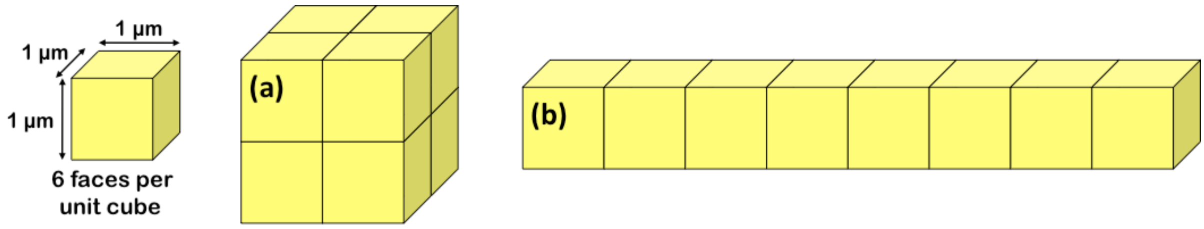
BIO-372 “MICROBIOLOGY” EXERCISES (WEEK 1)

Your Name : ____ Grade : _________

Your Partner: ____ Grade : _________

EXERCISE 1 "LIVING AT MICRO SCALE" :

Imagine two microorganisms with equal mass and volume but different shapes, (a) and (b):



1. Which shape has the lower ratio of surface area to volume (S/V ratio)?
☒ A. Shape (a).
☐ B. Shape (b).
☐ C. Shapes (a) and (b) have the same S/V ratio.
Explain your answer:

The two shapes have the same volume, equivalent to 8 unit cubes (8 μm^3). In shape (a) there are 24 faces exposed. In shape (b) there are 34 faces exposed. Put another way: both shapes, (a) and (b), have a volume of 8 μm^3. Shape (a) has a surface area of 24 μm^2 so its S/V ratio is 3 μm^{-1}. Shape (b) has a surface area of 34 μm^2 so its S/V ratio is 4.25 μm^{-1}.

2. Which shape is better optimized to conserve internal heat (for example, heat generated by metabolic processes)?
☒ A. Shape (a).
☐ B. Shape (b).
☐ C. Shapes (a) and (b) are equivalent with respect to conservation of internal heat.
Explain your answer:

Heat exchange between an organism and its environment can occur only through the surface of the organism. Thus, for an organism of a given volume and metabolic rate, the smaller the surface area is, the slower the heat loss also is. The shape that is best optimized for slow heat loss is the sphere, which has the lowest ratio of surface area to volume of any geometric shape. Any deviation from the spherical shape will promote faster heat loss.

3. Which shape is better optimized to promote rapid exchange of diffusible materials (for example, nutrients) between the outside and inside?
☐ A. Shape (a).
☒ B. Shape (b).
☐ C. Shapes (a) and (b) are equivalent with respect to exchange of diffusible materials.
Explain your answer:

Like heat, nutrient exchange between an organism and its environment can occur only through the surface of the organism. Thus, for an organism of a given volume, the larger the surface area is, the faster the rate of solute uptake from the environment also is (assuming that the density of nutrient transporters per unit of surface area is the same).

4. If cell (a) grows larger *while keeping the same shape*, how does the S/V ratio change?
☐ A. As the cell grows larger the S/V ratio increases.
☒ B. As the cell grows larger the S/V ratio decreases.
☐ C. As the cell grows larger the S/V ratio stays the same.

BIO-372 “MICROBIOLOGY” EXERCISES (WEEK 1)

Your Name : ______________________________________ Grade : __________

Your Partner: ______________________________________ Grade : __________

Explain your answer:

As a cell grows larger while maintaining the same shape, the surface area increases as the *square* of the characteristic dimension whereas the volume increases as the *cube* of the characteristic dimension. Thus, as the cell grows larger the volume increases more rapidly than the surface area, resulting in a decrease in the S/V ratio.

For example: referring to the schematic above, the unit cube has an S/V ratio of 6 μm^{-1} while shape (a), which has the same shape as the unit cube, has an S/V ratio of 3 μm^{-1}.

5. If cell (b) “stretches” to get longer and thinner *while keeping the same volume*, how would the S/V ratio change?
☒ A. As the cell stretches the S/V ratio increases.
☐ B. As the cell stretches the S/V ratio decreases.
☐ C. As the cell stretches the S/V ratio stays the same.
Explain your answer:

This point can be illustrated with a “Gedankenexperiment”.

Imagine that we stretch shape (b) to four times its original length while keeping the volume the same (V = 8 μm^3). There are many ways that we could do this but let’s keep things simple: we increase the x dimension of the unit cube to 4 μm while reducing the y and z dimensions of the unit cube to 0.5 μm each. Thus, each unit of the stretched shape measures 4 μm x 0.5 μm x 0.5 μm = 1 μm^3, which is the same volume as the original (unstretched) unit cube.

Original shape: S = 34 μm^2, V = 8 μm^3, and S/V = 4.25 μm^{-1}

Stretched shape: S = 64.5 μm^2, V = 8 μm^3, and S/V = 8.0625 μm^{-1}

Another way to think about this problem is to recall that the sphere is the geometric shape with the smallest S/V ratio for any given volume. Thus, the further a shape deviates from a sphere, the higher its S/V ratio will become. Although I admit that shape (b) in its original (unstretched) form doesn’t look much like a sphere, the stretched shape deviates even further from a sphere.

BIO-372 "MICROBIOLOGY" EXERCISES (WEEK 1)

Your Name : ______________________________________ Grade : __________

Your Partner: ______________________________________ Grade : __________

EXERCISE 2 "LIVING AT MICRO SCALE" :

1. Write the exponential growth equation:

$N = N_0 * e^{kt}$

and define each term below. Do not peek at the slides until you've made your best effort to write everything from memory!

N = the number of cells after an elapsed time (t)
N_0 = the number of cells at time $t = 0$
e = the base of the natural logarithm, equal to approximately 2.7183
k = the instantaneous growth rate constant
t = the time elapsed since the cell culture was initiated
t_d = the doubling time of the cell culture

2. Imagine a cell culture growing exponentially with a doubling time of 2.00 hours. The culture's instantaneous growth rate constant is:

Answer: $k = 0.347\ h^{-1}$

Show your work:

First, we rearrange the exponential growth rate equation to solve for k:

$k = (1/t) * \ln(N/N_0)$

Since we are solving for the situation where $t = t_d$ we can substitute:

$k = (1/t_d) * \ln(N/N_0)$

When $t = t_d$ then $N/N_0 = 2$ by definition, so we can further substitute and solve:

$k = (2.00\ h)^{-1} * \ln(2) = 0.347\ h^{-1}$

3. Imagine a cell culture growing exponentially with a growth rate constant of 1.40 per hour. The culture's doubling time is:

Answer: $t_d = 0.495$ (about 0.5) hours

Show your work:

First, we rearrange the exponential growth rate equation to solve for t:

$t = (1/k) * \ln(N/N_0)$

Since we want to solve for the doubling time we substitute t_d for t:

$t_d = (1/k) * \ln(N/N_0)$

When $t = t_d$ then $N/N_0 = 2$ by definition, so we can further substitute and solve:

Your Name : ____ Grade : __________

Your Partner: ____ Grade : __________

$t_d = (1.40\ h^{-1})^{-1} * ln(2) = 0.495$ or about 0.5 hours

4. Imagine a cell culture growing exponentially with a doubling time of 2.00 hours. Starting from one cell, how long would it take the culture to reach one million cells:

Answer: 39.8 (about 40) hours

Show your work:

First we need to compute the value of the instantaneous growth constant k:

$k = (1/t) * ln(N/N_0)$

Since we are solving for the situation where $t = t_d$ we can substitute:

$k = (1/t_d) * ln(N/N_0)$

When $t = t_d$ then $N/N_0 = 2$ by definition, so we can further substitute and solve:

$k = (2.00\ h)^{-1} * ln(2) = 0.347\ h^{-1}$

Now we know all of the variables that we need for our calculation:
$k = 0.347\ h^{-1}$
$N_0 = 1$
$N = 10^6$

First, we rearrange the exponential growth rate equation to solve for t:

$t = (1/k) * ln(N/N_0)$

Then we substitute and solve:

$t = (0.347\ h^{-1})^{-1} * ln(10^6) = 39.8$ (about 40) hours

5. Imagine a cell culture growing exponentially with a growth rate constant of 1.40 per hour. Starting from one cell, how long would it take the culture to reach one million cells:

Answer: 9.87 (about 10) hours

Show your work:

First, we rearrange the exponential growth rate equation to solve for t:

$t = (1/k) * ln(N/N_0)$

Then we substitute and solve:

$t = (1.40\ h^{-1})^{-1} * ln(10^6) = 9.87$ (about 10) hours

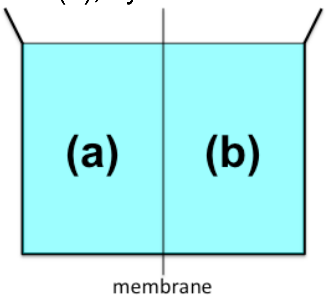
BIO-372 “MICROBIOLOGY” EXERCISES (WEEK 1)

Your Name : ________________________________ Grade : __________

Your Partner: ________________________________ Grade : __________

EXERCISE 3 "LIVING AT MICRO SCALE" :

Imagine a container filled with water and separated into two equal-volume compartments, (a) and (b), by a membrane that is permeable to water but impermeable to solutes.



1. Write the equation for the van’t Hoff relation:

$P = n * R * T * V^{-1}$

and define each term below. Do not peek at the slides until you’ve made your best effort to write everything from memory!

n = Number of moles of solute in excess in one compartment (e.g., intracellular) vs. the other compartment (e.g., extracellular)
P = Pressure in kg * m^{-1} * s^{-2}
R = The universal gas constant: 8.3 J * mol^{-1} * ˚K^{-1} or 8.3 kg * m^2 * s^{-2} * mol^{-1} * ˚K^{-1}
T = Absolute temperature in degrees Kelvin (˚K); remember, ˚K = ˚C + 273
V = Volume in m^3

2. If you add some solute to compartment (a), what happens?
☒ A. The volume of water increases in compartment (a) and decreases in compartment (b).
☐ B. The volume of water increases in compartment (b) and decreases in compartment (a).
☐ C. The volume of water remains the same in both compartments.
Explain your answer:

Adding solute to compartment (a) reduces the concentration of “free” water molecules because some water molecules become “bound” to the solute molecules as a solvation shell. Only “free” (non-bound) water molecules can pass through the semi-permeable membrane. Thus, the water action in compartment (b) will be higher than the water action in compartment (a) and there will be a net flow of water from compartment (b) to compartment (a). Stating the problem in probabilistic terms: if the concentration of “free” water molecules is higher in compartment (b) than compartment (a), then during a defined interval of time there will be more (b)-to-(a) transfer events than (a)-to-(b) transfer events.

3. If you add 0.2 moles (mol) of solute to compartment (a) with a volume (V) of one liter (0.001 m^3) at 27 ˚C (300 ˚K), the resulting osmotic pressure (P) would be:

~ 5 * 10^5 kg * m^{-1} * s^{-2}

Show your work:

n = 0.2 mol
R = 8.3 kg * m^2 * s^{-2} * mol^{-1} * ˚K^{-1}

Your Name : ______________________________ Grade : __________

Your Partner: ______________________________ Grade : __________

$T = 300\ ^{\circ}K$
$V = 1\ \text{liter} = 0.001\ m^3$

$P = n * R * T * V^{-1}$

$= (0.2\ \text{mol}) * (8.3\ kg * m^2 * s^{-2} * mol^{-1} * {}^{\circ}K^{-1}) * (300\ ^{\circ}K) * (0.001\ m^3)^{-1}$

$= 498{,}000\ kg * m^{-1} * s^{-2}$

$\sim 5 * 10^5\ kg * m^{-1} * s^{-2}$

4. Imagine a bacterium surrounded by a rigid (non-elastic) cell wall that is water-permeable. If you put the bacterium in a container filled with pure distilled water:
☒ A. The bacterium's internal turgor pressure increases.
☐ B. The bacterium's internal turgor pressure decreases.
☐ C. The bacterium's internal turgor pressure stays the same.
Explain your answer:

The bacterial cytoplasm contains a large concentration of solutes surrounded by solvation shells (bound water molecules). Thus, if the cell is placed in a container of pure distilled water, then the water action inside the cell is low compared to the water action outside the cell. Consequently, there will be a net transfer of water from outside to inside. Since the cell wall is rigid and cannot expand, this water transfer from outside to inside will continue until the resulting turgor pressure inside the cell is equal and opposite to the osmotic pressure. At this point, water transfer continues but the rate of water transfer into the cell is balanced by the rate of water transfer out of the cell.

5. If you change the shape of a bacterium from sphere-shaped to cube-shaped while maintaining the same size (volume), what happens?
☐ A. The bacterium's internal turgor pressure increases.
☐ B. The bacterium's internal turgor pressure decreases.
☒ C. The bacterium's internal turgor pressure stays the same.
Explain your answer:

If the volume stays the same then the pressure also stays the same. However, the cell wall tension will change: it will increase at the edges and corners of the cube-shaped cell for reasons discussed in my answers to Question 1 (see above). It is true that, if the cell volumes are equal, then the surface area of the cube-shaped cell is larger than the surface area of the sphere-shaped cell. This means that the rate of water transfer across the cell membrane is higher in the cube-shaped cell than the sphere-shaped cell. However, this is true in both directions (into and out of the cell) so the pressure will not change.