LESSON 4.3.2

Particle Interactions, Antiparticles and Conservation Laws

An antiparticle has the same rest mass as its corresponding particle, but opposite electric charge and opposite additive quantum numbers such as baryon and lepton number.

PARTICLE	SYMBOL	q / e	B	L
Proton	p	+1	+1	0
Antiproton	$\bar{p}$	-1	-1	0
Electron	e^-	-1	0	+1
Positron	e^+	+1	0	-1
Electron neutrino	ν_e	0	0	+1
Electron antineutrino	$\bar{\nu}_e$	0	0	-1
Photon	γ	0	0	0

e is the positive elementary charge. B here is baryon number, not magnetic flux density.

BARYON NUMBER B

Baryons have B = +1; antibaryons have B = -1. A quark has B = +1/3 and an antiquark -1/3. Mesons and leptons have B = 0.

LEPTON NUMBER L

Leptons have L = +1; antileptons have L = -1. Baryons, mesons and photons have L = 0. An antiparticle does not have negative mass.

Neutral does not mean identical to its antiparticle: a neutron and antineutron both have zero charge but opposite baryon number. The photon is its own antiparticle. A bar identifies many antiparticles.

1 Annihilation and pair production

Energy can be transferred between particle rest energy, kinetic energy and radiation; it is not destroyed.

ANNIHILATION: ELECTRON + POSITRON

$$e^- + e^+ \rightarrow \gamma + \gamma$$



Equal and opposite photon momenta when the initial pair is at rest.

For the two-photon channel with negligible initial kinetic energy, the photons travel in opposite directions and share the energy equally. One photon alone cannot conserve momentum for an isolated pair at rest.

$$E_{total} = 2m_ec^2 = 1.022 \text{ MeV; each photon: } 0.511 \text{ MeV}$$

PAIR PRODUCTION: PHOTON ENERGY CREATES A PAIR

$$\gamma \rightarrow e^- + e^+$$

Near a nucleus that also recoils (not shown in the shorthand equation).

The nearby nucleus takes recoil momentum so both energy and momentum can be conserved. A single photon cannot create this pair alone in empty space.

$$\text{Rest-energy requirement} = 2m_ec^2 = 1.022 \text{ MeV}$$

The threshold is just above this value for a finite-mass nucleus. At school level, recoil energy for a heavy nucleus is often neglected; excess energy becomes kinetic energy.

EXAMPLE: A 2.00 MeV PHOTON, NEGLECTING NUCLEAR RECOIL ENERGY

$$K_{electron} + K_{positron} = 2.00 - 1.022 = 0.978 \text{ MeV}$$

The two kinetic energies need not be equal. Include initial kinetic energy in annihilation totals.

2 Check every conserved quantity

For an isolated interaction, compare the totals before and after, not each particle separately.

CHARGE • BARYON NUMBER • LEPTON NUMBER

Add signed q, B and L values on each side. For the reactions here, the totals must match. Then check total energy, including rest energy, and momentum as a vector in every direction.

Passing these checks is necessary, but does not guarantee a reaction happens: sufficient energy and a permitted interaction are also needed.

WORKED EXAMPLE: FREE NEUTRON BETA-MINUS DECAY

$$n \longrightarrow p + e^{-} + \bar{\nu}_e$$

QUANTITY	BEFORE	AFTER	CHECK
q / e	0	+1 - 1 + 0 = 0	Equal
B	1	1 + 0 + 0 = 1	Equal
L	0	0 + 1 - 1 = 0	Equal

The antineutrino balances lepton number and carries energy and momentum.

WHY THE TWO-PARTICLE VERSION FAILS

$$n \longrightarrow p + e^{-}$$

Charge and baryon number match, but lepton number changes from 0 to +1. Reject this proposed reaction: it omits the antineutrino.

Rest mass and particle count need not be conserved. Do not mistake a positron for a proton: both have charge +e, but their masses and quantum numbers differ.

Source: Pearson IAL Physics, Unit 4 p. 31, points 116, 118 and 122-124.