CHAPTER 1

“TO SEEK OUT NEW LIFE . . .”

The opening sequences of both TOS and TNG mention that their mission is “to seek out new life.” While many viewers think of this mission in the context of other humanoid life forms depicted in the series, such as the Vulcans or Klingons or Andorians, fewer think of it in the context of entirely unfamiliar forms. Is such unfamiliar life likely, and what might a “new life form” look like? The first section of this chapter examines briefly the question of what “life” actually means and begins to examine its probability of occurrence. Many biology textbooks provide lists of characteristics of living organisms, but exceptions to some items in these lists abound even on our own planet. Might we expect similar forms to have arisen elsewhere in the universe? Furthermore, these lists are artificial in the sense that they were made based on observations of known organisms on Earth rather than derived from fundamental principles of biology and chemistry. Much of life is, for example, water and carbon based, but are these properties general to life or idiosyncratic to the observed single set of related life forms on Earth? The second section of the chapter goes into several properties associated with life on Earth, and considers what alternatives may be possible.
Lieutenant Commander Data is an android but has been considered throughout the series to be alive and self-aware. In this episode, he begins to question whether other machines he encountered are alive. He goes to the ship’s chief medical officer, Beverly Crusher, and asks what the definition of life is. She answers that “the broadest scientific definition might be that life is what enables plants and animals to consume food, derive energy from it, grow, adapt themselves to their surroundings, and reproduce.” Data is dissatisfied with this answer, noting fire “consumes fuel to produce energy, it grows, it creates offspring.” He then elaborates on an exception in the other direction, noting about himself that he does not grow or reproduce yet is considered alive. He further raises the question of whether something specific transpired to endow him with life between when he was merely component parts and when he became alive.

**DEFINING LIFE**

Much science-fiction writing and film (Star Trek or otherwise) considers the possibility of life on other worlds. We all ponder how likely extraterrestrial life is to arise and what form such life might take. To answer these questions, we need some idea of how to define life so that we may determine its likelihood and recognize it when we come upon it. To define life, we humans naturally first consider forms of life with which we are most familiar: life on Earth. We know that animals, plants, and fungi are alive. We are similarly convinced that various microscopic forms including bacteria, amoebae, and the parasite that causes giardia...
are alive. What attributes do these forms share? The textbook list of traits associated with life is similar to the ones that Doctor Crusher laid out in TNG “Quality of Life” above: acquiring or producing energy, some level of internal organization, maintenance of a constant internal environment, growth, reproduction, response to stimuli, and ability to adapt over generations.¹ Physicist Erwin Schrödinger highlighted in 1944 that living matter evades the decay to equilibrium.² Nonliving matter (whether never alive or now dead) tends to move to equilibrium with its environment: reaching a similar temperature, not growing or moving unless impacted by outside forces, etc. Life forms expend energy to remain distinct and out of equilibrium relative to their environment.

Let me use a bacterium that causes pneumonia, *Streptococcus pneumoniae*, as an illustrative example. It appears in the form of individual cells as units of life. Each cell takes up simple carbohydrates from its environment to use for energy; each has a defined structure with a wall and several specific surface proteins to maintain the internal environment; each has internal structures including a chromosome containing instructions for maintenance and reproduction; each grows and reproduces; each produces specific proteins in response to antibiotics; and several cell lineages have evolved over time, in some cases, unfortunately for us, to become resistant to commonly used antibiotics. Unambiguously, *Streptococcus pneumoniae* cells are alive.

While seemingly simple in some cases, defining life becomes a challenge when there is a mismatch between the list of characteristics and our instincts on whether something is alive. As Data noted, fire converts matter in its surroundings to energy and grows. A small spark from a fire can allow a separate fire to emerge, analogous to reproduction. Nonetheless, no biologist argues that fire is alive. Our homes have internal organization and
a constant internal environment in some respects, but we do not perceive them to be alive. On the other side, many organisms we presume to be alive—in addition to the android Data—are also unable to reproduce, such as the mule (the sterile hybrid offspring of a horse and donkey: see chapter 5). Besides reproduction, other attributes associated with life are not “essential” for life: we would not declare an individual “nonliving” solely because it failed to grow or if it reproduced as completely identical clones so that there was no potential to adapt over time.

There are also gray areas. Are viruses alive? Viruses require nonvirus host cells for reproduction, so they cannot reproduce independently. They do not generate or store energy but instead rely on host cells for energy for all functions. Some scientists have argued that these properties make them too dependent on other life forms to be considered alive. However, many living organisms are dependent on other individuals or species for their lives or reproduction. Medical professionals often talk about “killing viruses,” which implies that they are alive. Recent work shows individual viruses even exhibit a form of chemical communication that affects the behavior of other viruses. Overall, biologists are split on the question of whether viruses are alive or merely natural replicators that capitalize on and influence other living organisms. Viruses are not the only gray area. Transposable elements (DNA sequences that insert themselves into genomes and then make copies of themselves) and prions (misfolded proteins that change other proteins near them to their misfolded state) also self-replicate in a sense, but they are considered to be further from “living” than viruses.* As these ex-

* Prions are associated with various human and other mammalian diseases, and reference was made in *DS9* episode “Business as Usual” to leveraging prions as a weapon to kill 20 million people.
amples illustrate, there is no simple solution to defining life. In essence, “life” is an imprecise term used to define having many of a suite of particular traits, but with no specific number or absolute requirements of which traits from the suite must be included.

Despite this uncertainty, some very reputable biologists, including Nobel laureates, have argued that defining life precisely is not necessary for us to study the likelihood of life to arise or its possible origins. We still know many important components, and those can be researched individually or in groups. Life as we know it arguably has a chemical basis; venturing outside that constraint generally falls into the realms of philosophy and religion. With that in mind, some scientists have suggested that life can be described as a sustained chemical system that undergoes self-reproduction with the potential for some change over time (i.e., evolution).

**GENERATING NEW LIFE**

If the simplest form of new life is a sustained chemical system like that described above, such life has already been constructed in the laboratory using building blocks from existing life: specifically synthesized fragments of the nucleic acid RNA (also discussed in chapter 3). The first life on Earth may well have used RNA for heredity, since, unlike DNA or proteins, RNA has the ability to both transmit hereditary information and carry out some vital functions of the cell. Indeed, RNA is involved in the transmission of genetic information in some present-day viruses, such as HIV. Self-replicating combinations of RNA “instructions” have been assembled in the laboratory that, in the presence of the appropriate raw materials, make more copies of
themselves without any added directions or machinery (e.g., enzymes). More recent studies have given these RNAs the ability to produce other types of functional molecules. Hence, some of the most plausible models for early life on Earth include an RNA-based phase, making this particular example especially interesting for understanding the history of life on our own planet. Still, self-replication of genetic material alone does not make a “cell” as we know it today—metabolic processes must also occur, and the cell-replication machinery must remain physically distinct from its immediate surroundings. On the latter point, recent progress has been made in describing how membranes also may have evolved, to keep cells distinct.

Would the raw materials for life have been available on early prelife Earth, though? A famous experiment, published in 1953 by Stanley Miller, showed that amino acids, the building blocks of proteins, can form naturally without preexisting life in the presence of hydrogen, ammonia, methane, and water, when exposed to sparks (analogous to lightning). While we do not know with certainty the exact chemicals or their concentrations on Earth before life formed, these compounds are widespread in the universe, and related results were found in later studies using different chemicals (e.g., hydrogen sulfide) or different conditions. Additionally, numerical models suggest that long RNA molecules, potentially able to initiate primitive life, could have formed more than four billion years ago on Earth in the conditions present at the time. Altogether, the potential seems high for having the known raw materials for Earthlike life arise spontaneously in the universe.

Much of the text above focuses on the question of how life on Earth might have arisen—understanding a specific instance. If one is considering life on other worlds, we must focus on the more general question: how might life arise? While the studies
described above provide elegant proof of principle of the origin of basic life components from nonlife on an early Earth, they may not reflect the potential for life on other worlds accurately.

As such, a few scientists have taken an even more basic physical view in exploring the potential for the conditions associated with life to arise. Earth is an “open system,” in that not only do interactions happen between organisms and resources on the planet, but also energy is continually being provided to the planet via radiation from the sun. Many systems tend to spread energy out over time (increasing entropy, as per the second law of thermodynamics), but open systems can divide energy unequally since they are influenced by and can influence their surroundings. Under such conditions, and if surrounded by a liquid or gas (e.g., our planet’s oceans or atmosphere), theory suggests that matter may often gradually restructure itself so as to dissipate greater amounts of heat energy. Some physical scientists have argued that self-replication (reproduction) may achieve this outcome, since replication dissipates energy in an irreversible manner (i.e., one organism is more likely to replicate into two than two organisms are to fuse into one). General thermodynamic definitions of evolution predate this particular model, and certainly the applicability of this argument to the origin of life in particular is tenuous. However, the argument described above adds new dimensions, suggesting why processes associated with life may be somewhat likely to arise from basic principles of physics.

Taking all of the above together, “life” on other worlds may be simple and reasonably probable to exist but could arguably be chemical processes quite unlike the humanoid aliens observed in much of Star Trek or other science fiction. Such forms may be extremely difficult to notice, even from very close, and simple “scans” from space, such as those conducted in Star Trek, may easily miss them. Instead, Star Trek devotes much attention
to the “sentience” of life across the series: the crews often struggle to determine whether organisms that they encounter are self-aware. Undoubtedly, self-awareness would indicate that an entity is alive, but the vast majority of organisms we know or predict would not have this characteristic.

NEW LIFE IN *STAR TREK*

As in the example at the start of this section, *Star Trek* does consider the potential for life among constructed forms, in which the life-related processes may be electrical rather than chemical and some exceptions to the “characteristics of life” may apply. Two examples used in the series regularly are the *TNG* android character Data and the *VOY* holographic doctor. Both characters are essentially animated computer programs, yet both have most or all of the characteristics of life and are even self-aware. In fact, both reproduced in some sense: in *TNG* “The Offspring,” Data built a child (Lal) using neural transfers from himself, while in *VOY* “Real Life,” the holographic doctor created a holographic wife and children. Are these truly “offspring”? Counselor Troi emphasized to Captain Picard, “Why should biology rather than technology determine whether it is a child? Data has created an offspring. A new life out of his own being.”† Can a “manufactured” form be considered alive? Multiple religions suggest that existing species (including humans) were designed by a living creator, and no one argues that such a premise would mean the products are “not living.” Hence, constructed forms can be considered alive in principle, and we may be close to producing

† *TNG* “The Offspring.”
human-made forms that can be considered alive. One might wonder if perhaps the first new life we encounter may be a form that either we made ourselves or that others manufactured and sent out into the cosmos.

Nonetheless, when biologists discuss the origin of life, they typically consider life arising from raw materials of nonlife, and not initiated or produced by extant living forms. In that regard, while androids or computer programs may fit the definition of life, they did not arise from nonlife. I suggest a separation of “origin of life from nonlife” and “origin of new life from existing, albeit different, life.” Although many Star Trek episodes are devoted to the latter, fewer focus on the former. One passing reference was made in the DS9 episode “Playing God” to potential new life evidenced by “nonrandom thermodynamics,” akin to the basic physical view discussed above. However, few (if any) other references exist across the series.

HOW MUCH SHOULD LIFE ON EARTH RESEMBLE EXTRATERRESTRIAL LIFE?

Life forms on Earth are made from carbon-containing compounds and use water for their biochemical reactions. Many Earth life forms thrive at temperatures between 5°C and 40°C and release energy from respired oxygen. Should we expect extraterrestrial life to share such characteristics? The problem with extrapolation is that all of life on Earth is related in a strict sense: we share a common ancestor with every life form known on this planet (a topic discussed at greater length in chapter 2). Hence, while we know many life forms on Earth are water and carbon based, all of those forms are nonindependent, creating a problem for predicting what we may see elsewhere. This problem is analogous
to predicting the characteristics of a “sport” having only known soccer and some sports derived from it (e.g., American football). Knowing these sports, one might then predict “sports” to involve teams, scores, and putting an object into a goal defended by an opponent. While these attributes apply for some sports, like basketball or hockey, how well would such predictions apply to fencing or surfing? What about karate or boxing? Many sports have some means of scoring (albeit measured in very different ways) but do not involve putting objects into defended goals.

Through the next sections, we will consider a few specific characteristics of life on Earth, variations thereof observed on Earth, and, when possible, arguments for whether they may be typical or exceptional on other worlds. We will also look at whether and how variations were explored in the Star Trek series. In principle, one should predict that life forms on other worlds and in Star Trek should be more diverse than life on Earth if they do not share evolutionary ancestors with each other and with Earth’s life forms (but see chapter 2)—analogous to how unrelated people often exhibit greater variation in features than do genetically related people within a single family. Some of this predicted greater diversity is indeed reflected in the series.

WATER

TNG, Season 1, Episode 18, “Home Soil”
Some crew members find a nominally “inorganic” (not containing known building blocks of life such as carbon compounds) life form. It has no carbon, but it has silicon, germanium, and other elements. The life form eventually communicates with the crew and refers to the humans on the ship as “ugly, ugly, giant bags of mostly water.”

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The alien’s point is fair: humans are mostly water, as is most life on Earth. Much of the search for extraterrestrial life also focuses on water. Researchers with space telescopes emphasize investigations of planets in what they define as the “habitable zone” or “Goldilocks zone”: planets “not too close” yet “not too far” from their star for water to exist in liquid form on the surface of a rocky planet. In 2009, NASA launched the Kepler space telescope to seek and estimate the abundance of approximately Earth-sized planets in or near the habitable zones of their stars. Kepler-22b, Kepler-62f, and Kepler-452b are examples of such planets inferred.15 Many others have been found by other means: for example, seven planets with masses similar to Earth appear to orbit the dwarf star TRAPPIST-1 in its habitable zone,16 and planet LHS 1140b is in the habitable zone of its star and appears rocky and roughly Earth sized.17

Why liquid water? Water is the primary solvent for all life on Earth. Let me start with some very basic chemistry. Solvents are often in liquid form, and other chemicals dissolve in them. Solvents can get substances used in chemical reactions into the same phase so that molecules can collide with each other and react. Such reactions facilitate the sustained chemical systems we consider life, as discussed in the first section. While solvent-free reactions exist, having a solvent often greatly simplifies having sustained chemical reactions.

There are reasons that water may be generally, rather than rarely, the solvent used for life. The simplest reason has to do with sheer abundance. Water is composed of two hydrogen atoms and one oxygen atom. Hydrogen is, by far, the most abundant element in the universe. Oxygen is the third most abundant element in the universe. The second most abundant element, helium, is the least reactive in the periodic table, and therefore would not likely be a component of a solvent. Hence, by sheer
abundance and simplicity (three atoms), the constituents of water easily beat out all competing solvents.

Water has several other favorable properties. It is liquid at a broad range of temperatures. Water is a “polar” molecule, in that the oxygen atoms have a partially negative charge and the hydrogens have a partially positive charge, due to differences in electronegativity between those two elements. This property makes water particularly good at dissolving salts and other molecules that are polar by nature; in fact, water is capable of dissolving more substances than virtually any other liquid. Molecules that do not exhibit polarity, such as fats and some other molecules rich in hydrocarbons, do not dissolve in water. Nonpolarity is also sometimes beneficial, since nonpolar molecules in water are sometimes forced to interact with each other rather than with the solvent. These features work very well for living systems on Earth and are advantageous for organizing cell walls, mediating interactions among or folding of proteins, etc.\(^{18}\)

On the other hand, life on Earth has evolved around the use of water as a solvent for roughly four billion years, so water may now appear to be more “ideal” than it was when life first arose. In other words, while life on Earth today works splendidly with water but much less so with, for example, liquid ammonia, this contrast may result simply because of four billion years of natural selection optimizing living forms for use with a less-than-ideal water solvent rather than water having been ideal at the start.

In this regard, there are reasons that perhaps water may not be ideal as a solvent for life on other worlds. First, its liquid form is associated with rather high temperatures (0°C–100°C at Earth’s atmospheric pressure). The vast majority of the universe and, presumably, many planets are far colder than that. As implied above, atmospheric pressure is also important: liquid water cannot persist on Mars, for example, because ice transitions directly to water
vapor given the low atmospheric pressure. Water also damages or degrades some important molecules associated with life, such as some proteins, DNA, and RNA, but terrestrial life has adapted to mitigate this damage through repair or through producing more molecules than needed so damage to a subset can be tolerated.

Alternative potential solvents exist, including ones that are liquid at much colder temperatures. One of the most likely alternatives may be liquid ammonia. Like water, it is polar and can also dissolve many known organic compounds. It maintains a liquid state at −78°C to −33°C, but can be liquid at much broader temperatures if at high pressure. For example, ammonia is liquid from −77°C to 98°C at 60 times the atmospheric pressure of Earth, which is less than the pressure on the surface of Venus, for instance. Ammonia is abundant across the universe—the atmospheres of many of the outer planets in our solar system have it. Saturn’s largest moon, Titan, may even have subsurface ammonia-enriched liquid water oceans, which could function as a solvent mixture for life-related processes. Other solvents may work for life at distinct temperatures or pressures, such as high-pressure carbon dioxide or methane, or life may even possibly—though arguably more problematically—involve reactions in gaseous or solid phases.

We predict that alien life forms should sometimes also use water as a solvent, but they might also sometimes utilize alternative solvents. How well does life in Star Trek reflect this prediction? For simplicity in terms of scientific consideration throughout this entire chapter, I set aside any noncorporeal life forms from discussion, even though several have appeared in all of the Star Trek series. I similarly exclude species that readily change form or

‡ Some examples are the TOS Medusans, TNG Calamarain, DS9 Prophets, VOY Paxans, ENT wisps, and DIS Pahvans.
between states (e.g., solid to liquid) or between matter and energy. Finally, I only consider organisms that exist in normal space, not in fictional alternatives like “subspace” or “fluidic space.”

Alternatives to water-based life are not addressed directly in *Star Trek*, and this absence may reflect a real-world bias for seeking extraterrestrial water and seeking extraterrestrial life. In defense of the writers, the series tend to present characters spending most of their time in atmospheres, temperatures, and pressures not very different from what we experience indoors. As noted, many of the alternative solvents would be more likely to work in very different conditions, much higher pressure or much lower temperature for example, and therefore we do not expect to encounter them (or organisms based on them) in the series given the frequent depictions of human-comfortable conditions. Further, just as many nonwater solvents (e.g., alcohols, phenols) are toxic to life forms that we know (e.g., many, albeit not all, microbes), water may be disruptive or even toxic to non-water-based life forms. Hence, if the characters in the series are often present on planets with Earth-like atmospheres, they are intrinsically unlikely to encounter the full range of possible alternative life forms. I appreciate that NASA prioritizes Earth-like conditions in seeking new life since we do not yet know if any extraterrestrial life exists. However, because extraterrestrial life has been found in *Star Trek*, the USS Enterprise may be well advised to visit more planets with non-Earth-like conditions to better explore the boundaries of “new life,” as its mission purports to seek.

As early as 1962, biochemist and famous author Isaac Asimov wrote an elegant essay expressing his frustration with science fiction not being imaginative enough about life (e.g., always por-

§ Recurrent examples being *TNG* Q and *DS9* Changelings.
trayed as water/carbon based) and including a table showing hypothetical “life chemistry” combinations going from extremely high temperatures to near absolute zero. His table lists carbon-based proteins and nucleic acids—for example, DNA and RNA—in water interacting well in typical Earth temperatures, fluorocarbons in sulfur working at higher temperatures, and lipids in methane working at lower ones. Chemicals and their solvents must be considered as combinations: the solvent and the elemental basis of solid life need to interact appropriately and be able to do so in the specific environmental conditions of, for example, temperature and pressure. While acknowledging this fact, let me consider alternatives to carbon and other characteristics of life on Earth as well.

**CARBON**

*TOS*, Season 1, Episode 25, “The Devil in the Dark”

On a mining colony, the crew encounter a creature (identified later as a “Horta”) that appears to be made of rock. To attempt to make the humans leave the mining colony, the Horta steals the circulating pump that provides air (including oxygen) to the miners. The *Enterprise* crew begin to speculate about this mysterious life form, particularly after learning of silicon nodules found in the mines. Science officer Spock notes, “Life as we know it is universally based on some combination of carbon compounds, but what if life exists based on another element? For instance, silicon.” Skeptical, Doctor McCoy counters, “Silicon-based life is physiologically impossible, especially in an oxygen atmosphere.” After adjusting their scanning devices (tricorders) to look for silicon, they are able to find the Horta,
and when they injure it with their weapons, they find the piece cut from it is indeed made of silicon-based fibers.

Carbon is intrinsically related to life on Earth, so much so that it essentially defines life as we know it. The term “organic” is defined simply as relating to or derived from living organisms, but “organic compounds” and “organic chemistry” refer to matter that contains carbon atoms. Fundamental molecules of life on Earth are all carbon based: fats, carbohydrates, proteins, DNA, RNA—all of these have carbon atoms forming a so-called “carbon backbone.” Carbon is a relatively small, lightweight atom. Because of its position in a central column of the periodic table, carbon is able to bond with up to four other atoms and is quite versatile in being able to produce diverse structures (long, branching, or ring-like, for example). In much of the biochemistry on Earth, carbon atoms are bound to other carbon atoms as well as to hydrogen and oxygen, and sometimes nitrogen, phosphorus, and sulfur. For many reactions associated with metabolism or other life-related processes, carbon and/or hydrogen will dissociate from one of the other elements, and new bonds are formed soon thereafter.

Carbon is also the fourth most abundant element in the universe, making it a good candidate for life. As noted earlier from Stanley Miller’s classic experiments and various follow-up studies with varying conditions, nonbiological formation of many carbon-based compounds, such as amino acids, has occurred under laboratory conditions, again suggesting the feasibility of a similar process having occurred on other worlds. Indeed, scientists have even isolated extraterrestrially formed carbon-based amino acids, as well as components of DNA and RNA,**

** VOY “Body and Soul” mentioned “primitive strands of DNA” taken from a comet.
from meteorites, further demonstrating that these forms have arisen on other worlds and may be associated with life elsewhere. Finally, many carbon molecules used in life exhibit a geometric property called “chirality” (meaning they occur in two geometric forms that are mirror images of each other, like a person’s hands), and most naturally occurring sugars differ in their chirality from naturally occurring amino acids. This chirality allows for particular kinds of useful molecular interactions that are used in life.

Given all of these good properties, are there alternatives? As described in the example above, Star Trek explored one of the most often considered alternative elements: silicon. Situated immediately below carbon on the periodic table, it also shares the ability to bind with up to four other atoms and is almost as small. While carbon is more abundant in the universe at large, silicon is more abundant than carbon in the Earth’s crust. However, while carbon makes long chains with itself or binds with other elements, giving it a lot of flexibility, silicon binds more tightly to other elements like hydrogen or oxygen than to itself. Long-chain silicon–silicon molecules may decompose in water because silicon preferentially binds to the other atoms. Silicon molecules are also less likely to exhibit the chirality that carbon molecules do, diminishing flexibility. Most organic molecules do not contain silicon despite its abundance in Earth’s crust, although some laboratory evolution studies have produced bacteria that form molecules with carbon–silicon bonds across a range of conditions, illustrating some potential for “use” of silicon in life even if it were not the primary life element. (Interestingly, a silicon-based parasite was manufactured in VOY “The Disease,” which aired long before the real-world study described above.)

The tight bonding of silicon to oxygen would make silicon as a primary component of life very challenging on modern Earth.
Presumably it was for this reason that Doctor McCoy noted silicon-based life is physiologically impossible in an oxygen atmosphere. This bonding is what makes silicon dioxide a rather unreactive solid—in forms like quartz or sand—on Earth, whereas carbon dioxide is a gas that reacts more readily. However, Doctor McCoy did not address one related possibility: life involving repeating units of silicon and oxygen (“silicones”), perhaps with carbon too, may work well in worlds with much higher temperatures than are typical on Earth—potentially, in some respects, even better than our carbon-only-based forms.

Overall, it does seem that carbon has properties that make it unusually good for facilitating life, at least on planets with Earth-like conditions and perhaps even somewhat more generally. It may be the most abundant backbone upon which life would form. Nonetheless, we cannot exclude the possibility for non-carbon-based life.

As discussed, several non-carbon-based life forms have been highlighted in Star Trek, with the Horta being the best-known example. When Doctor McCoy noted that such an organism could not persist in an oxygen-based atmosphere, Mr. Spock suggested that perhaps it “can exist for brief periods in such an atmosphere before returning to its own environment.” Perhaps the Horta stole the pump that provided air to the human colony in this episode to reduce this oxygen exposure. Another example was the silicon-based form from TNG “Home Soil” mentioned in the preceding section. However, this life form seemed devoid of carbon, and yet it was hypothesized later in the episode that it used saline water in some way (either as nourishment or as a “connection” among cells). Without knowing the exact form of the silicon-based molecules, it is hard to assess how likely such an organism might be in such an environment. A silicon-based virus was found in one episode of ENT (“Observer Effect”), and
a gigantic, space-faring, silicon-based, crystalline entity was also depicted in a few episodes of TNG ("Datalore," "Silicon Avatar"). However, one of the more interesting possibilities was depicted in the Tholian species (TOS "The Tholian Web," ENT "In a Mirror, Darkly"). They have an exterior made of an unspecified mineral that could be silicon based, and they live at extremely high temperatures (>200°C). Again, details are not specified, but the show writers laudably thought "outside the box" in this choice, arguably with some consideration of the underlying science.††

In addition to demonstrating noncarbon compounds associated with life in Star Trek, the episodes described above also emphasize the variation in temperature experienced by life forms (from below −250°C in outer space to above +200°C, as the Tholians experience). The next section examines variation in temperature both on Earth and in space.

TEMPERATURE

VOY, Season 4, Episode 24, "Demon"

The USS Voyager has come to a "demon-class planet": with a toxic, radiation-filled atmosphere and a surface temperature in excess of 220°C. Nonetheless, upon exploring the surface, they find a life form called the "silver blood."

The range of temperatures among planets even just in our solar system is enormous, from roughly −210°C on Uranus to 460°C on the surface of Venus. This raises the question of what temperature

†† One exception to this is Neelix’s reference to a "xenon-based life form" in VOY "Hope and Fear." Not only is xenon a gas, but it does not bind to other elements easily. This suggestion is implausible based on what we know.
range can possibly support any form of life, known or hypothetical. As discussed earlier in the chapter, water being the solvent of life on Earth necessarily limits temperature conditions for life on Earth. I touch on the extremes of the range of temperatures experienced by living organisms on Earth only briefly because many books have been written about such “extremophiles.” One important distinction to retain in this discussion, however, is the difference between “tolerance”—meaning an organism can minimally survive under such conditions without dying, but perhaps only temporarily and/or without reproducing—and the conditions under which an organism can thrive and reproduce. Additionally, the conditions on our planet today may be quite unlike the conditions when life first arose, so the temperature range under which Earth life exists today may also differ from eons ago.28

Some heat-tolerant “hyperthermophile” species are known to survive and reproduce at temperatures near or above 100°C. For example, the archaeon microbe *Pyrococcus furiosus*, found in deep-sea hydrothermal vents, has an optimal growth temperature of 100°C and can reproduce every 37 minutes.29 The genus name essentially means “fireball.” Another archaeon microbe from hydrothermal vents, inelegantly described as “strain 121,” can grow at temperatures between 85°C and 121°C, reproducing after 24 hours at 121°C.30 These microbes could survive periods at 130°C and subsequently reproduce when the temperature cooled slightly.

At the other end, several cold-tolerant “psychrophile” species are known that can reproduce at temperatures near freezing and survive at much lower temperatures. For instance, the marine bacterium *Moritella profunda* grows best at 2°C or lower.31 Generally speaking though, free-living, single-celled microbes on Earth are presumed to be unlikely to be able to grow and reproduce below −20°C due to biophysical limitations associated with liquid water,32 although water can remain liquid at lower
temperatures if particular chemicals are dissolved in it. Multi-cellular organisms can potentially reproduce at lower temperatures; for example, emperor penguins can breed at temperatures of −40°C. Many organisms can survive (without growing or reproducing) at still lower temperatures. Tardigrades (also called water bears; more on these creatures in the Appendix) can survive submersion into liquid nitrogen (−196°C), and a handful of individuals studied even survived a few days’ exposure to the vacuum and radiation in low Earth orbit. However, some far more extreme stories concerning these interesting organisms (e.g., that they can survive freezing for 100 years) may have been exaggerated. Nonetheless, some bacteria were extracted from ancient ice cores dating back 120,000 years, and were able to reproduce after thawing. Clearly, some Earth organisms can tolerate very long and/or very cold freezing. These observations prompt the intriguing possibility that life similar to Earth’s may lie in wait on other worlds, perhaps even in our solar system.

What is observed in Star Trek? Many of the real-world examples described here involve microbes, and Star Trek rarely elaborates details on the ecology of microbes. Chief Engineer La Forge intriguingly suggested that thousands of single-celled life forms were present on “any planet’s surface” (TNG “Time’s Arrow, Part 1”), certainly implying diverse tolerances given the range of conditions across planets. Another noteworthy reference was Doctor Phlox’s (ENT “Breaking the Ice”) response to a question about whether germs can live in space. He noted there were millions of cataloged space-dwelling microbes that drift in dormant state through space and can then infect humanoids. While we know of no such species today, the existence of such microbes may be plausible given the diversity of life observed on Earth.

Several other much larger space-dwelling species were also observed in the various Star Trek series (e.g., TNG “Galaxy’s
Child,” VOY “Elogium,” DIS “Magic to Make the Sanest Man Go Mad”). At the warmer end, the previously mentioned Tholians (ENT “In a Mirror, Darkly”) require temperatures around 200°C, and the mimetic silver blood species (VOY “Demon”) was found on a planet with temperatures exceeding 200°C. Interestingly, many of the above-mentioned species are likely not water based (the gormagander being a likely exception, DIS “Will You Take My Hand”), potentially granting them the ability to thrive in conditions outside of those observed in life on Earth. However, I find it notable that the crews very rarely encounter alien species requiring cooling or heating space suits that maintain the occupant even 20°C above or below room temperature.‡‡ Generally speaking, the series tend to focus on aliens in room-temperature environments, and the possibility for extremophiles (relative to Earth environments) seems underexplored.

Finally, irrespective of chemical composition or temperature conditions, the processes associated with life necessarily require energy. The final section explores energy production on Earth and in Star Trek.

ENERGY

TNG, Season 4, Episode 16, “Galaxy’s Child”

The USS Enterprise-D encounters a space-faring life form orbiting a planet. It sends an energy field over the ship, and the crew are forced to shoot it to escape. However,

‡‡ The Nyrians in VOY “Displaced” are one exception since they preferred a temperature of 45°C (~20°C above room temperature). The Breen in DS9 are another possible exception since they wear “refrigeration suits,” but Weyoun in “The Changing Face of Evil” suggested the suits may not be related to temperature.
the life form had an offspring within its body, and the offspring emerges after the mother dies. The baby alien follows the ship, comes into contact with the hull, and as Science Officer Data observes, “the life form is draining energy directly from the fusion reactors.” Counselor Troi notes, “It’s feeding off the energy of the Enterprise as it would from its mother.”

Life forms need energy for maintaining themselves and eventually for reproducing. Energy must be captured from the environment, biochemically stored, and processed to be made available for use when needed. Animals such as humans consume other life forms (plants, fungi, and other animals) to get sugars and other nutrients to use as stored biochemical energy. We then use respiration to metabolize sugars and produce molecules that make energy more accessible to the cell (e.g., adenosine triphosphate, or ATP§§). Respiration can involve breaking down sugar in the presence of oxygen (called “aerobic respiration”) to make ATP, also producing carbon dioxide and water as side products. Much of this process occurs in cellular structures called mitochondria, to which we will return in chapter 2. ATP is the immediate source of energy for many of life’s processes, including transportation of molecules in and out of individual cells, cell division, muscle movement, and many more.

Similar processes lead to the breakdown of sugars and production of accessible energy without needing oxygen. Some bacteria and archaea break down sugars to produce energy without oxygen (via “anaerobic respiration”), particularly species that live in low oxygen environments. One example is the archaea

§§ The holographic doctor mentions adenosine triphosphate in regard to the captain’s respiration in VOY “Sacred Ground.”
that live in the gut of cows and other ruminants; these species help break down cellulose from plant material into energy, incidentally producing methane gas as a by-product. Oxygen is actually detrimental to the growth of some such organisms. Another process called fermentation can produce ATP from the breakdown of sugars without the need for oxygen gas. This process happens in our own muscle cells at times when we have too little oxygen for standard aerobic respiration, with an additional product being lactic acid. Many people are more familiar with the use of fermentation by yeasts, though, wherein both ATP and ethyl alcohol are products. In general, however, these processes tend to produce less energy than aerobic respiration in the organisms we know.

All of the above assumes that accessible energy for the cell (e.g., ATP) is primarily formed from the breakdown of sugars or other molecules acting as biochemical energy stores. In some sense, this pushes the question of “energy source” back a step: how are these sugars formed? Many readers will be at least loosely familiar with the process of photosynthesis, whereby plant cells take up carbon dioxide and water from the environment and convert them to simple sugars and oxygen using energy derived from sunlight. This process is common in plants, algae, and some forms of bacteria, and they absorb the energy from light in this process using a pigment, the most well-known being chlorophyll. Some other species also photosynthesize sugars but do not use water or produce oxygen as a result. For example, purple sulfur bacteria use light energy to convert carbon dioxide and hydrogen sulfide to sugars and elemental sulfur. In this case, photosynthesis works best under low light intensity and without oxygen, so these bacteria are found in salt marshes, in marine environments, and sometimes even in the guts of marine zooplankton.37
Although sunlight coming to the Earth’s surface may be an obvious energy source for sugar production, it is not the only energy source even among life forms on Earth. Some bacteria that live in deep parts of the ocean or in undersea hot springs use “chemosynthesis” rather than photosynthesis to make sugars, not requiring sunlight but instead utilizing energy released by chemical reactions involving hydrogen sulfide or methane. One species of green sulfur bacteria photosynthesizes using geothermal radiation rather than sunlight. Finally, some organisms seem to use ionizing radiation (e.g., gamma rays or X-rays) as an energy source. For example, at least two fungal species grow faster when exposed to ionizing radiation, and the bacterium *Desulforudis audaxviator* gets energy to make sugars from the decay of radioactive uranium in underground mines. This last example opens the question of whether life could, in principle, be powered by radiation from galactic cosmic rays hitting planetary surfaces. Such rays may be a powerful source of energy for life on planets bearing thin atmospheres.

I have stressed just some of the diversity of forms of energy production or release throughout this section but still only scratched the surface of the dimensions of diversity here on Earth. Again, we predict that life in outer space (and in *Star Trek*) should be at least as diverse, and arguably more diverse, than life on Earth. Basic animal and plant life are observed regularly through much of *Star Trek*, though typically the latter is not emphasized (see first example in Appendix). However, the silicon-based species mentioned at the beginning of this section on the planet Velara III in *TNG* “Home Soil” was said to be “photoelectric,” gaining energy from light. The crystalline entity in *TNG* “Datalore” and “Silicon Avatar” converts organic matter to usable energy, leaving behind hydrocarbons; as the organic matter in each case existed in an oxygen atmosphere, this could be analogous to the
energy-producing reactions involved in terrestrial respiration (if we ignore the problems raised in the previous section about silicon). As for energy producers, the Enterprise crew found a planet with plant life nowhere near a star in ENT “Rogue Planet”—perhaps the inhabitants obtained energy from the subsurface “thermal vents” mentioned in the episode.

In terms of energy usage, the Enterprise-D encounters space-dwelling beings that can drain energy from its fusion reactors in TNG “Galaxy’s Child” (quoted at the beginning of this section). What puzzled me in this episode was how an individual of this species drained energy without directly plugging into the reactors; the implication was that it was taking energy that would have been used by the ship rather than merely absorbing energy that was being lost into space. As an example of this point, photosynthesis by plants or energy absorbed by solar panels does not “drain” the sun in some way. However, the space-dwelling being was attached to the ship’s outer hull, so perhaps it was somehow drawing the power via conduits. Droplet-sized organisms called GS54 also drained energy from a spaceship from its exterior in DIS “Context Is for Kings.” Assuming some direct connections, such a drain may be possible in principle: some Earth microbes can directly accept and use electrons from electrodes for energy.42 In any case, I applaud the writers for thinking of unusual forms of energy production or usage by living forms.

Relatedly, Star Trek does mention a few extraterrestrial species that do not breathe oxygen, and presumably do not respire as we do. The Axanar in ENT “Fight or Flight” breathed a nitrogen-methane combination, and the Tesnians in ENT “Shuttlepod One” required “boron gas” (perhaps referring to boron bound to hydrogen, fluorine, or chlorine, since elemental boron is a solid at room temperature and pressure). Young Lorillians in ENT “Broken Bow” were said to breathe the gas “methyl oxide”
(a compound that either does not exist or is imprecisely named by our present standards: either two methyl groups would bind to oxygen resulting in what we call “dimethyl ether,” or a double bond of oxygen to CH₂ would produce what we call formaldehyde or methanal). DS9 also had a few species with distinct breathing requirements: the Yalosians (60% nitrogen, 10% benzene, and 30% hydrogen fluoride, in the episode “Improbable Cause”), the Lothra (hydrogen, in “Melora”), and possibly an unidentified silicate-based shape-shifting species (carbon dioxide at high concentrations, in “The Alternate”). There was a passing reference to anaerobic bacteria on the planet Kataan in TNG “The Inner Light.” Finally, of course, each of the series depicted various species that survived in space without ships or suits, so clearly not requiring (frequent access to) oxygen. Overall, the Star Trek series incorporate some diversity of approaches to energy production and energy processing for life.

**CLOSING REMARKS**

Isaac Asimov complained in 1962 of “the lack of imagination in movieland’s monsters. Their only attributes are their bigness and destructiveness. They include big apes, big octopuses (or is the word ‘octopodes’?), big eagles, big spiders, big amoebae.” Star Trek is not entirely innocent of Asimov’s complaint, in that one has to dig into the 6 nonanimated series and 13 movies to find references to what appear to be entirely “new” life forms, but I would suggest the series arguably do better than many popular science fiction depictions on television. I have only touched on a few parameters of life in this chapter, and I have left aside many obvious ones (e.g., extremes of size, or, as in TNG “Interface,” living while floating in a gaseous atmosphere
rather than on solid surfaces or in liquids). Further, much of this chapter has focused on attributes singly rather than in combinations. For an organism to survive on parts of Mars, for instance, it would have to be tolerant simultaneously of cold temperatures (especially at night), very low atmospheric pressure, lighter gravity, high radiation (via solar radiation and cosmic rays), virtual absence of liquid water and gaseous oxygen, and other demands. Most extraterrestrial life would very likely need to be simultaneously tolerant of multiple conditions that we perceive as extreme on Earth.

One other dimension worthy of more consideration in extraterrestrial life is “speed.” We think of life operating in time scales with which we are familiar. Could life exist at a much, much faster speed that makes it virtually unobservable? Star Trek touched on this briefly in TOS “Wink of an Eye,” with humanoids that moved around them so quickly that they sounded like a mere buzz to the crew, and VOY “Blink of an Eye,” in which time on a planet moved faster than in surrounding space. However, in both of these cases, the fast speed seemed a by-product of the environment rather than a fundamental difference in the biological processes of the life forms present. Alternatively, chemical or other reactions associated with life may proceed on a glacially slow time scale. Again, this came up briefly in TNG “Tin Man” with reference to the slow Chandrans, who took three days to say hello. However, one can imagine the possibility of life on a much slower time scale yet, potentially requiring millennia of observation to document basic life functions (as can be true for some Earth psychrophiles). Many other dimensions are also worth considering, going beyond what we find familiar.

*** One example of this from Star Trek is the Elaysian in DS9 “Melora,” whose physiology was not adapted to Earthlike gravity; see chapter 5.
Generally speaking, the mission of “seeking out new life” both in science and in science fiction can benefit from greater imagination regarding what “life” may be, its chemical and energetic bases, and where and how it may be observed. Still, the Star Trek writers have provided approachable entertainment that occasionally taps into these questions. They do “boldly go” at least a little way beyond where anyone has gone before (in real life). In subsequent chapters, I will delve less into diversity and more into the evolutionary biology of organisms both on Earth and as depicted in the series.