

New results on Ioffe-Ştefănescu magnetic trap

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Abstract

We analyze a magnetic trap based on a magnetic field whose density of energy has an isolated minimum point where the field is non-vanishing. Such elementary magnetic fields appear around suitable configurations of electric circuits.

Section 1 presents some ideas of Ioffe and Ştefănescu for realizing a magnetic trap using a union of electric circuits (an anti-Helmholtz pair and six rectilinear bars), and informs the readers about the actual theories and experiments regarding such devices. Section 2 gives the components of the magnetic field. Section 3 reproduces some simulations with MATHEMATICA that confirm the trapping phenomena.

Mathematics Subject Classification: 78A35, 49K10, 37C10.

Key words: magnetic flow, Ioffe - Ştefănescu magnetic trap, subharmonic functions.

1 Morphology of the magnetic trap

Any magnetic trap is intended to confine electrical charged particles in a small spatial region. This work follows the papers [1], [11], where the authors describe in detail the magnetic trap proposed in 1962 by Ioffe and co-workers [4]. We use a Biot-Savart-Laplace magnetic field H with a local minimum in the magnetic density of energy $f = \frac{1}{2}\|H\|^2$ (sub-harmonic function) at a point where H remains nonzero. The magnetic field is produced by a union of simple piecewise linear electric circuits and two circular coils, with suitable geometry. Such geometrical patterns were studied in Romania by Ştefănescu [6-8] and by Udrişte et. al. [8]-[15].

The configuration of the trap is described in Fig. 1. There are two main magnetic fields which superpose:

- a vertical magnetic mirror field produced by two anti-Helmholtz coils where flows the electric current I_1 (the mirror axis is denoted by Oz);
- a magnetic field generated by a piecewise rectilinear circuit made from six straight lines parallel to the magnetic mirror axis; the electric current flowing through is I_2 .

Let us denote by R the radius of the coils. In a Helmholtz disposition the two coils are separated by a distance $d = 2R$. Such an arrangement insures the best homogeneity of the field in the central region. Being interested to build a magnetic trap,

we choose opposite electric currents in the two coils. In this mirror design particles moving in the vertical direction are trapped indeed. The remainder straight lines insure trapping in the horizontal plane. They are tangent to the two circular coils as in Fig. 1 and intersect the xOy plane in six points, namely $(R, 0, 0)$, $(R/2, R\sqrt{3}/2, 0)$, $(-R/2, R\sqrt{3}/2, 0)$, $(-R, 0, 0)$, $(-R/2, -R\sqrt{3}/2, 0)$, $(R/2, -R\sqrt{3}/2, 0)$.

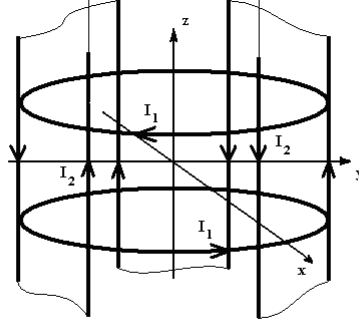


Fig. 1. Ioffe-Ştefănescu configuration of magnetic trap (after [4])

In an actual circuit the six vertical lines are linked by transverse electric lines. We assume that these lines as well as the supply battery are far enough and we approximate the magnetic field of the structure with the field given by six infinite vertical lines. The study of a real finite structure requires additional calculus. We did not take this approach because the horizontal segments connecting the vertical lines would produce an inhomogeneous field in the central indeed very far, or one uses additional compensating coils to annihilate this inhomogeneous field.

Some experiments in physics demand a homogeneous non-zero magnetic field in the central region. This is so, in particular, for Bose-Einstein condensation experiments (BEC), where spin-flip losses would appear in regions with zero magnetic field [3], [16]. The paper [2] presents three designs for a magnetic trap that will simultaneously confine neutral atoms and non-neutral plasma. Various configurations, containing static as well as rotating magnetic fields were proposed. They may easily be taken account for. For our study it is sufficient to add a constant magnetic field in the central region, and then we obtain a total magnetic field H with the density of energy, $f = \frac{1}{2}\|H\|^2$, satisfying

$$H(0, 0, 0) \neq 0, \quad df(0, 0, 0) = 0, \quad d^2f(0, 0, 0) > 0.$$

In this way, the density of energy of the magnetic field would have an isolated non-zero minimum in this region, its trapping characteristic being realized.

Our main concern is to further investigate the Ioffe - Ştefănescu magnetic trap, using the tools in the papers [1], [9-15]. While the papers [1],[11] used an approximation for the intervening elliptic integrals, this paper presents a new approach, using elliptic integrals. We have also changed some geometric factors, trying to obtain the greatest field homogeneity in the central region that contains plasma.

2 Components of the total magnetic field

The computations are made in the particular case $R = 1$. To have the better field homogeneity, the distance between the two coils must be $d = 2R$, but it may be changed in order to see the variations. The two electric currents may be equal, or they may be adjusted to achieve desired magnetic fields.

The 2D magnetic field:

$$\begin{aligned}
 H_x &= \frac{I_2}{2\pi} \left[\frac{y}{(x-1)^2 + y^2} - \frac{y - \sqrt{3}/2}{(x-1/2)^2 + (y - \sqrt{3}/2)^2} \right. \\
 &+ \frac{y - \sqrt{3}/2}{(x+1/2)^2 + (y - \sqrt{3}/2)^2} - \frac{y}{(x+1)^2 + y^2} \\
 &\left. + \frac{y + \sqrt{3}/2}{(x+1/2)^2 + (y + \sqrt{3}/2)^2} - \frac{y + \sqrt{3}/2}{(x-1/2)^2 + (y + \sqrt{3}/2)^2} \right] \\
 H_y &= \frac{I_2}{2\pi} \left[-\frac{x-1}{(x-1)^2 + y^2} + \frac{x-1/2}{(x-1/2)^2 + (y - \sqrt{3}/2)^2} \right. \\
 &- \frac{x+1/2}{(x+1/2)^2 + (y - \sqrt{3}/2)^2} + \frac{x+1}{(x+1)^2 + y^2} \\
 &\left. - \frac{x+1/2}{(x+1/2)^2 + (y + \sqrt{3}/2)^2} + \frac{x-1/2}{(x-1/2)^2 + (y + \sqrt{3}/2)^2} \right],
 \end{aligned}$$

where I_2 is the electric current.

For the magnetic field given by the two coils it is better first to compute its vectorial potential given by

$$\mathbf{A} = \frac{\mu_0 I_1}{4\pi} \oint \frac{d\mathbf{l}}{\|\mathbf{r}\|},$$

where μ_0 is the vacuum magnetic permeability, I_1 the electric current, $d\mathbf{l}$ the element of arc, $\|\mathbf{r}\|$ the distance between a point on the coil and the observation point $M(x, y, z)$ and the integral is taken around one or the other of the two coils. It is easier to work in cylindrical coordinates (ρ, φ, z) . Because $d\mathbf{l}$ rests in a plane parallel with the plane xOy , we find $A_z = 0$. A little computation [5] shows that A_ρ is also zero and the only non-zero component of \mathbf{A} is A_φ . Its expression is

$$A_\varphi(\rho, z) = \frac{\mu_0 I_1}{\pi \xi} \sqrt{\frac{R}{\rho}} \left[\left(1 - \frac{\xi^2}{2} \right) F(\xi^2) - E(\xi^2) \right],$$

where R is the common radius of the coils and ξ is given by

$$\xi^2 = \frac{4\rho R}{(R + \rho)^2 + (z \pm d)^2}.$$

The sign \pm at the denominator is $-$ for the upper coil and $+$ for the other one. The functions $F(\xi^2)$ and $E(\xi^2)$ are the complete elliptic integrals of the first kind, given

by

$$F(\xi^2) = \int_0^{\frac{\pi}{2}} \frac{d\psi}{\sqrt{1 - \xi^2 \cos^2 \psi}} \quad \text{and} \quad E(\xi^2) = \int_0^{\frac{\pi}{2}} \sqrt{1 - \xi^2 \cos^2 \psi} \, d\psi$$

(in the papers written in English, the elliptic function $F(\xi^2)$ is denoted by $K(\xi^2)$).

From the expression of $A_\varphi(\rho, z)$ we obtain the cylindrical components of the magnetic field:

$$H_\rho = -\frac{1}{\mu_0} \frac{\partial A_\varphi}{\partial z}, \quad H_\varphi = 0 \quad \text{and} \quad H_z = \frac{1}{\mu_0} \frac{1}{\rho} \frac{\partial}{\partial \rho} (\rho A_\varphi).$$

The Cartesian components of the mirror magnetic field are $H_x = H_\rho \cos \varphi$ and $H_y = H_\rho \sin \varphi$.

For all these functions, the origin belongs to the domain of definition. But the program, based on local formulas, may give errors for small values of the coordinate x . To avoid this, for $|x| < 10^{-4}$, we approximate the field by the leading terms in the Taylor developments.

3 Simulations using MATHEMATICA

The field of the infinite vertical lines

```
ClearAll [x, y, z, h1x, h1y, iel2]
iel2 = 1;
h1x[x_, y_, z_] := iel2*
(y/((x - 1)^2 + y^2) - (y - 0.5 * N[Sqrt[3]])/
((x - 0.5)^2 + (y - 0.5 * N[Sqrt[3]])^2) +
(y - 0.5 * N[Sqrt[3]])/((x + 0.5)^2 + (y - 0.5 * N[Sqrt[3]])^2) -
y/((x + 1)^2 + y^2) + (y + 0.5 * N[Sqrt[3]])/
((x + 0.5)^2 + (y + 0.5 * N[Sqrt[3]])^2) -
(y + 0.5 * N[Sqrt[3]])/((x - 0.5)^2 + (y + 0.5 * N[Sqrt[3]])^2));
h1y[x_, y_, z_] := iel2*
(-(x - 1)/((x - 1)^2 + y^2) + (x - 0.5)/((x - 0.5)^2 + (y - 0.5 * N[Sqrt[3]])^2) -
(x + 0.5)/((x + 0.5)^2 + (y - 0.5 * N[Sqrt[3]])^2) + (x + 1)/((x + 1)^2 + y^2) -
(x + 0.5)/((x + 0.5)^2 + (y + 0.5 * N[Sqrt[3]])^2) +
(x - 0.5)/((x - 0.5)^2 + (y + 0.5 * N[Sqrt[3]])^2));
```

The mirror field given by the two coils

```
ClearAll[a1, a2, b1x, b1y, b1z, b1r, b1z, b1zpol, b1theta, b2x, b2y, b2z,
b2zpol, b2r, b2z, b2theta, dist, x, y, z, r, z, R, theta, ksi1, ksi2, iel1, iel2]
R = 1.0; iel1 = 1; iel2 = 1; dist = 1;
r[x_, y_] = Sqrt[x^2 + y^2];
ksi1[r_, z_] = 4 * r * R / ((r + R)^2 + (z - dist * R)^2);
a1[r_, z_] = 2 * iel1 * Sqrt[R / (r * ksi1[r, z])] *
((1 - 0.5 * ksi1[r, z]) * EllipticK[ksi1[r, z]] - EllipticE[ksi1[r, z]]);
b1r[r_, z_] = -D[a1[r, z], z];
b1zpol[r_, z_] = D[r * a1[r, z], r] / r;
```

$$\begin{aligned}
ksi2[r_-, z_-] &= 4 * r * R / ((r + R)^2 + (z + dist * R)^2); \\
a2[r_-, z_-] &= -2 * iel1 * Sqrt[R / (r * ksi2[r, z])] * \\
&((1 - 0.5 * ksi2[r, z]) * EllipticK[ksi2[r, z]] - EllipticE[ksi2[r, z]]); \\
b2r[r_-, z_-] &= -D[a2[r, z], z]; \\
b2zpol[r_-, z_-] &= D[(r * a2[r, z]), r] / r;
\end{aligned}$$

$$b1x[x_-, y_-, z_-] = b1r[r[x, y], z] * \frac{1}{\sqrt{1 + \frac{y^2}{x^2}}}$$

$$b1y[x_-, y_-, z_-] = b1r[r[x, y], z] * \frac{y}{x\sqrt{1 + \frac{y^2}{x^2}}}$$

$$b1z[x_-, y_-, z_-] = b1zpol[r[x, y], z]$$

$$b1[x_-, y_-, z_-] = \{b1x[x, y, z], b1y[x, y, z], b1z[x, y, z]\}$$

$$b2x[x_-, y_-, z_-] = b2r[r[x, y], z] * \frac{1}{\sqrt{1 + \frac{y^2}{x^2}}}$$

$$b2y[x_-, y_-, z_-] = b2r[r[x, y], z] * \frac{y}{x\sqrt{1 + \frac{y^2}{x^2}}}$$

$$b2z[x_-, y_-, z_-] = b2zpol[r[x, y], z]$$

$$b2[x_-, y_-, z_-] = \{b2x[x, y, z], b2y[x, y, z], b2z[x, y, z]\}$$

The total field

```

ClearAll [htottruncx, htottruncy, htottruncz]
htottruncx[x_-, y_-, z_-] =
Normal[Series[b1x[x, y, z]+b2x[x, y, z], {x,0,1}, {y,0,1}, {z,0,1}]] ;
htottruncy[x_-, y_-, z_-] =
Normal[Series[b1y[x, y, z]+b2y[x, y, z], {x,0,1}, {y,0,1}, {z,0,1}]] ;
htottruncz[x_-, y_-, z_-] =
Normal[Series[b1z[x, y, z]+b2z[x, y, z], {x,0,1}, {y,0,1}, {z,0,1}]] ;
htotx[x_-, y_-, z_-] = Which[Abs[x] >= 0.00001, h1x[x, y, z]+b1x[x, y, z]+b2x[x, y, z],
Abs[x] < 0.00001, h1x[x, y, z]+htottruncx[x, y, z]] ;
htoty[x_-, y_-, z_-] = Which[Abs[x] >= 0.00001, h1y[x, y, z]+b1y[x, y, z]+b2y[x, y, z],
Abs[x] < 0.00001, h1y[x, y, z]+htottruncy[x, y, z]] ;
htotz[x_-, y_-, z_-] = Which[Abs[x] >= 0.00001, b1z[x, y, z]+b2z[x, y, z],
Abs[x] < 0.00001, htottruncz[x, y, z]] ;
htot[x_-, y_-, z_-] := {htotx [ x, y, z ], htoty [ x, y, z ], htotz [ x, y, z ]};
htotmod[x_-, y_-, z_-] := (htotx [ x, y, z ])^2 + (htoty [ x, y, z ])^2+
(htotz [ x, y, z ])^2;

```

The modulus of the total field

```
ClearAll [datamod, g]
datamod = Table[htotmod[x, y, z], {x, - 0.015, 0.015, .0015} ,
{y, - 0.015, 0.015, .0015} , {z, - 0.015, 0.015, .0015}} ;
g = ListContourPlot3D[datamod, Contours → { 0.0005} ,
ViewPoint → { - 1.5, 1, 1}]
```

The energetic function

```
ClearAll[energ1, energ2, energ3, energ]
energ1[x_, y_, z_] = D[(htotmod[x, y, z])^2, x] ;
energ2[x_, y_, z_] = D[(htotmod[x, y, z])^2, y] ;
energ3[x_, y_, z_] = D[(htotmod[x, y, z])^2, z] ;
energ[x_, y_, z_] = energ1[x, y, z]^2 + energ2[x, y, z]^2 + energ3[x, y, z]^2 ;
ClearAll [dataenerg, generg]
dataenerg = Table[energ[x, y, z], {x, - 0.01, 0.01, .002} ,
{y, - 0.01, 0.01, .002} , {z, - 0.01, 0.01, .002}} ;
generg = ListContourPlot3D[dataenerg, Contours → { 0.00000001, 0.000000005},
PlotRange → { 1, 7}, ViewPoint → { 0.2, 8, 4}]
```

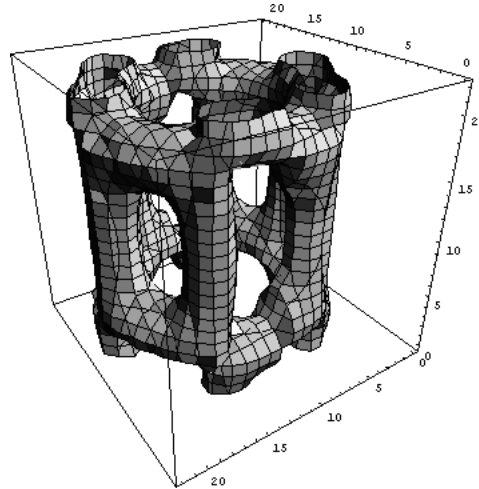


Fig. 2. Constant level set of magnetic energy, $\|H\|^2 = 40$ (arbitrary units)

Field lines

```
ClearAll[x, y, z, y1, y2, y3, t]
NDSolve[{x' [t] == htotx[x[t], y[t], z[t]], y' [t] ==htoty[x[t], y[t], z[t]],
z' [t] ==htotz[x[t], y[t], z[t]], x[0.00]== .2, y[0.00]==0.2, z[0.000]==0.2} ,
{x, y, z}, {t, 0, 400}, MaxSteps → 100000] ;
ParametricPlot3D[ Flatten[ {x[t] / . %, y[t] / . %, z[t] / . %} ] ,
{t, 0, 14, .01}, BoxRatios → {1, 1, 2} ,
PlotRange → {{ - 2, 2}, { - 2, 2}, { - 10, 10}} ,
ViewPoint → { 1.0, - 0.6, 0.6}]
```

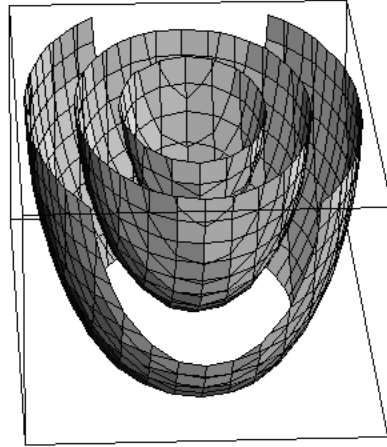


Fig. 3. The total field of the trap in the central region for three values of the energetic function $\|H\|^2$; from the inside outwards: $\|H\|^2 = 2 \cdot 10^{-4}, 5 \cdot 10^{-4}, 10^{-3}$ (arbitrary units)

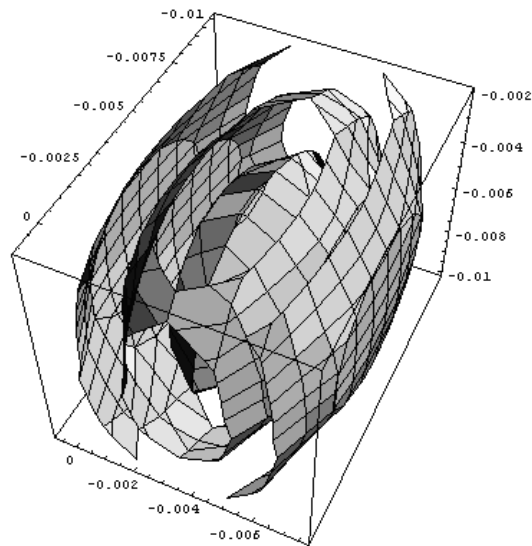


Fig. 4. The variation of the energetic function $\|\nabla\|H\|^2\|$ in the central region for two values: from the inside outwards, $\|\nabla\|H\|^2\| = 5 \cdot 10^{-10}$ and $\|\nabla\|H\|^2\| = 10^{-8}$ (arbitrary units)

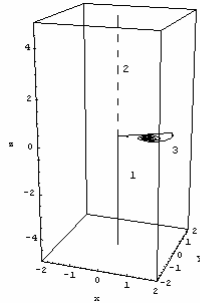


Fig. 5. Field lines for three different initial conditions: curve 1 ($x = 0.331, y = z = 0$); curve 2 (dashed, $x = 0.332, y = z = 0$); curve 3 (in the plane $z = 0; x = 0.35, y = z = 0$).

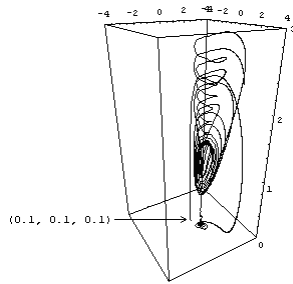


Fig. 6. Field lines for the initial conditions $x = y = z = 0.1$.

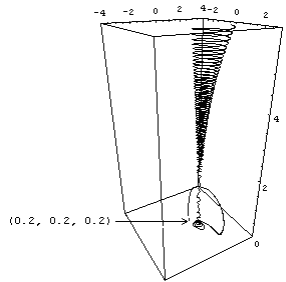


Fig. 7. Field lines for the initial conditions $x = y = z = 0.2$.

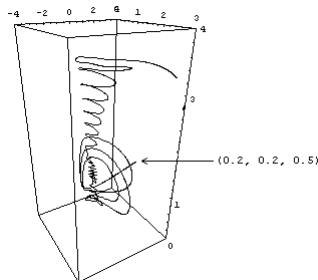


Fig. 8. Field lines for the initial conditions $x = y = 0.2, z = 0.5$.

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References

- [1] V. Ciancio, C. Udriște, *Ioffe-Ștefănescu magnetic trap*, Rev. Roum. Sci. Techn. Electrotechn. et Energ. 49, 2 (2004), 157-176.
- [2] Daniel H. E, Dubin: *Three designs for a magnetic trap that will simultaneously confine neutral atoms and a non-neutral plasma*, Physics of plasmas, 8, pp. 4331-4339, (2001).
- [3] U. Ernst, A. Marte, F. Schreck, J. Schuster, G. Rempe: *Bose Einstein condensation in a pure Ioffe-Pritchard field configuration*, Europhysics Letters, 41, pp. 1-6, (1998).
- [4] Yu. V. Gott, M. S. Ioffe, V. G. Tel'kovskii, *Nuclear Fusion*, 1962 Suppl., Part 3, p.1045.
- [5] J. D. Jackson: *Classical Electrodynamics, Magnetostatics*, J. Wiley & Sons, 1974.
- [6] S. S. Ștefănescu, *Lignes du champ magnetique autour d'une ramification de courants*, Bull. Math. Phys. Pures et Appl., 1-9 (1925); *Pour la prospection électrique du sous-sol*, Note présentée à l' Académie Roumaine (1927); *Pour la prospection électrique du sous-sol; étude du champ S normal*, Note présentée à l'Académie Roumaine (1928); *Lignes de champ magnétique autour d'une ramification de courants*, Bull.Math.Phys., l'Ec. Polytechnique,V Année,Fasc.14-16(1933-1934); *Lignes de champ magnétique d'un circuit filiforme, symétrique et plan, deux fois coudé*, Bull. Math. Pures et Appliquées, 1, 2 (1935-1936), 19-20; *Un nouveau cas d'application en électromagnétisme des fonctions cylindrique générales*, Bull. Math. Pures et Appliquées, 1, 2, 3: 22, 23, 24 (1936-1937); *Un cas particulier des lignes H algébrique*, Bull. Math. Pures et Appliquées, 1, 2, 3: 25, 26, 27, 1-7 (1937-1938); *Liniile de câmp magnetic ale unui curent electric filiform și plan de două ori cotit*, Comunicările Academiei, 1, No. 8 (1951), 769-774; *Liniile de câmp magnetic ale poligoanelor regulate de curenți rectilinii (I)*, St. Cerc. Fiz., 5, No. 1-2 (1954), 63-70; *Liniile de câmp magnetic ale poligoanelor regulate de curenți rectilinii (II)*, St. Cerc. Fiz., 6, No. 3 (1955), 459-471; *Asupra unor linii de câmp magnetic definite prin transcendente elementare*, St. Cerc. Fiz., 7, No. 4 (1956), 519-530; *Les lignes de champ magnétique d'un triangle de courants rectilignes*, Revue de Physique,1,(1956), 89-102; *Open magnetic field lines(I)*,Rev.Roum.Phys.3,2 (1958),151-166; *Liniile de câmp magnetic ale unui curent directiliniu strâmb*, St. Cerc. Fiz., 10, (1959), 381-399; *Liniile de câmp magnetic împrejurul unei prize de pământ într-un teren cu stratificație paralelă*, Probleme de Geofizică, 2, (1963), 135-145; *Liniile de câmp ale unui dreptunghi centrat de curenți rectilinii egali*, St. Cerc. Fiz., 21, No. 1 (1969), 21-32; *Nouveaux exemples de lignes de champ magnétique ouvertes*, Rev. Roum. Phys., 15, No. 1 (1970), 11-25; *Lignes de champ magnétiques d'un parallélogramme centré*

- de courant rectilignes égaux (I)*, Rev. Roum. Phys., 17, No. 9 (1972), 1041-1052; *Lignes de champ magnétiques d'un parallélogramme centré de courant rectilignes égaux (II)*, Rev. Roum. Phys., 18, No. 1 (1973), 35-48; *Sur les lignes du champ magnétique d'un circuit électrique en forme de losange aplati*, Rev. Roum. Phys., 21, No. 4 (1975), 421-430; *Sur les lignes du champ magnétique d'un ligne électrique bifilaire, plane symétriquement coudée*, Rev. Roum. Phys., 22, 9 (1979), 911-921; *Open magnetic field lines (II)*, Rev. Roum. Phys., 31, 7 (1986), 701-721; Addenda 1987- *Open magnetic field lines (III)*, Rev. Roum. Géol., Géophys., Géogr.-Géophysique, 31, (1987), 113-119; *Une hobby mathématique*, Rev. Roum. Phys., 31, (1997), 89-93; *Lignes H, circuits rectiligne coudées*, Manuscript Notices, 1944-1992 unpublished;
- [7] S. S. Ştefănescu, M. Nabighian: *Magnetic field lines of two equal rectilinear currents*, St. Cerc. Fiz., 3, (1960), 563-583; Rev. Roum. Géol. Géophys. et Géogr.-Géophys, 31, (1987), 95-112; *Asupra liniilor de câmp magnetic ale emiţătorului AB*, Probleme de Geofizică, 1, (1961), 181-186.
- [8] S. S. Ştefănescu, C. Udrişte, *Magnetic field lines around filiform electrical circuits of right angle type*, Sci. Bull. UPB. Series A: Appl. Math. Phys., 55, (1993), 3-18.
- [9] C. Udrişte, *Geometric Dynamics*, Southeast Asian Bulletin of Mathematics, Springer - Verlag, 24 (2000), 313-322.
- [10] C. Udrişte, *Geometric Dynamics*, Kluwer Academic Publishers, (2000).
- [11] C. Udrişte, *Magnetic Geometric Dynamics Around Ioffe-Ştefănescu Configuration*, Proceedings of the Conference of Geometry and Its Applications in Technology and the Workshop on Global Analysis, Differential Geometry and Lie Algebras, Aristotle University of Thessaloniki, 1999, BSG Proceedings 5, Ed. Grigorios Tsagas, Geometry Balkan Press (2001), 243-265.
- [12] C. Udrişte, M. Postolache, *Magnetic Fields Generated by Filiform Electric Circuits*, Geometry Balkan Press, Bucharest, (1999).
- [13] C. Udrişte, M. Postolache, *Atlas of Magnetic Geometric Dynamics*, Geometry Balkan Press, Bucharest, (2001).
- [14] C. Udrişte, *Tools of Geometric Dynamics*, Buletinul Institutului de Geodinamică, Romanian Academy, 14, 4 (2003), 1-26.
- [15] C. Udrişte, M. Ferrara, D. Oprea, *Economic Geometric Dynamics*, Geometry Balkan Press, 2004.
- [16] <http://cnat.snu.ac.kr./group/atomphoton/becresult.html> (26.10.2003);
- [17] <http://hubble.physik.uni-konstanz.de/jkrueger/msc/gif/node7.html> (04.11.2003).

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