

# TRANSPOSE OF LORENTZ TRANSFORMATION\*

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Good notations often play a central role in making theoretical advances in the physical sciences, where calculations can easily become lengthy. However, certain notations create more confusion than clarity for beginners.

A quick search reveals widespread confusion regarding index notation and the Einstein summation convention among students. In particular, the property

$$(\Lambda^t)^\mu{}_\nu = \Lambda_\nu{}^\mu \quad (1)$$

of the transpose of a matrix representing a Lorentz transformation is often misunderstood (see, for example, [Stack Exchange](#)). Of course, (1) is not the usual definition for the transpose of a matrix. To my surprise, I couldn't find any simple proof of this equality — just interminable discussions in forums. To make things worse, in many places, the discussions ended up being even more confusing. Unsatisfied with the answers out there, I decided to write and share the proof below, which I believe is accessible to physics students.

Before we prove (1), remember that the transpose of any square matrix  $M$ , usually denoted by  $M^t$ , is defined by

$$(M^t)_{\alpha\beta} = M_{\beta\alpha}. \quad (2)$$

**Proposition.** *Let  $\Lambda$  be the matrix of a Lorentz transformation. Then,*

$$(\Lambda^t)^\mu{}_\nu = \Lambda_\nu{}^\mu$$

and

$$(\Lambda^t)_\mu{}^\nu = \Lambda^\nu{}_\mu.$$

*Proof.* Let  $\eta$  denote the Minkowski metric. We'll prove the first one, since the second is analogous. For that, we simply compute

$$(\Lambda^t)^\mu{}_\nu = \eta^{\mu\alpha} (\Lambda^t)_{\alpha\nu} \stackrel{(2)}{=} \eta^{\mu\alpha} \Lambda_{\nu\alpha} = \Lambda_\nu{}^\mu. \quad \square$$

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\*This is a first draft. Future versions could evolve into lecture notes; who knows.