# Rapid Melting of Planetesimals Due to Radioactive Decay of Al-26 Decay: A Case Study of Planetary Bodies with variable Aluminum Abundance

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**Introduction:** The presence of $^{26}$Al in the early solar system, which decays to $^{26}$Mg, with a half-life of ~ 0.7 Ma, was postulated as a possible heat source [1] very soon after the discovery of $^{26}$Al . Aluminum is a major constituent element of rock forming minerals, and, therefore, $^{26}$Al could provide sufficient heat for the early melting and differentiation of planetesimals. The presence of Al-26 in eucrites like Piplia Kalan [2] demosntrated that Al-26 was present in sufficient quantities and planetesimals had accreted rapidly and undergo large scale melting and differentiation on short time scales. The CAIs from the Allende meteorite which are representative of some of the first solids synthesized in the solar system have an initial $^{26}$Al/$^{27}$Al ~ $5\times10^{-5}$ or even higher. Over the last two decades Al-Mg analyses of several hundred CAIs from different classes of primitive meteorites (see e.g., 3-5] provided evidence for the presence of $^{26}$Al with abundance similar to the canonical value. Al-Mg analyses of chondrules suggest that chondrules formed with much lower intial Al-26 abundance [4]. The lower initial abundance in chondrules have been tradionally been interpreted as indicative of later formation times of chondrules. Therefore accretion of chondritic parent bodies containing both CAIs and chondrules are extended and span an interval which could be nearly as long as ~ 5 Mys [4]. An extended preaccretionary history is hard top reconcile with the short dynamical lifetimes of chondrule-sized objects because of gas drag in the early solar nebula (e.g. [6]). Small objects like CAIs can survive for extended periods if they accreted into large ~ few to several kms that are not affected by gas drag. The question then is: What are the critical variables in the parameter that we should consider in modeling the thermal evolution of such bodies?

The thermal evolutionary models (e.g. [7]) use chondritic proportions of elemental abundances. Apart from the from the formation time of the planetary body which determines the initial abundance of Al-26, the physical variables which determine the thermal properties of the body, size of the body is a very important characteristic. The size of the body which determines the surface are to volume governs to efficiency of retention of energy within the body compared to its loss from the surface via radiation. In their paper Latourette and Wasserburg (1998) [8] have shown that small bodies of size ~ 5kms or so which formed at the same time as CAIs would not experience temperatures exceeding the solidus except in the core. If such small bodies form 1 Mys after CAI the peak temperatures of the body would not ~ 600K.

In this abstract we revisit this issue for the following: The U-Pb ages of angrites like Sahara 99555 are close to 4.5662 ±0.0001 billion years (based on Pb–Pb dating) [9] which is younger than the ages of CAIs of 4.5672 ± 0.0006 Gyr [10] by 1Ma. The ages of eucrites and the formation of Fe meteorites in some cases predates that of the chondrules. The petrography of the chondrules for a long time were considered nebular products and their origin was explained heating processes like shock related melting. However the origin of chondrules and sequestration of CAIs in small bodies have never been connected properly. The extent to which such small bodies heated by Al-26 provided the raw material for chondrule formation through impact disintegration has not been investigated.

**Methods:** We have solved the the heat diffusion equation with a source term in the transient case where temperature varies as function of radial location and time within the body. In case of a spherical body with an initial temperature of 100K heated by the decay of Al-26, the temperature evolution is governed by size, thermal properties, and concentration of Al-26. We have used the equation 4 given by Latourette and Wasserburg (1998) and used the parameters given in the table below.

Using this above equation and the parameters listed in the table we have solved the equation under the following conditions: (i) thermal properties of the body are not themselves dependent on temperature or composition, (ii) instantaneous accretion, (iii) rising temperatures and in excess of the solidus and melt generation do not alter the properties of the body, (iv)Al-26 is homogeneously distributed in the body (v) initial Al-26 in the solar system is $^{26}$Al/$^{27}$Al = $6\times10^{-6}$ (vi) the concentration of Al-26 has been varied by changing the proportion of CAIs and the complement of matrix in the planetary body. We plot below the results for a body formed very early in the solar system with CAI proportional abundance =25% and matrix =75%. CAI modal abundance is nearly a factor of 5 higher than the abundances observed in chondritis (e.g. Allende).

Discussions: For a normal chondritic body with initial $^{26}$Al/$^{27}$Al =$6\times10^{-6}$ we observe that nearly 50% of the inner core of the body attains temperature in excess of the solidus for basalts. For a body formed with a CAI component which is 5 times the normal abundance observed in chondrites (e.g. Allende) a 5 km object will attain solidus temperatures with in tens ofthousand years. Even the outer periphery will be substantially hotter than what is experienced by a normal chondrite like body of similar size. By increasing the CAI content to 25% we have increased the heat generation/per unit volume by Al-26 decay by order of magnitude and this brings about a drastic change in the time-temperature evolution of a planetary body. It is inevitable that if CAIs were rapidly forming in the solar nebula the proportion of CAIs were sequestered in earlier formed planetesimals. If such bodies contained variable proportion of CAIs their Al-26 concentration would be proportional to the CAI abundance in which Al is enriched compared to chondrites (Al2O3 ~ 3% in Allende; Al2O3 ~ 30% in Compact type A CAIs). This is perhaps the explanation for the presence of angrites like Sahara99555 whose parent bodies may have accreted rapidly and because of the higher Al-content dictated by the CAI-material which they accreted these bodies underwent rapid large scale melting to undergo complete differentiation and crystallization with in ~ a million years of the formation of CAIs.

**References:** [1] Urey H.C. (1955) Proc. Natl. Acad. Sci. US **41** 127 [2] Srinivasan et al. (1999) *Science* **284** 1348-1350 [3] MacPherson et al. (1994) *Meteoritics* **30** 365-386 [4] Russell et al., 1996 *Science* **273** 757-762.; [5] Huss et al. (2001) *Meteoritics & Planetary Science 36* 975-997. [6] Cameron A. (1995) *Meteoritics* **30** 133-161. [7] Ghosh and McSween (1998) Icarus 134 187-206. [8] LaTourette T. and Wasserburg G.J. (1998) *EPSL* **158** 91-108. [9] Baker J. et al. (2005) *Nature* **436** 1127-1131. [10] Amelin et al. (2002) *Science* **297** 1678-1683.

| | | Normal chondrite | Composition= Matrix =75% and CAI=25% |
|---|---|---|---|
| Thermal Diffusivity | κ (m2/s) | $7.6\text{x}10^{-7}$ | $7.6\text{x}10^{-7}$ |
| Density | ρ (Kg/m3) | 3300 | 3300 |
| Al-26 decay constant | λ (sec) | $3.19\text{x}10^{-14}$ | $3.19\text{x}10^{-14}$ |
| Conductivity | K (W/m-deg) | 2.1 | 2.1 |
| Radius | R (mts) | 7500 | 7500 |
| Positional radius | r (mts) | 6000 | 6000 |
| Energy generation per unit mass (at t =0) | H0 (W/Kg) | $3.264\text{x}10^{-7}$ | $1.15\text{x}10^{-6}$ |
| Formation Time of Planetary Body | tf (secs) | 0 million years | 0 million years |
| Heat Genration per unit volume by Al-26 decay | $A_i$@tf = 0Myr | 0.000891 | 0.003795 |