Microbes in Food
By Dennis Focht

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Dedication
This book is dedicated to Douglas and Lillian Focht, who instilled in their children the importance of knowledge and education.
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The inspiration for writing this book was long in coming, and I have literally hundreds of students to thank for putting (what was once) my lecture notes together in book form. The impetus for teaching a course in food microbiology came about more than a dozen years ago when several faculty members from many different departments on our campus put together an interdepartmental graduate program in microbiology. As UCR was in a rapid period of growth, we also took up the task of undergraduate instruction. At that time, the only microbiology courses offered were the introductory lecture and the laboratory. One of the organizers thought that a course in food microbiology would be very popular and relevant, to which we all agreed, but which to my astonishment, caused all eyes to be directed toward me. When I protested that it had been 30 years since I had a course in food microbiology, they all looked at each other and shook their heads, and confessed that I was unique among the group. From that time on, I have been the resident campus expert in food microbiology.

My research and interest has been in the field of bacterial metabolism and ecology, and so I have taken that approach in presenting “the microbe’s point of view” as it relates to his/her environment. Nevertheless, I have borrowed heavily from others in using material for presenting this viewpoint. One year before I was scheduled to teach the course, the edited book *Food Microbiology Fundamentals and Frontiers* by Michael Doyle, Larry Beuchat, and Thomas Montville was published by the ASM (American Society for Microbiology). This was a godsend, as a reference book, and provided much of the supporting data for important concepts to teach students. A newer edition has since come out, but there are some things that are timeless and will always be relevant.

*Microbes in Food* is organized in three sections. The first seven chapters in section I focus on the growth and inhibition of microorganisms. Section II (chapters 8–15) is about how microorganisms are used in food production and changes they bring about in food spoilage. Section III (chapters 16–25) deals with the nature of foodborne pathogens, disease symptoms, detection methods, risk assessment, and food safety regulations. Problem sets are given at the end of each section. This gives the student practice in answering questions for material that the instructor might give on a mid-term exam covering about 7 to 9 lectures.

I am grateful to the many students who anonymously provided me with encouraging end-of-course evaluations occasionally sprinkling the suggestions that “you should put your notes together and write a book.” Zhen Chen, who has been my teaching assistant for the last two years, provided the final encouragement, and told me not to change my unorthodox style in
light of student comments. I have always had a fond interest in history, and I have observed that students, contrary to popular misconceptions about young people, also do, particularly if it is tied to scientific relevance.

Finally, my wife Brenda proofread many drafts and made useful comments. Writing a book is a lot like woodworking. Construction of the project is a challenge and an enjoyment. It is the final, nitty-gritty aspects that are not as enjoyable, so her assistance in that part was quite helpful.
SECTION I

Growth, Physiology, and Ecology of Foodborne Microorganisms
INTRODUCTION

You have to eat, and what you eat, is your choice. Therefore, what you learn from this book, should be useful for the rest of your life, in evaluating when you may or may not encounter risks. For example, when you are invited to a friend’s home for dinner, and offered home canned carrots, do you just accept them, or do you politely ask how they were canned? If you are told thinat they were sterilized by boiling, do you accept that as being safe? If on the other hand, your host offers you some home-made raspberry jam, canned the same way, why would you accept it without further question? Or if you were on a picnic and used your pocket knife to cut up chicken to barbecue, wiped it clean with a handkerchief, and used it to slice an orange, would you be concerned about food poisoning from Salmonella?

Foods of 30 years ago that were not likely sources of pathogens, now turn up more frequently with what is referred to as “emerging pathogens.” A few noteworthy examples are hamburger, and the presence of Escherichia coli O157, a true (genetic basis) emerging pathogen, Listeria monocytogenes, and C. jejuni, two emerging pathogens caused by the centralization of food processing and demographic changes. These examples will be addressed in the last chapters of the book, with the intended purpose of making good judgments about food safety.

The globalization of world markets has also contributed to the introduction of pathogens that had been eliminated from the US food supply 50 years ago (e.g. helminth infections) because many of the LDCs (less developed countries) lack proper sanitation laws or don’t enforce the laws that they have. Because of proportionally lower transportation costs and greater demand for varied menus, food is no longer seasonal: it can literally be flown from anywhere in the world. Seedless grapes from Chile are a case in point: they have become very popular during the winter season in the northern hemisphere. Such a marketing strategy 30 years ago was limited: e.g. for $100 you might want to send a bunch of grapes to a good friend or family member during the Holiday Season. Now, it is fait accompli.

EARLY DEVELOPMENTS IN FOOD PRESERVATION AND SAFETY

According to Hartman (34), food spoilage and food poisoning were problems that must have continually plagued the human race. Imagine the predicament of Neanderthal or Cro-Magnon people 50,000 years ago after slaughtering a woolly mammoth and having a ton of meat to consume and make last until the next hunt.
During the end of the last Ice Age, nomadic populations of hunters and gatherers in the warm and fertile river basins of the Nile (Egypt), the Tigris and Euphrates (Iraq), the Indus (India), and the Yalu (China) turned to agriculture. Using carbon dating, the oldest known beginning of agriculture began near the Aswan Dam in Egypt about 17,000–19,000 BP (before present). Subsequently, methods for preserving and storing grain were developed.

By 7,000 BP, stable societies had developed in Egypt and Iraq. It was recognized that naturally dried grains from the harvest could be preserved indefinitely in the arid climate. Hieroglyphics of the time also depict the making of beer. Anthropologists and food scientists agree that the preservation of cereal grains by either drying or by fermentation represent the two oldest known methods of food preservation.

Salt was also recognized as an important food preservative. The salt of the Dead Sea was one reason for the Roman conquest of Palestine. The Romans paid their soldiers in salt. The old adage of “a man worth his salt,” or being “the salt of the earth,” comes from the importance of salt in the preservation of food. Salt made it feasible to feed a large army on the move.

For thousands of years, people recognized that diseases could be spread by foods. Pork, for example, is a potentially dangerous meat in a hot climate that harbors helminth pathogens (e.g. Trichinella), yet is less risky in cooler temperate climates. Although people must have known of the risks, religious laws in the Jewish (and later Hindu) faith, did not come about until the middle of the first millennium BC. Many of the religious edicts today would be viewed as good public health practices in food safety: namely, don’t eat spoiled rice, and don’t eat from plates that have been licked by pets.

In 900 AD, Leo VI of Byzantium issued the first non-sectarian food safety law, which forbade eating and manufacture of blood sausage. He was so severe about this that he fined the chief magistrate 10 lb. of gold. That would be 120 troy ounces, which at a market price of $1,000/oz would be over $100,000. It would not be until a thousand years later that the cause of this mysterious disease, botulism, would be discovered.

The oldest written food law, still in existence, is the German Rhineheitsgebot (German Purity Law) that was established in Bavaria in 1516. This law, still practiced in Germany, regulates the ingredients that are allowed in brewing beer.

Poisoning by spoiled grains (ergotism, caused by the mold Claviceps purpurea) was recognized by the Greeks and Romans and was widespread throughout the Middle Ages in Europe. The last reported case in the US was in 1825. Control was effected by discarding contaminated grains, and instituting better methods to assure thorough drying to prevent germination of mold spores.

In 1835, J. Paget made the first documented microscopic observation of food poisoning with Trichonella in infected meat. Yet, bacterial agents of decay went largely unrecognized for another 20 years until the work of Louis Pasteur.

**THE ADVENT OF THERMAL PROCESSING**

Recall earlier the importance of salt in feeding a large Roman Army on the move. It can not be overstressed that military demands led to the development of many novel food preservation methods. Napoleon said that “An army travels on its stomach.” The French government recognized this in
1795, when they offered a substantial award for a new preservation method. Nicholas Appert won the prize in 1805 for development of wide mouth bottles filled with food, which were corked, and heated in boiling water. At the insistence of the Emperor Napoleon, Appert published his work in 1810, the same year that an Englishman, Peter Durand, patented the use of tin cans for thermally processed food. The historical irony to this important development in modern warfare came about five years later with Napoleon’s defeat by the British army at Waterloo.

In 1860, I. Solomon, a Baltimore canner, developed a simple, but ingenious, way to reduce heating time from 6 hours to 25–40 minutes by adding CaCl₂ to water, which raised the boiling point to 116°C. This temperature and heating time, destroys spores of Clostridium, and hence the risk of botulism, though it was unknown then why this method removed this risk. Canned fruits and vegetables were part of a soldier’s rations, to both armies, during the ensuing American Civil War.

R. Chevalier-Appert, in 1853, was issued a patent for development of the first autoclave, yet it was not until twenty years later that the apparatus was used commercially. This device today is the standard procedure for effecting complete sterilization. (Note that the development of the autoclave preceded Solomon’s procedure yet was unknown or unaccepted in the US). Chevalier-Appert reasoned that heat destroyed the agents of putrefaction and fermentable principles, yet he had no idea what these agents were. Though Solomon and Chevalier-Appert understood the physics of how their inventions produced greater heat, their motivations were strictly commercial, namely to process as many cans of safe food in the shortest amount of time as possible. To put things in perspective, a worker in 1810 could produce 4 cans per day: manufacturers today turn out 400 cans per minute.

Louis Pasteur was the first to establish that microorganisms were the cause of food poisoning. He is therefore recognized as the founder of food microbiology. His process of pasteurization was first developed for destroying undesirable microorganisms in wine. It was later used in the UK and followed by the US to destroy pathogens in milk.

**EARLY MODERN DEVELOPMENTS IN FOOD SAFETY**

Britain was the first nation to make use of the new scientific discoveries on the nature of food spoilage by passing the British Food and Drugs Act in 1860. It took the US another 30 years to pass basically the same law in 1890, though it was poorly enforced. Both of these laws required the inspection of meat for sale. The establishment of the FDA (Food and Drug Agency) in the US in 1906 was the major law for protecting the public from unsafe foods. This legislation was passed the same year that Upton Sinclair wrote his classic novel *The Jungle*, which described the deplorable sanitary conditions that existed in the nation’s largest meatpacking houses in Chicago (59). Conditions were so abominable that most European countries banned the importation of US meat for sale. Very recently, public furor has arisen over the safety of the nation’s food supply, following the *Salmonella* outbreak in peanut butter cookies. This has involved legislative hearings and plans to reorganize the FDA and the USDA (US Department of Agriculture) as covered in the last two chapters of the book.

The US Pasteurized Milk Ordinance in 1924 specified not only the time and temperature, but also that the process must be conducted in approved equipment. This law was the
culmination of 100 years of experimental development. In 1824, William Dewees recom-
mended heating milk to the boiling point to increase shelf life. Gail Borden, a Texas inventor,
received a patent in 1853 for a combined process involving the condensation of milk under
vacuum at 50° to 60° C in the presence of added sugar. (Perhaps the name of the inventor and
the product are familiar items that you have seen on the supermarket shelf). Since milk has
been routinely pasteurized in the US, tuberculosis (caused by *Mycobacterium tuberculosis*)
and brucellosis (caused by *Brucella abortus*) have been eliminated as food pathogens and were not
covered by Doyle et al (21) a dozen years ago. Likewise, they will not be covered here.

**SUMMARY —**

**Emerging pathogens:**
- Centralization of food markets in the US has introduced new problems relating to food
  safety because of changes in demographics and concentration of potential pathogens
during processing.
- Lack of proper sanitary regulations in foreign countries, from which food has been
  imported, has reintroduced pathogens that had been eliminated from North American
  foods 50 years ago.

**Food preservation:**
- Earliest developments in food safety can be traced to domestication of grains.
- Fermentation (beer) is one of the two earliest known methods of food preservation.
- Drying of grains is the other old method of food preservation.
- Salt became the most important means of preservation of meat and perishable items
during Roman times.
- Thermal processing was first established by Nicholas Appert in 1805 by boiling sealed
  jars of food.
- Military needs drove the use and invention of two preservative methods: salt (Romans),
  heat (Napoleonic wars).
- The advent of high temperature steaming (autoclave) was inspired **not** by knowledge of
  spores or microorganisms, but the profit motive to process more food in a shorter time.
- Pasteur is recognized as the founder of food microbiology because he was the first to
  establish the foundation of food spoilage and fermentation being directly caused by
  growth of microorganisms in 1855.
- Invention of the autoclave: Chevalier-Appert in 1853.

**Food safety laws:**
- Establishment of religious laws (e.g. banning of pork) in the 2nd millennium B.C.
• First governmental law on food safety: 900 A.D. by Leo VI Byzantium Emperor, who banned blood sausage (cause of botulism).

• The oldest existing Food Law is the German Purity Law governing the production of beer in 1516.

• British Food and Drugs Act (1860) regulating inspection of meat for sale.

• Establishment of the US Food and Drug Administration (FDA) in 1906.

• US Pasteurized Milk Ordinance (1924) effectively eliminated tuberculosis and brucellosis as common food pathogens from dairy products.

Important point:
All laws and practices regarding food safety prior to Louis Pasteur, were devoid of any knowledge of microorganisms.
The beginning part of the bacterial growth curve is important in food spoilage, while the ending part of the growth curve is important in food production and fermentation. This is because spoilage is undesirable, and every effort is made to ensure that microbial numbers are kept to the lowest possible number that ensures no risk to quality or health. On the other hand, fermentation is desirable to achieve a finished product rapidly: hence, the higher the numbers, the higher the production rate of the desired product. There are three words, in the anachronism ITT (inoculation, time, and temperature) that characterize the growth of microorganisms and their relevance to food quality and safety. Eliminating the introduction (inoculation) of pathogens is desirable, but frequently unachievable. The other two determine how fast the microorganism will grow in the medium, and hence the risk to a consumer, or the desirability to a food producer (cheese, wine, beer).

### Kinetics of Exponential Growth

If any given bacterium were totally predictable, there would not be the plethora of mathematical models to describe the process. Rather than attempt to discuss and evaluate all the models and their shortcomings, this treatise is designed to help you understand how fast bacteria can grow, and to grasp some fundamental concepts of what we can predict with accuracy, and what we must rely on empirically. Bacteria divide by binary fission, and as long as they are actively dividing, their growth is, indeed very predictable. It is when they are not dividing that they cause problems in predicting their increases in numbers. For now, let us consider an actively growing population of cells $N$ below.

\[
\frac{dN}{dt} = \mu N
\]  

(1)

This is characteristic of a classic first-order reaction described in chemistry textbooks. The equation above says that the change in cell density $N$ over the same interval of time $t$ is equal to the product of the cell density and the rate constant.

Perhaps you may recall from calculus and algebra that

\[
\frac{dN}{N} = d(\log N)
\]  

(2)
Thus, equation 1 can be rewritten to give

\[
\frac{d(\log N)}{dt} = \mu
\]  

(3)

If you are wondering what intrinsic meaning this bizarre rate constant (\(\mu\) in units of reciprocal time), you are paying attention. We shall do what Jaques Monod suggested in 1941 when he published his PhD thesis on the kinetics of bacterial growth. Monod suggested that kinetic constants should be expressed in a binary system, because that is the way cells divide. Thus, the rate term from equation 4 can be converted below to doubling time \(t_d\): i.e. the time it takes for one cell division.

\[
\mu = \frac{\log 2}{t_d}
\]  

(4)

Before leaving this painful treatise in kinetics, clarification of how one can use these equations for calculating the growth of bacteria needs to be considered. Equation 3 can be solved by substitution from 4 and integration of both sides below using \(t_d\) (real time) instead of \(\mu\) as the rate constant (\(t_o = 0\)).

\[
\frac{N}{N_o} = \int d(\log N) = \int \frac{dt}{t_d}
\]  

(5)

To give

\[
N = N_o 2^{t/t_d}
\]  

(6)

where \(N_o\) is the initial cell density at the beginning of the exponential growth phase.

Let’s try an easy example. Given an initial cell density of 1.5 * 10^6 cells/ml, and a doubling time of 45 minutes, what would be the cell density after 4 hours? In this case, \(N_o = 1.5 * 10^6\) cells/ml, \(t_d = 0.75\) hr, and \(t = 4\) hr. If your calculator is working, the answer should be 6.0 * 10^7 cells/ml.

The next one is a little more difficult. How long will it take for a cell density of 2.0 * 10^9 cells/ml to be achieved from an initial density of 4.0 * 10^7 if the culture has a doubling time of 35 minutes? We have to modify equation 6, because today’s calculator is only half way there: it does exponents to any base, but not logarithms.

\[
t = \frac{(t_d) \log (N/N_o)}{\log 2}
\]  

(7)

And, the correct answer is 3.3 hr.
THE LAG PHASE

We have now shown that bacterial growth is exponential. However, inoculation of media with a cell suspension does not ensure that the culture will immediately start dividing. In fact, the lag period, a time interval in which cell division does not occur, is generally the rule. There is no single mechanism that explains or characterizes this phase, but it is known that this period is characterized by *de novo* (new) enzyme synthesis in order for the cell to adapt to its new environment. When cells are removed from the exponential growth phase and immediately transferred into media having the same identical composition and environmental characteristics (e.g. temperature, aeration, pH), there is no lag phase. Thus, the major constraints on rapid transition to exponential growth are as follows.

**Age of culture**

The older the culture, the longer the lag phase. Although much of this is due to a larger fraction of dead cells, older cultures tend to exhibit a non-culturable tendency: i.e., although they are viable, not all cells are readily able to divide and grow.

**Growth substrates**

Cultures transferred from rich media to poorer media will always exhibit a lag, but not the other way around. Cultures grown on defined media, which have to synthesize all vitamins, amino acids, etc. from inorganic N, P, and S, have no trouble shifting to a richer complex medium having all the ingredients that they are accustomed to making. When grown on rich media and then shifted to defined media, the lag period represents the synthesis of enzymes needed to make the vitamins and amino acids that were previously available in the medium.

**Environmental factors**

New enzymes may need to be synthesized to acclimatize the culture to different conditions. For example, facultative anaerobes need to gear up for differences in thermodynamic requirements from aerobic to anaerobic metabolism. The Pasteur Effect is one of nature’s metabolic marvels: despite the much lower energy yield through fermentation (substrate level phosphorylation), many facultative anaerobes (*Saccharomyces cerevisiae*, *Escherichia coli*), have the same doubling times when grown aerobically (oxidative, respiratory phosphorylation) or anaerobically (substrate level phosphorylation).

Finally, the discussion of a lag phase would be incomplete without showing why one does not construct bacterial growth curves using a linear scale. The second curve on the right hand side of Figure 2.1 contains the same data set, yet is plotted incorrectly. The most dramatic effect is the observation of a long false lag period. This would have catastrophic effects if it were used in determining the time in which food spoilage became significant. Moreover, linearized treatment of bacterial growth curves is neither conceptually correct, nor useful.

The bacterial growth curve (Figure 2.1) is applicable also to non-filamentous fungi, such as yeasts (e.g. *Saccharomyces*). The only difference here is that because of the larger size of eucaryotes, the numbers on the axis would be about 1 to 2 orders of magnitude less.
THE STATIONARY PHASE

This aspect of bacterial growth is important with those organisms that undergo profound metabolic and morphological changes, such as spore-forming bacteria. The idea that stationary growth occurs because of crowding or lack of resources is irrelevant to microorganisms for two reasons. First, substrates are never limited in the rich media that most microorganisms are grown on. Second, anyone who has observed colonies on petri plates will recognize that cells literally grow on top and around one another, and only in this case is there no more room to grow. Cell densities on agar plates are generally two orders of magnitude higher than what can be achieved in liquid cultures.

Oxygen deprivation and product inhibition are generally recognized as the two most important factors that cause cessation of exponential growth, particularly in liquid culture and in foods.

TEMPERATURE

Different microorganisms have distinct requirements as to the temperature at which they will grow. The best growth takes place within a range of their optimum temperature.
Most mesophilic microorganisms, including all eucaryotes, grow between 10°C and 40°C. Thermophilic growth, confined solely to prokaryotes, is defined as that occurring above 55°C. Psychrophilic growth, confined solely to prokaryotes isolated from Antarctica will not grow above 20°C. We will not be concerned with psychrophiles, but rather with psychrotrophs, which are mesophilic microorganisms that grow faster than other mesophiles at refrigeration temperatures below 10°C. This is an important aspect of food spoilage.

The influence of temperature on growth is related to the enzymatic actions of the cell. You may recall Arhenius kinetics from biochemistry class. We will deal with a more simple and relevant way of expressing this in direct units of temperature (°C instead of reciprocal °K) and activity. As the temperature is lowered, the enzyme activity, and thus the growth of the cell, is slowed. At the freezing point, metabolic activity ceases because of the direct retardation of enzyme activity and because the cell is deprived of water, which is essential for the uptake of nutrients as well as the removal of waste products. As temperature is raised above that for optimal growth, metabolic activity markedly increases, but at the same time, the rate of enzyme and protein breakdown (due to protein denaturation) markedly increases, resulting in damage and death of the cell.

There are two important comparisons shown in Figure 2.2.

1. The effect of temperature (the slope) is more pronounced upon *E. coli* than the psychrotroph.
2. Growth of *E. coli* ceases below 8°C, while the curve is still linear with the psychrotroph, to near freezing temperature.

What this shows, in practical terms, is that refrigeration is quite effective in inhibiting growth of *E. coli* and, by analogy, other enteric bacteria, such as *Salmonella*. It also clearly illustrates how much faster enteric bacteria grow in the absence of refrigeration. The other point is that refrigeration is much less effective in halting the growth of psychrotrophic bacteria. One of the major problems that we shall be revisiting in the later chapters is the increasing reliance today on refrigeration as the major method of food preservation. Improper refrigeration temperature is one factor that has resulted in the emergence of psychrotrophic pathogens (e.g. *Listeria monocytogenes*) that were not problematic food contaminants 30 years ago.

The effect of temperature on growth rates is an important consideration in shelf life of perishable foods and fermentation processes. It takes little predictive foresight to know that perishable food (e.g. a winter holiday turkey) left out in an unheated garage overnight (or even two nights) will pose minimal risk during the winter, in contrast to one left overnight after a spring festival in late April. For those who might ask why such an example is raised, wait until you have a house full of guests with more food left over than your refrigerator can physically accommodate. Do you throw out the extra food or feel confident that you can store it in the garage for a day or more? Let us ask the question then of how much faster a turkey will spoil at an average daily temperature of 10°C (outdoors in late December in Riverside, CA), compared to a warm late April week having an average temperature of 20°C. Growth at different temperatures (as shown above) can be very useful in predicting food spoilage caused by known microorganisms. Using the example from Figure 2.2, we would see that the growth
of *E. coli* would be five-fold higher at 20°C than at 10°C from the *Q*_10 value. This would mean that if it would spoil in one day at 20°C, it would take five days to spoil at 10°C.

**Q** _10 is the rate increase for a 10°C incremental increase in temperature._

\[
Q_{10} = \left(\frac{t_o}{t_1}\right)^{\Delta T/10}
\]  

(8)

\(t_o\) and \(t_1\) are the respective higher (slower growing) and lower (faster growing) doubling times, and \(\Delta T\) is the temperature difference between these two respective rates. (For \(\Delta T = 10\), \(Q_{10} = t_o/t_1\). A *Q*_10 value of 3 would mean that the growth rate of an organism would triple for every 10°C increase in temperature, or decrease by 1/3 for every 10°C decrease.

The rearrangement of equation 8 above is useful for determining temperature differences that are not in 10°C increments.

\[
t_o = t_1 Q_{10}^{\Delta T/10}
\]  

(9)

**FIGURE 2.2** The relationship between growth rate and temperature for a psychrotroph and a mesophile (*E. coli*). Note that doublings per hour are on a log scale. Compare the position of the vertical bars for each plot at 10°C and 20°C to the corresponding coordinates on the y axis. For *E. coli*, these are 0.08 and 0.40 doublings per hour, which represents a *Q*_10 value of 0.40/0.08 = 5.0 over this range. The *Q*_10 value for the psychrotroph is determined the same way. Redrawn from (39).
For example, if a bacterium doubles every 3 hours \((t_d = 3)\) at 20°C, how fast will it double \((D_1)\) at 27°C if the \(Q_{10}\) is 2.5? Putting these values into equation 9, gives

\[
3 = t_d * 2.5^{7/10}
\]

\[
t_{d1} = 3/1.8 = 1.8 \text{ hours}
\]

**RISK ASSESSMENT INCORPORATING KNOWLEDGE OF BACTERIAL GROWTH**

Although it would be desirable to have models that would give precise predictability on the growth of food microorganisms based on important environmental parameters, there is no known mechanistic way of modeling the lag phase, a crucial aspect in prediction of growth. Thus, all such modeling efforts are largely empirically derived. Reproducible data can be fit to equations, and used for prediction of safety and shelf life of foods under a given set of environmental conditions. We will deal with risk assessment and prevention later, but this would be a good time to introduce the subject because the rapid growth of bacteria (storage time and conditions) is one of the most important factors affecting food safety.

The data in Table 2.1 show the concentration *Salmonella* in processed chicken patties at different stages. Note that although the concentration is very low, the risk of infection is directly proportional to the amount of food consumed: e.g. 100g would be an average serving. This would yield a low probability, using the equation in Table 2.1, if the patties were consumed immediately after purchase, presumably frozen. However, this is unrealistic. Note, however, if the patties had thawed, and were left at room temperature for 5 hours, during which their interior temperature was 21°C, the probability of an infectious dose becomes quite high, as a result of microbial growth.

**TABLE 2.1** Risk infection of *Salmonella* from processed chicken patties. CFU = colony-forming unit, assumed to be equivalent to one cell (64).

<table>
<thead>
<tr>
<th>Process</th>
<th>Temperature, Time Interval</th>
<th>Average CFU/g</th>
<th>Infectious Dose Probability(a) 100g(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial distribution</td>
<td>—</td>
<td>1.9 \times 10^{-3}/g</td>
<td>0.0014</td>
</tr>
<tr>
<td>Storage</td>
<td>21°C, 5 hrs</td>
<td>1.4/g</td>
<td>0.65</td>
</tr>
<tr>
<td>Heating</td>
<td>60°C, 6 mins</td>
<td>3.3 \times 10^{-5}/g</td>
<td>2.5 \times 10^{-5}</td>
</tr>
</tbody>
</table>

\(a\) \(P = 1 - e^{-0.00752N}\), where \(N = \text{CFU/g} \times \text{g food consumed}\), and 0.00752 is the empirically derived probability of one cell causing an infective dose.

\(b\) amount of food consumed at this stage in the process.
The doubling time of *Salmonella* can be calculated from the increase in numbers during the 5 hours of storage. Knowing this, you can then calculate how long the patties would be safe for consumption after heating if they were left at room temperature for several hours. An example of how this would be germane to a hypothetical picnic condition is given in Problem set #1 at the end of this section.

**SUMMARY —**

- There are three recognized phases of batch culture growth of non-filamentous (unicellular) microorganisms.
- The lag phase is not predictably characterized by any kinetic consideration.
- Know the reasons why lag phases occur.
- The exponential or log phase represents the only true predictable aspect of modeling microbial growth. This is a first order reaction. Doubling time is an important kinetic determination.
- The stationary phase is not caused by crowding or depletion of nutrients, but by oxygen limitation and product inhibition.
- Knowledge of bacterial growth (e.g. doubling time) is useful in predicting shelf life and risks of infection from a pathogenic contaminant.
- Understand the meaning and concept of ITT.
- Prokaryotes can be characterized by their growth temperature ranges as thermophile, mesophile, psychrotroph.
- All thermophiles (growth at 55°C and higher) are prokaryotes.
- Psychrotrophic bacteria are those that grow better than other mesophilic bacteria at refrigerated temperatures.
- Know the difference between a psychrophile and a psychrotroph.
- Be able to convert rate processes at different temperatures by use of Q₁₀ kinetics.