

ANNALES DE L'I. H. P., SECTION A

JENG J. PERNG

A generalization of metric tensor and its application

Annales de l'I. H. P., section A, tome 13, n° 4 (1970), p. 287-293

http://www.numdam.org/item?id=AIHPA_1970__13_4_287_0

© Gauthier-Villars, 1970, tous droits réservés.

L'accès aux archives de la revue « Annales de l'I. H. P., section A » implique l'accord avec les conditions générales d'utilisation (<http://www.numdam.org/conditions>). Toute utilisation commerciale ou impression systématique est constitutive d'une infraction pénale. Toute copie ou impression de ce fichier doit contenir la présente mention de copyright.

NUMDAM

Article numérisé dans le cadre du programme
Numérisation de documents anciens mathématiques

<http://www.numdam.org/>

A generalization of metric tensor and its application

by

Jeng J. PERNG
National Taiwan University.

ABSTRACT. — The definition of metric tensor and the well known Ricci theorem are modified. The Einstein tensor and Maxwell equations are generalized. The field equations of gravitation and electricity are unified. The introduction of a metric in the space with symmetric connection is defined.

1. INTRODUCTION

The unified field theories as introduced by Einstein and others [1]-[8] are still unsolved today. These theories, in general, are different modifications of Einstein's gravitation theory and Riemann geometry. Therefore, the author believe that the modifications of these theories only may be the source of difficulties. Hence the unified field equation derived in this paper is based also on the generalization of Maxwell equations, the modifications of Ricci theorem and the definition of metric tensor. It will be shown below that the simplest coefficient of symmetric connection under which the unified field equation can be derived is

$$\Gamma_{\mu\nu}^{\sigma} = \left\{ \begin{matrix} \sigma \\ \mu\nu \end{matrix} \right\} + 2\alpha\epsilon_{\mu\nu}\epsilon^{\sigma s}\varphi_s$$

where $\left\{ \begin{matrix} \sigma \\ \mu\nu \end{matrix} \right\}$ is the Christoffel symbol formed with respect to the tensor $\epsilon_{\rho\sigma}$,

$\varkappa$ is an important universal constant and φ_s is the electromagnetic vector potential. Consequently there are four postulates:

i) In the fields of gravitation and electricity, the coefficient of connection of the space is symmetric and is defined by

$$\Gamma_{\mu\nu}^{\sigma} = \left\{ \begin{matrix} \sigma \\ \mu\nu \end{matrix} \right\} + 2\varkappa\varepsilon_{\mu\nu}\varepsilon^{\sigma s}\varphi_s \quad (1)$$

ii) The line element in this space is given by

$$ds^2 = \varepsilon_{mk}dx^m dx^k, \quad \varepsilon_{mk} = \frac{1}{2}(A_{mk} + A_{km}) \quad (2)$$

$$m, k = 1, 2, 3, 4 \quad x^4 = ict$$

where A_{ik} is given by the solution of the equation:

$$A_{ik;m} = \frac{\partial A_{ik}}{\partial x^m} - A_{hk}\Gamma_{im}^h - A_{ih}\Gamma_{km}^h = 0 \quad (3)$$

The condition of integrability is

$$A_{hk}B_{iml}^h + A_{ih}B_{kml}^h = 0 \quad (4)$$

(2) and (3) are the evident modifications of the well known Ricci theorem and the definition of metric tensor.

The semi-colon always indicates covariant differentiation with respect to $\Gamma_{\beta\gamma}^{\alpha}$. The determinant of A_{mk} does not vanish so that

$$A^{ik}A_{mk} = A^{ki}A_{km} = \delta_m^i.$$

In the following sections the tensors A_{mk} and A^{mk} always play the role of lowering and raising the indices respectively.

iii) Since the energy and mass are equivalent, the electromagnetic field is therefore equivalent to a gravitational field. Hence in the absence of gravitation, the space-time of an electromagnetic field is not « flat » *i. e.* the line element $ds^2 \neq \delta_{ik}dx^i dx^k$, it is valid only in empty space. The author therefore suppose that the line element is $ds^2 = X_{ik}dx^i dx^k$.

Hence the order of magnitude of the tensor X_{ik} is $X_{ik} \approx \delta_{ik}$. Consequently the space-time of electromagnetic field is « quasi-flat ».

iv) In the presence of gravitation, Maxwell equations are

$$F_{mk} = \varphi_{m;k} - \varphi_{k;m} = \frac{\partial \varphi_m}{\partial x^k} - \frac{\partial \varphi_k}{\partial x^m} \quad F_{;k}^{mk} = 0 \quad (5)$$

To remove the arbitrariness of φ_μ , it is natural to impose the condition

$$\varphi^\sigma_{;\sigma} = 0 \quad (6)$$

It is evidently a modification of Lorenz subsidiary condition of electromagnetic potential. According to *iii*) the Maxwell equations for electromagnetic field alone must be

$$\bar{F}_{mk} = \bar{\varphi}_{m|k} - \bar{\varphi}_{k|m} = \frac{\partial \bar{\varphi}_m}{\partial x^k} - \frac{\partial \bar{\varphi}_k}{\partial x^m}, \quad \bar{F}_{|k}^{mk} = 0 \quad (7)$$

where a solidus « | » indicate covariant differentiation with respect to $\bar{\Gamma}_{\beta\gamma}^\alpha$

$$\bar{\Gamma}_{\beta\gamma}^\alpha = \left\{ \begin{matrix} \alpha \\ \beta\gamma \end{matrix} \right\} + 2X_{\beta\gamma} X^{as} \bar{\varphi}_s, \quad X_{ik} = \frac{1}{2}(\bar{A}_{ik} + \bar{A}_{ki}), \quad \bar{A}_{ik|m} = 0, \quad \bar{\varphi}_{|\sigma}^\sigma = 0$$

and $\left\{ \begin{matrix} \alpha \\ \beta\gamma \end{matrix} \right\}$ is the Christoffel symbol with respect to the tensor X_{ik}

$$\therefore \bar{F}_{|\sigma}^{\mu\sigma} = \frac{\partial \bar{F}^{\mu\sigma}}{\partial x^\sigma} + \bar{\Gamma}_{\alpha\sigma}^\sigma \bar{F}^{\mu\alpha} = 0 \quad \therefore X_{ik} \approx \delta_{ik}, \quad \frac{\partial X_{ik}}{\partial x^m} \approx 0 \quad \therefore \left\{ \begin{matrix} \sigma \\ \alpha\sigma \end{matrix} \right\} \approx 0$$

$$\therefore \alpha \ll 1 \quad \therefore 2\alpha\varphi_\alpha \ll 1 \quad \therefore \bar{\Gamma}_{\alpha\sigma}^\sigma \ll 1$$

$$\therefore \bar{F}_{|\sigma}^{\mu\sigma} \approx \frac{\partial \bar{F}^{\mu\sigma}}{\partial x^\sigma} \approx 0$$

Since φ_μ , $\bar{\varphi}_\mu$ must be determined from (5) (7) therefore (5) is multiplied by $A_{m\mu}$

$$\begin{aligned} \therefore A_{m\mu} F_{;\sigma}^{\mu\sigma} &= F_{m;\sigma}^\sigma = (A^{s\sigma} F_{ms})_{;\sigma} = A^{s\sigma} F_{ms;\sigma} = A^{s\sigma} (\varphi_{m;s} - \varphi_{s;m})_{;\sigma} \\ &= A^{s\sigma} (\varphi_m)_{;s\sigma} - (A^{s\sigma} \varphi_s)_{;m\sigma} = A^{s\sigma} (\varphi_m)_{;s\sigma} - \varphi^\sigma_{;m\sigma} \\ &= A^{s\sigma} (\varphi_m)_{;s\sigma} - \varphi^\sigma_{;m\sigma} + \varphi^\sigma B_{\sigma m} = A^{s\sigma} (\varphi_m)_{;s\sigma} + \varphi^\sigma B_{\sigma m} = 0, \text{ by (6).} \\ \therefore \square \varphi_m &= -\varphi^\sigma B_{\sigma m}, \quad \square \equiv A^{s\sigma}(\dots)_{;s\sigma} \end{aligned} \quad (8)$$

The tensors $A_{\mu\sigma}$, $B_{\mu\sigma}$ and $X_{\mu\sigma}$ will be determined below.

Similarly, if there is no gravitation

$$\square \bar{\varphi}_m = -\bar{\varphi}^\sigma \bar{B}_{\sigma m} \quad (9)$$

where

$$\square \equiv \bar{A}^{s\sigma}(\dots)_{|s\sigma}$$

It should be noted that the first equation in (5) are the same as the ordinary Maxwell's equation, this means that the electromagnetic field strength is the same whether the space is flat or « quasi-flat ».

2. A GENERALIZATION OF EINSTEIN TENSOR

By the generalized Bianchi's identity

$$B_{jkl;m}^i + B_{jlm;k}^i + B_{jmk;l}^i = 0 \quad (10)$$

we get from (3) (10)

$$B_{ijkl;m} + B_{ijlm;k} + B_{ijmk;l} = 0, \quad B_{ijkl} \equiv A_{is} B_{sjkl}^s \quad (11)$$

(11) is multiplied by $A^{il}A^{jk}$, we get

$$\begin{aligned} A^{jk}B_{jk;m} - A^{jk}B_{jm;k} + A^{jk}B_{jmk;l} &= 0 \\ \delta_m^k B_{;k} - B_{m;k}^k + A^{jl}B_{jml;k}^k &= 0, \quad B_m^k \equiv A^{jk}B_{jm}^k \\ [\delta_m^k B - B_m^k + A^{jl}B_{jml}^k]_{;k} &= 0 \end{aligned} \quad (12)$$

From (4) we get

$$\begin{aligned} A^{sh}A^{jl}(A_{kh}B_{jml}^k + A_{jk}B_{hml}^k) &= 0 \\ A^{jl}B_{jlm}^k &= A^{kh}B_{hm}^k \end{aligned} \quad (13)$$

(12) becomes

$$[\delta_m^k B - B_m^k - A^{kh}B_{hm}^k]_{;k} = 0 \quad (14)$$

Let

$$P_m^k \equiv B_m^k + A^{kh}B_{hm}^k - \delta_m^k B$$

then

$$P_{m;k}^k = 0 \quad (15)$$

If

$$\varphi_\mu = 0 \quad \Gamma_{\beta\gamma}^\alpha = \left\{ \begin{matrix} \alpha \\ \beta\gamma \end{matrix} \right\} \quad B_{hm} = R_{hm}$$

$$\therefore P_m^k = 2 \left(R_m^k - \frac{1}{2} \delta_m^k R \right) \equiv 2G_m^k$$

$$\therefore G_m^k \equiv R_m^k - \frac{1}{2} \delta_m^k R$$

hence the solution of the equation $P_{m;k}^k = 0$ is $G_m^k = \lambda \delta_m^k$.

The tensor G_m^k is the well known Einstein tensor. Hence $\varepsilon_{\mu\nu}$ represents the gravitational potential. Consequently the tensor P_m^k is evidently a generalization of Einstein tensor. The equation $G_m^k = \lambda \delta_m^k$ has been taken by Einstein as the field equation of gravitation or

$$R_m^k - \frac{1}{2} \delta_m^k R = \lambda \delta_m^k \quad (16)$$

This fact suggest that the solution of (15) is the possible field equation of gravitation and electricity, that is,

$$P_m^k = C\delta_m^k$$

or:

$$B_m^k + A^{kh}B_{hm} - \delta_m^k B = C\delta_m^k \quad (17)$$

3. THE UNIFIED FIELD EQUATION

From (17), put $k = m$ we get $B = -2C$. $\therefore B_m^k + A^{kh}B_{hm} = -C\delta_m^k$. To determine C , let $\varphi_\mu = 0$ and compare with (16) we get $C = 2\lambda$

$$\therefore B_m^k + A^{kh}B_{hm} = -2\lambda\delta_m^k \quad (18)$$

(18) can be written

$$B_{km} + A_{ks}A^{sh}B_{hm} = -2\lambda A_{km} \quad (19)$$

or

$$(\delta_k^h + A_{ks}A^{sh})B_{hm} = -2\lambda A_{km} \quad (20)$$

Let

$$\begin{aligned} \alpha_k^h &\equiv \delta_k^h + A_{ks}A^{sh} & \bar{\alpha}_k^h &\equiv \delta_k^h + \bar{A}_{ks}\bar{A}^{sh} \\ \therefore \alpha_k^h B_{hm} &= -2\lambda A_{km} \end{aligned} \quad (21)$$

Suppose the determinant of α_k^h , $|\alpha_k^h| \neq 0$ so that $\alpha_r^m a_m^i = \alpha_m^i a_r^m = \delta_r^i$, (21) is multiplied by a_s^k

$$\therefore B_{sm} = -2\lambda a_s^k a_{km}$$

Let

$$\begin{aligned} \mathfrak{A}_{sm} &\equiv a_s^k A_{km} & \bar{\mathfrak{A}}_{sm} &\equiv \bar{a}_s^k \bar{A}_{km} \\ \therefore B_{sm} &= -2\lambda \mathfrak{A}_{sm} \end{aligned} \quad (22)$$

This equation is taken by the author as the unified field equation of gravitation and electricity.

(22) can be written in the form

$$F_{km} + \frac{1}{\mathfrak{A}} S_{km} = -\frac{2\lambda}{\mathfrak{A}} \mathfrak{A}_{km} \quad (23)$$

where

$$S_{km} = \frac{1}{2} \left(\frac{\partial \Gamma_{hk}^h}{\partial x^m} + \frac{\partial \Gamma_{hm}^h}{\partial x^k} \right) - \frac{\partial \Gamma_{km}^h}{\partial x^h} + \Gamma_{ki}^h \Gamma_{hm}^i - \Gamma_{km}^h \Gamma_{hi}^i$$

Let

$$Q_{km} \equiv \frac{1}{\varepsilon} S_{km} + \frac{2\lambda}{\varepsilon} \mathfrak{U}_{km}$$

than

$$F_{km} + Q_{km} = 0, \quad F^{km} + Q^{km} = 0 \quad (24)$$

$$\therefore F_{;m}^{km} + Q_{;m}^{km} = 0 \quad (25)$$

This equation is satisfied by

$$F_{;m}^{km} = 0 \quad (26) \quad Q_{;m}^{km} = 0 \quad (27)$$

(27) is just a restriction of the choice of the coordinates, such a restriction is evidently an analogue of the choice of coordinates given by Einstein in his general approximative solution of gravitational field equation [8]. Therefore, Maxwell equation is a consequence of the unified field equation. From (8) (22) we get

$$\boxed{\square} \varphi_m = 2\lambda \mathfrak{U}_{\sigma m} \varphi^\sigma \quad (28)$$

Since (22) (26) (27) must valid when there is no gravitation

$$\bar{B}_{\sigma m} = -2\lambda \bar{\mathfrak{U}}_{\sigma m} \quad (29)$$

Hence

$$\overline{\boxed{\square}} \bar{\varphi}_m = 2\lambda \bar{\mathfrak{U}}_{\sigma m} \bar{\varphi}^\sigma \quad (30)$$

$$\bar{F}_{|m}^{km} = 0 \quad \bar{Q}_{|m}^{km} = 0$$

The tensors φ_m , $A_{\mu\nu}$ are completely determined by

$$B_{\sigma m} = -2\lambda \mathfrak{U}_{\sigma m}, \quad \boxed{\square} \varphi_m = -\lambda \mathfrak{U}_{\sigma m} \varphi^\sigma \quad (31)$$

for there are 20 partial differential equations (31) satisfied by 20 unknowns φ_m , $A_{\mu\nu}$. Similarly, the equations (29) (30) with the boundary conditions

$$\varphi_m = 0 \quad X_{\mu\sigma} = \delta_{\mu\sigma}$$

completely determine the tensors $\bar{\varphi}_m$, $\bar{A}_{\sigma\mu}$.

4. DISCUSSION

The theory developed in this paper can be extended evidently to N-dimensional symmetric connected space and is equivalent to an introduction of

a metric in this space. Consequently, in a N-dimensional symmetric connected space with

$$\Gamma_{\mu\nu}^{\sigma} = \left\{ \begin{matrix} \sigma \\ \mu\nu \end{matrix} \right\} + C_{\mu\nu}^{\sigma}$$

where the tensor $C_{\mu\nu}^{\sigma}$ is known, we can define the metric tensors of this space from the solutions of the partial differential equations

$$B_{\rho\sigma} = -2\lambda\mathfrak{A}_{\rho\sigma}.$$

ACKNOWLEDGEMENTS

I would like to thank Prof. Dr. M. FIERZ of the Swiss Federal Institute of Technology, Zürich for his clear and critical comments.

REFERENCES

- [1] A. EINSTEIN and E. G. STRAUS, *Ann. Math.* (Princeton), t. **47** (2), 1946, p. 731.
- [2] A. EINSTEIN and B. KAUFMAN, *Ann. Math.* (Princeton), t. **62**, 1955, p. 128.
- [3] A. EINSTEIN, *The meaning of Relativity*, 5th ed., Princeton, 1955, Appendix II.
- [4] O. KLEIN, *Proceedings of the Berne Congress*, 1955.
- [5] H. WEYL, *Proceedings of the Berne Congress*, 1955.
- [6] M. FIERZ, *Helv. Phys. Acta*, t. **29**, 1956, p. 128.
- [7] P. G. BERGMANN, *Introduction to the Theory of Relativity*, 1942, p. 245-279.
- [8] W. PAULI, *Theory of Relativity*, 1958, p. 172-173, p. 223-232.
- [9] L. P. EISENHART, *Non-Riemannian Geometry*, 1927, p. 55-56.

(Manuscrit reçu le 22 mai 1970).
