A calculation of the transport of cosmic rays through the Galaxy requires attention to the decay of radioactive isotopes. Of these, the pure electron capture decays are particularly interesting because they can only occur before the particles are accelerated and fully stripped, or if they re-attach an electron in flight. Electron capture half-lives are listed in the Table of Isotopes for laboratory measurements on atoms with all their electrons attached. Decay can occur via capture of either innermost K-shell electron, or from capture of an L or higher shell electron. This is very different from the case in cosmic rays where the decaying atom will likely have only one attached electron. The listed half-lives must be corrected for the lack of additional electrons if they are to be used in a propagation calculation.

The correction is based on the following argument: Nuclear decay is governed by a transition rate \( \lambda \) (probability/time) that is the sum of the transition probabilities for each of the possible decay channels. In the case of the atom with filled shells,

\[
\lambda_{\text{filled}} = \lambda_K + \lambda_K + \lambda_L + \lambda_L + \lambda_L + \ldots
\]  

(1)

There is an equal probability of capturing either of the innermost K-shell electrons, \( \lambda_K = \lambda_K \equiv \lambda_K \). Also, for all isotopes of interest, capture from the L\(_1\) shell is dominant over capture from all higher shells, \( \lambda_L \equiv \lambda_L \). Neglecting these smaller contributions, the capture probability can be written:

\[
\lambda_{\text{filled}} = 2\lambda_K + \lambda_L
\]  

(2)

In the cosmic rays, there is only one attached electron, so only one decay channel: \( \lambda_{\text{CR}} = \lambda_K \).

The half-life is defined such that \( 0.5 = \exp(-\lambda T_{1/2}) \) or \( T_{1/2} = (1/\lambda) \ln 2 \).

\[
\frac{T_{1/2 \text{ CR}}}{T_{1/2 \text{ filled}}} = \frac{\lambda_{\text{filled}}}{\lambda_{\text{CR}}} = 2 + \frac{\lambda_L}{\lambda_K}
\]  

(3)

The last term is simply the L\(_1\)/K capture ratio described in Appendix V of the Table of Isotopes (7th Ed., 1978). In this table, the capture ratio is

\[
\frac{EC(L_1)}{EC(K)} = k_1(Z) \left[ \frac{E(EC) - BE(L_1)}{E(EC) - BE(K)} \right]^2
\]  

(4)

where \( E(EC) \) is the electron capture decay energy and \( BE(L_1) \) and \( BE(K) \) are the binding energies of the L\(_1\) and K shells respectively. Since in all isotopes of interest the binding energies are small compared to the decay energy, the term in brackets was dropped. The value of \( k_1(Z) \) is fit from the graph in the above reference and is taken to be:

\[
k_1(Z) = 9.5 \times 10^{-4} Z + 6.4 \times 10^{-2}
\]  

(5)

All relevant radioactive decays are listed in the following table. Only the pure electron capture modes are affected by this correction. The mode column identifies the type of decay; 1 is a \( \beta^- \) decay, 2 is \( \beta^+ \), and 3 is pure electron capture. The previous corrected half-lives come from the fortran version of the propagation code that had been used previously.
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Fig. 6. Subshell ratios for electron capture

Capture of electrons can occur from any atomic shell (X) for which $E_{EC}$, the total energy of the capture transition, is greater than $BE(X)$, the binding energy of the $X$ shell in the daughter nucleus. Theoretical values for the relative intensities of $K$, $L_1$, $L_2$, $L_3$, and $M+N+...$ capture are given in the formulas and graph below. They are derived from the calculations of Brysk and Rose.\(^{(1,2)}\)

$L_4/K$ capture ratio:

For allowed and first-forbidden nonunique transitions

$$\frac{EC(L_4)}{EC(K)} = k_4(Z)\frac{[E(EC) - BE(L_1)]^2}{[E(EC) - BE(K)]^2},$$

where $k_4(Z)$ is given by Fig. 6. For first-forbidden unique transitions

$$\frac{EC(L_4)}{EC(K)} = k_4(Z)\frac{[E(EC) - BE(L_1)]^4}{[E(EC) - BE(K)]^4}.$$

$L_2/L_1$ capture ratio:

$L_3$ capture is not possible in allowed transitions, and nearly always negligible in first-forbidden nonunique transitions. For first-forbidden unique transitions

$$\frac{EC(L_2)}{EC(L_1)} = k_3(Z)\frac{[E(EC) - BE(L_3)]^2}{[E(EC) - BE(L_1)]^4},$$

where $k_3(Z)$ is given by Fig. 6, and $E(EC)$, $BE(L_3)$, and $BE(L_1)$ are in units of MeV.

$L_3/L_1$ capture ratio:

The ratio of capture from $M$ and higher shells to capture from the $L$ shell is given directly by Fig. 6 if $E(EC) >> BE(L) - BE(M)$.

1) H. Brysk and M.E. Rose, ORNL-1830(55)