The Law of Entropy – a Critique

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CHAPTER 1
INTRODUCTION

After the *Law of Entropy* (alias, the *Second Law of Thermodynamics*) took a clear form in the 19th century, it proved to be very useful; and since it was confirmed again and again in all cases, it was slowly accepted as one of the basic laws of nature. It has become a postulate that is no longer questioned. Unfortunately, we usually do not realise that – like all other basic laws – the Law of Entropy is based only on experimental methods and, of course, the possibilities of the past time. It has never really been proven, at least not for the general case. For example, *Ilya Prigogine* [1] strongly doubts the general validity of the Second Law of Thermodynamics: The situation can change significantly when long-range forces act on thermodynamic particles, but also when some information about the initial conditions is retained in the system, despite the evolution of the system over time. The basic question of entropy still seems to be open, and now it certainly needs to be considered in the new light of the present time.

Indeed, all the experience of the last hundred years shows that the Law of Entropy is a good approximation for ordinary, well-known phenomena. In these pages, however, I will show that under certain conditions this law is likely to fail. Some conditions can already be seen from the *symmetry properties* of physical space and time.

For the sake of simplicity, I will restrict myself to one class of hypothetical phenomena that do not comply with the Second Law of Thermodynamics: we shall observe closed systems that are initially in *thermodynamic equilibrium*, but then, despite being completely separated from their surroundings, they spontaneously give rise to a current (e.g. heat flux, partial mass flux, electric current) that reduces the overall entropy of the system. These currents are therefore different in origin from those known from the thermodynamics of non-equilibrium processes and are caused by a gradient [2]. We will call this new type of currents *syntropic currents*.[1]

In the absence of a magnetic field or Coriolis forces, a physical system, even if it consists of a large number of *thermodynamic particles* (atoms, molecules ...), is still reversible in the microscopic sense, i.e. for individual particles (Onsager, see [2]). If such a system is in *thermodynamic equilibrium* (*TE*), some chosen state of a particle characterised by position, momentum, etc., is as likely as a state which differs from the original only in that the momentum and all other *temporally-odd* properties are reversed. This follows from the *principle of detailed equilibrium*. It is therefore impossible for such a system to generate a current spontaneously (without external influence). Indeed, an arbitrary current is a *temporally odd quantity* (it reverses direction when time reverses) and in *TE* a current in the opposite direction – with opposite impulses of the individual particles – is equally likely.

In this context, a *Maxwell's demon* (alias, "perpetual motion of the second kind") based on microscopic tiny valves that would only let gas molecules pass in one direction but not in the other is unrealistic. The atoms of the flaps must also be in *TE* with the gas and have the same

[1] Postscript (2024): At the time I called this the *dimentropic current*. I used that old term in the original text (in Slovene language) from 1984. In the present translation, however, I use the modern term *syntropic current*, because this new term began to be used elsewhere in the world a little later.

temperature. Because of their own thermal motion, the valves are confused and unable to receive information about the position and direction of the molecular motion, so they are unable to open and close at the right time [3].

The situation is quite different when the thermodynamic particles are subjected to *Coriolis forces* or *magnetic fields*. In both cases, these are long-range forces. The first case will not be considered here, because in our terrestrial conditions the influence of Coriolis forces on individual particles is negligibly small – but of course this is not the case for the evolution of stars and constellations!

CHAPTER 2
IN A HOMOGENEOUS MAGNETIC FIELD, THE ENTROPY LAW HOLDS [2]

So, we will focus our attention on the phenomena caused by the action of a magnetic field on a system of a large number of thermodynamic particles. Everything is in *TE*; both the material we observe and the source of the magnetic field itself. Of course, only stationary magnetic fields are relevant here, since variable magnetic fields are associated with irreversible phenomena in the material (e.g. electric current due to magnetic induction). Stationary magnetic fields may be in *TE* with their surroundings, since e.g. a permanent magnet can exhibit magnetic phenomena for an arbitrarily long period of time without being energised.

Let us start with a *homogeneous magnetic field*. However, it will be seen that in a homogeneous field the entropy law still holds. This realisation is unveiled after a few steps, which we will go through briefly in this chapter.

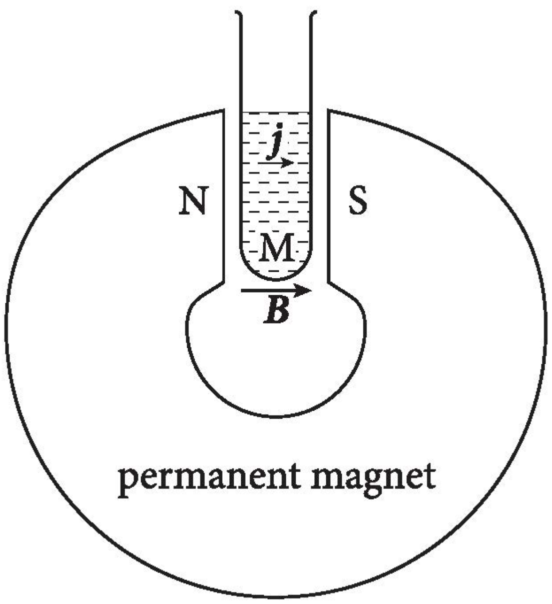

Figure 1.

[2] Postscript (2024): The whole of this Chapter 2 rests on weak arguments that I can no longer agree with (as shown in the footnotes 4, 5, 6, 7). According to my present opinion, the Second Law can be violated even by means of a *homogeneous* magnetic field. So, the reader may skip this whole chapter without harm. All the rest holds together well.

The problem we are considering can be reduced in its basic features to the following experiment (Figure 1). We measure a hypothetical syntropic current ***j*** (arrow) generated inside a substance *M*.[3] This syntropic current is due to the action of a homogeneous and stationary magnetic field ***B*** on the particles in substance *M*, and is not due to any irreversible transport phenomena due to "forces" (gradients) in the Onsager sense. So at the beginning of the experiment, when the field ***B*** is already applied and the hypothetical current ***j*** is already flowing, the substance *M* is in the state of *TE*. Slowly, a certain gradient appears in the substance *M* due to the current ***j***, but this is a consequence of the current ***j*** and not its cause. We are interested in the essence how this current is generated, so we will assume here without harm that substance *M* is in *TE* throughout the experiment.

A correct correspondence between the *symmetry properties* of the causes of a certain physical phenomenon and the symmetry properties of the resulting phenomenon is a necessary (but of course not also a sufficient) condition for the existence of that phenomenon. In our case, the hypothetical resulting phenomenon is the syntropic current ***j*** with symmetry properties of a *polar vector*, and the homogeneous magnetic field that is supposed to cause this current is described by the field density ***B*** displaying symmetry of an *axial vector*. The symmetry properties of cause and effect are therefore not the same. However, it is possible that several causes contribute simultaneously to the birth of the current ***j***, and that they couple to each other so that we get the correct symmetry of the combined effect. Therefore, let us investigate what else, besides the magnetic field, can influence the particles in the substance *M* !

Only those influences that can also act in *TE* need to be considered. Thus, electric field and other *gradient fields*, whose influence is related to macroscopic energy transfer, are dropped. What remains are the effects of the internal structure of the substance *M*. This substance can have different types of symmetry. Let us first consider a structure with *polar symmetry*, such as exists, for example, in *pyroelectric crystals*. Can information related to this symmetry be transmitted between the particles in *TE* ?

The particles carry information about the polar vector only when they are carriers of a current, otherwise the two opposite directions would be equivalent and we would not be able to determine the polar vector. But in Chapter 1 we have already excluded the possibility of this current, because of the principle of detailed equilibrium.[4]

For us, the most interesting are internal structures with space-symmetry of a certain *tensor*. Let us first see which symmetries come into play, so that the coupling of a magnetic field (field ***B***) with a tensor (tensor $\underline{\mathbf{T}}$) will give the current with a polar symmetry (vector of the current ***j***). Since the hypothetical current, i.e. the result of the coupling, is different from zero only when ***B*** and $\underline{\mathbf{T}}$ are simultaneously different from 0, we can formally write the coupling as the following sum:

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[3] The current *j* is a vector quantity since we speak about the *current density* inside the substance *M*, while the capital letter *J* will designate the complete syntropic current (a scalar quantity).

[4] Postscript (2024): The argument presented in this paragraph does not hold in a general sense. More recent research has revealed that, in certain cases, thermodynamic particles (e.g., electrons) can receive information of a polar vector even in the state of *TE*. An important result of this fact is a possibility of current generation if a magnetic field is coupled with the polar asymmetry inside a pyroelectric crystal or inside a modern semiconducting heterostructure. This may happen even inside a homogeneous magnetic field. Therefore, this whole Chapter 2 was based on a wrong assumption, with excessively firm restrictions.

$$j = \sum_{m,n} C_{m,n}\, T_m\, B^n \qquad (1)$$

$\mathbf{T}_m$ are tensors of different symmetries and $\boldsymbol{B}^n$ are different potentials of magnetic field density. Due to the principle of detailed equilibrium, the exponent *n* must be an *odd number* (implying, in particular, a linear dependence of the syntropic current on the magnetic field). The coefficients $C_{m,n}$ can only be different from 0 for those terms of the sum (1) in which the product $\mathbf{T}_m \cdot \boldsymbol{B}^n$ has the symmetry of a polar vector. Let us see how the eq. (1) transforms when space is mirrored. Due to the properties of polar and axial vectors, the determinant of the orthogonal matrix describing the transition of the tensor $\mathbf{T}_m$ from the original Cartesian co-ordering to the new, mirror symmetric co-ordering must be equal to –1. The tensor $\mathbf{T}_m$ is therefore an *alternating tensor* [4]. The alternating tensor of the *second rank* leads us to the *vector product*. In eq. (1) this would correspond to terms with polar vector $\boldsymbol{a}$:

$$j = \sum_{n=1,3,5\ldots} C_n\, a \times B^n, \qquad (2)$$

but we have already shown that the internal structure cannot interact with the symmetry of the polar vector in *TE*. So all C_n are equal to 0.

All that remains is the *third-rank alternating tensor*. This is by its nature a pure *pseudoscalar* (P). The corresponding terms in the sum (1) are written

$$j = \sum_{n=1,3,5\ldots} D_n\, P\, B^n \qquad (3)$$

The proof that all D_n are also equal to 0 is more complicated. The principle of *detailed equilibrium* would by itself allow the existence of a pseudoscalar influence **P** , since for a pseudoscalar all directions in space are equivalent. And indeed, it turns out that there is indeed some pseudoscalar influence on the particles in the *TE*. Although it is somewhat difficult to imagine a measurement in which the measuring device does not corrupt the *TE* in the measurand (but nevertheless extracts some information from it), we can find a substance in which we can directly observe the exchange of pseudoscalar information between particles : these are *cholesteric liquid crystals*. The chiral molecules in a layer are helically rotated with respect to the molecules in the adjacent layer. Since there is diffusion of molecules between adjacent layers, the molecules must, on average, move helically as they pass from one layer to another. The screw (a typical helical structure), in turn, has the symmetry of a pseudoscalar.

Let us try to understand the physical meaning of eq. (3). All substances with a pseudoscalar structure are *optically active*. The purest effect could be observed in isotropic optically active liquids, where the current $\boldsymbol{j}$ would not be distorted by various other effects of internal structure, such as they exist in crystals. The optically active molecules of these liquids are *chiral* (they have no *centre of inversion*), somewhat resembling a screw in shape. A striking example is the molecule of *transcyclooctene*.

Let's investigate the effect of a magnetic field on chiral molecules! Assume that the magnetic field slightly arranges the *angular momentum* of the molecules (the magnetic field and the angular momentum have the same symmetry properties). If so, more than one half of the molecules will rotate in some privileged direction. However, since molecules are helical in shape, and so, as we have seen (the example of cholesteric liquid crystals), there is some correlation between their momentum and their rotational quantity, rotating molecules also start to travel *translationally* – they get twisted in a particular direction, just like screws in wood if they are turned. In order to conserve the total momentum, the fluid must be at least *binary* so that the optically active molecules can be pushed in a certain direction away from something (they do not lean against the magnetic field, because the field only gives information about the axial vector and nothing more). This should result in a *partial mass flux* of each component in the optically active mixture (in the physical system as drawn in Figure 1).

The condition for a coupling of **P** and ***B*** is therefore some privileged orientation of the rotational amount of the molecules in the magnetic field. At first sight, it may seem that there is indeed a rotational ordering: the molecule has some *magnetic dipole moment* also due to the rotation of the whole molecule (and not only due to the magnetic moments of the electrons and nuclei), because the electric charge of an otherwise neutral molecule is unevenly distributed over the molecule. It is through this small, but not entirely negligible, magnetic moment that the magnetic field and the rotational amount of the molecules seem to be coupled.

The question of whether this really happens deserves all our attention. We will conclude as follows:

If we place a coil inside the external magnetic field of a permanent magnet and drive a certain electric current through it either in this direction or in the opposite direction, we expend the same amount of electric energy in both cases to bring about this change. Since there are no other energy contributions, the total energy of the magnetic field is also the same in both cases. Similarly with any constant magnetic dipole moment in an external field: the total energy does not depend on which direction it is rotated.[5] So also the energy of a rotating molecule (and by the laws of statistical mechanics, the *occupancy of a state*) does not depend on which way the molecule is rotating, provided, of course, that it has the same amount of rotation in the two opposite directions, and hence the same absolute magnitude of magnetic moment [5].

The conclusion is not yet quite complete. The *rotational states* of the molecules are slightly altered by the external magnetic field. The quantum states (and, at the macroscopic level, the phenomena of *ferromagnetism* and *superconductivity*) are determined by the condition that the *magnetic flux* through them is constant, not their magnetic moment.[6] If there were only a few of these states (nuclear magnetic resonance, *NMR*, is an example), we would not be able to find pairs of states with exactly opposite equal amounts of rotation. Although this difference is small in *NMR*, it is the only reason we can observe the arrangement of nuclei in the external field at all. Optically active molecules, on the other hand, have an enormous number of rotational states (at least a few hundred at the temperature that would be required to make the molecules sufficiently mobile), since their chiral structure is only possible at larger molecular masses and dimensions. So we are very close to the classical limit in which there are pairs of states with opposite equal amounts of rotation even in the presence of a magnetic field. Therefore, it would be very difficult to observe any rotational

[5] Postscript (2024): Like in the previous footnote, also this argument is not so clear. Magnetic moments on the quantum level are discrete (frozen quantum states), and so, they do not behave in the same way as the classical magnetic moments (e.g., the coils with continuous electric current). So again, the content of the entire Chapter 2 is questionable. The rest of argumentation in this chapter hints in this direction – although it is somehow confused.
[6] Postscript, 2024: Very unclear. I cannot remember my flux of thought in such a distant time.

ordering of whole molecules in a magnetic field. Computational estimates show that the phenomenon of magnetic separation of optically active mixtures would be completely impossible to detect. In practice, the D_n coefficients are all equal to 0. (However, who knows what might be going on somewhere in the universe with neutrinos, which also have a pseudoscalar internal structure?)

Perhaps someone could think of another possibility of pseudoscalar influence. The most trivial one is this: the substance *M* (as in Figure 1) is made of freely moving charged particles (rare-density plasma). As we know, the external magnetic field governs their orbital angular momentum. The helicity in this case should be the shape of the container. However, a homogeneous magnetic field maps the *isotropic velocity distribution* of the particles at each point inside the container into an identical isotropic distribution at any other point. Therefore, despite the helical shape of the container, we would not be able to measure any current at all.

There are also more unusual possibilities (e.g. the effect of a magnetic field on an electrically conducting chiral crystal with **P** symmetry of electronic states.) For any one I can think of, I have been unable to get a sense that any measurable syntropic current could have arisen in *TE*.

CHAPTER 3
THE LAW OF ENTROPY MAY FAIL IN AN INHOMOGENEOUS MAGNETIC FIELD

In an *inhomogeneous magnetic field*, these things are different in many ways. An inhomogeneous field contains more information than a homogeneous field, because in addition to the direction of the field, there is an additional spatial information related to the *gradient* of the magnetic field.

The system we are going to consider consists of either conductors with stationary electric currents or permanent magnets which generate a stationary magnetic field in the space around them. The conductors are correctly positioned (or the permanent magnets are correctly shaped) so that the stationary magnetic field around them is highly inhomogeneous.

Furthermore, the system in question also includes a large number of electrically charged particles (*low-density plasma*) moving in the magnetic field. The plasma is enclosed in a container and is in *TE* with the walls of the container. The wires or permanent magnets that form the field lie outside the container.

When we asked about the existence of the phenomenon in a homogeneous magnetic field, we had to assume chiral particles for symmetry reasons.[7] In an inhomogeneous field, however, there is a priori no such requirement for pseudoscalar particles, so the particles in the plasma can be ordinary ions or electrons.[8] This is because an inhomogeneous magnetic field, unlike a homogeneous one,

[7] Postscript (2024): Further research revealed that this argument is invalid. It is not obvious to introduce chiral particles, not even inside a homogeneous field. See the footnotes in Chapter 2.

[8] Ions are much heavier than electrons, so the influence of the magnetic field hardly changes their direction. If the field is enough weak, and if plasma is not too dense, then we can easily assume that the effect in consideration is produced only by electrons.

contains also information about a polar vector, e.g. grad ($\boldsymbol{B}^2$), or $\boldsymbol{B} \times$ grad ($\boldsymbol{B}^2$).

Let's assume that the plasma is very dilute. The particles collide with the walls of the container and occasionally with each other, but these collisions are quite rare inside a low-density plasma, so we can say that the particles feel only the influence of the magnetic field. Other effects (electric fields in the plasma, gravity, etc.) are small enough to be neglected.

Let us ask ourselves what this influence of the magnetic field is. In a highly dilute plasma, the electrically charged particles are affected only by the *Lorentz force* due to the thermal motion of these particles in the magnetic field. The trajectories are no longer straight but curved: if the field is homogeneous, these curves are segments of circles or helices, but in an inhomogeneous field the trajectories have a more complex shape.

Let's observe what happens in the time between two successive collisions with the wall. The particle's momentum is constantly changing in direction (but not in absolute size). So we can say that the particle is constantly receiving some information about the magnetic field. In the case of a homogeneous field, it is constantly receiving the same information and travelling along an equally-shaped trajectory all the time. However, if it is moving in an inhomogeneous field, it is successively acquiring different information. The field it is in at any given moment determines how strong a field it will be directed into later. We are no longer dealing with a kind of additive accumulation of mutually independent information, but the information about the field that the particle receives becomes dependent on the information received earlier. When a particle collides with another particle or with the wall of a container, what it has learnt from the field is forgotten, and then the whole complex process of information acquisition starts all over again - with new initial conditions.

It is interesting to note that this transfer of information takes place without a simultaneous transfer of energy. In the classical view, the Lorentz force on a particle is always perpendicular to the particle's velocity vector. Therefore, the energy of the particle does not change and the magnetic field does not expend energy to act on the plasma.

Let us look in a little more detail at what kind of information about the field is actually received by the particles. Well, it's connected to the spatial and temporal symmetry properties of the magnetic field. A magnetic field is a *temporally odd* quantity, which means that it suffers a change of sign if we fictitiously reverse the direction of time. However, in terms of its spatial properties, the magnetic field, expressed in terms of its density $\boldsymbol{B}$, is *an axial vector*. In addition, an inhomogeneous field contains some additional information about spatial broken symmetry.

The picture of the magnetic field in space can be given by the *magnetic field density* $\boldsymbol{B}$, or alternatively, by the *vector potential* $\boldsymbol{A}$. With usual assumption that div $\boldsymbol{A} = 0$ (*solenoidal vector potential*), the field $\boldsymbol{A}$ is everywhere uniquely determined, provided that we know the field $\boldsymbol{B}$ in the whole space. It may seem that in some cases there are several possible solutions of the solenoidal vector potential, e.g. for the case of a homogeneous magnetic field. The apparent multiplicity would not exist if we really knew the field $\boldsymbol{B}$ in the whole space : it cannot be homogeneous everywhere, since the magnetic lines of force form closed loops, irrespective of their size and shape.

The reverse is also true: from the vector potential ***A***, we can uniquely determine the density ***B***. So it doesn't matter whether the magnetic field is expressed in terms of ***A*** or ***B*** – in both cases the field image contains exactly the same information, which only becomes apparent from the field image over the whole space.

We know that a homogeneous magnetic field affects particles in a dilute plasma : they circulate. In this circulation we find all the information about the vector ***B*** (an axial vector, odd in time). And the information about the vector ***A*** ? This is only seen from the information about the field ***B*** in the whole space. If the particles have the opportunity to travel over a sufficiently large region of space between successive collisions (so large that the inhomogeneity of the field is already apparent), then the particles receive and express the information about the vector field ***B*** at the same time as they receive and express the information about the vector field ***A*** – because the two pieces of information are identical if taken over the whole field.

Thus, if we move to the whole space, we can summarise that the particles express not only the information about the time-odd axial vector ***B*** (the well-known "circulation" of particles), but also the information about the time-odd polar vector ***A***.

Each polar vector can be defined by two points T^- and T^+ (Figure 2), which lie along it and are different in some property, or in a strict sense, even opposite. Indeed, a system of two such points has the same symmetry properties as a polar vector.

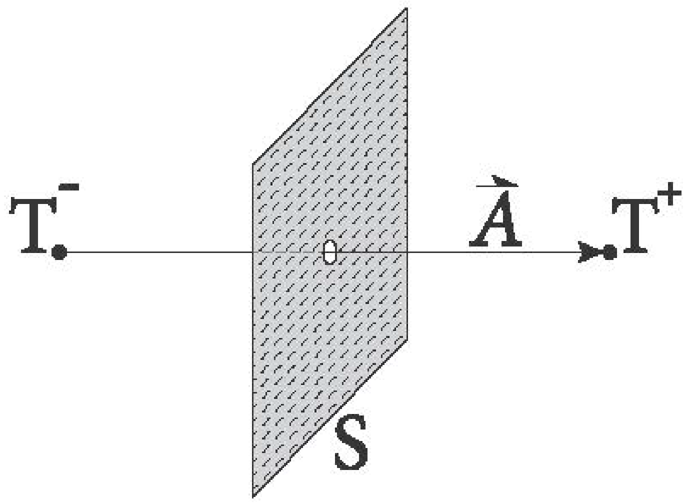

Figure 2.

Each time-odd quantity can be determined by the time derivative of a certain time-even quantity. The time-odd polar vector ***A*** is therefore exactly like this:

At the point T^+ there is a positive time derivative of some time-even physical quantity, and at the point T^- there is an opposite, i.e. negative derivative of the same quantity. It is as if this quantity was passing through the plane *S* to the other side – i.e. it is a flow of some as yet unknown quantity carried by particles.

Theory, known as *thermodynamics of non-equilibrium phenomena*, deals with known flows of *additive* quantities that are conserved inside a closed system: *electric current* (electric charge is carried), *diffusion* (partial mass of an individual component in the mixture is carried), *heat current* (thermal energy is carried).The current coupled to the vector ***A*** could carry a quantity, defined maybe as follows: All those particles which pass through the plane *S* along a given direction are distinguished from those travelling in the opposite direction, e.g., distinguished by the comprehensive trajectory curvature or by the length of the average free path between successive collisions. In these two cases, it is not primarily an additive quantity that is transferred, but some more complex property. On this abstract level, the presented abstract quantity can be further coupled to some physical effect. We do not know yet which kind of effect this is. So, this is why it is difficult to speak of "transfer".

Since symmetry reasons alone do not tell us which property is involved, we will work with a specific example: the motion of charged particles inside the magnetic field of a straight-line electric current.

CHAPTER 4
SETTING UP A SIMPLE PROBLEM : PARTICLE MOTION IN A MAGNETIC FIELD OF A STRAIGHT-LINE ELECTRIC CURRENT

A *stationary* electric current *I* is allowed to flow along a very long, straight-line wire, generating an inhomogeneous magnetic field (Figure 3). The *low-density plasma* is confined inside a space between two concentric tubes of good insulating material. The current *I* flows along the geometric axis of these two tubes. At both ends there are two metal electrodes of circular shape which enclose the plasma inside a *toroidal space* between the two tubes.

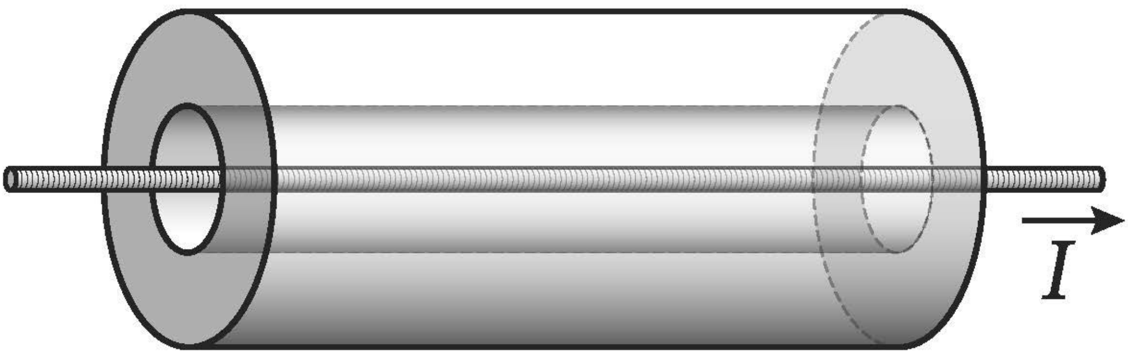

Figure 3.

There is no special excitation of the plasma from the outside; it remains ionised only because of the high temperature of the toroidal container. This temperature is the same everywhere and does not change with time. This creates the conditions for the *TE* of the plasma with its surroundings.

We have already described everything that goes into the system. The charged particles in the plasma are mainly only acted upon by *the Lorentz force* due to the magnetic field generated by the current *I*, and possibly also by an electric field, which will have to be taken into account if it turns out that some internal electric fields are spontaneously generated in the toroidal space due to the events in the equilibrium plasma. In addition, the particles feel short-range, short-lived forces here and there, when there is a collision between two particles or when a particle hits a wall. The scattering at the wall is strongly dominated when the plasma is sufficiently dilute. In this case the interactions between individual particles can be neglected. And, as mentioned in the previous section, it is this low-density possibility that we are interested in.

The physical system we are considering here is very different from those usually studied in *plasma physics*. The first difference that distinguishes our case is considerably low density of the plasma. The average particle trajectory is much larger than the dimensions of the container. The second feature is the perfect thermodynamic equilibrium of the plasma with the whole system. (Indeed, this condition represents the greatest difficulty in practical experiments of this kind.) The third secret lies in the correct strength of the magnetic field: the particles can accumulate most of their information when the radius of magnetic curvature of their trajectories is comparable to that of the toroidal container. This condition is fulfilled only in a weak magnetic field, which means that in practice great care must be taken to protect the plasma from many disturbing influences.

Therefore, although the behaviour of the plasma in the space around electric wires has been extensively investigated (especially in connection with *tokamak*-type projects), it has not shed any light on the problem of interest here. So we will start from the beginning.

The phenomenon can be treated to some extent theoretically. If we initially ignore the interference between several charged particles, we can write an equation of motion that takes into account the *magnetic* and *electric* forces on each particle. This equation determines the particle's trajectory between two successive collisions. For free particles in weak fields, the classical description is quite satisfactory. In the *international system* of units (*IS*), this equation therefore has the form:

$$\boldsymbol{r}'' = \frac{e}{m} \cdot (\boldsymbol{E} + \boldsymbol{r}' \times \boldsymbol{B}) \tag{4}$$

The vector ***r*** desigates the position in space [*x, y, z*]. Here, *e* is the electric charge of the particle, *m* is its mass, and ***B*** and ***E*** are vectors of the magnetic field density and electric field strength. The equation contains a single (') or double ('') derivation by time.

The field ***B*** applied to the particle is determined by the instantaneous distance of the particle to the wire (the scalar radius *r*, which is not to be confused with the vector ***r*** above, since all vectors are written in ***bold*** here). When this is taken into account, the vector equation (4) breaks down into a system of three scalar equations:

$$x'' = \frac{e}{m} \cdot \left[-\frac{b\, x\, z'}{x^2 + y^2} + \boldsymbol{E}_x \right] \tag{5a}$$

$$y'' = \frac{e}{m} \cdot \left[-\frac{b\, y\, z'}{x^2 + y^2} + \boldsymbol{E}_y \right] \tag{5b}$$

$$z'' = \frac{e}{m} \cdot \left[b \frac{(x^2 + y^2)'}{2(x^2 + y^2)} + \boldsymbol{E}_z \right] \tag{5c}$$

The parameter *b* is proportional to the current *I* which creates the magnetic field:

$$b = \frac{\mu_0\, I}{2\pi} \quad , \tag{6}$$

and the quantities E_x, E_y, E_z are the components of the electric field $\boldsymbol{E}$. The z-axis lies in the wire, in the direction of the current I.

If there is no electric field ($\boldsymbol{E} = 0$), the system of equations (5) can be solved analytically [6]. The solution is some function $z = z(r)$, which determines the trajectory of the particle and is expressed by a definite integral :

$$z = z_0 + \int_{r_0}^{r} \frac{[\, v_{zo} + \frac{e\,b}{m} \cdot \ln(\frac{r}{r_0})\,] \cdot \mathrm{d}r}{\sqrt{v_0^2 - \frac{r}{r_0} v_{\varphi 0}^2 - [\, v_{zo} + \frac{e\,b}{m} \cdot \ln(\frac{r}{r_0})\,]^2}} \qquad (7)$$

The above equation is written in *cylindrical coordinates* where [r, φ, z] stands for the particle position, and [v_r , v_φ , v_z] stands for its velocity $\boldsymbol{v}$. The resulting solution depends of course on the initial conditions : the initial distance to the wire (r_o) and the initial velocity $\boldsymbol{v}_o$ = [v_{ro} , $v_{\varphi o}$, v_{zo}]. It is shown (in the numerical simulation, see below) that the magnetic field traps the particle by moving it around a space bounded by some minimum and some maximum distance to the wire. We are particularly interested in Δz, i.e. the distance the particle travels in the z-direction, i.e. in direction from one circular electrode to the other, between two successive collisions with the wall.

If we wanted to see whether a plasma in a *TE* with the walls of a container is drifted somewhere by an inhomogeneous magnetic field (e.g. in the z-direction, thus giving rise to a hypothetical syntropic current $\boldsymbol{j}$ in the plasma), we would have to find the average of Δz, marked as $\langle \Delta z \rangle$, over all possible states in the *TE*, i.e. over all possible initial conditions.[9] These are determined at the instant the particle starts from a point on the wall. In *TE*, this initial condition is the *Boltzmann velocity distribution*.

This above average $\langle \Delta z \rangle$ cannot be calculated analytically. For this reason, and in order to take into account the possible influence of the electric field and maybe even the interactions between the particles, *Milan Hodoščcek* has developed the corresponding computer programs. So, our tandem has undertaken a computer simulation to study the motion of charged particles in rare-density plasma.

CHAPTER 5
NUMERICAL SIMULATION OF PARTICLE MOTION CONFIRMS THE HYPOTHESIS OF CURRENT GENERATION

In most of the examples, the computer calculated the trajectory of a single charged particle dropped into a toroidal space around a straight wire (Figure 4).

[9] Everywhere in this text, the sign ‹...› marks an averaged quantity.

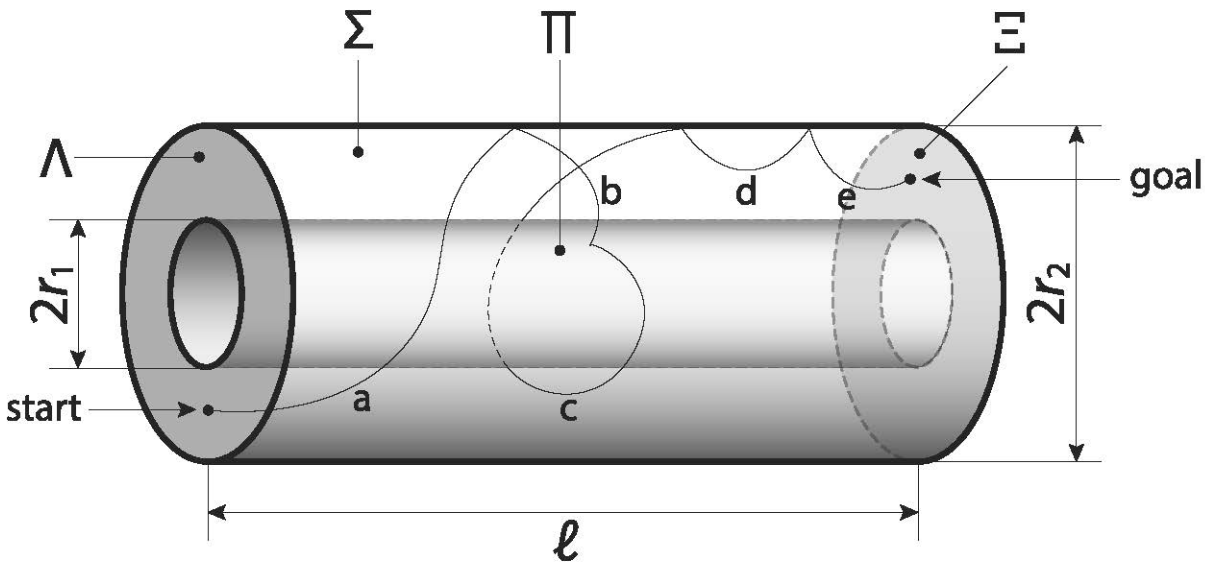

Figure 4 : The toroidal space around a straight wire is bounded by a closed surface ("wall"), whose parts are labelled in turn Λ, Ξ, Π, Σ (left and right electrodes, inner tube, outer tube).

Initially, the particle starts from a randomly chosen point on one of both electrodes, so that the probability distribution across the electrode is constant. The components of the initial velocity are determined randomly as well, but in such a way that the probability distribution of all possible velocities is the *Bolzmann distribution*. The temperature of the walls determines the average squared velocity $\langle v_o^2 \rangle$ in this distribution.

When the particle leaves the wall, it follows the system of equations (5) and travels along the trajectory *a* (see Figure 4). To solve this system, we used the *Bobkov* method [7]. This method is superior to the classical *Runge-Kutta* method because errors in tracing the particle trajectory are not added but averaged. The trajectory step can be increased by a factor of five and we can still maintain the same accuracy as with the Runge-Kutta method – and thus reducing the computation time by a certain factor.

Sooner or later, the particle hits the wall again. If this happens at the area Π or Σ (insulator), then the particle instantly forgets the former momentum of motion which is in tune with the physical reality. The particle scatters with the wall, a new starting velocity is assigned to it, and the whole procedure continues (see the trajectories *a*, *b*, *c*, ... in Fig. 4) until the particle lands on one of both electrodes (areas Λ or Ξ). In that moment, a *goal* is recorded on the left or the right side.

We imagined that the plasma is a rare-density *electron gas*, formed by *thermal emission* from the walls and in *TE* with them. All parts of the walls should have the same *work function* for electrons, so the probability of an electron evaporating from the left electrode is the same as the probability of an electron evaporating from the right electrode. Therefore, after each goal, it is determined impartially from which electrode a new electron will evaporate. The game is repeated in this way, and after a large number of hits on each side, it may become clear that the difference in goals is substantially too large and can no longer be explained by statistical fluctuations. But this may be precisely the hypothetical *syntropic current* in the plasma.

However, there is still a long way to go to confirm this, because great care has to be taken to ensure that the numerical simulation takes into account everything that would happen in a real plasma and can affect it significantly. In this text, we will point out such dangers as they arise, when it is easiest to avoid them.

We will express all the necessary parameters in *dimensionless* form. We first describe the so-called *basic case*, which is defined by the following data:

$\frac{e}{m} = 1$ (8a)

$\langle v_0^2 \rangle = 1$ (mean sqare of particle velocity) (8b)

$b = 1$ (parameter proportional to electric current along the central wire) (8c)

$2\, r_1 = 1$ (inner diameter) (8d)

$2\, r_2 = 3$ (outer diamter) (8e)

$\ell = 4$ (tube length) (8f)

$E_x = E_y = E_z = 0$ (electric field strength) (8g)

It is not difficult to show that, for these data, the radius of the toroidal container is approximately the same as the radius of magnetic curvature of the electron trajectories. In the following, all data not explicitly given will be as in the *basic case*.

In the basic case, the ratio of the areas of the outer and inner tubes is 3. Therefore, three times as many electrons evaporate into *TE* from the Σ region as from the Π region. Three times as many electrons must also arrive (in the stationary state) because these two walls are made of insulating material.

However, the simulation shows that this is not the case. The corresponding collision ratio was slightly greater than 3 (approximately 4). This means that the electron deficiency on the inner tube results in some radial electric field (E_r) which pulls the particles towards the inner wall, so that the corresponding collision ratio is exactly 3. This variant with a radial electric field, determined by the equations:

$$E_x = \frac{x\, E_0}{\sqrt{x^2 + y^2}} \tag{9a}$$

$$E_y = \frac{y\, E_0}{\sqrt{x^2 + y^2}} \tag{9b}$$

$E_z = 0$ (in the basic example) (10)

should be called *variant A*.

We also tried with another variant (Figure 5). In this design, the plasma can generate an electric field only along the z-axis (with zero value in the basic case), and there is no electric field in the radial direction, due to the short-circuiting between the inner and outer rings. When an electron collides with an inner or outer ring, it can evaporate back into the vacuum from the inner ring (probability ¼) or from the outer ring (probability ¾). This is *variant B*.

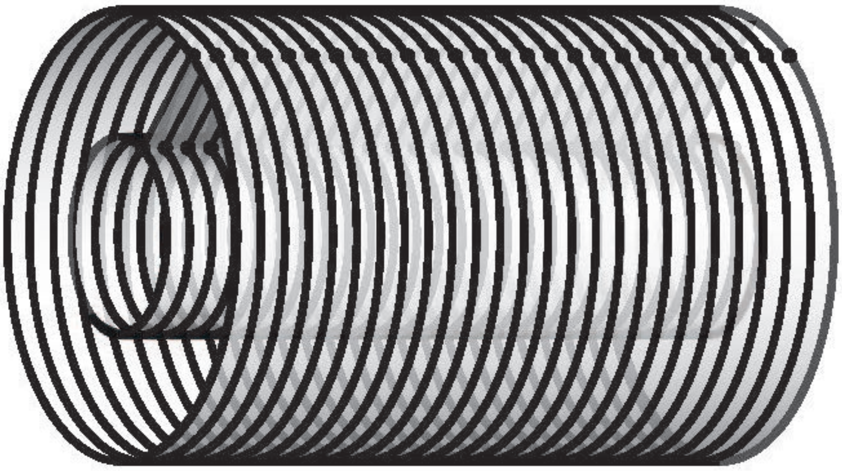

Figure 5 : The two tubes are composed of a large number of thin conductive rings which are insulated from each other. The complanar rings are connected by wires which, for clarity, are routed right through the plasma space in the Figure.

Similarly, we compared the number of electrons that collide with the Λ or Ξ region with the number of particles that collide with the Π or Σ region. This ratio was also not exactly right (basic case, variant B: ratio 0.27 instead of 0.33), which means that the circular electrodes would not get back all the electrons if there is a balanced thermal emission. We have not corrected this ratio with some new electric field, because the picture of this field between the corresponding wall areas would not be simple. So some analogy of the variant B would come into play: now all four zones (walls Λ, Ξ, Π, Σ) would be made of conducting material and all of them would be short-circuited. We did not do this because in such a design we would have had to give up the electric field in the *z*-axis direction, the effect of which on the plasma we studied later. We did something else, which was simply to get around the problem. Our analyses of the behaviour of the individual particles led us to believe that the uncovered loss of electrons mentioned above was not decisive for whether or not the hypothetical syntropic current in the plasma was generated. The phenomena at the electrodes only quantitatively affect the magnitude of this current. In this respect, the results of the simulation of particle motion in an infinitely long double tube, which will be discussed towards the end of this chapter, were particularly convincing. In this case, the two electrodes are very distant and therefore phenomena in their vicinity do not need to be taken into account. We estimated that the error due to this simplification was less than 10% in all our cases, which is already below the statistical error of our calculations. In the system of equations (5) we have therefore considered, within the limits of our accuracy, the electric fields as they would actually be generated in the experimental apparatus. For example, for the basic case in the variant B, we are allowed to write that everywhere $\boldsymbol{E} = 0$, provided that all the internal surfaces have the same *electron work function*.

At this point, we can ask whether low-density plasma can be presented with a single charged particle. A brief calculation shows that (for laboratory-size measurements) we are allowed to ignore interactions between particles in the plasma up to a particle density $n \approx 10^{10}\ \mathrm{m}^{-3}$. In one case, we have also taken into account isotropic scattering on the neighbouring plasma particles (those that approach the particle under consideration at randomly chosen instants). Since these collisions were rare, we did not observe any change in the resulting flux.

The more important question is whether the results for a single particle averaged over a sufficiently long time (we did the respective math) are identical to the average over a large number of particles. Since our particle roams freely in toroidal space, eventually visiting all the places that would otherwise be occupied by many other particles, this assumption is obviously justified.

The computation time was very long. The number of collisions of the particle against the wall was about $1{\cdot}10^{4}$, both in the basic case and in the cases with a different choice of input data. We plotted the difference of "goals" ($N = N_{\Xi} - N_{\Lambda}$) versus the dimensionless time t. After a thousand collisions, it started to appear that the difference N was out of statistical fluctuations. The derivative $J = \mathrm{d}N/\mathrm{d}t$ of the smoothed function N(t) was different from 0. This confirmed the hypothesis of the origin of the syntropic current J (related to the current density $\boldsymbol{j}$, proportional to J in numerical computation) which we call *the syntropic current*.

We worked through the *basic case* in both variants, A and B. In the variant A, we first had to determine the correct size of the constant E_o in equations (9). By experimenting, we came up with the result
$E_o = -\,0.045 \pm 0.005$.

We then compared the flux J for both variants :
$J = (8 \pm 2) \cdot 10^{-3}$ (variant A),
$J = (9 \pm 1) \cdot 10^{-3}$ (variant B).
So also the radial electric field does not affect the current significantly. All other cases were then treated only in the variant B.

Some of the results shown in Figure 6 confirmed the following assumptions:

- The syntropic current J is an *odd function* of the magnetic field density (proportional to the parameter b in dimensionless computation). Thus, for $b = +\,0.7$, the syntropic current is $J = +\,(7 \pm 1) \cdot 10^{-3}$; and for $b = -\,0.7$, it is $J = -\,(7 \pm 1) \cdot 10^{-3}$. If $b = 0$, then of course $J = 0$. The direction of the resulting flux J is the same as the direction of the current I which forms the magnetic field.
- The current J reaches the extreme value at $b \approx 1$. Then the radius of magnetic curvature of the electron trajectories is approximately equal to the radius of the toroidal container, so the electrons are picking up the most information about the inhomogeneous magnetic field along their path.
- If the magnetic field is very weak ($b < 1$), the dependence of J upon b is likely to be approximately linear. However, if the field is too strong (b ▯ 1), the function $J(b)$ asymptotically approaches 0.

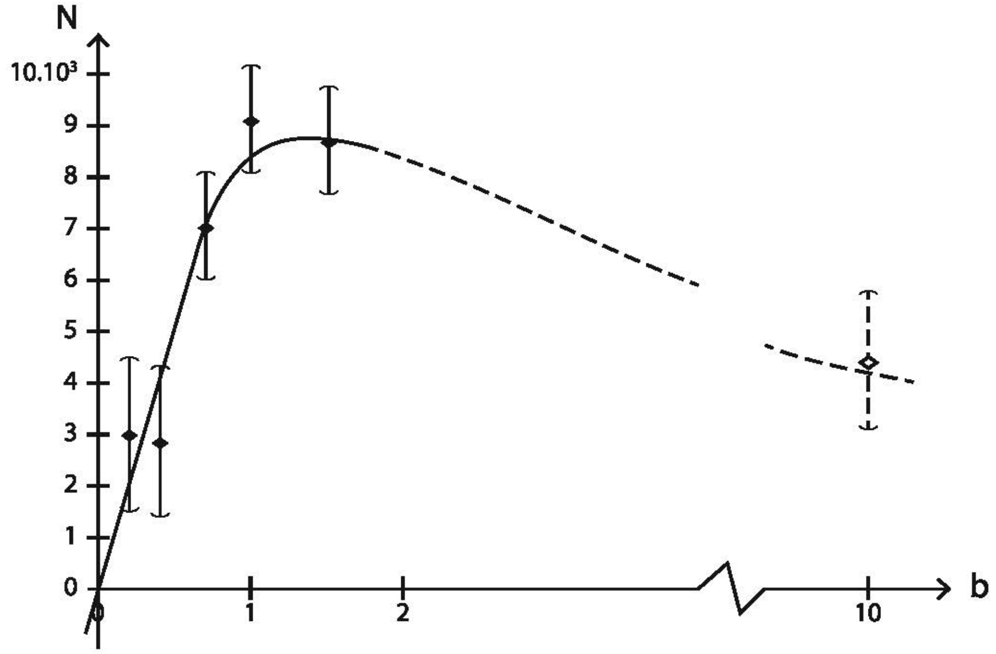

Figure 6 : Syntropic current vs. electric current along the central wire (basic case). The estimated statistical variances are indicated. The result for $b = 10$ is not reliable (the convergence of the algorithm has been verified only for $b \leq 1.5$).

In the next step, we dropped the condition $E_z = 0$, i.e. the short-circuit between the electrodes Λ and Ξ. Between the electrodes we connected an ohmic resistor R (Figure 7), so that the syntropic current J had to overcome a certain voltage ΔU. We achieved the homogeneity of the electric field between the electrodes by a mental trick : we extended the two electrodes on the outside (dashed in the Figure 7) and charged the surface Π with a suitable electric charge.

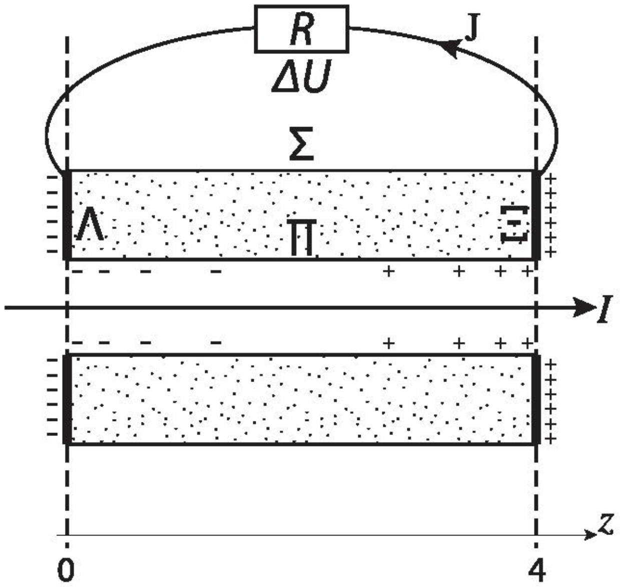

Figure 7.

This is only feasible in the variant A, but we still calculated with variant B, which gives (within our accuracy) the same results. Moreover, we soon realised that the current J is mainly affected only by the voltage between the electrodes and not by the exact picture of the electric field. For example, we obtained the same current J in the following two cases:

In the first case, the electric field $E_z = -0.05$ was homogeneous over the whole interval $z = [\,0\,;\,4\,]$.

In the second ("the double-grid case"), the field E_z was such a function of the coordinate z :
$E_z = -0.2$ over the interval $z = [\,0\,;\,0.5\,]$,
$E_z = 0$ over the interval $z = [\,0.5\,;\,3.5\,]$,
$E_z = -0.2$ over the interval $z = [\,3.5\,;\,4]$.

The voltage ΔU is the same in both cases.

Therefore, the fixed data $E_x = E_y = 0$, $E_z =$ const. were inserted into the equations (5), and then we calculated the magnitude of the current J at various values of the parameter E_z. The results for the basic case and for the case with a small gap between both tubes ($r_1 = 0.9$; $r_2 = 1.1$) are shown in Fig.

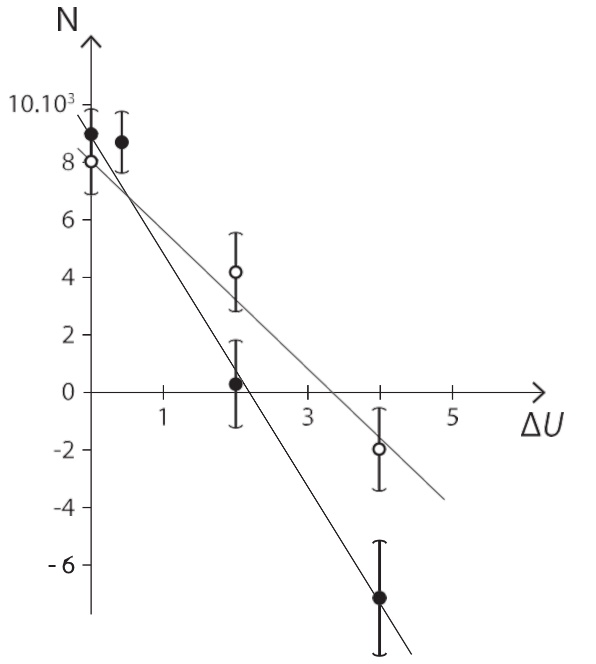

Figure 8. Syntropic current versus electrical voltage between the electrodes, for two different cases:
♦ basic case,

○ the case with a small gap between both tubes.

If we significantly reduce the spacing between the two concentric tubes ($r_2 - r_1$), the current J does not change at $\Delta U = 0$.

If the current $J > 0$ (Fig. 8), the particles travel on average *against* the external electric field (due to the voltage drop across the resistor R) and therefore they lose kinetic energy in the electric field. We observed the average $\langle v^2 \rangle$ of all the particles hitting the walls, and we found that it dropped below 1. It is only when the walls thermalize the plasma again that the particles just starting from the walls again have $\langle v^2 \rangle = 1$. This means that the electrical power being consumed at resistor R is coming from the internal (thermal) energy of the walls of the plasma container. In the next section, a more detailed analysis of the energy situation will refute each of the other possibilities.

One of the parameters that we varied was the length of the container ℓ . Some of the results shown in Fig. 9 suggest that for small lengths ℓ, the value of the current J limits towards the value of $J \approx 8{\cdot}10^{-3}$. The average free path of the particles is then very small, so the frequency of collisions with the walls is high. The difference of hits ΔN remains practically unchanged, however, probably because at very short free paths the particles cannot yet acquire sufficient information about the magnetic field.

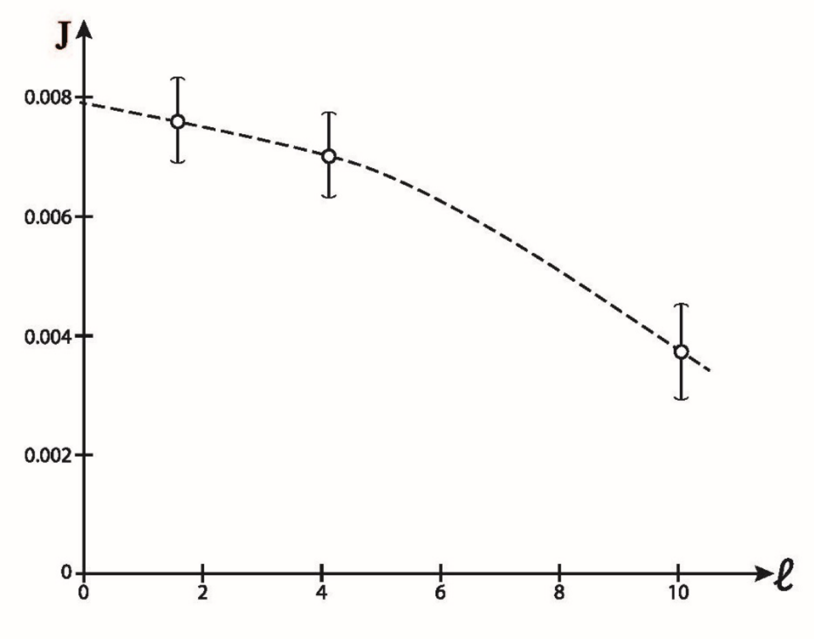

Figure 9: Syntropic current versus tube length ℓ (b = 0.7 ; all other data as for the basic case).

We tried to find out a little more about how the effect depends on the *free path* of the charged particles. From a point near the central wire, we sent 12 particles *isotropically* in all directions (in the directions towards the icosahedron's vertices, with the starting point at its centre), so that they all had the same absolute initial velocity, and observed the average displacement $\langle \Delta z \rangle$ of all twelve particles. It was (for t □ 1) approximately proportional to the fifth power of the travel time (t) or the free path. This dependence is of course different when we consider the situation in *TE* : the relaxation time ($t = \tau$) is then of the order of unity (accordingly to tube dimensions); and also all possible starting points and velocities have to be considered.

So we went back to the basic case and related cases, but this time we sorted the results for trajectories between two consecutive collisions by the relaxation time τ and the displacement $\langle \Delta z \rangle$ travelled by the particle during that time τ. Figure 10, which shows the ordered statistics for two cases, convinces us that the more time a particle has to sense the magnetic field, the more pronounced is the effect of orientation in the magnetic field. Therefore, particles with a very long relaxation time τ are the main contributors to the syntropic current. The average relaxation time is $\langle \tau \rangle = 1.5$ (for the basic case). Only 1% of the calculated trajectories have a relaxation time $\tau \geq 17$, but even this small fraction contributes as much as 50% of the syntropic current! In the second case (small gap between both tubes), the corresponding values are : $\langle \tau \rangle = 0.5$; 2.5 % of all particles have $\tau \geq 4$ and give 60% of the syntropic current.

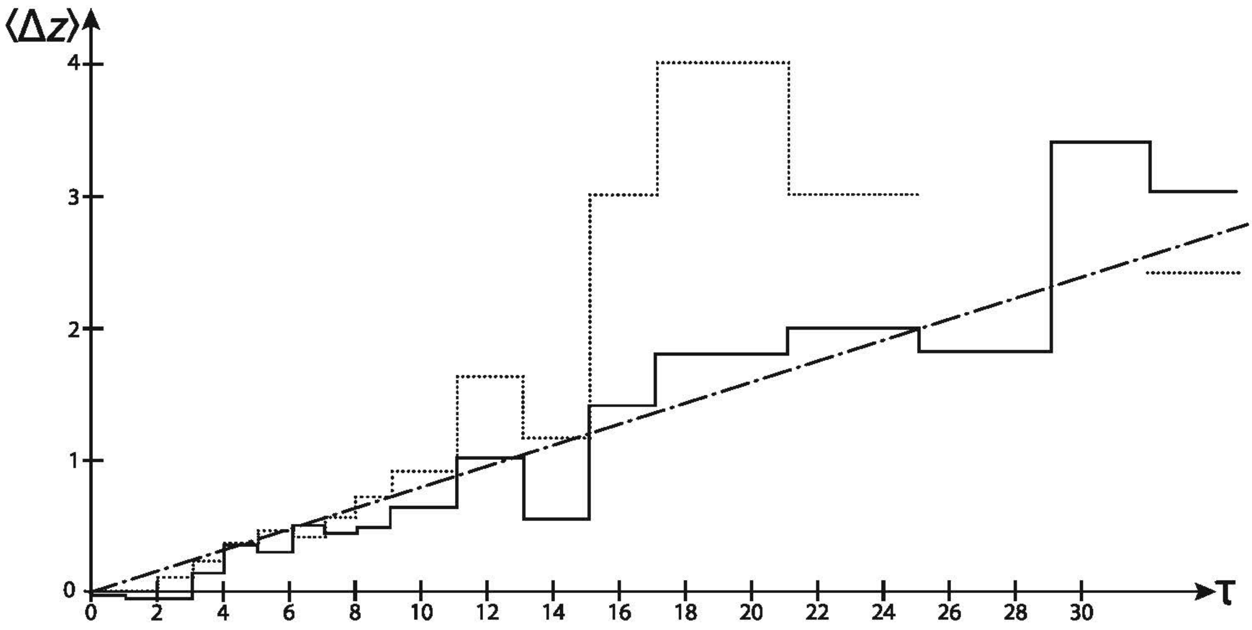

Figure 10 : Average distance travelled by a particle along the *z*-axis direction, between two consecutive collisions with the wall (time τ). Inside the interval $\tau \leq 11$, a linear relationship is evident: $\langle \Delta z \rangle \approx 0.075\ \tau$. For $\tau > 11$ the dispersion becomes large due to few particles with very long relaxation time τ. Drawn diagram: the basic case. Dotted diagram: the case with a small gap between both tubes ($r_1 = 0.9$; $r_2 = 1.1$).

We have analysed the trajectories of particles with very long relaxation time τ in more detail. In the absence of a magnetic field, it is practically not the case that the free path of a particle is ever accidentally extremely long. However, the magnetic field makes sure that some particles (those with the right initial conditions) get "trapped" in the magnetic field and circulate around (or rather: wrap around) the inner tube for a long time before hitting the wall again. In the basic case, the direct paths from one electrode to the other, i.e. of the type (Λ, Ξ) or (Ξ , Λ), are particularly important. On the way between the two electrodes, the particle of course continues to wrap around the narrower tube. The difference between the number of (Λ, Ξ) and (Ξ , Λ) events already gives most of the syntropic current. However, in the case of a smaller gap between both tubes, it is the (Π, Π) type trips that contribute most to the syntropic current.

Finally, we considered an infinitely long pair of concentric tubes ($\ell \to \infty$), between which the plasma is in *TE* with the walls. There are no electrodes here, so we did not count the goals, but observed the travel of a large number of particles (N = 8000) along the direction of the *z*-axis. These particles start from either the inner or outer tube, and we let them travel until the first following collision. In the absence of an electric field (variant B, $E_z = 0$), many of the particles would wiggle around in the magnetic field for an extremely long time before hitting one of the tubes again. The displacement Δz of these gliders was in almost all cases strongly positive. We have arranged some of the results of the statistical processing of the trajectory data in a table showing the distribution of particles along the axial (Δz) and azimuthal ($r \cdot \Delta\varphi$) components of the free path (see also the commentary to Fig. 11). Due to azimuthal symmetry, only the upper half of the table is shown ($\Delta\varphi > 0$). In place of the zeros, blank boxes are left.

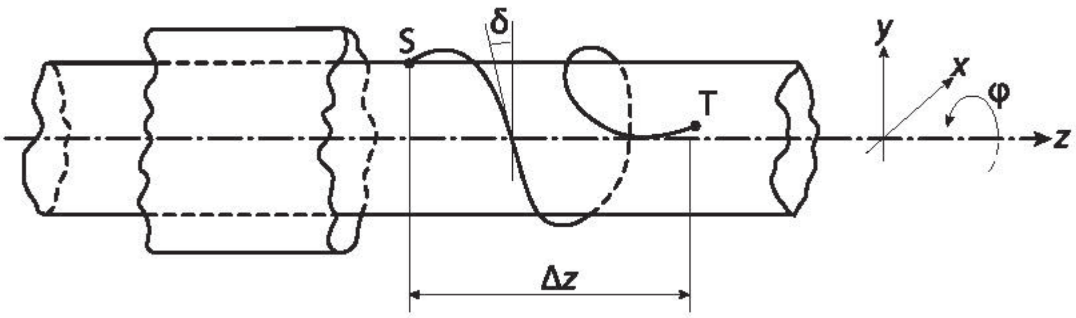

Figure 11: Between two successive impacts on a wall, the particle travels from the point *S* to *T*, changing its position by Δz in the *z*-axis direction and by $r \cdot \Delta\varphi$ in the azimuthal direction.

Δφ \ Δz		−1.6	−1.6	−1.6	−1.6	−1.6	−1.6	−1.6	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	ΣN
2.0														2		2	2	3		2	2	1	2	16
1.8												1	1	1	1		1							5
1.6														2	2									4
1.4											2	5	1	2	3	1	1	1		1				17
1.2									1	5	7	6	2	4	1		2	1						29
1.0						3	5	9	15	8	8	4	2	6	1	2								63
0.8				4	4	13	14	19	10	21	9	6	7	2	1	2	1		1					114
0.6		1	3	7	13	18	23	20	26	27	20	10	8	7	4	1	1							189
0.4		3	4	12	12	29	46	79	88	49	35	19	8	5	2	2	1							394
0.2	1	2	8	14	24	58	128	245	233	118	52	24	8	7	4		2							928
0	2	5	3	9	25	83	250	785	720	230	75	26	7	3	6	2								2231
ΣN	3	11	18	46	78	214	466	1157	1093	458	208	101	44	41	25	12	11	5	1	3	2	1	2	4000

Table: Distribution of particles according to $\Delta\varphi$ and Δz. There are 4000 particles starting in the *TE* from an inner or outer tube of infinite length. The angle $\Delta\varphi$ is given in radians. Parameters: $r_1 = 0.9$; $r_2 = 1.1$; $\langle v^2 \rangle = 1$; $b = 0.7$; $\boldsymbol{E} = 0$.

We see that for $\Delta\varphi < 0.8$, the centre of gravity of each row lies quite near the value $\Delta z = 0$. But it is different with $\Delta\varphi > 0.8$: then the centre of gravity lies close to the drawn diagonal line that gives an approximate average displacement $\langle \Delta z \rangle$ as a function of the azimuth $\Delta\varphi$:

$$\langle \Delta z \rangle \approx 1.33 \cdot |\Delta\varphi| - 1.07 \qquad (11)$$

The position and slope of this line gives us some information about the shape of the trajectories. For particles with a sufficiently long free path (and such particles are essential, as seen from the table), these are more or less pronounced *helices* with a *pitch angle* δ :

$$\delta = \text{arctg}\left[\frac{\Delta z}{r\,\Delta\varphi}\right] \approx 40° \text{ (approx. result for the average)} \qquad (12)$$

Computations have also been carried out for the case of an axial electric field ($E_z = -0.05$, the particles travel opposite to the electric field and therefore they lose kinetic energy). In this case, the syntropic current has dropped to ½ of the original value and, of course, so has dropped also the helical pitch expressed by tg δ. (In Figure 8, we have already seen this influence of voltage between both electrodes.) The angle δ also depends on the parameter b.

The velocity vector of a typical "sailor", in the narrow space between the two tubes, mainly consists only of axial and azimuthal components, which are approximately conserved during the time between two successive collisions, so that the pitch angle δ is constant during this time. The azimuthal component does not contribute to the Lorentz force, while the force due to the axial component of the velocity causes the particle to circulate (or to travel helically) around the inner tube. This centripetal force is directed inwards (and therefore allows circling around the inner tube) only for a positive axial component of particle velocity ; particles with a negative component are turned outwards towards the outer tube by the magnetic field. Therefore, the free path of the particles depends on the axial velocity component v_z. Those particles travelling in one direction are carried far by the magnetic field, while those travelling in the opposite direction are scattered more rapidly on the walls. This *anisotropy* in the free path (and in the relaxation time) causes the average particle axial velocity $\langle v_z \rangle$ to be different from 0. If all particles started at the same time, their velocity distribution would still be isotropic for a short time after the start, but as soon as the particles with a short relaxation time start to drop out of the game, the average $\langle v_z \rangle$ would skew in favour of the particles with a longer free path and therefore with a favoured direction of travel. This is the essential mechanism for the emergence of syntropic current. The topological properties of the container in which the plasma is confined (in this case, the torus) also seem to play an important role in this mechanism.[10]

The picture of streamlines is indeed a little more complicated. In the case B, two syntropic currents, axial and radial, are produced which are coupled to each other. However, this is not essential for a basic understanding of the cause of the phenomenon, so we have simplified the representation.

Let us return to the hypothesis stated in Chapter 3 : the vector of the syntropic current density $\boldsymbol{j}$ is *collinear* and proportional to the *vector potential* $\boldsymbol{A}$. In fact, now we can no longer expect that this is necessarily the case, since, as we have seen, the walls of the container, with their spatial characteristics, are also involved in the phenomenon.

We have looked for a picture of the streamlines (vector field $\boldsymbol{j}$) in toroidal space. Two cases have been worked on, firstly the basic case in the variant A. There is no radial flow here, so the current density $\boldsymbol{j}$ was indeed (within very loose precision) collinear with the vector field $\boldsymbol{A}$:

$$\boldsymbol{A} = (A_r, A_\varphi, A_z) = [\ 0,\ \ 0, -b \ln\left(\frac{r}{r_0}\right)\ ], \qquad (13)$$

where r_0 is an arbitrary constant. We determined it so that the radial dependence of the vector field $\boldsymbol{A}$ was most similar to the radial dependence of the vector field $\boldsymbol{j}$. However, an ideally convincing correspondence was not found.

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[10] In the A iteration, the average of the $\langle v_z \rangle$ for many paticles just before re-scattering against the wall is 0 again. This holds even though the particles are moving in the axial direction throughout. This is because this average is taken over particles, not over time, and different particles suffer a different relaxation time τ. In the case B, however, this average is different from 0 due to the influence of the radial current.

Then we calculated the following example : In addition to the azimuthal magnetic field which is related to the current through the central wire, also an axial component of the magnetic field (the component B_z) acts on the particles. In practice, this can be realised by winding an additional coil around the outer tube. In this case, the vector potential also contains an azimuthal component :

$$\boldsymbol{A} = [\, 0, \tfrac{1}{2} B_z\, r, - b \ln (\tfrac{r}{r_0})\,] \qquad (14)$$

When we calculated the vector field $\boldsymbol{j}$ (again in the variant A, because in the variant B the directions of both vector fields cannot match, due to the radial component of the current $\boldsymbol{j}$), we found something similar to the basic case : the match between both vector fields ($\boldsymbol{A}$ and $\boldsymbol{j}$) was good enough with regard to direction, but less so to the rest. In this case, the current $\boldsymbol{j}$ shows also an azimuthal component, which means that the "sailors" are travelling around the inner tube mainly along trajectories corresponding to the *left-handed helix* (if the quantities B_z and b are positive).

Finally, let us find a quantitative value that indicates how distinctly the initial chaotic movement of particles is diverted into a specific direction. We shall define the *rectifying factor* η by the relation:

$$\eta = \frac{|<v>|}{<|v|>} \qquad (15)$$

In each case, the value of η must lie between 0 and l. If the orientation was perfect, with all particles travelling in the same direction all the time, quite parallel to the z-axis, the factor η would reach unity. From the above results we can easily calculate η for our cases. For example, in the basic case we get $\eta \approx 0.02$, which is by no means negligibly small.

CHAPTER 6
THE ENTROPY LAW DOES NOT FIT THE DESCRIPTION OF THE PHENOMENON HERE

The final judgement of whether *a syntropic current* really occurs inside a plasma is, of course, a matter of Nature, and not of some ideas which can sooner or later force reality. Therefore it will be necessary to patiently wait for the results of laboratory experiments and other observations. At the time of writing (Spring 1984) the experiment is still in preparation because of a number of technical problems.

The results of the previous chapter are convincing at first sight, but one could find many objections to them. It is possible that the hypothetical syntropic current $\boldsymbol{j}$ does not flow after all, because some apparently "unimportant" detail (that was not taken into account in the numerical simulation) prevents it from doing so. For example, we have not taken into account the radiation of charged particles because of their irregular motion. But a brief calculation shows that the effect of radiation can be completely neglected. Furthermore, we have not taken into account that the syntropic current has its own magnetic field, which slightly modifies the original one. Even this influence is negligibly small under the conditions of a simple laboratory experiment. Thus, one could find any number of objections. The more important question now is whether, if the not-yet-fully-confirmed hypothesis of the syntropic current is correct, the entropy law is really no longer valid.

Let us draw a variant of the whole system whose entropy we are interested in (Fig. 12, compare also with Figure 3):

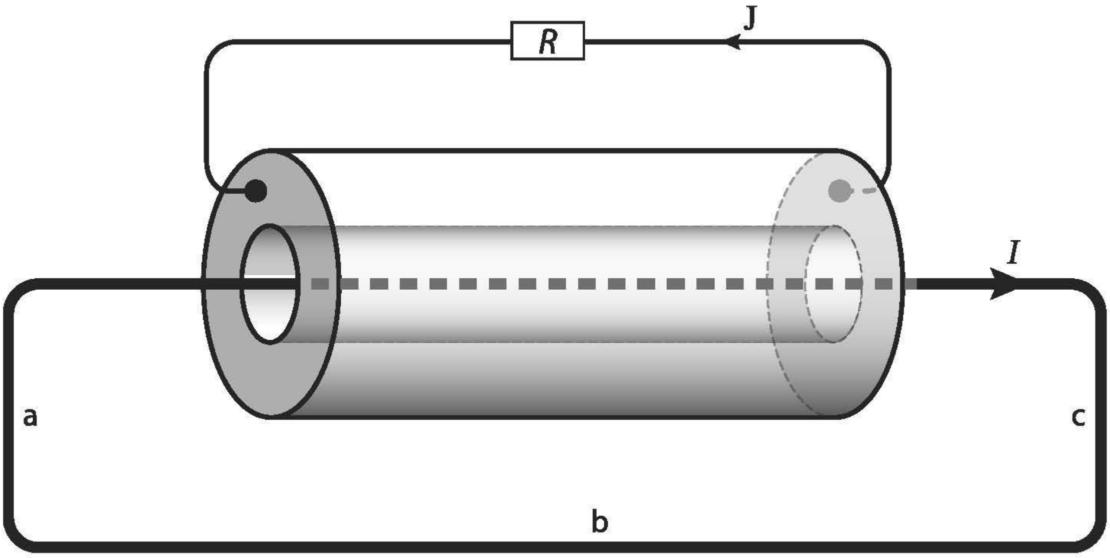

Figure 12 : A wire with an electric current I is made of a *superconducting* material and is short-circuited. Its sections a, b, c are enough far from the torus, so we can calculate with the magnetic field of a straight wire in the plasma region. The figure shows a physical system which is self-contained, isolated in all respects from its surroundings, and can therefore be considered as a self-contained whole. The syntropic current J is generated between both electrodes. In the previous section, it was observed that plasma (and with it the walls of the container) cools down while the resistor R heats. The temperature difference between these parts of a closed system increases. This system is very simple. It consists of only four elements: the plasma, the container, the resistor R and the superconducting wire with the current I. If the wire is ignored to begin with, the entropy of the whole system is obviously reduced.

Over time, the temperature difference between the plasma and the resistor R stabilises and, by means of classical heat conduction, returns all the energy back to the plasma. The phenomenon becomes completely stationary. Its existence still contradicts the entropy law (if we do not count the entropy of the central wire), since the energy dissipated at the resistance R can also be used to do some useful work. The inhomogeneous magnetic field is the *Maxwell's demon* that directs the plasma particles (with the help of the container walls), while the demon does not exhaust itself during the process. But is this really the case ? Let us also consider the central wire and show that the syntropic phenomenon has no effect whatsoever on the current I that forms the magnetic field!

The superconducting wire (imagine some exotic material that is superconducting at the temperature required for sufficient plasma density) is coupled to the rest of the system solely by a magnetic field. It is true that stationary electric fields are also generated in the torus, which, among other things, drive the current J, but do not affect the current I. (Anyone who does not believe this should imagine, instead of an ordinary superconducting wire, a coaxial conductor, whose outer metal sheath protects the inner superconducting conductor from external electric fields.)

The magnetic field is the sum of two contributions : The first part is due to the current I , and the second part is due to the current J (or the current density $\boldsymbol{j}$ inside the plasma). We will not consider the influence of the first part on the current I, since it is known that the intrinsic magnetic field maintains the current in a closed superconducting wire. This leaves the influence of the second part. Since this part of the magnetic field is also stationary (because of the stationarity of the whole phenomenon established above), it does not induce any electrical voltages in the superconducting loop and therefore does not change the current *I*. Thus the stationarity of the current *I* is also confirmed. The whole system (Figure 12) can remain in the conditions necessary for its operation for any length of time. The energy dissipated in the resistor *R* does not drain off the energy of the magnetic field: a stationary magnetic field cannot transmit energy. This can be seen also from the fact that the Lorentz force acting on a particle is always perpendicular to the velocity vector of that particle. Also, the amount of the kinetic energy that is continuously lost as the particles overcome the electric field inside the torus is not restored in the magnetic field, but only on the walls of the container.

There is another variant of the physical system (Figure 13) : The source of the inhomogeneous magnetic field is a permanent magnet M with iron poles (N, S) at both ends that are shaped as shown in the sketch. The solution of the *Laplace equation* of magnetostatics for this case shows that the field of such a magnet differs arbitrarily little from that of a straight wire, provided that r_1 is sufficiently small, r_2 and ℓ are sufficiently large, and the angle ϑ is not too wide. Only a segment P of the plasma torus remains. The syntropic current is smaller than in the "basic case" because the azimuthal displacement of the particles ($| r \cdot \Delta\varphi |$) is upward limited, which excludes the best "sailors". However, the current *J* occurs also in this case. This was confirmed by a computational analysis of particle trajectories.

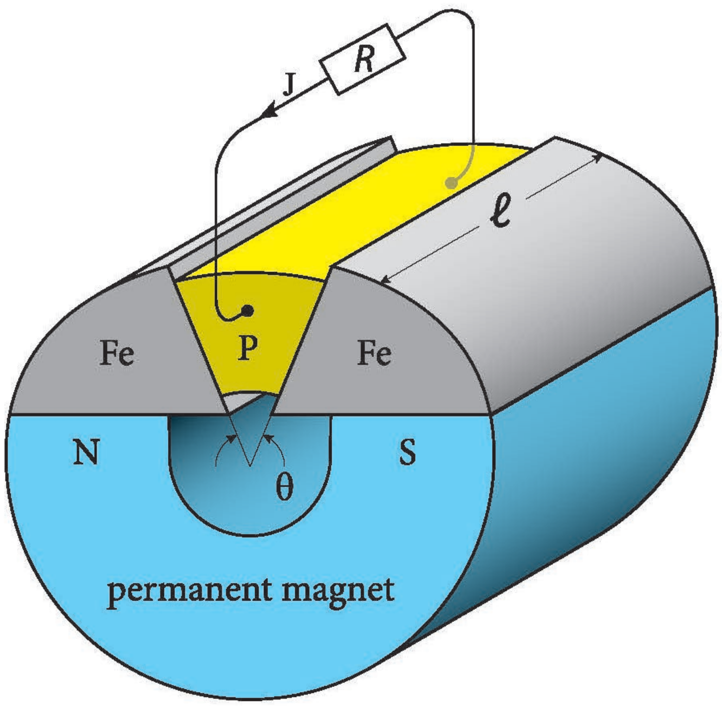

Figure 13.

So even the field of a permanent magnet can sustain a stationary syntropic phenomenon. Here it is even more obvious that the origin of the field does not change with time. The system shown in Figure 13 is not "exotic" and is practically quite feasible. The main problem is the internal surface of the container P, which must have very small *electron work function*. If one of the multilayered coatings with extremely low work function (e.g. the combination Ag-O-Cs) were used, a measurable current J would be obtained already at room temperature. Electric power J^2R is released at the resistor R, the container P remains slightly cooler than the surroundings, and no energy is needed to be artificially supplied to the system.

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