Section 4.6 – Applications and Models

Background of E. coli

The GI tract of most warm-blooded animals is colonized by *E. coli* within a few hours or days after birth by the bacterium ingested in foods or water or directly from other individuals. The human bowel is usually colonized within 40 hours of birth. *E. coli* can adhere to the mucus overlying the large intestine. Once established, an *E. coli* strain may persist for months or years. Resident strains shift over a long period (weeks to months), and more rapidly after enteric infection or antimicrobial chemotherapy that perturbs the normal flora. The basis for these shifts and the ecology of *Escherichia coli* in the intestine of humans are poorly understood despite the vast amount of information on almost every other aspect of the organism's existence. In fact, the entire DNA base sequence of the *E. coli* genome is known.

*E. coli* is the head of the large bacterial family, Enterobacteriaceae, the enteric bacteria, which are facultatively anaerobic Gram-negative rods that live in the intestinal tracts of animals in health and disease. The Enterobacteriaceae are among the most important bacteria medically. A number of genera within the family are human intestinal pathogens (e.g. *Salmonella*, *Shigella*, *Yersinia*). Several others are normal colonists of the human gastrointestinal tract (e.g. *Escherichia*, *Enterobacter*, *Klebsiella*), but these bacteria, as well, may be associated with diseases of humans.

Physiologically, *E. coli* is versatile and well-adapted to its characteristic habitats. It can grow in media with glucose as the sole organic constituent. Wild-type *E. coli* has no growth factor requirements, and metabolically it can transform glucose into all of the macromolecular components that make up the cell. The bacterium can grow in the presence or absence of O2. Under anaerobic conditions it will grow by means of fermentation, producing characteristic "mixed acids and gas" as end products. However, it can also grow by means of anaerobic respiration, since it is able to utilize NO3, NO2 or fumarate as final electron acceptors for respiratory electron transport processes. In part, this adapts *E. coli* to its intestinal (anaerobic) and its extraintestinal (aerobic or anaerobic) habitats.

*E. coli* can respond to environmental signals such as chemicals, pH, temperature, osmolarity, etc., in a number of very remarkable ways considering it is a single-celled organism. For example, it can sense the presence or absence of chemicals and gases in its environment and swim towards or away from them. Or it can stop swimming and grow fimbriae that will specifically attach it to a cell or surface receptor. In response to change in temperature and osmolarity it can vary the pore diameter of its outer membrane porins to accommodate larger molecules (nutrients) or to exclude inhibitory substances. With its complex mechanisms for regulation of metabolism the bacterium can survey the chemical contents its environment in advance of synthesizing any enzymes necessary to use these compounds. It does not wastefully produce enzymes for degradation of carbon sources unless they are available, and it does not produce enzymes for synthesis of metabolites if they are available as nutrients in the environment.

*E. coli* is a consistent inhabitant of the human intestinal tract, and it is the predominant facultative organism in the human GI tract; however, it makes up a very small proportion of the total bacterial content. The number of anaerobic Bacteroides in the bowel outnumber *E. coli* by at least 20:1. The regular presence of *E. coli* in the human intestine and feces has led to tracking the bacterium in nature as an indicator of fecal pollution and water contamination. As such, it is taken to mean that, wherever *E. coli* is found, there may be fecal contamination by intestinal parasites of humans.

Over 700 antigenic types or serotypes of *E. coli* have been recognized based on O, H, and K antigens. Serotyping is important in distinguishing the small number of strains that actually cause disease. *E. coli* is responsible for three types of infections in humans: urinary tract infections (UTI), neonatal meningitis, and intestinal diseases (gastroenteritis). These three diseases depend on a specific array of pathogenic (virulence) determinants.

Source: http://www.bact.wisc.edu/Bact330/lectureecoli
So, what does this have to do with me?

The rare strain of *E. coli* that gets a lot of "press" is indeed a bad bug, it's *E. coli* O157:H7, a member of the EHEC - enterohemorrhagic *E. coli* group. Enterohemorrhagic means an intestinally-related (here we are at the Greek word *enterikos* again) organism which causes hemorrhaging - and therefore, loss of blood.

Unless there is a cut in the meat, the meat below the surface is normally sterile (unless there is some intracellular organism present). However, whether or not some intracellular bug is around, the outside surfaces of all meat will have bacteria present - so - if some meat happens to be contaminated with the rare *E. coli* strain, O157:H7, it will be on the surface of the meat, and not down inside the fibers of the meat. However, as soon as the meat is cut with a knife or punctured with a fork, the knife blade or fork tine will carry the bacterial cells down into the cut or puncture - usually, such a situation is relatively safe because we cook the meat - certainly we cook the surface of the meat. Remember though, bacteria are _really_ small, so even a tiny, pretty much invisible cut in the meat could introduce bacteria down inside. In the case of *E. coli* O157:H7, the total number of bacteria required for infection appears to be about 10 - that's right, only 10 bacterial cells! Therefore, it is always safest to cook all meat at least until the juices of the meat run absolutely clear - not pink - clear.

Now, if the meat is ground (we call it hamburger if it's ground beef) we have a much more risky situation because any bacterial cells originally only on the surface of the meat, will now be distributed throughout the preparation. It is very important in this case to thoroughly cook the meat - until the juices run absolutely clear. Actually, the latest recommendation is that each hamburger pattie must reach an internal temperature of 160 degrees F. Apparently, viable (living) *E. coli* have been isolated from hamburger meat cooked to the point of "juices running clear". This procedure is very similar to that one would use to cook pork or perhaps a Thanksgiving turkey, e.g., observe the internal temperature of the meat before it is served.

Just remember, if you like your meat and especially hamburgers, "rare", you are taking a significant risk. It is also important to realize that meat may not be the only source of contamination with such bacteria or other dangerous bacteria - any contaminated water source or contaminated person can load these bacteria onto vegetables, etc. So, it is a good idea to be careful with everything - wash fresh fruit, vegetables, etc., _thoroughly_ before eating. This last statement is very important, since as mentioned above, recent cases of O157:H7 infection have been found associated with non-pasteurized apple juice. This organism is apparently spreading around and about. So, it is important to be vigilant and aware.

Source:  http://falcon.cc.ukans.edu/~jbrown/ecoli.html

The generation time, which varies among bacteria, is controlled by many environmental conditions and by the nature of the bacterial species. The composition of the growth medium is a major factor controlling the growth rate. The growth rate increases up to a maximum when the medium provides a better energy source and more of the biosynthetic intermediates that the cell would otherwise have to make for itself. *E. coli* can double every 20 minutes.

Source:  http://www.britannica.com/bcom/eb/article/1/0,5716,119291+12+110416,00.html

Questions:

− While cooking dinner you place uncooked chicken infected with E coli on your counter. After removing the chicken to cook it, one cell remains. Find an equation for the number of cells, \( Y \), at any time, \( t \).

− How long until enough cells are present to make someone sick?

− If you don’t clean it adequately, and leave it until just before bed to clean (4 ½ hours later), how many cells are present?

− If your cleaning product kills 99.9% of E coli bacteria cells and you clean at the time mentioned in number 3, can you still get sick? How many cells would be left after cleaning?
Half Life and Doubling Time:

- Recall: So \( b \) is the base value in the equation \( y(t) = k b^t \), and \( r \) is the rate of growth (or decay) in the equation \( y(t) = P_0 e^{k t} \). Here \( k \) is called the exponential growth rate. Be careful of the difference between this \( k \) and the plain growth rate \( (r) \) given above.

- We can also talk about the exponential form of the equation as \( y(t) = P_0 e^{k t} \). Here \( k \) is called the exponential growth rate.

- **Half life** is the amount of time it takes for a substance to decay to half of its original quantity. It represents exponential decay. The half life and decay rate are obviously related:
  \[
  T = \frac{\ln(0.5)}{\ln b} \quad \text{or} \quad b = \left( \frac{1}{2} \right)^{1/T}
  \]

- **Doubling time** is the amount of time it takes for a substance to double its original quantity. It represents exponential growth. The doubling time and growth rate are obviously related:
  \[
  T = \frac{\ln(2)}{\ln b} \quad \text{or} \quad b = 2^{1/T}
  \]

- **Example. see book (ver.2 page 399 number 2 / ver.3 page 419 number 2)**
  
  Exponential growth rate is 11.7%, so \( k = 0.117 \).
  
  The initial population, \( P_0 \), is 100 rabbits.
  
  So the equation is \( y(t) = 100 e^{0.117 t} \).
  
  After 7 days, \( y(7) = 100 e^{0.117(7)} = 226.82 \) or 227 rabbits.
  
  After 2 weeks (14 days), \( y(14) = 100 e^{0.117(14)} \approx 514 \) rabbits.

  Doubling time:
  \[
  200 = 100 (e^{0.117})^T \]
  \[
  \ln 2 = T \ln e^{0.117} \]
  \[
  T = \frac{\ln 2}{0.117} \approx 5.9 \text{ days}
  \]