On the Half-Life of $^{44}$Ti in Young Supernova Remnants

Eric B. Norman and Edgardo Browne
Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720
ebnorman@lbl.gov

Abstract: The electron-capture decay rate of $^{44}$Ti strongly depends on the number of atomic electrons that are bound to the nucleus. Recent x-ray observations of the Cas A and RXJ0852.0-4622 supernova remnants suggest that conditions of high temperatures and low densities exist in these objects. Under such conditions, the half-life of $^{44}$Ti would be significantly longer than its laboratory value. This effect implies that only an upper limit on the mass of $^{44}$Ti ejected by supernovae can be deduced from gamma-ray observations of these two supernova remnants.

The long-lived radioisotope $^{44}$Ti is currently of considerable interest in astrophysics. The relevant portions of its decay scheme and that of its daughter, $^{44}$Sc, are shown in Figure 1. $^{44}$Ti decays via electron-capture to $^{44}$Sc emitting $\gamma$-rays of 68, 78, and a very weak one of 146 keV. $^{44}$Sc subsequently decays via electron capture and positron emission with a 3.9-hour half-life to $^{44}$Ca emitting an 1157-keV $\gamma$-ray.

$^{44}$Ti is one of the few long-lived $\gamma$-ray emitting nuclides expected to be produced in substantial amounts during a supernova explosion (Clayton, 1982). Its characteristic 1157-keV $\gamma$ ray was observed from the young supernova remnant Cassiopeia A [Cas A] (Iyudin et al., 1994) and more recently from supernova remnant, RXJ0852.0-4622 (Aschenbach, 1998; Iyudin et al., 1998). In order to deduce the mass of $^{44}$Ti ejected in these explosions using the $\gamma$-ray fluxes measured from these supernova remnants, one needs to know their ages and distances as well as the half-life of $^{44}$Ti.

For Cas A, there are reasonably good historical records that this supernova exploded in about 1680. For RXJ0852.0-4622, Aschenbach (1998) has estimated an age of less than 1500 years and Iyudin et al. (1998) estimated about 680 years. Until last year, there was great uncertainty in the
half-life of $^{44}\text{Ti}$ because published values ranged from 39.0 years (Meissner, 1996) to 66.6 years (Alburger and Harbottle, 1990). The results of four recent experimental studies (Norman et al., 1998; Ahmad et al., 1998, Gorres et al., 1998; Wietfeldt et al., 1999) however, have yielded a consistent value of $60 \pm 1$ years for the laboratory half-life of $^{44}\text{Ti}$.

![Figure 1. Decay schemes of $^{44}\text{Ti}$ and $^{44}\text{Sc}$. All energies are given in keV.](image)

In the laboratory the electron-capture decay of $^{44}\text{Ti}$ takes place with neutral atoms. Thus, 22 bound atomic electrons surround the $^{44}\text{Ti}$ nucleus. The binding energy of a 1s electron in a neutral Ti atom is 4.966 keV, and that of a 2s electron is 0.564 keV. For a neutral $^{44}\text{Ti}$ atom, the probability of electron capture from the K. (1s) shell is 0.8891 and from the L-shell (2s) is 0.0960. Therefore, neglecting electron screening, for a charge-state $19^+\text{Ti}$ ion (i.e., one electron in the 2s shell) its half-life would be $\left(\frac{60\text{yr}}{0.9371}\right) = 64$ years. For a charge-state $20^+$ ion (zero electrons in the 2s shell) its half-life would be $\left(\frac{60\text{yr}}{0.8891}\right) = 67.5$ years, and for a charge-state $21^+$ ion (one electron in the 1s shell) its half-life would be $\left(\frac{60\text{yr}}{0.4446}\right) = 135$ years. Finally, for a charge-state $22^+$ $^{44}\text{Ti}$ ion (no bound electrons), electron capture decay would not be possible and the nucleus would become stable.