

Electric Field Effects on Fiber Alignment using an Auxiliary Electrode during Electrospinning

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and

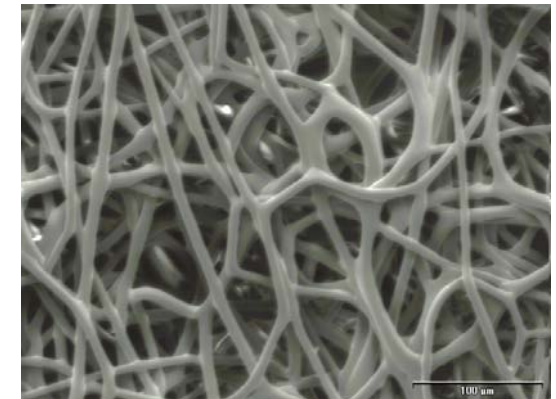
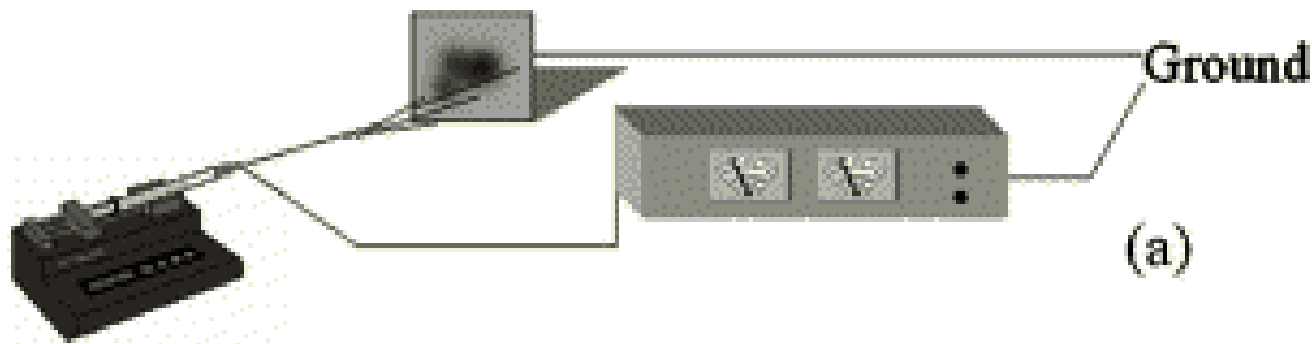
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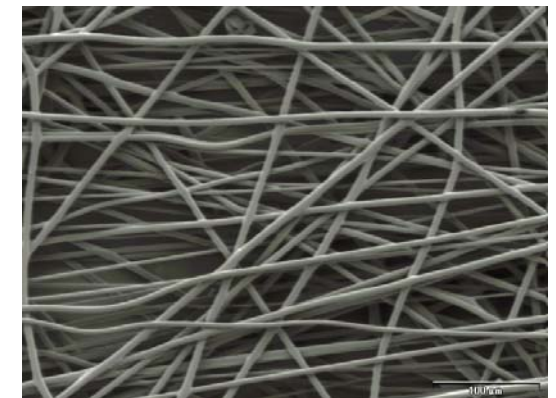
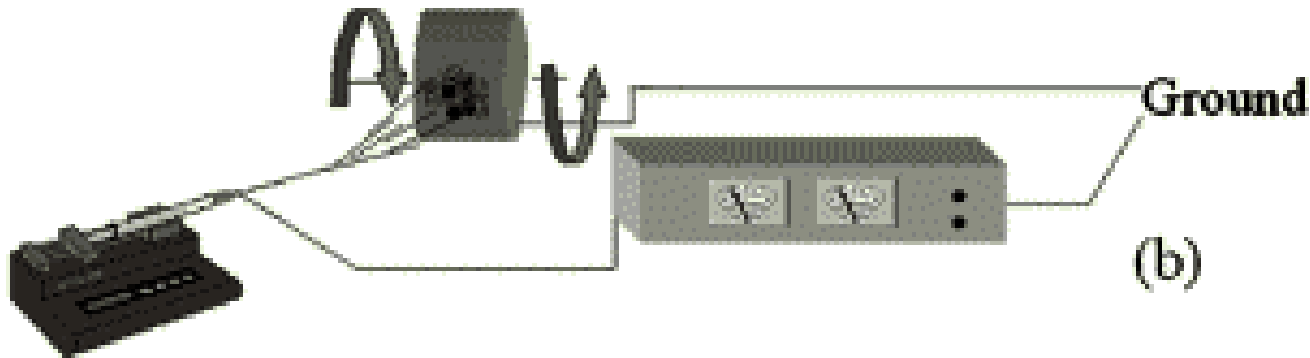
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Electrospinning Overview



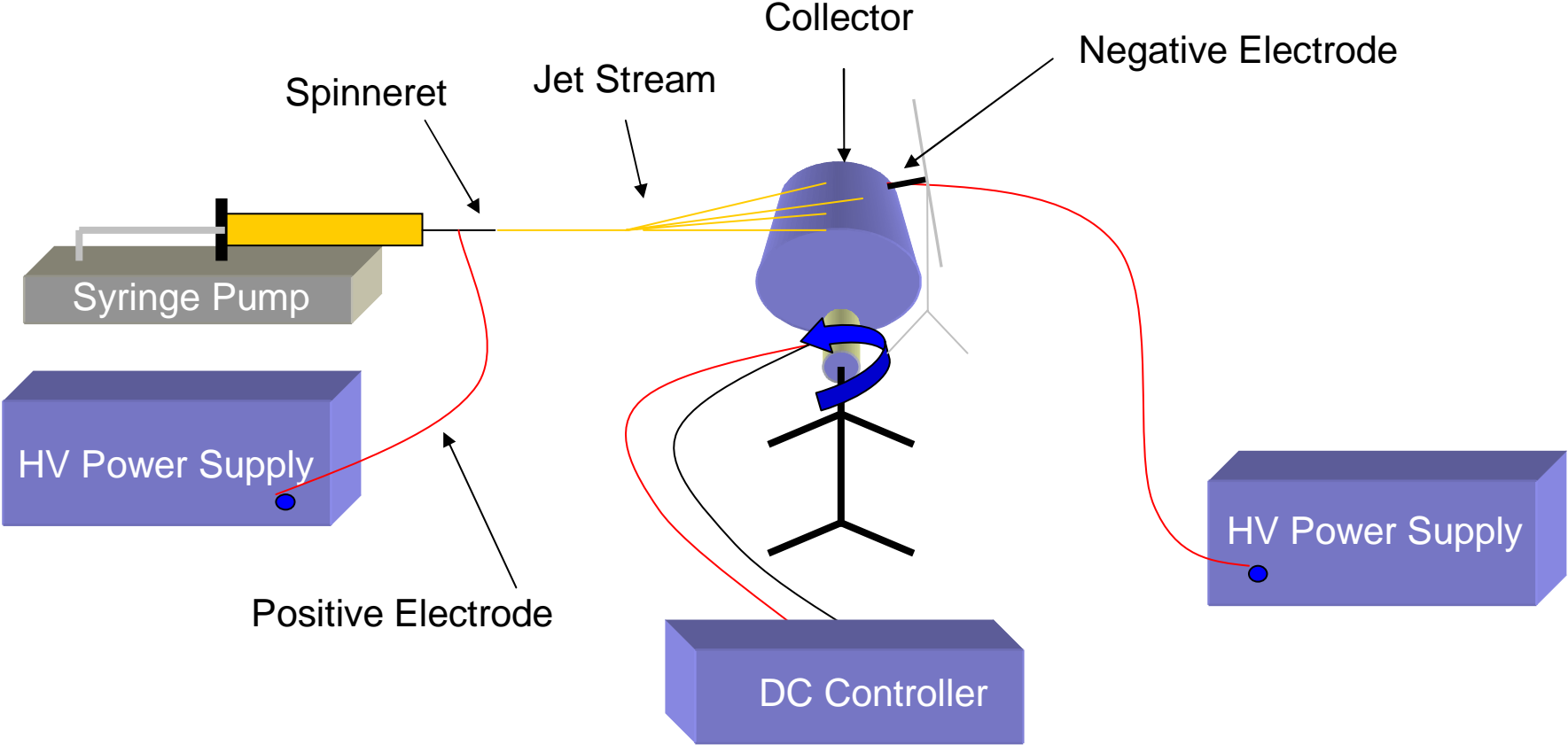
Static Collector



Rotating Collector

Fennessy, S and Farris, R. Fabrication of aligned and molecularly oriented electrospun polyacrylonitrile nanofibers and the behavior of their twisted yarns. *Polymer* 2004; 45 (12): 4217-25.

Experimental Set-up



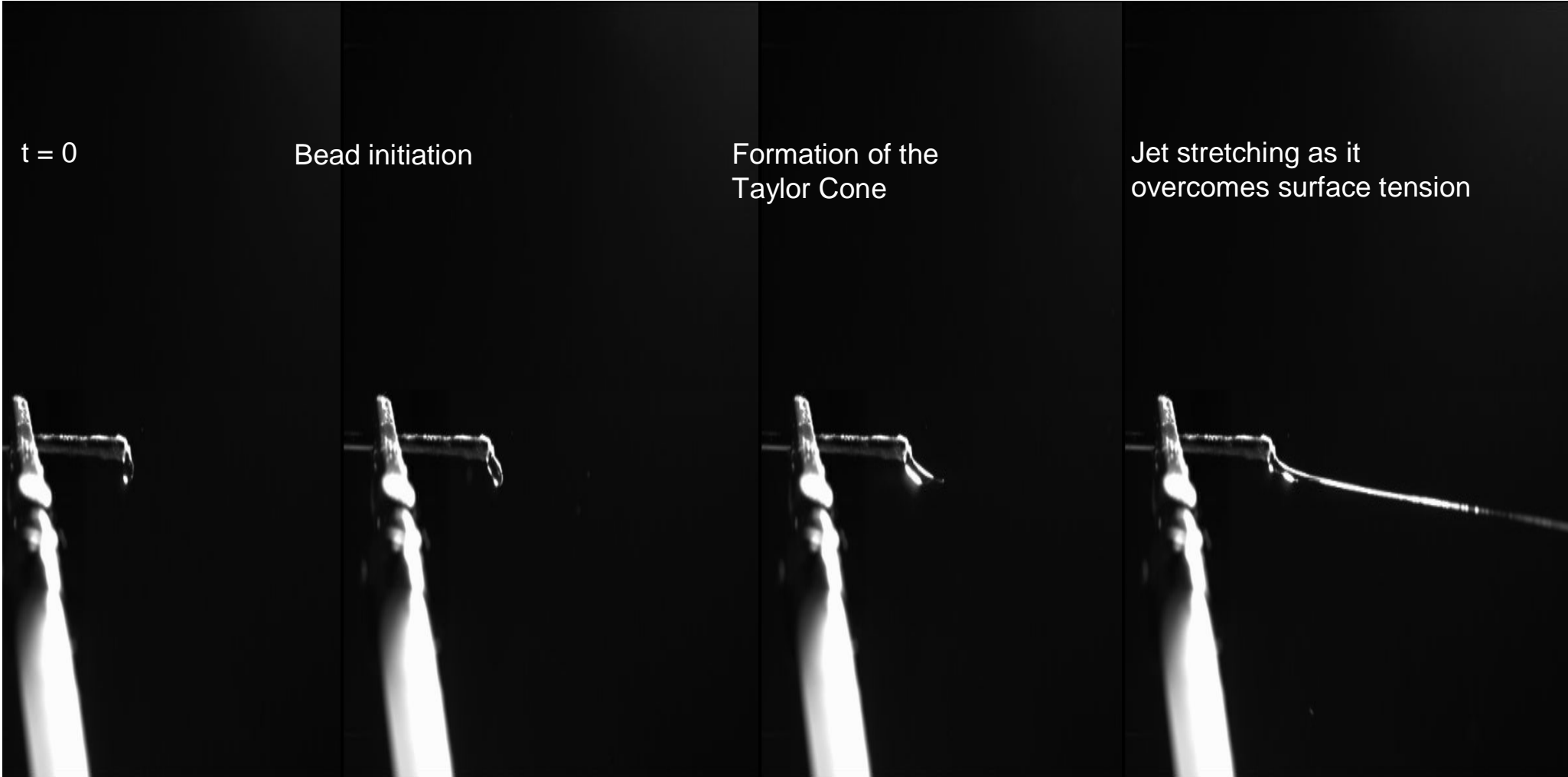
Jet Exit

$t = 0$

Bead initiation

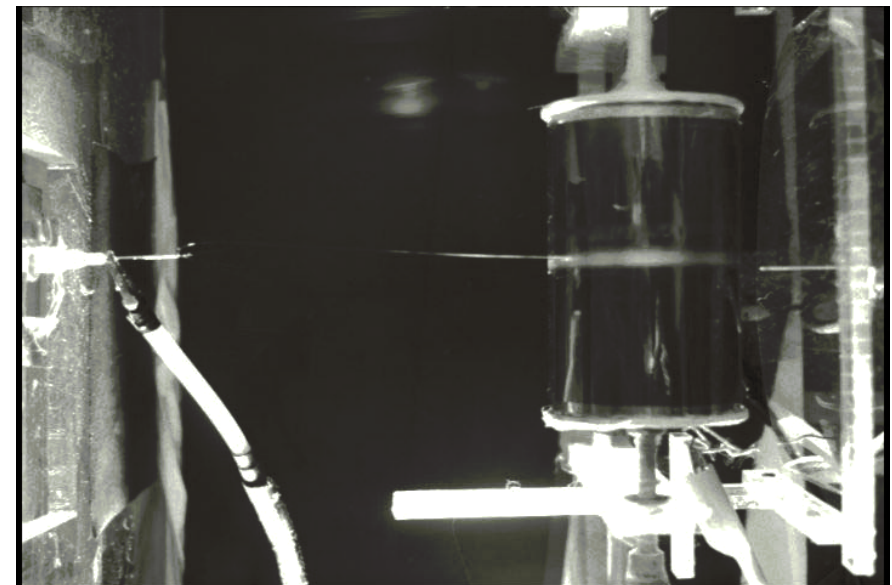
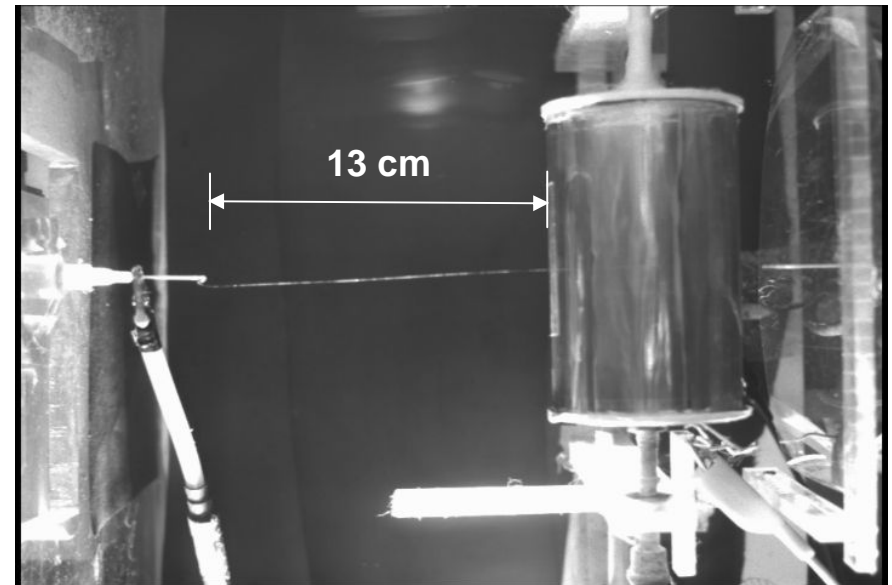
Formation of the
Taylor Cone

Jet stretching as it
overcomes surface tension

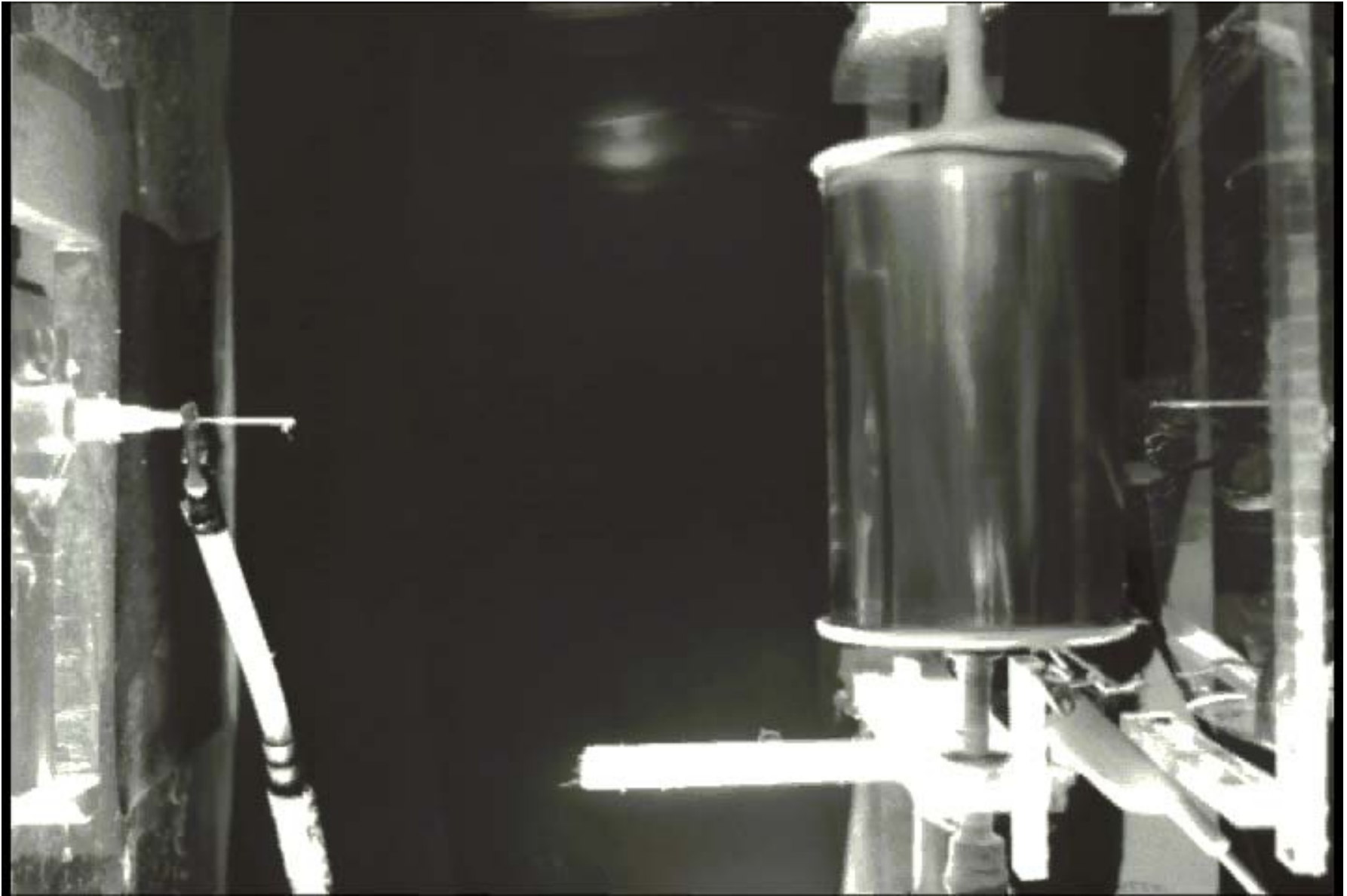


Auxiliary Electrode Effects

- Fiber is pulled towards the auxiliary electrode and collected on a rotating mandrel
- Auxiliary electrode controlling fiber placement and orientation
- No whipping generated
- No notable bending instability in the jet
- Auxiliary electrode continues to direct fiber placement and orientation over time (t = 5 minutes)

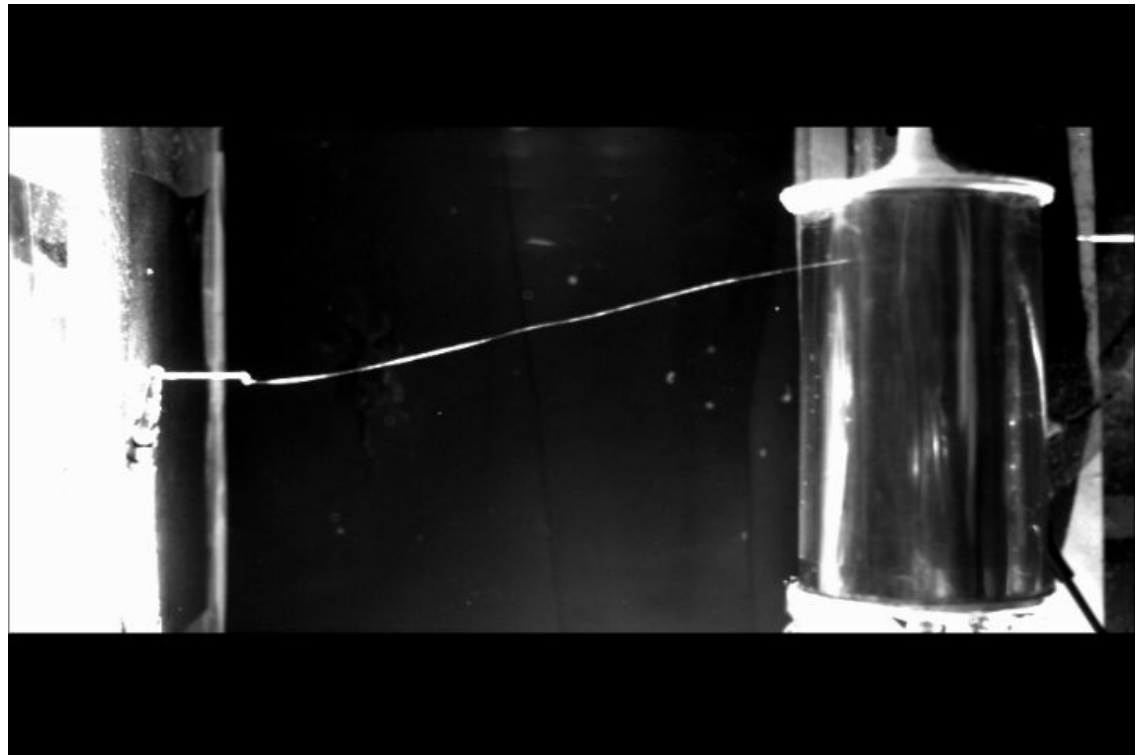


Electrospinning High Speed Video

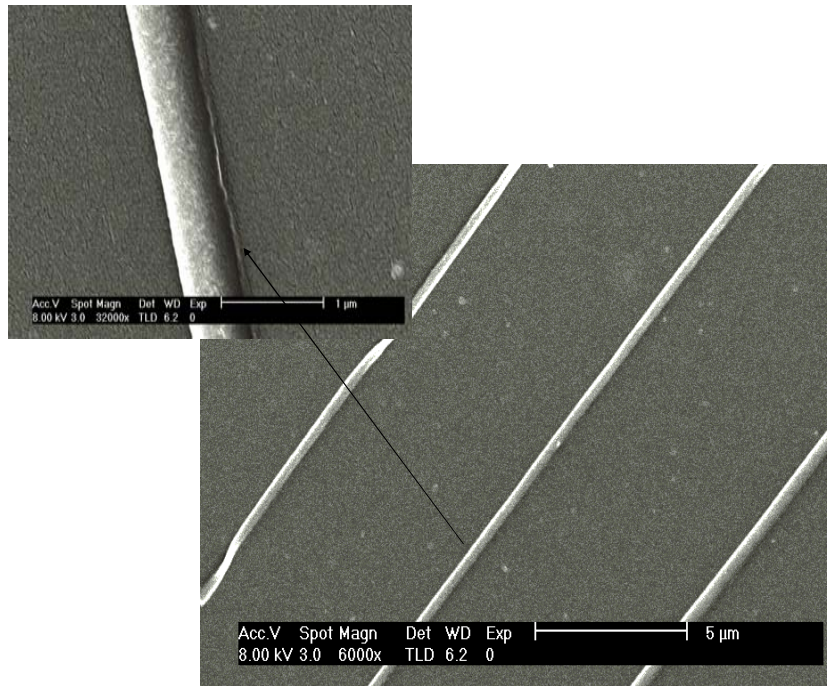


Effect of Auxiliary Electrode Position

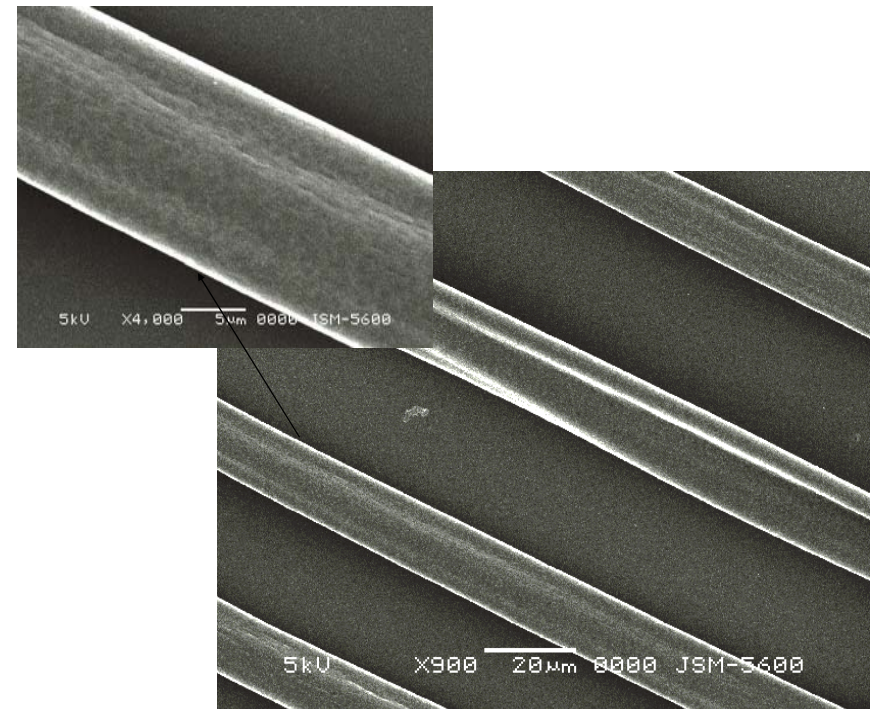
- Auxiliary electrode offset from spinneret
- Fiber is controlled by the field created between the auxiliary electrode and the spinneret
- Auxiliary electrode controls placement and orientation of fiber



Micro & Nano Fibers Produced



500nm Diameter Polyglycolic Acid (PGA) Fibers

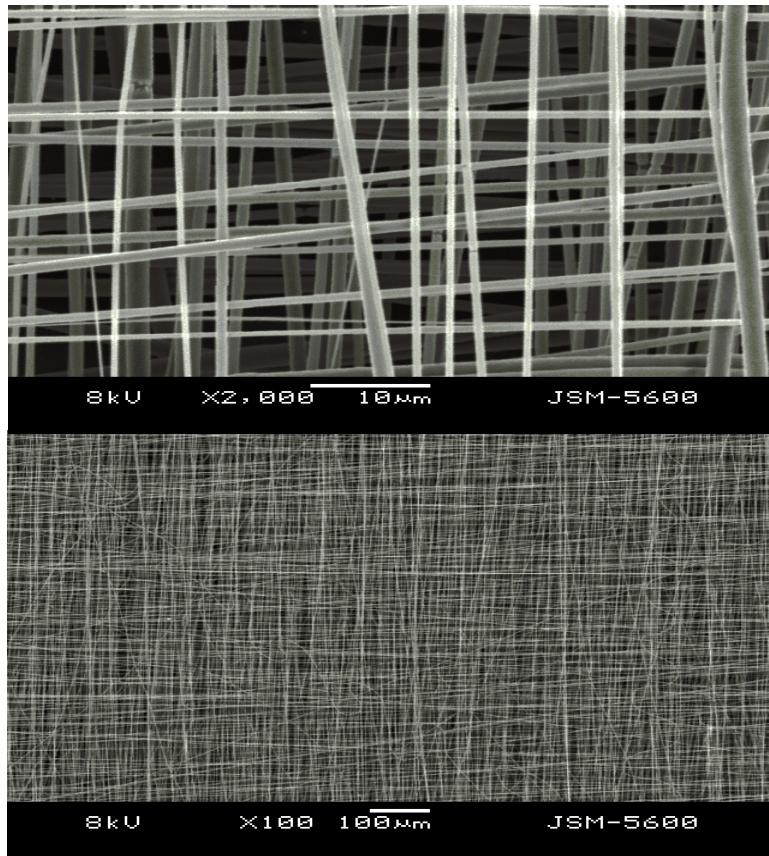


10 μm Diameter LaRC CP2 Polyimide Fibers

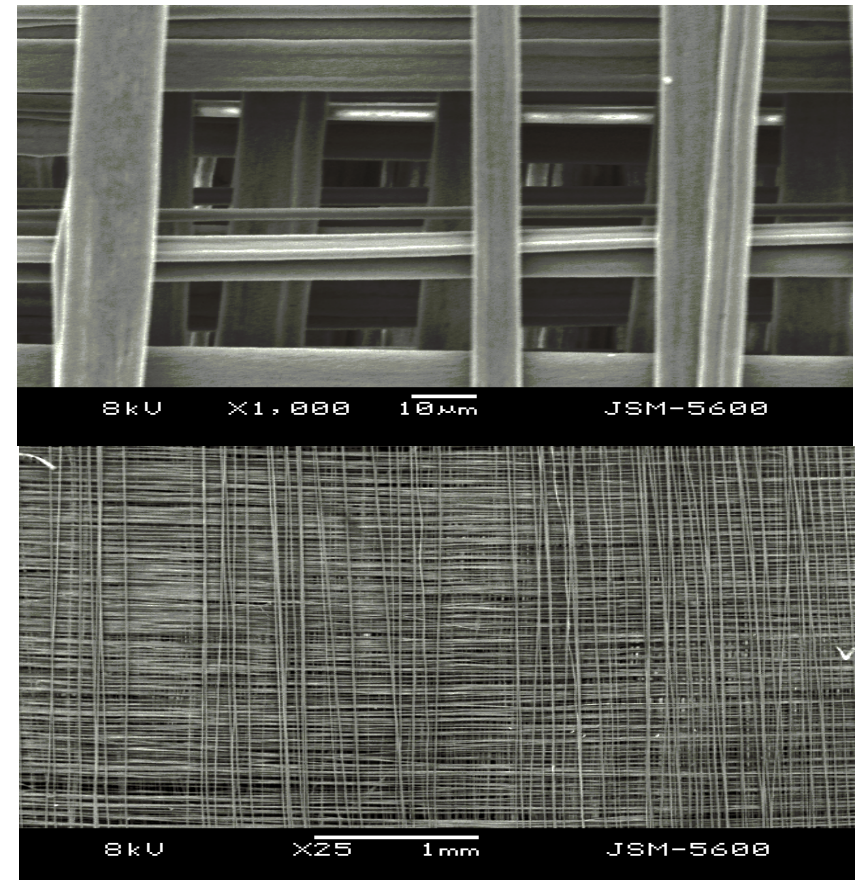
Other materials spun include: polylactic acid, polycaprolactone, polystyrene, polyethylene oxide

Micro and Nano Fibrous Mats

30 Layer Aligned Mats

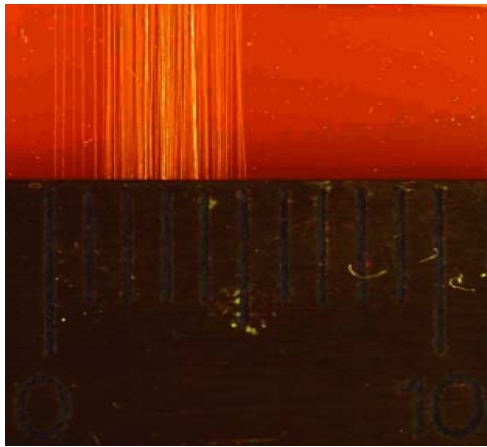


PGA 30 Layer mat: top image at 2000x; bottom image at 25x

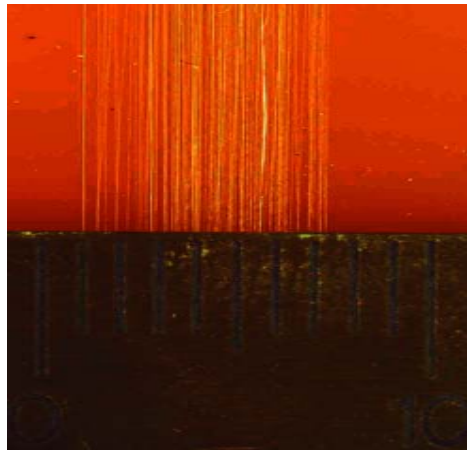


CP2 30 Layer mat: top image at 1000x; bottom image at 100x

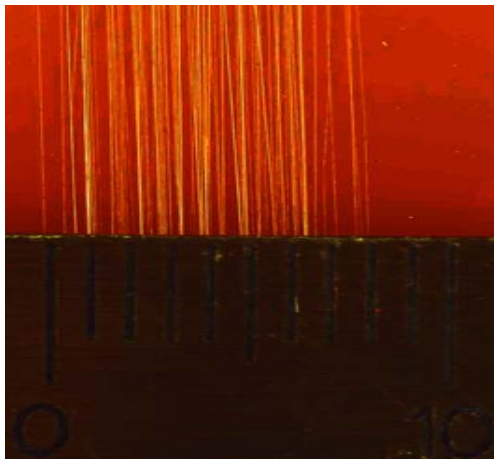
Field Effect on Fiber Distribution



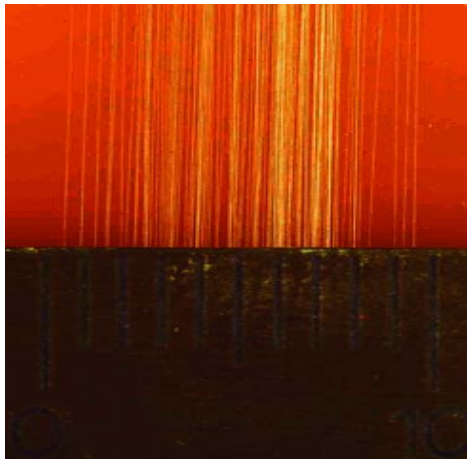
D = 5cm



D = 10cm



D = 15cm



D = 20cm

- Field strength varied by altering the distance between the spinneret and the collector
- Mat width increased as distance from collector increased
- Average Mat Widths:
 - D = 5cm: ~ 5mm
 - D = 10cm: ~ 6mm
 - D = 15cm: ~ 8mm
 - D = 20cm: ~ 10mm
- The density of the fiber distribution is proportional to the field strength

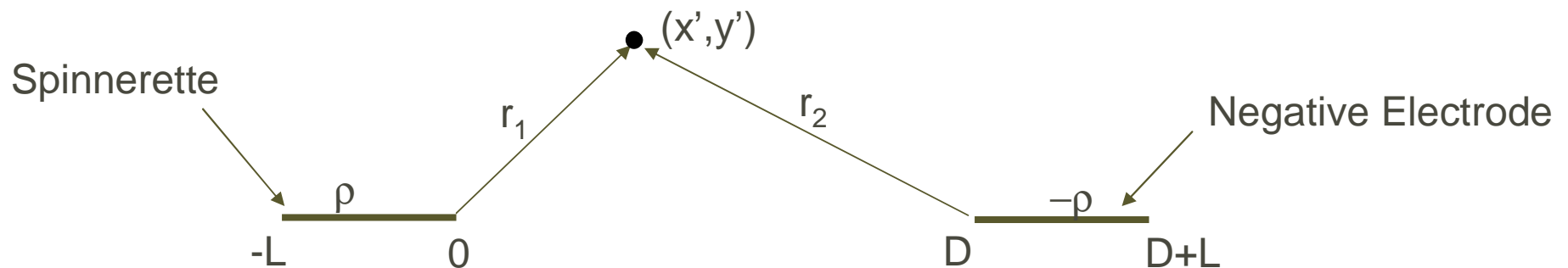
Modeling

- The electrostatic forces acting on the fiber during electrospinning can be calculated as the product of the local electric field and the charge on the polymer.

$$\vec{F}_e = q\vec{E}$$

- The electric field is calculated from the gradient of the electric potential. For two needle electrodes at $\pm V$ this is:

$$\vec{E}(x', y') = -\nabla \left[\rho \int_{-L}^0 dx / ((x'-x)^2 + y'^2) - \rho \int_D^{D+L} dx / ((x'-x)^2 + y'^2) \right]$$



Modeling: continued

- The charge density ρ is calculated based upon the required charge to bring the potential on the needle to the operating voltage of +/- 10 kV.

$$V(x', y') = 10000 = \frac{1}{\epsilon} \rho \int_{-L/2}^{L/2} dx / (x^2 + y'^2)^{1/2}, \quad \rho = \frac{10000\epsilon}{\int_{-L/2}^{L/2} dx / (x^2 + y'^2)^{1/2}}$$

- $(x', y') = (0, 6.35 \times 10^{-4})$

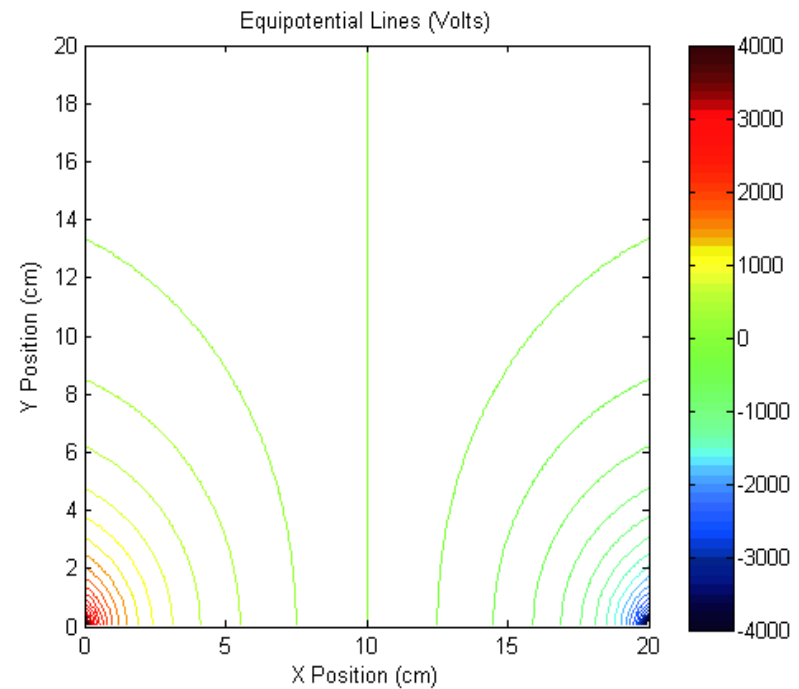
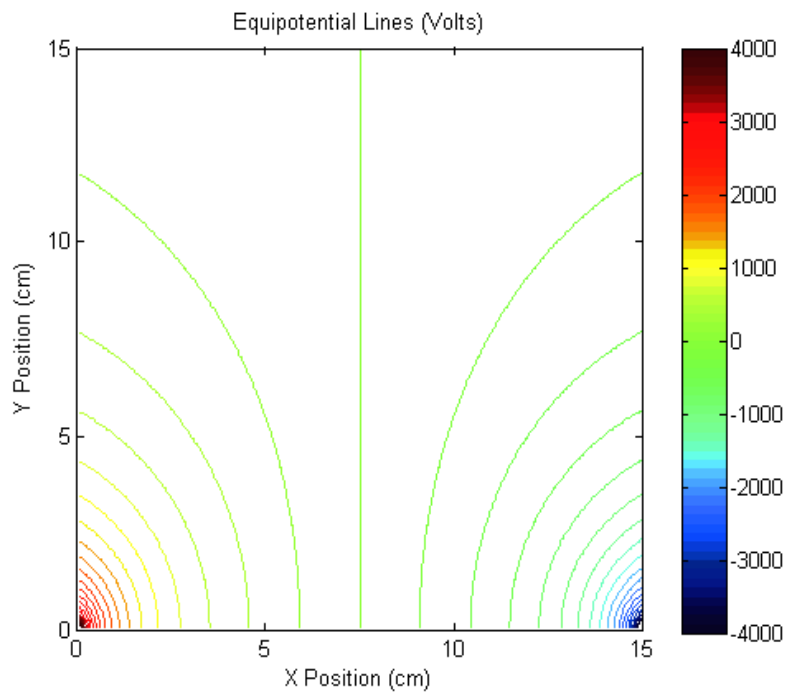
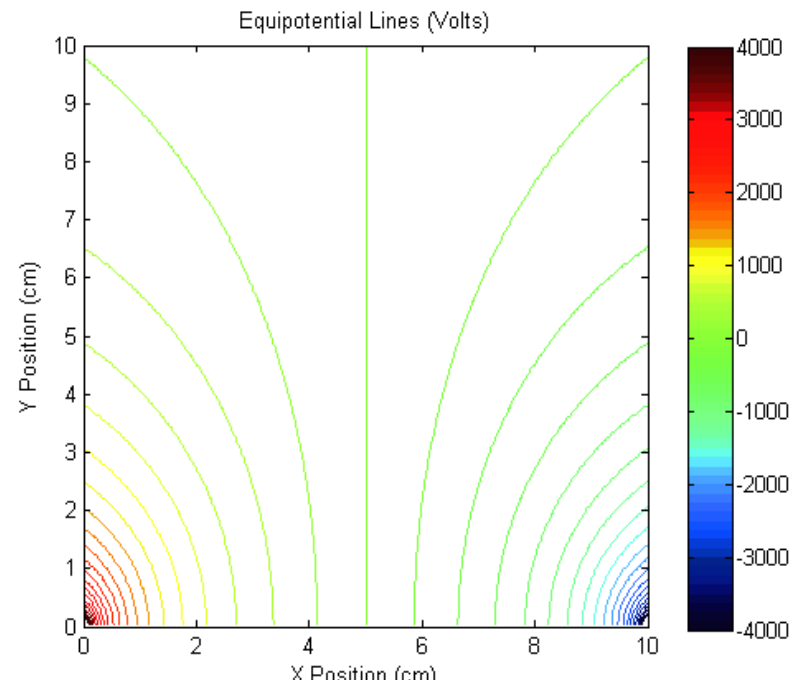
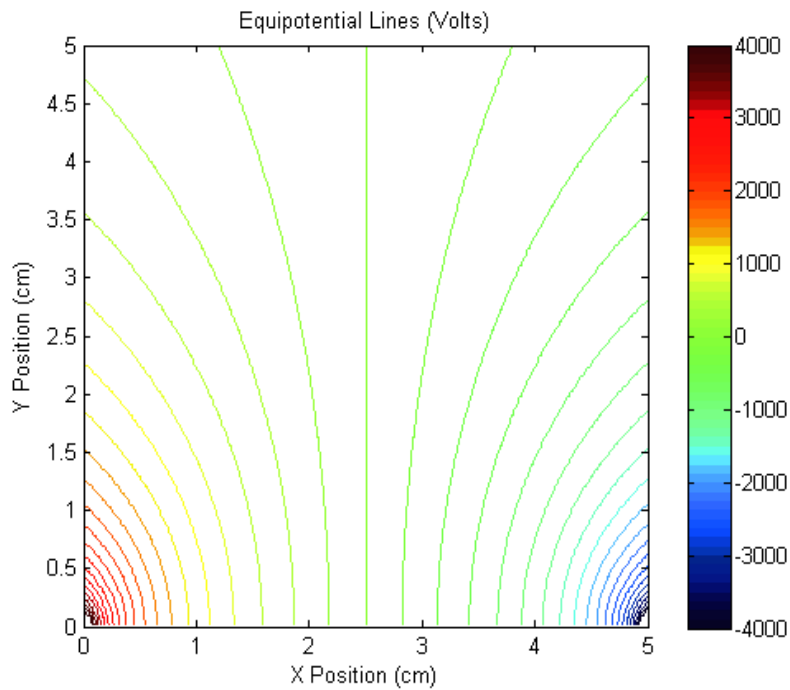


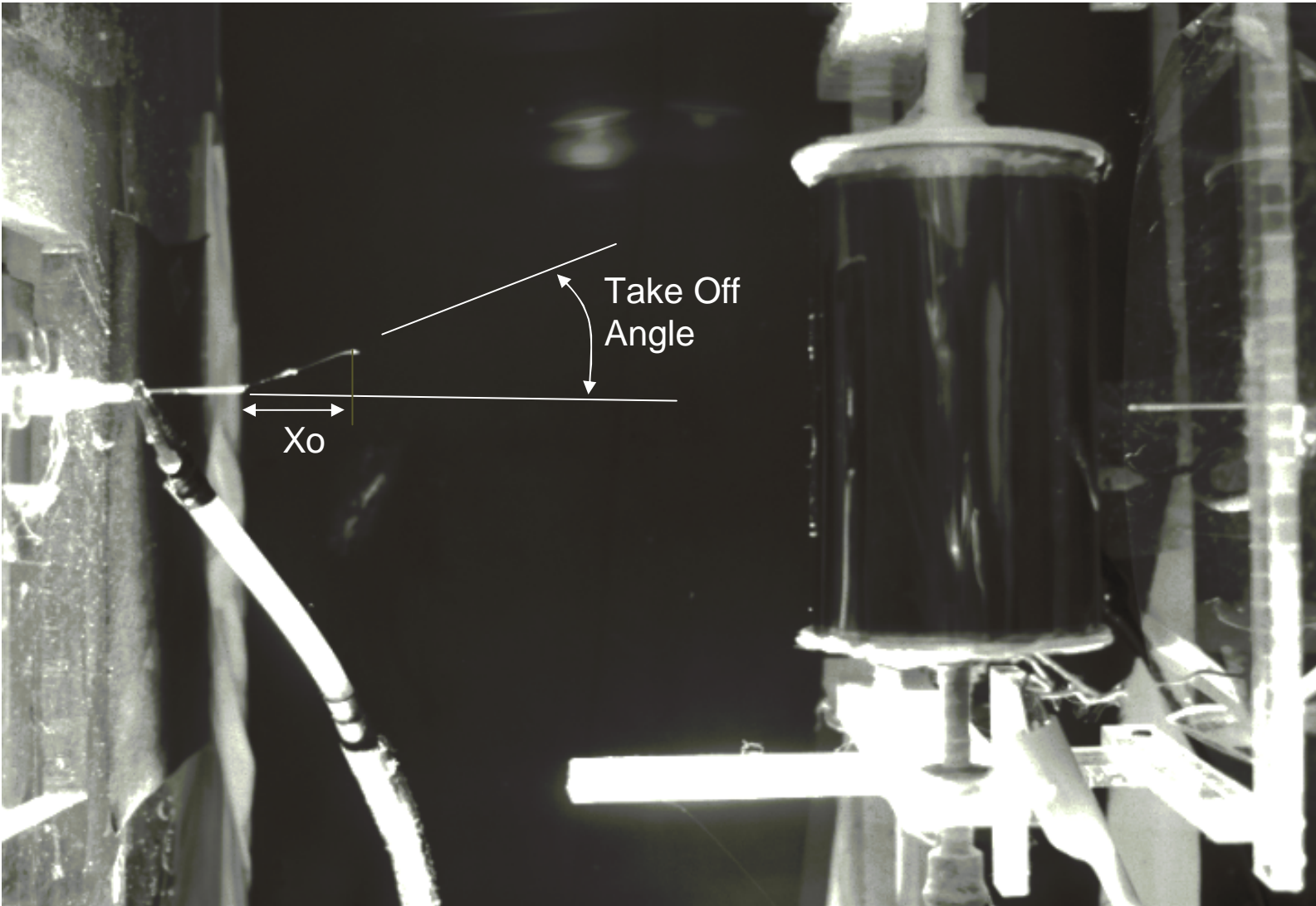
- Taking the charge q on a particle of polymer as that required to bring the surface potential to the operating voltage defines all parameters needed to calculate the electrostatic force throughout the interaction region.
- Classical equations of motion for the simplified system can then be generated from

$$\vec{A} = \vec{F} / m = q\vec{E} / m$$

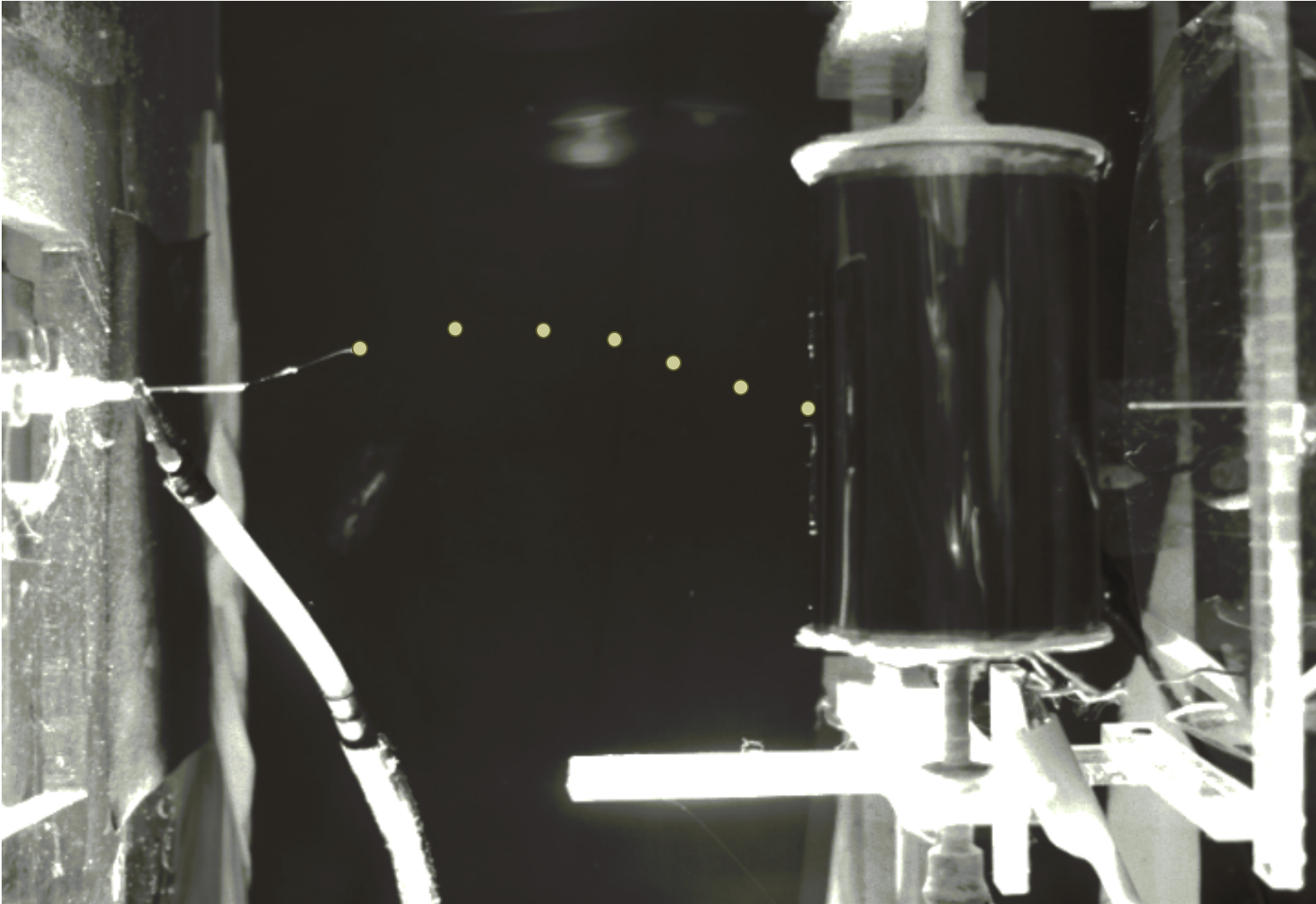
- Additional terms to account for surface tension and drag are required to model the actual dynamics of the electrospinning and have been incorporated as adjustable parameters in the equations of motion.

Equipotential Lines for Needle Electrodes, 5cm Long

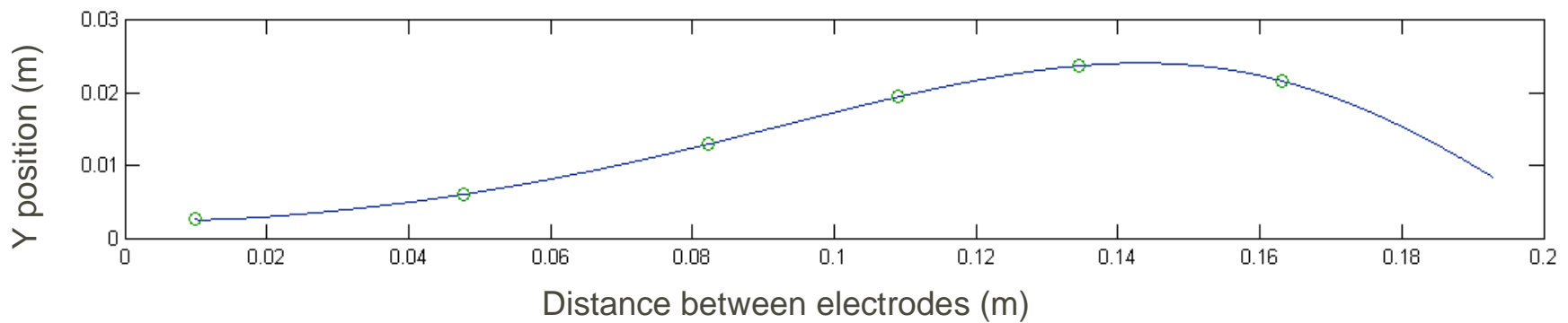
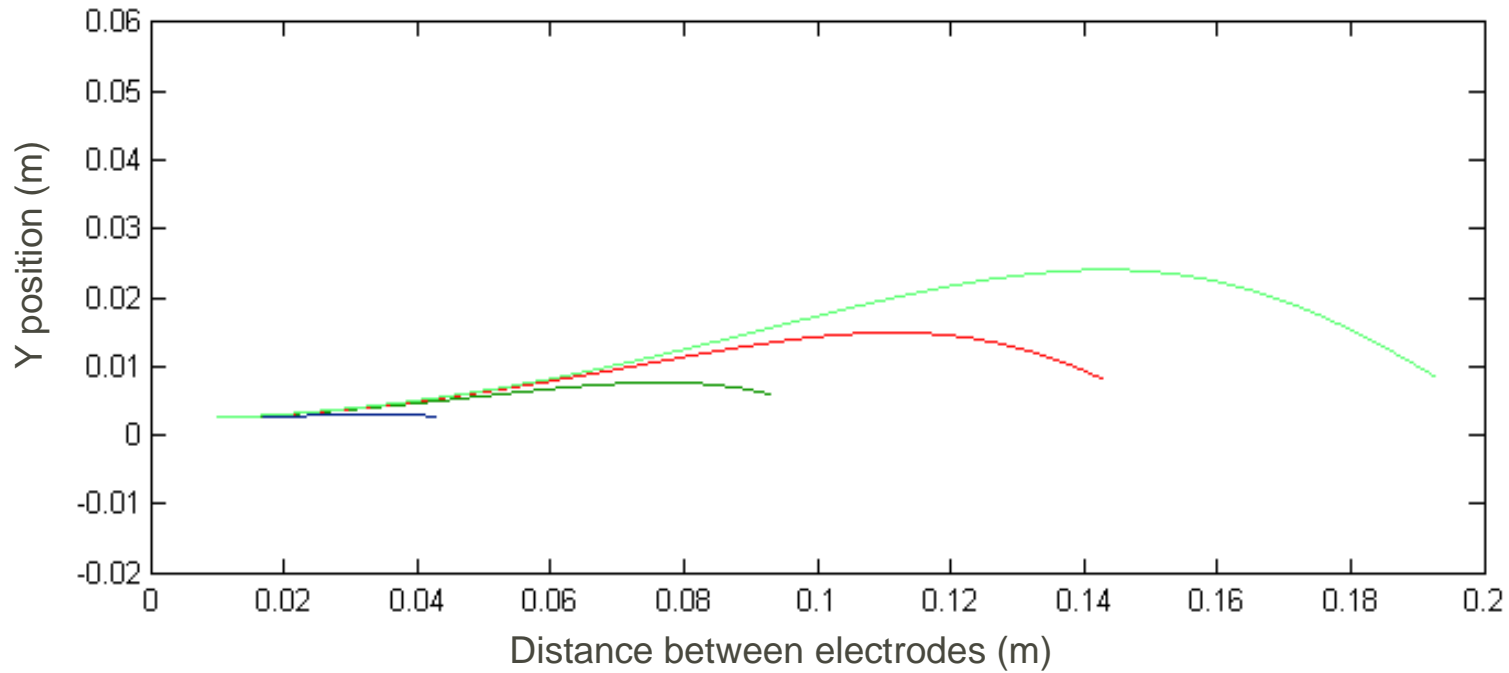




$X_o = 1-2 \text{ cm}$, Take off Angle $> \sim 15$ degrees

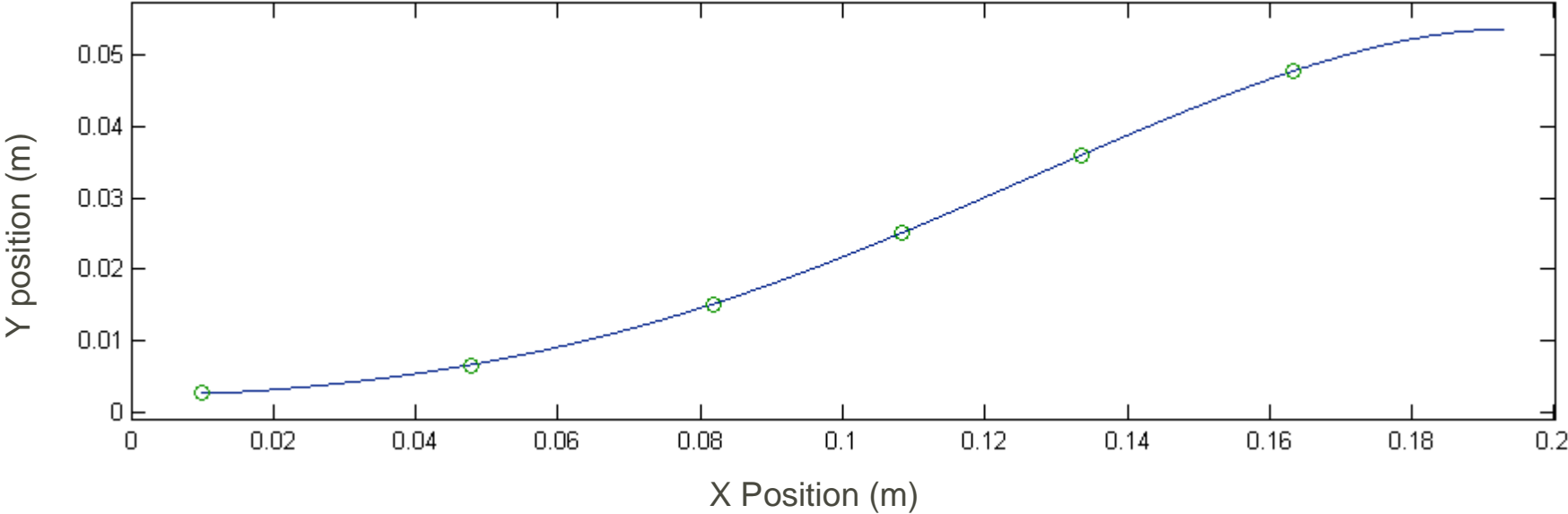
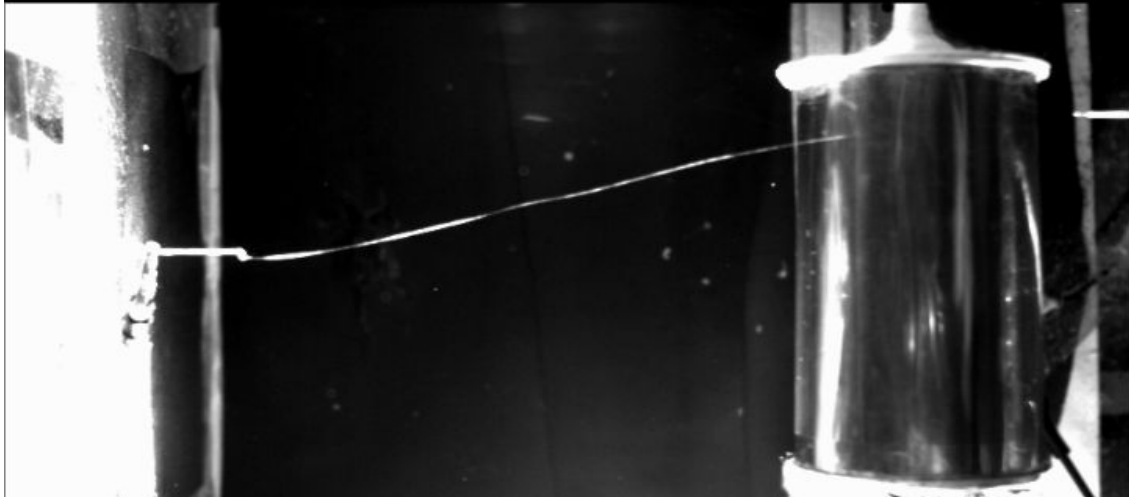


Calculated trajectories: 5, 10, 15 & 20cm electrode spacing



$x_0 = .01$, angle = 15 degrees

Off Axis Auxiliary Electrode



Field Strength Effects

- Study to assess the effect of altering the field strength with voltage held constant at +/- 10kV at distances of 5 cm, 10 cm, 15 cm and 20 cm
- Fiber morphology and diameter: were not significantly affected
- Fiber distribution: mat width varied with varying field strength
- Theoretical predictions of field strength determined at +/- 10kV using Matlab
- Correlated well with experimental data for overall fiber distribution

Potential Applications

- Filters
- Membranes
- Textiles
- Scaffolds for tissue engineering
- Drug delivery

