ON ELECTROMAGNETIC INDUCTION IN EINSTEIN'S UNIFIED FIELD THEORY

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A cylindrically symmetric unified field associated with translatory and uniformly variable magnetic field is considered and a particular solution of the field equations in Einstein's unified field theory (Kashyap & Upadhyay 1973) is obtained.

INTRODUCTION

In Einstein's unified field theory the composite field is given by the real non-symmetric tensor $g_{\lambda\mu}$ defined as

$$g_{\lambda\mu} = g_{\underline{\lambda\mu}} + g_{\underset{\vee}{\lambda\mu}}, \qquad \dots(1)$$

where $g_{\underline{\lambda\mu}}$ is symmetric and $g_{\underset{\vee}{\lambda\mu}}$ is skew-symmetric in λ and μ. The symmetric $g_{\underline{\lambda\mu}}$ coincides with the metric tensor of Riemannian space-time and the skew-symmetric $g_{\underset{\vee}{\lambda\mu}}$ is used to interpret the electromagnetic phenomena. In case the tensor $g_{\lambda\mu}$ exhibits cylindrical symmetry, its symmetric and skew-symmetric parts separately remain invariant under the group of transformations

$$\left.\begin{aligned} \bar{x}^2 &= x^2 + a, \\ \bar{x}^3 &= x^3 + b, \\ \text{and} \quad \bar{x}^2 &= -x^2, \ \bar{x}^3 = -x^3, \end{aligned}\right\} \qquad \dots(2)$$

where a and b are arbitrary constants. Under this group of transformations, the symmetric $g_{\underline{\lambda\mu}}$ provides the space-time metric

$$ds^2 = A(dt^2 - d\rho^2) - Bd\phi^2 - Cdz^2 \qquad \dots(3)$$

in cylindrical polar coordinates (ρ, ϕ, z, t), where

$$\left.\begin{aligned} g_{11} &= -g_{44} = -A, \\ g_{22} &= -B, \ g_{33} = -C, \\ g_{\underline{\lambda\mu}} &= 0 \ (\lambda \neq \mu). \end{aligned}\right\} \qquad \dots(4)$$

Also, all the six components of the skew-symmetric $\underset{\vee}{g}_{\lambda\mu}$ exhibiting cylindrical symmetry are, in general, different from zero. It is found that all the non-zero components of $\underline{g}_{\lambda\mu}$ and $\underset{\vee}{g}_{\lambda\mu}$ are functions of ρ and t alone.

The physical significance of the skew-symmetric $\underset{\vee}{g}_{23}$, $\underset{\vee}{g}_{24}$ and $\underset{\vee}{g}_{34}$ has been given by Kashyap and Upadhyay (1973), Tiwari and Kashyap (1972) and Kashyap and Ram (1975). The unified field associated with $\underset{\vee}{g}_{23}$ corresponds to an electrically charged infinite cylindrical surface with its axis at $\rho = 0$. The case of $\underset{\vee}{g}_{24}$ exhibits the phenomena of magnetic induction due to current along $\rho = 0$. In the case of $\underset{\vee}{g}_{34}$, there is an electric current produced by uniform rate of change of magnetic flux in the direction of $\rho = 0$. In the present paper we discuss the unified field associated with $\underset{\vee}{g}_{13}$ which, like $\underset{\vee}{g}_{34}$, again gives the phenomena of electromagnetic induction.

FIELD EQUATIONS

Here we consider the unified field as characterized by

and
$$\left.\begin{array}{l} g_{11} = -\, g_{44} = -\, A, \\ g_{22} = -\, B, \;\; g_{33} = -\, C, \\ \underset{\vee}{g}_{13} = \psi, \end{array}\right\} \qquad \ldots(5)$$

all being functions of ρ and t alone. The field equations used by us are those of Einstein (1953) :

$$g_{\lambda\mu,\nu} - g_{\alpha\mu}\, \Gamma^{\alpha}_{\lambda\nu} - g_{\lambda\alpha}\, \Gamma^{\alpha}_{\nu\mu} = 0, \qquad \ldots(6a)$$

$$\underset{\vee}{\Gamma}^{\alpha}_{\lambda\alpha} = 0, \qquad \ldots(6b)$$

$$\underline{R}_{\lambda\mu} = 0 \qquad \ldots(6c)$$

and

$$\underset{\vee}{R}_{[\lambda\mu,\nu]} = 0, \qquad \ldots(6d)$$

where

$$\underline{R}_{\lambda\mu} = \underline{\Gamma}^{\alpha}_{\lambda\mu,\alpha} - \tfrac{1}{2}\left(\underline{\Gamma}^{\alpha}_{\lambda\alpha,\mu} + \underline{\Gamma}^{\alpha}_{\mu\alpha,\lambda}\right) + \underline{\Gamma}^{\beta}_{\lambda\mu}\,\underline{\Gamma}^{\alpha}_{\beta\alpha} - \underline{\Gamma}^{\beta}_{\lambda\alpha}\,\underline{\Gamma}^{\alpha}_{\beta\mu} - \underset{\vee}{\Gamma}^{\beta}_{\lambda\alpha}\,\underset{\vee}{\Gamma}^{\alpha}_{\beta\mu}$$

$$\underset{\vee}{R}_{\lambda\mu} = \underset{\vee}{\Gamma}^{\alpha}_{\lambda\mu,\alpha} + \underset{\vee}{\Gamma}^{\beta}_{\lambda\mu}\,\underline{\Gamma}^{\alpha}_{\beta\alpha} - \underline{\Gamma}^{\beta}_{\lambda\alpha}\,\underset{\vee}{\Gamma}^{\alpha}_{\beta\mu} - \underset{\vee}{\Gamma}^{\beta}_{\lambda\alpha}\,\underline{\Gamma}^{\alpha}_{\beta\mu} \qquad \ldots(7)$$

in the usual notations. Hereafter, the differentiation with respect to ρ and t are represented throughout by the suffixes 1 and 4 respectively followed by comma (e.g., $\partial A/\partial\rho = A_{,1}$ and $\partial A/\partial t = A_{,4}$).

The field equations ($6a$) determine the affine connections for the unified field (5). In terms of these affine connections we obtain the components of $R_{\underline{\lambda\mu}}$ and $R_{\underset{\vee}{\lambda\mu}}$ from (7). Thus, from ($6b$) to ($6d$), we have the field equations as follows :—

$$\psi\left[\frac{A_{,1}}{A}+\frac{B_{,1}}{B}-\left(\frac{A_{,1}}{A}-\frac{C_{,1}}{C}-\frac{2\psi_{,1}}{\psi}\right)\left(1+\frac{\psi^2}{AC}\right)^{-1}\right]=0. \qquad \ldots(8a)$$

$$-K_{11}-\frac{2\psi}{A}\underset{\vee}{\Gamma}{}^{3}_{14,4}+\frac{\psi}{C}\underset{\vee}{\Gamma}{}^{1}_{13,1}+\frac{\psi}{A}\left(\frac{5A_{,4}}{2A}-\frac{B_{,4}}{B}-\frac{C_{,4}}{C}-\frac{2\psi_{,4}}{\psi}\right)\underset{\vee}{\Gamma}{}^{3}_{14}$$
$$-\frac{\psi}{C}\left(\frac{A_{,1}}{2A}-\frac{\psi_{,1}}{\psi}\right)\underset{\vee}{}{}^{1}_{13}+\frac{\psi A_{,4}}{2AC}\underset{\vee}{\Gamma}{}^{1}_{34}-\left(\frac{\psi}{C}\underset{\vee}{\Gamma}{}^{1}_{13}\right)^2$$
$$-2\left(\frac{\psi}{A}\underset{\vee}{\Gamma}{}^{3}_{14}\right)^2-\frac{2\psi^2}{AC}\underset{\vee}{\Gamma}{}^{1}_{34}\underset{\vee}{\Gamma}{}^{3}_{14}+2\underset{\vee}{\Gamma}{}^{3}_{14}\underset{\vee}{\Gamma}{}^{4}_{13}=0. \qquad \ldots(8b)$$

$$-K_{22}+\frac{\psi}{2A}\left(\frac{B_{,1}}{C}\underset{\vee}{\Gamma}{}^{1}_{13}+\frac{B_{,4}}{C}\underset{\vee}{\Gamma}{}^{1}_{34}-\frac{B_{,4}}{A}\underset{\vee}{\Gamma}{}^{3}_{14}\right)=0. \qquad \ldots(8c)$$

$$-K_{33}+\frac{2\psi}{A}\left(\underset{\vee}{\Gamma}{}^{1}_{13,1}+\underset{\vee}{\Gamma}{}^{1}_{34,4}\right)+\frac{\psi^2}{4A^2}\left(\frac{A^2_{,1}}{A^2}+\frac{B^2_{,1}}{B^2}\right)$$
$$+\left[\frac{\psi}{A}\left(\frac{B_{,1}}{B}-\frac{3C_{,1}}{2C}+\frac{2\psi_{,1}}{\psi}\right)+\left(1+\frac{2\psi^2}{AC}\right)\underset{\vee}{\Gamma}{}^{1}_{13}\right]\underset{\vee}{\Gamma}{}^{1}_{13}$$
$$+\frac{\psi}{A}\left(\frac{B_{,4}}{B}-\frac{3C_{,4}}{2C}+\frac{2\psi_{,4}}{\psi}-\frac{2\psi}{C}\underset{\vee}{\Gamma}{}^{1}_{34}\right)\underset{\vee}{\Gamma}{}^{1}_{34}$$
$$-\frac{\psi}{2A^2}\left(C_{,4}+4\psi\underset{\vee}{\Gamma}{}^{1}_{34}\right)\underset{\vee}{\Gamma}{}^{3}_{14}-2\underset{\vee}{\Gamma}{}^{1}_{34}\underset{\vee}{\Gamma}{}^{4}_{13}=0 \qquad \ldots(8d)$$

$$-K_{44}+\frac{\psi}{AC}\left(C\underset{\vee}{\Gamma}{}^{3}_{14,4}-A\underset{\vee}{\Gamma}{}^{1}_{34,4}\right)-\frac{\psi}{A}\left(\frac{A_{,4}}{2A}-\frac{\psi_{,4}}{\psi}+\frac{\psi}{A}\underset{\vee}{\Gamma}{}^{3}_{14}\right)\underset{\vee}{\Gamma}{}^{3}_{14}$$
$$+\frac{\psi}{C}\left(\frac{A_{,4}}{2A}-\frac{\psi_{,4}}{\psi}-\frac{\psi}{C}\underset{\vee}{\Gamma}{}^{1}_{34}\right)\underset{\vee}{\Gamma}{}^{1}_{34}$$
$$-\frac{\psi A_{,1}}{2AC}\underset{\vee}{\Gamma}{}^{1}_{13}+2\underset{\vee}{\Gamma}{}^{1}_{34}\underset{\vee}{\Gamma}{}^{3}_{14}=0. \qquad \ldots(8e)$$

$$-K_{14}-\frac{\psi}{2AC}\left(A\underset{\vee}{\Gamma}{}^{1}_{34,1}+C\underset{\vee}{\Gamma}{}^{3}_{14,1}-A\underset{\vee}{\Gamma}{}^{1}_{13,4}\right)$$
$$-\frac{\psi}{2A}\left(\frac{\psi_{,1}}{\psi}-\frac{A_{,1}}{A}+\frac{B_{,1}}{B}+\frac{C_{,1}}{C}\right)\underset{\vee}{\Gamma}{}^{3}_{14}$$
$$+\frac{\psi}{2C}\left(\frac{A_{,1}}{A}-\frac{\psi_{,1}}{\psi}-\frac{2\psi}{C}\underset{\vee}{\Gamma}{}^{1}_{13}\right)\underset{\vee}{\Gamma}{}^{1}_{34}$$
$$-\left[\frac{\psi}{2C}\left(\frac{A_{,4}}{A}-\frac{\psi_{,4}}{\psi}\right)+\left(1-\frac{\psi^2}{AC}\right)\underset{\vee}{\Gamma}{}^{3}_{14}\right]\underset{\vee}{\Gamma}{}^{1}_{13}=0. \qquad \ldots(8f)$$

and

$$R_{\underset{\vee}{13},4} + R_{\underset{\vee}{34},1} = 0, \qquad \ldots(8g)$$

where

$$K_{11} = \tfrac{1}{2}\left(\frac{A_{,11}}{A} + \frac{B_{,11}}{B} + \frac{C_{,11}}{C} - \frac{A_{,44}}{A}\right)$$
$$- \frac{1}{4}\left[2\left(\frac{A_{,1}}{A}\right)^2 + \left(\frac{B_{,1}}{B}\right)^2 + \left(\frac{C_{,1}}{C}\right)^2 - 2\left(\frac{A_{,4}}{A}\right)^2\right.$$
$$\left. + \frac{A_{,1}B_{,1} + A_{,4}B_{,4}}{AB} + \frac{A_{,1}C_{,1} + A_{,4}C_{,4}}{AC}\right],$$

$$K_{22} = \frac{1}{2A}\left[B_{,11} - B_{,44} - \tfrac{1}{2}\left(\frac{B_{,1}^2 - B_{,4}^2}{B} - \frac{B_{,1}C_{,1} - B_{,4}C_{,4}}{C}\right)\right],$$

$$K_{33} = \frac{1}{2A}\left[C_{,11} - C_{,44} - \tfrac{1}{2}\left(\frac{C_{,1}^2 - C_{,4}^2}{C} - \frac{B_{,1}C_{,1} - B_{,4}C_{,4}}{B}\right)\right],$$

$$K_{44} = \tfrac{1}{2}\left(\frac{A_{,44}}{A} + \frac{B_{,44}}{B} + \frac{C_{,44}}{C} - \frac{A_{,11}}{A}\right)$$
$$- \frac{1}{4}\left[2\left(\frac{A_{,4}}{A}\right)^2 + \left(\frac{B_{,4}}{B}\right)^2 + \left(\frac{C_{,4}}{C}\right)^2\right.$$
$$\left. - 2\left(\frac{A_{,1}}{A}\right)^2 + \frac{A_{,1}B_{,1} + A_{,4}B_{,4}}{AB} + \frac{A_{,1}C_{,1} + A_{,4}C_{,4}}{AC}\right],$$

$$K_{14} = \tfrac{1}{2}\left(\frac{B_{,14}}{B} + \frac{C_{,14}}{C} - \frac{B_{,1}B_{,4}}{2B^2} - \frac{C_{,1}C_{,4}}{2C^2}\right.$$
$$\left. - \frac{A_{,1}B_{,4} + A_{,4}B_{,1}}{2AB} - \frac{A_{,1}C_{,4} + A_{,4}C_{,1}}{2AC}\right)$$

$$R_{\underset{\vee}{13}} = \Gamma^1_{\underset{\vee}{13},1} + \Gamma^4_{\underset{\vee}{13},4} + \tfrac{1}{2}\left(\frac{A_{,1}}{A} + \frac{B_{,1}}{B}\right)\Gamma^1_{\underset{\vee}{13}}$$
$$+ \tfrac{1}{2}\left(\frac{A_{,4}}{A} + \frac{B_{,4}}{B}\right)\Gamma^4_{\underset{\vee}{13}} + \frac{1}{2A}\left(A_{,4}\,\Gamma^1_{\underset{\vee}{34}} - C_{,4}\,\Gamma^3_{\underset{\vee}{14}}\right)$$
$$- \frac{4\psi}{A}\,\Gamma^1_{34}\,\Gamma^3_{\underset{\vee}{14}} + \frac{\psi}{4A}\left(\frac{A_{,1}^2}{A^2} + \frac{B_{,1}^2}{B^2}\right)$$

$$R_{\underset{\vee}{34}} = \Gamma^1_{\underset{\vee}{34},1} + \tfrac{1}{2}\left(\frac{A_{,1}}{A} + \frac{B_{,1}}{B}\right)\Gamma^1_{\underset{\vee}{34}} + \frac{1}{2A^3}\left(A^2C_{,1} - \psi^2A_{,1}\right)\Gamma^3_{\underset{\vee}{14}}$$
$$+ \frac{1}{2A}\left(A_{,1}\,\Gamma^4_{\underset{\vee}{13}} + A_{,4}\,\Gamma^1_{\underset{\vee}{13}}\right)$$
$$- \frac{3\psi}{A}\,\Gamma^1_{\underset{\vee}{13}}\,\Gamma^3_{\underset{\vee}{14}} + \frac{\psi}{2A}\left(\frac{A_{,14}}{A} - \frac{3A_{,1}A_{,4}}{2A^2} + \frac{A_{,1}\psi_{,4}}{A\psi}\right.$$
$$\left. + \frac{A_{,1}B_{,4}}{2AB} - \frac{B_{,1}B_{,4}}{2B^2}\right),$$

$$\underset{\vee}{\Gamma^1_{13}} = \frac{\psi C}{AC + \psi^2}\left(\frac{A_{,1}}{2A} + \frac{C_{,1}}{2C} - \frac{\psi_{,1}}{\psi}\right),$$

$$2\underset{\vee}{\Gamma^4_{13}} = \frac{C^2}{AC + \psi^2}\left[\left(\frac{\psi}{C}\right)_4 - \frac{\psi^2}{C^2}\left(\frac{\psi}{A}\right)_{,4}\right] - \frac{\psi A_{,4}}{A^2},$$

$$2\underset{\vee}{\Gamma^3_{14}} = \frac{A^2C^2}{A^2C^2 - \psi^4}\left[-\left(\frac{\psi}{C}\right)_{,4} + \frac{\psi^2}{C^2}\left(\frac{\psi}{A}\right)_{,4}\right]$$

and

$$\underset{\vee}{\Gamma^1_{34}} = \frac{\psi}{2A}\left(\frac{\psi_{,4}}{\psi} - \frac{A_{,4}}{A}\right) + \frac{\psi^2}{A^2}\underset{\vee}{\Gamma^3_{14}}.$$

SOLUTION OF THE FIELD EQUATIONS

The field equations (8) are nonlinear with respect to the field variables $g_{\lambda\mu}$ and are quite complicated on account of which a rigorous solution is difficult to obtain. As a linear theory accounts, with a considerable degree of accuracy, for the description of physical phenomena it is not unreasonable to assume that the field variables are small quantities. Let us take

$$\left.\begin{aligned} A &= 1 + \alpha, \\ B &= \rho^2 + \beta \\ C &= 1 + \gamma. \end{aligned}\right\} \quad \text{and} \qquad \ldots(9)$$

The order of smallness of the field variables is as follows :

$$\left.\begin{aligned} \psi &\equiv O(1) \\ \alpha, \beta, \gamma &\equiv O(2) \end{aligned}\right\} \quad \text{and} \qquad \ldots(10)$$

Upto the second order of smallness, the field equations (8) reduce to

$$\psi_{,1} + \frac{\psi}{\rho} = 0, \qquad \ldots(11a)$$

$$\alpha_{,11} - \alpha_{,44} - \frac{\alpha_{,1}}{\rho} + \frac{1}{\rho}\left(\frac{\beta}{\rho}\right)_{,11} + \gamma_{,11}$$

$$= - 2\psi(\psi_{,11} - \psi_{,44}) - 2\psi^2_{,1} + \psi^2_{,4}, \qquad \ldots(11b)$$

$$\left(\frac{\beta}{\rho}\right)_{,11} - \left(\frac{\beta}{\rho}\right)_{,44} + \gamma_{,1} = - 2\psi\psi_{,1}, \qquad \ldots(11c)$$

$$\gamma_{,11} - \gamma_{,44} + \frac{\gamma_{,1}}{\rho} = - 2\psi\left(2\psi_{,11} - \psi_{,44} + \frac{\psi_{,1}}{\rho} - \frac{2\psi}{\rho^2}\right) - 2\psi^2_{,1} + \psi^2_{,4}, \ldots(11d)$$

$$\alpha_{,11} - \alpha_{,44} + \frac{\alpha_{,1}}{\rho} - \frac{\beta_{,44}}{\rho^2} - \gamma_{,44} = 2\psi_{,44} + 3\psi^2_{,4}, \qquad \ldots(11e)$$

$$\frac{1}{\rho}\left(\frac{\beta}{\rho}\right)_{,14} + \gamma_{,14} - \frac{\alpha_{,4}}{\rho} = -\psi\left(\psi_{,14} - \frac{\psi_{,4}}{\rho}\right) - 2\psi_{,1}\,\psi_{,4} \qquad \text{...(11}f\text{)}$$

and

$$\left(\psi_{,11} - \psi_{,44} + \frac{\psi_{,1}}{\rho} - \frac{\psi}{\rho^2}\right)_{,4} = 0 \qquad \text{...(11}g\text{)}$$

The equation (11a), after integration, gives

$$\psi = \frac{T}{\rho}, \qquad \text{...(12)}$$

where $T[\equiv T(t)]$ is an arbitrary function. Substituting the value of ψ from (12) in (11g), we obtain

$$T_{,44} = 0 \qquad \text{...(13)}$$

from which we have

$$T = kt, \qquad \text{...(14)}$$

k being constant of integration. Therefore, from (12) and (14) we have

$$\psi = k\left(\frac{t}{\rho}\right). \qquad \text{...(15)}$$

Substituting the value of ψ in the equation (11d) we obtain

$$\gamma_{,11} - \gamma_{,44} + \frac{\gamma_{,1}}{\rho} = \frac{k^2}{\rho^2}\left(1 - \frac{4t^2}{\rho^2}\right), \qquad \text{...(16)}$$

which provides the solution

$$\gamma = -\frac{k^2}{2}\left[(\log\rho)^2 + \frac{2t^2}{\rho^2}\right]. \qquad \text{...(17)}$$

We omit the solution of the homogeneous part since the gravitational field is purely due to electromagnetic field. Substituting the values of ψ and γ in (11c) we have

$$\left(\frac{\beta}{\rho}\right)_{,11} - \left(\frac{\beta}{\rho}\right)_{,44} = \frac{\log\rho}{\rho}, \qquad \text{...(18)}$$

which gives the following solution

$$\beta = \frac{k^2}{2}\,\rho^2(\log\rho - 2)\log\rho. \qquad \text{...(19)}$$

Putting the values of ψ, β and γ in the equation (11f) we obtain

$$\alpha_{,4} = 0, \qquad \text{...(20)}$$

which suggests that α is a function ρ only. Let us put

$$\alpha = F(\rho). \qquad \text{...(21)}$$

Substituting the values of α, β, γ and ψ so obtained in the equation (11*b*), we obtain

$$\left(\frac{F_{,1}}{\rho}\right)_{,1} = \frac{2k^2}{\rho^3}(1 - \log \rho), \qquad \ldots(22)$$

which, after integration, provides

$$F = \tfrac{1}{2} k^2(\log \rho - 1) \log \rho. \qquad \ldots(23)$$

Therefore, from (21) and (23) we have

$$\alpha = \tfrac{1}{2} k^2(\log \rho - 1) \log \rho. \qquad \ldots(24)$$

Discussion

The results of our present investigation resemble those obtained by Kashyap and Ram (1975) in the following respects :

(*a*) The density of the electric current which is in the ϕ-direction varies inversely as the square of the distance from the z-axis. Classically an electric current of this type is induced by a continuous uniform increase of magnetic flux in the z-direction.

(*b*) The measure of force on a test particle initially at rest along ρ-line is the same in both cases and it is given by

$$\frac{d^2\rho}{dt^2} = -\frac{k^2}{4\rho}(2 \log \rho - 1). \qquad \ldots(25)$$

However, the gravitational fields produced by $\underset{\vee}{g_{34}}$ and $\underset{\vee}{g_{13}}$ are different. The corresponding metric potentials implying this difference are as follows :

In the case of $\underset{\vee}{g_{34}}$:

$$\left.\begin{aligned} \alpha &= \tfrac{1}{2} k^2(\log \rho - 2t - 1) \log \rho; \\ \beta &= \tfrac{1}{2} k^2\rho^2 [(\log \rho - 2t - 2) \log \rho + 2]; \\ \text{and} \quad \gamma &= \tfrac{1}{2} k^2(\log \rho + 2t) \log \rho. \end{aligned}\right\} \qquad \ldots(26)$$

In the case of $\underset{\vee}{g_{13}}$:

$$\left.\begin{aligned} \alpha &= \tfrac{1}{2} k^2(\log \rho - 1) \log \rho; \\ \beta &= \tfrac{1}{2} k^2\rho^2(\log \rho - 2) \log \rho; \\ \text{and} \quad \gamma &= -\tfrac{1}{2} k^2\left[(\log \rho)^2 + \frac{2t^2}{\rho^2}\right]. \end{aligned}\right\} \qquad \ldots(27)$$

From (26) and (27) it is obvious that in the present case α and β are functions of ρ alone whereas in Kashyap and Ram (1975) they are functions of ρ and t both. It is also worth noting that α in (27) is obtained by putting $t = 0$ in (26).

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