DNA Mechanics Inside Plectonemes, Nucleosomes and Chromatin Fibers

Lanzani, G.

Author: Lanzani, Giovanni
Title: DNA mechanics inside plectonemes, nucleosomes and chromatin fibers
Issue Date: 2013-10-02

Introduction

All general laws are imprecise and all precise laws are banal.

It's much better to have a complicated Hamiltonian with a simple domain than a simple Hamiltonian in a complicated domain.

I'll leave a small hole in the proof, but a finite one. For those of you not following the course about logic, it means that it can be filled with a countable amount of steps.

If I say $1 - 1 < 2$, that's true, but not really optimal.

Giancarlo Benettin

Living in a natural world means we are surrounded by things that are there regardless of our presence. We call these things "nature". A marked difference between humans and animals is whether we accept this "nature" as it is. Many animals build their homes by altering "nature", but no species knows which laws make it possible for the home not to fall apart. Humans are different. If I went to physics, it was because the "how" was far more interesting than any other question. Someone may object why I didn't became an engineer then. There are two reasons for that. The first is the one that I gave to my wife one of the first time I met her. That happened when I was a freshman in physics, hence the slang:

> Because, you see, every time a law of nature is confirmed by experiments, I feel like the harmony of the universe is preserved. And this is, you know, cool.

I was probably referring to general relativity, a theory criticized by many, if not most, physicists back then, proven to be correct by experiments. Years later, a dear friend of mine, described the second reason much better than I could possibly do, so the next words are his

> In the modern world, the beauty and essence of physics tend to be assigned to the endeavor of finding a single, simplest, and unifying principle describing the root of everything we can observe around us.[1]

With such a premise, the reader should be surprised this thesis is about biophysics, a lesser "physics" when compared to string theory and cosmology, where the above principles are felt more strongly. To understand why that is, we need a detour. We'll have many throughout the thesis, but like every other tour, the intention is to have a good time while we're at it.

The everyday operations taking place in our body strikingly resemble the activity of a public library. Without much thinking we read books so full with words that, when aligned on a single line of text, would easily cover the distance between our home and our workplace. But instead of jogging while reading, people were smart enough to condense text in lines, lines in pages, pages in books and books in library shelves.

Books remain thus widely accessible and easily readable while being compact. But what part of our organism has a similar behaviour? It turns out that DNA, the molecule contained in the nucleus of each human cell and carrying our genetic information, is also stored in an extremely compact fashion. I am shorter (but thicker!) than the total DNA contained in every one of my cells. No wonder then that nature had to find a clever

[1] This is probably the line that separates physicists from engineers: *the single, simplest and unifying principle*.

way to compact DNA so that it fits inside our cells' nuclei (which are approximately one millionth of a meter wide). And things are more complicated than with written words, because DNA is a semi-flexible, negatively charged polymer, so it does not like to be bent, twisted or packed together.

A first hint of universality, the *unifying principle*, is already there. *Polymers* are ubiquitous around us: DNA, proteins, cellulose, PVC and many more. While they have the most disparate usages, their behavior is universally described by simple laws (see section 1.1). For example the entropy makes a polymer behave like a spring, even though the two objects have nothing else in common.

A second hint will come only later (in section 1.2): most of the shapes that DNA will be assumed to have are derived by looking at the motion of a *pendulum*. This fascinating analogy was first noted by Gustav Kirchhoff in 1859. The German physicist was not thinking at polymers though, but at elastic lines, or *elastica*. To understand the elastica we can use mechanical equilibrium, variational calculus and elliptic integrals. Moreover, besides the pendulum, it is analogous to a sheet holding a volume of water and the surface of a capillary [38].

Studying DNA then is not as narrow as it may seems. DNA as a polymer, or as an elastica, means that we can re-use centuries old results to study a relative newcomer in physics textbooks, without losing any generality. And without knowing, or liking, anything about biology or chemistry.[2]

But let me present in more details what the thesis tries to accomplish. With the aim of better understanding the compaction and de-compaction of DNA we will first, in chapter 1, introduce the reader to the basic physics behind DNA. Then, in chapter 2 we present the driving forces in the equilibrium of the chromatin fiber. The chromatin fiber is a cylinder that reduces the space needed to store the genetic code. However, since we still need to access the genetic code "trapped" in the chromatin, we will look at how to (transiently) unwrap DNA from the nucleosomes, chromatin's core constituents, in chapter 3. Last, but not least, we will look at the effects of torque and tension on naked DNA, in chapter 4.

[2] I can hear the sighs of relief from here.