Electrophoresis v2

Biologists use electrophoresis to sort DNA segments by size. (Perhaps you've done this in a biology lab!) DNA segments are placed at one end of a gel. DNA is negatively charged (with a charge of two electrons per base pair). Then biologists “run the gel” by generating an electric field through connecting anodes and cathodes at the ends of the gel. This causes the negative DNA segments to accelerate towards the positive end of the gel. After running the gel, smaller DNA segments have moved farther from the starting end. In this problem we will try to understand why the smaller DNA segments move farther.

1. Each base pair of a DNA molecule has a negative charge of -2 elementary charges. Defining whatever variables you find appropriate, come up with an expression for:
   a) the total charge of a DNA segment of \(N\) base pairs
   b) the total mass of a DNA segment of \(N\) base pairs
   c) the total length of a DNA segment of \(N\) base pairs

2. To understand how electrophoresis works, let’s first start with the simplest possible setup: let’s ignore the gel and assume that the experiment is taking place in a vacuum, so the only force acting on the DNA segments is the electrostatic force due to a constant electric field. This field is constant everywhere.
   a) Using whatever representational tools are useful (free-body diagrams, system schemas, equations, etc.), model how this electrostatic force acts on DNA segments of different sizes. (Does this force have a different effect on different-sized segments of DNA?)
   b) Does this explain how electrophoresis separates DNA segments by size?

3. Obviously, a gel is not a vacuum! So now let’s include the effects of the gel. Let’s consider drag forces that are proportional to the cross-sectional area. Once again, model how the forces (electrostatic and drag) act on DNA segments of different sizes. Again, do these forces have different effects on different-sized segments of DNA? Your findings may depend on your assumptions about geometry, so try it for both
   a) assuming that the DNA segment is basically shaped like a long straight rope (as illustrated in the picture at the bottom)
   b) assuming that the DNA segment curls up into (approximately) a sphere.
   (Hint: Think about the volume of a sphere made out of a given number of base pairs where each base pair has the same mass, and then think about the cross-sectional area of that sphere.)

http://umdberg.pbworks.com/w/page/60207204/Electrophoresis%20v2?mode=embedded
(Feel free to try out any other geometries too!)

4. Given that we know electrophoresis is used to separate DNA segments by size, with **smaller segments moving farther** in a given amount of time, have we come up with a model that explains this result? If not, what assumptions that we have made need to be reconsidered? Is there another model that can account for this result?