

# Physics 226

## Relativity

time dilation/Lorentz contraction:  $\gamma = 1/\sqrt{1 - \vec{v}^2/c^2}$

4-coordinates:  $x^\mu = (x^0, x^1, x^2, x^3), \quad x^0 = ct$

Lorentz transformation matrix:  $\| \Lambda^\mu{}_\nu \| = \begin{pmatrix} \gamma & \gamma(v/c) & 0 & 0 \\ \gamma(v/c) & \gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$  for boost along  $\hat{x}^1$

Lorentz invariant dot product:  $a \cdot b = a^0 b^0 - \vec{a} \cdot \vec{b} = a^0 b^0 - a^1 b^1 - a^2 b^2 - a^3 b^3$

invariant interval:  $(\Delta x)^2 = (\Delta x^0)^2 - (\Delta x^1)^2 - (\Delta x^2)^2 - (\Delta x^3)^2$

4-velocity:  $u = \frac{dx(\tau)}{d\tau}, \quad u^\mu = (\gamma c, \gamma \vec{v}), \quad u^2 = c^2$

4-momentum:  $p = m u, \quad p^\mu = (E/c, \vec{p}) = (\gamma m c, \gamma m \vec{v})$   
 $p^2 = (E/c)^2 - \vec{p}^2 = m^2 c^2$

4-force:  $f = \frac{dp}{d\tau}, \quad p \cdot f = 0$

4-acceleration:  $a = \frac{du}{d\tau}, \quad u \cdot a = 0$

constant acceleration:  $u^0(\tau)/c = \cosh \frac{F\tau}{mc}, \quad u^1(\tau)/c = \sinh \frac{F\tau}{mc}$

wave-vector:  $k^\mu = (\omega/c, \vec{k})$

observed frequency:  $\omega_{\text{obs}} = u_{\text{obs}} \cdot k$

E&M field strength:  $\| F^\mu{}_\nu \| = \begin{pmatrix} 0 & E_x & E_y & E_z \\ E_x & 0 & cB_z & -cB_y \\ E_y & -cB_z & 0 & cB_x \\ E_z & cB_y & -cB_x & 0 \end{pmatrix}$

Lorentz force:  $f_{\text{Lorentz}}^\mu = \frac{q}{c} F^\mu{}_\nu u^\nu$

## $SU(2)$ Transformations

Pauli matrices:  $\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$

Transformation:  $T_k(\alpha) = e^{i\sigma_k \alpha/2}$

## Constants and Units

$$c = 2.997 \dots \times 10^8 \text{ m/s}$$

$$\hbar = 6.582 \dots \times 10^{-22} \text{ MeV s}$$

$$\hbar c = 197.3 \dots \text{ MeV fm}, \quad 1 \text{ fm} = 10^{-15} \text{ m}$$

$$(\hbar c)^2 = 0.389 \dots \text{ GeV}^2 \text{ mbarn}, \quad 1 \text{ barn} = 10^{-28} \text{ m}^2$$

$$\alpha = e^2/(4\pi\epsilon_0\hbar c) = 1/137.0 \dots$$

## Nuclei

nucleus	symbol	rest energy	lifetime	spin*	decay type
neutron	$n$	939.6 MeV	15 min	1/2	$\beta$ decay
hydrogen	${}^1_1\text{H}$	938.27 MeV	stable	1/2	—
deuterium	${}^2_1\text{H}$	1875.61 MeV	stable	1	—
tritium	${}^3_1\text{H}$	2808.92 MeV	17.8 yr	1/2	$\beta$ decay
helium-3	${}^3_2\text{He}$	2808.39 MeV	stable	1/2	—
helium-4	${}^4_2\text{He}$	3727.38 MeV	stable	0	—
helium-6	${}^6_2\text{He}$	5605.5 MeV	1.16 s	0	$\beta$ decay
lithium-6	${}^6_3\text{Li}$	5601.5 MeV	stable	1	—
lithium-7	${}^7_3\text{Li}$	6533.8 MeV	stable	3/2	—
beryllium-7	${}^7_4\text{Be}$	6534.2 MeV	77 day	3/2	$e^-$ capture
beryllium-10	${}^{10}_4\text{Be}$	9325.5 MeV	2.2 Myr	0	$\beta$ decay
boron-10	${}^{10}_5\text{B}$	9324.4 MeV	stable	3	—
boron-11	${}^{11}_5\text{B}$	10253 MeV	stable	3/2	—
boron-14	${}^{14}_5\text{B}$	13062 MeV	18 ms	2	$\beta$ decay
carbon-11	${}^{11}_6\text{C}$	10254 MeV	29 m	3/2	$e^+$ emission
carbon-12	${}^{12}_6\text{C}$	11175 MeV	stable	0	—
carbon-14	${}^{14}_6\text{C}$	13041 MeV	5.7 Kyr	0	$\beta$ decay
nitrogen-14	${}^{14}_7\text{N}$	13041 MeV	stable	1	—
calcium-41	${}^{41}_{20}\text{Ca}$	38146 MeV	1.5 Myr	7/2	$e^-$ capture
bismuth-209	${}^{209}_{83}\text{Bi}$	194622 MeV	$2 \times 10^{19}$ yr	9/2	$\alpha$ decay

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\*In units of  $\hbar$ .

## Leptons

particle	symbol	rest energy	lifetime	spin*	charge <sup>†</sup>	<i>L</i>
electron (anti)neutrino	$\nu_e(\bar{\nu}_e)$	< 2 eV	$\approx$ stable	1/2	0	+1(-1)
muon (anti)neutrino	$\nu_\mu(\bar{\nu}_\mu)$	< 2 eV	$\approx$ stable	1/2	0	+1(-1)
tau (anti)neutrino	$\nu_\tau(\bar{\nu}_\tau)$	< 2 eV	$\approx$ stable	1/2	0	+1(-1)
electron(positron)	$e^-(e^+)$	0.511 MeV	stable	1/2	-1(+1)	+1(-1)
muon(antimuon)	$\mu^-(\mu^+)$	105.7 MeV	2 $\mu$ s	1/2	-1(+1)	+1(-1)
tau(antitau)	$\tau^-(\tau^+)$	1777 MeV	0.3 ps	1/2	-1(+1)	+1(-1)

## Hadrons

particle	symbol	rest energy	lifetime	spin	charge	<i>B</i>
pion	$\pi^0$	135.0 MeV	$8 \times 10^{-17}$ s	0	0	0
pion	$\pi^+, \pi^-$	139.57 MeV	26 ns	0	+1, -1	0
kaon	$K^+, K^-$	493.7 MeV	12 ns	0	+1, -1	0
kaon	$K^0$	497.7 MeV	90 ps/51 ns	0	0	0
eta	$\eta$	547.5 MeV	$5 \times 10^{-19}$ s	0	0	0
rho	$\rho^+, \rho^0, \rho^-$	775 MeV	$4 \times 10^{-24}$ s	1	+1, 0, -1	0
omega	$\omega$	783 MeV	$8 \times 10^{-23}$ s	1	0	0
(anti)proton	$p(\bar{p})$	938 MeV	stable	1/2	+1(-1)	1(-1)
(anti)neutron	$n(\bar{n})$	940 MeV	886 s	1/2	0	1(-1)
eta-prime	$\eta'$	958 MeV	$3 \times 10^{-21}$ s	0	0	0
Lambda	$\Lambda$	1116 MeV	0.26 ns	1/2	0	1
Delta	$\Delta^{++}, \Delta^+, \Delta^0, \Delta^-$	1232 MeV	$6 \times 10^{-24}$ s	3/2	+2, +1, 0, -1	1
Cascade	$\Xi^0$	1315 MeV	0.29 ns	1/2	0	1
Cascade	$\Xi^-$	1321 MeV	0.16 ns	1/2	-1	1
Omega	$\Omega^-$	1672 MeV	0.08 ns	3/2	-1	1

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<sup>†</sup>In units of  $|e| = 1.602 \dots \times 10^{-19}$  C.