Origin of Life Biology Lab Report

Valerie Sun

AP Biology Periods 6–7

February 2022

1 Introduction, Procedure, and Hypothesis

The purpose of this lab was to model the environment of the early Earth. Our experiment involved counting *coacervates*, black dots of macromolecules that resemble pockets of life, in order to gauge the suitability for life in various conditions. We modeled the number of coacervates as functions of temperature, pH, and $[H^+]$ to understand the basis and conditions of the formation of life.

Our hypothesis was that there were (1) an inverse relationship between temperature and the number of coacervates as well as (2) a direct relationship in the number of coacervates with respect to $[H^+]$ and pH. This theory explains the process by which life evolved on Earth after its temperature cooled down. Additionally, this hypothesis is congruent with the explanation that complex forms of organisms began to exist after the concentration of oxygen in the atmosphere increased.

2 Pre-Lab Questions

1. *What are the characteristics of life?*
   The characteristics of life include being able to (1) respond to the environment, (2) reproduce, (3) grow and develop over time, (4) exhibit homeostasis, and (5) process energy.

2. *Describe one hypothesis about how living organisms arose on Earth.*
Macromolcules began to evolve from contents of meteors and other natural phenomenona, allowing the development of RNA and, eventually, DNA and proteins. The evolution of aerobic respiration occurred when early bacteria began to increase the concentration of oxygen in the atmosphere due to photosynthesis. This process facilitated the development of aerobic respiration as an integral part of modern-day species.

3 pH vs. Number of Coacervates

Our methods (as a class) involved adding varying drops of an acid to lower the pH of the concentration. The data of the results are shown in Table 1, and the graph showing the relationship is shown in Figure 1.

pH	Average Number of Coacervates	Standard Error of the Mean
1	1.67	0.88
1.5	6.56	3.14
2	10.71	3.65
2.5	18.65	7.49
3	10.31	2.14
3.5	8.14	5.39
4	5.47	3.39
4.5	4.67	2.4
5	0.67	0.3
5.5	1	1
6	0	0

Table 1: The relationship between pH and the average number of coacervates, with standard error.

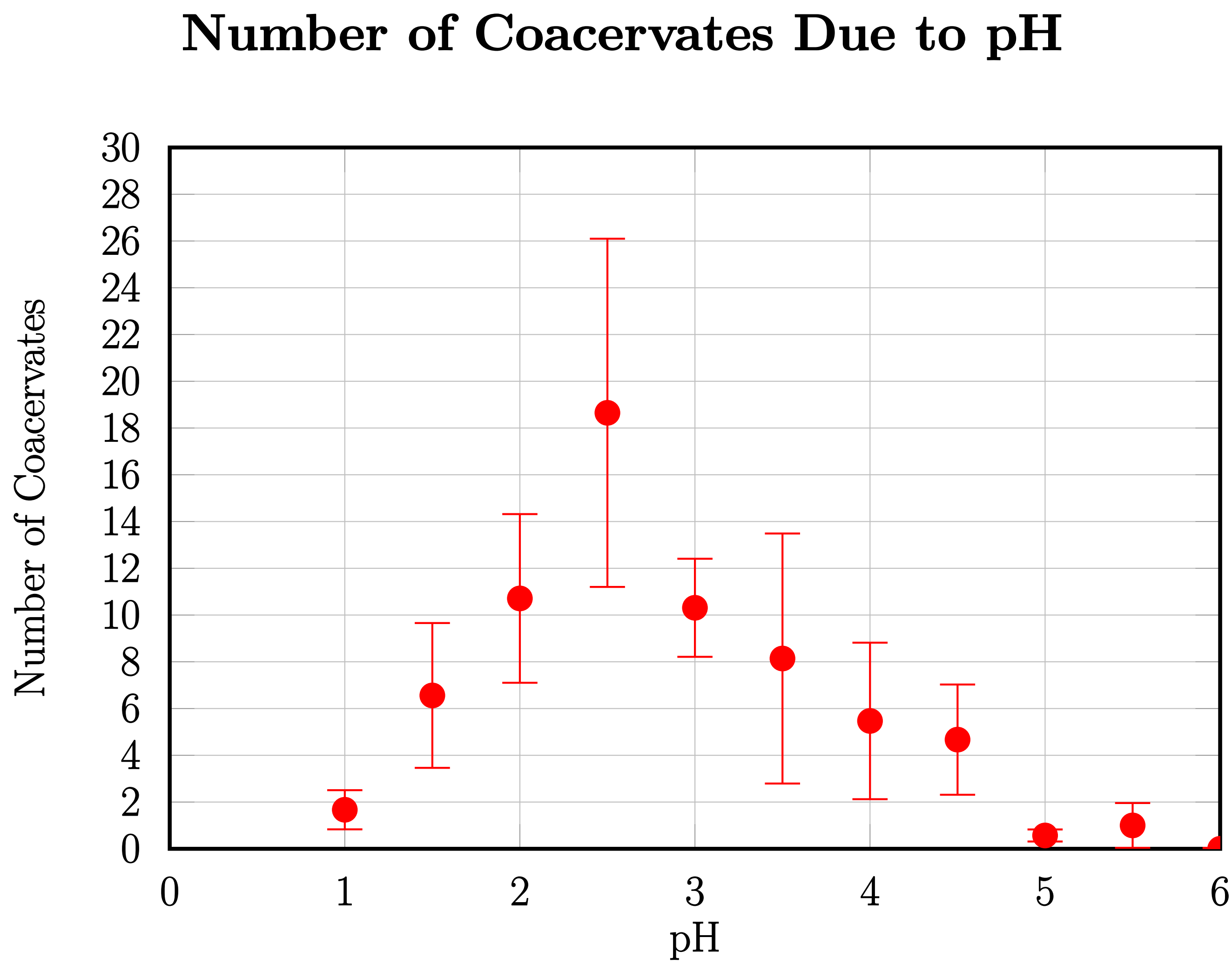

Figure 1: The graph of the average number of coacervates observed in the class for selected values of pH.

From Figure 1, the number of coacervates in the sample is highest at pH levels between 2 and 3. Error bars overlap, however, so it cannot be concluded that the maximum value lies on this interval. It is likely, though, that the optimal pH lies between pH = 2 and pH = 4.5 because any data points outside of that range possess error bars that do not overlap the error bars of data points inside the range. Conversely, the lowest number of coacervates occurs at pH = 0 and pH $\geqslant$ 6. These results are intuitive because pH values of 2–3 are the conditions under which many species' organs and bodily processes function.

4 Concentration of Hydrogen Ions vs. Number of Coacervates

The pattern in Figure 1 is related to the trend in Figure 2, in which the number of coacervates is graphed with respect to $[H^+]$, due to the logarithmic relationship between pH and $[H^+]$:

$$\text{pH} = -\log[H^+] \iff [H^+] = 10^{-\text{pH}}.$$

This equation shows that the values in Table 2 are simply a transformation of the data in Table 1.

$[H^+]$	Average Number of Coacervates	Standard Error of the Mean
1.00×10^{-1}	1.67	0.88
3.16×10^{-2}	6.56	3.14
1.00×10^{-2}	10.71	3.65
3.16×10^{-3}	18.65	7.49
1.00×10^{-3}	10.31	2.14
3.16×10^{-4}	8.14	5.39
1.00×10^{-4}	5.47	3.39
3.16×10^{-5}	4.67	2.4
1.00×10^{-5}	0.67	0.3
3.16×10^{-6}	1	1
1.00×10^{-6}	0	0

Table 2: The relationship between $[H^+]$ and the average number of coacervates, with standard error.

The number of coacervates in the sample is highest at a level of 3.16×10^{-3} M, but it cannot be inferred that this value is truly the maximum due to the overlapping standard error bars of the other data points. In spite of this result, the maximum likely resides in the interval between 10^{-5} M and 10^{-1} M; any values outside of that range contain error bars that do not cross the ones in the central peak. The interval of the maximum number of coacervates in the sample directly corresponds to the peak in Figure 1 at pH levels 2 and 3. Conversely, at low concentrations of hydrogen ions—namely, for $[H^+] \leqslant 10^{-6}$ M—no coacervates were observed. Hydrogen ions are essential for the creation of organic compounds and in cellular respiration (namely, in activating ATP synthase to supply organisms with energy). These processes enable the survival of aerobic organisms, so this result is logical because an insufficient quantity inhibits these steps.

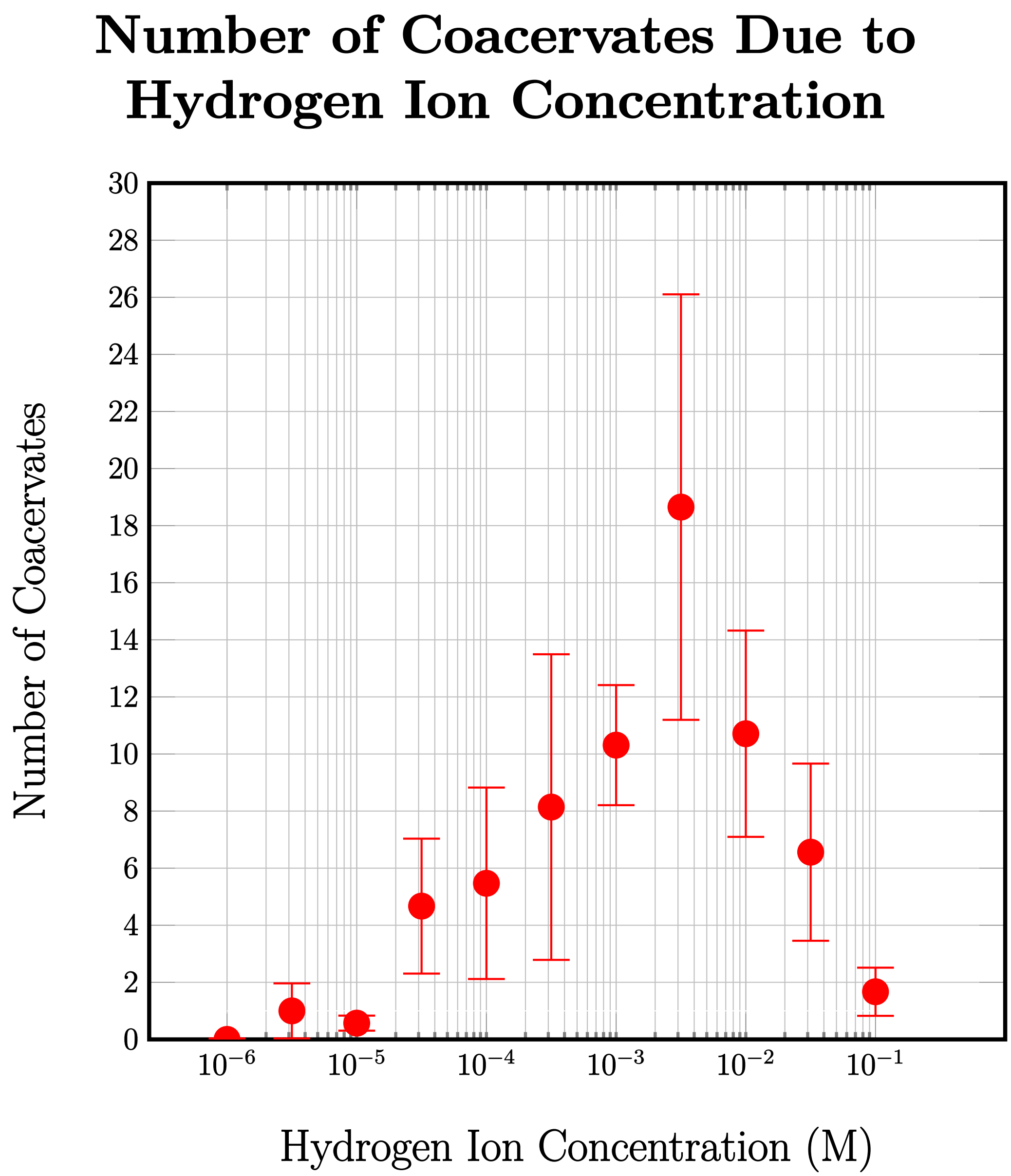

Figure 2: The graph of the average number of coacervates observed in the class for selected values of [H^+].

5 Temperature vs. Number of Coacervates

Table 3 and Figure 3 show the data of the relationship between temperature and the number of coacervates. There is an inverse relationship between the two quantities: As temperature is increased, the amount of coacervates decreases. At 100 ℃, we counted zero coacervates. With this observation, the lack of coacervates indicates that at that temperature there was no potential for life forming. This result is intuitive because many organisms began to form as Earth cooled down, meaning that higher temperatures were unsustainable for them. Additionally, at 0 ℃ we counted the greatest number of coacervates, revealing that 0 ℃ is likely the optimal temperature for life to develop on Earth. Moreover, by the *Ideal Gas Law*,

$$PV = nRT\,,$$

temperature varies directly to pressure. Thus, as the temperature of the Earth's atmosphere increases, its pressure also rises. This increase could be unsurvivable for many species—for example, a human can survive in conditions of no larger than nine times the strength of the gravitational field on Earth.

Temperature (℃)	Observed Number of Coacervates
0	29
23	13
40	13
100	0

Table 3: The relationship between temperature and our observed number of coacervates.

Number of Coacervates Due to Temperature

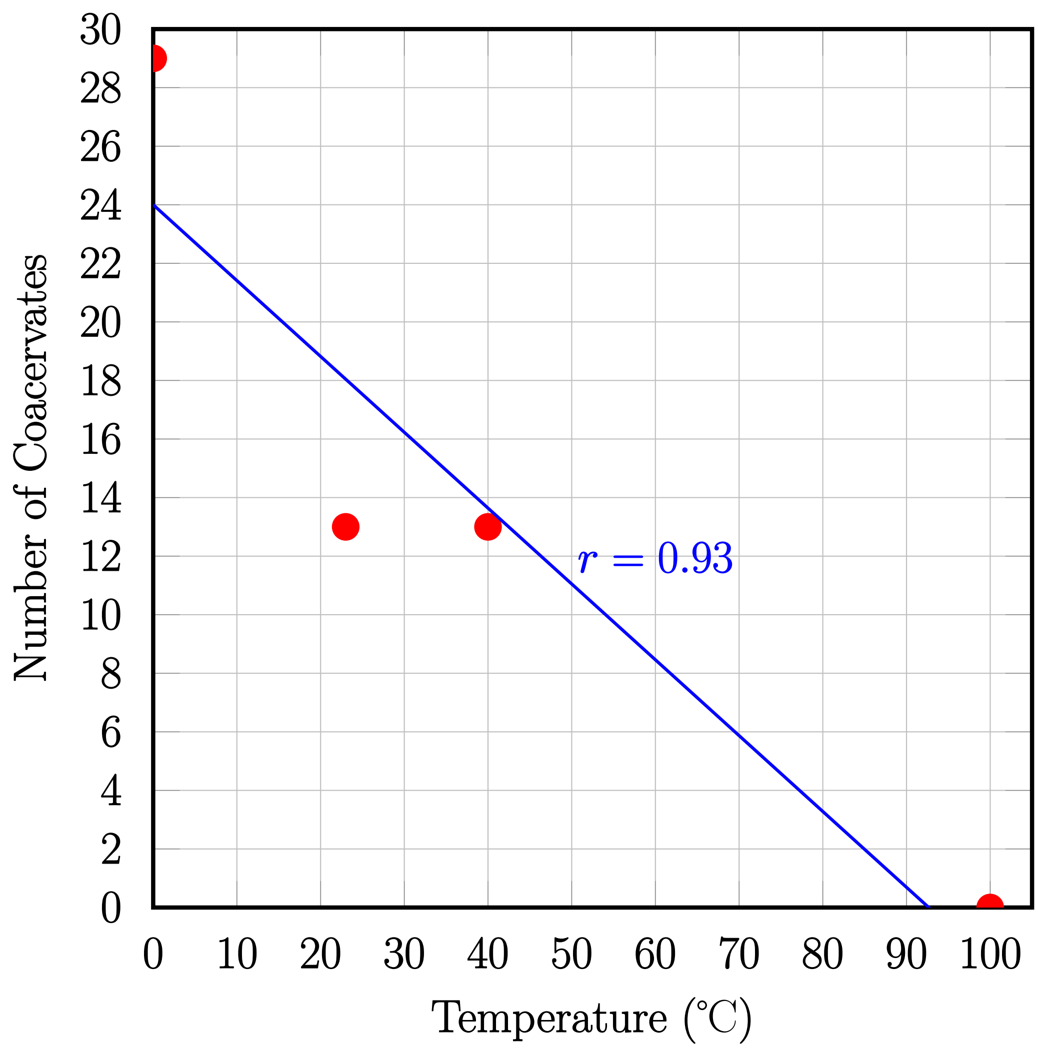

Figure 3: The graph of the average number of coacervates observed in the class due to temperature (in °C).

From Figure 3, there is a preliminary strong inverse relationship between y = number of coacervates and x = temperature in °C, with $r = 0.93$ and the equation of the least-squares regression line being

$$y = 24.3 - 0.259x\,.$$

6 Conclusion and Confounding Factors

From this experiment, our data support a preliminary conclusion that pH levels of 2–3 (corresponding to a H^+ concentration between 10×10^{-3} M and 10×10^{-2} M) and low temperatures (0–40 °C) contributed to the optimal conditions on Earth because we observed the most coacervates. Furthermore, at more-basic pH values—namely, for pH $\geqslant 6$—as well as at boiling point, we found no coacervates. We attribute these findings to deduce that these conditions were unsustainable for life on Earth. Therefore, hypothesis (1)—the inverse relationship between temperature and the number of coacervates—was affirmed by these results. However, hypothesis (2)—a direct relationship between the number of coacervates with respect to $[H^+]$ and pH—applied only for pH $\leqslant 3$. There was a significant decline in the number of coacervates for any higher values of pH, or for lower concentrations of $[H^+]$.

There are a number of limitations in this experiment with confounding factors and experimental errors. The main confounding factor is the nonuniform density, ρ, of the concentration in the test tube. At a height h in the tube, it was clear that

$$\frac{\partial \rho}{\partial h} \neq 0\,,$$

meaning the density differed at varying heights in the tube. We first sampled the surface of the concentration (i.e., at the tip of the test tube) and found no coacervates. However, we began to find them after sampling the bottom of the test tubes. This experience demonstrates the sampling variability involved in this procedure. A method to remedy this error is to sample entire tubes to avoid any sampling variation. A computer could be used to scan for coacervates in the solution. Furthermore, interpersonal and intrapersonal biases were shown when we qualitatively measured the pH of a solution by judging its color. A solution could be to utilize technology to quantitatively measure pH.

There existed a lack of definitive statistical evidence of where was the value of pH or $[H^+]$ corresponding to the maximum number of coacervates as a result of the overlapping error bars. A method to attain more-conclusive data is to conduct more samples because standard error decreases as more values are obtained.