Chapter 1

Life

1. (a) The number of cells in 10 L of saturated culture is :

$10\text{ L} \times 10^3\text{ mL/L} \times 10^{10}\text{ cells/mL} = 10^{14}$ cells.

$2^n = 10^{14}$ where n is the number of doublings.

$n = 14/\log 2 = 46.5$

Since each doubling takes 20 min = 1/3 hour,

Time to reach a saturated culture is 46.5/3 = **15.5 hours.**

(b) Volume of an *E. coli* cell $= \pi\rho^2\eta = \pi \times (1 \times 10^{-6}\text{ m}/2)^2 \times 2 \times 10^{-6}\text{ m}$

$= 1.57 \times 10^{-18}\text{ m}^3$

Volume of $1\text{ km}^3 = (10^3\text{ m})^3$ $= 10^9\text{ m}^3$

Number of *E. coli* in 1 km^3 $= 10^9\text{ m}^3/1.57 \times 10^{-18}\text{ m}^3$

$= 6.37 \times 10^{26}$ *E. coli*

$2^n = 6.37 \times 10^{26}$

$n = \log (6.37 \times 10^{26})/\log 2 = 89$ doublings

Time to reach 1 km^3 volume = 89/3 = **29.7 hours**

2. See Figures 1-2 and 1-5. An animal cell possessing mitochondria, peroxisomes, and cilia, in addition to a nucleus, has **four lines of descent.**

3. (a) For an *E. coli* cell:

Surface area of cylinder $= 2\pi rh + 2\pi r^2$

$= 2\pi\,(1 \times 10^{-6}\text{ m}/2) \times 2 \times 10^{-6}\text{ m} + 2\pi\,(1 \times 10^{-6}\text{ m}/2)^2$

$= 7.85 \times 10^{-12}\text{ m}^2$

Volume $= \pi r^2 h = \pi\,(1 \times 10^{-6}\text{ m}/2)^2 \times 2 \times 10^{-6}\text{ m} = 1.57 \times 10^{-18}\text{ m}^3$

Surface-to-volume ratio $= 7.85 \times 10^{-12}\text{ m}^2/1.57 \times 10^{-18}\text{ m}^3 = 5 \times 10^6\text{ m}^{-1}$

For a eukaryotic cell:

Surface area $= 4\pi r^2$

Volume $= \frac{4}{3}\pi r^3$

$$\text{Surface-to-volume ratio} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3} = 3r^{-1}$$

$= 3 \times 2/20 \times 10^{-6}\text{ m} = 3.0 \times 10^5\text{ m}^{-1}$

Thus, the ratio of these two surface-to-volume ratios is

E. coli/eukaryotic $= 5 \times 10^6\text{ m}^{-1}/3.0 \times 10^5\text{ m}^{-1} =$ **17**

Since cells must take in all nutrients through their surfaces, the *E. coli* cell can absorb nutrients 17 times faster per unit volume. Thus, an *E. coli* cell can have a 17 times greater metabolism per unit volume than the eukaryotic cell, all else being equal.

(b) A single microvillus adds the volume

$\pi \times (0.1 \times 10^{-6}\ \text{m}/2)^2 \times 1 \times 10^{-6}\ \text{m} = 7.85 \times 10^{-21}\ \text{m}^3$

and the surface area

$$\pi \times 0.1 \times 10^{-6}\ \text{m} \times 1 \times 10^{-6}\ \text{m} = 3.14 \times 10^{-13}\ \text{m}^2$$

to the brush border cell (the top of the cylinder is not added surface area since the cell has this surface area without the microvilli). The area on the eukaryotic cell that is covered with microvilli is

$$0.20 \times 4\pi \times (20 \times 10^{-6}/2)^2 = 2.5 \times 10^{-10}\ \text{m}^2$$

There is one microvillus per $(0.2 \times 10^{-6}\ \text{m})^2 = 4 \times 10^{-14}\ \text{m}^2$

$$\text{Number of microvilli} = 2.5 \times 10^{-10}\ \text{m}^2/4 \times 10^{-14}\ \text{m}^2 = 6250$$

Volume of cell with microvilli

$$= \frac{4}{3}\pi \times (20 \times 10^{-6}\ \text{m}/2)^3 + 6250 \times 7.85 \times 10^{-21}\ \text{m}^3$$

$$= 4.19 \times 10^{-15}\ \text{m}^3 + 4.91 \times 10^{-17}\ \text{m}^3 = 4.23 \times 10^{-15}\ \text{m}^3$$

Area of the brush border cell

$$= 4\pi \times (20 \times 10^{-6}\ \text{m}/2)^2 + 6250 \times 3.14 \times 10^{-13}\ \text{m}^2$$

$$= 1.26 \times 10^{-9}\ \text{m}^2 + 1.96 \times 10^{-9}\ \text{m}^2 = 3.16 \times 10^{-9}\ \text{m}^2$$

Surface-to-volume ratio of cell with microvilli

$$= 3.16 \times 10^{-9}\ \text{m}^2/4.23 \times 10^{-15}\ \text{m}^3$$

$$= 7.47 \times 10^{5}\ \text{m}^{-1}$$

Thus, the microvilli have increased the surface-to-volume ratio of the brush border cell by a factor of $7.47 \times 10^5/3.0 \times 10^5 =$ **2.49.**

4. (a) Volume of *E. coli* cell $= \pi\ (1 \times 10^{-6}\ \text{m}/2) \times 2 \times 10^{-6}\ \text{m} \times 10^3\ \text{L·m}^{-3} = 1.57 \times 10^{-15}\ \text{L}$

Number of moles of the protein in an *E. coli*

$$= 2\ \text{molecules}/6.02 \times 10^{23}\ \text{molecules·mol}^{-1} = 3.32 \times 10^{-24}\ \text{mol}$$

Concentration of the protein $= 3.32 \times 10^{-24}\ \text{mol}\ /1.57 \times 10^{-15}\ \text{L} =$ $\mathbf{2.11 \times 10^{-9}}\boldsymbol{M}$

(b) 1 m*M* concentration contains $6.02 \times 10^{23} \times 10^{-3}$ molecules·L^{-1}

$= 6.02 \times 10^{20}$ molecules·L^{-1}

Number of molecules in an *E. coli* cell

$= 1.57 \times 10^{-15}$ L $\times 6.02 \times 10^{20}$ molecules·L^{-1}

= **9.45×10^5 molecules of glucose**

5. (a) Volume of *E. coli* cell $= \pi \times (1 \times 10^{-6}/2)^2 \times 2 \times 10^{-6}$ m^3 $= 1.57 \times 10^{-18}$ m^3

Volume of DNA

$= \pi \times (20$ Å $\times 10^{-10}$ m·Å$^{-1}/2)^2 \times 1.6$ mm $\times 10^{-3}$ m/mm $= 5.03 \times 10^{-21}$ m^3

Fraction of volume of an *E. coli* cell occupied by DNA

$= 5.03 \times 10^{-21}$ m$^3/1.57 \times 10^{-18}$ = **3.20×10^{-3}**

(b) Volume of human cell $= \frac{4}{3}\pi \times (20 \times 10^{-6}/2)^3$ m^3 $= 4.19 \times 10^{-15}$ m^3

Volume of human DNA

$= 700 \times$ volume of *E. coli* DNA $= 700 \times 5.03 \times 10^{-21}$ m^3

$= 3.52 \times 10^{-18}$ m^3

Fraction of volume of human cell occupied by DNA

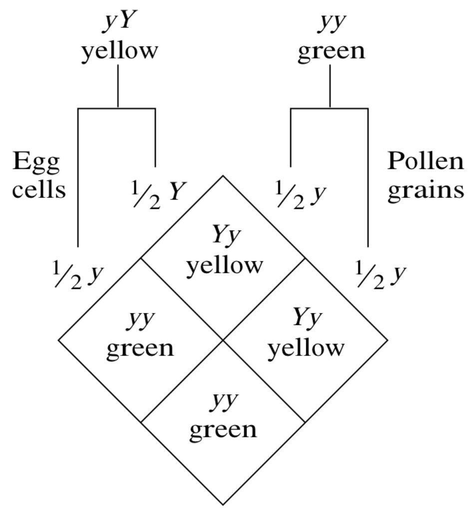
$= 3.52 \times 10^{-18}$ m$^3/4.19 \times 10^{-15}$ m^3 = **8.40×10^{-4}**

6. Since it is likely that any life forms on the planet will be microscopic, they will have to be detected by chemical means. Such life forms may not have macromolecules that resemble those of terrestrial life forms but they will most probably have some sort of a carbon based metabolism. Thus, if the life forms were supplied with radioactively labeled nutrients, their ability to incorporate the label into new compounds would indicate their existence. [Such experiments were carried out on Mars by the Viking landers in 1976. The results were negative. See Horowitz, H.N., The Search for Life on Mars, *Sci. Am.* **237**(5): 52-61 (1977).]

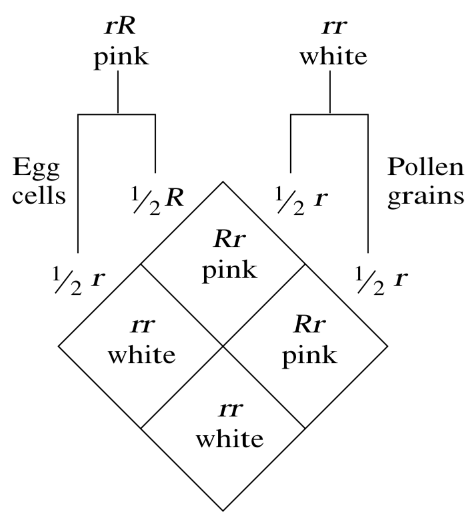
7. With the earth so cold and dark, those eukaryotic species unable to withstand the cold, particularly those from the tropics, would rapidly die out. As time passed, surviving plants would be unable to photosynthesize so that they and the other

surviving eukaryotes would eventually starve. Once the nuclear winter had passed, the destruction of almost all ecosystems would further aid in the demise of eukaryotes. Although prokaryotes would also be badly affected by a nuclear winter, their capacity to remain dormant and even frozen for nearly indefinite time periods would help them survive this difficult period. Their ability to live in environments hostile to eukaryotes together with their ability to rapidly adapt to new environments would further aid their survival after the nuclear winter.

8. The testcross for peas involves a cross between the F_1 heterozygote *Yy* and the parent that is homozygous for the recessive trait *yy*.



Half the progeny of this testcross will be green (*yy*) and half will be yellow (*Yy*). For snapdragons, in which *r* and *R* are codominant, this would be, using the white parent in the testcross:



which yields progeny half of which are pink (*Rr*) and half of which are white (*rr*).

9. **The father of child 1 is male 1** because any child of male 2, being N (L^NL^N genotype), would have to be either MN or N in phenotype, whereas male 1, being MN (L^ML^N genotype) could have a type M child with a type M mother.

   The father of child 2 could be either male 1 or male 2 according to the data given since either male could have children of the blood type given with the mother.

   The father of child 3 is male 2 because male 2, having type AB (I^AI^B genotype), could have a type AB child with the type B mother (I^BI^B or I^Bi genotype) whereas male 1, who is also type B, could only have a type B or possibly type O child with the mother.

10. The color blind allele is sex-linked; that is, it is carried on the X chromosome. Thus , the children would have the genotypes:

    XX (mother) × $X^{CB}Y$ (father) (X^{CB} contains the color blind allele)

    ↓

    XX^{CB} daughter (carrier) + XX^{CB} daughter (carrier) + XY son + XY son

    None of the sons but all of the daughters will receive the color blind allele. The daughters with the color blind allele will be phenotypically normal because the color blind trait is recessive. However, they are "carriers" of the allele.

    For the second generation, only the offspring of the carrier need be considered:

    XX^{CB} (carrier) × XY (normal male)

    ↓

    XX daughter + $X^{CB}X$ daughter (carrier) + XY son + $X^{CB}Y$ son (color blind)

    Thus, half the daughters of the carrier will also be carriers and half the sons will be color blind.

11. The purple and green photosynthetic bacteria are obligate anaerobes that require the presence of CO_2 and H_2S to carry out photosynthesis. It is therefore likely that these compounds, but not O_2, were abundant in the earth's atmosphere when these organisms first arose.