Part A (*do any 4 of the questions 1-7*) [32 marks]

1. Design **any two** of the following experiments explaining clearly the logic and essential steps: **[8]**
   a. Measure Boltzmann constant k_B through a macroscopic experiment
   b. Measure angular velocity of flagellar rotation of a motile bacteria
   c. Measure persistence length of actin
   d. Measure effect of an externally added activator of intrinsic and extrinsic noise in gene expression in *E. coli*
   e. Measure persistence length of DNA of known length but imaged as a "blob".

2. "For a charged protein in a salt solution with charge density, c_∞= 200 mM, typical for K$^+$ ions in the cell interior, the Debye screening length (λ_D) is roughly 0.7 nm. This means that beyond this distance the charge on the protein will not be "felt" by other charges."
   a. Will the Debye screening length increase or decrease when: **[2]**
      i. Temperature in increased; ii. c_∞ of K$^+$ ions is decreased
   b. The charge density (units: C/m^3) of the Debye cloud is given by : $\rho(x) = -\frac{\sigma}{\lambda_D} e^{-\frac{x}{\lambda_D}}$, where σ has units: C/m^2 and represents surface charge density of the charged (say) DNA immersed in the salt solution.
      i. Estimate σ for DNA. **[2]**
      ii. Find the conc. of K$^+$ ions 5 nm away from the DNA. **[2]**
      iii. Use $V(x) = -\frac{\sigma\lambda_D}{D\varepsilon_0} e^{-\frac{x}{\lambda_D}}$ to **explain** how in the presence of salt, strength of Coulombic interactions become "shorter" ranged. **[2]**

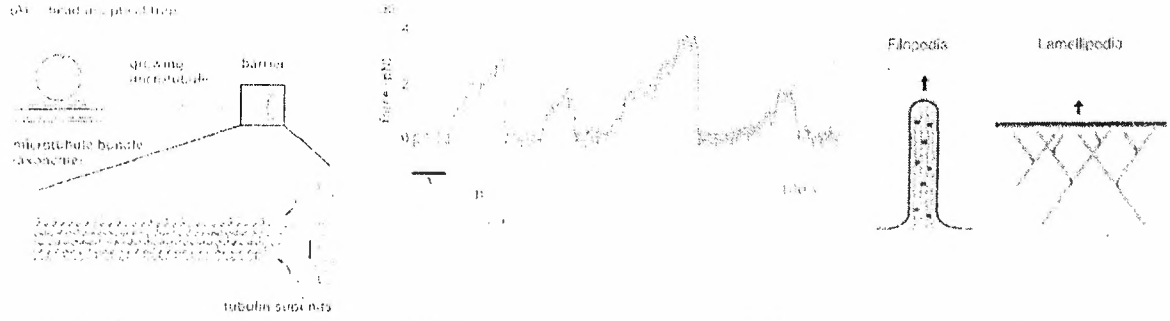
3. Show how a bead (size > wavelength of light) with higher refractive index than water (in which it is immersed) will refract a focussed beam when placed on the optical axis but just after the focal point along the direction of propagation of light. Therefore, show in which direction would it feel forces due its having deflected individual rays. **[8]**

4.
   a. What kind of trajectory do motile bacteria (like *E. coli*) take during movement? Draw and show the two different phases. **[2]**
   b. Why are the two different phases needed? What would happen if only the first or the second phase characterized its movement? **[2]**
   c. Estimate for how long (time) and how much (distance) will a bacterium move afer it shuts down the rotatory motor that helps the flagella propel it OR how long (and after what distance) will its kinetic energy be dissipated by viscous forces. Use 30 μm/s for bacteria's velocity, viscosity of water (0.001 Pa-s) **[4]**

5. Write in maximum two lines, importance of thermal energy (k_BT) in & effect of increasing T in: **[8]**
   a. Reaction rates
   b. Fluctuations in reaction states
   c. Intrinsic noise in gene expression
   d. Attractive/repulsive forces between charged entities in salty solution
   e. Bending of polymer-like bio-molecules (DNA, actin filaments, microtubules)
   f. Transport of nutrients in small cells like bacteria

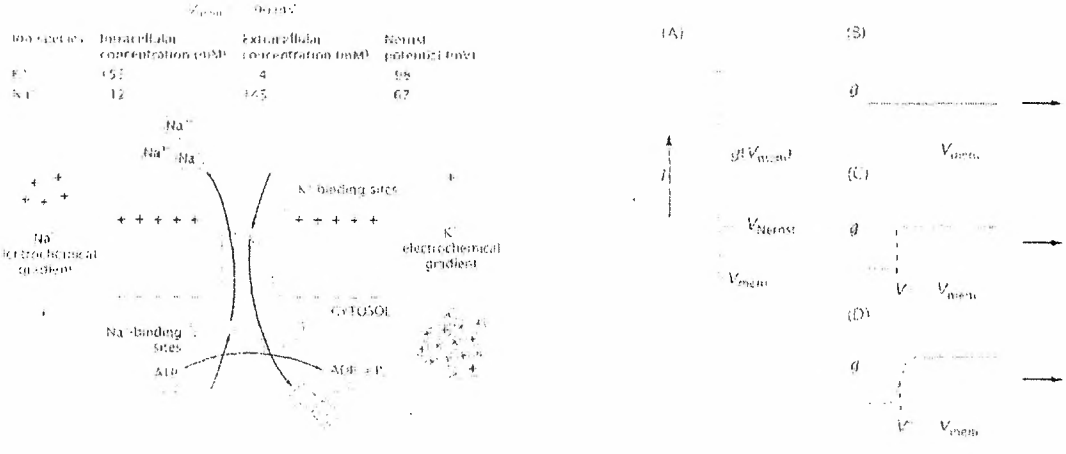
g. Strength of hydrophobic interactions
h. Membrane potential of a cell

6.



a. What is plotted in Fig (B)? From which part of Fig(A) is the measurement done? **[2]**
b. Explain what leads to the measurements at the A, B and C sections of Fig (B)? **[2]**
c. In a reaction $\{m + P \rightleftharpoons Pm\}$, $K_d = \frac{[m][P]}{[Pm]}$, where m represents monomer, P polymer and Pm the elongated polymer. At what concentration of the monomer will [Pm]/[P] be 1. **[1]**
d. If polymerization also needs movement of a barrier (Force from barrier = F) by a distance δ, what happens to the reaction? **[1]**
e. In the rightmost panel of the figure above, explain how the arrangement geometry of actin filaments are used to either polymerize against higher force at the expense of displacement or make bigger displacements at the expense of force tolerance. Clearly indicate what is acting as the barrier and in which configuration what is maximized? **[2]**

7.



a. Which biomolecule is depicted in the figure above (left). Use the information given to estimate the energy cost associated with one cycle of working of the molecule. If 1 ATP hydrolysis releases ~20k_BT, comment about its efficiency. **[4]**
b. The right figure above represents a patch of a membrane. What does g(V_{mem}) represent? While membrane component gives rise to g? What feature of the molecule make g a function of V_{mem}? What determines V*? **[2]**
c. Draw the expected I-V curves for (B), (C) and (D). **[2]**

PART B (18 marks - *do any 9 of the questions 1-12*)

Write True or False **giving reasons**.

1. Persistence length of a polymer decreases on increasing temperature or decreasing its length.
2. Buckling force of a polymer decreases on increasing temperature or decreasing its length.
3. Membrane capacitance depends on dielectric constant of cytoplasm.
4. The cell with highest notch activity in a group of neighbouring cells further represses notch activity in its neighbours.
5. Lotka-Volterra model always predicts periodic oscillations in prey and predator population dynamics.
6. The Lotka-Volterra model doesn't consider (explicitly or implicitly) the death rate of prey or the birth rate of predator.
7. The fixed point of a prey-predator system depends on number of prey and predators present.
8. The number of prey at fixed point depends on predator's death rate and the prey's growth rate.
9. Viscosity of air increases with increasing temperature.
10. Bacteria modulate their run length to outdo nutrient diffusion during foraging for nutrients.
11. Bacteria "run" but also mimic random walk.
12. Light can be used in experiments to visualize molecules (using fluorescence) but not impart forces.

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