

## BUILDING BLOCKS OF MATTER

These basic constituents of matter are spin- $\frac{1}{2}$  fermions: quarks and leptons. These carry various charges including: electric charge,  $Q$ , baryon number,  $B$  and lepton number,  $L$ . Quarks carry a three-valued charge called colour; they are never seen as free particles but are always confined in colourless hadrons, either mesons ( $q\bar{q}$ ) or baryons ( $qqq$ ). For quarks and hadrons we define the third component of the isospin,  $I_3$ . They form multiplets with isospin  $I$  where  $I_3 = +I, \dots, -I$ .

Everyday matter consists mainly of up quarks,  $u$ , down quarks,  $d$  and electrons,  $e^-$ . Weak  $\beta$  decays of unstable nuclei produce electron neutrinos,  $\nu_e$ .

particle	$B$	$L$	$Q$	$I$	$I_3$	Mass
$u$	$+\frac{1}{3}$	0	$+\frac{2}{3}$	$\frac{1}{2}$	$+\frac{1}{2}$	$\sim 300 \text{ MeV}^*$ $2.5 \text{ MeV}^\dagger$
$d$	$+\frac{1}{3}$	0	$-\frac{1}{3}$	$\frac{1}{2}$	$-\frac{1}{2}$	$\sim 300 \text{ MeV}^*$ $5 \text{ MeV}^\dagger$
$e^-$	0	+1	-1	-	-	0.511 MeV
$\nu_e$	0	+1	0	-	-	$< 0.25 \text{ eV}$

\* “constituent” mass relevant to hadron structure;  $\dagger$  “current” mass relevant to high energy processes

Their antiparticles,  $\bar{u}$ ,  $\bar{d}$ ,  $e^+$  and  $\bar{\nu}_e$ , have the same masses as their partners but opposite values for  $B$ ,  $L$ ,  $Q$  and  $I_3$ . Fermions and antifermions have opposite intrinsic parities; by convention we assign  $P = +1$  to the fermions. The charges of the light quarks and antiquarks can be related to their isospins by  $Q = \frac{1}{2} B + I_3$ .

The fundamental forces between these particles are mediated by bosons. Most of these are spin-1 (vector or “gauge”) bosons, namely photons,  $\gamma$ , gluons,  $g$ , and weak bosons,  $W^\pm$  and  $Z^0$ . However, we now know that there is also a spin-0 Higgs boson,  $H^0$ . All of these have  $B = L = 0$ . Two,  $W^\pm$ , carry electric charge, and the gluons have 8 possible colour charges.

force	particle	$Q$	$J^{PC}$ *	Mass
strong	$g$	0	$1^-$	$0^\dagger$
EM	$\gamma$	0	$1^{--}$	0
weak	$W^\pm$	$\pm 1$	1	80.4 GeV
	$Z^0$	0	1	91.2 GeV
	$H^0$	0	0	126 GeV

\*  $C$  is not defined for the coloured gluons; neither  $P$  nor  $C$  is defined for the weak bosons;  $\dagger$  confined

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