Research Project 1

Planetary Exploration

Group 4: The Einswines

Farzeen, Saniyah; Hamze, Celine; Nandi, Sulagna; Osman, Sara; Wang, Heidi

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Introduction

Given the vastness of the universe, it is unlikely that humans are the only life form. The cosmic landscape is so vast that it is almost beyond comprehension, and with advances in astronomy, we are constantly finding new exoplanets—some even in what we call the "habitable zone," where liquid water can exist, which is a crucial ingredient for *life as we know it*. Since our technology is not advanced enough to reach those distant worlds, we focus on the next closest option, Mars. There is evidence suggesting Mars could potentially host life, either now or in the past.

It is important to realize that our human understanding of life is limited. Just because life on Earth requires water and specific conditions doesn't mean life elsewhere requires the same. There could be entirely different forms of life that do not match what we typically imagine. Thus, the universe is too vast for us to assume that life only exists the way humans have experienced it on Earth.

Exoplanet Information

The Definition of a Habitable Zone

Habitable zones – also known as Goldilocks zones - are regions within a planetary system where conditions are viable for the existence of liquid water on a planet's surface (Ramirez 2018). The temperature of a planet plays a significant role in allowing the presence of liquid water on its surface. Additionally, planetary conditions like the energy emitted by the central star, and how much of it is absorbed, are also crucial indicators of where a habitable zone may lie. The orbit of the planet follows a clear, elliptical pattern where they are not too close, yet not too far from the

star, making them the most favourable planets for hosting life. Habitable zones differ depending on the conditions of the primary star. For stars such as our sun, which are both larger and hotter, they would have wider zones for habitability. In contrast, stars such as *red dwarfs,* the most common star in our solar system, would have much narrower habitable zones. Thus, planets within that zone would also be subjected to greater intensity levels of X-ray and UV radiation (NASA 2019). Distance from the star is not the sole factor in determining a planet's ability to sustain potential life. For example, although the moon lies within the solar system's habitable zone, its inability to preserve an atmosphere and lack of liquid water, render it inhospitable to host life as we know it. (NASA 2019).

Eccentricity and obliquity are additional factors that determine the habitability of exoplanets. Eccentricity is defined as the extent to which a planet's orbit deviates from a perfectly circular orbit to an elliptical orbit. Orbits with an eccentricity of 0 are completely circular around their star, while orbits with an eccentricity of 1 are linear. A common misconception about Earth is that it has a circular orbit, when in reality, like most of the planets in the solar system, Earth's orbit is slightly elliptical with a present-day eccentricity value of 0.0167 (Loutre 2009). The article by (Dressing et al 2010) revealed that exoplanets with near zero eccentricities similar to Earth are unique. Approximately 40% of exoplanets with measured eccentricities have an eccentric orbit greater than Pluto (e = 0.2488) and about 10% have an orbit with an eccentricity greater than 0.5. When a planet has a large eccentricity, their distance from their star fluctuates dramatically through its orbit, leading to extreme season and temperature variations. Long winters during the planet's apastron increases its chance of global freezing (Dressing et al 2010), eradicating possibilities of life.

Obliquity refers to the angle of a planet's rotational axis as it rotates around the sun. The tilt of the axis allows the differences in seasons. Greater tilts create extreme seasonal contrast, including warmer summers and colder winters, which contributes to challenges for the development of life. Planets may enter what is known as a snowball state (Cabej 2020). During the transition to a snowball state, the accumulation of ice and snow on a planet's surface increases its albedo, causing more solar radiation and reflection, which further decreases the temperature. This sets off a positive feedback loop, where the higher albedo leads to more ice formation, eventually locking the planet into a snowball state.

Therefore, the criteria used to assess whether a planet and its orbit are suitable for life must also consider several factors. A planet's ability to support life long-term, the constant availability of different energy sources such as thermal and internal energy, and whether living beings would have the necessary resources to sustain themselves are all viable metrics. A good habitable zone relies not only on the planet itself but also on the star it orbits and its interactions with other planets (Meadows, Barnes 2018) This assumption reflects an anthropocentric bias, limiting the scope of our search for life to conditions that resemble those on Earth. However, current research is beginning to challenge these assumptions, exploring alternative environments and life forms that may not rely on the same conditions as Earth-based life. In our work on orbitals, we are examining how certain extremophiles might survive in extraterrestrial environments, particularly those with unique chemical compositions that differ from Earth’s atmosphere.

Orbit Parameters

The distance from the sun directly affects a planet's average temperature, influencing the potential presence of liquid water on the planet. For this reason, the habitable zone (HZ) must

fall within a specific range of distances from the sun, where conditions are warm enough for water to remain in liquid form (Abe et al. 2011). This ensures that the average temperature is neither too cold such that the water freezes, nor too hot such that the water evaporates. However, a planet's temperature is determined by numerous factors other than its distance from a star. These factors include how much energy is emitted by the star, as well as how much energy is absorbed by the planet. The amount of energy absorbed by the planet further depends on the radius of the planet's orbit, the planet's surface reflectivity (albedo), and atmosphere of the planet (NASA 2023). The innermost circular orbit that would keep Earth in the HZ is the highest mean temperature at which water would stay in liquid form. Similarly, the outermost circular orbit that would keep Earth in the HZ is the lowest mean temperature at which water would remain liquid. Equation 1, where $L_{\odot}$ is the solar constant; σ is the Stefan-Boltzmann constant; a is average albedo; and R is the radius of the orbit, is used to calculate the average temperature on the planet.

$$T = \left(\frac{A_{abs}}{A_{rad}} \frac{L_{\odot}(1-a)}{4\pi\sigma R^2{}_{orbit}}\right)^{\frac{1}{4}} \tag{1}$$

To consider the greenhouse effect, we use the constant 0.816 instead of using $\left(\frac{A_{abs}}{A_{rad}}\right)^{\frac{1}{4}} = (0.25)^{\frac{1}{4}} = 0.717$ which ignores the presence of the Earth's atmosphere and results in a lower temperature estimate. Rearranging the equation to solve for the orbit,

$$R = \left(\frac{L_{\odot}(1-a)}{4\pi\sigma\left(\frac{T}{0.816}\right)^4}\right)^{\frac{1}{2}} \tag{2}$$

Substituting for all the constants,

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

Average Earth albedo (a) = 0.367

Minimum Mean Temperature in the HZ = 273 K (Temperature at which water freezes)

Maximum Mean Temperature in the HZ = 373 K (Temperature at which water boils)

As per those calculations, the radius of the innermost circular orbit would be 0.591 AU, while the radius of the outermost circular orbit would be 1.104 AU. The semi-major axis can be calculated by taking the average of the innermost and outermost orbital radius. Our semi-major axis was calculated to be 0.848 AU. Our semi-minor axis on the other hand was found to be 0.808 AU. Using the equation for eccentricity and substituting the values,

$$e = \sqrt{1 - \frac{b^2}{a^2}} \tag{3}$$

We find that the value of eccentricity is 0.304, meaning that the most eccentric orbit which would keep Earth in the habitable zone would have an eccentricity of 0.304, being moderately elliptical. The orbital boundaries of the habitable zone are shown below in Figure 1, as well as the most elliptical orbit that would keep Earth in the HZ.

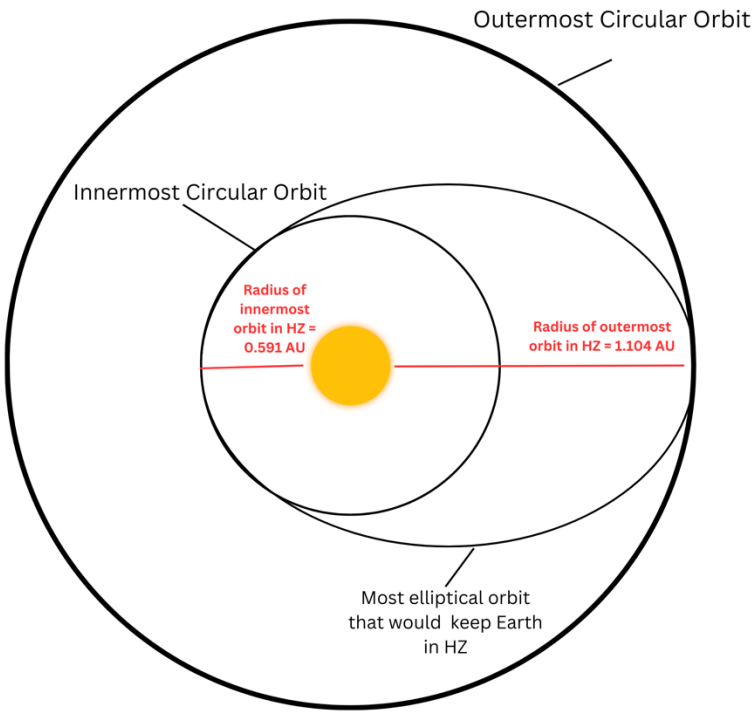

Figure 1: A diagram showing the most elliptical orbit, as well as the outermost and innermost circular orbits that would keep Earth in the HZ (Figure by current authors).

Hohmann Transfer Orbit

The Hohmann transfer orbit is often recognized as the most energy efficient method to transfer a satellite between circular orbits (Kluever 2003). By aligning Earth's orbit with Mars, there will be no additional fuel required for a change in direction. Instead, the Hohmann transfer orbit requires only two impulsive engine burns. The first is done to establish the transfer orbit and the second engine burn is done to adjust the speed to match Mars orbit. This is illustrated in Figure 2, where r_1 represents the distance from the Sun to Earth's orbit and r_1 represented the distance from the Sun to Mars's orbit.

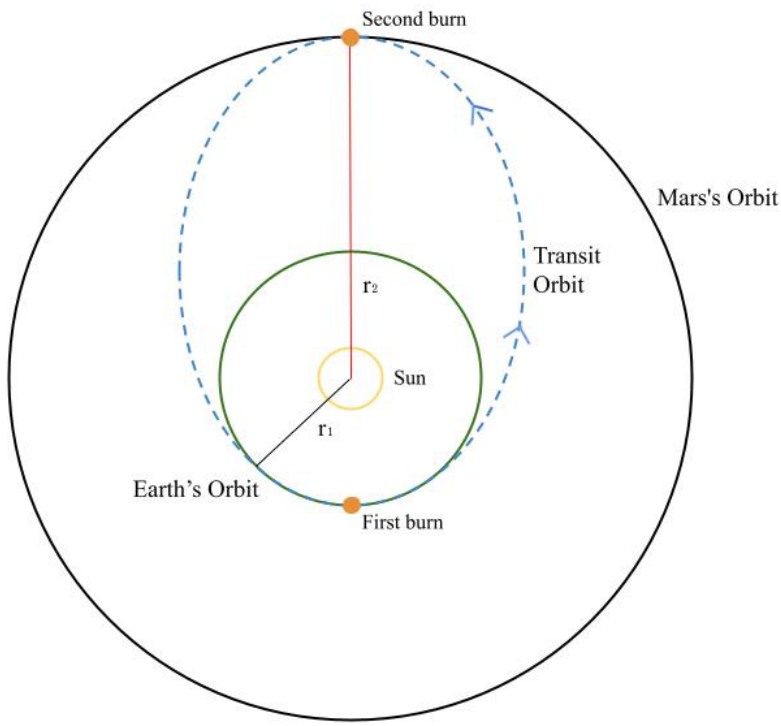

Figure 2: A diagram depicting the Hohmann transfer orbit, the inner circle will be recognized as Earth's orbit and the outer circle is the target – Mar's Orbit (Wang 2024)

The basis of the Hohmann Transfer lies within Newton's postulates. Newton provided a thought experiment saying, if a cannon were fired from a tall mountain, it would be subjected to two factors: its gravitational force and its inertia, or the natural tendency for the cannon ball to move in a straight direction. If the cannon's velocity is too slow, the cannonball will fall back to Earth; if it is too fast, it will escape into space. A specific velocity, known as orbital velocity, allows the cannonball to maintain a stable orbit around the Earth. At this speed, the cannonball continuously falls toward the Earth due to gravity but never actually lands. The only force acting upon the cannonball is gravity. For an object to be in circular orbit, its centripetal force must equal its gravitational force. This provides the equation,

$$F_c = F_g \tag{4}$$

Which can be expanded into,

$$\frac{mv^2}{r} = \frac{GMm}{r^2} \tag{5}$$

Where M, in this specific situation, refers to the mass of the sun. m, refers to the mass of the satellite and r refers to the radius from the Sun to the circular orbit in specific. When simplified, the equation to calculate the velocity required for a circular orbit can be derived.

$$v = \sqrt{\frac{GM}{r}} \tag{6}$$

Where G is the universal gravitational constant, 6.67×10^{-11}, and M refers to the mass of the sun at $1.989 \times 10^{30} kg$. The circular orbits of Earth and Mars are provided as 29,784m/s and 24,080m/s, respectively (Williams 2024). The next step in the Hohmann transfer is to calculate the speed the rocket needs to kick it off into the transit orbit. This requires mechanical energy. The mechanical energy of an object is defined as the sum of kinetic energy and its gravitational potential energy:

$$ME = K_e + U \tag{7}$$

Similarly to how a ball, when thrown into the air, loses kinetic energy and gains potential energy, a satellite, when moving further away from the sun's gravitations pull, will gain potential energy, and lose kinetic. The mechanical energy of the satellite, exclusively when under a gravitational force, will not change throughout its transit indicating that solving for the mechanical energy at any point of the orbit will provide the mechanical energy at all points of the transit orbit. The equation for kinetic energy is as follows:

$$K_e = \frac{1}{2}mv^2 \tag{8}$$

Which can be further expanded as velocity squared can be rewritten as $\frac{GM}{r}$. Therefore, the equation for kinetic energy is:

$$K_e = \frac{GMm}{2r} \tag{9}$$

The equation for potential gravitational energy is:

$$U = -G\frac{Mm}{r} \tag{10}$$

Therefore, to calculate the mechanical energy at a point on the transit orbit, the equation is:

$$ME = \frac{GMm}{2r} - G\frac{Mm}{r}$$

$$ME = -\frac{GMm}{2r} \tag{11}$$

However, this equation only applies to circular orbits. Transit orbits are elliptical (figure 3) therefore the equation must be adjusted accordingly. The r value is changed to an a value where instead of requiring the radius of a circular orbit, the equation now needs the length of the semi-major axis of the elliptical orbit. The equation for the mechanical energy is:

$$ME = -\frac{GMm}{2a} \tag{12}$$

As seen in Figure 3, distance between the Sun and Earth and the Sun and Mars, when added together form the major axis of the transit orbit.

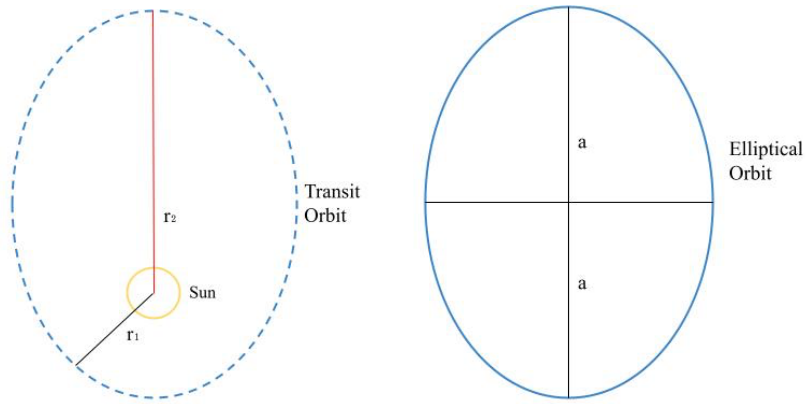

Figure 3: An illustration depicting the relationship between the two distances from the inner orbit to the outer orbit and the semi-major axis (Wang 2024).

Therefore, the equation for mechanical energy can be simplified further to:

$$ME = -\frac{GMm}{r_1+r_2} \tag{13}$$

Where r_1 is equal to 149,597,870,700m and $r_2$is equal to 233,390,000,000m. To solve for the velocity required to send the satellite into the transit orbit, all three equations are needed to derive for the speed.

$$-\frac{GMm}{r_1+r_2} = \frac{1}{2}mv^2 - G\frac{Mm}{r}$$

$$v = \sqrt{2GM(\frac{1}{r} - \frac{1}{r_1+r_2})} \tag{14}$$

With this equation, the velocity needed to send the satellite into the transit orbit and the velocity needed to kick the satellite back into Mar's orbit can be acquired. The velocity at the first burn is calculated to 32,860.74m/s and the velocity at the second burn is calculated to 21,112.90m/s.

The next aspect of the Hohmann transfer is to calculate the duration of the transit orbit. This can be done by applying Kepler's 3rd law to an elliptical orbit. The equation for Kepler's third law for a circular orbit is as follows:

$$T^2 = \left(\frac{4\pi^2}{GM}\right) r^3 \tag{15}$$

Similarly to equation 10, this equation needs to be adjusted for an elliptical orbit, resulting in the following equation:

$$T^2 = \left(\frac{4\pi^2}{GM}\right) a^3 \tag{16}$$

As stated, the major axis can be calculated as $r_1 + r_1$, however since this requires the semi-major axis, the major axis is halved, creating the resulting equation:

$$T^2 = \left(\frac{4\pi^2}{GM}\right) (\frac{r_1 + r_2}{2})^3$$

$$T = \sqrt{(\frac{4\pi^2}{GM})(\frac{r_1+r_2}{2})^3} \tag{17}$$

Equation 17 refers to the time for a full period of an orbit. The Hohmann transit orbit on the other hand is requires half of a period, as it burns off to land on mars. Therefore, the final equation to calculate the transit time in years is:

$$T = \frac{\sqrt{(\frac{4\pi^2}{GM})(\frac{r_1+r_2}{2})^3}}{2} \tag{18}$$

When calculated, this results in a transit time of 0.715 years, or an estimated value of 261 days or 8.5 months.

The final calculation required is the window of opportunity for the placement of Mars when the Hohmann transfer is to take place. Since Mars rotates around the Sun much slower than Earth, for the satellite to meet Mars at the 8.5-month mark, Mars must have some distance ahead of Earth when the Hohmann transfer begins. This can be calculated with the following equation using the ratios between angles and time:

$$\frac{T}{P} = \frac{180-\theta}{360} \tag{19}$$

Where T refers to the transit time using the Hohmann transfer and P refers to Mar's period in years. After calculations, θ is calculated to be $44°$. This indicates that the window of opportunity for a mission to Mars can only occur when Mars is $44°$ ahead of Earth. Therefore, in a Hohmann transfer, the satellite must be launched off Earth's orbit when Mars is 44° ahead of Earth. Then it must spend 8.5 months in the transfer orbit before its second impulsive burn where it will adjust to Mars circular orbit and land. Using the synodic period formula will allow us to calculate the next window where Mars and Earth will align again, allowing a return trip. The synodic period formula is as follows:

$$Synodic\ period = \frac{1}{\left|\frac{1}{SP_1} - \frac{1}{SP_2}\right|} \tag{20}$$

Where SP_1refers to Earth's period, 365 days, and SP_2 refers to Mar's period in Earth days, 687 days (Chimera 2024). This calculates to a synodic period of 778 days. Therefore, it will take 778 days for Earth and Mars to align again to perform a return trip using the Hohmann transfer orbit. This time also considers the 261 days for the initial trip to Mars. When Earth and Mars align again where Mars is 44° ahead, the satellite will launch back into the transfer orbit, returning to

Earth in another 261 days. Overall, it will take a total of 1039 days, or around 2.88 years, for a trip and return trip to Mars.

Orbital Models

Integrating Computer Programming with Mathematical Models in Scientific Research

In today's scientific world, collaboration across different fields is more important than ever. Researchers from physics, biology, chemistry, and environmental science frequently work together to address complex, interconnected challenges. An invaluable tool that has emerged within this interdisciplinary work is the integration of mathematical models with computer code. Take, for example, orbital models, which predict the paths of planets, asteroids, and spacecraft. These models are crucial in astronomy and space exploration, allowing scientists and engineers to simulate gravitational interactions, forecast potential collisions, and ensure the safe navigation of space missions. Beyond just orbital models, integrating math with code empowers researchers across various disciplines to simulate, analyze, and predict complex phenomena, allowing them to answer questions that would be impractical to address using only traditional methods.

One of the primary advantages of using computer code in research is its capacity to automate calculations, particularly when handling large volumes of data. For example, astronomers studying orbital paths or analyzing vast imaging datasets from telescopes rely on immense quantities of information. Coding enables these repetitive tasks to be processed automatically, allowing researchers to work more efficiently without manually calculating each data point. This

automation is essential for tasks like mapping planetary surfaces or modeling the orbits of celestial bodies, which would be incredibly time-consuming and prone to error if done manually.

Computer code inherently reduces human error by enforcing strict logical rules and automated error-checking mechanisms. When conducting research that requires high precision, such as predicting gravitational interactions between planets or modeling climates on distant worlds, even minor miscalculations can result in significant inaccuracies. Coding languages and software tools offer built-in error-checking that helps scientists achieve the accuracy necessary for reliable results. This systematic approach to error management is critical for producing trustworthy scientific data and models.

One important application of computer programming is in the simulation of planetary systems. Through coding, scientists can model complex processes, such as atmospheric dynamics or tectonic activity, under a range of hypothetical conditions. These simulations enable researchers to explore potential outcomes, test mission scenarios, and assess planetary habitability without relying solely on real-time data, which may take years to collect or may not even be accessible. For example, when preparing for a Mars landing, scientists use simulations to predict weather patterns, surface stability, and potential hazards, providing mission planners with critical information that would be difficult to obtain from theoretical models alone.

Coded models offer an adaptability that is difficult to achieve with traditional methods. As new data becomes available—whether through updated observations, advanced instruments, or unexpected discoveries—scientists can adjust their models quickly and efficiently. This adaptability is crucial throughout various mission phases, including preparation, observation, and analysis. For instance, as a spacecraft approaches a planet and gathers data, scientists can refine

model parameters to improve predictions about gravitational effects or atmospheric composition, both of which are critical for the mission's success.

The integration of code and mathematical models takes scientific investigation beyond what algebraic methods or standard calculators can achieve. Here is how this combination enhances research capabilities.

Computer code allows researchers to process complex calculations repeatedly and efficiently across vast datasets. For example, studying the topography of Mars involves analyzing a multitude of variables across the planet's surface, a task far beyond the capabilities of a calculator or simple algebraic equations. Programming languages like Python, R, and MATLAB enable scientists to handle millions of data points, identify patterns, and make sense of vast quantities of information in a way that would be impractical to do manually.

Once a coded model is set up, it often requires minimal manual effort beyond initial configuration and data input. In contrast, manual calculations demand constant attention and repeated data entry. Code-based models, however, can run autonomously, which not only saves researchers valuable time but also reduces the chance of human error from repetitive data handling. This is especially beneficial in fields like climate science, where complex models run continuously to simulate weather patterns or long-term climate trends.

Mathematical models combined with code excel at handling high-dimensional, multi-variable datasets that traditional algebraic methods or calculators are not designed to process effectively. For example, researchers studying Mars' topography might need to consider multiple factors, such as altitude, rock density, soil composition, and erosion rates, all at once. Integrating these variables in a meaningful way requires multidimensional data processing, which only a coded

model can handle effectively. Coding enables researchers to visualize these complex relationships through multidimensional plots and simulations, providing insights that would be difficult to attain through manual calculations alone.

Coding languages have built-in error-checking functions that ensure calculations are executed consistently and accurately at every stage of an analysis. In multi-step manual calculations, especially for intricate tasks like trajectory predictions or environmental modeling, small errors can accumulate, leading to significant deviations in results. Code automates error-checking and ensures that intermediate steps are executed with precision. This consistency is especially critical in fields like aerospace engineering, where even minor miscalculations could lead to catastrophic mission failures.

A crucial advantage of coded models is their adaptability. Unlike algebraic approaches, coded models can be updated dynamically with new information. For instance, during a space mission, scientists might receive updated data from onboard sensors, such as measurements of atmospheric composition or gravitational anomalies. By incorporating this new data, researchers can refine their predictions and continually improve the model's reliability. This adaptability is essential for long-term missions or experiments, where evolving conditions and real-time data can enhance the model's accuracy and relevance.

Integrating mathematical models with computer code has transformed interdisciplinary science, allowing researchers to explore complex phenomena with greater efficiency, accuracy, and adaptability than ever before. The automation, precision, simulation capabilities, and flexibility that code offers have made it an indispensable tool for advancing our understanding of the world. By surpassing the limitations of algebraic methods and calculators, coded models enable

scientists to tackle large-scale problems, process immense datasets, and make precise predictions that are essential to modern research.

Through the integration of mathematics and coding, scientists can build sophisticated models that not only provide answers but also evolve with new data, ensuring that our scientific knowledge remains relevant and continues to grow with each discovery.

Applications of Computer Programming with Mathematical Models

One example that demonstrates the power of combining computer code with mathematical models was Problem 6 in Computer Lab 1b, which involved graphing a three-dimensional parametric function, as shown in Figure 4. This activity aimed to match a specific parametric equation to one of several provided graphs, each representing a unique curve in three-dimensional space. Since the shapes of these curves were complex and required precise calculations, plotting them by hand would have been almost impossible. Manually graphing each point would be extremely time-consuming and prone to error, especially given the need to capture each curve's exact flow and orientation.

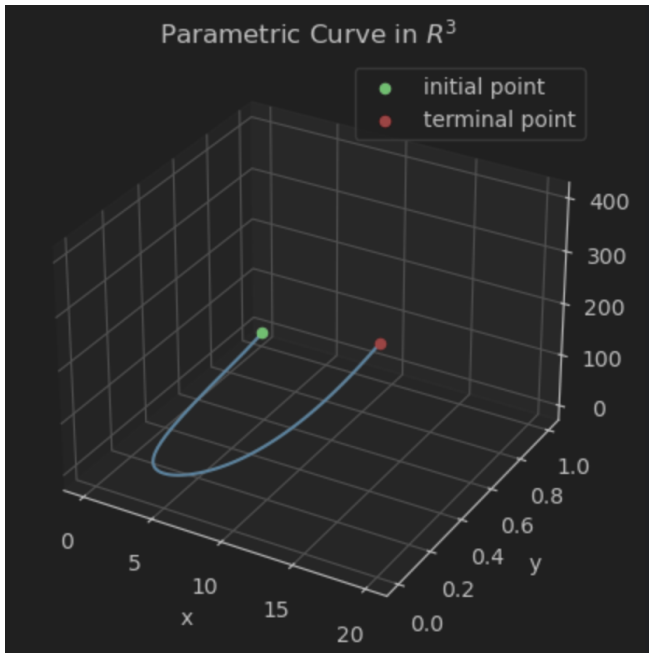

Figure 4: Three-dimensional graph of a parametric function

Using computer code made this task both practical and efficient. By inputting the equations into a coding environment, the computer handled all the calculations and generated accurate, smooth graphs that showed the true shapes of the curves. This automated process not only saved a tremendous amount of time but also produced highly accurate visual representations, making it much easier to identify which graph matched the function. This activity illustrated just how essential computer programming can be in mathematical modeling, particularly when working with detailed three-dimensional functions that would be unmanageable to graph by hand.

Finding the Collision of Two Orbiting Particles

In the study of planetary motion, accurately determining when two orbiting particles might collide is essential. This calculation is useful for predicting various events, such as potential asteroid impacts or close encounters between celestial bodies. In Problem 5 of Computer Lab 1b,

this concept was applied by calculating the intersection point of two particles moving along defined paths, as shown in Figure 5.

The solution involved four functions of t: x1(t), y1(t), x2(t), and y2(t). Here, x1(t) and y1(t) provided the coordinates of the first particle, while x2(t) and y2(t) represented those of the second. These coordinates offered each particle's precise x and y positions over time, enabling detailed tracking of their movements.

To locate the collision point, the distance between the particles was calculated at each small, regular interval of t. Instances where this distance approached zero indicated a moment when the particles were nearly or exactly overlapping, signaling a collision. By identifying the index in the t array where this near-zero distance occurred, the approximate time of collision was determined.

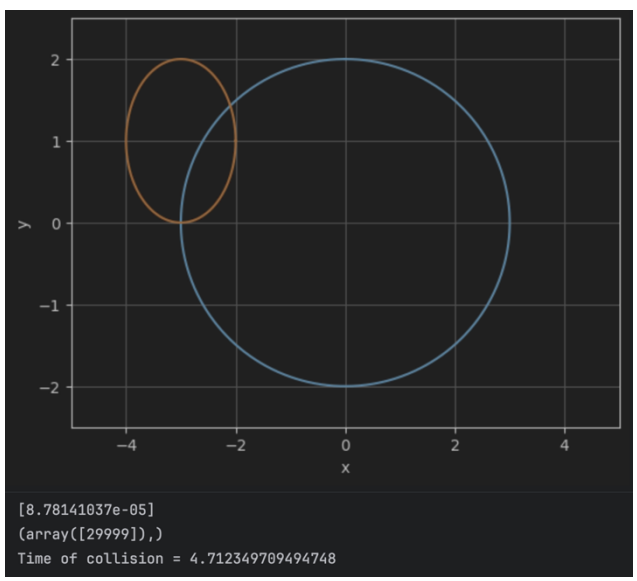

Figure 5: Orbital paths of two particles showing two intersection points

Usefulness of Parametric Curves and Polar Coordinates in Planetary Motion

Parametric curves and polar coordinates are extremely useful tools for studying planetary motion because they mirror the way planets naturally move through space. With parametric curves, time is treated as an independent factor that influences the planet's position in three-dimensional space, represented by the x, y, and z axes (Hartman et al. 2017a). Time itself is not one of these axes but is instead used to show the continuous movement of a planet along its path. This setup is ideal for visualizing orbits, as it allows the planet's position to be updated smoothly over time, revealing the complex trajectories that planetary bodies follow.

Polar coordinates, on the other hand, are especially well-suited to describing the circular or elliptical paths typical of planetary orbits. In this system, a point in space is represented by its distance from a central point (known as r) and its angle (or θ) relative to a fixed direction, usually measured counterclockwise from the positive x-axis (Hartman et al. 2017b). This approach is effective because planetary orbits naturally depend on both distance from the center of rotation and angular displacement from a starting position. As planets orbit, both their distance from the center and their angular position continuously change, and polar coordinates capture this motion in a straightforward and efficient way.

One advantage of polar coordinates is that they can easily be converted to rectangular coordinates, providing a way to move between circular orbits and the familiar grid system used in everyday math. Through simple formulas, such as $x = r*\cos(\theta)$ and $y = r*\sin(\theta)$ scientists can translate between polar and rectangular coordinates, enabling them to study both the overall shape of an orbit and the precise location of a planet at a specific time.

Parametric curves and polar coordinates allow planetary motion to be modeled accurately and intuitively. These tools make it possible to see and analyze orbits as dynamic paths that reflect the actual motion of planets in space, offering a clearer understanding of how celestial bodies move across the cosmos.

Solar System Analogue Environment – Mars:

Scientific Objective

The primary goal of this mission is to explore whether Mars, like Earth, could host life by investigating how well microbial extremophiles can survive in its subsurface briny water. Water is crucial for life, and while Mars has extreme surface conditions—like freezing temperatures, high radiation levels, and low atmospheric pressure—there is promising evidence that liquid brine might exist beneath the surface. Recent findings indicate that brine could remain liquid in those depths, making this research essential (Hensley, 2024).

Studying halophiles—organisms that flourish in high-salt environments on Earth—gives us a glimpse into the potential for life on Mars. These creatures thrive in extreme places like salt flats and hydrothermal vents, relying on unique biochemical pathways to survive in conditions that are high in salt and low in nutrients (Rampelotto, 2013). By exploring whether these halophiles—or similar organisms from Mars—could withstand Martian brine, we can gain valuable insights into how life can adapt and persist in the universe.

This mission is part of a larger quest to push the limits of what we consider habitable environments beyond our planet. If we discover that life can survive in Martian brine, it suggests that life might emerge in conditions similar to those on Mars. It also broadens our criteria for

habitability when looking at exoplanets with extreme environments. This is significant for astrobiology, as it challenges the traditional belief that life needs Earth-like conditions, opening new possibilities for life in a variety of planetary settings.

Justification for an Unpiloted Mission

Unpiloted missions to Mars have several key advantages, especially regarding astronaut safety, costs, and tech testing. A significant benefit is the elimination of risks to human life. Uncrewed missions protect astronauts from serious hazards like radiation exposure and the detrimental effects of microgravity on the body. For instance, astronauts could face dangerous levels of galactic cosmic rays and solar particle events, increasing their risk of cancer and other health issues (Blaber et al. 2010; Cucinotta et al. 2013).

Lack of gravity can lead to bone density loss, early onset osteoporosis, and other physical and psychological challenges (Blaber et al. 2010; Oluwafemi et al. 2021). Astronauts must manage significant workloads and complex conflicts, but their performance can suffer from psychosocial stressors and disrupted sleep, which are common during space missions (Wu et al. 2018). Sleep deprivation and disturbances to circadian rhythms due to the lack of a natural 24-hour clock can impair decision-making and jeopardize mission goals (Oluwafemi et al. 2021). While research on cognitive impairment from space radiation in humans is limited, studies on rodents indicate that recognition memory can decline within two weeks of exposure, with working memory affected after several months (Britten et al. 2012).

Isolation and homesickness are also significant concerns for astronauts living in confined spaces far from home. These challenges emphasize the need to carefully evaluate systems and technology before sending humans into space.

Physiological	Performance	Interpersonal	Psychiatric
Space sickness	Disorientation	Tension	Adjustment disorders
Vestibular problems	Visual illusions	Withdrawal/territorial behavior	Somatoform disorders
Sleep disturbances	Attention deficits	Lack of privacy	Depression
Bodily fluid shifts	Error proneness	Scapegoating	Suicidal thoughts
Bone loss and hypercalcemia	Psychomotor problems	Affect displacement	Asthenia

Figure 6: Examples of stresses encountered during piloted space missions (Kanas and Manzey 2008).

Unpiloted missions also effectively test spacecraft systems without the pressures of human safety concerns, allowing for longer durations than piloted missions. This results in increased data collection and exploration of Mars.

Challenges accompany uncrewed missions as well. One major downside is the risk of losing valuable scientific experiments. For instance, during the NS-23 incident, the booster was lost due to a thermo-structural failure, resulting in the loss of the mission's payload (NSE 2024). This situation emphasizes the potential pitfalls of uncrewed missions, where crucial data may be missed if something goes wrong.

Another issue involves decision-making. Uncrewed missions often rely on pre-programmed commands, making reacting quickly to unexpected problems challenging. Communication delays can complicate matters during missions far from Earth. If equipment or software malfunctions, the absence of personnel on board to troubleshoot can lead to inconvenient situations.

Despite these challenges, the benefits of unpiloted missions—such as protecting human life, allowing for rigorous testing of technology, and minimizing financial risks—make them a prudent choice for exploring Mars.

Research Significance and Understanding of Extremophiles in the Search for Life on Mars

Can microbial extremophiles survive in the briny subsurface waters of Mars? This question is central to understanding whether life can exist beyond Earth. Water is a vital element for life, and evidence suggests that liquid brine may exist beneath Mars's surface; therefore, further exploration is crucial (Hensley, 2023). Studying how organisms adapt to extreme conditions could yield valuable insights into the possibility of life on Mars. The presence of brine highlights the potential for sustaining microbial life, like Earth's environments where halophiles thrive.

Experimental Design and Relevance of Gale Crater

This study aims to investigate halophiles directly in Martian conditions—specifically, within subsurface salty environments. In-situ methods, which involve studying organisms in their natural environments rather than controlled lab settings, will be employed to examine these fascinating organisms that thrive in Earth's most saline spots, such as salt lakes and hydrothermal vents (Rampelotto 2013). To simulate Martian conditions, we plan to use ground-penetrating radar and soil probes to detect brine, while spectrometers will analyze mineral compositions. Sensors will monitor temperature, radiation, and pressure. Understanding the unique biochemical pathways that allow halophiles to flourish in such extreme conditions will offer valuable insights into what life might endure on Mars (Rampelotto 2013). These adaptations are crucial for survival in environments with high salinity and variable temperatures (Rothschild 2004)

The Gale Crater presents a compelling site for conducting this research. Geological features within this area indicate it once harboured water, making it a primary candidate for where briny conditions could exist ("A Guide to Gale Crater - NASA Science," n.d.). The sedimentary rock layers here tell a story about Mars' watery past, which is crucial for determining if life could have ever thrived on the planet ("A Guide to Gale Crater - NASA Science," n.d.). By studying how extremophiles survive in the unique geology of Gale Crater, valuable data can be gathered about the habitability of Mars and the potential for life on exoplanets with similar conditions (Rampelotto, 2013).

Further investigation underscores the compelling interactions between extremophiles and their respective environments, particularly concerning biogeochemical cycles. Studies indicate that biogeochemical processes such as carbon and nitrogen cycling can occur even in extreme saline conditions, suggesting that life could thrive in similar extraterrestrial settings (Merino et al. 2019). Demonstrating that halophiles can endure in Martian brine would open a world of possibilities regarding the existence of life in other harsh environments (Merino et al. 2019). Additionally, examining the role of these extremophiles in biogeochemical cycles emphasizes their significance in nutrient cycling and supporting ecosystem dynamics, even under extreme conditions (Merino et al. 2019). Investigating these processes in Martian environments could offer crucial insights into how life could be sustained on Mars and potentially beyond.

Landing and Usage Site on Mars

The potential landing site chosen is illustrated below in Figure 7. The location has a latitude of 4°25'37.89"S and a longitude of 138° 7'32.70"E. The landing site in specific is 3900m below sea level, at the base of *Aeolis Mons*, a mountain within the Gale crater.

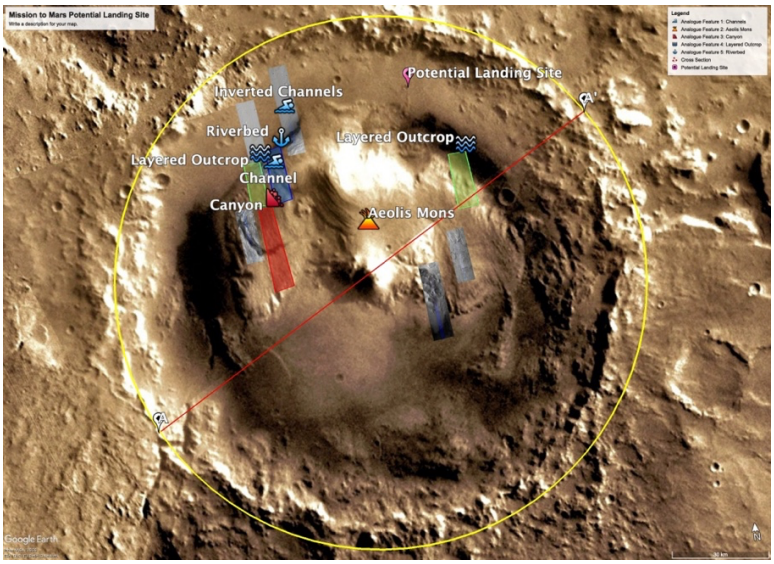

Figure 7: The proposed landing site accompanied with its cross section and its surrounding Earth analogous features. (Google Earth Pro 2024)

The specific location was chosen due to its many surrounding earth analogous features such as channels and riverbed. Most of these features point towards potential evidence of water on Mars, allowing the rover to gather necessary samples for further investigation upon Earth. In a previous mission to Mars in 2012, the NASA rover curiosity uncovered layers of sedimentary sequences, as seen in Figure 8, near the edges of *Aeolis Mons* within the Gale crater. (NASA Mars Rover Curiosity Nears Mountain-Base Outcrop 2014).

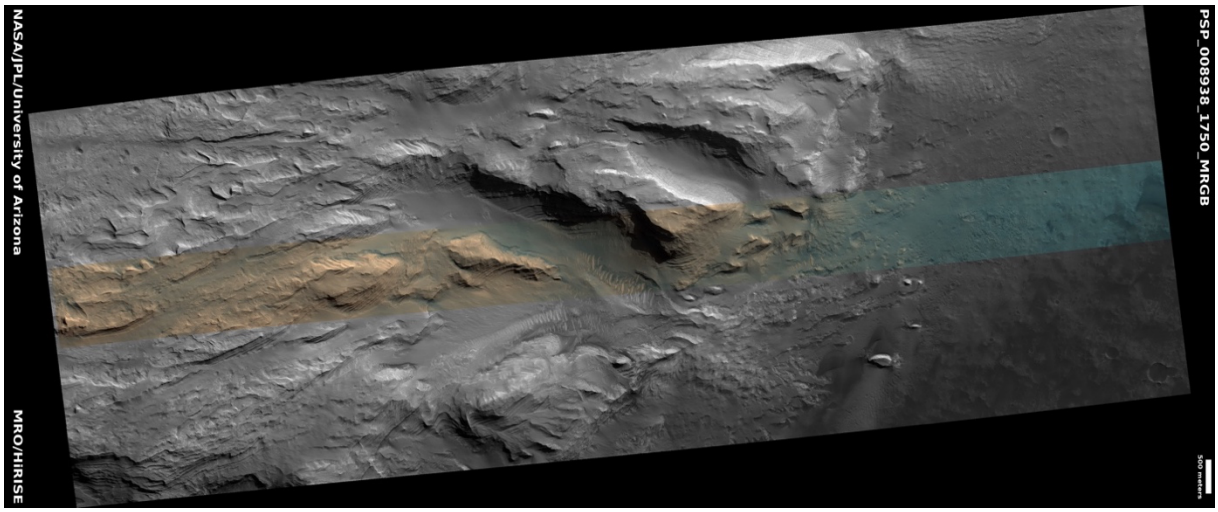

Figure 8: Imaging of the layered outcrop at 4.93°S 138.35°E within the Gale Crater. (HiRISE 2008)

These features play an integral role of uncovering Mars history as its deposits were most likely eroded through media transports such as wind or water, indicating past surface processes A prominent hypothesis suggests that the formation of the deposits occurred through evaporating groundwater, creating the sulfate-rich, fluvial sedimentary layers. (Andrews et al 2010). The ground water, when evaporated, would leave behind residues of evaporite precipitation, cementing the sediments into layers. These layers provide a record of the aqueous activity that took place on the surface of Mars, affirming the presence of liquid water in which took place on the surface. Investigating further, it is also suggested that it is the same process which created the sulphate-rich layers near the low areas of *Aeolis Mons* (Andrews et al 2012), the central peak of the Gale Crater. *Aeolis Mons*, which can be seen in Figure 9*,* is a 5.5km mountain which was built through layers. First through the income of through the income of lake and river sediments and later through desert sediments and wind during Mars drying period (Bordajandi, Brogan 2024)

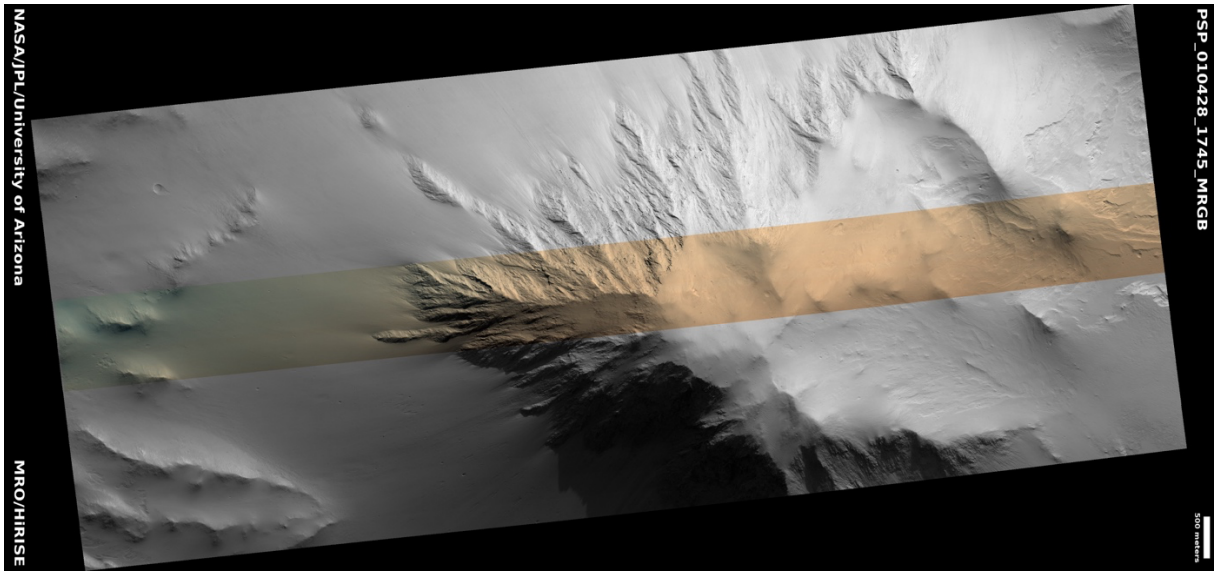

Figure 9: Imaging of Aeolis Mons (HiRISE 2008)

Thorough investigation of the stratigraphy of the Gale crater can also provide integral insight into the past climate on Mars. The lower strata of *Aeolis Mons* contain fluvial, deltaic, and lacustrine deposits while higher layers reveal Stimson formation of cross bedded sandstone (Banham 2017) The Stimson formation suggest a dry, aeolian, dune system, which may imply a drier environment at that time, contrasting with the lower layers of *Aeolis Mons* which point towards the presence of liquid water. By analyzing Gale's crater, valuable evidence about the changing evolution of Mars' atmosphere and surface conditions are able to be obtained. Detailed studies and research, such as analyzing the mineral compositions on the surface of the Gale crater, may unveil additional evidence which will clarify whether Mars had the environment capable of hosting microbial life as we know it, ultimately confirming habitability on Mars.

The Chemistry of Liquid Water on Mars

When examining landing sites like the Gale Crater, significant factors must be considered before determining their habitability. One of which is the possible presence of liquid water. Making up

71% of the Earth's surface, liquid water's many special properties that make it crucial in sustaining life on a planet. The most important of those properties are the ability to establish hydrogen bonds, its high polarity, and the ability to reduce electrostatic forces between charged particles due to its high dielectric constant (Brack 1993). Based on molecular weight, water should be a gas under standard terrestrial conditions by comparison with similar compounds like CO_2, SO_2, and H_2S which exist as gases at these temperatures. However, water's ability to form hydrogen bonds makes it a highly polar molecule with strong intermolecular forces resulting in a much higher boiling point of ~100°C as opposed to ~50°C which is the average boiling point of the smallest alcohols. Figure 10 below shows a comparison between the boiling point, as well as the dielectric constant of water compared to various alcohols.

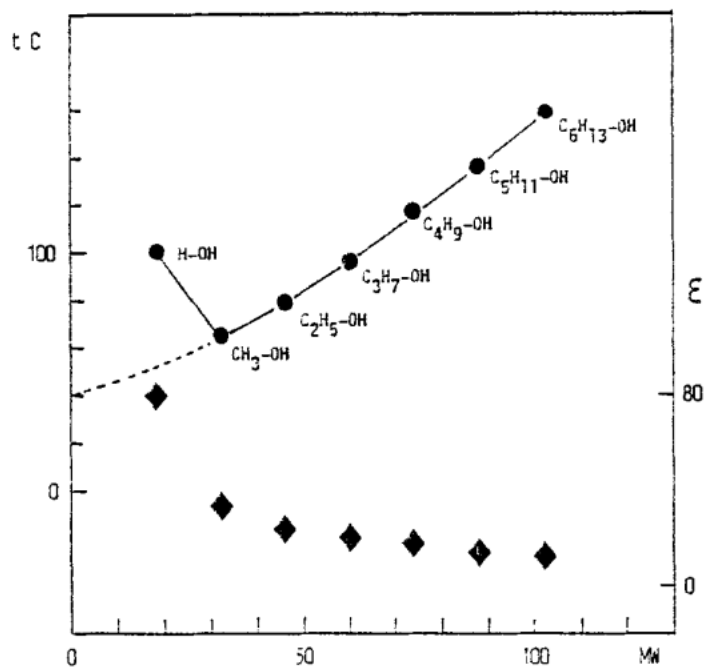

Figure 10: The boiling point (●) in °C and dielectric constant (◆) of water compared to various alcohols (Brack 1993).

Water's role as a universal solvent is essential for life because it acts as a medium for biochemical reactions to sustain life (Ball 2007). Water's high dielectric constant allows it to act as a powerful solvent for ions, charged DNA, and protein particles. Being a solvent prevents the aggregation and crystallization ion of ions of opposite charges, keeping them dissolved and available for cellular processes. On the other hand, hydrophobic solutes in water experience a force that causes them to cluster. This is also important for various biological processes, such as burying the hydrophobic residues in polypeptides, causing them to fold and keep their compact forms to form firm structures essential for protein stability and function.

For a planet to support free-flowing water, we must consider a range of factors, like its mass, internal heat flux, elemental composition, and how much energy it gets from its star. Models of thermochemical equilibrium, cloud condensation, and energy transport play crucial roles in determining whether a planet can sustain the right conditions for water. The water cycle allows water to move through different phases, fueled by chemical interactions and thermodynamics, with exchanges happening between the atmosphere and the rocks beneath the surface.

In ecosystems, the movement of water relies heavily on available energy. Several sources contribute to this, including radiation, short-wave solar energy, long-wave radiation from clouds and gases, and sensible and latent heat (Miller, 1977). Latent heat is significant for phase changes, like the 2,500 kJ/kg needed to vaporize water (Miller, 1977). Water's molecular structure—two hydrogen atoms bonded to one oxygen atom—gives it cohesive properties, making it abundant in moist areas (National Library of Medicine, 2024). According to the National Library of Medicine, for water to stay liquid, temperatures must be between 0°C and 100°C. Figure 11 shown below shows the three phases of water under different temperatures and atmospheric pressures.

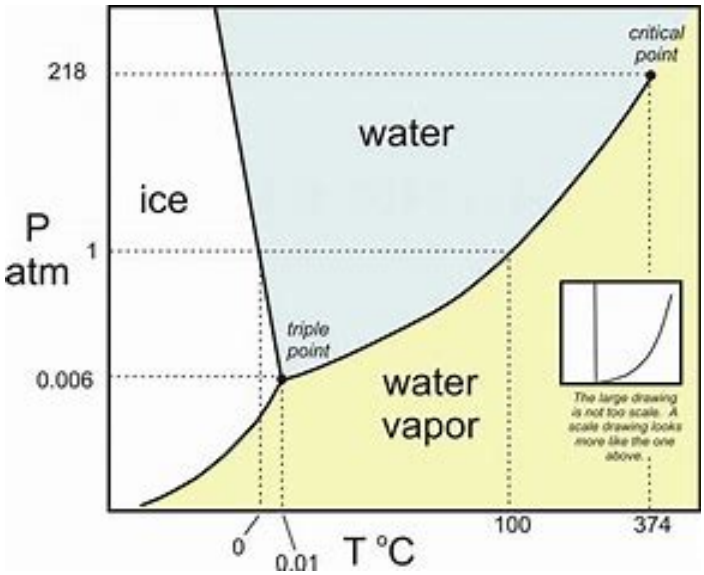

Figure 11: A phase diagram showing the relationship between temperature (°C), pressure (atm) and the different phases of water, including a triple point where all three phases coexist, and a critical point where water cannot exist as a liquid even under high pressure (Socratic 2018).

On Earth, precipitation is the primary water source, bringing up the interesting question of whether it rains on Mars. Although there's evidence that flowing water may have existed in the past, the absence of carbonate deposits suggest otherwise (Craddock, 2002).

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

$$HCO_3^- \rightleftharpoons CO_3^{2-} + H^+$$

$$CO_3^{2-} + Ca^{2+} \rightarrow CaCO_3(s)$$

The equations above demonstrate how liquid water's past existence leads to the presence of solid carbonate deposits. Aqueous chemistry explores the study of water-based solutions, their interactions, and reactions. Thus, it plays a significant role in understanding the search for liquid

water on Mars. As researchers continue to compare Mars' current atmosphere to its past one, it can be seen that the once-present liquid water had a high level of acidity. This may be due to groundwater upwelling. The excess acidity in base anions of ancient Martian rocks is supposed to be a reason for Fe oxidation, forming precipitates containing oxidized Fe3+ minerals. Subsurface waters present on Ancient Mars were rich in Fe2+ and, therefore, acidified after the iron oxidation due to exposure to O2 or photooxidation or ultraviolet radiation.

$$Fe^{2+}(aq) + H_2O + h\nu = Fe^{3+}(aq) + OH^- + 0.5H_2 \quad (1)$$

$$Fe^{2+}(aq) + 0.25O_2(aq) + H^+ = Fe^{3+}(aq) + 0.5H_2O \quad (2)$$

$$0.5H_2O + h\nu = 0.25O_2 + H^+ + e^- \quad (2a)$$

$$H_2O + e^- = OH^- + 0.5H_2 \quad (2b)$$

Figure 12: Depicts the two possible ways in which water could have been oxidized on Mars, acidifying the water supply (Hurowitz, 2010).

The speculated existence of liquid water on Mars would need a large greenhouse effect to still be present. Scientists believe that it was the existence of high partial pressure of atmospheric CO2 on Mars which allowed for its presence in the past (Catling, 1999). A lot has changed in Mars's chemical and atmospheric condition and makeup since its formation, which is why a very small amount of liquid water can be found today relative to the previous amounts. Mars' current atmospheric pressure, 600 pascals, is lower than what it once was and the melting point of waters vapor pressure (Nazari-Sharabian, 2020). This means that no liquid water can easily exist.

Past Martian missions have used gamma ray spectroscopy on the surface to detect the spectra of gamma rays emitted from Mars (Nazari-Sharabian, 2020). It was revealed that a great abundance of the Martian surface contained hydrogen. According to Nazari-Sharabian, the same hydrogen

found in the molecular formula of ice. This discovery led to a series of inquiries, and based on stoichiometric calculations, the upper meter of surface on Mars contains solid ice due to the conversion of fluxes. Thus, ice is plentiful on its surface, but due to the planet's instability, it is covered by layer(s) of dusty rock. The liquid water believed to have existed during Mars' Noachian era may no longer re-exist due to the planet's atmospheric loss to space, also known as hydrodynamic escape (Nazari-Sharabian, 2020). This is classified as the exit of heavier atoms due to collisions with lighter atoms, and about 60% of Mars' Noachian atmosphere has been eliminated due to bombardment of meteorites and asteroids leaving scientists wondering if the planet will ever be able to sustain liquid water again (Nazari-Sharabian, 2020).

A significant area of aqueous chemistry focuses on the presence and sustainability of aqueous solutions—where water is the solvent. From the Mars Phoenix lander exploration, we know perchlorate salts exist on the Martian surface. This finding is crucial for understanding the potential for liquid water as these salts can absorb water vapour through deliquescence, forming aqueous solutions (Gough, 2014). When the atmospheric humidity reaches or exceeds the deliquescence relative humidity (DRH), which can be as low as 38% for perchlorates, brines can form on Mars (Gough, 2014).

Launched in 2008, the Phoenix lander discovered not only perchlorate salts, like sodium perchlorate and magnesium perchlorate, but also other soluble salts, such as chlorides, sulfates, carbonates, magnesium, sodium, calcium, and potassium in Martian regolith (Gough, 2014). These salts vary in concentration and solubility, with some being more deliquescent than others.

Research regarding two-salt mixtures from these Martian salts, showed that raising humidity to a eutonic relative humidity allowed for an aqueous phase to form. Eutonic relative humidity is the lowest level at which two components can dissolve (Brooks, 2002). For a mixture to turn into an

aqueous solution, it can either have a eutonic relative humidity lower than the relative humidity of either salt or reach an aqueous phase at a humidity lower than the DRH of the least deliquescent salt (the one with the higher DRH) (Gough, 2020).

The colligative properties of water allow it to lower its freezing point and elevate its boiling point depending on the properties of the solute (Akhter and Alam, 2023). As shown below in Figure 13, when salt is added to water, the freezing point is lowered as the ions interfere with the solid structure of ice, and the boiling point is elevated due to the solute's interference with the formation of vapour bubbles. In the case of Mars, which has perchlorates and other soluble salts in its soil, these colligative properties could potentially allow liquid water to exist in an otherwise harsh environment.

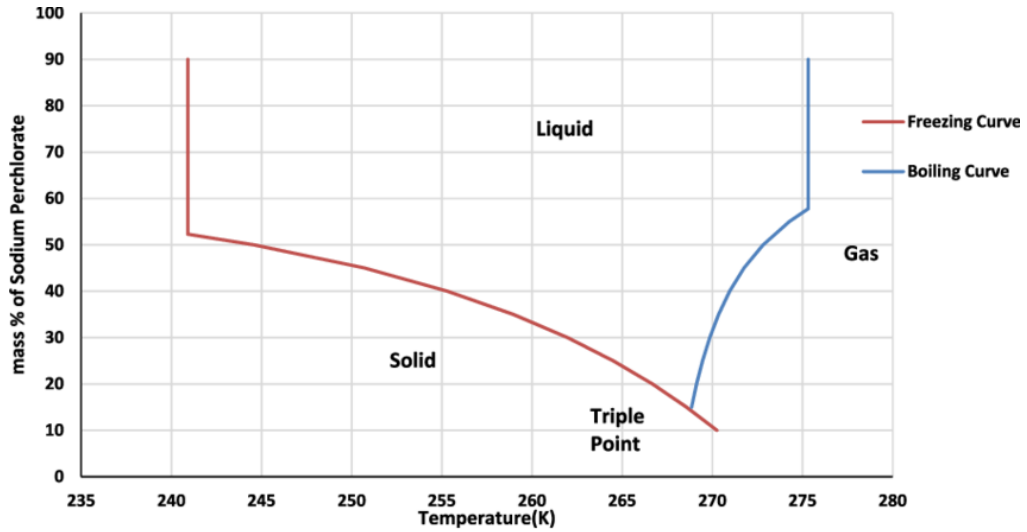

Figure 13: Phase diagram of a sodium perchlorate solution that shows the relationship between phase transitions, temperature and mass of sodium perchlorate in the solution (Nair and Vibhu Unnikrishnan 2020).

Understanding the chemical conditions needed for complete deliquescence and the initial formation of aqueous solutions is vital for examining the stability and behaviour of water on Mars.

Earth Analogue Experiment:

Investigating the Survival of Extremophiles under Simulated Martian Conditions:

Learning Targets

1. Develop skills in designing and executing a microbiological experiment.
2. Apply serial dilution techniques to obtain measurable bacterial counts under different conditions.
3. Assess and analyze environmental factors—temperature, salinity, and UV exposure—impacting microbial growth and survival.
4. Communicate results effectively through data analysis, graphs, and conclusions.

Safety Notes

1. Personal Protective Equipment (PPE): Wear lab coats, gloves, and safety goggles.
2. Sterile Technique: Use aseptic methods to prevent contamination. Avoid opening Petri dishes and containers more than necessary.
3. UV Light Precautions: UV radiation exposure can be harmful. Use UV light sources cautiously, ensuring protective covers are in place to avoid direct skin or eye exposure.
4. Disinfection: Clean the lab bench with disinfectants such as Dettol before and after the experiment. Dispose of all cultures and contaminated materials in biohazard waste bins.

Pre-Lab Preparation

1. Review Protocol: Carefully read the entire procedure and ensure understanding of all steps.
2. Aseptic Techniques Review: Watch a tutorial video on aseptic techniques if you are unfamiliar with streaking or handling bacterial cultures.

Pre-Lab Questions

1. Psychrophiles are said to be the product of the adaptations of microorganisms in the past (Jin, 2022). Expand on how the adaptation of species has led to the upbringing of extremophiles as such. What classifies them as extremophiles?
2. Humans rely on biogeochemical cycles like the oxygen and water cycle in order to survive. Do you think extremophiles like psychrophiles, and halophiles are able to survive in the absence of these cycles? Explain why or why not.

Introduction and Background Information

As we explore the potential for life beyond Earth, one focus is on identifying environments where life could exist under extreme conditions. Mars presents a particularly challenging environment with its frigid temperatures, high salinity, and intense UV radiation. This lab will investigate whether certain Earth microorganisms known as extremophiles could survive under conditions like those found in the Gale Crater on Mars.

Extremophiles: Extremophiles are microorganisms that have adapted to thrive in extreme environments. This can include high salinity, extreme cold, or intense radiation, which would be inhospitable to most other life forms. For this experiment, we will be focusing on two types of extremophiles:

- Psychrophiles (cold-loving organisms): Psychrophiles can survive and grow at exceptionally low temperatures, typically found in environments such as polar ice caps or deep ocean waters. We will be using Pseudomonas syringae.
- Halophiles (salt-loving organisms): Halophiles are adapted to high salinity environments, such as salt lakes or brine pools, where they survive despite high salt concentrations. We will be using Halobacterium.

Studying these extremophiles allows us to simulate and understand the potential survival mechanisms life might need in environments like Mars.

Mars-like Conditions in the Gale Crater: The Gale Crater on Mars is thought to have once hosted liquid water and even a lake, based on data collected by NASA's Curiosity rover. However, Mars today is far less hospitable:

- Low Temperatures: Mars has an average surface temperature of about -63°C and can drop as low as -125°C. In our experiment, a cold incubation chamber will be used to approximate Martian temperatures in a laboratory setting.
- High Salinity: Saline environments on Mars are likely due to minerals such as perchlorates and sulphates, which create briny conditions that could be toxic or challenging for most organisms. In this lab, we simulate varying levels of salinity (1%, 5%, and 10% NaCl) to test the tolerance of extremophiles to these conditions.
- UV Radiation Exposure: Mars lacks a protective ozone layer, leading to intense ultraviolet radiation on its surface. This radiation can damage DNA and cellular structures in organisms, making it a significant barrier to life. In the experiment, we will expose cultures to UV light to mimic similar conditions found on Mars.

Project Rationale

This experiment gives us a better idea of how life might survive in extreme Martian-like conditions. By looking at how extremophiles like psychrophiles and halophiles adapt to high salinity, freezing temperatures, and UV radiation, we can uncover key details that could help future missions search for life on Mars or other icy, briny places in our solar system.

Research Question(s)

1. How does salinity affect the survival rates of Pseudomonas syringae and Halobacterium under Mars-like conditions?
2. What is the impact of UV radiation exposure on the growth of these extremophiles at low temperatures?
3. How do the combined effects of high salinity, low temperature, and UV exposure influence the overall viability of the microorganisms?

Hypotheses

1. Salinity Hypothesis: Higher salinity will reduce the growth and survival of both Pseudomonas syringae and Halobacterium.
2. UV Radiation Hypothesis: UV radiation exposure will significantly inhibit the survival of the extremophiles.
3. Combined Effects Hypothesis: The combination of high salinity, low temperatures, and UV exposure will have a cumulative negative effect on extremophile survival, potentially rendering Mars-like environments uninhabitable for these organisms.

Materials

Biological Materials:

- Pseudomonas syringae (psychrophile) culture: Used to assess cold tolerance under Martian-like conditions.
- Halobacterium (halophile) culture: Used to test salt tolerance and survival in high-salinity conditions.

Nutrient Plates and Solutions

- Nutrient Agar Plates: (10 plates per salinity concentration, 30 total plates) for growing the cultures under different experimental conditions.
- Brine Solution: Prepared with NaCl to simulate Martian-like saline conditions. Prepare three concentrations:
    - Low Salinity: 1% NaCl (10 g NaCl in 1 L distilled water)
    - Medium Salinity: 5% NaCl (50 g NaCl in 1 L distilled water)
    - High Salinity: 10% NaCl (100 g NaCl in 1 L distilled water)

Environmental Setup/Equipment:

- Cold Incubation Chamber: Maintained at -20°C to replicate Martian temperatures.
- UV Light Source: Emits UV light at a wavelength of 254 nm to simulate Martian UV radiation exposure.
- Heated Inoculation Loop: For sterile transfer of cultures without contamination.
- Incubator: Set to 20-25°C to maintain control groups under Earth-like conditions.
- Spectrophotometer: A device that measures the amount of light absorbed by a sample. Helps determine the concentration of substances in a solution by assessing how much light passes through it.

- Petri Dishes: Used to prepare control and experimental agar plates.
- Saline Solution: (for dilutions and plate preparation)
- Ice Cubes from Brine Solution: Used to simulate frozen Martian conditions on some plates

Methods and Procedures

Preparation Phase

1. Prepare Brine Solutions

Create solutions with different salt concentrations to study extremophiles.

- Low Salinity (1% NaCl):
  - Measure 10 grams of sodium chloride (NaCl) and dissolve it in 1 litre of distilled water. Stir until fully dissolved.
- Medium Salinity (5% NaCl):
  - Measure 50 grams of NaCl and dissolve it in 1 litre of distilled water.
- High Salinity (10% NaCl):
  - Measure 100 grams of NaCl and dissolve it in 1 litre of distilled water.
- Labelling: Label each container with its salt concentration, date, and your initials to avoid confusion later.

2. Culture Extremophiles

Inoculate Nutrient Broth

1. **Inoculation:**

For Pseudomonas syringae:

- Open the culture container and use a sterile loop to collect a small colony.
- Transfer this colony into a flask with 50 mL of nutrient broth, stirring gently to mix.

For Halobacterium:

- Repeat the same steps with a new loop, inoculating a separate flask of nutrient broth.

2. **Label the Flasks:**

- Clearly label each flask with the organism's name, date, and your initials.

Incubation

1. **Incubate the Cultures:**
   - Place the labelled flasks in an incubator (20-25°C) for 24 to 48 hours.
2. **Monitor Growth:**
   - Check the flasks for cloudiness, which indicates bacterial growth.

Experimental Setup

3. Inoculate Agar Plates

Transfer bacteria onto the agar plates to test their growth in different salt levels.

- **Preparation for Inoculation:**
  - Use a sterile inoculation loop to take 100 µL of each bacterial culture and put it in separate sterile containers.
- **Inoculation by Salinity Group:**
  - Group A (Low Salinity): Inoculate ten plates with the 1% NaCl solution.

  - Group B (Medium Salinity): Inoculate ten plates with the 5% NaCl solution.
  - Group C (High Salinity): Inoculate ten plates with the 10% NaCl solution.
- Spreading the Culture: Use a sterile spreader to evenly cover the surface of the agar with the bacterial solution. Let the plates sit for 10 minutes to absorb the culture.

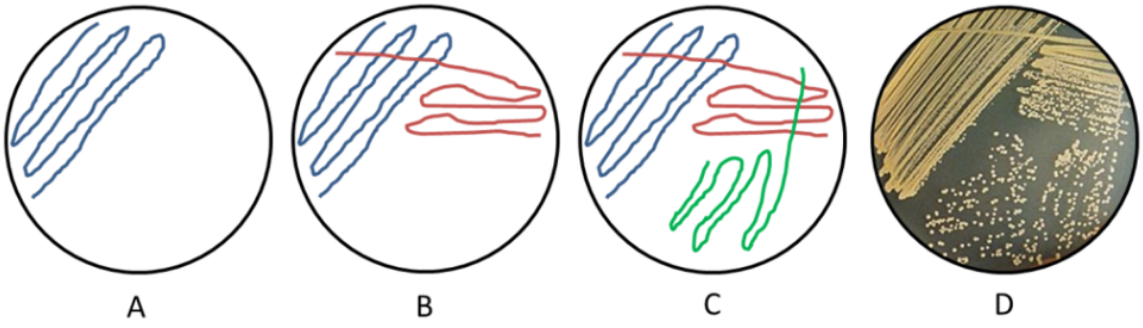

Figure 14: The streak plate method illustrates the dilution of bacteria across three streaks (A-C), resulting in isolated colonies (D) (Ellis 2022).

4. Prepare Control Plates

Set up control plates to compare against experimental results.

- **Control Groups:**
  - Inoculate ten additional plates for each extremophile with nutrient broth (no salt added).
  - Label these as control plates and keep them separate from the experimental ones.

Incubation Phase

5. Set Up Experimental Conditions

Create the right environment for the bacteria to grow.

- **A. Cold Incubation:**
  - Place all inoculated plates (experimental and control) in a cold chamber set to -20°C. Make sure the temperature remains stable.
- B. UV Radiation Exposure:
  - Select Plates for UV Exposure: Pick half of the plates from each salinity level (5 plates from each group) to expose to UV light.
  - UV Treatment: Put selected plates under UV light at a wavelength of 254 nm for 30 minutes. This simulates Martian UV conditions.
  - After exposure, all plates are returned to the cold chamber.

Monitoring and Data Collection

6. Monitor Growth

Observe and record how well the bacteria grow under different conditions.

A. Incubation and Observation:

- Keep all plates in the cold chamber for 24 hours. After this period, check for microbial growth. Look for signs like colonies forming, colour changes, or texture differences.

B. Measurements (Liquid Cultures):

- Take a small sample from the liquid cultures and use a spectrophotometer to measure how cloudy it is (turbidity). Compare these readings with control plates to assess growth.

C. Data Documentation:

- Record your findings in a table with columns for:
  - Presence or absence of growth
  - Characteristics of colonies (colour, texture, shape)
  - Size of colonies (if applicable)

Condition	**Turbidity (Control)**	**Turbidity (Low Salinity)**	**Turbidity (Medium Salinity)**	**Turbidity (High Salinity)**	**UV Exposed?**
-20°C, No UV					**No**
-20°C, UV					**Yes**

Condition	**Qualitative Observations**
-20°C, No UV	
-20°C, UV	

Table 1: Template of a summary table for recording qualitative and quantitative data.

D. Graphs and Visual Data:

- Make graphs comparing survival rates across different salt and UV conditions. Include pictures of plates showing the different growth patterns.

Assessment

Data Analysis and Interpretation:

- Analyze Survival Rates: Calculate how many colonies survived in each condition based on your observations and turbidity measurements.
- Graphs: Create visual graphs to compare survival rates, focusing on how salinity and UV exposure affected growth.

Condition	Excellent (4)	Good (3)	Satisfactory (2)	Needs Improvement (1)
Data Accuracy	All data accurately recorded and calculated	Minor errors	Moderate errors	Major errors, missing data
Observation Detail	Highly detailed, accurate observations	Mostly detailed observations	Basic observations with minor omissions	Lacks detail, incomplete observations
Interpretation Quality	Thorough, insightful interpretation	Clear, logical interpretation	Some insight, but lacks depth	Lacks understanding
Conclusion Validity	Strong, well-supported conclusions	Supported conclusions	Conclusions with partial support	Conclusions not supported

Table 2: A rubric detailing the performance levels across four types of criteria

Resource List:

- Equipment: Cold incubation chamber, UV light source, spectrophotometer, inoculation loop, sterile Petri dishes, spreader.
- Reagents and Materials: Nutrient agar, sodium chloride, sterile saline solution.
- Pre-lab Preparations: Label plates, sterilize equipment, prepare brine solutions, and set up incubation and UV equipment.

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Appendix A

$$T = \left(\frac{A_{abs}}{A_{rad}} \frac{L_{\odot}(1-a)}{4\pi\sigma R^2{}_{orbit}}\right)^{\frac{1}{4}}$$

To make sure we can produce Earth's average temperature using this equation, we substitute in all the constants including Average Earth albedo (a) = 0.367, the radius of the Earth's orbit around the sun ($R_{orbit} = 1.496 \times 10^{11}$m), the Stefan-Boltzmann constant (5.670 x 10^{-8} W/m^2) and the solar constant ($L_{\odot} = 3.846 \times 10^{26}$). The ratio of $\frac{A_{abs}}{A_{rad}}$ is $\frac{\pi r^2}{4\pi r^2}$. However, instead of substituting $\frac{1}{4}$ in place of $\frac{A_{abs}}{A_{rad}}$, we use the 0.816 which is a more accurate value that takes into account greenhouse effect.

$$T = \left(0.816 \times \frac{(3.846 \times 10^{26})(1-0.367)}{4(3.14)(5.670 \text{ x } 10^{-8})(1.496 \times 10^{11})^2}\right)^{\frac{1}{4}}$$

$$= \sim 14.4°\text{C}$$

To calculate the innermost orbit that would keep Earth in the habitable zone, we substitute in the maximum temperature that would keep water liquid,

$$R_{max} = \left(\frac{L_{\odot(1-a)}}{4\pi\sigma\left(\frac{T}{0.816}\right)^4}\right)^{\frac{1}{2}}$$

$$= \left(\frac{(3.846 \times 10^{26})(1-0.367)}{4(3.14)(5.670 \text{ x } 10^{-8})\left(\frac{373}{0.816}\right)^4}\right)^{\frac{1}{2}}$$

$$= 0.591 \text{ AU}$$

To calculate the outermost orbit that would keep Earth in the habitable zone, we substitute in the minimum temperature that would keep water liquid,

$$R_{min} = \left(\frac{L_{\odot}(1-a)}{4\pi\sigma\left(\frac{T}{0.816}\right)^4}\right)^{\frac{1}{2}}$$

$$= \left(\frac{(3.846 \times 10^{26})(1-0.367)}{4(3.14)(5.670 \text{ x } 10^{-8})\left(\frac{273}{0.816}\right)^4}\right)^{\frac{1}{2}}$$

= 1.104 AU

To calculate the most eccentric orbit that would keep Earth in the habitable zone, we substitute in the length of the semimajor axis for *a* and the length of the semi minor axis for *b*.

The length of the semimajor axis is

$$a = \frac{(R_{min} + R_{max})}{2}$$

$$= \frac{(1.104 + 0.591)}{2}$$

= 0.848

$$b = (R_{min} \times R_{\max})^{0.5}$$

$$=(1.104 + 0.591)^{0.5}$$

= 0.808

$$e = \sqrt{1 - \frac{b^2}{a^2}}$$

$$= \sqrt{1 - \frac{0.808^2}{0.848^2}}$$

$$= 0.304$$

Velocity at first burn in a Hohmann transfer orbit:

$$v = \sqrt{2GM(\frac{1}{r} - \frac{1}{r_1 + r_2})}$$

$$v = \sqrt{2(6.67 \times 10^{-11})(1.989 \times 10^{30})(\frac{1}{149597870700} - \frac{1}{149597870700 + 233390000000})}$$

$$v = 32860.74 m/s$$

Velocity at second burn in a Hohmann transfer orbit:

$$v = \sqrt{2GM(\frac{1}{r} - \frac{1}{r_1 + r_2})}$$

$$v = \sqrt{2(6.67 \times 10^{-11})(1.989 \times 10^{30})(\frac{1}{233390000000} - \frac{1}{149597870700 + 233390000000})}$$

$$v = 21112.90 m/s$$

Transit time in years in a Hohmann transfer orbit:

$$T = \frac{\sqrt{(\frac{4\pi^2}{GM})(\frac{r_1 + r_2}{2})^3}}{2}$$

$$T = \frac{\sqrt{(\frac{4\pi^2}{(6.67 \times 10^{-11})(1.989 \times 10^{30})})(\frac{149597870700 + 233390000000}{2})^3}}{2}$$

$$T = 0.715\ years$$

Angle of Mars for the window of opportunity:

$$\frac{T}{P} = \frac{180 - \theta}{360}$$

$$\frac{0.715}{1.88} = \frac{180 - \theta}{360}$$

$$\theta = 44°$$

Synodic period for the next opportunity for the Hohmann transfer orbit:

$$Synodic\ period = \frac{1}{\left|\frac{1}{SP_1} - \frac{1}{SP_2}\right|}$$

$$Synodic\ period = \frac{1}{\left|\frac{1}{365} - \frac{1}{687}\right|}$$

$$Synodic\ period = 787\ days$$

Appendix B

Python code for Lab 1A problems:

Question 1:

```
# for part (a)

x = np.linspace(0.0001,10,100)
plt.plot(x,np.log2(x))
plt.grid()
plt.show()
✓ [44] 355ms
```

```
# for part (b)

x = np.linspace(-10,10,100)
plt.plot(x,4*x)
plt.plot(x,x**4)
plt.grid()
plt.show()
✓ [6] 100ms
```

```
# for part (c)

x = np.linspace(-10,10,100)
plt.plot(x, np.arctan(x))
plt.grid()
plt.show()
✓ [5] 136ms
```

```
# for part (d)
✓ [2] < 10 ms
```

```
---------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
<ipython-input-1-c1802f9587ed> in <module>
      5 n = 100
      6
----> 7 x = np.linspace(a,b,n)
      8
      9 y1 = 2*x

NameError: name 'np' is not defined
```

Question 2

```
a = 0
b = 4
n = 100

t = np.linspace(a,b,n)
S = 14*np.exp(-0.63*t)  # note: e^x is entered in Python as np.exp(x)

for i in range(0,n):
    print("(", t[i], ",", S[i], ")")

plt.plot(t,S)
plt.title("Exponential decay")
plt.xlabel('t')
plt.ylabel('S')
plt.grid()
plt.show()
[19]
```

Question 3:

```
# run this cell  --- ignore the code in this cell if you wish
# Here Jupyter reads data from a file and plots it
# NOTE: YOU MUST BE CONNECTED TO THE INTERNET TO UPLOAD THE DATA (otherwise Jupyter will send you an error message)

data = pd.read_csv("https://ms.mcmaster.ca/lovric/labsdata/functionsdata1.csv")
x=[]
y=[]
for i in range (0,len(data)):
    x.append(data.iloc[i,0])
    y.append(data.iloc[i,1])
# print("Data has been read!")

xs=[0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17]  # from here on - various setups to produce a graph
ys=[10,20,30,40,50,60,70,80,90,100]
plt.scatter(x,y,color='royalblue',marker="o")
plt.xlabel("x",fontsize=10)
plt.ylabel("y",fontsize=10)
plt.title(" ")
plt.xlim([-0.6,17.5])
plt.ylim([-2,104])
plt.xticks(xs,xs)
plt.yticks(ys,ys)
plt.grid()
plt.show()
✓ [10] 193ms
```

Question 4:

```python
# to the plot of y=sin(x/2) on the interval [a,b] we now add its inverse function

# define endpoints [a,b] and number of points to be generated
a = -np.pi
b = np.pi
n = 100

# define y=sin(x/2) as a table of values, with n values for x and y
x = np.linspace(a,b,n)
y = np.sin(x/2)

# plot the function sin(x/2) on [a,b]
plt.plot(x,y, label = 'y=sin (x/2)')

# now plot the graph of the inverse function in the same coordinate system
plt.plot(y,x, label = 'y-inverse')  # note that we switched x and y (that's how we get the inverse!)
plt.title(" ")
plt.xlabel('x')
plt.ylabel('y')
plt.legend()
plt.grid()
plt.show()

# run this cell
✓ [45] 758ms
```

Question 5:

```python
# We already have a functioning code for a table of values, so we copy/paste/modify :)

a = -0.9999999999  # we start with the interval [-1,1]
b = 0.0000000001   # since it is about the limit at zero, we will investigate the values on both sides of zero
n = 20  # n defines the size of the table of values
x = np.linspace(a,b,n)
y = 1.47*x*np.exp(-x)*np.sin(3.3/x)

# printing the table of values: from here on, nothing needs to be changed!
for i in range(0,n):
    print(x[i],"   ", y[i])

# run this cell as is, to start
✓ [48] 20ms
```

Question 6:

```python
## using IVT to find solutions of equations

a = 0.54   # keep in mind that there is a logarithm involved!!!
b = 0.56
n = 1000

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()
✓ [20] 130ms
```

Question 7:

```python
conc_prime = []  # initially the array is empty, as we have not done any calculations
time = []
data = pd.read_csv("https://ms.mcmaster.ca/lovric/labsdata/concentrationdata.csv")
time=[]
conc=[]
for i in range (0,len(data)):
    time.append(data.iloc[i,0])
    conc.append(data.iloc[i,1])

for i in range (0,len(data)-1):
    aroc = (conc[i+1]-conc[i])/(time[i+1]-time[i])  # use forward differences (slope of secant line)
    conc_prime.append(aroc) # add this 'average rate of change' to the list conc_prime
conc_prime.append(aroc)  # when i = len(data), i.e., for the last difference quotient, just use the last computed value

print(np.max(conc_prime))
maxIndex = np.argmax(conc_prime)
print(maxIndex)
print(time[60])

plt.plot(time, conc, color = 'blue')
plt.title(" ")
plt.xlabel("time")
plt.ylabel(" ")
plt.grid()
plt.show()
✓ [43] 176ms
```

Python code for Lab 1B problems:

Question 1:

```python
# code for problem 1 (note: you can use the '+' button on the menu bar above to add cells as you need them)

def drawLineSegment(x1, y1, x2, y2):
    t = np.linspace(0, 1, 10)
    x = x1 + (x2 - x1) * t
    y = y1 + (y2 - y1) * t
    plt.plot(x, y)
    plt.xlabel('x')
    plt.ylabel('y')
    plt.xlim(-10, 10)  # define limits for x-axis
    plt.ylim(-10, 10)  # define limits for y-axis
    plt.grid()
    plt.show()
    length = np.sqrt((x2 - x1) ** 2 + (y2 - y1) ** 2)
    print("The length of the line segment is", length)
```

```python
def triangle():
    t = np.linspace(0, 1, 10)
    xab = 1 + 3 * t
    yab = 1 + t

    xbc = 4 - t
    ybc = 2 - 7 * t

    xca = 3 - 2 * t
    yca = -5 + 6 * t

    plt.plot(xab, yab)
    plt.plot(xbc, ybc)
    plt.plot(xca, yca)
    plt.xlabel('x')
    plt.ylabel('y')
    plt.xlim(-10, 10)  # define limits for x-axis
    plt.ylim(-10, 10)  # define limits for y-axis
    plt.grid()
    plt.show()


triangle()
```

Question 2:

```python
# code for problem 2

def drawTopHalfCircle(r, h, k):
    t = np.linspace(0, np.pi, 1000)
    x = h + r * np.cos(t)
    y = k + r * np.sin(t)
    plt.grid()
    plt.xlabel('x')
    plt.ylabel('y')
    plt.xlim(-20, 20)  # define limits for x-axis
    plt.ylim(-20, 20)  # define limits for y-axis
    plt.plot(x, y)
    plt.show()


drawTopHalfCircle(11, 1, -9)
[11]
```

Question 3:

```python
# code for problem 3
def drawEllipse(a, b):
    t = np.linspace(0, 2 * np.pi, 1000)
    x = a * np.cos(t)
    y = b * np.sin(t)
    plt.grid()
    plt.xlabel('x')
    plt.ylabel('y')
    plt.xlim(-10, 10)  # define limits for x-axis
    plt.ylim(-10, 10)  # define limits for y-axis
    plt.plot(x, y)
    plt.show()


drawEllipse(3, 1)
drawEllipse(3, 2)
drawEllipse(3, 4)
drawEllipse(3, 8)
[12]
```

Question 4:

```python
# code for problem 4
def drawFunctions():
    x1 = np.linspace(-5, 5, 100)
    y1 = x1 ** 3 - 4 * x1
    y2 = np.linspace(-5, 5, 100)
    x2 = y2 ** 3 - 4 * y2

    plt.grid()
    plt.xlabel('x')
    plt.ylabel('y')
    plt.xlim(-4, 4)  # define limits for x-axis
    plt.ylim(-4, 4)  # define limits for y-axis
    plt.plot(x1, y1)
    plt.plot(x2, y2)
    plt.show()


drawFunctions()
[13]
```

Question 5:

```python
# code for problem 5
def intersections():
    t = np.linspace(0, 2 * np.pi, 40000)

    x1 = 3 * np.sin(t)
    y1 = 2 * np.cos(t)
    x2 = -3 + np.cos(t)
    y2 = 1 + np.sin(t)

    plt.grid()
    plt.xlabel('x')
    plt.ylabel('y')
    plt.xlim(-5, 5)  # define limits for x-axis
    plt.ylim(-2.5, 2.5)  # define limits for y-axis
    plt.plot(x1, y1)
    plt.plot(x2, y2)
    plt.show()

    distances = np.sqrt((x2 - x1) ** 2 + (y2 - y1) ** 2)
    # print(distances[distances < 0.0001])
    # print(np.where(distances < 0.0001))
    # print(np.argmin(distances))
    print("Time of collision = " + str(t[np.argmin(distances)]))

intersections()
✓ [5] 106ms
```

Question 6:

```
# code for problem 6
n = 100
a = 0
b = 20
t = np.linspace(a, b, n + 1)

# define parametric equations for curve C
x = t
y = 1 / (1 + t ** 2)
z = t ** 2

# format plot
fig = plt.figure()
ax = fig.add_subplot(111, projection='3d')
ax.plot(x, y, z)
ax.scatter(x[0], y[0], z[0], color="g", label="initial point")
ax.scatter(x[n], y[n], z[n], color="r", label="terminal point")
ax.set_xlabel('x')
ax.set_ylabel('y')
ax.set_zlabel('z')
plt.title("Parametric Curve in $R^3$")
plt.legend()
plt.show()
[19]
```