Advancing Electrical Propulsion via Electrosprays

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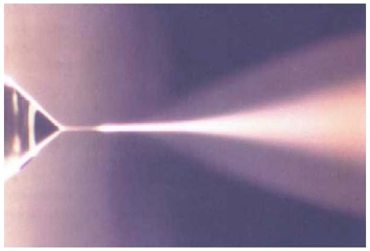
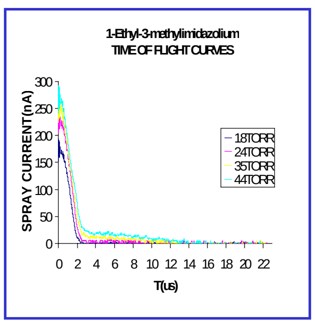
Electrospray



Sufficiently high electric fields applied to a liquid meniscus tend to pull it into a pointed shape, or Taylor cone. For suitable values of the applied voltage and the liquid flow rate fed, a steady jet is emitted from the cone apex. The jet eventually breaks up into a spray of charged droplets, often called an electrospray. Its most singular feature is an ability to produce drops of fairly uniform size, down to diameters as small as 20 nm. No other means to atomize liquids into such small fragments is known. Because these highly charged nanodrops can be accelerated electrostatically to high velocities, they are of considerable interest in space propulsion.

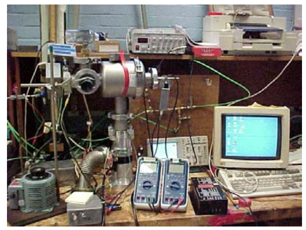
Heavy-ion Propulsion

Taylor cones of high conductivity liquids form very sharp tips. When the associated surface electric fields exceed one or a few V/nm, solution ions are ejected directly from the liquid into the surrounding medium. The double step structure associated to this mixed emission of ions and drops is illustrated in the TOF curves to the right (middle). Although this mixed regime is inefficient for electrical propulsion, attaining a purely ionic regime (no drops) is of interest, particularly because no alternative scheme is known to produce relatively large ions for space propulsion.

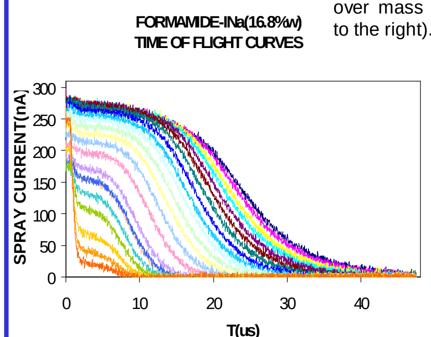


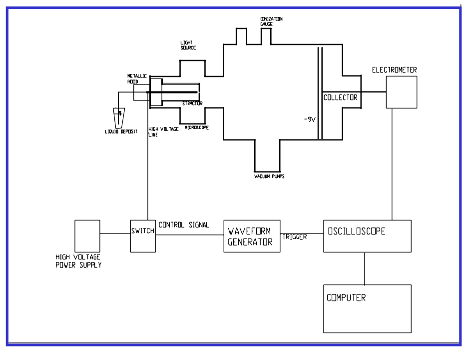
Under AFOSR sponsorship, we have recently discovered that the pure ionic regimen can indeed be reached. This is seen in the TOF spectra to the left, taken with the ionic liquid EMI-BF_4. As the liquid flow rate is decreased, one sees the gradual reduction of the second step (the drops), until their complete disappearance in the lowest TOF curve. We are presently investigating the analogous production of much heavier ions.

Time Of Flight Technique (TOF)



In the Time Of Flight (TOF) technique, an electrospray is formed in a high vacuum system. After interrupting the high voltage at time t = 0, one records the current received at a collector as a function of t. The time taken by the various drops to reach the collector yields their velocity, and hence their charge over mass ratio q/m (equations to the right). Several TOF curves are shown to the left for formamide seeded with NaI. At diminishing flow rates (lower curves), one sees the appearance of ions (step to the left). At higher flow rates only drops are visible (step to the right).



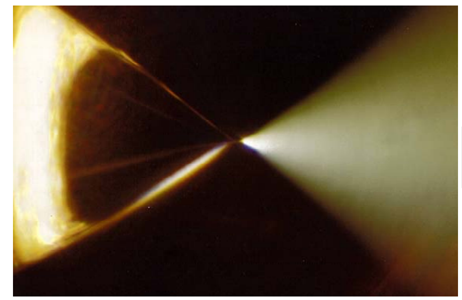


Experimental setup for the TOF system.

Research carried out in collaboration with Dr. M. Gamero (Busek Co. Inc.), and Prof M. Martinez Sanchez (MIT) under sponsorship from NASA and the AFOSR

Electrical Propulsion

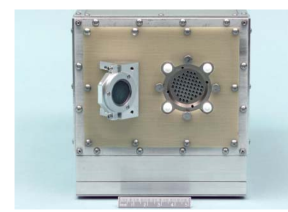
Thrust can be produced by merely ejecting the electrosprayed charged nanodrops or ions into space, after accelerating them electrostatically to high speeds. Each Taylor cone can produce thrust in the range of 1 μN, which is of interest in some special applications involving formation flying or microsatellites. The small size of each Taylor cone enables in principle packing many thousands of them into micro-machined arrays. The thrust T and specific charge q/m are written below in terms of the TOF curves I(t), the flight length L and the acceleration voltage ϕ:



$$T = \frac{2\Phi}{L^2}\int I(t)dt$$

$$q/m = \frac{1}{2\phi}\left(\frac{L}{TOF}\right)^2$$

Busek's Colloid Thruster Prototype



Busek's colloid thruster prototype, built as part of Disturbance Reduction System concept study (Jet Propulsion Laboratory) selected for the Space Technology & Opportunity. It features an electrospray source with 57 individual emitters (1-20 micro-Newton thrust throatability, 0.1 micro-Newton resolution), a carbon nanotube field emission cathode, propellant feed system and power processing unit.