



HAL
open science

The Newtonian Potential and the Demagnetizing Factors of the General Ellipsoid

Giovanni Di Fratta

► **To cite this version:**

Giovanni Di Fratta. The Newtonian Potential and the Demagnetizing Factors of the General Ellipsoid. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 2016, 472 (2190), pp.20160197. 10.1098/rspa.2016.0197 . hal-01592829

HAL Id: hal-01592829

<https://hal.science/hal-01592829v1>

Submitted on 25 Sep 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

THE NEWTONIAN POTENTIAL AND THE DEMAGNETIZING FACTORS OF THE GENERAL ELLIPSOID

GIOVANNI DI FRATTA
CMAP, École Polytechnique,
route de Saclay,
91128 Palaiseau Cedex,
FRANCE

Abstract. The objective of this paper is to present a modern and concise new derivation for the explicit expression of the interior and exterior Newtonian potential generated by homogeneous ellipsoidal domains in \mathbb{R}^N (with $N \geq 3$). The very short argument is essentially based on the application of REYNOLDS transport theorem in connection with GREEN-STOKES integral representation formula for smooth functions on bounded domains of \mathbb{R}^N , which permits to reduce the N -dimensional problem to a 1-dimensional one. Due to its high physical relevance, a separate section is devoted to the derivation of the *demagnetizing factors* of the general ellipsoid which are one of the most fundamental quantities in ferromagnetism.

1 HISTORICAL INTRODUCTION, MOTIVATIONS

The computation of the gravitational potential induced by an homogeneous ellipsoid was one of the most important problems in mathematics for more than two centuries after NEWTON enunciated his universal law of gravitation [6, 8, 9, 24, 30, 31].

Once fixed an ellipsoidal domain Ω of \mathbb{R}^3 , the problem consists in finding an *explicit* expression for the Newtonian potential induced by a constant mass/charge density on Ω [14]:

$$\mathcal{N}_\Omega[1_\Omega](x) := \frac{1}{4\pi} \int_\Omega \frac{1}{|x-y|} dy, \quad (1)$$

in the internal points of Ω (*interior problem*) and in the exterior points of Ω (*exterior problem*).

In the case of a homogeneous *spherically symmetric* region, NEWTON (in 1687) proved what nowadays is known as NEWTON'S SHELL THEOREM [3, 24]: *if Ω is an homogeneous¹ spherical region centered at the origin, then for all $t > 1$, $\mathcal{N}_{t\Omega \setminus \Omega}[1_{t\Omega \setminus \Omega}]$ is constant in Ω , i.e. $t\Omega \setminus \Omega$ (the so called *hollow ball*) induces no gravitational force inside Ω . Moreover, a spherically symmetric body affects external objects gravitationally as though all of its mass were concentrated at a point at its center.*

For what concerns an ellipsoidal domain Ω of \mathbb{R}^3 , the *ellipsoidal interior* problem was for the first time solved by GAUSS (in 1813) by the means of what it is in present days known as the GAUSS divergence theorem [16]. Later, in 1839, DIRICHLET proposed a solution of the interior problem based on the theory of FOURIER integrals [21].

The results of GAUSS and DIRICHLET can be summarized by saying that if Ω is an ellipsoidal domain centered at the origin, then the gravitational potential induced by an homogeneous ellipsoid in its internal points is a second order polynomial. In other terms:

$$\mathcal{N}_\Omega[1_\Omega](x) = c - Px \cdot x \quad \forall x \in \Omega, \quad (2)$$

¹By an *homogeneous* region of \mathbb{R}^N we mean an open and connected subset of \mathbb{R}^N endowed by a constant density of masses/charges.

for some constant $c \in \mathbb{R}$ and some matrix $P \in \mathbb{R}^{3 \times 3}$ whose values can be expressed in terms of elliptic integrals [20, 35].

Remark 1.1. For the sake of completeness we recall that the converse statement (the *inverse homogeneous ellipsoid problem*) is also true [11, 14, 18], namely: *if Ω is a bounded domain of \mathbb{R}^N such that $\mathbb{R}^N \setminus \Omega$ is connected and (2) holds, then Ω is an ellipsoid.* Historically speaking the inverse homogeneous ellipsoid problem was for the first time solved by DIVE [12] in 1931 for $N = 3$ and in 1932 by HÖLDER [17] for $N = 2$. A modern proof of this result can be found in DIBENEDETTO and FRIEDMAN [11] who, in 1985, extended it to all $N \geq 2$. In 1994, KARP [18], by the means of certain topological methods, obtained an alternative proof of the inverse homogeneous ellipsoid problem.

Despite the well-knownness of (2) in the mathematical and physical community, and its importance in theoretical and applied studies [1, 5, 7, 32, 33, 10, 25], rigorous proofs of that result are not readily available in the literature: to the best knowledge of the author, relative modern treatments of the interior problem can be found in [20] and [35], and more recently in [22] and [26] where also the exterior problem is investigated. However, in all the cited references, the solution of the problem is always based on the use of ellipsoidal coordinates which tends to focus the attention on the computational details of the question rather than on its geometric counterpart. Eventually, modern proofs of Newton's theorem and relation (2), as well as far reaching beautiful generalizations, can be found in [19] where nevertheless the problem of finding an analytic expression for the coefficients c and P is not touched.

Aim of this paper is to give a modern and concise derivation for the expression of the *interior* and *exterior* Newtonian potential (induced by homogeneous ellipsoids). The very short argument is essentially based on the application of REYNOLDS transport theorem in connection with GREEN-STOKES integral representation formula for smooth functions on bounded domains of \mathbb{R}^N . This approach permits to reduce the N -dimensional problem to a 1-dimensional one, providing (in particular) at once a proof of (2) together with an explicit expression of the coefficients P and c in terms of 1-dimensional integrals. More precisely, the paper is organized as follows:

Section 2 is devoted to the main result of the paper. We give a concise proof of the homogeneous ellipsoid problem. For completeness, we then derive NEWTON'S SHELL THEOREM as an immediate corollary.

In Section 3 we focus the attention to the three dimensional case. An expression in terms of the elliptic integrals is given for the coefficients of P . Due to its physical relevance, particular attention is paid to the eigenvalues of P . Indeed, when $N = 3$, the matrix P and its eigenvalues, known in the theory of ferromagnetism respectively as *the demagnetization tensor* and *the demagnetizing factors*, are one of the most important and well-studied quantities of ferromagnetism [1, 2, 5, 7, 10, 25]. In fact, the following magnetostatic counterpart of the homogeneous ellipsoid problem holds: *given a uniformly magnetized ellipsoid, the induced magnetic field is also uniform inside the ellipsoid.* This result was for the first time showed by POISSON [28], while an explicit expression for the demagnetizing factors was for the first time obtained by MAXWELL [23]. Their importance is in that they encapsulate the self-interaction of magnetized bodies: their knowledge being equivalent to the one of the corresponding demagnetizing (stray) fields [5].

2 THE INTERIOR AND EXTERIOR POTENTIAL OF AN HOMOGENEOUS ELLIPSOID

In what follows we denote by Ω the ellipsoidal domain of \mathbb{R}^N ($N \geq 3$) having a_1, a_2, \dots, a_N as semi-axes lengths. We then denote by $(\Omega_t)_{t \in [0, +\infty)}$ the family of ellipsoidal domains of

\mathbb{R}^N , given by the inverse image $\phi_t^{-1}(B_N)$ of the unit ball of \mathbb{R}^N under the one parameter family of diffeomorphisms $\phi_t : x \in \mathbb{R}^N \mapsto \sqrt{A_t}x \in \mathbb{R}^N$, where

$$\sqrt{A_t} := \text{diag} \left[\frac{1}{\sqrt{a_1^2 + t}}, \frac{1}{\sqrt{a_2^2 + t}}, \dots, \frac{1}{\sqrt{a_N^2 + t}} \right]. \quad (3)$$

Note that each diffeomorphism ϕ_t^{-1} maps the unit ball of \mathbb{R}^N onto the ellipsoidal domain of \mathbb{R}^N defined by the position $\Omega_t = \{x \in \mathbb{R}^N : |\phi_t(x)|^2 \leq 1\}$. In particular $\partial\Omega_t = \{x \in \mathbb{R}^N : |\phi_t(x)|^2 = 1\}$ and $\Omega \equiv \Omega_0$. Finally, we denote by $\mathcal{N}_{\Omega_t}[1_{\Omega_t}]$ the Newtonian potential generated by the uniform space density of masses or charges on Ω_t :

$$\mathcal{N}_{\Omega_t}[1_{\Omega_t}](x) = c_N \int_{\Omega_t} \frac{1}{|x - y|^{N-2}} d\tau(y), \quad (4)$$

with $c_N := [(N-2)\omega_N]^{-1}$ and ω_N the surface measure of the unit sphere in \mathbb{R}^N (cfr. [13, 14]).

The main result of the paper is stated in the following:

Theorem 2.1. *Let $\Omega = \{x \in \mathbb{R}^N : |\phi_0(x)|^2 \leq 1\}$ be the ellipsoidal domain of \mathbb{R}^N having $(a_1, a_2, \dots, a_N) \in \mathbb{R}_+^N$ as semi-axes lengths. For every $x \in \mathbb{R}^N$*

$$\mathcal{N}_{\Omega}[1_{\Omega}](x) = \frac{1}{4} \int_{\tau(x)}^{+\infty} \gamma_t (1 - A_t x \cdot x) dt, \quad \gamma_t := \prod_{i=1}^N \frac{a_i}{\sqrt{a_i^2 + t}}, \quad (5)$$

where we have denoted by τ the non-negative real valued function

$$\tau : x \in \mathbb{R}^N \mapsto \begin{cases} 0 & \text{if } x \in \bar{\Omega} \\ \tau(x) & \text{if } x \in \Omega^c \cap \partial\Omega_{\tau(x)} \end{cases}. \quad (6)$$

Remark 2.1. For general ellipsoidal domains the integral in (5) can be evaluated by the means of the theory of elliptic integrals (cfr. [4, 29]). The function τ defined by (6) can be computed by solving the equation $\partial\Omega_{\tau(x)} = \{x \in \mathbb{R}^N : |\phi_{\tau(x)}(x)|^2 = 1\}$. In particular, when Ω is a spherical region of radius a (centered around the origin), the function τ reduces to the function equal to $|x|^2 - a^2$ if $x \in \mathbb{R}^N \setminus \Omega$, zero otherwise, and the integral in (5) can be readily computed.

Proof. For every $t \in \mathbb{R}^+$, the function $|\phi_t|^2 - 1$ is the unique solution of the homogeneous DIRICHLET problem for the POISSON equation $u = 2 \text{tr}(A_t)$ in Ω_t , $u \equiv 0$ on $\partial\Omega_t$. Thus, according to the GREEN-STOKES representation formula (see [14]), for every $t \in \mathbb{R}^+$ we have

$$(|\phi_t|^2 - 1)1_{\Omega_t} = -2 \text{tr}(A_t)\mathcal{N}_{\Omega_t}[1_{\Omega_t}] + \mathcal{S}_{\partial\Omega_t}[\partial_{\mathbf{n}}|\phi_t|^2] \quad \text{in } \mathbb{R}^N \setminus \partial\Omega_t, \quad (7)$$

where we have denoted by

$$\mathcal{S}_{\partial\Omega_t}[\partial_{\mathbf{n}}|\phi_t|^2](x) := c_N \int_{\partial\Omega_t} \frac{\partial_{\mathbf{n}(y)}|\phi_t(y)|^2}{|x - y|^{N-2}} d\sigma(y), \quad (8)$$

the simple layer potential generated by the space density of masses or charges $\partial_{\mathbf{n}}|\phi_t|^2$ concentrated on $\partial\Omega_t$ (cfr. [13, 14]). Next, we observe that the N -dimensional Newtonian kernel $|x|^{2-N}$ is in $W_{\text{loc}}^{1,1}(\mathbb{R}^N)$, therefore due to REYNOLDS transport theorem,

$$\partial_t \mathcal{N}_{\Omega_t}[1_{\Omega_t}] = c_N \int_{\partial\Omega_t} \frac{\mathbf{v}_t(y) \cdot \mathbf{n}(y)}{|x - y|^{N-2}} d\sigma(y) = \frac{1}{4} \mathcal{S}_{\partial\Omega_t}[\partial_{\mathbf{n}}|\phi_t|^2], \quad (9)$$

where we have denoted by $\mathbf{v}_t := \partial_t[\phi_t^{-1}] \circ \phi_t$ the eulerian velocity field associated to the motion ϕ_t^{-1} , for which one has

$$\mathbf{v}_t(y) := \partial_t[\phi_t^{-1}] \circ \phi_t(y) = \frac{1}{2}A_t y = \frac{1}{4}\nabla|\phi_t(y)|^2 \quad \forall (t, y) \in \mathbb{R}^+ \times \partial\Omega_t. \quad (10)$$

Hence, substituting (9) into (7) we get

$$\frac{1}{4}(|\phi_t(x)|^2 - 1)1_{\Omega_t}(x) = -\frac{1}{2}\text{tr}(A_t)\mathcal{N}_{\Omega_t}[1_{\Omega_t}](x) + \partial_t\mathcal{N}_{\Omega_t}[1_{\Omega_t}](x) \quad \forall x \in \mathbb{R}^N \setminus \partial\Omega_t. \quad (11)$$

Moreover, by the assignment

$$\gamma_t := \exp\left(-\frac{1}{2}\int_0^t \text{tr}(A_s)ds\right) = \prod_{i=1}^N \frac{a_i}{\sqrt{a_i^2 + t}} \quad , \quad \gamma_0 = 1, \quad (12)$$

the equality (11) reads as

$$\partial_t(\gamma_t\mathcal{N}_{\Omega_t}[1_{\Omega_t}]) = \frac{1}{4}\gamma_t(|\phi_t|^2 - 1)1_{\Omega_t} \quad \forall x \in \mathbb{R}^N \setminus \partial\Omega_t. \quad (13)$$

Thus, once introduced the non-negative real function defined by (6) we have, for every $t \in \mathbb{R}^+$ and for every $x \in \mathbb{R}^N$

$$\partial_t(\gamma_t\mathcal{N}_{\Omega_t}[1_{\Omega_t}]) (x) = \frac{1}{4}\gamma_t(|\phi_t(x)|^2 - 1)1_{[\tau(x), +\infty)}(t). \quad (14)$$

Integrating both members of (14) on $[0, +\infty)$; taking into account that due to the well-known decay at infinity of the Newtonian potential [34] one has $\lim_{t \rightarrow +\infty} \gamma_t\mathcal{N}_{\Omega_t}[1_{\Omega_t}] = 0$; we finish with (5). \square

Corollary 2.1. (NEWTON'S SHELL THEOREM) *Let $\Omega \subseteq \mathbb{R}^3$ be an homogeneous spherical region (centered around the origin) of radius a and of total mass M . For every $x \in \mathbb{R}^3 \setminus \Omega$ the induced gravitational potential is the same as though all of its mass were concentrated at a point at its center. Moreover, for all $t > 1$, $\mathcal{N}_{t\Omega \setminus \Omega}[1_{t\Omega \setminus \Omega}]$ is constant in Ω , i.e. the hollow ball induces no gravitational force inside Ω .*

Proof. We denote by $\rho 1_{\Omega}(x)$, ($\rho := M/|\Omega|$) the uniform density of mass in Ω . The gravitational potential induced by ρ in \mathbb{R}^3 is then given by $u_{\rho} = 4\pi G\mathcal{N}_{\Omega}[\rho] = 4\pi G\mathcal{N}_{\Omega}[1_{\Omega}]$, where we have denoted by G the *gravitational constant*. In this geometrical setting the function τ defined by (6) reduces to the function $\tau(x) := (|x|^2 - a^2)1_{\mathbb{R}^N \setminus \Omega}(x)$ and the integral in (5) immediately gives

$$u_{\rho}(x) = \frac{2}{3}\pi G\rho \left(\frac{a^2}{2} - |x|^2\right) \quad \text{if } x \in \bar{\Omega} \quad , \quad u_{\rho}(x) = \frac{4}{3}\pi a^3 \frac{G\rho}{|x|} = \frac{GM}{|x|} \quad \text{if } x \in \mathbb{R}^3 \setminus \Omega. \quad (15)$$

Thus, for every $x \in \mathbb{R}^3 \setminus \Omega$ the induced gravitational potential is equal to the one induced by a DIRAC mass concentrated in the center of Ω . The gravitational field is given by $\mathbf{g} := -\nabla u_{\rho}$ and the fact that the hollow ball $t\Omega \setminus \Omega$, $t > 1$, induces no gravitational force inside Ω can be immediately seen by splitting the uniform density of mass in $t\Omega \setminus \Omega$ in the form $\rho = (M/|t\Omega \setminus \Omega|)1_{t\Omega} - (M/|t\Omega \setminus \Omega|)1_{\Omega}$. Indeed by linearity we get that u_{ρ} is constant in Ω and therefore $\mathbf{g} = \mathbf{0}$. \square

3 THE DEMAGNETIZING FACTORS OF THE GENERAL ELLIPSOID

We know focus on the three-dimensional framework ($N = 3$) and, in particular, on the so-called demagnetizing factors of the general ellipsoid [25]. To this end we recall that the demagnetizing (stray) field $\mathbf{h}[\mathbf{m}]$ associated to a magnetization $\mathbf{m} \in C^\infty(\bar{\Omega})$ can be expressed as the gradient field of a suitable magnetostatic potential $\varphi_{\mathbf{m}}$ (see [15, 27]). Precisely $\varphi_{\mathbf{m}} := -\operatorname{div} \mathcal{N}_\Omega[\mathbf{m}]$ and $\mathbf{h}[\mathbf{m}] := -\nabla \varphi_{\mathbf{m}}$ in \mathbb{R}^3 . In particular, if \mathbf{m} is constant in Ω , then $\varphi_{\mathbf{m}} = -\mathbf{m} \cdot \nabla \mathcal{N}_\Omega[1_\Omega]$. Thus from (5):

$$\varphi_{\mathbf{m}}(x) = Px \cdot \mathbf{m} \quad , \quad \mathbf{h}[\mathbf{m}] = -P\mathbf{m} \quad \forall x \in \Omega, \quad (16)$$

where we have denote by $P := \nabla \mathcal{N}_\Omega[1_\Omega]$ the diagonal matrix, known in literature as the *demagnetizing tensor*, whose diagonal i -entry (the i -th *demagnetizing factor*), by virtue of (5), is given by

$$P_i := \frac{1}{2} \int_0^{+\infty} \frac{1}{(a_i^2 + t)} \prod_{j=1}^3 \frac{a_j}{\sqrt{a_j^2 + t}} dt \quad \forall i \in \mathbb{N}_3. \quad (17)$$

Proposition 3.1. *We have $P_i \geq 0$ for every $i \in \mathbb{N}_3$ and if $a_1 \geq a_2 \geq a_3$ then $P_1 \leq P_2 \leq P_3$. The trace of P satisfy the relation $\operatorname{tr}(P) = 1$.*

Proof. The first statement is obvious. The relation $\operatorname{tr}(P) = 1$ can of course be verified by a direct evaluation of the integrals in (17), but it is also possible to observe that since the Newtonian potential $\mathcal{N}_\Omega[1_\Omega]$ satisfies the POISSON equation $\Delta \mathcal{N}_\Omega[1_\Omega] = -1_\Omega$, one has $\operatorname{tr}(P) = \operatorname{div}(Px) = -\Delta \mathcal{N}_\Omega[1_\Omega] = 1_\Omega$. \square

Assuming $a_1 \geq a_2 \geq a_3$, from (17) and the theory of elliptic integrals we get

$$P_1 = 1 - P_2 - P_3 \quad (18)$$

$$P_2 = -\frac{a_3}{a_2^2 - a_3^2} \left[a_3 - \frac{a_1 a_2}{(a_1^2 - a_2^2)^{1/2}} E \left(\arccos \left(\frac{a_2}{a_1} \right) \middle| \frac{a_1^2 - a_3^2}{a_1^2 - a_2^2} \right) \right] \quad (19)$$

$$P_3 = +\frac{a_2}{a_2^2 - a_3^2} \left[a_2 - \frac{a_1 a_3}{(a_2^2 - a_3^2)^{1/2}} E \left(\arccos \left(\frac{a_3}{a_1} \right) \middle| \frac{a_1^2 - a_2^2}{a_1^2 - a_3^2} \right) \right], \quad (20)$$

where, for every $y \in \mathbb{R}$ and every $0 < p < 1$ we have denoted by

$$E(y|p) := \int_0^y (1 - p \sin^2 \theta)^{1/2} d\theta, \quad (21)$$

the incomplete elliptic integral of the second kind expressed in *parameter form* [4, 29]. In particular, in the case of a *prolate spheroid* ($a_1 \geq a_2 = a_3$) we get

$$P_1 = -\frac{a_3^2}{(a_1^2 - a_3^2)^{3/2}} \left[(a_1^2 - a_3^2)^{1/2} + a_1 \operatorname{arccoth} \left(\frac{a_1}{(a_1^2 - a_3^2)^{1/2}} \right) \right], \quad (22)$$

$$P_2 = P_3 = \frac{1 - P_1}{2}, \quad (23)$$

while in the case of an *oblate spheroid* ($a_1 = a_2 \geq a_3$)

$$P_1 = P_2 = \frac{1 - P_3}{2}, \quad (24)$$

$$P_3 = \frac{a_1^2}{(a_1^2 - a_3^2)^{3/2}} \left[(a_1^2 - a_3^2)^{1/2} + a_3 \arctan \left(\frac{a_3}{(a_1^2 - a_3^2)^{1/2}} \right) - a_3 \frac{\pi}{2} \right]. \quad (25)$$

Finally, in the case of a *sphere* ($a_1 = a_2 = a_3$) one finish with $P_1 = P_2 = P_3 = \frac{1}{3}$.

4 ACKNOWLEDGMENTS

This work was partially supported by the labex LMH through the grant ANR-11-LABX-0056-LMH in the “*Programme des Investissements d’Avenir*”.

REFERENCES

- [1] François Alouges and Karine Beauchard. Magnetization switching on small ferromagnetic ellipsoidal samples. *ESAIM: Control, Optimisation and Calculus of Variations*, 15(03):676–711, 2009.
- [2] François Alouges, Giovanni Di Fratta, and Benoit Merlet. Liouville type results for local minimizers of the micromagnetic energy. *Calculus of Variations and Partial Differential Equations*, pages 1–36.
- [3] R. Arens. Newton’s observations about the field of a uniform thin spherical shell. *Note di Matematica*, 10(suppl. 1):39–45, 1990.
- [4] Milton Abramowitz and Irene A Stegun. *Handbook of mathematical functions: with formulas, graphs, and mathematical tables*, volume 55. Dover publications, 1965.
- [5] M. Beleggia and M. De Graef. On the computation of the demagnetization tensor field for an arbitrary particle shape using a fourier space approach. *Journal of magnetism and magnetic materials*, 263(1):0, 2003.
- [6] E. Beltrami. *Sulla teoria dell’attrazione degli ellissoidi: memoria del Prof. Eugenio Beltrami*. Tip. Gamberini e Parmeggiani, 1880.
- [7] W. F. Brown. *Magnetostatic Principles in Ferromagnetism*. North-Holland Publishing Co, 1962.
- [8] E. Daniele. Sul problema dell’induzione magnetica di un ellissoide a tre assi. *Il Nuovo Cimento (1911-1923)*, 1(1):421–430, 1911.
- [9] E. Daniele. Sull’impiego delle funzioni ellissoidali armoniche nei problemi relativi ad un involucro ellissoidico. *Il Nuovo Cimento (1911-1923)*, 2(1):445–452, 1911.
- [10] G Di Fratta, C Serpico, and M d’Aquino. A generalization of the fundamental theorem of brown for fine ferromagnetic particles. *Physica B: Condensed Matter*, 2011.
- [11] E. DiBenedetto and A. Friedman. Bubble growth in porous media. *Indiana Univ. Math. J*, 35(2):573–606, 1986.
- [12] P. Dive. Attraction des ellipsoïdes homogènes et réciproques d’un théorème de newton. *Bulletin de la Société Mathématique de France*, 59:128–140, 1931.
- [13] R. Dautray and J.L. Lions. *Mathematical Analysis and Numerical Methods for Science and Technology: Physical Origins and Classical Methods*, volume 1. Springer Verlag, 2000.
- [14] E. DiBenedetto. *Partial Differential Equations. Cornerstones* (Birkhäuser Verlag). Birkhäuser Boston, 2010.
- [15] M.J. Friedman. Mathematical study of the nonlinear singular integral magnetic field equation. I. *SIAM Journal on Applied Mathematics*, 39(1):14–20, 1980.

- [16] CF Gauss. Theoria attractionis corporum sphaeroidicorum ellipticorum homogeneorum methodo novo tractate. *Commentationes Societatis Regiae Scientiarum Göttingensis Recentiores. vIII*, 1813.
- [17] E. Hölder. Über eine potentialtheoretische eigenschaft der ellipse. *Mathematische Zeitschrift*, 35(1):632–643, 1932.
- [18] L. Karp. On the newtonian potential of ellipsoids. *Complex Variables and Elliptic Equations*, 25(4):367–371, 1994.
- [19] Dmitry Khavinson and Erik Lundberg. A tale of ellipsoids in potential theory. *Not. AMS*, 61:148–156.
- [20] O.D. Kellogg. *Foundations of potential theory*, volume 31. Dover Publications, 2010.
- [21] L. Kroneker. *Dirichlet's Werke*. Chelsea, New York, 1969.
- [22] T Miloh. A note on the potential of a homogeneous ellipsoid in ellipsoidal coordinates. *Journal of Physics A: Mathematical and General*, 23(4):581, 1999.
- [23] J.C. Maxwell. *A treatise on electricity and magnetism*. Oxford: Clarendon Press, 1873.
- [24] S.I. Newton. *Philosophiae naturalis principia mathematica*, volume 1. Dawson, 1687.
- [25] JA Osborn. Demagnetizing factors of the general ellipsoid. *Physical Review*, 67(11-12):351–357, 1945.
- [26] Vladimír Pohánka. Gravitational field of the homogeneous rotational ellipsoidal body: a simple derivation and applications. *Contributions to Geophysics and Geodesy*, 41(2):117–157, 2011.
- [27] Dirk Praetorius. Analysis of the operator $\Delta^{-1}\text{div}$ arising in magnetic models. *Journal for Analysis and its Applications*, 23(3):589–605, 2004.
- [28] S.D. Poisson. *Second mémoire sur la théorie du magnétisme*. Imprimerie royale, 1825.
- [29] Viktor Prasolov and Yuri Solov'yev. *Elliptic Functions and Elliptic Integrals*, volume 170. American Mathematical Society, 1997.
- [30] M Rahman and M Rahman. On the newtonian potentials of heterogeneous ellipsoids and elliptical discs. *Proceedings of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, 457(2013):2227–2250, 2001.
- [31] H. Shahgholian. On the newtonian potential of a heterogeneous ellipsoid. *SIAM journal on mathematical analysis*, 22(5):1246–1255, 1991.
- [32] A. De Simone. Energy minimizers for large ferromagnetic bodies. *Arch. Rat. Mech. Anal.*, 125, 1993.
- [33] A. De Simone. Hysteresis and Imperfections Sensitivity in Small Ferromagnetic Particles. *Mecca.*, 30, 1995.
- [34] S. Salsa. *Partial differential equations in action: from modelling to theory*. Springer, 2010.
- [35] J.A. Stratton. *Electromagnetic theory*, volume 33. Wiley-IEEE Press, 2007.