o G\uo ~qOH_9e |Oe9§_®_§´ r |O®_O ° s

q9HO §_h O $(t;x)$! O®O j§
Tn} ro v os]L_h q9HO §_h O
S_Xo] ° n}eL e_j O
8 j n@ O}®O} I °_§\ 9 HenHc 9 j L 9 }«eO}
Gn j §_§«§O 9 j L _j O}§_9e T}9 h O

ouo i O ° §n j _9 j §\On}´

ą §°n n@ O}®O}I $(t;x;y;z)$ 9 j L $(t^0;x^0;y^0;z^0)$

ą }Oe9§_®O qOOL v _j x]L_}OH§_n j

ouou o W9e_eO9 j §}9 j Tn} h 9§_n j

$$\begin{cases} x = x^0 + vt \\ y = y^0 \\ z = z^0 \\ t = t^0 \end{cases} \quad \text{r§_h O _ 9@ ne«§Os}$$ ros

ouou© p }_j H_qeO nT Ox«_®9eO j HO _j i O ° §n j]¸ §\On}´

ou Sn} §\O O®O j§ _j S 9 j L S^0J §_h O _ 9@ ne«§O

$$S : (t;x;y;z)$$
$$S^0 : (t^0;x^0;y^0;z^0)$$

^T °O °9 j§ §n h O9 «}O §\O eO j X§\ nT 9 h n®_j X n@aOH§

¯O j OOL §n h O9 «}O §\O Hnn}L_j 9§O nT O j L _h «§9 j On« e´u S_X©] h O9 «}O O j L

ou qOOL

$$\begin{cases} \underline{x} = \underline{x}^0 + v \\ \underline{y} = \underline{y}^0 \\ \underline{z} = \underline{z}^0 \end{cases}$$

ou 9HHO}eO}9§_n j

$$\boldsymbol{x} = \boldsymbol{x}^0; \quad \boldsymbol{y} = \boldsymbol{y}^0; \quad \boldsymbol{z} = \boldsymbol{z}^0$$

ou© ~qOH_9e |Oe9§_®_§´

N_j §O_j I ¦ °n qn §_§«e9§O nT ~u | u p o u 8ee _j O}§_9e n@ O}®O} 9}O Ox_®9eO j§u p©u ¦ \O qOOL nT e_X\§ nT e_X\§ c _ §\O h 9O Tn} 9ee n@ O}®O} r$c = 299792458$ h / su

^T °O O§ $c = 1$ r}Oe9§_®_ §_H « j _§s
S_X ¨] ²§ L_9X}9 h

ou©uo dn}0j§¶ §}9j Tn}h9§_nj r**Bondi** k]T9H§n}s

k T9H§n} H\9}9H§0}_¶0 §\0 L_¸0}0jH0 @0§°00j i0°§nj]¸ §\0n}´ 9jL ~u|u

S_XV] ²§ L_9X}9h °_§\ 8?

n §\9§ $k = k(v)$J 9jL _§ h« § @0 9 e_j09} }0e9§_nj @0§°00j $(t; x)$ 9jL $(t'; x')$ _jH0 §\0 T}00 hn§_nj h« § @0 §\0 9h0J _u0u

$$\text{T}\}00\ \text{hn§\_nj}\text{I} \quad \begin{cases} x = x_0 + ut \\ x' = x'_0 + u't' \end{cases} \tag{©}$$

S_XU] §}_9jXe0

§\0j _T $t_1 = T$ 9jL $t_2 = k^2 T$ r 00 S_XU] §o§©sJ °0 \9®0

$$\begin{cases} t = (k^2 + 1)T/2 \\ x = (k^2 - 1)T/2 \end{cases} \tag{¨}$$

_jH0 $v = x/t = (k^2 - 1)/(k^2 + 1) < 1$ °0 \9®0 §\0 T9H§n}

$$k = \sqrt{\frac{1 + v}{1 - v}} \tag{V}$$

| hc r | 0e9§_®_ §_H Knqqe0} 0¸0H§sI ¦\0 T}0x«0jH0 $\omega = 2\pi/T$J °0 \9®0

$$\begin{aligned} T &\to T' = kT \\ \omega &\to \omega' = \omega/k \end{aligned} \tag{U}$$

^T $v > 0 \Rightarrow k > 1$I $\omega' < \omega$ r}0L _T§s ^T $v < 0 \Rightarrow k < 1$I $\omega' < \omega$ r@e«0 _T§s

^j i0°§nj]¸ §\0n}´

$$\begin{cases} x = x' + vt \\ \dot{x} = \dot{x}' + v \quad \text{r8LL§n\_j Tn}\}\text{h«e9s} \end{cases} \tag{£}$$

S_X£] 8?G °n}eL e_j0

$$\begin{aligned} k_{AB} &= \sqrt{\frac{1 + v_{AB}}{1 - v_{AB}}} \\ k_{BC} &= \sqrt{\frac{1 + v_{BC}}{1 - v_{BC}}} \\ k_{AC} &= \sqrt{\frac{1 + v_{AC}}{1 - v_{AC}}} = \sqrt{\frac{(1 + v_{AB})(1 + v_{BC})}{(1 - v_{AB})(1 - v_{BC})}} \end{aligned} \tag{¢}$$

ne®_jX §\9§

$$v_{AC} = \frac{v_{AB} + v_{BC}}{1 + v_{AB}v_{BC}} = \frac{v_{AB} + v_{BC}}{1 + v_{AB}v_{BC}/c^2} \tag{P}$$

0²9hqe0I _T $v_{BC} = c$¥ °0 \9®0 $v_{AC} = \dfrac{c + v_{BC}}{1 + v_{BC}c/c^2} = c$ _T $v_{AC} = c$J °0 \9®0 $v_{AC} = \dfrac{v_{AC} + c}{1 + cv_{BC}/c^2} = c$

^j T9H§J

$$v_{AV} - 1 = \frac{(v_{AC} - 1)(1 - v_{BC})}{1 + v_{AB}v_{BC}} < 0 \qquad \text{rks}$$

° \0j $v_{AB}; v_{BC} < 1$I ~u | u $!$ i 0 ° §nj

| h cI

ou h 9 _®0 q9}§_HeO $m \neq 0$I $v < 1$ n} $v < c$

©u g 9 eO q9}§_HeO $m = 1$I $v = 1$ n} $v = c$

OuXu *photon*J *graviton*J *neutrino*

¯ \9§ 9@n«§ §\0 | Oe9§_nj @0§°00j §°n q9HO §_h 0 Hnn}L_j 9§0 nT §\0 9 h 0 0®0j § PI

S_X¢ en}0j §¶] §}9j Tn} h 9§_nj

@´ k]T9H§n}

ou $t' - x' = k(t - x)$

©u $t + x = k(t' + x')$

ne®_j X §\9§

$$t' = \frac{t - vx}{\sqrt{1 - v^2}}; \quad x' = \frac{x - vt}{\sqrt{1 - v^2}} \quad ° \backslash 0\}0\ (c = 1): \qquad \text{ro·s}$$

| h cI

ou $t^2 - x^2 = (t')^2 - (x')^2$ r i n h]N«He_L09 j s ^§ H9eeOL *Minkkowski space*u

©u Hn h q9}_ _n j

W9e_e09 j	dn}0 j §¶
$t' = t$	$t' = \frac{t - vx}{\sqrt{1 - v^2}}$
$x' = x - vt$	$x' = \frac{x - vt}{\sqrt{1 - v^2}}$
$y' = y$	$y' = y$
$z' = z$	$z' = z$

S_XP] h n®_j X T}9 h 0

¨u K0» j _§_n j I _j §0}®9e @0§°00j §°n 0®0j § P_1 9 j L P_2I

ą »_j _§0 ^j §0}®9e

$$s^2 = (t_2 - t_1)^2 - (x_2 - x_1)^2 - (y_2 - y_1)^2 - (z_2 - z_1)^2 \qquad \text{roos}$$

ą _j T0 j _§0 § h 9ee _j §0}®9e

$$(ds)^2 = (dt)^2 - (dx)^2 - (dy)^2 - (dz)^2 \qquad \text{ro©s}$$

ou }0®_ 0 §\0 n}L0}

$$t' = \frac{t - vx/c^2}{\sqrt{1 - v^2/c^2}}, \quad x' = \frac{x - vt/c^2}{\sqrt{1 - v^2/c^2}} \qquad \text{ro¨s}$$

ou©u© dn}0j§¶ §}9j Tn}h9§_nj

N_j §0_jI ¦°n qn §_§«e9§0 nT ~u|u p^u 8ee _j0}§_9e n@ 0}®0} 9}0 0x_®9e0j§up^^u ¦\0 q00L nT e_X\§ nT e_X\§