Planetary Exploration

Research Project 1

Group 13

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1. Exoplanet Information

A habitable zone is defined as the range in distances within which a planet must orbit a star for life to exist (Brennan, 2021). In order to contextualise this parameter, we must first consider what characteristics a planet must possess to host life. Though there is no proof that a planet must be around Earth's size and composition in order to host life, this assumption will be a point of reference for the concepts and calculations that are to be explored, considering the success of life on Earth compared to the Jovian planets. Based on life as we know it, the most important factors to consider when defining the habitable zone are the presence of liquid water and its energy source(s) (Brennan, 2021; Croft, 2021; Merino, et al., 2019). Thus, we define a habitable zone as the zone that surrounds a star wherein liquid pure water can exist.

Liquid Water

Liquid water is considered by many scholars as the main limiting factor of life (Merino, et al., 2019). Part of why water is so important to life is because of its vitality in supporting cellular structure due to its polarity and cohesivity, alongside other factors such as its role in DNA synthesis and versatility in biochemical reactions (Sargen, 2019). Pure liquid water freezes at 0ºC (273.15K) and boils at 100ºC (373.15K). Thus, theoretically, a habitable zone must be at a distance from the star such that its temperature is no less than 273.15K and no more than 373.15K. For clarity's sake, the distance range from a star that allows for the presence of liquid water on a planet will be referred to as the Liquid Water Zone (LWZ). Additional factors to consider include a planet's albedo, its greenhouse effect, atmospheric pressure, and salinity, as they also influence the LWZ.

Influences on the Liquid Water Zone

Albedo is defined as the amount of solar radiation reflected by a given surface. It is usually expressed as a percentage or decimal representing the amount of light reflected divided by the amount of light that hits that surface- an albedo of a would mean all incident light is reflected (University of Calgary, n.d.). Albedo is important to understand when investigating Habitable zones since it significantly affects the amount of energy that is absorbed by a planet's surface, and thus the temperature of that planet. Earth's overall albedo is an average of the various surface albedos such as those of forests and oceans, which have low albedo, compared to those of glaciers and deserts, which have high albedo. The average bond albedo of these unique surfaces is 0.299. There are two types of albedo: geometric and bond albedo. Geometric albedo measures the amount of radiation relative to a Flat Lambertian Surface, a disk the same size and position as the astronomical body which would reflect 100% of incident radiation. (Centre for Near Earth Object Studies. n.d.). Earth's geometric albedo is 0.367. Bond albedo is the ratio of the total incident light from the Sun, referring to its specific wavelength and size, reflected by the Earth to the total energy the Earth intercepts from the Sun. (Nave, 2005) In the context of our habitable zone calculations, we use bond albedo because we are studying planetary bodies similar to Earth, and solar bodies similar to the Sun. Geometric albedo is a comparison to an ideal flat surface, not a sphere, so it is less accurate when considering planets. Furthermore, geometric albedo does not consider the Sun's unique power output on the Earth, thus bond albedo is considered for analogue stars and planets.

An understanding of Albedo can help us determine the composition of a planet's surface, and furthermore identify if it is suitable for life. To fully comprehend the effects of albedo on planetary characteristics, we can investigate the impact of the features of different rocky planets on their albedos (Figure 1).

Planet	Mercury	Venus	Earth	Moon	Mars	Pluto
Geometric Albedo	0.138	0.84	0.367	0.113	0.15	0.44-0.61
Bond Albedo	0.119	0.75	0.29	0.123	0.16	0.4

Planet	Jupiter	Saturn	Uranus	Neptune
Bond Albedo	0.343 +/-0.032	0.342+/-0.030	0.290+/-0.051	0.31+/-0.04

Figure 1: Geometric and bond albedos of the planets in our solar system. (Nave, 2005.)

Starting with the Earth, we can look at the different materials that cover the surface and reflect or absorb the light. Liquid water covers most of Earth's surface, and mainly absorbs sunlight, possessing an albedo of approximately 0.10 (Markings, 2019). The albedo of sand and soil is also relatively low, ranging from 0.15 to 0.45. Snow on the other hand is incredibly reflective, having an albedo of around 0.90. Atmospheric clouds have an albedo of about 50%. All of these components added together give an average albedo of 0.299. As for the other rocky planets, we can similarly estimate an albedo. For starters, Mercury is composed mostly of dark, porous rock, and thus has a low albedo of 0.119. In order to be habitable, Mercury's atmosphere would need to be much thicker in order to regulate the extreme temperatures it receives from solar radiation. Mercury's orbit is much too close to the Sun to be within the habitable zone, hence it would need a much higher albedo to reflect the incoming solar radiation in order for liquid water to exist on the surface. On the other hand, Venus' surface is obscured by a dense sulfuric acid atmosphere, which reflects the majority of incident solar radiation. Though it has the highest albedo of the solar system, at 0.75, which one might think would result in a lower temperature, the greenhouse effect caused by the thick atmosphere leads to extremely high surface temperatures (Squyres, 2023). To be considered habitable, Venus would need a decrease in atmospheric density, which would result in a lower albedo. Finally, the surface of Mars is mainly a red soil, which includes glass particles and common volcanic materials making it relatively dark. It does not have a very thick atmosphere, so like on Mercury, the atmosphere can be ignored when computing albedo. Overall, Mars has a bond albedo of 16%. Though whether or not life can exist on Mars is still being studied, it is conceivable that it would be more habitable if it had a higher albedo and thicker atmosphere that would regulate its extreme temperatures.

What the albedos of the different planets tell us is that the albedo and atmospheric composition, which informs the greenhouse effect, must be analysed together in order to get a complete picture of the habitability of a planet. The greenhouse effect is a factor worth exploring when looking at habitable exoplanets. This effect describes the relationship between the heat of a planet and its atmospheric composition. The denser the gas layer on the planet is, the more heat will be trapped inside. Chemical profile and planetary size impact atmospheric thickness. Too thin an atmosphere might leave the planet without an insulating blanket and protective shield. The planet would then have a harder time trapping heat, while an atmosphere that is too thick might trap too much heat, both of which might deter the presence of life. Earth is sufficiently massive such that it holds an atmosphere about 100 kilometres thick, keeping the surface within a temperature range that can support life (Cowing, 2018).

There are some considerations other than the greenhouse effect and albedo that might affect the liquid water range on a planet (Figure 2; Hadhazy, 2013). Atmospheric pressure, for example, impacts water's freezing and boiling points and thus it can dictate the LWZ of an exoplanet. Higher pressures lead to lower freezing points and higher boiling points. Salinity has similar properties. The greater the salinity of water, the lower the freezing point and the higher the boiling point. Thus, life may be able to survive at temperatures lower than the freezing point or higher than the boiling point of distilled water under such stresses.

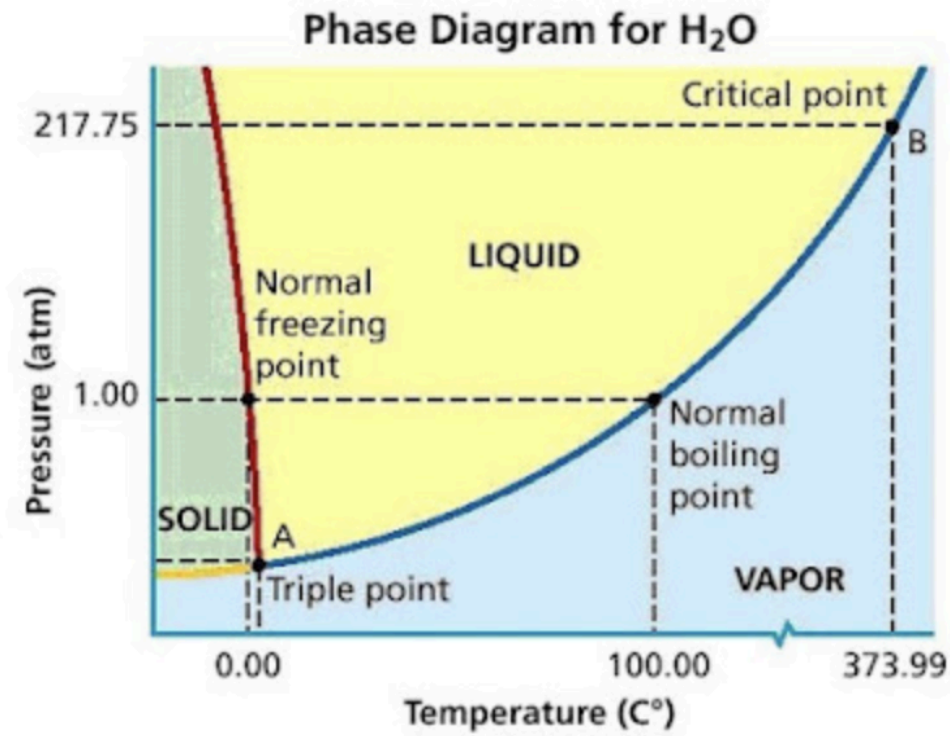


Figure 2: Phase diagram of pure water at increasing pressure and temperature. At higher pressures, liquid water can exist at higher temperatures (boiling point elevation) (Ernest, 2017)

Habitable Orbital Range and Eccentricity of Earth as a Reference

Calculating the outermost and innermost circular orbits, as well as the greatest degree of eccentricity a planet might possess that allows it to remain within the LWZ, is possible as long as the variables of luminosity of the star, bond albedo, greenhouse effect, and desired temperature are given. While these values differ depending on star and planet, by using an Earth-Sun analogous system as reference for habitable exoplanets, these calculations are possible. This approximation is reasonable as life is observed on Earth, thus Earth-Sun analogous systems are ideal candidates for exoplanet exploration. However, other systems should still be explored and the following calculations would need to be altered for such systems. Despite the importance of salinity and atmospheric pressure in regulating a planet's temperature parameters, since we cannot predict the prevalence of these factors on different exoplanets, it is most accurate to calculate a planet's orbital range as well as its eccentricity using the temperature constraints of the freezing and boiling points of pure water (H_2O) at 1 atm, between 0ºC (273.15K) and 100ºC (373.15K). Thus, our habitable zone definition is also based on these parameters. The $R_{maximum}$ = 2.355 x 10^{11} m, $R_{minimum}$ = 1.262 x 10^{11}m, and $e_{maximum}$ = 0.844 (Expanded on in Appendix A). The most eccentric orbit allowed by these constraints is shown in Figure 3.

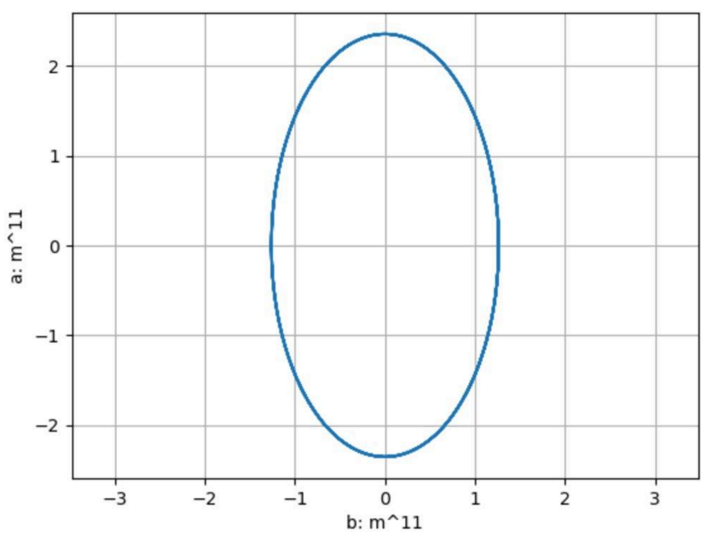


Figure 3. Visual representation of the most eccentric possible orbit of a planet in the solar system that allows it to remain habitable (See Appendix B).

Energy Source

Within the Milky Way Galaxy there exist many stars that may serve as sources of energy to the planets that orbit them. Stars akin to the Sun in size, longevity, composition, and more are classified as G stars. Conventional wisdom should direct life-exploratory efforts towards these types of stars, considering that the Sun has housed life for approximately 4 billion years. However, G type stars are far less abundant in the Milky Way Galaxy compared to smaller M dwarfs, which are also longer-lived and more likely to have Earth-akin planets within their LWZ. Though they offer some advantages, M dwarfs pose unique challenges as well (Brennan, 2021).

Accounting for Ionising Radiation

As M dwarfs are far smaller and dimmer than G stars, their LWZ is far closer to the star than in a G star system. This increases the intensity of ionising radiation on these planets by factors of up to hundreds of thousands (Brennan, 2021). Ionising radiation is characterised by the ability to break molecular bonds which occurs at frequencies encompassing UV light, X-Rays, and Gamma Rays. This form of radiation is particularly dangerous as it has the capacity to damage cells and DNA which can cause deleterious mutations (Gronstal, 2023). However, there is an intermediate K dwarf type star that might be the solution to the restrictions of both G stars and M dwarfs. K dwarfs fall between G stars and M dwarfs in abundance, luminosity, size, and thus both orbital radius of the LWZ and intensity of ionising radiation (Brennan, 2021). Henceforth, it is conceivable that some forms of life could thrive on Earth-analogue planets within the LWZs of K dwarfs. Considering that the Earth is able to shield some ionising radiation thanks to its atmosphere and magnetic field, if the hypothetical host planet also had these defences it would be able to orbit closer to its star, providing further evidence of the potential of a K dwarf system to host life (Gronstal, 2023). Such context points researchers towards searching for exoplanets capable of life primarily in K dwarf systems (Brennan, 2021). This also informs the appropriate definition of a habitable zone as the area around a minimum K dwarf sized star wherein pure liquid water can exist.

Binary Star Systems

Another characteristic to consider with respect to the energy source is whether the stellar system is single or binary. Though single star systems are assumed to be the ideal candidates to have exoplanets that possess habitable qualities, as they are analogous to the Sun, considering the abundance of binary star systems in the Milky Way, to ignore them would be injudicious (Anderson, 2022). As well, many exoplanets have been found orbiting binary stars, up to 143 as of July 2019 (Stewart, 2020). Various orbits are possible in these star systems, most notably including P-orbits, T-orbits, and S-orbits. P-orbits describe the behaviour of planets that orbit around both stars in a binary system. T-orbits describe the behaviour of a system in which one of the stars is very low-mass in comparison to the other, leading the smaller star to orbit the more massive one and the exoplanet to share its orbit. Exoplanets with T-orbits are only hypothetical, as none have actually been discovered, while both P-orbits and S-orbits have been shown to exist. Finally, S-orbits describe the behaviour of an exoplanet that orbits only one of the stars in its system. The star being orbited is referred to as the host star, while the other is the secondary star (Eggl, et al., 2012). The majority of known exoplanets in binary systems exhibit S-orbital behaviour (Stewart, 2020). This prompts the inquiry “can S-type binary stars harbour habitable worlds?” (Eggl, et al., 2012). The biggest difference between determining the habitable zone of single and binary star systems is that there is a third gravitational force to consider in binary star systems. This means there are additional gravitational influences on the planet’s orbit that lead to secular perturbations in the planet's orbit and eccentricity. It was concluded, though, that for planets with surface oceans and Earth-like atmospheres, intense dichotomies in insolation as a result of the aforementioned gravitational influence can be buffered up to an eccentricity of approximately 0.7, as long as the average insolation of the planet is comparable with that of Earth. The impact of the radiation of the secondary star is deemed negligible until it exceeds the luminosity of the host star by a factor of 4 (Eggl, et al., 2012). Thus, for a binary star, the habitable zone is constrained to exoplanets with S-orbits in which the luminosity of the secondary star is not greater than 4x that of the host star. Additionally, the planet must have surface oceans or an Earth-like atmosphere, alongside an eccentricity of no more than approximately 0.7 and an average insolation comparable to that of Earth. Further expanding these parameters to other binary orbit configurations may be possible, but more research must be done to substantiate the incentive to do so. The same parameters as previously discussed must also remain true, as the habitable zone must fall within the LWZ and the binary star system in total must not exceed the ionising radiation levels of approximately a K-dwarf.

Finalised Definition

In conclusion, a habitable zone is the zone that surrounds a star no smaller than a K-dwarf in which a planet could sustain temperatures between 273.15K and 373.15K. As is substantiated by the provided calculations, bond albedo, greenhouse effect, and luminosity of the star impact the habitable zone and thus must be considered in its definition. Binary star systems come with more complexity, but are also capable of hosting potentially habitable exoplanets. An important note to consider is that even if a planet met all the criteria for being within a habitable zone, it must still possess the necessary biogenic elements and a stable environment in which evolution can take place in order to sustain life (Croft, 2021). As well, some extreme circumstances can expand the parameters outlined in the habitable zone definition. In other words, not all planets in the habitable zone are habitable, and not all habitable planets are in the habitable zone. Rather, habitable zones are a worthy starting point in the search for extraterrestrial life.

2. Orbital Models

The Value of Coding in Modern Interdisciplinary Science

In recent times, computer programming and coding have taken on an increasingly vital role in many scientific disciplines. Due to the ability of computers to process information more rapidly than humans, coding has become a valuable tool in the analysis of large data-sets, the solving of intricate problems and modelling complex systems. In particular, the integration of computer code and mathematical models allows us to properly model and understand complex phenomena beyond what a human can achieve through manual computation.

Computer code is essential to the analysis of modern data sets, which tend to be too large for human analysis. Data analysis is vital to a range of scientific disciplines, from genetics to astronomy. One example is the field involved in the analysis of biological data sets, known as bioinformatics, which takes advantage of computational systems and their ability to better understand the vast array of information that genes carry. The Human Genome Project (HGP) (Chial, 2008) is an example of a large-scale analysis of biological data that made strong use of computer code. The ever-expanding nature of genetic data generated by the HGP necessitated the development of various computer databases capable of effectively managing and organising the growing dataset. These databases include tools such as the Entrez browser, a service courtesy of the National Center for Biotechnology Information which retrieves both DNA and protein sequences (Bayat, 2002).

Along with data analysis, computer code can be used to create mathematical models of complex systems. This is particularly useful in the field of physics and chemistry, where elaborate phenomena are often simplified into models in order to make and test predictions. These models have real world applications. For example, mathematical and computational modelling can aid in the creation of fluid models that enhance our understanding of fluid dynamics (Tillman, et al., 2012). Using similar computational techniques, we can use computer code to model planetary orbits by mathematical means.

In order to illustrate how computer code can be used to solve mathematical problems that would otherwise be extremely difficult to solve algebraically, we use the example of question 6 of Computer Lab 1a, in which we use computer code to approximate the solution to the equation $f(x) = ln(x) + 2x^2$ by the Intermediate Value Theorem (IVT) (Figure 4).

```
In [6]: ## using IVT to find solutions of equations

        a = 0.1   # keep in mind that there is a logarithm involved!!!
        b = 0.9
        n = 10000

        x = np.linspace(a,b,n+1)
        y = np.log(x) + 2*(x**2) # change function in this line (note that ln(x) is np.log(x) in Python)


        # no need to change this part, or anything below
        for i in range (1, n+1):
            if y[i-1] == 0.:
                print("One solution of f(x)=0 is", x[i-1])
            if y[i-1] * y[i] < 0.:
                print("f(x)=0 has a solution between", x[i-1], "and", x[i])
            if y[i] == 0.:
                print("One solution of f(x)=0 is", x[i])

        plt.plot(x,y)
        plt.grid()
        plt.show()
```

Figure 4. This code generates n+1 values of x on the interval [0.1, 0.9], then evaluates $y = f(x)$ *at each of those values of x. A for-loop is then used to determine if a solution to f(x) exists on the interval between subsequent generated values of x, or is equal to one of those values of x (iTeach, 2023).*

In a problem such as this, where we try to find a solution or "root" of a function, we would initially try to find a solution algebraically. Setting $f(x)$ equal to 0, we can rearrange such that $ln(x) =- (2x^2)$. This is impossible to solve algebraically because the value of $ln(x)$ can never be negative. However we know by the IVT that, since the function is continuous and changes signs between $f(0.1)$ and $f(0.9)$, the equation does have a solution on the interval [0.1, 0.9]. Thus we can use computer code to approximate the point at which $f(x)$ intersects the x-axis. In our code (Figure 5), we define the value x, restricted to the domain [0.1, 0.9], the value $y = f(x)$, and the number of x-values generated on that interval. We then use a for loop to iterate the value of y for each x value we generated, checking whether the sign of $f(x)$ changes between any two subsequent x values. This allows us to narrow down the final interval on which $f(x)$ has a solution to [0.58416, 0.58424]. Thus we can say that the function has a solution at $x = 0.5842$, accurate to 4 decimal places.

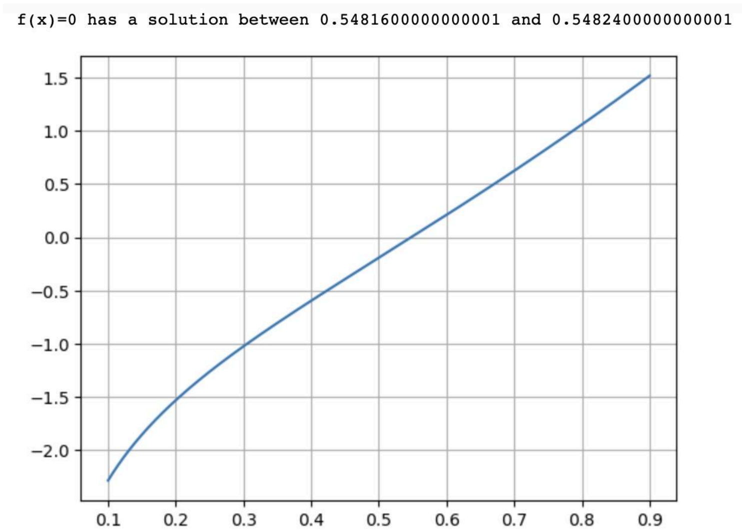


Figure 5. This graph represents the function $f(x) = ln(x) + 2x^2$ *on an interval [0.1, 0.9]. The statement above indicates that f(x) has a solution on the interval [0.58416, 0.58424], as determined through the code in Figure 4.*

Modelling Planetary Orbits Using Mathematical Models in Python

To model the motion of planetary bodies using computer code, we can use parametric equations and special functions within Python to approximate the orbital paths we are modelling in two dimensions. In addition to being able to generate these representations of planetary orbits, Python allows us to find the intersections and collisions between two orbital paths. This is exemplified in the problem from Computer Lab 1a, where we must find the intersection and collision points between the paths of two particles, as shown in Figure 6.

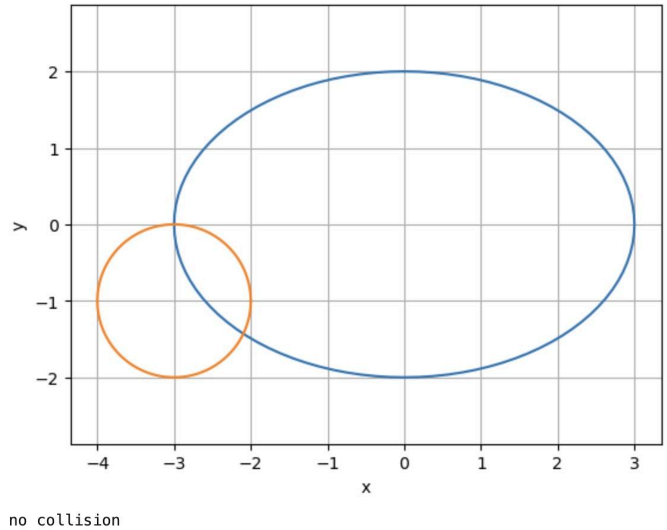


Figure 6. Graphical representation of the parametric curves defined by the parametric equations below. Two intersection points between the curves can be identified visually. See Figure 7 for code used to generate these curves.

Given two curves, defined as (x_1, y_1) and (x_2, y_2), the intersections can be determined by plotting these curves using Python (Figure 7). Through examining the graphical representation, we can observe two points of intersection between the two curves. Determining collision points, however, is more complicated. A collision is defined as the intersection of the two curves at the same time, *t.* Since the x and y coordinates of a parametric curve are defined as functions of *t,* $(x(t),\ y(t))$, we can find collision points by searching for a value of t where both the x-coordinates and y-coordinates of each curve are equal to each other (Figure 7).

$$x_1 = 3sin(t)$$

$$y_1 = 2cos(t)$$

$$x_2 = cos(t) - 3$$

$$y_2 = sin(t) - 1$$

```
[15]: # code for problem 5

n = 100
t = np.linspace(0,2*np.pi,n+1)

x1 = 3*np.sin(t)
y1 = 2*np.cos(t)

x2 = np.cos(t) - 3
y2 = np.sin(t) - 1

plt.plot(x1,y1)
plt.plot(x2,y2)
plt.xlabel('x')
plt.ylabel('y')
plt.axis('equal')
plt.grid()
plt.show()

def collision(time):
    for i in range(len(t)):
        if (x1[i] == x2[i]) and (y1[i] == y2[i]):
            return "collision at " + t[i]
    return "no collision"

print(collision(t))
```

Figure 7. In order to generate the parametric curves in Figure 6, the module MatPlotLib is used to plot the curves based on the equations above (iTeach, 2023). To find collision points, we define a function, wherein we use a for-loop to check whether the x- and y-coordinates at each value of t are equal to each other, and return that value of t if so, and the string "no collision" if not.

As illustrated in the prior example, the integration of Python code and mathematics is an excellent tool to model planetary orbits. Parametric equations, in particular, allow us to define circular and elliptical paths that approximate planetary motion. In order to parameterize circular and elliptical curves, we generally define x and y as some sinusoidal function of t, either cos(t) or sin(t), modified in some way in order to better resemble the orbital paths we seek to model. For instance, a parametric curve defined as $(x, y) = (cos(t), sin(t))$ will create a circle with a radius of 1. By creating parametric equations for circular orbits based on these sinusoidal equations, we can graphically represent the minimum and maximum orbital radii for the habitable zone of the solar system, along with Earth's orbit (Figure 8). In order to stretch the curve to represent the maximum and minimum orbits, we multiply the parametric equations of x and y by the maximum and minimum orbital radii, divided by a factor of 10^{11} (Appendix B), such that x_1 and y_1 are stretched by a factor of 1.26, and x_2 and y_2 are stretched by a factor of 2.355. Similarly, parametric equations for Earth's orbit are generated by stretching x_3 and y_3 by a factor of 1.49, as Earth's average orbital radius is 1.49×10^{11} m (Williams, 2014). The resulting graph of each of the curves represents the average orbital radius of Earth and the maximum and minimum radii of the habitable zone.

In addition to using parametric equations to study planetary motion and orbital paths, we can use polar coordinates to more accurately define orbital position relative to the Sun. Polar coordinates are defined by (r, θ), where r is the radius and θ is the angle of the radius from a reference axis, usually the positive x-axis. This is contrasted with the traditional Cartesian coordinates used above to define our parametric curves, where (x, y) describes the x- and y-coordinates relative to some Cartesian plane with perpendicular axes, the x-axis and y-axis. In cases of circular and elliptical motion, such as planetary orbits, where there is no clear x- and y-axis defined, polar coordinates can be a more useful and substantial mathematical description of planetary position relative to the Sun.

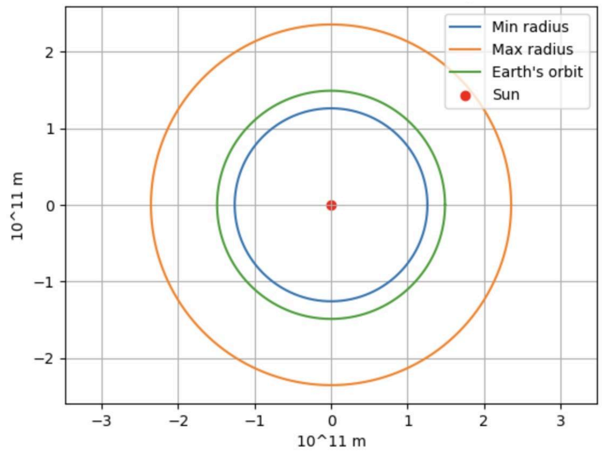


Figure 8. The minimum and maximum allowed orbits for the solar system's habitable zone, as well as the mean orbit of the Earth around the Sun, represented graphically in two dimensions using Python code written in Jupyter (See Appendix B)

3. Solar System Analogue Environment

Primary Goals

Our Mars mission aims to identify potential lipid traces within Martian sediments. Such findings would provide compelling evidence of either past or ongoing life on Mars. By exploring analogous planets for signs of life, we can also gain valuable insights into their potential for developing biosystems capable of supporting human habitation on exoplanets.

Analogous to Earth's history, Mars is currently in its Amazonian period, approximately 2.9 billion years from present Earth conditions. Its surface geology is characterised by barren, cold, and hyperarid conditions, which seem to indicate a lack of life. Regardless, given Mars' likely history of liquid water on its surface, microscopic remnants of historic life could remain in certain Martian environments, particularly fossilised remains in its subsurface (Finkel, et al., 2023). Present life could also be found preserved beneath ground, sheltered from the harsh contemporary surface conditions on Mars.

Consequently, geological samples extracted from Mars may contain specific indicators of past life. Biomarkers, which are distinctive biochemical substances shared among various life forms, are of particular interest in this context. DNA, RNA, proteins, and lipids are all considered biomarkers. Lipids, in particular, are very well preserved over long periods of time and are resistant to harsh conditions, setting them apart from other potential biomarkers (Finkel, et al., 2023; Simoneit, et al., 1998). Most importantly, lipids are considered precursory to the generation of life on Earth, and are thus shared by most if not all cellular life, found even in the Last Universal Common Ancestor (LUCA) (Glansdorff, et al., 2008). On Earth, most environments analogous to present and past conditions on Mars host some degree of extremophilic organisms. While many of these extremophiles fall outside of the Eukarya domain, lipid biomarkers are present even amongst these single-cellular microorganisms, further displaying the effective membrane-forming properties of lipids, even in geochemically hostile environments (Finkel, et al., 2023). Lipids are also especially useful in detecting life on exoplanets given their unique abilities to retain diagnostic information about their sources for thousands of millions of years, an extremely helpful feature given the vast geological ages of planetary bodies. Conclusively, the presence of lipids in the sediments of planets such as Mars would have remarkably high confidence in predicting any historic presence of life. Searching for lipids on Mars thus also has significant implications in our search for habitable analogous exoplanets, as we can learn from the current and past conditions in which Mars may have had or continues to host life.

Experiment Design

Gas chromatography-mass spectrometry (GC-MS) is an established method of detecting and identifying organic compounds in sample mixtures, which could be used to detect lipids preserved in extraterrestrial sediment samples (Tan, et al., 2018). Analysis starts with the gas chromatograph, where a sample is vaporised into the gas phase to be separated into its individual chemical constituents in a capillary column. As each compound is separated, they're removed from the column at a different time based on certain chemical characteristics, called their retention time. As they leave the column, they are further fragmented by a mass spectrometer, where ions can be separated and analysed for compound identification based on commercially available libraries of mass spectra ratios. The legitimate applicability of this method to our project is supported by a 2018 experiment that investigated lipid degradation of Mars-Analogue mineral contents in Martian environments using GC-MS.

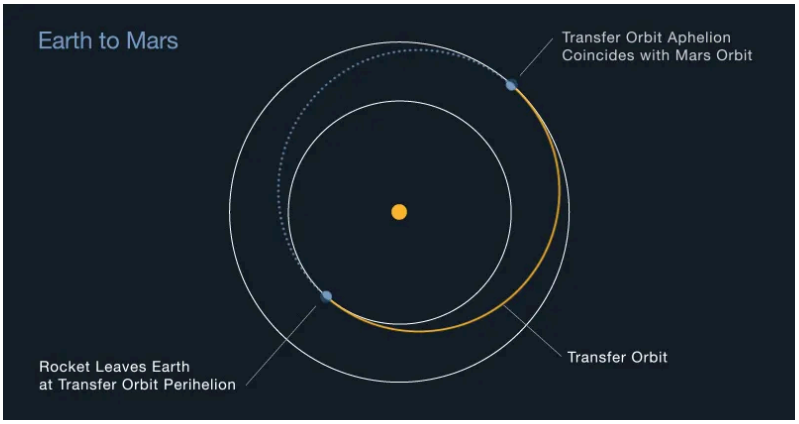


Figure 9. The Hohmann transfer orbit from Earth to Mars takes advantage of Earth's angular momentum to launch a spacecraft along Earth's orbit at its perihelion when it is closest to the sun. (NASA, 2023b).

Thus, we'd like to propose a Lander-Rover expedition to Mars equipped with GC-MS technology in order to search for lipids, and consequently, past life on Mars. It is best that this mission remains unpiloted out of practicality. For one, the journey to Mars is long: Mars is about 55 million kilometres away at its closest point, with the travel time lasting an average of 7 months (Ho, 2023). However, with Earth and Mars orbiting the Sun at different speeds and distances (Learn, 2021), this travel time can vary, with the most efficient path only opening up every 25-26 months, or around 2 years. This path considers the use of Hohmann transfer orbits, flight trajectories that allow spacecraft to optimise energy expenditure (NASA, 2023b). When travelling between planets, it's important to choose a flight path that requires the least amount of fuel in order to be economically aware. Thus, spacecraft are launched in the direction of Earth's revolution around the Sun for an added acceleration; we can take advantage of Earth's angular momentum when a spacecraft is launched at periapsis, with an orbit to have an aphelion within Mars' orbit (Figure 9). There is then the additional consideration that the spacecraft must intersect Mars' orbit when Mars is at that position, in order to have a minimum-energy transfer orbit. All these factors lead to the 25-26 month opportune trajectory, which would mean piloted missions would be away from Earth for extremely long periods of time. (Nasa, 2023b). Aside from technology, as it stands, we don't know enough about how a human body would survive outside Earth for several months or even years of space travel, introducing inherent and tremendous risk to human health. One prominent example would be the effects of cosmic radiation and an increased risk for cancer. What's more, very little is known about the mental implications of extended space-travel time as well. (Learn, 2021). Social decline would influence scientific processes, exacerbated by certain detrimental social behaviours of a crew stuck together with no escape for many months, such as negative groupthink. While current simulations such as NASA's CHAPEA (NASA, 2023a) have set out to address these shortcomings, current technology dictates that a piloted mission to Mars is dangerous, if not completely unrealistic (Finkel, et al., 2023). As our current proposed mission using modern GC-MS technology and related spacecraft equipment remains perfectly feasible unpiloted, adding a human factor to our experiment would not imbue our mission of any significant importance.

Our Lander-Rover expedition is loosely inspired by NASA's 1997 Pathfinder-Sojourner mission, which, while not its primary goal, similarly employed scientific instruments to analyse Martian geology and sediment composition (NASA, 2023). A lander spacecraft could be sent to land on the surface of Mars, deploying an integrated rover to explore Mars' topology and collect sediment samples for analysis using GC-MS. Our ideal landing site would be near a crater on Mars, particularly those that contain clay sediments as an indication of possible subsurface liquid water. It has been generally accepted within the scientific community that Mars once had vast regions of liquid water, which remains evident today in small amounts within the planet's ice caps and atmosphere. In a 2021 study by Scheller, et al., it was hypothesised that the rapid disappearance of liquid water on Mars' surface was attributed to water sequestration due to atmospheric escape and irreversible chemical weathering. In Mars' Noachian period, water would have potentially followed a similar water cycle as the one found on Earth, but as time went on water was locked into Mars' crust, up to the point that the only atmospheric water exchange was between polar ice caps and Mars' atmosphere (Scheller, et al., 2021). In the atmosphere, water vapour is split into hydrogen and oxygen, of which hydrogen, being such a light atom, can be easily blown out away by solar winds due to Mars' thinner atmosphere, partially contributing to water loss on Mars (Jakosky, et al., 2017). Alternatively, on Earth, hydrated sediments can re-evaporate into the atmosphere due to its dynamic crust, which shifts sediments around, releasing water molecules from sediments' crystalline structures. However, Mars' stable crust and a lack of movement allows water to chemically bind to mineral structures, locking it in. Using simulations on Mars' historical topography, Scheller, et al. framed crustal hydration as a water sink, with water lost through crystal hydration and atmospheric escape varying in ratios up to a maximum of 99:1 respectively. (Scheller, et al., 2021). This strongly suggests that the liquid water on Mars did not disappear, rather it was relocated beneath Mars' surface (Figure 10) and can now only be found in subterranean environments, which is consequently where we have the highest chance of finding life.

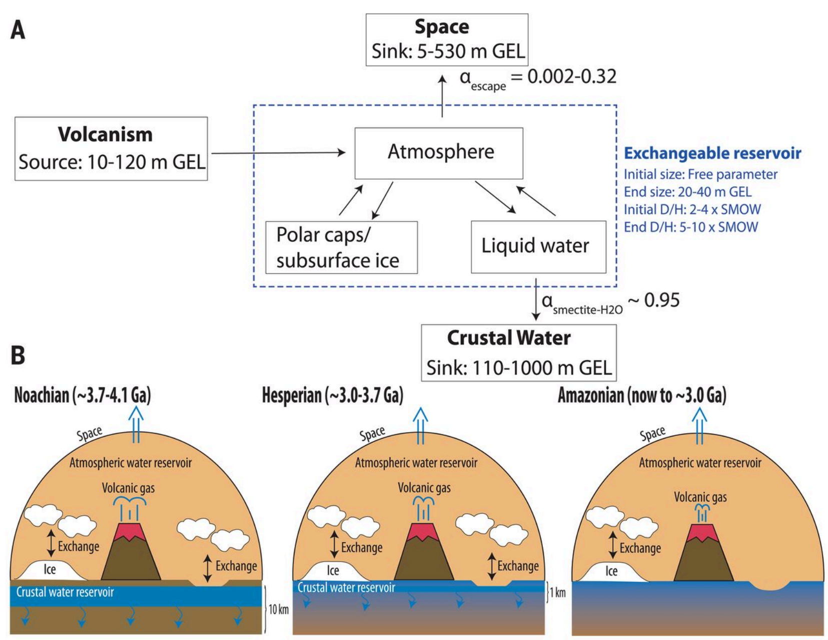


Figure 10. Diagram illustrating possible water movement on Mars (Scheller, et al., 2021).

Modelling Life on Mars

Water appears to be a strict precursor to life, even within extraterrestrial environments, because life requires liquid solvents for particulate transfer through membranes. Water is further considered the most likely cosmic solvent due to its abundance across various extraterrestrial bodies, as well as its physicochemical properties, such as its polarity. (Schwieterman, et al., 2018). While some extremophiles have been found to survive on very little water, no known organism has yet to be identified as surviving on no water altogether. While life may exist on extrasolar planets, the search for life on Mars must be limited to our current understanding of life. Thus, liquid water, even in miniscule amounts, is imperative to the survival of carbon-based life and, further, clay is critical in finding liquid water on Mars. On Earth, most clay minerals form when sediments are exposed to water or steam for elongated periods of time, breaking the molecules down into small and fine particles less than two micrometres in diameter. Moreover, clay minerals share similar chemical compositions and crystal structures that allow them to have a great affinity towards water molecules. Assuming analogous origins for clay on Mars, these characteristics indicate that clay sediments have a close relationship to the presence of liquid water. The presence of older clay sediments may signify a historical presence of water, while younger clay formations may lead us to present subterranean liquid water. (Foley, 1999). On Earth, clay sediments are mostly found in the upper layer of our crust. Similarly, on Mars, clay sediments have been found near the surface thanks to impact craters which expose and disturb the sediments making up Mars' upper crust.

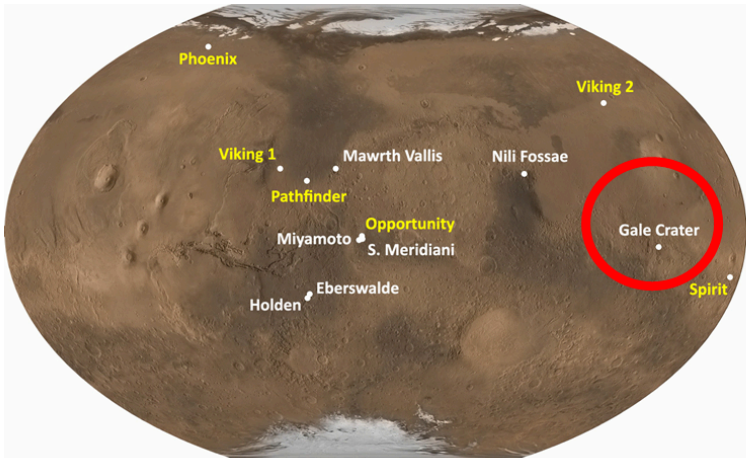
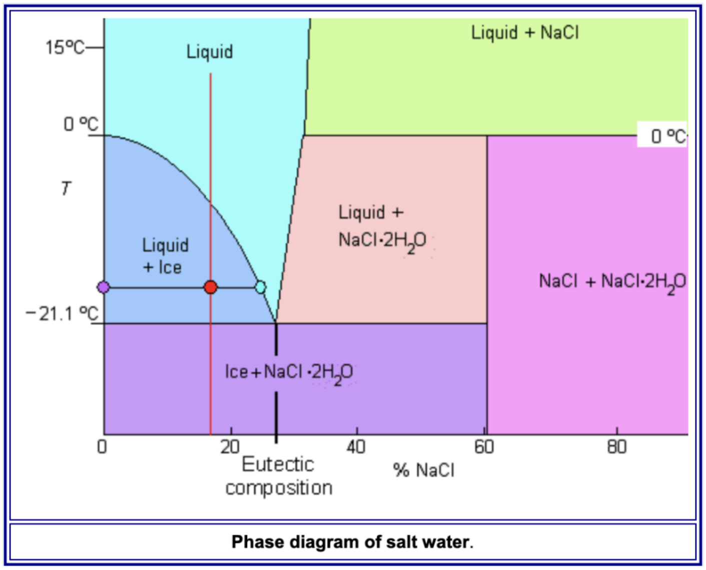


Figure 11. Location of Gale Crater on Mars (CNES, 2011).

Gale crater (Figure 11) is one example of a region on Mars where liquid water has been hypothesised to have existed in the past due to mineral remnants of glauconitic clays. The makeup of this mineral further suggests that stable conditions with temperatures around -3 to 15 degrees celsius may have existed in this region, conducive to the possibility of life. (O'Callaghan, 2021). Additional hydrated silicas and water-rich fracture halos have also been found in the Gale Crater, substantiating a possibility of past and present liquid water in this location. In fact, past missions to Mars have generated powerful evidence proposing that Gale Crater was once a Martian saline paleolake, an effective host for ancient aqueous ecosystems (Ho, n.d.). Saline environments, curiously, have unique properties that would suggest the presence of liquid water (Figure 12). By lowering the freezing point, saline water trapped beneath the Martian sediment would remain liquid, as opposed to forming ice crystals within the soil.



Phase diagram of salt water.

Figure 12: Phase diagram of salt water, showing the phases of water at increasing concentrations of NaCl and increasing temperatures. At higher salinities, liquid water can exist at lower temperatures. (Föll. 2012.)

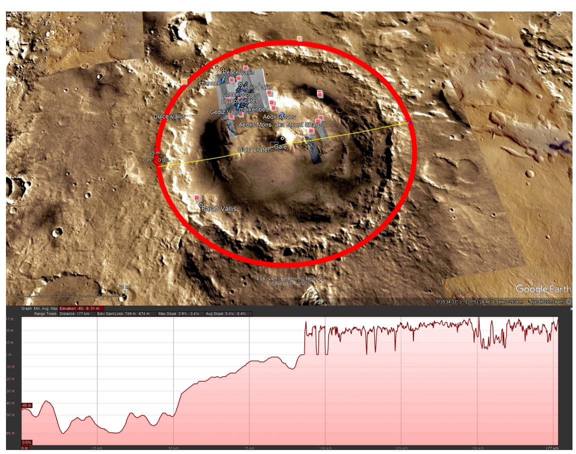


Figure 13. Elevation profile of Gale Crater on Mars, min elevation at -65m and max elevation 9m. Low elevation indicates a good landing site (Google, 2023).

Furthermore, on Earth, saline paleolake environments are well studied, with plenty of past research regarding microbial communities and lipid biomarkers that would indicate past life, to compare to an analogous location on Mars, that being the aforementioned Gale Crater (Finkel, et al., 2023). Conclusively, the possible presence of water makes Gale crater a reasonable landing site to choose, in combination with its suitability for spacecraft landing. A safe landing site has to have a low elevation to allow for the longest descent, no large rocks or otherwise possibly dangerous landforms, and be within a temperate enough climate that the spacecraft would be able to remain intact and functional (NASA, 2023). Gale Crater meets all of these criteria, with an elevation of 4400m below Martian sea level, flat topography, and coordinates close to the equator. Environments near the equator are important, as the climate remains the most stable without vicious day-night weather cycles, as well as plenty of solar radiation to be repurposed into solar energy if needed (Ho, n.d.). Interestingly, Gale Crater was selected as the final landing site for NASA's Mars Curiosity Rover in a foundational search for water on Mars.

In Closing

Prospectively, our lander-rover mission to Mars' Gale Crater would send a spacecraft along the Hohmann Transfer Orbit, dispatch a surface rover to collect sediment samples, and return the samples to the lander for gas chromatography sample analysis in detection of lipids. Furthermore, if lipid compounds are able to be identified by consequent mass spectrometry, they can be cross-compared to libraries on Earth, providing insight into the types of biological organisms that may have once been present on Mars. The utilisation of a rover expands the scope of our sample, as a penetrative spacecraft or other methods of sample collection would be limited to around the landing site only. If lipids are able to be located on Mars, extinct or extant life could subsequently be predicted on Mars. Through searching for lipids, it's possible we would find either past or current life, and we could predict the age of the lipids through carbon and isotopic dating. Identification of fossilised sediments would suggest historic life, while the identification of younger intact lipids may suggest more recent life. As we are searching for life on Mars based on the assumption that it would share characteristics with cellular life on Earth, if life were to be found on Mars through identification of lipids, significant implications could be had on the definition of cellular life and the origins of cosmic life. For one, if life on Mars and Earth are similar, it may suggest a common ancestor between the two as well as the possibility that life started on another planet, and was then transferred to Earth in which life flourished due to Earth's habitability. Moreover, if Mars indeed hosted Earth-like life, it raises questions about the historical habitability of Martian climate. This information could further be invaluable in the search for habitable planets beyond our solar system through offering insights into the conditions that led to the decline of life on the Martian surface. Conclusively, our mission endeavours to uncover potential life on Mars while reshaping our understanding of life's origins and its existence in the cosmos.

4. Earth Analogue Experiment

Research Questions

While reading through and undertaking this lab, students should keep the following questions in mind:

1. What is a good bio-marker to detect past or present life on Earth? Can we apply this biomarker to the Martian environment?
2. How can we detect and analyse bio-markers on Mars?

Project Rationale

When looking for life on Mars, a helpful starting point is analysing life on Earth. While there is a great diversity of organisms on Earth, they are all composed of cells. An integral part of all cells is the cell membrane; a semipermeable membrane composed of organic compounds including lipids. On Earth, lipids can be found in soil as evidence of animals, plants, microorganisms or decomposing organic matter (Ding, et al., 2020). Since lipids continue to display membrane-forming properties even in harsh conditions, they are effective biomarkers in the search for potential past or present life on Mars.

In this lab, students will learn how to extract and analyse lipids from substances. First, students will use the Folch method to extract lipids from foods, specifically from avocados and egg yolks. The Folch method is the predecessor to the Bligh and Dyer method, which is used for extracting lipids from soils (Brewer, et al., 2015). Typically, the Folch method employs a 2:1:0.75 ratio of chloroform:methanol:water/salt solution to partition a substance into a biphasic system of lipid and non-lipid phases (Saini, et al., 2021).

After performing successful lipid extractions, students will analyse their samples using thin-layer chromatography (TLC). TLC separates the different chemical components of a mixture using a stationary polar phase and a mobile non-polar phase (Fuchs, et al., 2011). A TLC plate, the stationary phase, is dabbed with a sample and then inserted into a chamber filled with a solvent, the mobile phase (Figure 14). Once the solvent has risen to the top of the TLC plate, the results may be visualised by means of UV light or staining.

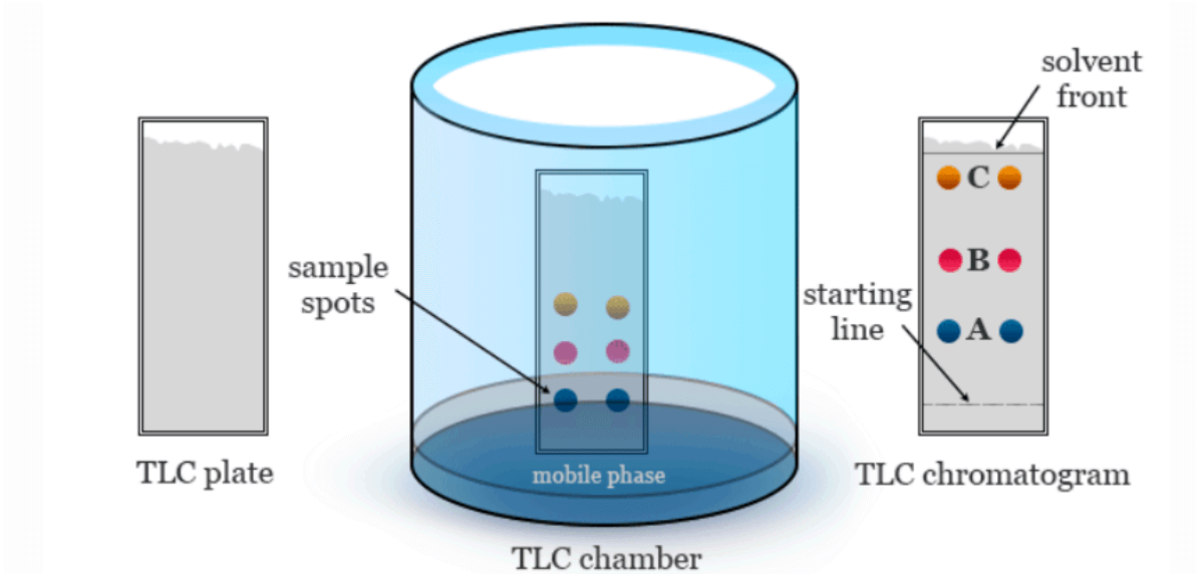


Figure 14. Thin-layer chromatography, a method of chemical analysis used to separate different components of a mixture. Students will use it to analyse the polarity of lipids within different lipid extractions. (Sonika, 2023).

Hypothesis

It is hypothesised that TLC results will show that lipids of various polarities are found in the lipid extracts. Therefore, if similar experiments were to be carried out on Mars, vital lipids of various polarities would be found during analysis.

Pre-lab Questions

1) Research the MSDS of chloroform and methanol. Report the hazard statements for each, as well as what protective equipment should be worn while handling each chemical.
2) A 1 g tissue sample containing 1 mL of water is to be analysed using the Folch method. A 20 mL chloroform:methanol solution is created and mixed with the tissue sample to

help extract lipids. How much NaCl solution should be added to fulfil the 2:1:0.75 chloroform:methanol:water/salt solution ratio?

ANSWER: The 2:1:0.75 ratio may be condensed to a 3:075 ratio, seeing as students are given an amount for the chloroform:methanol solution. Letting the initial ratio = 3:0.75 and the new ratio = 20:x, students must solve for x. Students must then subtract 1 from x, as 1mL is the initial amount of water in the tissue. The answer is 4 mL.

Materials

- 2 g of egg yolk
- 2 g of mashed avocado flesh
- 100% chloroform
- 100% methanol
- 0.73% saline (NaCl solution)
- 15 mL test tubes and test tube caps
- Test tube rack
- P 1000 and blue micro-pipette tips
- 10 mL glass pipettes and rubber pipette bulbs
- Pipette waste beaker
- Benchtop centrifuge
- Pre-prepared TLC chamber, includes:
- 6.5 x 3 cm silica-coated TLC plates

- Resublimed iodine crystals
- 250 mL mason jar

Lab Personnel:

- Russ Ellis, Lab Coordinator
- Chemistry Teaching Assistant (TA)

Before the Lab

Food samples will be prepared before the lab. Avocado flesh must be ground into a fine paste, as well eggs must be cracked and their yolks separated. 2 g of each food sample will be placed in 15 mL test tubes and distributed to each fume hood.

Additionally, solvent solution and TLC chambers must be prepared. Working under a fume hood, petroleum ether, diethyl ether and anhydrous acetic acid must be mixed at a ratio of 84:15:1. 250 mL beakers must be filled to a height of 0.7 mm with solvent solution, filter paper must be added and watch glasses must be placed atop each beaker. TLC chambers can then be left at each fume hood to equilibrate for 10 minutes.

Procedure

Exercise 1 - Creating a Chloroform:Methanol Solution

1. Working in a fume hood, begin by labelling a 15 mL test tube as "chloroform:methanol."
2. Use a glass pipette to add 4 mL of chloroform to the test tube. Place the pipette into the pipette waste beaker.
3. Using a new glass pipette, add 2 mL of methanol to the test tube.

4. Cap the test tube and invert it 5 times. Place the solution aside on your test tube rack.

Exercise 2 - Lipid Extraction

1. Working under the fume hood, use a pipette to add 1 mL of chloroform:methanol solution to the 2 g avocado sample. Place a cap on the test tube and shake for 30 seconds.
2. Using a P1000 and a blue tip, add 250 µL of 0.73% saline solution to the avocado sample. Dispose of the tip. Cap the tube and shake for another 30 seconds.
3. Repeat steps 1-2 for the 2 g egg yolk sample.
4. Spin the test tubes in a benchtop centrifuge for 2 minutes at 2,500 rpm. Remove the tubes when done, being sure not to disturb the phase separation.
5. Using a pipette, transfer the top methanol-water phase from the avocado sample into liquid waste. Transfer the remaining chloroform-lipid phase to a fresh test tube and label it.
6. Repeat step 5 for the egg yolk sample and place both tubes on the rack. Dispose of any used pipettes into the designated beaker.

   ASSESSMENT 1: The biphasic systems created in the samples involve methanol-water and chloroform-lipid phases. The lipids are drawn to the chloroform, and water to the methanol. What can you hypothesise about the polarities of both substances?

   ANSWER: Lipids are nonpolar, thus they will be drawn to the non-polar phase. Therefore, chloroform is nonpolar. Water is polar and drawn to the polar phase. Methanol is polar.

Exercise 3 - TLC Analysis of Lipid Extracts

1. Using a pencil and a ruler, lightly draw a line across the TLC plate 1 cm from the bottom. Split the plate into two lanes. Label one as avocado, and the other as egg yolk.
2. Using a P10 and a yellow tip, spot 5 µL of the avocado extract on the starting line in the appropriate lane. Let it dry. Spot 5 µL another 4 times for a total of 25 µL. Dispose of the tip.
3. Repeat step 2 for the egg yolk extract.
4. Place the plate into the TLC chamber, in front of the filter. Place the watch glass back on top and allow the solvent to move up the plate.
5. While the plate develops, place 5-10 iodine crystals into the 250 mL mason jar. Close the jar and place the iodine chamber aside.
6. Once the solvent is approximately 1 cm from the top of the plate, remove it from the chamber. Mark where the solvent has reached with a pencil. Let the plate dry.
7. Once the plate is dry, place it into the iodine chamber, securing the lid. Allow the plate to sit until stained (about 3-5 minutes). Once stained, lightly outline the spots with a pencil.
8. Clean up once done. Leave TLC chambers at fume hoods. All chemicals must be poured into liquid waste and glass pipettes must be put in the appropriate waste beaker. Rinse any test tubes, remove any labels, and leave them to dry on the test-tube racks.

   ASSESSMENT 2: As mentioned above, TLC plates are typically polar, while solvent solutions are non-polar. During TLC, chemical components separate based on polarity.

   a) On your TLC plate, draw an arrow to represent the direction in which polarity is increasing. Label it as such and submit a picture.

b) Explain what this indicates about the interaction between chemical components, TLC plates and solvents.

ANSWER:

a) The arrow should be pointing towards the baseline on the plate.

b) Polar components stay near the baseline, as they stick better to the polar TLC plates. Non-polar components move with the solvent away from the baseline. This is because the solvent is also non-polar.

ASSESSMENT 3: The retention factor (R_f) is used to report the results of a TLC plate. To measure R_f, use the equation:

$$R_f = \frac{distance\ travelled\ by\ compound}{distance\ travelled\ by\ solvent\ front}$$

In this equation, distance travelled by compound is the measurement from the baseline to the compound's new location (middle of spot). Distance travelled by solvent front is the measurement from the baseline to the solvent front. R_f values should be between 0 and 1.

a) Calculate the R_f of each spot and note them on the TLC plate. As polarity increases, does the R_f increase or decrease? How about when polarity decreases?

b) If lipids extracted from Martian soil were shown to contain a type of lipid with an R_f of 0.22, what does the polarity of this lipid type indicate?

ANSWER:

a) As polarity increases, the R_f decreases and vice versa.

b) It would indicate a lipid with a higher polarity, which would be a phospholipid. This is important, as phospholipids are a key component of cell membranes, found in all organisms. Thus, phospholipids are a good bioindicator for life.

Rubric

Pre-lab Question 1:

Score (/2)	0	1	2
	Student has provided no answer or incorrect hazard information.	Student has provided a partially correct answer, but is missing one component.	Student has provided correct hazard statements and protective gear.

Pre-lab Question 2:

Score (/2)	0	1	2
	Student has provided no answer or incorrect answer with no steps.	Student has provided incorrect answer, but has shown the relevant steps.	Student has provided correct answer with the correct steps.

ASSESSMENT 1:

Score (/2)	0	1	2
	Student has provided no answer or an irrelevant hypothesis.	Student has provided a partially correct hypothesis, but lacks detail.	Student has a correct hypothesis.

ASSESSMENT 2:

Score (/3)	0	1	2	3
	Student has provided no answers or an incorrectly labelled plate and no explanation.	Student has provided the proper labelling but an incorrect explanation.	Student has provided the proper labelling and a semi-correct explanation, but lacks detail.	Student has provided the proper labelling and a correct explanation.

ASSESSMENT 3:

Score (/3)	0	1	2	3
	Student has provided no answers or incorrect answers with irrelevant explanations.	Student has identified the correct relationship between R_f and polarity, but has failed to apply this knowledge to lipids on Mars.	Student has identified the correct relationship between R_f and polarity, and has semi-correctly applied this knowledge to lipids on Mars.	Student has identified the correct relationship between R_f and polarity, and has correctly applied this knowledge to lipids on Mars.

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6. Appendices

Appendix A - Orbital Parameter Calculations

Given:

$T_{maximum} = 373.15$ K

$\sigma = 5.67 \times 10^{-8}$ $Wm^{-2}K^{-4}$

$T_{minimum} = 273.15$ K

Greenhouse Effect = 0.816, a = 0.299

$L_{\odot} = 3.846 \times 10^{26}$ W

Required:

$R_{maximum} = ?$ m

$R_{minimum} = ?$ m

$e_{maximum} = ?$

Equations:

$$T = \sqrt[4]{\frac{(Greenhouse\ Effect)\times(L_{\odot})\times(1-a)}{4\pi\times(\sigma)\times(R)^2}}$$

$$R = \sqrt{\frac{(Greenhouse\ Effect)\times(L_{\odot})\times(1-a)}{4\pi\times(\sigma)\times(T)^4}}$$

$$e = \sqrt{1 - \frac{R_{minimum}^{2}}{R_{maximum}^{2}}}$$

Analysis:

$$R_{minimum} = \sqrt{\frac{(Greenhouse\ Effect)\times(L_{\odot})\times(1-a)}{4\pi\times(\sigma)\times(T_{maximum})^4}} = \sqrt{\frac{(0.816)\times(3.846\times10^{26})\times(1-0.299)}{4\pi\times(5.67\times10^{-8})\times(373.15)^4}} = 1.262 \text{ x } 10^{11}\text{m},$$

$$R_{maximum} = \sqrt{\frac{(Greenhouse\ Effect)\times(L_{\odot})\times(1-a)}{4\pi\times(\sigma)\times(T_{minimum})^4}} = \sqrt{\frac{(0.816)\times(3.846\times10^{26})\times(1-0.299)}{4\pi\times(5.67\times10^{-8})\times(273.15)^4}} = 2.355 \text{ x } 10^{11}\text{ m},$$

$$e_{maximum} = \sqrt{1-\frac{R_{minimum}^2}{R_{maximum}^2}} = \sqrt{1-\frac{(1.262\times10^{11})^2}{(2.355\times10^{11})^2}} = 0.844$$

Therefore:

$R_{maximum} = 2.355 \text{ x } 10^{11}$ m, $R_{minimum} = 1.262 \text{ x } 10^{11}$m, $e_{maximum} = 0.844$

Appendix B - Python Codes for Orbital Parameters

In [9]:
```
#Imports
import numpy as np
import math
import matplotlib.pyplot as plt
%matplotlib inline
```

In [11]:
```
#2D Parametrics
n = 1000
a = -15
b = 15
t = np.linspace(a,b,n+1)

x1= 1.262*np.cos(t)
y1= 2.355*np.sin(t)


plt.plot(x1,y1)
plt.xlabel('b: m^11')
plt.ylabel('a: m^11')
plt.axis('equal')
plt.title('Most Eccentric Orbit Allowed')
plt.grid()
plt.show()
```

Figure 15. Code for Figure 3, utilising parametric equations to graph an ellipse from maximum and minimum orbits to find max eccentricity (iTeach, 2023).

```
[2]: import numpy as np
     import math
     import matplotlib.pyplot as plt
     %matplotlib inline
```

```
[24]: n = 1000
      t = np.linspace(0,2*np.pi,n+1)


      x1 = 1.26*np.cos(t)
      y1 = 1.26*np.sin(t)

      x2 = 2.355*np.cos(t)
      y2 = 2.355*np.sin(t)

      x3 = 1.49*np.cos(t) #average orbital radius of Earth
      y3 = 1.49*np.sin(t) #average orbital radius of Earth

      plt.plot(x1,y1, label="Min radius") #this will be minimum orbital radius for the solar system's habitable zone
      plt.plot(x2,y2, label="Max radius") #this will be maximum orbital radius for the solar system's habitable zone
      plt.plot(x3, y3, label="Earth's orbit")
      plt.scatter(0,0, color='r', label="Sun")
      plt.xlabel('10^11 m')
      plt.ylabel('10^11 m')
      plt.axis('equal')
      plt.title("Maximum, Minimum and Most Eccentric Orbital Radii for the Solar System's Circumstellar Habitable Zone")
      plt.legend(loc=1)
      plt.grid()
      plt.show()
```

Figure 16. Code for creating a plot, based on parametric equations, to represent the minimum and maximum orbital radii of the habitable zone, as well as Earth's orbit (See Figure 8).