BE/APh161: Physical Biology of the Cell
Homework 6
Due Date: Wednesday, Feb. 15, 2017

"It would not be incorrect to say that their drills are battles without bloodshed, and the battles – bloody drills." - Josephus Flavius, Book 3, Chapter 5, Line 75 of *The Jewish War Against the Romans*

1. Flies by the numbers.

In this problem, like with our treatment of bacteria in class earlier in the term, we try to systematically explore some of the quantitative features of the *Drosophila* embryo.

(a) Make a sketch of an adult *Drosophila* with scale bars indicating the sizes of the head, wings and eyes. Using your sketch and your scale bars estimate the number of cells in the fly eye and the fly wing. For the eye, make sure you look at the structure of the eye and explain the key elements (see Figure 20.32 of PBOC2, for example). As usual, make sure you provide the rationale for your estimates.

(b) Examine Figure 1 and use it to estimate the time to replicate the genome given the speed of replication in flies of approximately 30 bp/s.

(c) Do problem 20.2 of PBOC2. This part of the problem is intended to give a feeling for the time it takes to transcribe genes crucial for embryonic development.

(d) Write a code in either Matlab or Python in order to segment the movies of transcription in *Drosophila* and use the result to estimate the transcription rate. The concept of the experiment leading to your analysis is shown in Figure 2. The TAs will have a help session in which they walk you through this entire process for those that are interested.

2. Setting up the fly body plan.

In class we examined how using a steady-state solution to the reaction diffusion equation for Bicoid, we could understand how the exponential profile

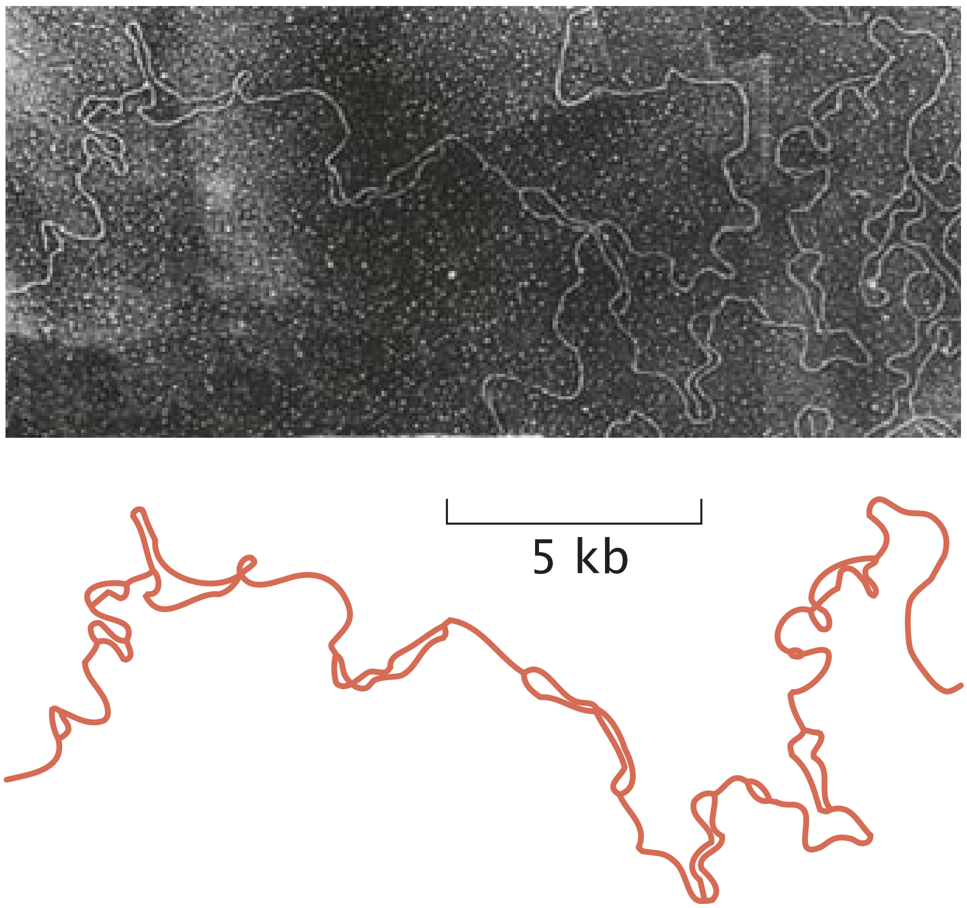
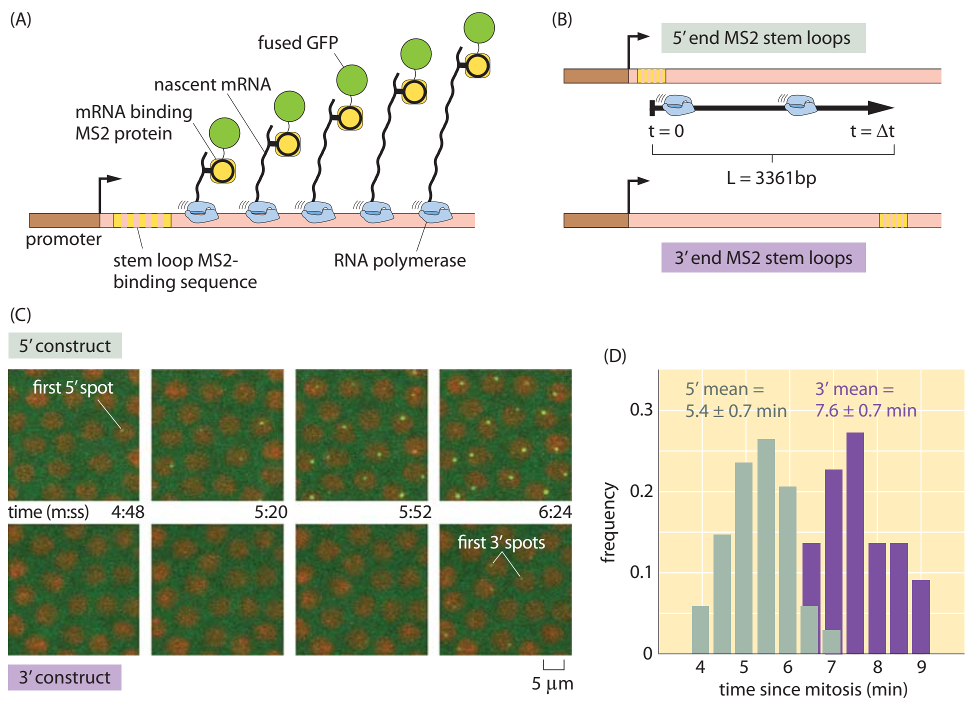


Figure 1: Electron microscopy image of DNA from the fly genome being replicated.



$$\Longrightarrow \text{transcription rate} = \frac{\text{length}}{\text{time difference}} = \frac{L}{\Delta t} = \frac{3361\,\text{bp}}{2.2\text{ min}} \approx 1500\text{ nt/min} \approx 25\text{ nt/s}$$

Figure 2: Measuring the transcription rate in flies.

is set up.

(a) Give a brief description (a paragraph or less) of the Bicoid gradient in *Drosophila* and how it is relevant to fly development.

(b) Repeat a derivation of the reaction-diffusion equation and justify the form

$$\frac{\partial c(x,t)}{\partial t} = D\frac{\partial^2 c(x,t)}{\partial x^2} - \frac{c(x,t)}{\tau}. \tag{1}$$

Make sure you explain carefully where all of these terms come from. Specifically, what I am hoping is that you will imitate what I did in class with the little boxes and working out number of molecules entering and leaving, but now you will include the degradation as a sink term that can also change the number of particles in that small volume.

(c) Now solve this equation in steady-state by finding the general solution subject to the boundary condition that $J(0,t) = j_0$ and $J(L,t) = 0$. Make sure you explain what these boundary conditions mean relative to the biology of the problem. Suggest approximations that can be made to simplify the result to that I presented in class.

(d) Describe the observed concentration profile of Bicoid along the anterior-posterior axis of the fly mathematically. What is the functional form?