

# An exact solution of the equation

Autor(en): **Novello, Mario**

Objektyp: **Article**

Zeitschrift: **Helvetica Physica Acta**

Band (Jahr): **44 (1971)**

Heft 6

PDF erstellt am: **13.09.2024**

Persistenter Link: <https://doi.org/10.5169/seals-114305>

## **Nutzungsbedingungen**

Die ETH-Bibliothek ist Anbieterin der digitalisierten Zeitschriften. Sie besitzt keine Urheberrechte an den Inhalten der Zeitschriften. Die Rechte liegen in der Regel bei den Herausgebern.

Die auf der Plattform e-periodica veröffentlichten Dokumente stehen für nicht-kommerzielle Zwecke in Lehre und Forschung sowie für die private Nutzung frei zur Verfügung. Einzelne Dateien oder Ausdrucke aus diesem Angebot können zusammen mit diesen Nutzungsbedingungen und den korrekten Herkunftsbezeichnungen weitergegeben werden.

Das Veröffentlichen von Bildern in Print- und Online-Publikationen ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Die systematische Speicherung von Teilen des elektronischen Angebots auf anderen Servern bedarf ebenfalls des schriftlichen Einverständnisses der Rechteinhaber.

## **Haftungsausschluss**

Alle Angaben erfolgen ohne Gewähr für Vollständigkeit oder Richtigkeit. Es wird keine Haftung übernommen für Schäden durch die Verwendung von Informationen aus diesem Online-Angebot oder durch das Fehlen von Informationen. Dies gilt auch für Inhalte Dritter, die über dieses Angebot zugänglich sind.

# An Exact Solution of the $\Gamma$ Equation<sup>1)</sup>

by **Mario Novello**

Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil  
Université de Genève, Geneva

(9. III. 71)

*Abstract.* We try to evaluate a solution of the  $\Gamma$  equation [1] with spherical symmetry and statical condition. We arrive at Schwarzschild's solution, as it would be expected. Some comments about the possibility of obtaining other solutions are set up.

## 1. Introduction

In a recent paper [1] we have shown that it is possible to consider Einstein's gravitational theory as a consequence of an interaction between 'internal' objects. In this paper it is our purpose to obtain an exact solution of the fundamental  $\Gamma$  equation and to relate this solution to Einstein's equations.

## 2. The Fundamental Variables

Let us resume, briefly, the properties of the fundamental objects  $\Gamma_{\mu}^{AB}(x)$ . In a change of coordinates the  $\Gamma$ 's behave as a vector, that is,

$$\Gamma'^{\mu}(x') = \frac{\partial x'^{\mu}}{\partial x^{\alpha}} \Gamma^{\alpha}(x). \quad (1)$$

Besides this, they have internal indices, such that they may suffer a transformation like

$$\Gamma'^{\mu AB}(x) = M^A{}_C(x) \Gamma^{\mu CD}(x) \bar{M}^T{}_D{}^B(x) \quad (2)$$

where  $A, B, C, D$  may have the values 0, 1, 2, 3 ( $T$  is the transposed and the bar means conjugate).

We do not need, for the time being, to specify the properties of  $M^B{}_A(x)$ . We only assume that they are non-singular, everywhere.

The  $\Gamma$ 's have the property that

$$\{\Gamma^{\mu}(x), \Gamma^{\nu}(x)\} = 2 g^{\mu\nu}(x) 1 \quad (3)$$

---

<sup>1)</sup> This work has been supported by 'Coordenação do aperfeiçoamento de pessoal de nível superior (Capes-Brazil)'.

where

$$\{A, B\} = A B + B A \quad (4)$$

$g^{\mu\nu}(x)$  is the metric tensor. 1 is the identity of the Clifford algebra.

Furthermore there is a  $\Gamma^{5 AB}(x)$  such that

$$\Gamma^{5 AB}(x') = M^A{}_C(x) \Gamma^{5 CD}(x) \overline{M}^T{}_D{}^B(x). \quad (5)$$

As a consequence of (1) and (2) we see that the usual derivative is not a good geometrical object, and we are obliged to introduce a covariant derivative, defined by

$$\Gamma_{\mu||\nu}(x) = \Gamma_{\mu|\nu} - \{\varepsilon_{\mu\nu}\} \Gamma_\varepsilon + [\tau_\nu \Gamma_\mu] \quad (6)$$

where

$$\Gamma_{\mu|\nu}(x) = \frac{\partial \Gamma_\mu(x)}{\partial x^\nu}$$

$\{\varepsilon_{\mu\nu}\}$  is the Christoffel symbol.  $\tau_\nu$  is a sort of internal affinity.

We introduce here an hypothesis that makes a strong restriction on the permissible internal transformations. We assume that the  $M(x)$  that generates an infinitesimal transformation (2) is of the form

$$M^{AB}(x) \simeq \mathbf{1} + \varepsilon \xi_\alpha(x) U^{\alpha AB}(x) + \varepsilon \xi_{\alpha||\beta}(x) U^{\alpha\beta AB}(x) + O(\varepsilon^2) \quad (7)$$

where

$$U_{\alpha\beta}^{AB} = \frac{1}{8} [\Gamma_\alpha, \Gamma_\beta]^{AB}.$$

This choice is such as to permit us to consider the internal transformation as a coordinate transformation of the type

$$x^\alpha \rightarrow \tilde{x}^\alpha = x^\alpha + \varepsilon \xi^\alpha(x).$$

If we look for the conditions necessary to make this identification we arrive at

$$\Gamma_{\mu||\nu}^{AB}(x) = \sigma [U_\nu(x), \Gamma_\mu(x)]^{AB}, \quad \sigma \text{ is a constant} \quad (8)$$

(we put  $\sigma = 1$  in the rest of this paper).

If we look for an object  $U_\nu$  which is a member of the Clifford algebra but such that it does not introduce any new field, we see that this object has the form

$$U_\nu^{AB}(x) = \Gamma_\nu^{AB}(x) + (\Gamma_\nu(x) \Gamma^5(x))^{AB}. \quad (9)$$

A straightforward calculation shows that the covariant derivative is not commutative and that we may write

$$\Gamma_{\alpha||\beta||\lambda} - \Gamma_{\alpha||\lambda||\beta} = R_{\alpha\varepsilon\beta\lambda} \Gamma^\varepsilon + [R_{\beta\lambda}, \Gamma_\alpha] \quad (10)$$

where

$R_{\alpha\varepsilon\beta\lambda}$  is the Riemann tensor,

$R_{\beta\lambda}^{AB}$  is the internal curvature.

### 3. Radial Symmetry

It is an easy matter to show that Einstein's equations of the gravitational theory are obtained as a consequence of the equation

$$[R_{\alpha\beta}, F^{\alpha}] = 0 \quad (11)$$

in the absence of matter.

We will look now for a solution of this equation such that

$$F_{\mu} = F_{\mu}(r, \theta) \quad (12)$$

where  $r$  is the radial distance. We will use a spherical system of coordinates and we identify

$$x^0 = t, \quad x^1 = r, \quad x^2 = \theta, \quad x^3 = \phi. \quad (13)$$

Condition (12) implies that the metric tensor has spherical symmetry too. We next assume that

$$F_0(r) F_0(r) = e^{\nu(r)} \mathbf{1}, \quad (14)$$

$$F_1(r) F_1(r) = -e^{\lambda(r)} \mathbf{1}, \quad (15)$$

$$F_2(r) F_2(r) = -r^2 \mathbf{1}, \quad (16)$$

$$F_3(r, \theta) F_3(r, \theta) = -r^2 \sin^2 \theta \mathbf{1}. \quad (17)$$

These conditions are equivalent to assume that the infinitesimal length is

$$ds^2 = e^{\nu(r)} (dx^0)^2 - e^{\lambda(r)} (dr)^2 - r^2 (d\theta)^2 - r^2 \sin^2 \theta (d\phi)^2. \quad (18)$$

From equations (14), (15), (16) and (17) we obtain

$$F_{0|r} = \frac{\nu'}{2} F_0, \quad (19)$$

$$F_{1|r} = \frac{\lambda'}{2} F_1, \quad (20)$$

$$F_{2|r} = \frac{1}{r} F_2, \quad (21)$$

$$F_{3|r} = \frac{1}{r} F_3, \quad (22)$$

$$F_{3|\theta} = \cotg \theta F_3, \quad (23)$$

where

$$\nu' = \frac{d\nu}{dr}.$$

From (6) and (19) we obtain

$$\Gamma_{0||r} = \Gamma_{0|r} - \{\varepsilon\}_{01} \Gamma_\varepsilon + [\tau_1, \Gamma_0], \quad (24)$$

$$\Gamma_{0||r} = 2 \Gamma_1 \Gamma_0. \quad (25)$$

Then,

$$[\tau_1, \Gamma_0] = 2 \Gamma_1 \Gamma_0. \quad (26)$$

In a same manner we obtain

$$[\tau_1, \Gamma_1] = 2 e^\lambda \Gamma^5, \quad (27)$$

$$[\tau_1, \Gamma_2] = 2 \Gamma_1 \Gamma_2, \quad (28)$$

$$[\tau_1, \Gamma_3] = 2 \Gamma_1 \Gamma_3. \quad (29)$$

Expressions (26) to (29) implies that a non-trivial  $\tau_1$  has the form

$$\tau_1 = \Gamma_1 + \Gamma_1 \Gamma^5. \quad (30)$$

By the same manner we arrive at the following expressions

$$[\tau_0, \Gamma_0] = \frac{\nu'}{2} e^{\nu-\lambda} \Gamma_1 - 2 e^\nu \Gamma^5, \quad (31)$$

$$[\tau_0, \Gamma_1] = 2 \Gamma_0 \Gamma_1 + \frac{\nu'}{2} \Gamma_0, \quad (32)$$

$$[\tau_0, \Gamma_2] = 2 \Gamma_0 \Gamma_2, \quad (33)$$

$$[\tau_0, \Gamma_3] = 2 \Gamma_0 \Gamma_3, \quad (34)$$

and we see  $\tau_0$  has the form

$$\tau_0 = \Gamma_0 + \Gamma_0 \Gamma^5 + \frac{\nu'}{4} e^{-\lambda} \Gamma_1 \Gamma_0. \quad (35)$$

Analogously, we have

$$[\tau_2, \Gamma_0] = 2 \Gamma_2 \Gamma_0, \quad (36)$$

$$[\tau_2, \Gamma_1] = 2 \Gamma_2 \Gamma_1 + \frac{1}{r} \Gamma_2, \quad (37)$$

$$[\tau_2, \Gamma_2] = 2 r^2 \Gamma^5 - r e^{-\lambda} \Gamma_1, \quad (38)$$

$$[\tau_2, \Gamma_3] = 2 \Gamma_2 \Gamma_3, \quad (39)$$

and we obtain

$$\tau_2 = \Gamma_2 + \Gamma_2 \Gamma^5 - \frac{e^{-\lambda}}{2r} \Gamma_2 \Gamma_1. \quad (40)$$

And, by the same procedure,

$$[\tau_3, \Gamma_0] = 2 \Gamma_3 \Gamma_0, \quad (41)$$

$$[\tau_3, \Gamma_1] = 2 \Gamma_3 \Gamma_1 + \frac{1}{r} \Gamma_3, \quad (42)$$

$$[\tau_3, \Gamma_2] = 2 \Gamma_3 \Gamma_2 + \cotg \theta \Gamma_3, \quad (43)$$

$$[\tau_3, \Gamma_3] = 2 r^2 \text{sen}^2 \theta \Gamma_5 - r \text{sen}^2 \theta e^{-\lambda} \Gamma_1 - \text{sen} \theta \cos \theta \Gamma_2, \quad (44)$$

and we obtain

$$\tau_3 = \Gamma_3 + \Gamma_3 \Gamma_5 - \frac{e^{-\lambda}}{2r} \Gamma_3 \Gamma_1 - \frac{\cotg \theta}{2r^2} \Gamma_3 \Gamma_2. \quad (45)$$

With these values of the internal affinities we may evaluate the internal curvature by the expression

$$R_{\alpha\beta} = \tau_{\alpha|\beta} - \tau_{\beta|\alpha} + [\tau_\beta, \tau_\alpha]. \quad (46)$$

If we evaluate this, we obtain

$$R_{01} = \frac{e^{-\lambda}}{4} \left\{ \nu'' - \frac{\nu' \lambda'}{2} + \frac{\nu'^2}{2} \right\} \Gamma_1 \Gamma_0, \quad (47)$$

$$R_{02} = \frac{e^{-\lambda}}{4} \cdot \frac{\nu'}{r} \cdot \Gamma_2 \Gamma_0, \quad (48)$$

$$R_{03} = \frac{e^{-\lambda}}{4} \cdot \frac{\nu'}{r} \cdot \Gamma_3 \Gamma_0, \quad (49)$$

$$R_{12} = \frac{e^{-\lambda}}{4} \cdot \left( -\frac{\lambda'}{r} \right) \cdot \Gamma_2 \Gamma_1, \quad (50)$$

$$R_{13} = \frac{e^{-\lambda}}{4} \cdot \left( -\frac{\lambda'}{r} \right) \cdot \Gamma_3 \Gamma_1, \quad (51)$$

$$R_{23} = \frac{1}{2r^2} \cdot (e^{-\lambda} - 1) \cdot \Gamma_3 \Gamma_2. \quad (52)$$

From these expressions and from the equation (11) we obtain the following equations

$$[R_{0\mu}, \Gamma^\mu] = 0 \quad (53)$$

gives

$$\nu'' + \frac{\nu'^2}{2} - \nu' \lambda' + \frac{2\nu'}{r} = 0, \quad (54)$$

$$[R_{1\mu}, \Gamma^\mu] = 0 \quad (55)$$

gives

$$v'' + \frac{v'^2}{2} - v' \lambda' - \frac{2 \lambda'}{r} = 0, \quad (56)$$

$$[R_{2\mu}, \Gamma^\mu] = 0 \quad (57)$$

gives

$$1 - e^\lambda = r \lambda'. \quad (58)$$

$$[R_{3\mu}, \Gamma^\mu] = 0 \quad (59)$$

gives

$$1 - e^\lambda = r \lambda'. \quad (60)$$

From these equations we see that

$$v' + \lambda' = 0 \quad (61)$$

and

$$(r e^{-\lambda}) = \text{constant}. \quad (62)$$

With the Minkowskian boundary condition we arrive at the Schwarzschild's solution of Einstein's equation. This is not surprising because, as we said, the equation (11) may give origin to Einstein's equation. What we have obtained is another way to arrive at the solutions of these equations, and we expect that others solutions may be obtained by this method.

### Acknowledgements

It is a pleasure to thank Professor J. M. Jauch for the hospitality at the 'Université de Genève' and for very interesting conversations.

### REFERENCES

- [1] MARIO NOVELLO, *Gravitation as a Consequence of the Self-Interaction of the  $\Gamma$ -Fields*. (To be published in J. Math. Phys.)
- [2] ADLER, BAZIN and SCHIFFER, *Introduction to General Relativity* (McGraw Hill, New York 1965).