The oxygen isotopic systematics observed in chondritic materials [1] may reflect the large-scale oxygen isotopic evolution of the inner solar nebula gas which results from the enhanced supply of $^{18}$O-poor H$_2$O produced in the parent molecular cloud or the outer solar nebula [2,3]. The enhanced H$_2$O supply is caused by the evaporation of the icy component in dust aggregates which migrated from the cold outer nebula associated with loss of orbital angular momentum due to the head wind of the nebula gas.

The degree and duration of the H$_2$O enhancement depend on the size of dust aggregates and the condition of the nebula such as mass, radius, intensity of turbulence, etc. In the turbulent nebula gas, a dust aggregate grows up by sweeping suspended dust grains with micron-size. The collision velocity increases with the size of aggregate and little sticking occurs at high velocity collision. According to our theoretical analysis, the individual aggregate stops growing at its mass comparable to chondrules in the inner nebula and $10^3$ times greater in the outer nebula when we adopt the intensity of turbulence and the stickiness of dust grains consistent with observations of protoplanetary disks [4] and experiments on dust aggregation [5].

To reproduce the oxygen isotopic systematics and chronology [6] of the chondritic materials simultaneously, several-fold enhancement of H$_2$O relative to the solar composition must be sustained during $> 2$ Myr after the start of disk accretion. Our numerical simulation of the H$_2$O enhancement process for the obtained aggregate size shows that the requirement is satisfied when we take the initial radius and total mass of the nebula greater than $\sim 500$ AU and $\sim 0.05M_\odot$, respectively. The initial condition is consistent with observed protoplanetary disks but much larger than the minimum mass solar nebula [7] which is reconstructed from the mass distribution of the present solar system. This implies that the region containing solid component shrinks as a result of the inward migration of dust aggregates in the early solar nebula.

References