

Title: PSI 2018/2019 - Relativity - Lecture 7

Date: Sep 11, 2018 09:00 AM

URL: <http://pirsa.org/18090006>

Abstract:

CORRECTION OF BIG MISTAKE YESTERDAY

• PROVING THE EQUIVALENCE PRINCIPLE

$$X \rightarrow X'$$

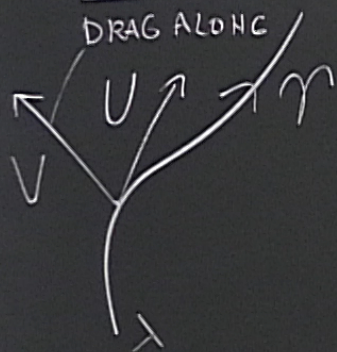
$$X'^{\alpha} = \Lambda^{\alpha}_{\beta} X^{\beta} + O(x^2) \Leftrightarrow X^{\alpha} = \tilde{A}^{\alpha}_{\beta} X'^{\beta} + O(x^2)$$

$$g'^{\alpha\beta}(p) = \frac{\partial x^{\alpha}}{\partial x'^{\alpha}} \frac{\partial x^{\beta}}{\partial x'^{\beta}} g_{\alpha\beta} = \tilde{A}^{\alpha}_{\alpha} \tilde{A}^{\beta}_{\beta} g_{\alpha\beta} = \eta_{\alpha\beta}$$

↑ INVERSE TO A^{α}_{β}

(COUNTING WORKS ANYWAY 😊)

PARALLEL TRANSPORT



V^α IS PARALLEL TRANSPORTED
ALONG γ

$$U^\mu \nabla_\mu V^\alpha = D_\lambda V^\alpha = \frac{DV^\alpha}{d\lambda} = \dot{V}^\alpha = 0$$

• LET V & W ARE PARALLEL TRANSPORTED ALONG γ

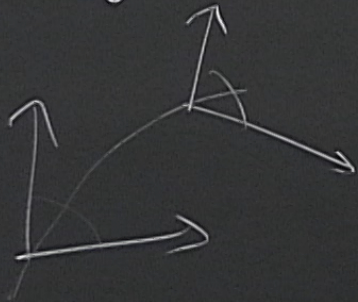
$$\dot{V} = 0 = \dot{W} \Rightarrow \frac{D}{d\tau} \left(\underset{\substack{\uparrow \\ \text{SCALAR PRODUCT}}}{V \cdot W} \right) = \frac{D}{d\tau} (V^\alpha W^\beta g_{\alpha\beta})$$

$$= V^\alpha W^\beta \underbrace{\frac{Dg_{\alpha\beta}}{d\tau}}$$

$$= -V^\alpha W^\beta \nabla_\mu g_{\alpha\beta}$$

• LET V & W ARE PARALLEL TRANSPORTED ALONG γ

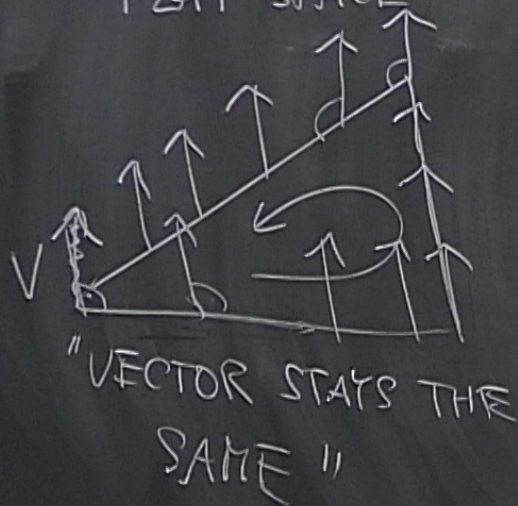
$$\dot{V} = 0 = \dot{W} \Rightarrow \frac{D}{dt} (V^\alpha W^\beta \underset{\substack{\uparrow \\ \text{SCALAR PRODUCT}}}{g_{\alpha\beta}}) = \frac{D}{dt} (V^\alpha W^\beta g_{\alpha\beta})$$



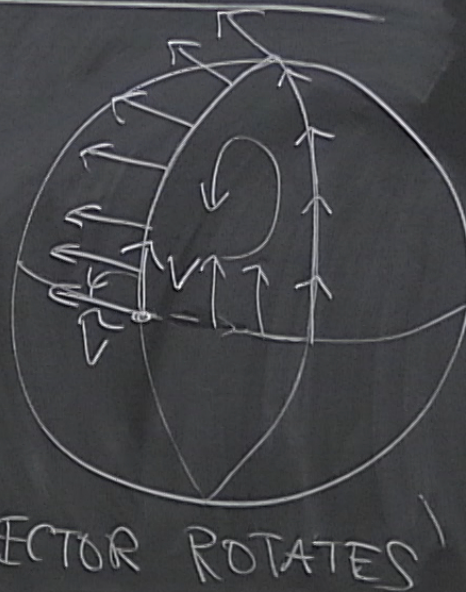
$$= V^\alpha W^\beta \underbrace{\frac{Dg_{\alpha\beta}}{dt}}_{\text{UMD}_{H g_{\alpha\beta}}} \stackrel{\text{WOULD BE NICE}}{=} 0$$

PARALLEL TRANSPORT ALONG A LOOP

FLAT SPACE



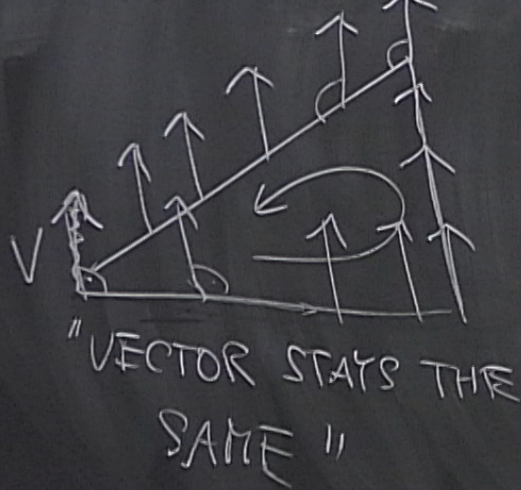
VS.



PARALLEL TRANSPORT ALONG A LOOP

• FIRS

FLAT SPACE



VS.



'VECTOR ROTATES' - MANIFESTATION THAT SPACE IS CURVED.

• FIRST LOOK AT KILLING VECTORS

LET γ BE A GEODESIC WITH TANGENT U , $\dot{U}=0$
LET $\underline{X}$ BE ANOTHER VECTOR

$$C =$$

• FIRST LOOK AT KILLING VECTORS

LET σ BE A GEODESIC WITH TANGENT U , $\dot{U}=0$

LET ξ BE ANOTHER VECTOR

$$C \equiv U \cdot \xi = U^\alpha \xi_\alpha$$

LET: $0 \stackrel{\uparrow}{=} \dot{C} = \nabla_U (U^\alpha \xi_\alpha) = (\nabla_U U^\alpha) \xi_\alpha + U^\alpha U^\beta \nabla_\beta \xi_\alpha$

↑
REQUIRE

LET γ BE A GEODESIC WITH $\dot{\gamma}$

LET ξ BE ANOTHER VECTOR

$$C \equiv U \cdot \xi = U^\alpha \xi_\alpha$$

LET: $0 \stackrel{\uparrow}{=} \dot{C} = \nabla_U (U^\alpha \xi_\alpha) = \underbrace{(\nabla_U U^\alpha)}_{=0} \xi_\alpha + U^\alpha \underbrace{\nabla_U \xi_\alpha}_{=0}$

REQUIRE

SAME "

VECTOR ROTATES

MANIFESTATION
THAT SPACE IS CURVED

IF TRUE FOR EVERY GEODESIC

$$\nabla_\alpha \xi_\beta = 0 \Rightarrow \boxed{\nabla_\alpha \xi_\beta + \nabla_\beta \xi_\alpha = 0}$$

SAME "

VECTOR ROTATES

MANIFESTATION
THAT SPACE IS CURVED

IF TRUE FOR EVERY GEODESIC

$$\nabla_{(\alpha} \xi_{\beta)} = 0 \quad \boxed{\nabla_{\alpha} \xi_{\beta} + \nabla_{\beta} \xi_{\alpha} = 0}$$

KILLING VECTOR EQ

ξ^{α} DESCRIBES A SYMMETRY
OF THE SPACETIME.

• FIRST LOOK AT KILLING VECTORS

LET σ BE A GEODESIC WITH TANGENT U , $\dot{U}=0$
 LET ξ BE ANOTHER VECTOR

$$C \equiv U \cdot \xi = U^\alpha \xi_\alpha \dots \text{CONSERVED Q} \dots \text{LINEAR IN } U$$

LET: $0 \stackrel{\uparrow}{=} \dot{C} = \nabla_U (U^\alpha \xi_\alpha) = \underbrace{(\nabla_U U^\alpha)}_{=0} \xi_\alpha + U^\alpha \underbrace{\nabla_U \xi_\alpha}_{\neq 0}$

↑
REQUIRE

STATIONARY
 IS CURVED.

f) CURVATURE

2 VALUE MOTIVATIONS

CONSIDER A_μ .. GAUGE FIELD ... COVARIANT DERIVATIVE,

$$D_\mu = \partial_\mu + A_\mu$$

f) CURVATURE

2 VALUE MOTIVATIONS

CONSIDER A_μ GAUGE FIELD ... COVARIANT DERIVATIVE.

$$D_\mu = \partial_\mu + A_\mu$$

$$\begin{aligned} [D_\mu, D_\nu] &= (\partial_\mu + A_\mu)(\partial_\nu + A_\nu) - (\partial_\nu + A_\nu)(\partial_\mu + A_\mu) \\ &= \underbrace{\partial_\mu \partial_\nu - \partial_\nu \partial_\mu}_0 + \partial_\mu A_\nu - \partial_\nu A_\mu + A_\mu A_\nu - A_\nu A_\mu \end{aligned}$$

f) CURVATURE

2 VALUE MOTIVATIONS

CONSIDER A_μ .. GAUGE FIELD ... COVARIANT DERIVATIVE,

$$D_\mu = \partial_\mu + A_\mu$$

↑ CONNECTION

$$\begin{aligned} [D_\mu, D_\nu] &= (\partial_\mu + A_\mu)(\partial_\nu + A_\nu) - (\partial_\nu + A_\nu)(\partial_\mu + A_\mu) \\ &= \underbrace{\partial_\mu \partial_\nu - \partial_\nu \partial_\mu}_0 + \partial_\mu A_\nu - \partial_\nu A_\mu + \underbrace{A_\mu A_\nu - A_\nu A_\mu}_{[A_\mu, A_\nu]} \end{aligned}$$

f) CURVATURE

2 VALUABLE MOTIVATIONS

CONSIDER A_μ .. GAUGE FIELD ... COVARIANT DERIVATIVE,

$$D_\mu = \partial_\mu + A_\mu$$

↑ CONNECTION

$$\begin{aligned} [D_\mu, D_\nu] &= (\partial_\mu + A_\mu)(\partial_\nu + A_\nu) - (\partial_\nu + A_\nu)(\partial_\mu + A_\mu) \\ &= \underbrace{\partial_\mu \partial_\nu - \partial_\nu \partial_\mu}_0 + \underbrace{\partial_\mu A_\nu - \partial_\nu A_\mu}_{F_{\mu\nu}} + \underbrace{A_\mu A_\nu - A_\nu A_\mu}_{[A_\mu, A_\nu]} = \underline{F_{\mu\nu}} \end{aligned}$$

OF THE SPACETIME.

$$= \frac{\partial \mu \partial \nu - \partial \nu \partial \mu}{\partial} + \partial \mu A \nu$$

GRAVITY

VEILBEINS e^a_μ

CONNECTION: $\omega_\mu{}^a{}_b$

$$e = \sqrt{|g|} \leftrightarrow g_{\mu\nu} = e^a_\mu e^b_\nu \underline{\eta_{ab}}$$

$$\nabla_\mu e_b = \omega_\mu{}^a{}_b e_a$$

GRAVITY

VEILBEINS e^a_μ

CONNECTION: $\omega_\mu{}^a{}_b$

$$e = \sqrt{g} \leftrightarrow g_{\mu\nu} = e^a_\mu e^b_\nu \underline{\eta_{ab}}$$

$$\nabla_\mu e^b = \omega_\mu{}^a{}_b e^a$$

$$D_\mu = \partial_\mu + \omega_\mu$$

$$[D_\mu, D_\nu]^a{}_b = \partial_\mu \omega_\nu{}^a{}_b - \partial_\nu \omega_\mu{}^a{}_b + [\omega_\mu, \omega_\nu]^a{}_b = \underline{R_{\mu\nu}{}^a{}_b}$$

CURVATURE OF GRAVITY

THE SPACETIME.

$$= \underbrace{\partial_\mu \partial_\nu - \partial_\nu \partial_\mu}_{=0} + \underbrace{\partial_\mu A_\nu - \partial_\nu A_\mu}_{F_{\mu\nu}} + \underbrace{A_\mu A_\nu - A_\nu A_\mu}_{=0} = F_{\mu\nu}$$

GRAVITY

VEILBEINS e_μ^a
CONNECTION: $\omega_\mu^a{}_b$

$$e = \sqrt{g} \hookrightarrow g_{\mu\nu} = e^a{}_\mu e^b{}_\nu \eta_{ab}$$

$$\nabla_\mu e_b = \omega_\mu^a{}_b e_a$$

$$D_\mu = \partial_\mu + \omega_\mu$$

$$[D_\mu, D_\nu]^a{}_b = \partial_\mu \omega_\nu^a{}_b - \partial_\nu \omega_\mu^a{}_b + [\omega_\mu, \omega_\nu]^a{}_b = \underline{R_{\mu\nu}^a{}_b}$$

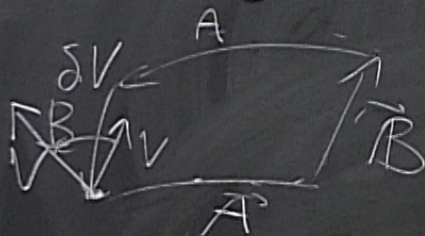
CURVATURE OF GRAVITY

$$\nabla_\mu e^a{}_\nu = 0$$

$$\nabla_\mu g^{\mu\nu} = 0$$

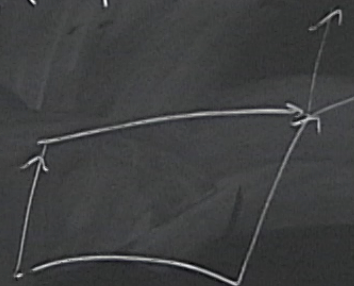
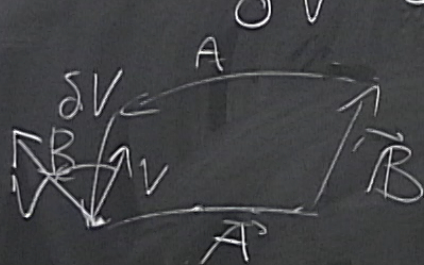
MOTIVATION 2 - HOW VECTOR ROTATES

$$\delta V^\alpha \propto R(A, B)^\alpha{}_\beta V^\beta = \underbrace{R^\alpha{}_\beta \propto A^\mu B^\nu}_{\text{RIEMANN TENSOR (CURVATURE)}} V^\beta$$



MOTIVATION 2 - HOW VECTOR ROTATES.

$$\delta V^\alpha \propto R(A, B)^\alpha{}_\beta V^\beta = \underbrace{R^\alpha{}_\beta}_{\text{RIEMANN TENSOR (CURVATURE)}} A^\mu B^\mu V^\beta$$



RIEMANN TENSOR
(CURVATURE)

$\propto A^{\alpha} B^{\beta} V^{\gamma}$

IN TENSOR
ATURE)

DEF:

$$[\nabla_{\mu}, \nabla_{\nu}] V^{\sigma} = R^{\sigma}_{\mu\nu\rho} V^{\rho}$$

↑
RIEMANN TENSOR

$\propto A^{\alpha} B^{\beta} V^{\gamma}$

IN TENSOR
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DEF:

$$[\nabla_{\mu}, \nabla_{\nu}] V^{\sigma} = R^{\sigma}_{\mu\nu\alpha} V^{\alpha}$$

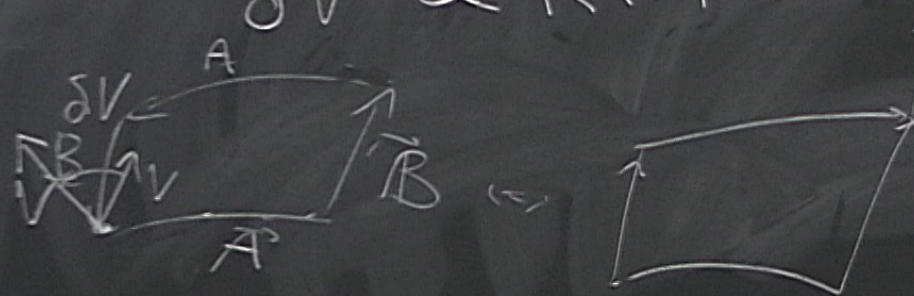
↑
RIEMANN TENSOR

(DERIVATIVE TERMS DO EXIST IF
YOU HAVE NON-TRIVIAL TORSION

$$-T^{\sigma}_{\mu\nu} \nabla_{\sigma} V^{\alpha}$$



MOTIVATION 2 - HOW VECTOR ROTATES.

$$\delta V^\alpha \propto R(A, B)^\alpha{}_\beta V^\beta = \underbrace{R^\alpha{}_\beta A^\mu A^\nu}_{\text{RIEMANN TENSOR (CURVATURE)}} V^\beta$$


IT FOLLOWS FROM DEFINITION:

$$R^{\rho}{}_{\sigma\mu\nu} = \partial_{\mu}\Gamma^{\rho}_{\nu\sigma} - \partial_{\nu}\Gamma^{\rho}_{\mu\sigma} + \Gamma^{\rho}_{\mu\lambda}\Gamma^{\lambda}_{\nu\sigma} - \Gamma^{\rho}_{\nu\lambda}\Gamma^{\lambda}_{\mu\sigma}$$

$$= \partial\Gamma - \partial\Gamma + \Gamma\Gamma - \Gamma\Gamma$$

PROPERTIES. $R_{\alpha\beta\gamma\delta} = g_{\alpha\alpha'} R^{\alpha'}{}_{\beta\gamma\delta}$

$$R_{\alpha\beta\gamma\delta}$$

IT FOLLOWS FROM DEFINITION:

$$R^{\rho}{}_{\sigma\mu\nu} = \partial_{\mu}\Gamma^{\rho}_{\nu\sigma} - \partial_{\nu}\Gamma^{\rho}_{\mu\sigma} + \Gamma^{\rho}_{\mu\lambda}\Gamma^{\lambda}_{\nu\sigma} - \Gamma^{\rho}_{\nu\lambda}\Gamma^{\lambda}_{\mu\sigma}$$

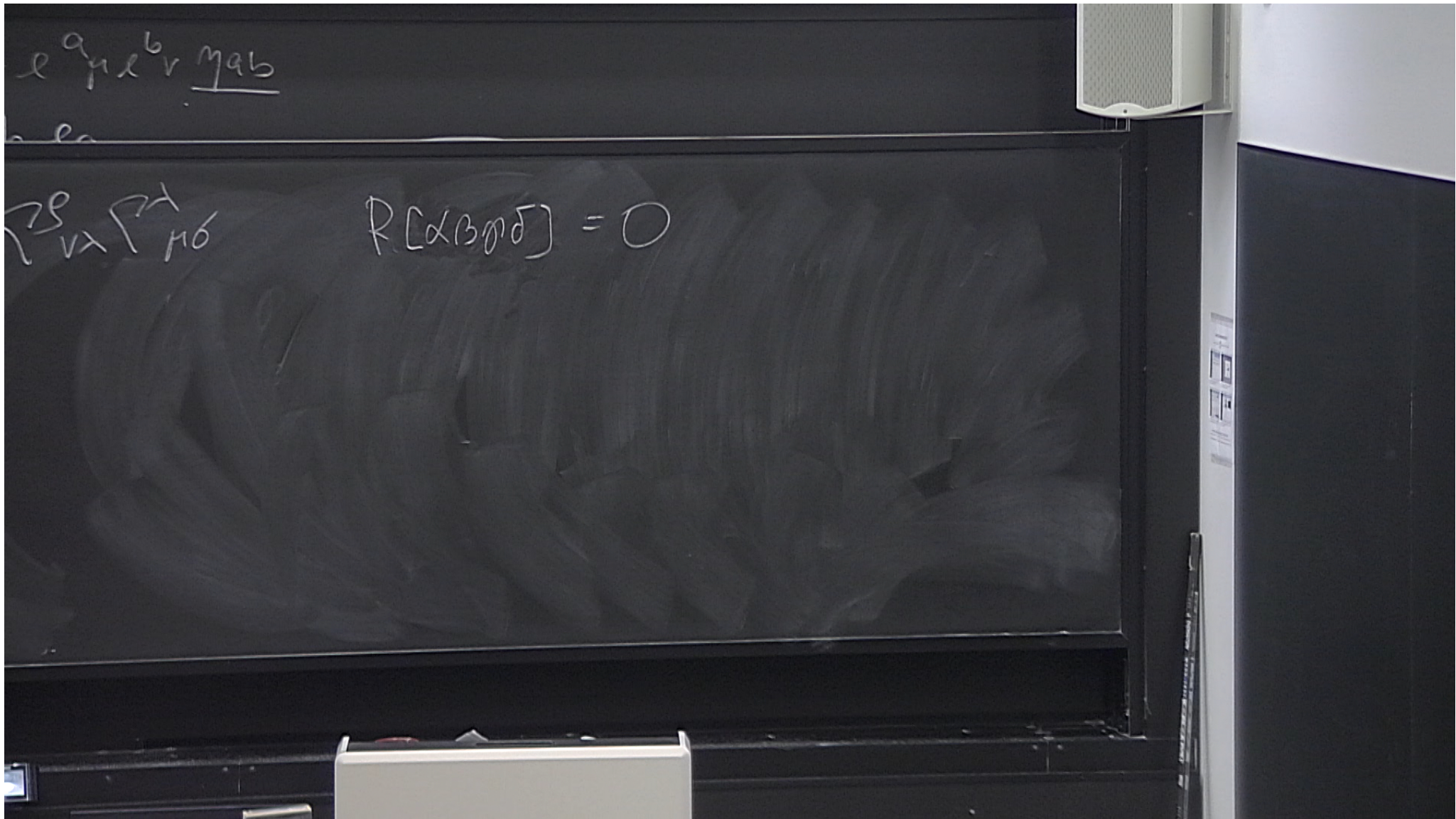
$$= \partial_{\mu}\Gamma^{\rho}_{\nu\sigma} - \partial_{\nu}\Gamma^{\rho}_{\mu\sigma} + \Gamma^{\rho}_{\mu\lambda}\Gamma^{\lambda}_{\nu\sigma} - \Gamma^{\rho}_{\nu\lambda}\Gamma^{\lambda}_{\mu\sigma}$$

PROPERTIES

$$R_{\alpha\beta\gamma\delta} = g_{\alpha\alpha'} R^{\alpha'}{}_{\beta\gamma\delta}$$

$$R_{\alpha\beta\gamma\delta} = R_{\gamma\delta\alpha\beta} = -R_{\delta\gamma\alpha\beta} = +R_{\delta\gamma\beta\alpha}$$

SYMMETRIC



$$\Gamma_{\nu\lambda}^{\rho} \Gamma_{\mu\sigma}^{\rho}$$

$$R[\alpha\beta\eta\delta] = 0 \quad (2)$$

$$R\alpha[\beta\eta\delta]_c = 0 \quad \text{FOLLOWS FROM (1) \& (2)}$$

$$\boxed{R\alpha[\beta\eta\delta; \mathcal{X}]_c = 0} \quad (3)$$

(1)

$$\boxed{\nabla_\mu g_{\nu}^{\mu} = 0} \quad \boxed{\nabla_\mu g^{\mu\nu} = 0}$$

RE

THE MOTIVATIONS

SCALAR FIELD

COVARIANT DERIVATIVE.

GRAVITY VEILBEINS χ_μ $\chi = \chi_\mu \leftrightarrow \gamma_{\mu\nu} = \chi_\mu \chi_\nu$ 195

HOW MANY COMPONENTS (?) IN d -DIMENSIONS.

— RESTRICTED BY (1) & (2)

$$R_{\alpha\beta\gamma\delta}$$

A B

INDEX A TAKES $m = \binom{d}{2} = \frac{d(d-1)}{2}$ VALUES

B ——— || ———
 $R_{AB} \cdot \frac{m(m+1)}{2}$ VALUES

$$g \leftrightarrow g_{\mu\nu} = \eta_{\mu\nu} + \frac{2}{\Lambda^2} \partial_\mu \partial_\nu \phi$$

$$e_1 = \dots$$

(2) GIVE $\binom{d}{4}$ CONSTRAINTS

ES $m = \binom{d}{2} = \frac{d(d-1)}{2}$
VALUES

11
VALUES

$$\#_{\text{RIEMANN}} = \frac{m(m+1)}{2} - \binom{d}{4} = \frac{d^2}{12} (d^2 - 1)$$

(2) GIVE $\binom{d}{4}$ CONSTRAINTS

ES $m = \binom{d}{2} = \frac{d(d-1)}{2}$
VALUES

$$\#_{\text{RIEMANN}} = \frac{m(m+1)}{2} - \binom{d}{4} = \frac{d^2}{12} (d^2 - 1)$$

11
VALUES

$d=4$

$\frac{16}{12} \cdot 15 = \underline{20}$

PRECISELY 20 2ND-ORDER
DERIVATIVES OF METRIC
THAT WE CANNOT GET RID
OF BY EQ. PRINCIPLE.

$+ [w_{\mu\nu}]^a_b = \underline{R_{\mu\nu}^a_b}$

• FLATNESS. DEF. SPACETIME IS FLAT IF THERE EXISTS
A COORDINATE TRANSF. WHICH BRINGS
METRIC INTO MINK METRIC

$$g = \eta$$

• FLATNESS. DEF. SPACETIME IS FLAT IF THERE EXISTS
A COORDINATE TRANSF. WHICH BRINGS
METRIC INTO MINK METRIC

$$g = \eta \dots \underline{\text{EVERYWHERE}}$$

ERE EXISTS
BRINGS

THEOREM: THE SPACETIME IS FLAT IFF
THE RIEMANN TENSOR VANISHES EVERYWHERE

RABBITS, RELATIONS, AND KINS OF RIEMANN FAMILY

RICCI TENSOR

$$R_{\mu\nu} = R^{\alpha}{}_{\mu\alpha\nu} = R_{\nu\mu}$$

$$\frac{d(d+1)}{2} \text{ COMPS}$$

RABBITS, RELATIONS, AND KINS OF RIEMANN FAMILY

RICCI TENSOR

$$R_{\mu\nu} = R^{\alpha}{}_{\mu\alpha\nu} = R_{\nu\mu} \\ = R_{\mu\nu}(\mathcal{P})$$

$\frac{d(d+1)}{2}$ COMPS

RICCI SCALAR

$$R = R^{\mu}{}_{\mu} = g^{\mu\nu} R_{\mu\nu} = R(g, \mathcal{P}) \quad | \text{COMP}$$

$\frac{\lambda(d+1)}{2}$ COMPTS

EINSTEIN TENSOR

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu}$$

1 COMPT

$\frac{1}{2}(d+1)$
COMPTS

EINSTEIN TENSOR

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu}$$

(3) $\rightarrow$

$$\nabla_{\mu} G^{\mu\nu} = 0$$

BIANCHI IDENTITY

WEYL TENSOR

$$\underline{C^{\alpha}_{\beta\gamma\delta}}$$

RIEMANN =

SAME SYMMETRIES
AS RIEMANN

WEYL TENSOR

RIEMANN =

$$\underline{C^{\alpha}{}_{\beta\gamma\delta}}$$

SAME SYMMETRIES
AS RIEMANN

$$C^{\alpha}{}_{\beta\alpha\delta} = "C_{\beta\delta}" = 0$$

WEYL TENSOR

$$\boxed{\text{RIEMANN} = \text{RICCI} + \text{WEYL}}$$

$$\underline{C^{\alpha}{}_{\beta\gamma\delta}}$$

SAME SYMMETRIES
AS RIEMANN

$$C^{\alpha}{}_{\beta\alpha\delta} = "C_{\beta\delta}" = 0$$

ALGEBRAIC CLASSIFICATION
(SPECIAL ALG. TYPE ALLOWS
ONE TO SIMPLIFY EE)

BIANCHI IDENTITY

THEOREM: WEYL VANISHES IFF SPACETIME
IS CONFORMALLY FLAT

$$g_{\mu\nu} = \Omega^2(x) \gamma_{\mu\nu}$$

CLASSIFICATION

ALG. TYPE ALLOWS
SIMPLIFY EE)

BIANCHI IDENTITY

THEOREM: WEYL VANISHES IFF SPACETIME
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CLASSIFICATION

ALG. TYPE ALLOWS
SIMPLIFY EE)

$$g_{\mu\nu} = \Omega^2(x) \gamma_{\mu\nu}$$

CONF. SYMMETRY

$g_{\mu\nu} \rightarrow \Omega^2 g_{\mu\nu} \dots$ NOTHING HAPPENS.

BIANCHI IDENTITY

THEOREM: WEYL VANISHES IFF SPACETIME
IS CONFORMALLY FLAT

CLASSIFICATION

ALG. TYPE ALLOWS
SIMPLIFY EE)

$$g_{\mu\nu} = \Omega^2(x) \gamma_{\mu\nu}$$

CONF. SYMMETRY

C^∞
 $\beta g_{\mu\nu}$

$g_{\mu\nu} \rightarrow \Omega^2 g_{\mu\nu} \dots$ NOTHING HAPPENS.

BIANCHI IDENTITY

THEOREM: WEYL VANISHES IFF SPACETIME
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CLASSIFICATION

ALG. TYPE ALLOWS
SIMPLIFY EE)

$$g_{\mu\nu} = \Omega^2(x) \gamma_{\mu\nu}$$

CONF. SYMMETRY $g_{\mu\nu} \rightarrow \Omega^2 g_{\mu\nu} \dots$ NOTHING HAPPENS.

$$C^{\alpha}{}_{\beta\gamma\delta} \rightarrow C^{\alpha}{}_{\beta\gamma\delta}$$

• FLATNESS. DEF: SPACETIME IS FLAT IF THERE EXIST
A COORDINATE TRANSF. WHICH BRINGS

UNIQUENESS OF EINSTEIN EQS:

$$D^{\mu\nu}(g, \partial g, \partial^2 g) = 8\pi G T^{\mu\nu}$$

↓ NEXT. LIMIT

$$\nabla^2 \phi = 4\pi G \rho$$

CONSERVATION OF $T^{\mu\nu}$: $\nabla_\mu T^{\mu\nu} = 0$

$$\Rightarrow \nabla_\mu T^{\mu\nu}$$

• FLATNESS. DEF.: SPACETIME IS FLAT IF THERE EXISTS
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EQS:

$$8\pi G T^{\mu\nu}$$

LIMIT

$$\pi G \rho$$

$$T^{\mu\nu} = 0$$

$$\Rightarrow \boxed{\nabla_{\mu} T^{\mu\nu} = 0}$$

EINSTEIN TENSOR IS AN EXAMPLE.

$$\Rightarrow \boxed{\nabla_\mu D^{\mu\nu} = 0}$$

EINSTEIN TENSOR IS AN EXAMPLE.

$$G^{\mu\nu} + \underbrace{\Lambda}_{\text{CONSTANT}} g^{\mu\nu} = D^{\mu\nu}$$

$$\Rightarrow \boxed{\nabla_\mu D^{\mu\nu} = 0}$$

EINSTEIN TENSOR IS AN EXAMPLE.

$$G^{\mu\nu} + \underbrace{\Lambda}_{\text{CONSTANT}} g^{\mu\nu} = D^{\mu\nu}$$

SMALL.

$$\nabla_\mu D^{\mu\nu} = 0$$

INSTEIN TENSOR IS AN EXAMPLE.

$$+ \underbrace{\Lambda}_{\text{CONSTANT}} g^{\mu\nu} D_\mu D_\nu$$

$$\underbrace{R^{\mu\nu} - \frac{1}{2} R g^{\mu\nu}}_{G^{\mu\nu}} + \Lambda g^{\mu\nu} = 8\pi G T^{\mu\nu}$$

$$\nabla_\mu D^{\mu\nu} = 0$$

INSTEIN TENSOR IS AN EXAMPLE.

$$+ \underbrace{\Lambda}_{\substack{\uparrow \\ \text{CONSTANT}}} g^{\mu\nu} = D^{\mu\nu}$$

CONSTANT ... SMALL.

$$\underbrace{R^{\mu\nu} - \frac{1}{2} R g^{\mu\nu}}_{G^{\mu\nu}} + \underbrace{\Lambda}_{\substack{\uparrow \\ \text{COSMOLOGICAL CONSTANT}}} g^{\mu\nu} = 8\pi G T^{\mu\nu}$$

1H (FAMOUS)

COSMOLOGICAL CONSTANT



$$\nabla_\mu D^{\mu\nu} = 0$$

EINSTEIN TENSOR IS AN EXAMPLE.

$$+ \underbrace{\Lambda}_{\substack{\uparrow \\ \text{CONSTANT}}} g^{\mu\nu} = D^{\mu\nu}$$

SMALL

$$\underbrace{R^{\mu\nu} - \frac{1}{2} R g^{\mu\nu}}_{G^{\mu\nu}} + \underbrace{\Lambda}_{\substack{\uparrow \\ \text{COSMOLOGICAL CONSTANT}}} g^{\mu\nu} = 8\pi G T^{\mu\nu}$$

1H (FAMOUS)

COSMOLOGICAL CONSTANT

" BIGGEST BLUNDER OF
EINSTEIN'S LIFE "

$$\nabla_\mu D^{\mu\nu} = 0$$

EINSTEIN TENSOR IS AN EXAMPLE.

$$+ \underbrace{\Lambda}_{\text{CONSTANT}} g^{\mu\nu} = D^{\mu\nu}$$

CONSTANT ... SMALL.

10^{120}

$$\underbrace{R^{\mu\nu} - \frac{1}{2} R g^{\mu\nu}}_{G^{\mu\nu}} + \underbrace{\Lambda}_{\text{COSMOLOGICAL CONSTANT}} g^{\mu\nu} = 8\pi G T^{\mu\nu}$$

Λ (FAMOUS)

COSMOLOGICAL CONSTANT

"BIGGEST BLUNDER OF
EINSTEIN'S LIFE"

EINSTEIN TENSOR IS AN EXAMPLE.

$$+ \Lambda g^{\mu\nu} = D^{\mu\nu}$$

CONSTANT SMALL.

10^{120}

" BIGGEST BLUNDER OF
EINSTEIN'S LIFE "
COSMOLOGICAL CONSTANT PROBLEM,

$G^{\mu\nu}$
H (FAMOUS)

COSMOLOGICAL CONSTANT