic field density $\boldsymbol{B}$. A model of low-density plasma is assumed. (a) analytical approximations for very strong and very weak field, (b) computer simulation, (c) experimental curve (p = 5cm, d = 1.5cm, D = 3cm, T = 453 K).

3. E X P E R I M E N T A L   A N A L Y S I S

(A) PLASMA DEVICE

The behaviour of plasma in inhomogeneous magnetic fields has been thoroughly studied, but the problem presented here is slightly different. There are at least three specific requirements :

(a) Plasma should be in a complete TE, together with the walls of the container. If not, numerous side-effects (e.g. thermoelectric and other non-equilibrium phenomena) would complicate both plasma behaviour and measurements, and make a clear understanding impossible. Any artificial excitation of plasma is unacceptable.

(b) To obtain an easily measurable current J, the following quantities should be of the same order of magnitude : linear dimensions of the container (p or d), mean free path of plasma particles, radius of curvature due to the Lorentz force acting upon charged particles, and the characteristic length of the magnetic field inhomogeneity. (An explanation is given in the discussion.) In practice, this means a low-density plasma and a weak magnetic field.

(c) Not only is field inhomogeneity of crucial importance here, but also the topology of the electrodes should be harmonised with the topology of the magnetic field. Therefore, the shape and position of both coils and electrodes must be carefully studied.

If one tries to fulfill these conditions, it appears that any method other than the use of electron gas due to thermoionic emission from the walls gives rise to enormous problems with suitable materials. So a special vacuum device was developed with a low and uniform electron work function Φ over the whole inner surface. The plasma container was made of Jena*AR glass. A subatomic film of cesium vapour adsorbed on the inner surface of the glass tube proved to be a suitable material with a low electron work function. In order to keep the inner surface as pure as possible (the slightest impurities can cause considerable differences in the electron work function causing quite disturbing electric fields in the interior), the electrodes were coated onto the outer surface of the glass tube utilising electric conduction through glass at an elevated temperature. Precise dimensions in Fig.1 are :

d = 1.44 cm (inner diameter), p = 5 cm, l = 10 cm (two helical turns of each electrode).

Coil dimensions : D = 3 cm, L = 22.5 cm (4.5 helical turns).

The main parts of the experimental system are shown in Fig.5. The principal glass tube, kept in the main thermostat at a temperature T_s, is connected by a capillary to a side-chamber where a small amount of metallic cesium is kept at a temperature T_p . The successive steps in the fabrication of the whole glass system (cleansing of the inner surfaces, evacuation and degassing, introducing cesium) are described in [ref. 3, 4a].

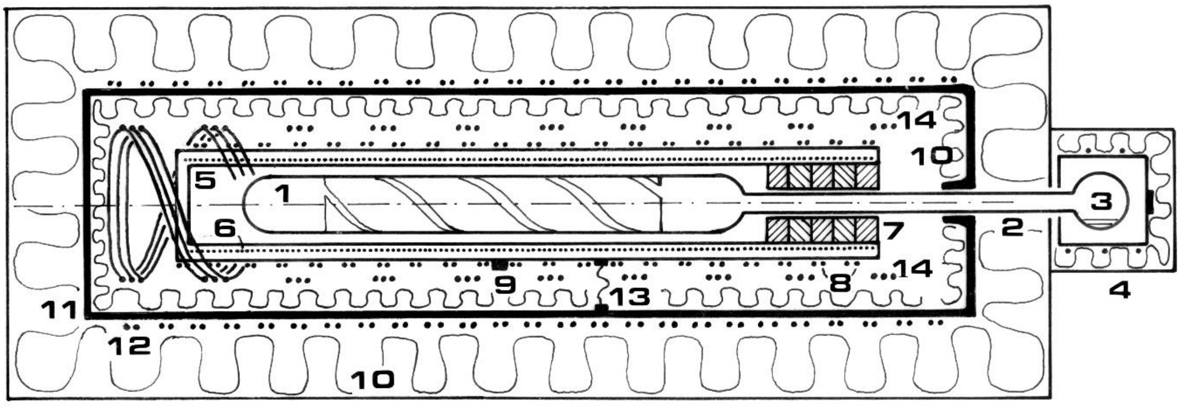

Fig. 5. Experimental apparatus (mechanical, not to scale and simplified) comprised of : 1 – glass tube with a pair of helical electrodes, 2 – glass capillary, 3 – chamber with liquid cesium, 4 – supplementary thermostat maintaining a chosen vapour pressure of cesium, 5 – inner thermostat ("heat pipe"), 6 – fine metal grid soaked with water, 7 – copper/teflon rings, 8 – inner thermostat heater, 9 – inner thermostat temperature sensor (Pt resistor), 10 – heat insulating material, 11 – outer thermostat, 12 – outer thermostat heater, 13 – thermocouple between inner and outer thermostat, 14 – double helix coil.

The temperature T_p defines the vapour pressure of cesium in the whole vacuum system. The amount of vapour that is distilled into the main tube can be calculated. After a certain time, an equilibrium between cesium vapour and adsorbed cesium is established in the main glass tube [ref. 5]. The values of both T_s and T_p had to be chosen carefully. T_s should be neither too low (poor electron emission, low conductance through glass) nor too high (irreversible chemical reactions between cesium and glass, chemical resistance of other materials, electric leakage between electrodes etc.). Thus, all experiments had to be carried out with T_s = 160-210 °C. AR-glass (soda-lime glass) was chosen because of its good resistance to alkalis and because of the correct value of its electric conductivity (10^6 Ω m at 185 °C). On the other hand, the best values of T_p are between 30 and 50 °C. Cesium impregnates the glass structure mesh several atoms in depth, but the integral amount of the cesium layer is still subatomic. Impregnation is nearly reversible below 200 °C. The electrical resistance of the cesium-doped glass layer is high enough (typically : several GΩ) to prevent electric leakage from the area of one electrode to another. If T_p < 50 °C, the density of cesium vapour is so low that interactions between free cesium atoms and free electrons do not appreciably influence the measured effect. In fact, some experience is necessary before one obtains good and stable thermionic emission. For instance, very good results were obtained by the following procedure : (i) rising T_p to 90°C for several hours with T_s = 195 °C ("cesium flood"), then (ii) letting the whole system cool slowly to room temperature (but with $T_s > T_p$) and the next day, (iii) starting with T_s = 180-195 °C and T_p = 45-50 °C. From the Richardson-Dushman plot, the values of 1.1 eV for Φ and 1 A/cm^{2}K^2 for the emission constant A were obtained. The negative charge of the plasma cloud diminishes the thermionic current between the electrodes by a further factor of approx. 100. The thermionic current density is about 2 nA/cm^2 at T_s = 195 °C.

Considerable effort was given to temperature control, in order to be free of numerous non-equilibrium side-effects. The temperature T_s was kept uniform in time and space (along the tube), with deviations much lower than 0.005 K. Uniformity in space was ensured by a specially designed, water-filled heat pipe (Fig.5) made from two concentric copper tubes welded together and a fine metal grid placed in a precisely determined amount of water. To prevent cold passing along the capillary, it was placed in a series of rings made alternatively of thermally conductive (copper) and insulation (teflon) material. Time stability was assured by a platinum resistor integrated into a Wheatstone bridge with thermally stabilised metal-film resistors at the input of a sensitive amplifier feeding the heater [ref. 6]. This internal thermostat is helped by an external one that is electronically set to a temperature of 10 K below T_s (Fig. 5, 6).

The geomagnetic field was compensated by separate coils. The thermocouple contained a minute amount of iron wire, but otherwise no ferromagnetic materials were used.

(B) MEASURING METHOD

By using of statistical mechanics, it is easy to show that for low density electron plasma we have the following relation :

$$J / J_0 = \eta = \frac{e}{k\,T} \cdot U \,, \qquad (9)$$

if $U \ll \frac{k\,T}{e}$ $\qquad$ ($\frac{k\,T}{e}$ = 40 mV at T = 190 °C)

Here, U is the voltage generated in plasma between the helical electrodes, measured by a voltmeter with a very high input impedance. Thus, the quantities η and U are linearly related, and measurements of η become quite easy to perform. We can see from (9) and the previous calculations of η that U should be a few mV in magnitude.

The signal from the electrodes was led to the input of a low-noise & low-drift instrumentation amplifier, with input FETs shunted by a resistor of 20 MΩ and a capacitor of 1000 pF. The inner impedance of plasma was much lower (< 1 MΩ) therefore (9) gives the correct voltage.

After the values of T_s and T_p had been determined, enough time was left for perfect temperature stabilisation. Then the torsic magnetic field was established by letting a regulated current pass through the helical coil. The dependence of U on the magnetic field $\boldsymbol{B}$ was then plotted (Fig.6). Some typical curves are shown in Fig.7. Field $\boldsymbol{B}$ changed slowly in sweeps with a typical period of about 20 s, but measurements with different sweep frequencies (from 0 to 1 Hz) were also performed.

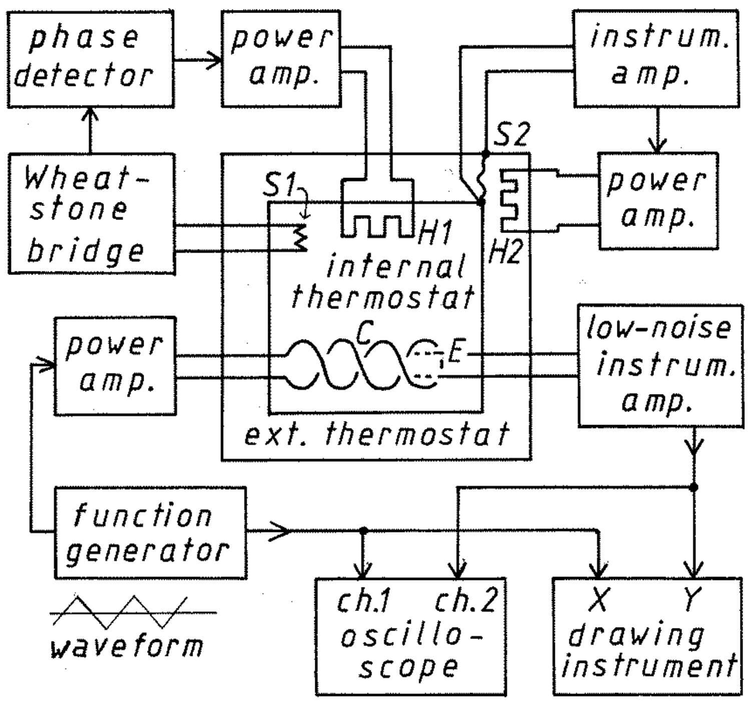

Fig. 6. Experimental apparatus (electrical, simplified). H_1, H_2 = heaters, S_1 = Pt thermistor, S_2 = thermocouple, C = helical coil, E = path to helical electrodes.

4. DISCUSSION

At each set of parameters T_s and T_p, the curves U (**B**) were reproducible and stable. First of all, it is quite easy to see that the measured effect is due to plasma behaviour : the curves U (**B**) flatten down completely as soon as a strong permanent magnet is brought close to the system. Now it can be shown that the measured effect was born by direct influence of the torsic magnetic field upon electrons in TE plasma and not by some strange cross-effect.

The current could be due to some thermal effects in plasma, conditioned by eventual temperature gradients. But this seems very unlikely. First, there was very good thermal stabilisation along the whole main tube length and during the full duration of the experiment. The coil was wound out of the inner thermostat. Second, if the current had been generated by thermal effects (heating of the coil) it would have been, by using arguments of symmetry, an even function of the applied field – but the plots exhibit an odd dependence. Additional tests with a slowly changing temperature T_s have verified no infulence over the basic features of the curves presented in Fig.7.

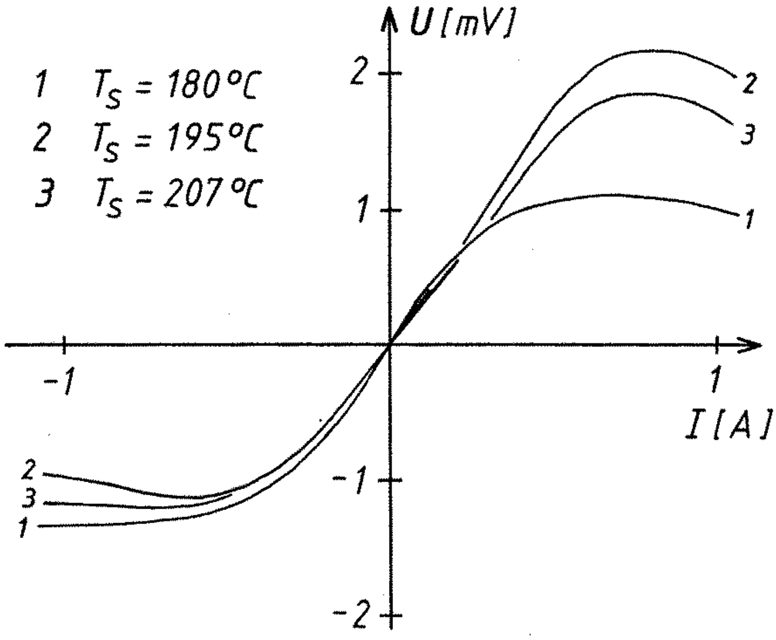

Fig. 7. Typical plots $U(\boldsymbol{B})$ showing dependence of voltage generated in plasma on field-generating current I. (The central field is 1 gauss at I = 0.46 A). T_s = nominal plasma temperature.

Another cause of the measured voltage could be the electromagnetic coupling between the AC-supplied coil (0.05 Hz) and the electrodes, since a certain mutual inductance/capacitance exists between them. But this effect should exibit a certain phase shift and also an explicit frequency dependence. Nothing like this was observed. The measured voltage $U = U(\boldsymbol{B})$ was well in phase with the coil-supplying current and fell within the range of 0 to 1 Hz independent of frequency, including DC measurements. It is easy to determine that the voltage generated by magnetic induction between both electrodes was smaller than 50 nV at 0.05 Hz. Capacitive coupling produced more of a problem, but, with the use of a standard grounding technique, undesirable interferences were also brought down to more than 30 dB below the main signal.

Since there is firm evidence of an odd dependence of U upon the stationary magnetic field $\boldsymbol{B}$, only one disturbing effect remains to examine : The measured voltage U could be produced by some kind of Hall effect in plasma. This possibility should be based upon the following mechanism : Certain poorly determined non-equilibrium phenomena produce weak DC electric currents in plasma that, in turn, yield the measured voltage U through the Hall effect when the magnetic field is applied. However, there are at least two objections to this possibility, and each will be dealt with in turn : (i) In fact, weak non-equilibrium electric currents do flow inside the vacuum tube, for two main reasons : First, galvanic potentials in glass due to surface inhomogeneity (contamination from previous measurements of electric resistance, imperfect cleansing), and second, external electromagnetic interferences, rectified by possible non-linear effects. Such currents produce their own DC voltages (in the absence of the magnetic field) that can be measured between the electrodes. But these voltages were smaller than the m. field-dependent voltage U, and it seems unlikely that the Hall voltage would be greater than the primary one. Moreover, after the probe had been subjected to various modes of treatment of the inner surface, different galvanic potentials resulted, but the magnetic field-dependent voltage U ($\boldsymbol{B}$) did not change. (ii) The position of the glass tube with regard to the helical coil plays an important role in additional tests. When the insulating gap between both helical electrodes is in the nearest position to the coil turns (as in Fig.1) the effect presented in the theoretical part of this paper is maximal and two other effects (electromagnetic induction, ordinary or first-term Hall effect) are minimal, ideally zero. But when the insulating gap lies between the turns of the helical coil, just the inverse happens. These characteristics can be deduced from arguments of symmetry. The observed effect was maximal in the former case and zero in the latter, therefore the ordinary Hall effect can be excluded. Some higher-order Hall effect (with chirality of the field and/or electrodes obviously included) could eventually display the right symmetry characteristics, but in this case it is highly improbable that the Hall voltage would exceed the primary one. No concrete model was found for such an extraordinary Hall effect and surely the model presented in the previous chapters of this paper is much more simple and probable.

Theoretical and experimental results should now be compared. Using (9), the directioning factor η, as a function of field $\boldsymbol{B}$, was calculated from the experimental plots U ($\boldsymbol{B}$). These values, averaged over several curves (Fig.7), give the experimental curve $\eta(\boldsymbol{B})$ (Fig. 4c). There is a fairly good agreement between analytical and numerical curves (Fig. 4a, 4b), and the moderate discrepancy is mainly due to the approximations used in analytical and numerical calculations (torsic magnetic field, simplified electrode geometry, evaluation of certain averages, expansion into a time-dependent series ; construction of the coil from 26 segments etc.). However, the experimental curve seems to be in poor agreement, especially with weak magnetic fields. This disagreement is not explained until one takes into account several additional influences over plasma behaviour:

(i) Although plasma is in TE (within itself and also with the walls), the effective temperature of free electrons in a vacuum is slightly higher than that of the walls, because of a potential barrier at the surface of the thermoemissive layer (through which electrons must pass before they evaporate). However, the average height (0.3 eV ?), the effective width (0.8 nm ?), and the transmittance D (D = 0.01 from the emission constant A) are somewhat uncertain, so the effective temperature calculated from this data ($T_{\text{eff}} \approx 1.5\ T_{\text{s}}$) is only an estimated value.

(ii) Plasma is of a low density ($n = 3.5 \cdot 10^5\ /\text{cm}^3$) only near the geometrical axis of the glass tube, its density doubles at the distance from the axis $r = 0.55\ d/2$, but close to the inner surface, n is much greater (by a factor of approx. 100, the exact value is determined by the intensity of thermionic emission). The plasma inhomogeneity is due to the negative electrostatic potential of the plasma cloud. The influence of the torsic magnetic field on electrons is disturbed by the electric field in plasma to such a degree that only influence on the central part of the electron trajectories contributes to the measured effect. Therefore, the effective width of the glass tube is smaller ($d_{\text{eff}} = 0.45\ d \ldots 0.65\ d$), and as we see from (7), η can be fundamentaly changed with weak magnetic fields.

(iii) Because of a high plasma density near the inner surface of the tube, there is an electric leakage along the walls. The voltage between the electrodes is reduced in this way, especially with weak magnetic fields. The reduction factor is between approx. 3 (weak field) and 1 (very strong field).

It is practically impossible to construct an exact model (yielding exact values of η) including all necessary details, of which only the major ones were listed here. Moreover, the required parameters could not be precisely determined by measurements. Thus, the exact theoretical curve η ($\boldsymbol{B}$) is replaced by a wider region η ($\boldsymbol{B}$) (Fig.8). Within the accuracy range, one can notice a close agreement between theoretical and experimental results.

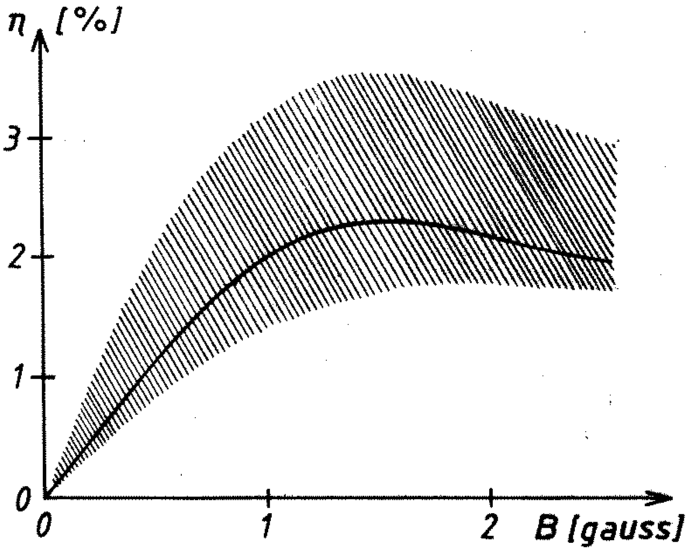

Fig. 8. Comparison of theoretical and experimental results for $\eta(\boldsymbol{B})$, with effective electron temperature and realistic plasma density taken into account. Shaded: theoretical. Curve: experimental, according to parameters: T_{eff} = 1.5 T_s (drawn out). p = 5 cm, d = 1.44 cm, D = 3 cm, T_s = 460 K.

5. THE SECOND LAW OF THERMODYNAMICS

There is a good reason to believe that the measured current can be born spontaneously under strict conditions of TE. There is every indication that the only external means was a stationary and inhomogeneous magnetic field applied to the system. This chapter will define and explain the term "spontaneous genration of current".

The investigation of energy and entropy in plasma leads to the most striking results. First of all, we shall observe the behaviour of a simple physical system (Fig.9) that is thermally, and, in any other respect, isolated from external surroundings, so it can be considered as a self-supporting whole. It consists of four parts only : plasma, the container, resistance R, and the helical coil carrying the stationary current I. The dissipative resistance R is used instead of the input impedance of the measuring apparatus. The helical coil is made of a superconductive material and is itself short-circuited. By this method the power-supply can be eliminated. The observed system is left to stabilize in its own TE and, according to the Second Law, one may expect that the same temperature T is restored throughout.

If there were suitable materials with a very low value of the electron work fuction, there would be an abundant electron emission leading to a measurable current even if the whole system was kept at room temperature. (Unfortunately, it is very difficult to produce materials of this kind, like Ag-O-Cs film [ref. 4b], with a uniform work function over the whole inner surface. Internal electric fields resulting from this irregularity would influence plasma behaviour too much, so that any interpretation of the measured results would be quite unreliable.) The selection of temperature *T* depends on the choice of materials used in the system, otherwise, or theoretically it can be any temperature above absolute zero. The existence of materials superconducting at the same temperature is again a technological and not a fundamental problem.

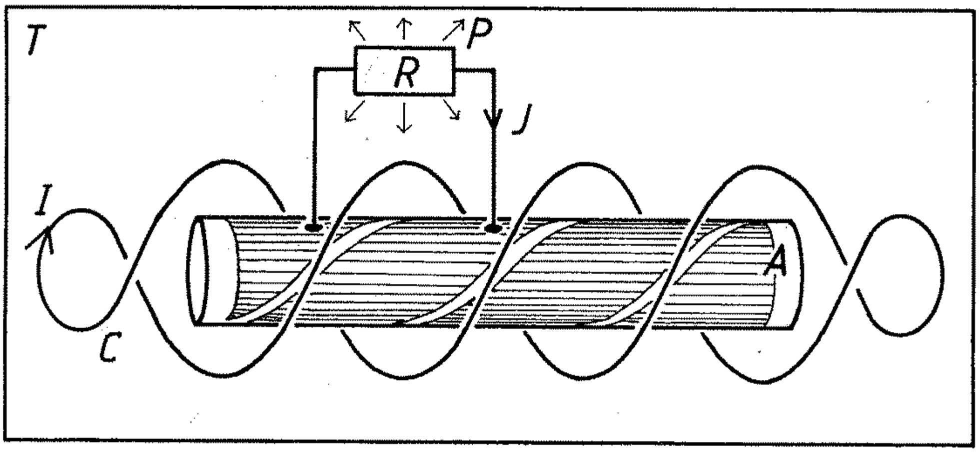

Fig. 9. Self-supporting system, independent of surroundings. Its initial temperature is *T*. C is the superconductive coil. The electric power *P* is dissipated in resistor *R*, its source is plasma container A. Thus *R* is spontaneously made slightly warmer than A.

Does the effect dealt with in this paper, also occur inside the system in Fig.9 ? Yes, as nothing has changed fundamentally in the whole system.

Consequently, electric power $P = R \cdot J^2$ is being dissipated in resistance *R*. Resistance *R* becomes warmer while the plasma container becomes cooler. Why? In plasma, the current *J* flows against the potential difference *U* between both electrodes. It is not *U* that makes current *J*, but the inhomogeneous magnetic field with its implicate ordering abilities. *U* is only the consequence of *J* when the electrodes are not short-circuited. Therefore, on their way from one electrode to another, electrons lose a part of their kinetic energy in favour of electric energy (= *eU*). The walls thermalize plasma repeatedly. Thus, the energy loss leads to the cooling of electrodes below the ambient temperature. Various computer simulations based on a different container and coil topology, but with spontaneously generated electric fields in plasma taken into account [ref. 1], confirmed the effect of cooling in plasma.

Sooner or later, the temperature difference between the plasma container and the dissipative resistance *R* becomes stationary and, by means of classical thermal conduction, heat returns back to the plasma, once more. The whole process is totally stationary, including the integrated electric and magnetic fields. Current *I* is constant in time (superconduction) as is *J*, since *J* is uniformly dependent on *I*.

The only link between *I* and *J* are electromagnetic fields. These do not convey energy from *I* to *J* or vice versa. The eventual electric fields between the helical coil and plasma can be easily shielded by a metal envelope around the plasma container. It is evident that this shielding is not absolutely necessary. However, a magnetic field obviously exists there, but it is clear from the Maxwell equations (absence of magnetic monopoles) that the stationary magnetic field is not able to convey energy. The magnetic part of the Lorentz force (1) is always perpendicular to the velocity vector of the chosen particle which is being affected magnetically only in its direction, but not in its absolute value. Thus, a particle receives from the magnetic field only information about the field itself, but not its energy. Power *P* does not come from magnetic field energy. On the energy level there is no coupling between *I* and *J*, the current *I* (and hence also *J*) is not diminished and the whole system can remain under the conditions necessary for its functioning for an arbitrary length of time. It is also easy to show that both currents are stable to fluctations.

So, in spite of the fact that there was considearable power consumption during measurements (coil, thermostat and measuring apparatus supply), external effects could be theoretically brought down to zero, as in Fig.9. The large energy consumption was necessary only to make measurements easier. With the continuing development of various technologies and materials, energy consumption could some day be eliminated.

Another variant of power-free magnetic field generation is the use of a permanent magnet with helically twisted poles (Fig.10). An experiment of this kind has actually been carried out. The torsic-like magnetic field near the geometrical axis of the glass tube was rather weak, so only the linear part of the plot *U* (***B***) could be verified. In this range, agreement within the measurement accuracy parameters (10%) was excellent, which clearly demonstrated the way in which the magnetic field is produced makes no difference.

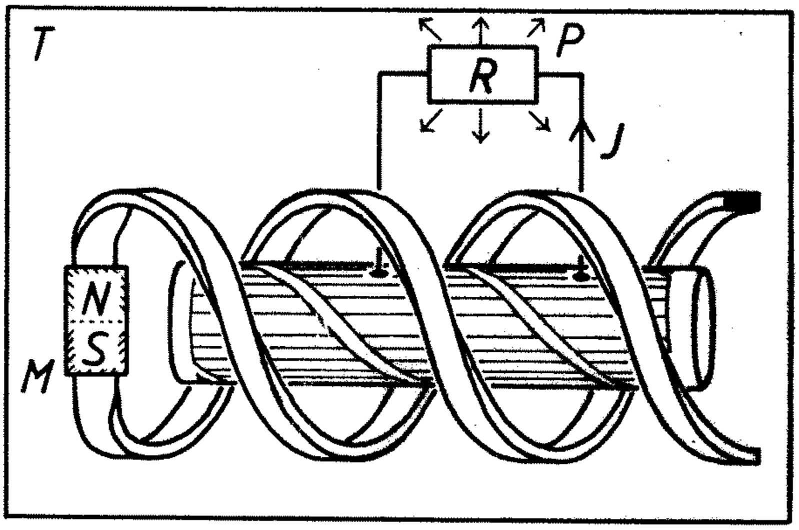

Fig. 10. Another variant of PMSK. The torsic-like magnetic field is restored by using helically twisted poles (N, S) of a permanent magnet M.

The Second Law of Thermodynamics ("entropy law") can be expressed in different mutually equivalent forms. From these we shall study the statement on the impossibility of the "perpetual-motion machine of the second kind" (PMSK), because this statement can be connected to a simple stationary process (like DC measurements preseneted in this paper, or like the process shown in Fig.9). Other forms of the Second Law (e.g. impossibility of the total entropy decrease inside an isolated system) deal with the temporal evolution of the whole system, which may be a little more complicated.

PMSK can be defined as a "self-acting machine carrying heat continuously from a colder to a hotter body and producing no other external effect". On the basis of what has been established it seems probable that the system shown in Fig.9 fulfils this condition.

Although the Second Law of Thermodynamics has been regarded for over a century as one of the basic laws which describe the behaviour of Nature, in the last twenty years there is growing doubt about its universal validity. For instance, Prigogine [ref. 7] states it could be different if also long-range forces among particles are considered and/or if the considered system of particles possesses a certain "memory".

Here, both conditions are fulfilled. It seems that the Second law in the strictest sense can be violated. If an externally isolated system (Fig.9) was initially in TE (with maximum entropy), it escapes this equilibrium spontaneously, toward a state with a lower entropy. This internal organising of matter is oriented in time ; thus, according to microscopic reversibility [ref. 8], it cannot be accomplished without a magnetic field or Coriolis forces. For this reason, microscopic valves (composed of several atoms each), that let molecules of gass from one side of a tiny wall but reflect molecules from the other side, do not act as a Maxwell demon [ref. 9].

Rather complex theoretical arguments suggest that it is very hard (if not impossible) to find a case of Second Law violation, when a homogeneous magnetic field is applied to any system of particles. (For reasons of symmetry, chiral particles are required. Optically active mixtures seem to be the best solution. However, only a negligible current may be created in them by means of a homogeneous magnetic field.) [1]

Results become different when the field is strongly inhomogeneous (which means that, within the distance of a mean free path of plasma particles, there is already a considerable relative change of applied field). The following discussion concerns inhomogeneous magnetic fields. It can be demonstrated that, along its trajectory between two succesive collisions, each charged particle gathers some complex, non-additive information about the magnetic field. One part of this information displays the same spatial and temporal symmetry as the vector potential $\boldsymbol{A}$, and is manifested in the progression of the particle velocity vector. This is not an additive kind of information, because the inhomogeneous field that defines the Lorentz force varies in intensity and direction in different areas, and the actual position of the particle is again determined by the field which has previously influenced this particle. So, we are dealing with a rather complex kind of memory inherent in each separate particle. (It is easy to guess here why the measured effect is distinctive only in low-density plasma.)

Magnetic field can be expressed either in terms of magnetic field density vector $\boldsymbol{B}$ (axial vector) or as vector potential $\boldsymbol{A}$ (polar vector). If $\boldsymbol{A}$ is fixed by an additional assumption (for instance, div $\boldsymbol{A}$ = 0), then, mathematically, both vector fields contain exactly the same information : Field $\boldsymbol{B}$ can be derived from field $\boldsymbol{A}$ (namely, $\boldsymbol{B}$ = rot $\boldsymbol{A}$) and vice versa (the latter can be done, if we know field $\boldsymbol{B}$ within the whole space) [ref. 10]. So, the information expressed by $\boldsymbol{A}$ or $\boldsymbol{B}$ is homomorphic only when we consider $\boldsymbol{A}$ or $\boldsymbol{B}$ in the whole space. Some real field has to be observed. The homogeneous field is not a real field because it cannot be homogeneous in the whole space, hence it contains no information about $\boldsymbol{A}$. (Mathematically, in this case $\boldsymbol{A}$

[1] Postscript (2024): Further research revealed that the Second Law can be violated even by means of a *homogeneous* magnetic field. For instance, see my book *From Entropy to Syntropy*.

cannot be found in a uniform way.) In this sense, theoretical physics deals very little with real magnetic fields.

When a magnetic field is applied to low-density plasma, charged particles move along circular, helical or (as in an inhomogeneous field) more complicated trajectories with the same space and time properties as field ***B***, characterized by the axial vector with adjoined information about field inhomogeneity (space properties) which changes the sign if the direction of time is reversed (we call this a temporally odd vector). But since there is a homomorphism between the information fields ***A*** and ***B***, the symmetry properties of field ***A*** (temporally odd polar vector) should be manifested in the particle motion.

Every polar vector can be defined by two end points P^- and P^+ (Fig.11) with different (or rather, opposite) characteristics. In other words, a pair of such points displays the same properties of symmetry as a polar vector. Moreover, every temporally odd quantity can be defined by a time-derivative of a certain temporally even quantity. Therefore, in point P^+ there exists a positive time-derivative of a certain temporally even physical quantity, and in the point P^- there exists the opposite, thence a negative derivative of the same quantity. This is identical to the flow of this quantity across plane S.

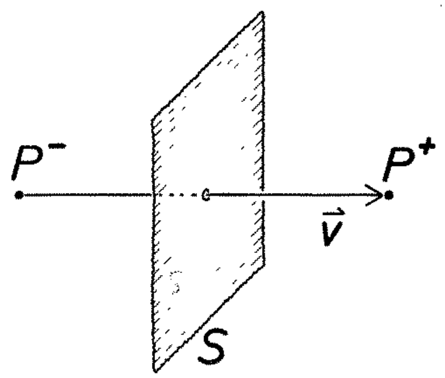

Fig. 11. Representation of a temporally odd polar vector ***v*** by the flow of a certain physical quantity from P^- to P^+.

This mysterious quantity may be suggested by the thermodynamics of irreversible processes : mass, energy or electric charge (which are all additive and invariant inside an isolated system), and the currents attached to them would be : diffusion current, heat conduction, and electric current, respectively. The example discussed in this paper certifies that the flow is of this type and can be measured directly. Its direction is determined by vector potential ***A*** and partially also by the shape of the walls. It will be defined as a *dimentropic current*. This current is induced by a static inhomogeneous magnetic field and not by some outer "force" in the Onsager sense [ref. 8]. The Onsager currents increase the entropy of the whole physical system, while the dimentropic currents diminish it (hence the name).

Therefore, it can be concluded that a Maxwell demon can exist in plasma. Each separate particle is its own Maxwell demon requiring no transfer of energy. This possibility has always been overlooked. The transfer of information is not necessarily related to energy transfer – the subtle idea of information should not be confused with the more rigid principles of energy.

Two necesarry conditions are not likely to occur "by accident", so it is quite natural that the dimentropic effect had not been detected before. These are :

(i) the extraordinary shape of both field and electrodes,
(ii) the precisely defined values of both magnetic field density and plasma density.

Plasma does not exist in vacuum only. This paper deals with quasi-free electrons in vacuum because this is the best way to obtain a simple, initial understanding about a new class of phenomena – but there is an infinity of other possibilities left. I hope that my work will contribute to further investigations.

A C K N O W L E D G M E N T S

I would be very pleased to mention everyone who has offered assistance for this project. Unfortunately, shortage of space prevents me from naming them all. Milan Hodoščĕk outstandingly carried out the computer programming work. Andrej Kregar provided valuable assistance in the field of electronics. The vacuum tube with cesium was procured by the late Evgen Kansky. Experimental work was performed in the laboratories of the Iskra – Center for Electrooptics where it received the wholehearted support of many colleagues. There were also many others without whom I could not have completed this project. Many years were spent on preparations, trial experiments and developing ideas, but eventually working on the project became so simple and natural that everything ran smoothly. I am happy to have shared in this experience.

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