If a liquid is replaced by volcanism on the surface of Enceladus, some of it will evaporate into space. The resulting cloud of gas will expand and supersaturate as its temperature drops and ice grains will nucleate. It is possible that the E-Ring around Saturn is created by such a process.

The E-Ring was well imaged during Earth's last ring crossing in 1979-80. Analysis of CCD observations indicates that the ring has a brightness peak at the orbit of Enceladus, suggesting that the satellite is the source of the ring material [1]. If the present orbit can be a retrograde orbit, then a retrograde ring is possible [2].

The most likely process for creating the E-Ring is a volcanic eruption of a water-ammonia magma, as the NH$_3$-H$_2$O system has a eutectic point at 173°K [7].

Y. P. Raizer [8] examined the condensation of a gas sphere expanding adiabatically in vacuo. Using homogeneous nucleation theory, he derived approximate expressions for the number of condensation centers and the number of molecules per particle. Given the initial parameters, one can calculate the nucleation rate, the maximum supersaturation, and the final grain radius. For example, if a pool of NH$_3$-H$_2$O liquid is erupted onto the surface of Enceladus, ammonia will evaporate into space (as will H$_2$O, but the vapor pressure of NH$_3$ is 3 to 4 orders of magnitude greater than that of H$_2$O at 173-193°K). The ammonia gas will expand, saturate (at 144°K) and then supersaturate, at which point solid-phase nucleation will commence [Fig. 1]. Nucleation rate is exponentially dependent upon supersaturation, which reaches a maximum and decreases as the thermodynamic pathway of the system follows the solid/vapor equilibrium curve. The nucleated particles continue to grow until the system has expanded to the point where vaporization is as likely as nucleation, then the grains cool to the ambient temperature (about 60°K). If ammonia ice grains will result from a 173°K NH$_3$-H$_2$O cloud of radius 300 m over a pool of eutectic NH$_3$-H$_2$O liquid of similar radius. Larger source regions or higher magma temperatures yield larger particles, and smaller or cooler clouds produce smaller particles. For an ammonia cloud with initial radius R at 173°K, the final radius of nucleated grains is approximately r = 7.9 x 10^-9 g m^{-0.88} (gas units). The degree of nucleation weakly depends on initial conditions and is about 30% at 173°K. Raizer's theory can be modified to consider a spherically symmetric gas cloud expanding away from a linear source (crack). An initial cloud radius similar to that in the spherical symmetric case yields only slightly larger grains. Although nucleated grains will not in general be spherical, they will tend toward sphericity as they are eroded and evaporate.

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The velocity of the ammonia ice grains (7.7 x 10^3 cm s^{-1} at 173°K) is greater than Enceladus' escape velocity (2.1 x 10^3 cm s^{-1}), but less than the escape velocity from Saturn (1.8 x 10^4 cm s^{-1} from the orbit of Enceladus), so the particles go into orbit around Saturn. The lifetime of NH$_3$-H$_2$O or NH$_3$ liquid against sputtering by energetic oxygen ions in the Saturnian magnetosphere is on the order of 10^6 years, requiring very recent rejuvenation of the ring [9,10].

Evaporation lifetimes vary strongly with temperature, being longer than sputtering lifetimes at NH$_3$ grain temperatures below 70°K, or for H$_2$O below 110°K. The sputtering loss rate is about 10^{-16} g cm^{-2} s^{-1}, so a mass flux of about 0.1 g s^{-1} from Enceladus is required to maintain the ring. This flux corresponds to a loss of at least 1.4 x 10^{10} of the mass of Enceladus over the age of the solar system. More than this fraction of Enceladus must be melted to provide the above mass of ammonia since the eutectic mole fraction of NH$_3$ is 34.6%. The surface of the "lava" will freeze rapidly, but volatiles dissolved in the magma may cause the frozen surface to break and expose fresh liquid to space.

Figure 1: Pressure-temperature diagram illustrating the approximate path followed by an expanding and nucleating ammonia gas cloud derived from an evaporating eutectic NH$_3$-H$_2$O liquid. The triple point of NH$_3$ is at 193.7°K, 6 x 10^{-2} bar.
The observed geometry of the E-ring has not been adequately explained, in particular, the vertical thickening with increasing distance from Saturn is not understood. Dynamical evolution requires more than the shock lifetime of the ring to produce the present configuration: at the present grain density of $4 \times 10^{-9} \text{ cm}^{-3}$, the mean time between collisions is at least 300 years. NH$_3$ particles nucleated from a $173^\circ$K melt will leave Enceladus at $7.3 \times 10^3 \text{ cm s}^{-1}$ and form a lens-shaped ring extending from $3.15$ to $5.01 \text{ R}_S$ with a vertical thickness of about $3 \times 10^4 \text{ km}$ (Fig. 2). To achieve the present shape of the ring, some other mechanism(s) must be invoked. Gravitational scattering by the larger satellites Tethys and Dione may be important to the evolution of the ring. The magnetospheric plasma probably imparts an electrostatic potential on the grains, causing orbital perturbations due to Lorentz forcing. If a $\mu$g ammonia grain is charged to a voltage similar to the plasma electron energy (over 20 eV), the Lorentz force will be over 1% of the gravitational force. Radiation pressure will make the orbits gradually decay, and direct particle drag from impinging ions and distant Coulomb drag spread the ring at a rate dependent on the grain charge and plasma parameters. A numerical model including these effects would contribute much toward the understanding of the E-ring's structure.

![Diagram of Saturn and E-Ring](image)

**Figure 2:** Comparison of initial distribution of ammonia ice grains formed from a $173^\circ$K melt (top) and the three-dimensional distribution of E-ring particles found by Baum et al. [1]. M.E.T.D and R mark the orbits of Mimas, Enceladus, Tethys, Dione and Rhea, respectively. Filled circles represent the attenuation per kilometer (left-hand ordinate) in the equatorial plane, while open circles represent the true physical thickness (right-hand ordinate) measured perpendicular to the equatorial plane.

**REFERENCES**