Effects of Radionuclides on the Ionization State of Dense Cloud Cores and Protoplanetary Disks

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We reinvestigate the ionization rates by radionuclides with the abundances in the primitive solar nebula by adopting the revised data on nuclides, extending the decay processes, and surveying radionuclides more extensively. Although the ionization rates by ^{232}Th, ^{235}U, and ^{238}U have become at least 10 times the previous ones, the total ionization rate by the long-lived radionuclides, $1.4 \times 10^{-22}\mathrm{s}^{-1}$ per hydrogen molecule, is still mostly contributed by ^{40}K. Among the short-lived radionuclides which are extinct in the present solar system, ^{26}Al is the dominant ionization source with the rate $(7 - 10) \times 10^{-19}\,\mathrm{s}^{-1}$, overwhelming the long-lived nuclides. With the average interstellar abundance of ^{26}Al estimated from γ-ray observation of the galactic plane, the ionization rate is 8 times smaller than this. In addition, ^{60}Fe and ^{36}Cl, whose ionization rates with the abundances in the primitive solar nebula are at least 10 times smaller than that of ^{26}Al, can be more efficient than the long-lived nuclides. In protoplanetary disks the ionization rate by radionuclides depends sensitive on the growth and sedimentation of dust particles. Ionization by radionuclides is quite inefficient when the mean dust size is greater than about 1 cm. Using these ionization rates we investigate the ionization state for some configurations of the clouds. We find that in dynamically collapsing very dense cloud cores the short-lived radionuclides are more efficient ionization source than cosmic rays when the mean pressure $n(\mathrm{H_2})\,T \gtrsim 1 \times 10^{14}\,\mathrm{cm^{-3}\,K}$. We improve the attenuation law of cosmic rays in geometrically thin disks. Using this law we find that the dead zones in protoplanetary disks are significantly larger than those obtained in the previous work.