Name:______________________________

Biology 3820
Physical Principles in Biology
Fall Semester 2015

Final Exam
18 December 2015

100 points total
Be sure to show your work and include correct units in all of your answers!

1. Suppose that someone were to make some six-sided dice with a twist: Instead of dots representing the numbers one to six, these dice only have one, two, three or four dots on a side, but there are two sides with two dots and two sides with three dots. Consider a game where two of these special dice are thrown and the score is determined as the sum of the two sides that land facing upwards. Assume that the dice are fair, that is the probability of any side landing upwards is the same as for any other side.

   (a) (5 pts) Calculate the probabilities for a single die landing with one, two, three or four dots displayed.

   (b) (5 pts) If the sample set for this game is defined as the list of sequences of the numbers showing for the two dice, how many outcomes are in the sample set?

(c) (5 pts) Which outcomes in the sample set have the highest probabilities? What is the probability for each of these outcomes?

(d) (5 pts) Which outcomes in the sample set have the lowest probabilities? What is the probability for each of these outcomes?

(e) (5 pts) If the event E_6 is defined as the set of all outcomes for which the sum is 6, list the outcomes in this event and calculateis the probability of this event.

Name:______________________________

2. Someone has left the following bit of Python code on a computer, but hasn't done a very good job of documenting what it does:

```
import random
def f(a,b):
    c = 0.0
    for i in range(a):
        d = random.randint(0,1);
        if d ==1:
            c += b
        else:
            c += -2*b
    return c
```

(a) (4 pts) Describe what the function f(a,b) does and what the input parameters represent.

(b) (3 pts) Suppose that the function f(50,0.75) were executed. What are the minimum and maximum values that could be returned by the function?

Name:____________________________

(c) (3 pts) What is the most likely value to be returned by executing `f(50,0.75)`?

3. Because of the advances in electronic image sensors and the intense signal from green fluorescent protein (GFP), it is possible to experimentally monitor the diffusion of single copies of this molecule. An intrepid scientist has followed the path of 1,000 individual GFP molecules for a period of 1 s and has found that the RMS distance traveled along a single direction is 6 μm. These measurements were performed at a temperature of 25°C. The molecular mass of GFP is 26.9 kDa.

   (a) (6 pts) Calculate the diffusion coefficient of GFP under these conditions.

   (b) (6 pts) Calculate the RMS velocity at which a GFP molecule moves between collisions under these conditions.

(c) (6 pts) Calculate the average distance, δ_x, that a GFP molecule would move along a single direction before changing directions during diffusion.

4. Consider a yeast cell, with a diameter of $4\,\mu$m, that is relying primarily on glucose for its metabolic energy. Fortunately, the extracellular concentration of glucose is relatively high, 20 mM, and the cell contains transporter protein molecules in its membrane that allow glucose to diffuse in as the intracellular glucose is consumed. The intracellular concentration of glucose is 1.5 mM and remains constant as glucose diffuses into the cell and is consumed at equal rates. Assume for the following that the diffusion coefficient of glucose is $6\times10^{-10}\,\text{m}^2/\text{s}$ and that the membrane transporter proteins can be approximated as cylindrical pores with a radius of 0.5 nm and a length of 50 nm.

   (a) (6 pts) What is the flux, J, of glucose molecules through the pores of the transporters, in units of moles/(m^2s)?

Name:________________________________

(b) (6 pts) Assume that the cell is consuming 10×10^{-17} moles of glucose per second. How many transporter molecules would the cell need to satisfy its glucose hunger?

(c) (6 pts) In fact, the glucose transporter molecules must be more complex than simple pores in the membrane. Briefly explain why.

Name:____________________________

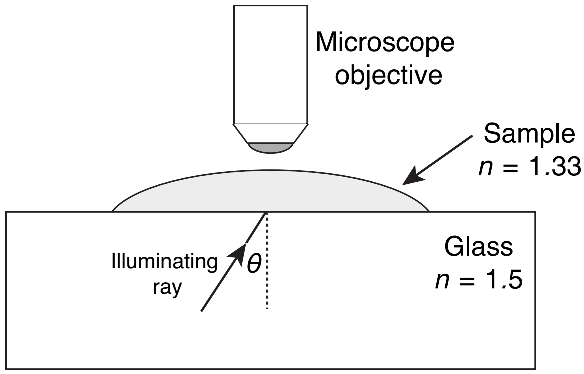
5. The yeast cell described in the previous problem has been transferred to a drop of water, with a total volume of $1\,\mu$L. The cell suddenly explodes, allowing all of its contents to be diluted into the water. The temperature of the solution is 25°C.

   (a) (6 pts) What is the concentration of glucose now in the water drop?

   (b) (6 pts) Calculate the change in entropy and the change in free energy associated with the release of the glucose from the yeast cell to the total volume of the water drop.

Name:______________________________

6. The diagram below shows an arrangement for total internal reflectance fluorescence (TIRF) microscopy.



The key element is a glass block through which illuminating light rays pass at an angle set to produce total internal reflectance between the glass and the sample above it. The indices of refraction for the glass and sample are indicated in the drawing.

(a) (5 pts) Calculate the angle from the normal, labeled θ in the diagram, that will produce total internal reflectance of the illuminating ray.

Name:____________________________

(b) (6 pts) Briefly explain the special advantage that TIRF microscopy offers over conventional epifluorescence microscopy and how the arrangement illustrated above provides this advantage.

(c) (6 pts) Briefly describe a specific kind of biological structure for which TIRF microscopy is particularly suitable.