10. PASSAGE OF PARTICLES THROUGH MATTER

Revised June 1994.

10.1. Notation

Table 10.1: The notation and values given in Table 1.1 are used. The kinematic variables β and γ have the usual meanings. Other variables used in this section are summarized below.

Symbol	Definition	Units or Value
α	Fine structure constant	$1/137.035\,989\,5(61)$
M	Incident particle mass	MeV/c^2
E	Incident particle energy γMc^2	MeV
T	Kinetic energy	MeV
m_ec^2	Electron mass $\times\ c^2$	$0.510\,999\,06(15)$ MeV
r_e	Classical electron radius $e^2/4\pi\epsilon_0 m_ec^2$	$2.817\,940\,92(38)$ fm
N_A	Avogadro's number	$6.022\,136\,7(36) \times 10^{23}\ \mathrm{mol}^{-1}$
ze	Charge of incident particle	
Z	Atomic number of medium	
A	Atomic mass of medium	$\mathrm{g\ mol}^{-1}$
K/A	$4\pi N_A r_e^2 m_ec^2/A$	$0.307\,075\ \mathrm{MeV\ g}^{-1}\ \mathrm{cm}^2$ for $A = 1\ \mathrm{g\ mol}^{-1}$
δ	Density effect correction to ionization energy loss	
$\hbar\omega_p$	Plasma energy $\sqrt{4\pi N_e r_e^3}\ m_ec^2/\alpha$	$28.816\sqrt{\rho\langle Z/A\rangle}\ \mathrm{eV}^{(a)}$
w_j	Fraction by weight of the jth element in a compound or mixture	
n_j	$\propto$ number of jth kind of atoms in a compound or mixture	
X_0	Radiation length	$\mathrm{g}^{-1}\ \mathrm{cm}^2$
E_c	Critical energy	MeV
E_s	Scale energy $\sqrt{4\pi/\alpha}\ m_ec^2$	21.2052 MeV
R_M	Molière radius	$\mathrm{MeV\ g}^{-1}\ \mathrm{cm}^2$

$^{(a)}$ For ρ in $\mathrm{g\ cm}^{-3}$.

10.2. Ionization energy loss by heavy particles [1–5]

Moderately relativistic charged particles other than electrons lose energy in matter primarily by ionization. If the incident particle velocity βc is larger than that of orbital electrons ($\sim Z\alpha c$) and small enough that radiative effects do not dominate (for example, pion energy smaller than 100–200 GeV in iron), then the mean rate of energy loss (or stopping power) is given by the Bethe-Bloch equation,

$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2}\right]\ . \tag{10.1}$$

Here $T_{\max}$ is the maximum kinetic energy which can be imparted to a free electron in a single collision, and the other variables are defined in Table 10.1. The units are chosen so that dx is measured in mass