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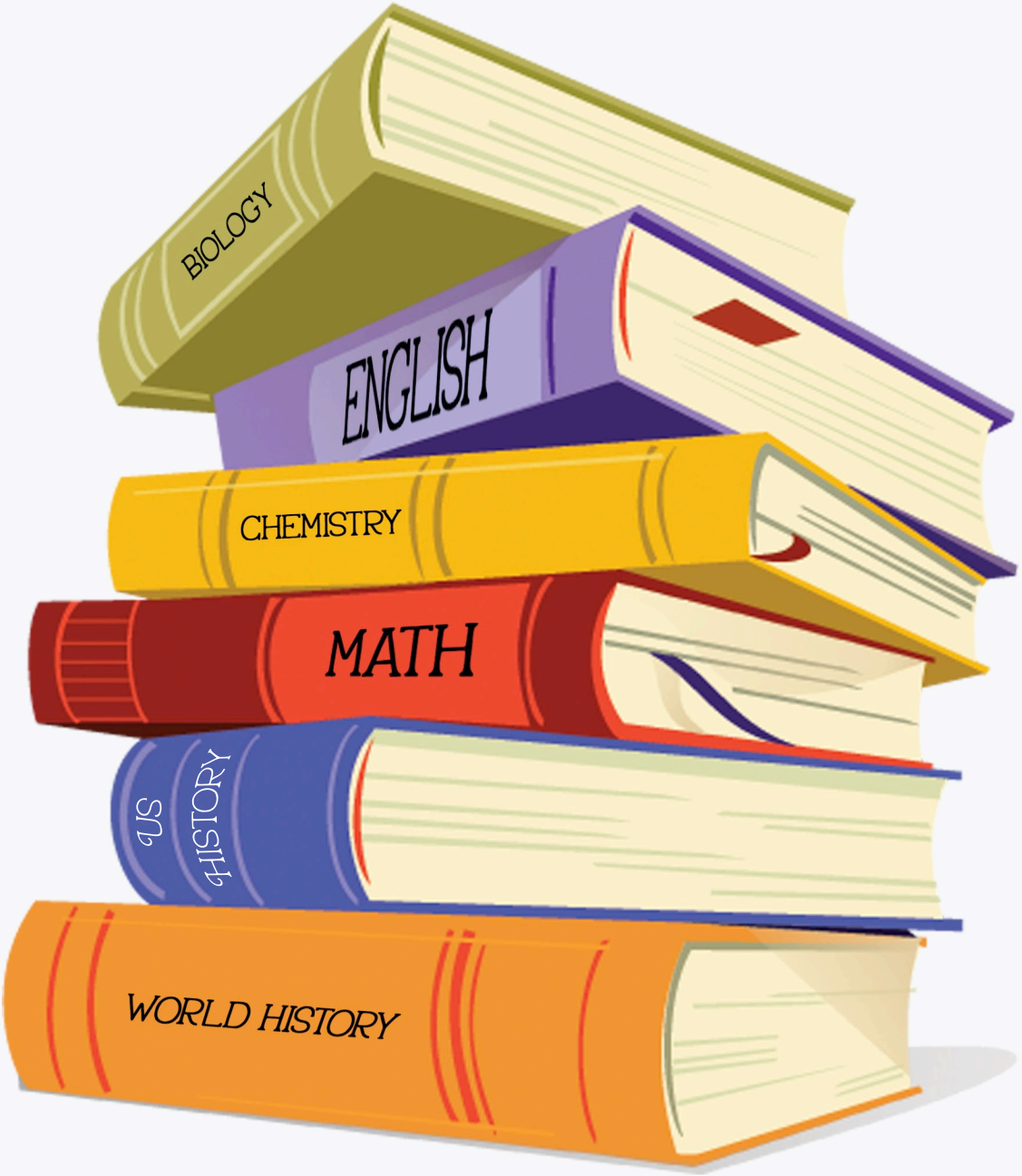

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The Acorn, Kirby's nonfiction journal, publishes student's academic work biannually. Our editors review all work anonymously and provide grammatical edits before confirming any major structural changes made with the original authors. Submit to nonfiction@kirby.org or join as a staff member; meetings are held on Thursdays at lunch.

Dear Reader,

As this school year comes to an end, the Acorn Staff and I decided to put together a large collection of works covering almost every topic, making this the longest issue we've ever published. We start off our issue with a critique of institutional hyperrealism and inaction, a type of paper this journal is excited to highlight. We then continue into our humanities papers with two historical essays about the dirty election of 1800 and nuclear deterrence, leading with two literary analysis essays on *Notes From Underground* and *The Handmaid's Tale*. We finish off our issue with some interesting STEM research in using asparagus extract as an antibacterial agent, the magnetotactic evolution of motile bacteria, and the Hill Cypher and RSA cryptography.

As this is our last issue of the year, I want to thank the department heads (Annika, Michelle, and Max) and all the editors for their hard work looking over papers and putting in so much hard work: your effort has not gone unnoticed. I want to thank the authors of all these works for submitting your amazing work to the Acorn and for being flexible when working with us and our edits. I finally want to thank you, the reader, for picking up a copy and reading your peers' or students' writing. Happy Reading!

- Sonya Koltchev

Stimulated Justice:

A Binary Critique of Institutional Hyperrealism

By Ian Hess

Prologue:

This ***binary critique*** serves a dual purpose: it is an attempt to create a universally applicable method with which to analyze and critique the inaction of institutions, and it is a demonstration of this method. Due to the nature of this work, the structure may seem unusual; it consists of two parts, ***The Universal***, in which the method is established, and ***The Particular*** in which the method is applied. The heterogeneous nature of the piece demands a tonal shift from one section to the other, as the development of theory behind the method may be largely impersonal, but in usage, a sense of urgency is inherent as is the case in all advocacy...

"First, I must confess that over the last few years I have been gravely disappointed with...the white moderate who is more devoted to "order" than to justice; who prefers a negative peace which is the absence of tension to a positive peace which is the presence of justice."

Dr. Martin Luther King Jr. (April 16, 1963)

The Universal

As an immense cultural and sociopolitical upheaval toils in the streets, forcing the slow, rusted gears of institutions to turn, while those at the head of our institutions, those wielding power over society, are forced to choose: action or inaction? In this hyperconnected day and age, one in which social media provides immediate and consummate knowledge and interchange, accountability is considered a powerful word. It belies a unique intersection of contemporary understandings of community and justice. Suppose an institution is in a perpetual state of inaction, it may be called unbudging; within

moments, a movement will have gathered seeking to hold this institution accountable for its misdeeds. The former notions of community and justice return in spades, as a community has formed around a perceived injustice, in order to enact their unified brand of "ought" upon the world. The phenomenon described, which takes many forms and is unimaginably fluid, is often referred to sneeringly as "cancel culture." Regardless of one's personal perspectives on the matter of "cancelling," it is pertinent to understand that this process is dependent on communities formed, typically online, over shared conceptions of justice. This new wave of mass-mobilization of communities to seek justice is why "accountability," is such a strong word, and how, perhaps shockingly, it has become just that. Again, putting aside personal feelings of whether "cancel culture" is right or wrong, we must observe critically what has arisen from it. As online communities of justice amass more power and prestige, becoming the tool of the people to seek that ever alluring word "accountability" be it in people or institutions, those with power, those who are subject to the subversions of power that are created by this new communalized perception of justice, seek to protect themselves, to entrench themselves deeper into the norms of the power structures so that they may pass invisibly through the waves of power emanating from the people. Unconsciously, the great struggle for accountability has inadvertently given institutions the means to escape such a fate.

Accountability, such a responsible sounding term, has the clear and resounding implication that it is enough to merely take responsibility for your actions. Atonement is a non-issue; no higher standard of behavior is expected. This is evidenced by the proliferation of "cancelled" entertainment industry figures who have clung to success by "taking responsibility for their actions" after repeat and flagrant displays mocking communal justice norms (Lars von Trier[1], Mel Gibson[2], Alec Baldwin[3],

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[1] Lindsey Romain, "The House That Lars Von Trier Built, and That I Live In: Features: Roger Ebert," Features | Roger Ebert (Roger Ebert, 2018), https://www.rogerebert.com/features/the-house-that-lars-von-trier-built-and-that-i-live-in. (This is both a review, and a collection of allegations against von Trier with relevant links)

[2] Elizabeth Wagmeister, "How Does Mel Gibson Still Have a Career?," Variety (Variety, July 2, 2020), https://variety.com/2020/film/news/mel-gibson-controversies-career-1234696080/#!

[3] Aurelie Corinthios, "Alec Baldwin: A History of the Actor's Arrests and Other Brushes with the Law," PEOPLE.com (People, November 5, 2018), https://people.com/tv/alec-baldwin-history-arrests-paparazzi/.

Mark Wahlberg[4], Kanye West[5], et al.). Companies that repeatedly spur ethical practices while profusely apologizing (or being apologized for by publicists and remaining powerful institutions). (Amazon[6], Tesla[7], Uber[8], Apple[9], Foxconn[10], ASDA Walmart[11], Coca-Cola[12], Nestle[13], et al.) are another indication of this sordid situation. The constancy of some of these cultural landmarks is permitted by their knowledge that the safest place to be when communities are forming around shared notions of justice is within those communities, sycophantically professing those same notions of justice.

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[4] Isobel Lewis, "The Full List of Mark Wahlberg's Racist Hate Crimes," The Independent (Independent Digital News and Media, June 10, 2020), https://www.independent.co.uk/arts-entertainment/films/news/mark-wahlberg-racist-hate-crimes-wikipedia-history-george-floyd-blm-protests-a9554191.html.

[5]Joe Coscarelli, "In Kanye West, the Right Sees Truth-Telling and a Rare A-List Ally," The New York Times (The New York Times, April 27, 2018), https://www.nytimes.com/2018/04/27/arts/music/kanye-west-trump-conservatives.html.

[6] Peace and World Affairs Berkley Center for Religion, "Is Amazon Ethical?," Berkley Center fo Religion, Peace and World Affairs, 2019, https://berkleycenter.georgetown.edu/posts/is-amazon-ethical.

[7] Alan Ohnsman, "Inside Tesla's Model 3 Factory, Where Safety Violations Keep Rising," Forbes (Forbes, 2019), https://www.forbes.com/sites/alanohnsman/2019/03/01/tesla-safety-violations-dwarf-big-us-auto-plants-in-aftermath-of-musks-model-3-push/?sh=5388624154ce.

[8] Cyrus Farivar, "Uber, Lyft Likely Violated California Labor Law, Appeals Court Finds," NBCNews.com (NBCUniversal News Group, October 23, 2020), https://www.nbcnews.com/tech/tech-news/uber-lyft-likely-violated-california-labor-law-appeals-court-finds-n1244386.

[9] Reed Albergotti, "Apple Accused of Worker Violations in Chinese Factories," The Washington Post (WP Company, September 9, 2019), https://www.washingtonpost.com/technology/2019/09/09/apple-accused-worker-violations-chinese-factories-by-labor-rights-group/.

[10] Brian Merchant, "Life and Death in Apple's Forbidden City," The Guardian (Guardian News and Media, June 18, 2017), https://www.theguardian.com/technology/2017/jun/18/foxconn-life-death-forbidden-city-longhua-suicide-apple-iphone-brian-merchant-one-device-extract.

[11] Conal Walsh, "Wal-Mart 'Is Anti-Union and Has Used Sweatshops'," The Guardian (Guardian News and Media, January 26, 2003), https://www.theguardian.com/business/2003/jan/26/supermarkets.theobserver2.

[12] Jennifer Sawayda, Kevin Sample, and Rob Boostrum, "The Coca-Cola Company Struggles with Ethical Crises," Center for Ethical Organizational Cultures (Auburn University, 2014), https://harbert.auburn.edu/binaries/documents/center-for-ethical-organizational-cultures/cases/coca-cola.pdf, 7.

[13] Rachel Siegel and Peter Whoriskey, "Hershey, Nestle and Mars Won't Promise Their Chocolate Is Free of Child Labor," The Washington Post (WP Company, June 5, 2019), https://www.washingtonpost.com/graphics/2019/business/hershey-nestle-mars-chocolate-child-labor-west-africa/.

Individuals such as Andrew Cuomo, who conceal themselves from communities of justice by framing themselves as part of "the movement"[14] while engaging in horrendous behavior,[15] exemplify this manipulation. Privileges granted by such framing have limits as evidenced by the recent allegations against Cuomo, but it is worth noting that his power as governor has not been rescinded as of yet.[16] In the case of institutions, it is common to put on a show of action, yet remain in a state of inaction. Failed attempts, like those of Pepsi and their Kendal Jenner commercial[17] spring to mind, but there is a far more insidious version of this that exists: companies, organizations, and all other sorts of institutions hire diversity and representation consultants in the ultimate empty show of action. There is in fact a massive upswing in the hiring of these specialists[18], coinciding perfectly with the rise of communal justice.

One may wonder how an institution creating a role for the express purpose of ushering in a culture shift could possibly not be considered action. While the diversity consultant position has potential, the cynical usage of it by institutions leads those filling the position to frequently vacate it and search for opportunities to create change elsewhere.[19] The usage of the term "consultant" is

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[14] Laura Nahmias, "Cuomo Considers Himself a Feminist," Politico PRO (Capitol News Company, November 3, 2014), https://www.politico.com/states/new-york/albany/story/2014/11/cuomo-considers-himself-a-feminist-017114.

[15] "The Claims against Cuomo: A Look at the Women's Allegations," AP NEWS (Associated Press, March 11, 2021), https://apnews.com/article/new-york-andrew-cuomo-6e3c286c9ccfde352fc7b15ae7be9f70.

[16] Chris Cillizza, "Analysis: Andrew Cuomo (Still) Isn't Resigning," CNN (Cable News Network, April 22, 2021), https://www.cnn.com/2021/04/22/politics/andrew-cuomo-scandal-political-attention-span/index.html.

[17]Daniel Victor, "Pepsi Pulls Ad Accused of Trivializing Black Lives Matter," The New York Times (The New York Times, April 5, 2017), https://www.nytimes.com/2017/04/05/business/kendall-jenner-pepsi-ad.html.

[18] Karen Gilchrist, "Hiring Experts Expect Demand for This Role to Surge in 2020 - and It Can Pay a Median of $126,000," CNBC (CNBC, January 2, 2020), https://www.cnbc.com/2020/01/02/demand-for-diversity-and-inclusion-professionals-set-to-rise-in-2020.html.

[19] Chip Cutter and Lauren Weber, "Demand for Chief Diversity Officers Is High. So Is Turnover.," The Wall Street Journal (Dow Jones & Company, July 13, 2020), https://www.wsj.com/articles/demand-for-chief-diversity-officers-is-high-so-is-turnover-11594638000.

intentional: the function served by "full-time positions" is that of a consultant, given the high rate of job turnover.[20]

So it is to be understood that individuals may pay publicists and institutions may pay consultants in order to stave off the tides of communal justice. This is the modern indulgence. As those with the most power are most afraid of the great "accountability" since they have the most to lose, they find that there is very little for them to fear after all, as for a price, their image may be indurated against that which they would have feared had it not been for their immense power. This is the source of the great separation of the word "accountability" from its power and its given meaning. By engaging in purely symbolic acts, those with power immunize themselves from "accountability" reducing said "accountability" to an empty sign. In common parlance, this is understood as "virtue signaling." Those with power signify that they are in alignment with those communities who would otherwise target them as sources of injustice. Returning to the instance of the unbudging institution, the natural recourse is to first "take responsibility" to end the current "cancellation" and then to "virtue signal" by hiring a consultant so that in the future, said institution will not be a target of future "cancelling." Thus unbudging institutions are perceived to be acting without ever doing so, by simulating a state of action, without transitioning to a state of action. In other words, they have ***simulated justice***.

In the instance of an unbudging institution, an offer with heavy subtext is made by said entity to communities of justice: "take the (image of) change we are presenting (appear pragmatic, sensible), or leave it (to appear militant, obstinate)." This counterfeit choice is even more deceitful when one understands the true extent to which institutions are able to subvert the very grounds on which communities of justice would stand.

A distinction must be made between the states of action and inaction. A state of action is one in which efforts are made to further specific ideological or political ideals. A state of inaction is the inverse of the former state. One must bear in mind the important caveat that, in both states, actions not furthering said ideals can be made without forcing a movement from one state to another: the level

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[20] Ibid.

of action specified by this nomenclature is only that of the ideals. In the context of communal justice and institutional accountability, the ideals in these states are those held by the communities of justice.

Of just as much import as the action-inaction distinction is the definition of simulation provided by Jean Baudrillard. He writes in *Simulacra and Simulation:*

> To dissimulate is to feign not to have what one has. To simulate is to feign to have what one hasn't. One implies a presence, the other an absence. But the matter is more complicated, since to simulate is not simply to feign: "Someone who feigns an illness can simply go to bed and pretend he is ill. Someone who simulates an illness produces in himself some of the symptoms" (Littre). Thus, feigning or dissimulating leaves [intact] the reality principle...: the difference is always clear, it is only masked; whereas simulation threatens the difference between "true" and "false", between "real" and "imaginary". Since the simulator produces "true" symptoms, is he or she ill or not? The simulator cannot be treated objectively either as ill, or as not ill. (1994a, 3).[21]

By simulating action or justice, an institution is not merely pretending to do those things, but, quite insidiously, interpolating signs that signify nothing into a system of signs signifying reality, obfuscating reality itself, allowing for the unreal to seem more real than the real. In a way, through this process of simulation, the terms on which one could understand "justice" or "action" are actually redefined by the substitution of signs: the "'true' symptoms" are produced, but they are only true if these signs are taken to semiotically represent real things. For instance, by disavowing previous inaction, and hiring a diversity consultant, an unbudging institution is doubly deceiving its critics: it produces a sign to represent the reality of action (disavowal, which aligns in part with the ends its critics have in mind), and then produces a second sign, under the same pretense of action, but this time it does not represent reality; it is a representation of nothing, taken as a representation of reality (hiring a diversity consultant, which has nothing to do with the ends its critics have in mind, but will be used as proof of

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[21]Jean Baudrillard, "Simulacra and Simulation" Baudrillard, Jean - Simulacra And Simulation - WordPress.com,, 2014, https://0ducks.files.wordpress.com/2014/12/simulacra-and-simulation-by-jean-baudrillard.pdf , 3.

action all the same). It is the insistence that the second production of a sign is indeed action, combined with the representational signs of the first production that redefines "action" and "justice." Such an institution is doing nothing (remaining in a state of inaction), and in this nothing, signifies nothing (the practice of the institution would not otherwise qualify as action). The term used by Baudrillard to express the condition brought about by the simulation of reality is ***hyperreal***. In his words: "Simulation is...the generation by models of a real without origin or reality: a hyperreal"[22] While the notion of a hyperreality precluding intellectual liberation is certainly daunting, Žižek offers a solution in respect to the hyperreal disposition: "The proper answer to [institutions claiming to act and do so justly] is not therefore '[you] are really not [doing those things]' but '[this claim to action and justice] has nothing to do with [action and justice]; the ideological figure of [action and justice] is a way to stitch up the inconsistency of our own ideological system."[23] The conclusion of Žižek's statement is that only through the realization of and acceptance of the limited scope of possible knowledge and the process by which this subjectivity is shaped, that one can force this substituted reality to circumvent itself. To do so is not to broach an underlying reality, it is merely to deny an institution's claim that it is acting in a just manner (or at all, for that matter), thereby exposing the lack of reality. The next step in enacting change despite the ideological curtailment faced by communities of justice, is "not to disregard the explicit letter of the Law on behalf of the underlying fantasies, but to *stick this letter against the fantasy which sustains it.*"[24] The unmasking of the reality of institutional justice as a sham, combined with a precocious, literal interpretation of their empty promises, is the "truly subversive thing"[25] that must be done for the sake of progress.

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[22] Jean Baudrillard, "Simulacra and Simulation" Baudrillard, Jean - Simulacra And Simulation - WordPress.com, 2014, https://0ducks.files.wordpress.com/2014/12/simulacra-and-simulation-by-jean-baudrillard.pdf , 1.

[23] Žižek Slavoj, *The Sublime Object of Ideology* (London: Verso, 2009), 49.

[24] Žižek Slavoj, *The Plague of Fantasies* (London: Verso, 2009), 38.

[25] Ibid.

With these perspectives, an order of operations, an ontology of deception and manipulation by institutions, can now be made explicit: an institution will transgress in some way, when attempts to hold it accountable are made, it will issue an apology, signifying change, before turning to a diversity consultant or some other signification of nothing interpreted as a signification of change, consequently repelling all criticism through the interpolation of its "nothing signifying nothing" into the system of signs signifying change.

The Particular

On June 15, 2020, an email was sent by the Kirby Board of Trustees to the Kirby community, offering an explanation for their conspicuous failure to endorse the Black Lives Matter movement. In this message, the Board revealed their fundamental misunderstanding of the movement, characterizing it as a "political entity or organization." While there does exist an organization known as "Black Lives Matter," the movement as a whole is not at the behest of that organization, and they are affiliated only in terms of their goals. According to *Chicago Tribune* journalist Milan Polk, "The Black Lives Matter movement comprises a broad array of people and organizations. The slogan 'Black Lives Matter' itself remains untrademarked by any group"[26] In the language of ***The Universal***, it is the shared ideal of a community of justice. Black Lives Matter as an ideal is distinct from an entity or organization, in that it holds no legal or official status, and contains no corporeal leadership; it is an ideology expressed in kind by a diverse swath of the global populace. After making this twofold error of failing to grasp the essence of Black Lives Matter, and reaffirming their untenable position of not endorsing it, the Board expressed several platitudes including the sentiment that "There is no adequate way to right those wrongs [of discrimination, isolation, and exclusion of POC members of Kirby]" and ended their communication for the time being. Three days later, on the 18th of June, the Board rescinded their previous position, stating unequivocally that they had "made a mistake and...stand in full support of Black Lives Matter."

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[26] Milan Polk Lauren Leazenby, "What You Need to Know About Black Lives Matter in 10 Questions," chicagotribune.com, September 3, 2020, https://www.chicagotribune.com/lifestyles/ct-life-cb-black-lives-matter-chicago-20200903-xh75kbw5nfdk5joudlsgb2viwq-story.html.

Among an array of banal promises - such as "town halls," which is on the surface promising, except for the fact that attendance is optional and requires a form submission, hereby limiting the potential value of public speech, and overall participation - one point stood out: their commitment to "Create a full time position to focus solely on the work of anti-racism and social justice;" this clearly insinuated that they intended to hire a diversity consultant.[27]

The debacle resumed on March 15th, 2021, when the "Anti-Racist Task Force" hosted the weekly All School Meeting. In this spectacle of vacuity, several prescient points touched upon within this paper were manifested. Virtue signaling abounded: embellished talk of "progress," as well as whitewashed methods of exploring racial injustice. Furthering the general sense of dismay, students were given prosaic responses to legitimate concerns: a students query about the lack of Black representation within Kirby faculty was met with the tokenization of a single faculty member, as if the presence of one member of a minority group is equivalent to fair and proportionate representation. The concept of tokenization merits a paper of its own, but it is commonly understood as "'the practice of doing something (such as hiring a person who belongs to a minority group) only to prevent criticism and give the appearance that people are being treated fairly' [with the acknowledgement that] intent is important in deciding whether or not a company is engaging in tokenism."[28] Kirby certainly expressed tokenizing intent in the cynical gesticulation towards their sole Black faculty member to deflect criticism. The most damning instance of Kirby's lack of commitment in regards to facilitating a safe and diverse space was their response to a student, Dahlia Seid-Valencia, who voiced that she and other people of color at Kirby, including faculty, faced immense discrimination. Seid-Valencia was

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[27] In the final stages of this paper, an email was sent to all Kirby students, entitled "Introducing our new Chief Diversity Officer." This is the realization of the promise made by the Board of Trustees, but not the promise that was asked for. Nowhere within the email can references be found as to *how* the CDO will improve Kirby. The majority of the email was dedicated to their credentials. While the manner in which the fulfillment of the CDO position has played out certainly fits within the framework of "virtue signaling," it does problematize the analysis of a particularly contentious All School Meeting; the CDO had not been hired at the time. Given that this paper is focused on Kirby as a whole, the analysis has been left unchanged, since the points made earlier about CDO's being ineffectual stand as they are, and Kirby was in charge of the "Anti-Racist Task Force" regardless of whether or not the CDO was involved the planning of the event.

[28] Kara Sherrer, "What Is Tokenism, and Why Does It Matter in the Workplace?," Vanderbilt Business School (Vanderbilt University, June 22, 2020), https://business.vanderbilt.edu/news/2018/02/26/tokenism-in-the-workplace/.

informed that there were unspecified "weekly meetings," in which what she had to say would be more appropriate, but that her input was valuable.[29]

By now, the emergence of resemblances between the "unbudging institution" detailed in ***The Universal***, and the actions taken by Kirby in this ***Particular*** should be apparent. In case the analogous nature of these instances is not clear, an attempt to elucidate will be made: firstly, Kirby begins in a state of inaction by maintaining a limbic position in which it disavows that which Black Lives Matter fights against, but refrains from endorsing the movement or making meaningful change to progress the goals of the movement; next, a community of justice forms in earnest, pressuring Kirby to change its position; Kirby, in response to this compulsory reaction, rather than transitioning to a state of action, simulates action by repeating its disavowal, this time including an endorsement and, crucially, a promise to fill a position for a diversity consultant, never budging from its state of inaction. This chain of events seems to mirror the method of the institution evading accountability: an institution will transgress in some way. When attempts to hold it accountable are made, it will issue an apology, signifying change, before turning to a diversity consultant or some other signification of nothing interpreted as a signification of change, consequently repelling all criticism through the interpolation of its "nothing signifying nothing" into the system of signs signifying change.

While Kirby has thus far failed to enact the change sought by many members of its community, it is not perfectly in line with the "unbudging institution:" the CDO was not responsible for the events of the "Anti-Racist Task Force" led ASM, as the position was filled after the fact, and no ill-intent is immediately perceptible, meaning that real change is still possible. At present, Kirby is at a crossroads: the community will be waiting to see which path Kirby takes.

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[29] In a private conversation, Seid-Valencia expressed frustration and disappointment in regards to Kirby's handling of this situation. In a dialogue with members of the administration, she felt that the admin used their hiring of a CDO as leverage against her position.

Epilogue:

This paper is a lament of sorts: it is not an attack on institutions, but an expression of sorrow for the deception they impose on themselves and others, through ***simulated justice***. Everything detailed thus far in both ***The Universal*** and ***The Particular,*** the replacement of discernible reality with the ***hyperreal***, and the suspension of justice that this serves, is in a sense, tragic. While critique is the method, and progress is the objective, it is a somber understanding that one must come to in order to fully grasp the magnitude of these affairs. It is not with anger or spite that change will come about, but with a mood of solemnity.

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The Original Dirty Election:

The Propaganda and Campaign Techniques in the Election of 1800

By Lila-Rose Roberts

With each presidential election cycle the United States goes through, the media calls it the "dirtiest election ever" because of the brutal campaign tactics, including print media and political campaigns. But where did this process of political slander and propaganda begin? In the election of 1800, two parties arose in the first ever partisan election: the Federalists and the Democratic Republicans. The campaign methods that were used are noteworthy because they clearly divided the election and the candidates, and also shaped the political culture of the country leading up to and following the election. These two parties relentlessly battled each other in the press, inventing new tactics to both shame and support candidates. Nicknamed "the revolution of 1800," the election of 1800 was the first time that power in the government had dramatically shifted from one party to the other. The public press was overflowing with information and rumors: the moral charges against the Republican candidate Jefferson, as well as Hamilton's plan to bring Adams, another Federalist, down were precedents for public political smear, acting as catalysts for the political turmoil of the period. The morality of the election campaigns of both parties was questioned in Republican and Federalist newspapers, as well as the political tours and speeches. The outcome of the election was ultimately decided by Federalist James Bayard of Delaware, but the patterns that emerged resulted from the parties. The combination of the techniques used in the Federalist press against candidates and the Republican campaign for support for Jefferson began the partisan campaign cycle and characterized election tactics for the elections to come.

In the press, certain words—liberty, love of country, Federalism, Republicanism, democracy, Jacobin, glory, philosophy, and honor—were used so often that to some, they seemed like empty words. The election was said to be a war fought using words, because even the highest ranking

politicians would use obscene language to defend themselves and their ideas while attacking their opponents.[30] Michael Bloomberg, a modern American politician and businessman, speaks to the morality of elections that involve defamation. The prejudices and views about published libel are easily reversed when the judgment being made "depends on the party affiliation of the person who committed it, they're being dishonest with themselves and with the public."[31] This creates an "us versus them" mentality, which promotes loyalty, not to the Constitution and patriotic ideals, but to a certain political party. Additionally, the battle for office for want of power, not public service, causes people to lose their honesty quickly.[32] To remain morally pure, none of the major presidential candidates personally campaigned against the other party in the early stages of the election. The most common way to get information was on the street, where rumors about the candidates openly circulated. Adams was "distinguished, disputatious, short, ugly, hot-tempered, upstanding, provincial, learned,"[33] and he signed the Sedition Act so that he could put those with differing opinions in jail (or possibly protect the country from anarchists). Jefferson was said to be, "tall, humorless, moody, zealous, cosmopolitan."[34] Even while the political discourse on the streets used immature ideas and obscene gossip, the idea of logos became very popular: common newspapers and pamphlets were filled with "'inside' personal references, Latin quotations, and esoteric allusions to classical texts."[35]

Instead of being discussed in a debate or interviews, "campaign battles were waged between the political party newspapers, a propaganda device rooted in the anti-British pamphlets of the American

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[30]Susan Dunn, *Jefferson's Second Revolution: The Election Crisis of 1800 and the Triumph of Republicanism* (New York: Houghton Mifflin Company, 2004), 138.

[31]Michael Bloomberg, "Here's an Honor Code for Life," Vital Speeches of the Day, May 12, 2017, accessed September 23, 2019, https://www.bloomberg.com/opinion/articles/2018-05-12/michael-bloomberg-at-rice-university.

[32]Bloomberg, "Here's an Honor Code for Life."

[33]Jill Lepore, "Party Time: Smear tactics, skulduggery, and the début of American democracy," The New Yorker, September 10, 2007, accessed September 24, 2019, https://www.newyorker.com/magazine/2007/09/17/party-time.

[34]Lepore, "Party Time."

[35]Dunn, *Jefferson's Second Revolution*, 139.

Revolution," which eventually "mercilessly criticized their respective opposing candidates."[36] Partisan newspapers were cropping up everywhere, and "by 1790, the country had about one hundred newspapers; by 1800, the number had more than doubled."[37] Names of party-controlled newspapers were often connected to American ideals and other sources that might make their information and opinions seem more valid. Papers critiqued both sides of the election, but politically neutral papers were viewed as weak. Newspaper editors and journalists felt that the public deserved a clear, concise view of what was happening in the presidential race (even though practically every newspaper had a political bias). Press companies that had a constant supply of information on the election, the candidates, and current governmental affairs (like the Philadelphia Aurora) were more successful and helped boost active citizenship and discussion about the election.

Federalists were immobile on the newsprint scene for the beginning of the election, but as the balloting drew closer, they began to mercilessly defend and express their opinions. Since the party consisted of the majority New England landholders, they felt that engaging in public discourse about the party and its politics would be too much interclass mixing. Suddenly, there was a change and they began to heavily and harshly critique Jefferson; this change began when they realized internally, the party was falling apart and tried to use mutual hatred of Jefferson to reunite the party.[38] The Federalists were not organized in their media campaign, with their media being "more amateurish and consisted of an improvisational effort to respond to the charges of their foes."[39] Later in the decade, they began to sort out a system relying on the Federalist party's economic success and connections, which were used to print pamphlets and broadsides. When the Federalist party began to split into those who supported John Adams and High Federalists, those who agreed with Alexander Hamilton's ideas, the stories, and

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[36]Peter Onuf, "Thomas Jefferson: Campaigns and Elections," Miller Center, accessed September 23, 2019, https://millercenter.org/president/jefferson/campaigns-and-elections.

[37]Dunn, *Jefferson's Second Revolution*, 139.

[38]Ibid, 146.

[39]John Ferling, *Adams vs. Jefferson: The Tumultuous Election of 1800* (Oxford: Oxford University Press, 2004), 149.

rumors that came out of the split were suddenly directly accusing and shaming other candidates—even the opposing Federalist candidate. The fracturing of the party occurred when Hamilton, the prime example of an active citizen and politician who was willing to go to extremes to reach an end that satisfied his political wants, published an essay in October that condemned the Adams administration, but not necessarily encouraging support of Jefferson.[40] The brutal open letter to Adams rivaled commentary by some authors who were in jail under the Sedition Act. While the Federalist party was struggling to support one candidate, the Republicans were securing their policies both privately and publicly. Jefferson began to lay the groundwork of the policies that would take top priority in his campaign. He called them his "political faith," and they could be placed into three categories: "restoring civil liberties; curbing the excessive growth and power of the national government, particularly of its executive branch; and protecting states' rights."[41] He argued that he would defend the rights of states and citizens, using policy, principle, and action to back up his claims while the Federalists only wanted to be in office because it was the highest position of power available.

The newspapers that Thomas Jefferson was involved in used words like people, happiness, enjoyment, democracy, and change: simple words, intentionally inclusive, and designed to appeal to a wide range of voters. Newspapers that argued from a Jeffersonian Republican perspective called him a "friend of the people" and directly marketed the idea that Jefferson was a man of the world who was available to everyone and anyone, a fairly new idea.[42] The circulation of news about Jefferson and the Republican party drastically increased during the years leading up to 1800. Five years before the election, Republican newspapers made up fourteen percent of the nation's newspapers; three years later, that number doubled.[43] Jefferson did not personally write any press against the other party, nor

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[40]Peter Feuerherd, "The First Ugly Election: American, 1800," JSTOR Daily, July 4, 2016, accessed October 1, 2019, https://daily.jstor.org/first-ugly-election-america-1800/.

[41]Edward J Larson, *A Magnificent Catastrophe: The Tumultuous Election of 1800* (New York: Simon & Schuster, 2007), 155.

[42]Dunn, *Jefferson's Second Revolution*, 142.

[43]Ferling, *Adams vs. Jefferson*, 134.

did he critique them as harshly as they accused him. He would not write anything that bashed the Federalists, but encouraged it and helped pay for and distribute these pamphlets and books. James Callender, a Scotsman who fled both Scotland and Ireland because of the trouble his political commentary caused, was beginning to write The Prospect Before Us: a book addressing the policies and personalities of the Federalist party. He sent Jefferson the opening pages, who encouraged him to publish the book, but Callender was later arrested under the Sedition Act. In The Prospect Before Us, he accused Adams and the Federalist party of tricking their way into presidential success, Washington secretly wanted to be a dictator, and Hamilton was willing to sell out the new country to Great Britain.[44]

The media against the candidates was plentiful and increasingly hostile. Instead of positively supporting their candidate, "[b]oth parties engaged in what now would be termed negative campaigning, an assault on their adversary's program and leadership rather than an emphasis on their own platform."[45] Printed campaigning became a sort of back and forth, which focused widely on the faults of the opposing party and their candidate, rather than trying to gain support. All candidates were widely critiqued, and new rumors were published daily. The popularity of campaign lies and truths grew: stories about a person that was oversimplified and glorified their achievements, first effectively used in the election of 1800.[46] Jefferson, "a godless Jacobin who would unleash the forces of bloody terror upon the land,"[47] was the most common subject of this gossip, and there were three main stories that circulated: he was an atheist, he was in love with France, and he was immoral. The rumor about atheism was particularly weighty: the first time that religion was such a major playing card in a political election, the American people wanted to be led by someone who would allow for religious freedom but also who conformed to their ideas about being pious and a good Christian. Sometimes Adams was

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[44]Ibid, 136.

[45]Ibid, 151.

[46]James Parton, "The Presidential Election of 1800," *The Atlantic*, July, 1873, accessed October 8, 2019, https://www.theatlantic.com/magazine/archive/1873/07/the-presidential-election-of-1800/307019/.

[47]Onuf, "Thomas Jefferson."

even more clear about his dissent from common Christian beliefs than Jefferson, but he still clearly self identified as a Christian. This is the basis of this campaign lie about Jefferson: the fact that his opponent was clearly Christian, and explicitly stated his beliefs, meant that he was not. Dr. John Mason, a critical preacher and "ardent politician, as patriotic and well-intentioned a gentlemen as then lived"[48] first cried that Jefferson was denouncing the Christian faith after reading Notes on the State of Virginia, a book published by Jefferson. Jefferson's comments about religion in Notes on the State of Virginia were some of the only ones that he made, where he wrote that "it does me no injury for my neighbor to say there are twenty gods, or no god. It neither picks my pocket nor breaks my leg."[49] Jefferson himself attributed the religious rumors to the fact that he was so clear about the separation of Church and State. Before, there had been no problem nor need for discussion surrounding religion. He carefully monitored his speech so as not to disturb anyone else's religious liberty, but he gave equal attention to maintaining and not compromising his own beliefs. The other rumors mainly concerned the fact that the Republicans preferred an alliance with France over Great Britain and the evidence that Jefferson had fathered children with one of his slaves. In addition to specific falsities being spread, name calling was an extremely common form of negative campaigning. Candidates often did not write critiques of their opponents, but would participate by campaigning in mediums other than print.

Positive campaigning was both in newspapers and in person. In late May, John Adams embarked on a political tour. He met with politicians and officials, gave public addresses, and tried to garner support for his reelection. While Adams was touring the states, he toasted two popular Anti Federalists who played big parts in the revolution and ultimately contributed to independence for America, John Hancock, and Samuel Adams. This displeased the High Federalists, and Adams' speech was eventually used against him in the press.[50] The other main tour that took place was also in the Federalist party: in June, near the end of Hamilton's term as Inspector General of the Additional

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[48]Ferling, *Adams v. Jefferson*, 134.

[49]Parton, "The Presidential Election of 1800."

[50]Larson, *A Magnificent Catastrophe*, 148.

Army, he set out to undermine Adams. His sudden shift of support was received by the Republicans gladly; the general public denounced Hamilton as a trustworthy politician. How could someone so involved suddenly turn against his own party? Planning to parade through the country, full military style, Hamilton was on a mission to meet with Federalist leaders in order to secure their votes for Charles Pinckney, the other Federalist candidate for the presidency. In Connecticut, Massachusetts, New Hampshire, and Rhode Island Hamilton outright told Federalist leaders that the only viable way to have a truly federal government was to elect Pinckney.[51] Ultimately, all that his campaign did was solidify state electors' beliefs. With Adams taken care of, Pinckney became the new target. The Republicans believed that Hamilton would be able to control him in office and that the whole country would be uprooted by Hamilton, who "behind the closed doors of [the Constitutional Convention]... had endorsed monarchy."[52] The gossip about major characters in the election gave them reputations that helped to determine the outcome of the election and would be known about for centuries afterwards.

While historians mostly agree that the campaign tactics and result of the election of 1800 were revolutionary, the focus should be on the long term effects of the election. The fact that the new country managed to survive the election without splitting was somewhat of a surprise. The polar partisanship of the country leading up to the elections was already setting up a tumultuous election season because "during the 1790s the country's political fabric was so rent by the 'baneful effects of the spirit of party.'"[53] Some might argue that the partisan campaigning pattern would have emerged over the years no matter the outcome or tactics of the election of 1800, but 1792 was the first time that clear partisan opinions began to emerge in public media.[54] If it were not for the unhappiness that festered

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[51]Ibid.

[52]Ferling, *Adams vs. Jefferson*, 147.

[53]Thomas Jefferson Encyclopedia, "Election of 1800," Thomas Jefferson Foundation, accessed October 1, 2019, https://www.monticello.org/site/research-and-collections/election-1800.

[54]Joanne B Freedman, "The Presidential Election of 1800: A Story of Crisis, Controversy, and Change," The Gilder Lehrman Institute of American History, accessed October 9, 2019, https://ap.gilderlehrman.org/essay/presidential-election-1800-story-crisis-controversy-and-change.

during Adams' presidency, the election of 1800 would not have been such a turbulent series of events, and wouldn't have featured such open political discourse about the candidates and their policies. This particular election was the first to feature two clearly divided, self identified parties who labeled the other as the opposition.

The end of the election was just as messy as the campaigning itself. When presidential electors voted for the first time, they did not distinguish between the office of vice president and president on the ballot. This meant that there was no clear winner because Jefferson and Aaron Burr, the other Republican candidate, tied. The voting was handed over to the Federalist-dominated House of Representatives, where each state voted as a unit. Congress voted over thirty times, but neither Burr nor Jefferson won the majority of nine states that were needed for victory. Before the thirty sixth voting, Federalist James A. Bayard of Delaware made it public that he was going to break the stalemate. When the House voted the next time, he (and other Federalists from South Carolina, Vermont, and Maryland) cast blank ballots: Jefferson won.[55] There were valid reasons why Representative Bayard had voted in that manner: he found issues when it came to the intentions of the Federalists, that they seemed "willing to sacrifice the Union rather than install Jefferson as president."[56] Between loyalty to the Federalists and Delaware, he wanted his home state to be protected.[57]

The political chronology leading up to the election is crucial to consider. The 1790s posed serious questions and obstacles that shaped the future of the nation and the election process. From Hamilton's financial plan and the whiskey tax in the early 1790s to the Jay Treaty, the XYZ Affair, and the Alien and Sedition Acts in the latter half, the citizens of the new country faced the task of forming political alliances and opinions much sooner than had seemed necessary.[58] The original "dirty election" featured the first partisan newspapers; name calling, political slander, and election tours; and the basis

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[55]Library of Congress, "The Presidential Election of 1800: A Resource Guide," Web Guides, Library of Congress, accessed October 1, 2019, https://www.loc.gov/rr/program/bib/elections/election1800.html.

[56]Freedman, "The Presidential Election."

[57]Ibid.

[58]Ibid.

of campaigning for years to come. The tactics used by the Republicans and the Federalists set up a pattern that would invite partisan campaigning into the United States of America, while inspiring the propaganda of current elections with media based accusations and rumors.

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Nuclear Deterrence's Effectivity During the Cold War

By Fiona Landau

Following World War II, a new world order came about, pitting the US against the Soviet Union. Thanks to the US nuclear attack on Japan, an arms race ensued. As the US and the USSR developed more Nuclear weapons, people started theorizing about how to keep themselves from destroying the planet. The central theory was known as "deterrence," or when "one power uses the threat of reprisal effectively to preclude an attack from an adversary power."[59] Based on this idea, deterrence and the proliferation of nuclear weapons that it spurred should have kept the Nuclear war in check during the Cold War, yet did the opposite and increased the likelihood of nuclear warfare. The subsequent "race" to create more destructive weapons in order to deter the enemy raised global tensions, and the potential for misunderstandings brought the world closer to nuclear annihilation.

During the Cold War, the theory of deterrence fed the race for nuclear domination, which created increasingly destructive weapons, which in turn increased the threat of war. When atomic weapons were first developed during World War II, pre-existing tensions between the Soviet Union and the US grew. The US adopted the theory of deterrence in an attempt to keep potential nuclear destruction at bay. In 1953, Secretary of State John Dulles claimed that "the way to deter aggression is for the free community to be willing and able to respond vigorously at places and with means of its own choosing. ... [T]he President and his advisors had to make some basic policy decisions ... [and it] was to depend primarily upon a great capacity to retaliate instantly."[60] Deciding on this idea of mutually assured destruction seemed like a good idea at the time, but because both countries competed for power, the nuclear arms race started. In Michael McGwire's article, "Nuclear Deterrence," the

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[59]Andea Groce. "Deterrence & Escalation: Hom, " *U.S. Naval War College*, January 16, 2019, accessed May 25, 2019, https://usnwc.libguides.com/deterrence.

[60]Edward H. Judge and John W. Langdon, eds. *The Cold War through documents* (London: Rowman and littlefield, 2018), 101.

author explains that because the authorities always assumed the worst case scenario, they deemed more weapons necessary:

> The deterrers hypothesized a malevolent Soviet Union anxious to exploit any chance to destroy the US, assumed a president easily blackmailed into inactivity, and then considered every possible scenario to assess what was needed. The answer was always 'more.'[61]

The US and the Soviet Union were constantly developing new weapons which put everyone in even more danger and caused even more instability than before.

The threat of increasingly destructive nuclear weapons raised instability, paranoia, and tensions. During the Cold War, whenever either side showed any movement, the other would instantly prepare to retaliate. One instance of this was the Cuban Missile Crisis. Following the Bay of Pigs, the Soviet Union was worried that the US would attack Cuba again, as the Soviet Union was interested in protecting Cuba's communist government. They also felt like the US had more powerful weapons, making the Soviet Union vulnerable to attack. The Soviet Union decided to station their nuclear weapons in Cuba because it would protect the Cuban government and "it would in the eyes of Khrushchev equalize 'what the West likes to call the *balance of power.*'"[62] The US felt threatened by this, so they wanted the Soviet Union to take their weapons out of Cuba. The US and the Soviet Union watched each other's actions closely because of the possibility that the other would strike first. Everyone thought that this situation would end in a nuclear war if neither of them agreed on a solution. Eventually, the Soviet Union agreed that if the US did not interfere with the Cuban government in the future, and if they took their weapons out of Turkey, the Soviet Union would take their weapons out of Cuba. Both countries withdrew their weapons, and this brought an end to the Cuban Missile Crisis. Due to the high tensions and a possibility for misunderstandings, many think

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[61]Michael MccGwire. "Nuclear Deterrence." *International Affairs (Royal Institute of International Affairs 1944-)* 82, no. 4 (2006): 771-84. http://www.jstor.org/stable/3874158.

[62]Atomic Heritage, "Nuclear Close Calls: The Cuban Missile Crisis," *Atomic Heritage Foundation*, June 15, 2018, accessed May 12, 2019, https://www.atomicheritage.org/history/nuclear-close-calls-cuban-missile-crisis.

that this crisis "marked the closest point that the world had ever come to global nuclear war."[63] The majority of the reason this happened was because the Soviet Union was afraid of having less power than the US. This is one example of how deterrence caused instability and led to misunderstandings that put everyone in danger.

Due to growing tensions and increasingly destructive nuclear weapons, misunderstandings could cause larger consequences, putting the world on the brink of another world war. People were on edge because of the possibility of being destroyed, so any miscommunication or understanding could be interpreted as a deliberate beginning of war. One example of this was the Able Archer incident. The US was doing their annual exercises in order to train and prepare for the possibility of war.[64] When the Soviet Union saw the US moving all of their weapons, they thought the US was preparing to attack. They went on high alert and prepared themselves. For about nine days, the Soviet Union and the US were very close to war until the US finished their exercise and the Soviet Union stood down. During the exercise, the US didn't realize how severely the Soviet Union was reacting, and "commanders on the scene were not aware of any pronounced superpower tension, and the Soviet activities were not seen in their totality until long after the exercise was over."[65] War could have started just because of a routine exercise, without the US even realizing that their actions had been misinterpreted. This shows how severe the consequences of simple misunderstandings can be when relying on the theory of deterrence to keep world peace.

Deterrence does not work because it cannot account for miscommunications, misunderstandings, and raised tensions, increasing the likelihood of mistakes and war. The fact that the world has not yet broken out into a nuclear war is purely due to luck. Relying on luck to keep the world from Nuclear destruction was never a stable option. Contrary to the theory of deterrence,

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[63]Editors of Encyclopaedia Britannica. "Cuban missile crisis," *Encyclopaedia Britannica*, May 23, 2019, accessed May 25, 2019, https://www.britannica.com/event/Cuban-missile-crisis.

[64]Atomic Heritage, "Nuclear Close Calls: Able Archer 83," *Atomic Heritage Foundation*, June 15, 2018, accessed May 12, 2019, https://www.atomicheritage.org/history/nuclear-close-calls-able-archer-83.

[65]Ibid.

stockpiling powerful weapons to deter potential attacks puts everyone in more danger than if no one had any nuclear weapons at all. A nuclearized world is not sustainable because of how high the risk of war is, which means that this nuclear race needs to stop before a Nuclear war begins. The US should take steps toward denuclearization and encourage other countries to do the same.

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Notes from Underground: Liza's Impact on the Narrator

By Max Coté

In the first half of Fyodor Dostoevsky's novel *Notes from Underground,* the narrator spends much of his time contemplating various theoretical situations and how to approach different social interactions, regardless of whether or not they will be realized. Although he rarely goes through with his imagined courses of action, the narrator's reasoning on why he holds certain dispositions about human nature; and his need to rationalize every interaction he has manifest themselves in the final two scenes of the novel. These scenes provide important context on the reasoning behind the narrator's justification for limiting his personal interactions, and why he decides to portray himself in how he does. In the last two scenes when the narrator condemns Liza, he proves that he only has the capacity to feel negative emotions and is unable to accept human decency as genuine, which is the primary reason why he inevitably is unable to form connections with people.

In the second to last scene, the narrator's failure to manipulate Liza and her ability to provoke guilt in him cause the narrator to self-reflect and question whether his skepticism of Liza's virtue is justified. In this scene, Liza comes to visit the narrator in his home, per the narrator's prior invitation. The narrator makes clear to the reader that his intention behind inviting Liza was to attempt to assert dominance over her and to try and make her feel sorry for herself. The narrator begins to confront Liza; however, his efforts to incite self-pity in her backfire. Liza responds honorably to the narrator, suggesting she is putting a burden on the narrator. However, "... as soon as [the narrator] saw this first flash of injured dignity [he] simply trembled with anger and at once burst out" (Dostoevsky 120). The narrator's reaction to Liza is a key example of his inability to accept good human nature as genuine, and it aggravates him that Liza would respond in such a respectful way to his discourtesy towards her. The narrator continues to attempt to exploit her, but as she continues to be unprovoked by him. He becomes extremely irritated, leading to him going on a tirade in which he condemns Liza for coming to

visit him: "'And you, what did you come here for? To teach us morals, or what? Power, power, that's what I wanted then, the game was what I wanted, I wanted to achieve your tears, your humiliation, your hysterics—that's what I wanted then!" (121). After the narrator vilifies Liza, he expects her to feel ashamed and to look to him for guidance; however, she is able to realize the narrator's attack on her is rooted in his inability to see benevolence. Rather than feeling remorseful for her own life decisions, she is grateful for the narrator's allowing her the opportunity to reflect on herself. Liza appreciates the narrator's effort to better herself as a person, and she believes that he had good intentions. After the narrator ends his speech, he proceeds to have an outburst of emotions, and in response, Liza attempts to console him:

> The frightened and insulted feeling in her face first gave way to rueful amazement. And when I began calling myself a scoundrel and a blackguard, and my tears poured down ... She suddenly jumped from her chair on some irrepressible impulse, ... Then she suddenly rushed to me, threw her arms about my neck, and burst into tears. I, too, could not help myself and broke into such sobbing as had never happened to me before. (123)

In this moment, Liza allows the narrator to be vulnerable, and it seems he has never had a moment of raw emotion such as this. However, due to the narrator's inability to allow himself to give in to his emotions, he struggles to embrace Liza. The narrator compulsively feels the need to dominate Liza, stating that "[he] was ashamed to look at her, another feeling suddenly kindled and flared up in [his] heart ... the feeling of domination and possession" (124). This is another example of how the narrator's disposition of human emotions, in this case being in love, hinders him from making connections with others.

In the final scene, the narrator's inability to accept emotions as genuine is further proven to inhibit his ability to participate in basic human interaction. As Liza stands outside the narrator's apartment while she prepares to leave, he goes to say goodbye to her, handing her a bill with no clear reason why. However, after the narrator hears her leave the building, he turns and sees a "crumpled blue five-rouble bill" on his table (127). The narrator is astounded that she had done such a noble thing, and it seems that he did not believe she would be capable of such an honorable and virtuous act. The

narrator elaborated on his response, stating that "[he] had in fact so little respect for people, that [he] could scarcely imagine, she too, would do that. [He] couldn't bear it" (127). As seen in previous scenes, it is clear that the narrator often surrounds himself with people who lack integrity and nobility, and due to this, he did not consider the fact that people could act in such a way. However, due to this socialization, he treated Liza in a way that he believed was acceptable, and his attempt to manipulate her, destroyed his chances of forming a connection. After she leaves, he realizes the mistake he has made: "To fall down before her, and to weep in repentance, to kiss her feet, to beg forgiveness ... never will I recall this moment with indifference" (128). He recognizes that this moment with Liza may have been his last chance to create a meaningful connection with another person, but his own pride, self-pity, and his outlook on love led to his poor decisions. Earlier in this scene, he revealed that "in [his] underground dreams as well, [he] never pictured love to myself otherwise than as a struggle; for me it was always started from hatred and ended with moral subjugation" (125). This thought enforces his reasoning for his attempts to dominate Liza in the previous scene, which backfired greatly in disfavor of the narrator.

Throughout the novel, it is made clear that the narrator struggles with human interaction. This struggle is accentuated in the final two scenes in which the narrator endures many complex emotions during his connection with Liza. These interactions seem to be key memories that the narrator struggles to stomach, and they are seemingly part of the reason why he carries himself the way he does. The narrator does not allow himself to become close to anyone, primarily due to his pessimistic behavior surrounding the formation of relationships. Because of the narrator's inability to experience positive emotions as genuine and only accept emotions that cause him pain and self-pity, he struggles to form connections with others and thus is considered a social reject.

The Truth Behind Atwood's Work of Dystopian Fiction

By Sahar Nangoli

The Republic of Gilead, a dystopia created by Margaret Atwood, allows for the rape of women, demonization of feminism, execution of members of the LGBTQ+ community, and the stripping of women's sexual freedom. Although horrendous, the incidents of state violence in the novel are not works of Atwood's imagination, as the entire novel represents real world historical events. Atwood's *The Handmaid's Tale* is set in The Republic of Gilead in the 2000's Boston area. The book explores this new society formed by a recent revolution through the narration of Offred, a handmaid. Her perspective shows the changes to today's society, including extreme forms of gender discrimination. At first, Gilead's laws and customs seem repulsive and immensely unrealistic; however, every method mentioned in *The Handmaid's Tale* mirrors events in the real world. The novel's representation of The Republic of Gilead shows the paranoia surrounding female sexual and educational freedom, in addition to strict theocracies; Atwood's novel suggests the oppressive government strategies are inspired by real-world political contexts. *The Handmaid's Tale's* portrayal of inequality between the sexes acts as a cautionary tale of the alarming reality the world has approached one too many times.

Although the paranoia surrounding female sexual freedom from government legislation seems implausible for today's society, Atwood's construct is based on precedents of the Bible's teachings and various countries' regulation of women. Offred, the narrator of *The Handmaid's Tale,* explains an essential part of the Gileadean regime, the Ceremony, where the commander of the household attempts to impregnate the Handmaid, who has been unwillingly conscripted as a sex slave, to impregnate her. Fertile women are captured and imprisoned by the government, to be treated as human breeding stock. The government justifies this action by instilling religious texts into the Handmaids' heads from the moment they are detained by the government in the Red Center; for example, God would say to Noah and Adam, "*Be fruitful, and multiply, and replenish the earth"*

(Atwood 88). Women were not allowed to read, so the Handmaids would listen to voice recordings of men reading excerpts representing sexual surrogacy where "[a] maid Bilhah who bear upon my knees, that I may also have children by her" (88). The maid acts simply as a body to birth a child for the Commander's wives. These anecdotes outlined the foundation of Gilead's philosophy of women's sexual freedom: it doesn't exist. According to the religion of Gilead, fertile women were put on Earth to bear children for those who cannot. The concept of dehumanizing women to a level where they are separated into categories of fertility is unknown to the environment of 2020 America; however, this type of sexual surrogacy and regulation is familiar to the world. In Genesis, an account of the creation of the world in the Bible, Leah, an infertile wife, claims, "Behold my maid....She shall bear upon my knees, that I may also have children by her" (Gen 80). This underlying theme is analogous to Gilead's regime, where a woman's job is to bear a child for another. Gilead's leaders utilized excerpts out of context in the Bible to justify their actions against Handmaids. The dehumanization of these women is similarly presented in the way they are portrayed to the rest of Gilead, wearing "both red dresses and white wings of the Handmaids" (26). The regime converted a society where everyone would express passion and individuality through fashion to labeling these women with the same clothing. Atwood's inspiration behind the full coverage, uniform look derives from a trip she took to Afghanistan in 1978, where she observed the majority of women wearing chadors. Under the Taliban control of Afghanistan, women were required to wear this garment, which is all black and covers every aspect of a woman's body except the eyes. Essentially, Gilead law encouraged everyone to see Handmaids as the same, simply placed on earth to fulfill their job. Offred reflects on the way society views her as "a container, it's only the inside of [her] body which is important... the outside can become hard and wrinkled... like the shell of a nut"(96). It is clear to the Handmaids that they have no sexual freedom in Gilead. Offred understands that all Gilead cares about is her ability to bear children, and any harm done to the outside of her is irrelevant to what society values. She has no power to decide what happens to her or her body. Similarly, Ceausescu, the former dictator of Romania, caused a rise of 500,000 orphans in 1989 by banning abortions and contraceptives in the country. The country's population increased by more than 6% in 4 years, as the dictator ordered all women subject to regular gynecological

exams at their place of work to to detect pregnancy prior to a possible abortion. Romania's extreme control of women in the population acted as a precedent to Gilead's authority over the Handmaids. Similar to the laws which restricted female sexual freedom, Gilead controlled every woman's economic freedom.

Women's economic freedom in America to work, own property, and be self-sufficient seems to be a given in the modern era; however, the world has a history of expelling women from universities, linking women's wage to child-bearing, and denying women education. Similarly, the Republic of Gilead's representation of women's educational and economic freedom constraints their ability to be intellectually independent. The society attempts to force women to lose their sense of individuality, and unite together under Gilead's prejudices: identical physical appearance, education (none), and purpose (childbearing). Offred explains her loss of one of her intellectual capabilities: reading. During the ceremony, the Commander reads an excerpt from the Bible, and Offred comments on how "we can be read to from him, but we cannot read. Our heads turn towards him, we are expectant, here comes our bedtime story" (87). Offred is haunted in situations like this, where men gain this power over any freedom women previously had. In a situation where Offred could easily read provided text, the right is taken from her; she has to listen to someone else read, knowing that the ability to publicly display any knowledge of the activity would resort to extreme punishment. Similarly, women were isolated from access to any form of economic property. In America today, all women are legally allowed to have money; however, in Gilead, the government improvised many alternatives from giving women currency. For example, the Handmaids have the responsibility of running errands like grocery shopping but are given tokens instead of money. Offred describes the concept when receiving the tokens from "Rita's outstretched hand. They have pictures on them of things they can be exchanged for: twelve eggs, a piece of cheese" (11). The government of the Republic took the basic norms most women of Gilead were used to and manipulated them in a way that restricted the population's economic freedom. The Handsmaids were treated like children through use of monetary-replacing tokens. The currency removed any sort of individual thought or choice these women previously possessed. Atwood's inspiration is derived from multiple countries' oppression of the intellectual

capabilities of women, including Iran and Afghanistan. The revolution in Iran, which put Ruhollah Khomeini in a position of dictatorship, caused women to descend from a class of well educated, free leaders to expelled students: major expulsions of mass numbers of women from universities occured in order to "un"educate their class. The Taliban's control over Afghanistan left a severe bruise on the country. Years after the US military intervened in the terrorist group's reign, the country remains to have an estimated two thirds population of uneducated women. The restriction of education and public displays of literacy by women in Gilead was justified by the government's strict theocratic methods.

Various examples of inequality in Gilead can be viewed as unjustifiable; however, the Republic of Gilead defended and enforced their ways through a strict, theocratic government. From the moment the Handmaids are detained by the government and held in the Red Center, they are brainwashed into their new way of life. The Aunts, women who educate the Handmaids on the new rules and punish them for wrongdoings, enforced the laws through references from the Bible. A man in the novel is accused of raping a woman, a crime he did not commit; nevertheless, the act of rape is and should be a crime in any context. In Gilead, however, the Aunts introduce his crime by decribing his penalty: "The penalty for rape, as you know, is death. Deuteronomy 22:23-29... one woman was pregnant and the baby died" (278). The Handmaids proceed to charge at the man, running him over with their steps, stomping on him and eventually killing him. The importance of this act of violence is the Aunt's reference to Deuteronomy, which is a text that occurs in the Torah. Essentially, this act deserved punishment by law because it goes against the words of a religious text, an action commonly known to theocracies. Similarly, in a country like Saudi Arabia, the government establishes laws and enforces punishment based on the Quran, the holy book for Islam. During the holy month of Ramadan, when Muslims are instructed to fast, it is illegal to drink liquid or eat food in public. The public practice of any religion other than Islam is illegal as well. Someone can practice privately, but public showings of alternate religions will cause consequences. The country also banned women from obtaining driving licenses until two years ago, because the government believed every woman should have a male guardian under the Islamic law known as Wahhabism. The theocracy in Gilead is a reflection of

modern day theocratic governments. Although society may be doubtful of the realism behind the laws depicted, Atwood's description should show the world how alarming the truths of many governments in today's world are.

The Handmaid's Tale is a two hundred and ninety-five page warning. The shocking reality behind each nauseating depiction of sexism should have created an uproar in society when this book was published in 1998; however, people continue to turn a blind eye in regards to these issues. If there is any chance of avoiding Gilead becoming a reality across the world any more than it already has, *The Handmaid's Tale* needs to be addressed as a cautionary tale. This novel is not fiction; it is reality.

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String Theory: The Final Frontier or Theorists' Dead End

By Anna Aiono

Over 2,400 years ago, around 400 BCE, a Greek philosopher named Democritus hypothesized that all matter in the universe could be broken down into tiny, indivisible particles called *atomos*. There was neither scientific evidence nor experimental research to support this theory, and yet, Democritus was on the right track. Through the centuries (and with the development of the scientific method as well as technology), scientists have gone on to unearth not just the atoms which make up our universe, but the particles which make up an atom, including the electron, proton, and neutron. And though atoms themselves *are* divisible, the quest for the most refined bit of matter still sits on the shoulders of the scientific community. Luckily for modern theorists (and Democritus), that indivisible particle may finally be in reach.

Enter string theory. Contrary to what its name might suggest, this idea has little to do with your guitar or violin, though is not wholly unrelated. If we divide those guitar strings into their atomic makeup, we will see atoms, and subatomic particles like electrons, protons and neutrons. Going further, we can divide the protons and neutrons into quarks. All of these tiny particles differ in various ways, but string theory could miraculously unite them all, by taking our division a step further. The basis of string theory posits that each elementary particle is actually made up of one-dimensional strings. According to string theorist Brian Greene, these one-dimensional strings are about "a million billion times smaller" than any known elementary particle, and could be the ultimate breakdown of matter[66].

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[66]Brian Greene, "Why String Theory Still Offers Hope We Can Unify Physics," Smithsonianmag.com, January 2015, Accessed July 30, 2020, https://www.smithsonianmag.com/science-nature/string-theory-about-unravel-180953637/?page=2.

But how do these strings "work"? And how is it that we can still differentiate between particles if they are all essentially made of the same thing? In order to answer that, we must travel back to the turn of the twentieth century, when physics was taking a revolutionary turn. We generally refer to this time as a shift from classical, Newtonian physics to radicalized, modern physics. During the early 1900s, we saw the birth of two new realms: general relativity and quantum mechanics. Albert Einstein is known for postulating the former, and disputing the latter. He rejected new particle theories so often that he set about attempting to resolve his own theories of gravity to meld with the nature of these very tiny particles[67]. Alas, he did not live to unify them. However, another physicist named Theodor Kaluza set about with a similar goal of unifying gravity and electromagnetism using Einstein's theory of general relativity. This theory posits that space (more esoterically, spacetime) will curve due to massive objects, similar to how a bowling ball on a linen sheet will cause it to droop. This is why you may often hear space referred to as a "fabric." Thus, gravity is directly linked to the curvature of spacetime, since more massive bodies create greater curvature, and objects follow the path of that curvature, simply gravitating towards that more massive body. Kaluza wondered if it would be possible to apply similar ideas for the electromagnetic force, speculating that this could act by following warps and curves as well. Yet, what was there to warp and curve? Spacetime, as far as we could tell, is already curved for gravity - so what medium could describe the electromagnetic force?

Kaluza then posited that that medium could simply be an *extra* dimension. This was very odd, considering that we move through our lives in a typical three-dimensional world - if there were to be other dimensions, shouldn't we be able to see them? However, when Kaluza tested this by adding a dimension to the already-derived general relativity equations, and when he did, an equation describing the electromagnetic force miraculously "popped-out."[68]

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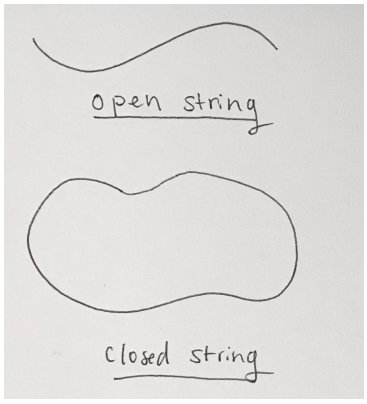
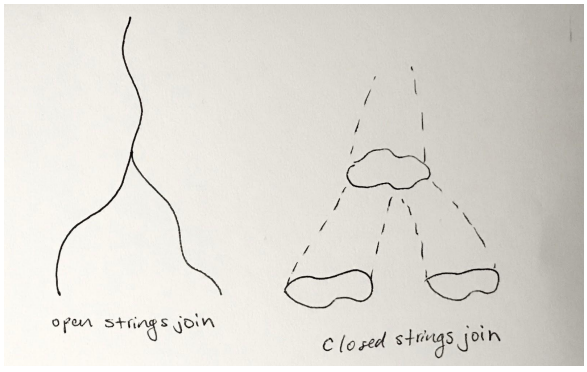
[67]"Big Questions: Superstrings," NASA.gov, High Energy Astrophysics Science Archive Research Center, accessed July 30, 2020, https://imagine.gsfc.nasa.gov/science/questions/superstring.html.

[68]Brian Greene, "String Theory," YouTube video, 19:09, posted by TED-Ed, August 9, 2013, https://www.youtube.com/watch?v=kF4ju6j6aLE.

To further support this, physicist Oskar Klein suggested in the 1920s that this seemingly-invisible fourth dimension could exist, but was too small for us to experience. Curled up in the fabric of spacetime, this extra dimension could only be accessible for organisms that were just as tiny as it. It is similar to the pile of carpets: from our lofty perspective, the carpet looks two-dimensional, completely flat. Yet, if we get down on our stomachs, we see that the carpet's miniature tufts are quite three-dimensional. Furthermore, an ant crawling around those tufts could move around them in the same three-dimensional manner that we move around our world - up, down, back, forth, right, left. Yet, as we are not ant-sized, we cannot move in the carpet in this way, and go on treating it as two-dimensional. Likewise, the extra dimension could be there, but scaled and curled up so minutely that we remain unaware of its existence.

Though plausible in theory, Kaluza's electromagnetic-bending fourth dimension did not work in practice. It was tossed-off and forgotten for some time, until, many years later, string theory was born. The idea goes like this: every elementary particle, like the electrons and quarks aforementioned, can be broken down even further into string-like filaments. These strings can be open, closed, joined together, or split apart[69] (see figures to the left). They undulate, quite like waves on a rope, and their vibrational patterns are what distinguish the particles they make up. Different vibrational patterns correspond to a particle's "identity," giving it unique properties like its mass or electric charge.





Though this has nothing to do with the extra-dimensions idea at first glance, a deep delve into the associated mathematics reveals how it has everything to do with the nature of strings. Contrary to Kaluza's theory, however, infinitesimally small strings would not vibrate in just one extra dimension, but *ten* spatial

[69]Stephen Hawking, *A Brief History of Time* (Bronx, NY: Ishi Press International, 2020), 159.

dimensions in total (and one time dimension). In accordance with Klein's theory, these strings could operate - if the extra dimensions were on the order of 10^{-33} meters[70]. Furthermore, the shape of these dimensions would determine strings' unique vibrational patterns. This is similar to how the shape of an instrument determines its tone color - like a narrow saxophone versus a wide tuba.

String theory initially began in the 1960s, as a way to describe the strong nuclear force, which is essentially what binds a nucleus together. The force between the protons and neutrons would connect via strings, similar to what physicist Steven Hawking refers to "a spider's web."[71] Yet string theory has given way to a vast majority of predictions which could refine and revise our current description of the world. For starters, string theory could finally give us a reason for why the universal constants (values of certain entities which are observed to be consistent no matter when or where) which physicists (and chemists) encounter are the way they are. The mass of an electron, for example, has only ever been found through precise empirical data. However, if we could calculate the exact geometric conditions in which strings vibrate, and thus calculate their resulting vibrational patterns, we could, in theory, derive those universal constants. Should we be able to do this, we could finally have a fundamental explanation for why our universe is the way it is, and why we exist in it. Indeed, if the universal constants within our universe were even a bit different, the human species would probably have never existed. Thus, we could owe our entire lives to tiny, undulating strings (someone once quipped to me that string theory was a "basically a religion", and I believe this only further supports it).

On the topic of universes, the mathematics behind string theory reveals many of them - 10^{500}, in fact. This is due to the seemingly endless possibility of extra-dimension shapes[72]. At first, theorists posited that only one of these shapes was the right one - the one in which strings could properly operate. Yet, as Brian Greene writes of fellow physicist Leonard Susskind, he argues that "perhaps there

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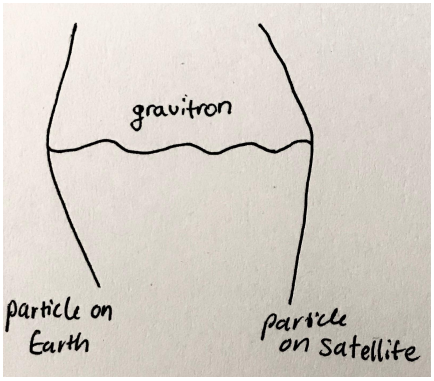
[70]"Big Questions: Superstrings," NASA.gov, High Energy Astrophysics Science Archive Research Center, accessed July 30, 2020, https://imagine.gsfc.nasa.gov/science/questions/superstring.html.

[71]Stephen Hawking, *A Brief History of Time* (Bronx, NY: Ishi Press International, 2020), 161.

[72]Adam Mann, "What Is String Theory?" Livescience.com. March 20, 2019. Accessed July 30, 2020. https://www.livescience.com/65033-what-is-string-theory.html.

isn't a right shape", and that maybe, in accordance with string theory, each of these shapes could give way to the extra dimensions in *other* universes[73]. This further supports the conception of a multiverse, in which our universe is only one of many. Indeed, the reason that we exist on our own, and not some wholly other place, goes back to the idea of the universal constants, or as Greene aptly puts, "local bylaws."[74] Our universe would differ from others by the unique shape of our extra-dimensions, which would give way to the vibrational string patterns coincidentally tailored for human existence.

Perhaps the most consequential prediction of string theory is that it could do what has not yet been done. One of the most basic problems plaguing physicists today is that of the four fundamental forces: the gravitational, electromagnetic, strong and weak nuclear forces. For a brief recap, gravity is what keeps you rooted to your chair, electromagnetism fuels your lightbulb, the strong force keeps nuclei intact, and the weak force interacts during radioactive decay (though this force is still quite mysterious). Since Theodor Kaluza's time, we've managed to unite three of the four forces - all except gravity. This is because all except gravity work over very short distances - i.e., on a subatomic scale. Gravity, on the other hand, works over vast distances (indeed, it is what keeps our solar system together), but essentially breaks down on a subatomic level. In other words, gravity mostly deals with the very large, and the other three forces with the very small. It has been challenging to devise a feasible theory which unifies the four forces, more commonly known as a "grand unified theory." There are many contending ideas, and string theory is among the most popular, elegant, and controversial.



As aforementioned, string theory breaks down each elementary particle, like an electron or a quark, into string-like components. Strings would act like cable connectors between particles, where their strings would break off or join together depending on their

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[73]Brian Greene, "Why String Theory Still Offers Hope We Can Unify Physics," Smithsonianmag.com, January 2015, accessed July 30, 2020, https://www.smithsonianmag.com/science-nature/string-theory-about-unravel-180953637/?page=2.

[74]Ibid.

emission or absorption. This would also include force-carrying particles known as bosons. One hypothetical boson particle is known as the gravitron. Hence the name, this particle would "carry" the force of gravity between two others. For example, a particle on the Earth could emit a gravitron and a particle on a satellite could absorb it, thus perpetuating the force of gravity between them (see figure to the left). But, considering their internal strings, it would correspond to the gravitron's strings breaking off from the Earth's particles, and joining with the satellite's particles - "rather like plumbing in a way,"[75] as Stephen Hawking writes. The strings would do this not only for the gravitron, but for every force-carrying particle. Furthermore, the strings would be found in *every* particle, not just the force-carrying particles. Simply put, this would unify every force, and every particle. All of nature would reduce to strings.

String theory as a grand unified theory is plausible, but it comes with a catch. It lacks any concrete proof, and has for some time. In fact, both the empirical baselessness and seemingly endless constructions of string theory has led to harsh criticism in the past, with people questioning whether or not to pursue it further, and some even calling it pseudoscience. We are limited by our technology, where even the most refined detectors cannot possibly resolve to the minute realm of strings. Will we ever find conclusive confirmation, if we do not have the resources to do so? Additionally, the plethora of possible extra-dimension shapes prompting a multiverse is very questionable, especially considering the state of our universe. Assuming string theory, could we detect these other universes? While the broad-strokes of string theory seem promising, the fine details still proffer problems yet to be solved[76].

Nonetheless, string theory persists. And it seems to be on a testable pathway. In Geneva, Switzerland, the Large Hadron Collider will continue to run tests, literally, "running" protons together, smashing them at near-light speeds. The hope is that, by colliding them with mighty energy, some particle debris may eject - flying off not just into our space, but into one of the extra dimensions.

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[75]Stephen Hawking, *A Brief History of Time* (Bronx, NY: Ishi Press International, 2020), 160.

[76]Dr. David Tong, "String Theory," Pdf. document, University of Cambridge, January 2009, accessed July 30, 2020, https://www.damtp.cam.ac.uk/user/tong/string/string.pdf.

We could measure the amount of energy before the collision, and compare it to that after the collision. According to the law of conservation of energy, these energies *should* be the same. Thus, if some specific amount of energy is missing from the system, and if the conditions match what's expected, it would evidence the existence of extra-dimensions. Should the extra-dimensions be real, we could begin to believe string theory is, as well.

There lies a long and possibly perilous path among string theorists. If it proves to be false, it would be a great disappointment indeed. And yet, string theory has brought forth a whole new framework for looking at the world, for constructing grand unified theories, and for inspiring new approaches to make sense of both the very small, and the very large. Besides seamlessly connecting the two pillars of modern physics - that is, quantum mechanics and general relativity - a closer inspection of string theory yields possible answers to deeply ingrained questions. From the nature of universal constants, to the possibility of a multiverse, to the very constituents of matter and space as indivisible and extra-dimensional, string theory clearly cannot be ignored just yet. In the end, there is hope that the truth behind it will be revealed - preferably, with no strings attached.

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Green Synthesis of Silver Nanoparticles Using Asparagus Extract and Their Use as Antibacterial Agent

By Konish Bhattacharya

Abstract

In this project, silver nanoparticles were synthesized from silver nitrate using Asparagus extract containing the flavonoid quercetin (a green synthesizer). The objective was to test if a plant-derived flavonoid can be used as a reducing agent to synthesize silver nanoparticles from silver nitrate solution, and whether it could be employed to kill harmful bacteria.

Materials: Asparagus stems, silver nitrate ($AgNO_3$) 0.01 M aqueous solution, distilled water, quercetin, polyvinylpyrrolidone, petri dish for bacteria colony.

Methods: Silver nitrate aqueous solution was prepared by dissolving 170 mg of Silver nitrate powder in 100 mL of distilled water. Asparagus extract was prepared by heating one cup distilled water and five Asparagus stems in low flame for one and half hours. In direct sunlight, four different concentrations of asparagus extract (2 mL, 4mL, 6mL, 8mL) were added to separate cups, each containing 20mL of 0.01 M silver nitrate aqueous solution. The change of color of the solution over time was noted. Experiment was repeated in ambient light.

In the laboratory, a drop of silver Nanoparticles was made with 4mL asparagus extract and 20mL of 0.01 silver nitrate aqueous solution. It was placed on two petri dishes containing E.Coli and S. Epidermidis bacteria.

Results: The color of silver nitrate solution changed once asparagus extract was added, which means silver nanoparticles were produced. The bacteria test result showed these nanoparticles cleared both the

E.coli and S. Epidermidis colonies which means the silver nanoparticles were effective as an antibacterial agent.

Conclusion: In this experiment, the use of asparagus as a source of quercetin is a novel approach. This is an environmentally friendly process. These silver nanoparticles exhibited strong anti-bacterial properties against both Gram-negative and Gram-Positive bacteria. Nanoparticles have unique properties due to which bacteria are unable to develop immunity. Thus, medicine produced by nanoparticles can be more effective than conventional antibiotics.

Introduction

Nanoparticles:

- Nanoparticles are ultrafine particles which are within a range of 1 to 100 nanometers (0.001 to 0.1 micrometer). Although nanoparticles are too small to be seen by the naked eye, nanoparticles made of metal such as silver change color when they interact with light and leave signs of their presence (Invigorate).
- Nanoparticles exhibit greater chemical reactivity than larger size particles. With nanotechnology, scientists have designed new materials, components or systems that have improved quality of life.
- Researchers in the medical field are using silver nanoparticles to develop more targeted treatment for drug resistant bacteria.

Silver Nanoparticles:

- The use of silverware during ancient periods was common across the globe. It was probably due to the knowledge of its antimicrobial action. There are records regarding therapeutic application of silver as early as 300 BC. Until the discovery of antibiotics by Alexander Flemming, silver was commonly used as an antimicrobial agent.

- Metal nanoparticles are used for the treatment of several diseases. Researchers in the medical field are using silver nanoparticles to develop more targeted treatment for drug resistant bacteria.
- Therefore, a low-cost, non-toxic and eco-friendly method to produce silver nanoparticles is important to expand their biomedical applications.

Flavonoids:

- Many plants contain a group of substances called flavonoids which provide health benefits. These also can act as reducing agents or antioxidants.
- These molecules also provide anti-viral, anti-bacterial, anti-inflammatory, anti-allergic effects.

Quercetin:

- Quercetin is a type of flavonoid which is found naturally in several fruits, vegetables and herbs. In alternative medicine it is said to help with allergies, cardiovascular diseases, inflammation and colds.

Asparagus:

- Asparagus has unique nutritional properties. Researchers have identified nearly 100 phytonutrient compounds in asparagus. Asparagus is an outstanding source of quercetin.

Purpose

- The objective of this project was to test whether a plant derived flavonoid can be used to synthesize silver nanoparticles from silver nitrate solution.
- If synthesized, could the silver nanoparticles be employed to kill harmful bacteria?
- Bacteria or fungus affect human health negatively and it is important to find an environment friendly way to eradicate them.

Question

- How do flavonoids of asparagus affect the formation of silver nanoparticles and what is the effect of silver nanoparticles on bacteria?

Hypothesis

- If flavonoids reduce silver ions to silver nanoparticles, and sunlight affects the speed of this reduction process, and I can make flavonoid solutions from asparagus extracts and test the formation of silver nanoparticles in various light conditions, then the solutions with higher quantity of flavonoids will produce the silver nanoparticles faster, especially in direct sunlight.
- Higher temperature and sunlight are known to help the synthesis of nanoparticles.

Materials and Method

Materials:

1. Asparagus stems
2. Silver nitrate 0.01 M aqueous solution
3. Storage flask
4. Measuring cylinder
5. Measuring cups
6. Small beakers
7. Small storage bottle
8. Dropper
9. Strainer
10. Distilled water

11. Tap water
12. Stove top
13. Pan
14. Camera
15. Stop watch
16. Labels
17. Lab book
18. Quercetin
19. Polyvinylpyrrolidone
20. Filter paper
21. Petri dish for bacteria colony

Method:

1. 170 mg of silver nitrate powder was dissolved in 100 mL of distilled water to prepare silver nitrate aqueous solution
1. All glassware materials were washed with tap water first and then with distilled water.
2. 5 asparagus stems were cut into small pieces and placed in a clean pan containing one cup of distilled water. The pan was heated in low flame for one and half hours. This solution was cooled, filtered, and stored in a bottle. Now the asparagus extract is ready.
3. 20 mL of 0.01 M silver nitrate aqueous solution was poured in a glass beaker.
4. 2 mL of asparagus extract was poured in a measuring cylinder.
5. The measured asparagus extract was added to the measured silver nitrate aqueous solution in direct sunlight.
6. Photographs were taken as the color of the solution changed. Also, time taken for different color changes was noted using a watch. This data was noted in the lab book.

7. Steps 3 to 6 were repeated three more times, each time changing the amount of Asparagus extract to 4 ml, 6 ml and 8 ml respectively.
8. Steps 3 to 7 were repeated, but this time instead of direct sunlight the experiment was done in ambient light.
9. A pinch of Polyvinylpyrrolidone powder was dissolved in 10 mL of distilled water, and some of it was drawn into a glass dropper.
10. Steps 1 to 7 were repeated now with 4 ml asparagus extract two more times, once in sunlight and once in ambient light. This time a drop of Polyvinylpyrrolidone was added to the solution of asparagus extract and silver nitrate as soon as the color of solution changed to pink. This stabilized the solution in the same condition. The duration of stabilization was also noted and recorded in the lab book.
11. A pinch of quercetin powder was dissolved in 20 mL of distilled water. A drop of this quercetin solution was then added to the 20 mL of 0.01 M Silver nitrate aqueous solution and observed for color change and time taken for the color changes.
12. In the laboratory two separate petri dishes were prepared with colonies of two types of bacteria, E. Coli and S. Epidermidis, one in each dish.
13. A fresh batch of Silver nanoparticles was made by mixing 4 mL of Asparagus extract and 20 mL of 0.01 Silver nitrate aqueous solution. As soon as the solution turned pink, some of the solution was collected using a dropper and one drop each was placed on small round filter paper which were placed on two petri dishes with colonies of E. Coli and S. Epidermidis.
14. To compare this result with silver nitrate solution alone, step 13 was repeated without the asparagus extract.
15. After 2 days, in the laboratory the size of the area of clearing of bacterial colonies around the round filter papers in the petri dishes were noted and recorded in the lab book.

Figure 1: Color Change of Nanoparticles in Solution with Different Concentrations of Asparagus Extract in Direct Light.

	No Color	Light Pink	Pink	Pink Red	Red	Dark Red	Brown Red	Brown
2 mL	2	1	1	1	1	2	1	1
4 mL	0		1	1		1	1	1
6 mL	0				1			2
8 mL	0				1			1

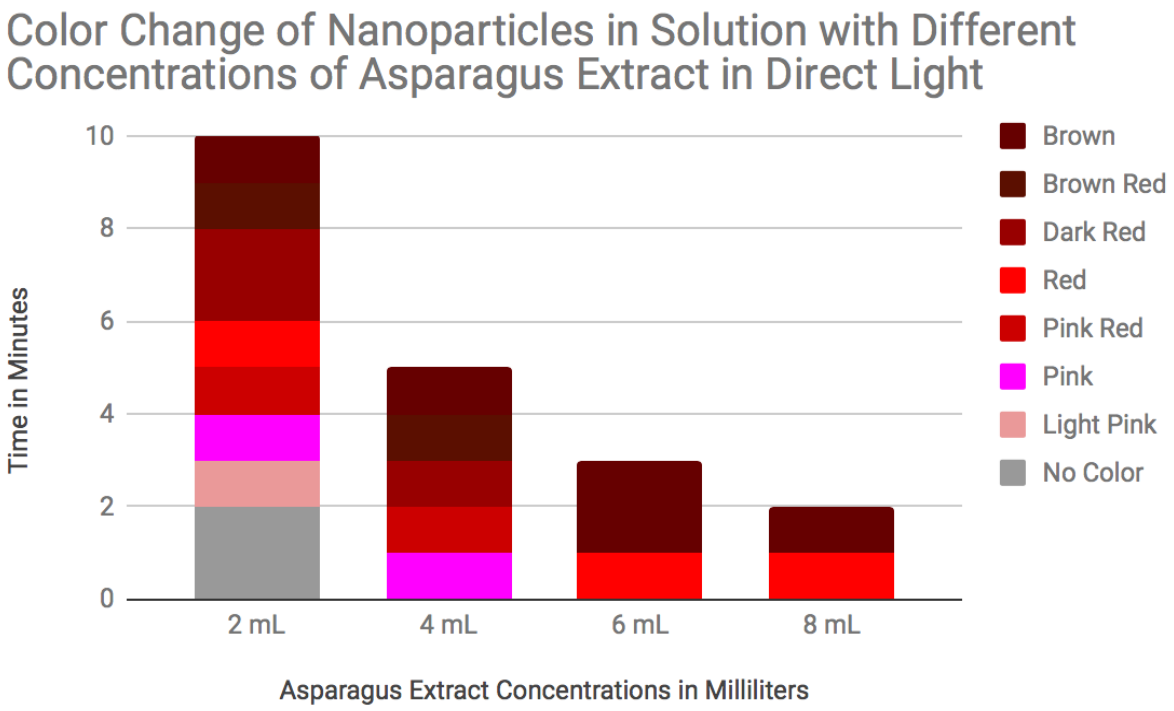


Figure 2: Color Change of Nanoparticle in Solution with Different Concentrations of Asparagus Extract in Ambient Light.

	No Color	Light Pink	Pink	Pink Red	Red	Dark Red
2 mL	3	3	4			
4 mL	0	3	5	2		
6 mL	2	3	2	1	2	
8 mL	2	3	2	1	2	

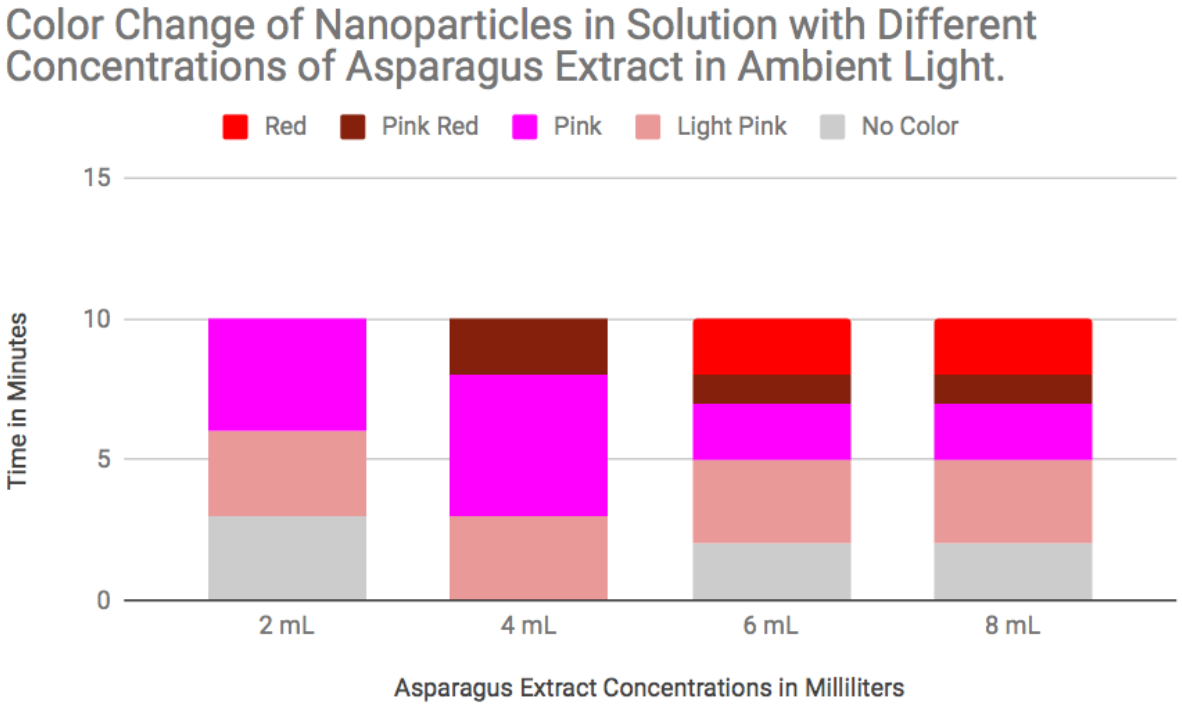


Figure 3: Color Change of Nanoparticles using Polyvinylpyrrolidone to Stabilize Color in Different Atmospheres of Light.

	4 mL in direct Sunlight	4 mL in ambient Light
No Color	0	20
Light Pink	1	23
Pink	1	46
Light Red	5	0
Red	6	0
Dark Red	2	0

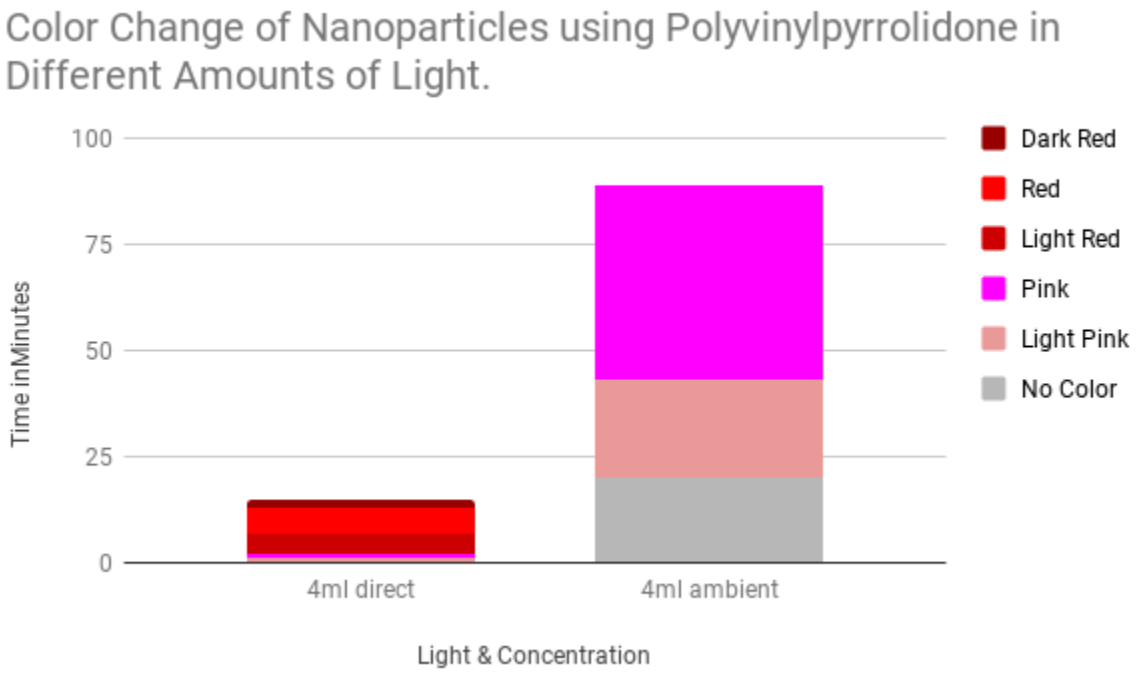
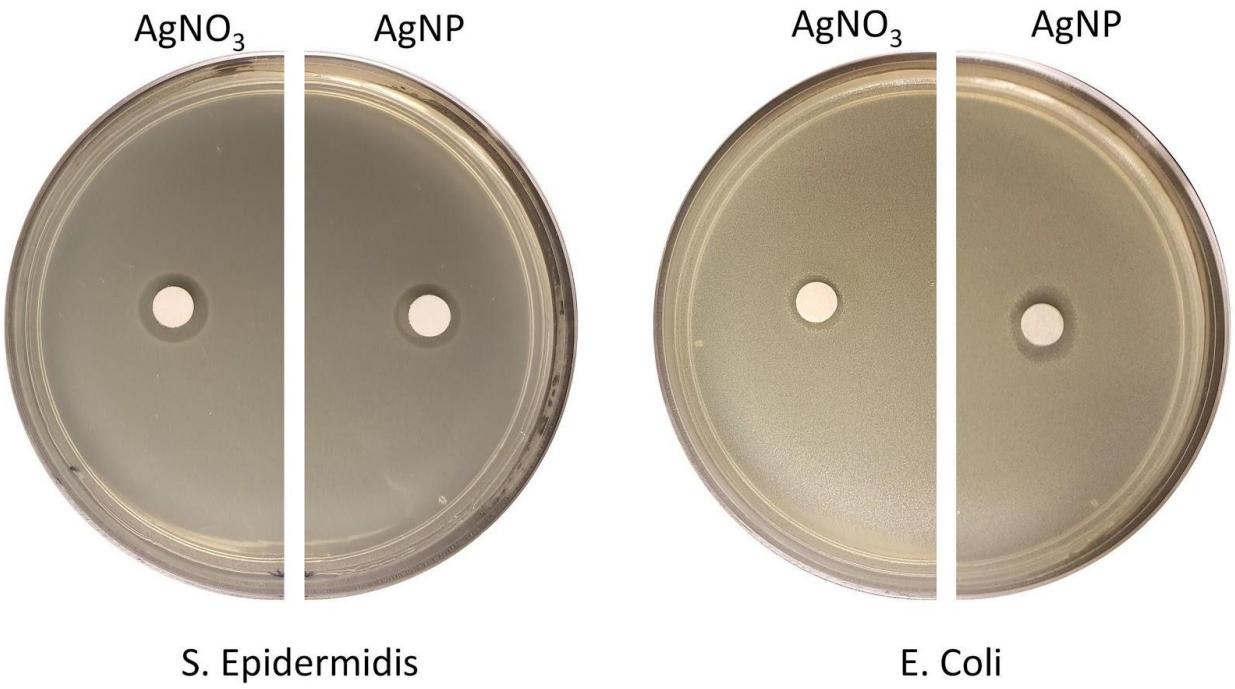


Figure 4: Effect of Silver Nanoparticles compared to the effect of Silver Nitrate on Bacterias, E Coli. and S. Epidermidis.



Result

The first two tables and corresponding graphs show the change of color in nanoparticle solutions over time in minutes. Figure 1 shows the experiment done in sunlight. Figure 2 shows the experiment done in ambient light, without direct sunlight.

Figure 1 shows the change of color in the solution of silver nitrate and different amounts of Asparagus extract. In lower quantities of Asparagus extract, the variation in color change was more visible than in higher quantities. In higher quantities of Asparagus extract, the color changed faster.

Figure 2 shows data in ambient light. The color change in the presence of direct sunlight was faster than in ambient light.

Figure 3 shows two sets of experiments, one in direct sunlight and the other in ambient light. In both experiments, 4 mL of Asparagus extract was added to the Silver nitrate solution. As the silver nanoparticle formed and the color of the solution became pink, a stabilizing agent named Polyvinylpyrrolidone was added to stabilize the silver nanoparticles. The silver nanoparticles remained stable for a longer period when the experiment was done in ambient light.

To verify that quercetin is the flavonoid that reduces the agent that makes silver nanoparticles from Silver nitrate, a quercetin experiment was done. A pinch of store-bought quercetin powder was dissolved in alcohol. A drop of it was added to 0.01 M Silver nitrate solution. The appropriate color change indicated formation of silver nanoparticles. Image 1 shows the color of the solution of this experiment.

To see the effect of silver nanoparticles on bacteria, colonies of E. Coli and S. Epidermidis bacteria were grown in two separate petri dishes. A drop of silver nanoparticle solution was placed in both the colonies. For comparison, a drop of 0.01 Silver nitrate solution was also placed on petri dishes of both types of bacteria colonies. Figure 4 shows nanoparticle solution from Asparagus extract cleared both

the bacteria types effectively. The Silver nitrate solution worked equally well in the S. Epidermidis colony, but the silver nanoparticle solution worked better on the E. Coli colony.

Surprisingly, the change of color of nanoparticles in sunlight was extremely fast.

Conclusion

Explanation:

Asparagus was used in this experiment because it was found to have a large amount of quercetin. Quercetin was found to be a reduction agent that created the nanoparticles.

Silver nitrate salt ($AgNO_3$) in aqueous solution exists as charged particles, Ag+ and NO_3- ions. The Positively charged Ag+ ion needs an electron (e-, a negative charged particle) to become a neutral Silver atom (Ag). The quercetin solution provides the needed electron to reduce the positively charged Silver ion to become a Silver atom (Ag). Once silver atoms form, several of these atoms coagulate to form a Silver nanoparticle.

$$Ag+ + e- \xrightarrow{\text{Sunlight energy}} Ag.$$

Sunlight has the spectrum of light in all wavelengths and some of these lights provide the energy to release the electrons from the flavonoids more readily. Essentially this speeds up the above reduction reaction.

Polyvinylpyrrolidone is a stabilizing agent that forms a protective coating around each atom to stop them from coming together and coagulate easily

All bacteria use an enzyme to metabolize Oxygen. Once inside the bacterial cell the silver ion impairs this enzyme and therefore the oxygen uptake. This kills the bacteria by almost suffocating. Silver

nanoparticles can enter bacterial cell walls in different ways because of their small size and variation in the sizes. Since there are no definite patterns of this invasion, the bacteria cannot adapt to it. Thus, for killing drug resistant bacteria Silver nanoparticles are more effective.

Interpreting the Results:

In this experiment, the color of Silver nitrate solution changed once Asparagus extract was added to it, which means Silver nanoparticles were being produced. The color of silver nanoparticles depends on the particle size in the solution (Solomon,2007). During this experiment the solution color changed from yellow to pink to red to brown. The color changed as the particle sizes increased through the chemical reaction. As the particle size of the Silver nanoparticles increased, sedimentation started.

My data supports my hypothesis. My experiment with quercetin proved that this flavonoid is responsible for the sedimentation process. In this experiment, the flavonoids in the Asparagus extract reduced the Silver ions in the solution, which then produced Silver nanoparticles. The experiment in sunlight showed faster production of Silver nanoparticles than in indirect, ambient light. The solution with a higher quantity of flavonoids produced nanoparticles faster. The reaction happened so quickly that you couldn't see the various changes in color.

It was observed that when 4 ml of Asparagus extract was used, the transformation to color to pink was seen most clearly. That's why I focused further tests on the 4 mL concentration.

The experiment with bacteria was done using the pink colored Silver nanoparticles as in this size range coagulation or sedimentation of the silver nanoparticles was rarely visible and wouldn't interfere visually. The bacteria test result shows these nanoparticles cleared both E. Coli and S. Epidermidis bacterial colonies in the petri dishes, which means the Silver nanoparticles are effective as an antibacterial agent.

Limitations of Conclusions:

Strong conclusions can be made from these experiments as the tests were done in several different ways (different amounts of Asparagus extract and different light conditions) to verify the result. The quercetin test on Silver nitrate solution was done to verify that quercetin is the main flavonoid that helped produce Silver nanoparticles by reducing the Silver ions in the silver nitrate solution. The bacteria tests were done twice, once with the filter paper and once without, to verify these Silver nanoparticles work as antibacterial agents. To verify these results the same experiments can be repeated a few more times.

Reflection on Methods:

I experimented with four different concentrations of asparagus extracts, and then chose the concentration that was most favorable for further experiments that worked well. One uncontrolled variable was the determination of color change in solution, which was done by looking at it, i.e. direct observation. This uncontrolled variable probably didn't have a large effect on my results as the particle sizes were still small and there was rarely any sedimentation.

Once I had to repeat an experiment that was done in milder sunlight as the sunlight on that day was not as strong as the previous experiment day. To make the data comparable, I waited for another day of full sunlight and did the experiment during the same time of the day as the previous experiment.

Implications:

Nanotechnology is important in medical science as it fights bacteria in such a unique way that it becomes difficult for the bacteria to develop immunity. Thus, medicine produced by nanoparticles may become more effective to kill harmful bacteria than conventional antibiotics. The use of asparagus extract to produce nanoparticles is an environmentally friendly process. Green synthesis does not need

to use toxic materials. Moreover, Asparagus is easily available in America and it has a high concentration of quercetin, which is the flavonoid needed to produce the Silver nanoparticles.

Next Steps:

I would like to classify the components that are present in Asparagus extract and look for a method to isolate the quercetin. That way, a green source of quercetin could be made available for the medical research community. I also could do experiments using different quercetin sources and other reducing agents. In addition, I can experiment with Nanoparticle size and its effect on antibacterial properties.

Glossary of Terms

- Antibacterial- active against bacteria
- Antibiotics- a medicine that destroys microorganisms
- Antioxidants- a substance that removes possibly damaging oxidizing agents in an organism.
- Aqueous solution- a solution in which the solvent is water
- Catalyst- a substance that increases the rate of a chemical reaction without itself undergoing any permanent chemical change.
- Toxic- poisonous
- Bacteria:
    - Bacteria are microscopic living organisms which can be dangerous to the human body.
    - Escherichia Coli (E. Coli) and Staphylococcus Epidermidis (S. Epidermidis) are gram-negative and gram-positive bacteria respectively. Gram-negative bacteria's cell membranes are thin but difficult to penetrate, they are often resistant to antibiotics and other antibacterial interventions. The protective covering of these bacteria makes them difficult to kill and eradicate. Gram-positive bacteria's cell membrane is thicker than gram-negative and capable of absorbing lots of foreign material.

- S. Epidermidis mainly colonized human skin and is a health concern due to its involvement in hospital acquired infections (ScienceDirect.com).
- Some types of E. Coli bacteria can be harmful to the human body and can cause illness like diarrhea, abdominal pain, fever.

- Green Synthesis:
  - Synthesis happens when two or more substances combine to produce a single product.
  - Green Chemistry is the utilization of a set of principles that reduces or eliminates the use of hazardous substances in the design, manufacture and application of chemical products.
  - The main advantage of a green process for synthesis of silver nanoparticles is that it does not use toxic chemicals.
  - Silver nanoparticles made with plant extract are environmentally friendly and can be cost effective.

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Investigating the Magnetotactic Evolution of Motile Bacteria Through the Effects of a Neodymium Magnetic Field

By Michelle Nazareth

Abstract

Bacteria play important roles in our bodies, the environment, and natural ecosystems. Some bacteria are motile, using flagella to swim toward or away from stimuli such as chemicals, nutrients, and light. To produce motility, flagellar rotation is driven by a flux of protons through a motor embedded in the cell membrane. Natural magnetic fields are associated with magnetite, a common form of iron minerals. A few species, called magnetotactic bacteria, contain magnetite nodules that act as a compass to direct their motility by aligning them with Earth's magnetic field. The objective of this research was to understand how bacteria first evolved this ability. Therefore, strong magnetic fields were used to affect the motility of a mixed culture of known soil bacteria. An experimental protocol was developed in which motile bacteria swam through the 1.25T neodymium magnetic field into a fresh LB culture medium. After an overnight incubation, bacteria that had passed through the field were visualized with Gram staining and viewed at 1000X magnification. Control samples contained both gram-positive and gram-negative bacteria, stained purple and pink respectively. The magnetic field caused a differential response in the composition of the motile species compared to controls in the absence of the field. Surprisingly, magnetic samples contained mostly gram-negative bacteria. Additionally, the mean number of bacteria present in magnetic samples was statistically significantly less than the mean number of bacteria in the control samples at the α=.01 level. To confirm this effect, 16s rRNA analysis was performed, which confirmed that different bacterial species were present in the control and test samples. For instance, species such *Turicibacter*, *Romboustia*, and *Bacillus* sp. were present in control samples, but absent in the magnetic field samples. This effect has not been previously reported, and

confirms that magnetic fields have a filtering effect on the motility of mixed bacterial species normally present in soil, even though they have not deposited magnetite nodules. I propose the hypothesis that magnetic fields associated with magnetite minerals could have had a selective effect on populations of the first motile bacterial species, which was later amplified as they evolved the ability to deposit intracellular magnetite nodules.

Introduction:

Bacteria play vital roles in our bodies, environments, and ecosystems. Some are important to health, such as the human intestinal flora, while others, like Streptococcus and Staphylococcus, can cause disease. About 80% of the world's bacteria are motile, meaning that they can swim toward or away from stimuli, such as chemicals, nutrients, and light (7). Additionally, a few motile bacterial species contain particles of the mineral magnetite. These act as a natural compass and allow the bacteria to orient themselves based on Earth's geomagnetic field. But can a strong magnetic field affect the motility of ordinary bacteria? This project investigates the effects of magnetic fields on common soil bacteria and proposes ways that magnetotactic bacteria evolved from soil bacteria.

Motile Bacteria

Some bacteria are motile, mobilized by one or more flagella that are rotated by a motor embedded in the membrane (Figure 1). Motile bacteria are attracted to nutrients through a process called chemotaxis. The flagella propels the bacteria through the medium, giving them a better chance to find the necessary nutrients to survive.

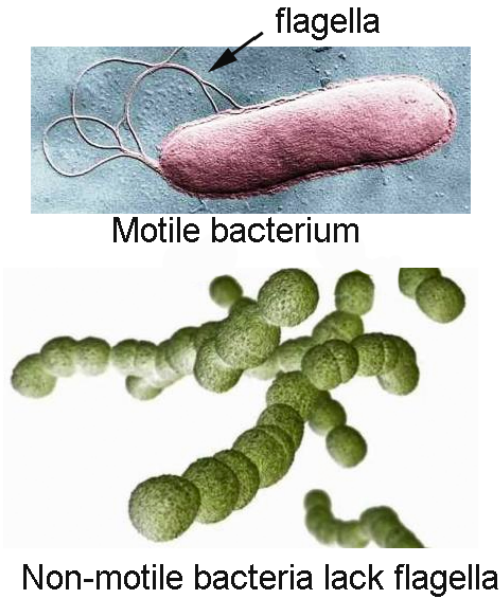


Figure 1. Motile bacteria possess flagella, while non-motile bacteria do not.

The flagellar motor is driven by a flux of protons, as shown in Figure 2. Just as magnetic fields affect electrical currents in wires, they can also be expected to affect protonic currents moving through the motor. Bacterial proton transport systems are driven by electron transport. Protons are pumped out, which causes the motor to rotate as they diffuse back into the cell due to the proton gradient. The rotor portion of the motor converts electrochemical energy into mechanical energy through a proton current as thousands of protons per second flow through (5). As a result, the flagella rotates hundreds of times per second.

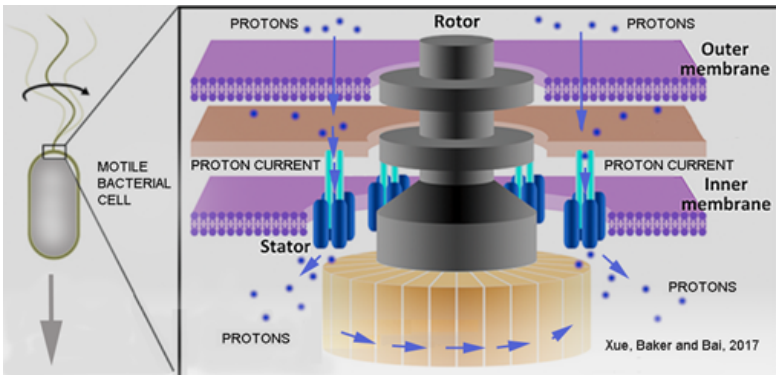


Figure 2. Bacterial flagellar rotor (Adapted from Xue et al. 2017)

Magnetotaxis

Some species of motile bacteria are magnetotactic (Figure 3). In magnetotaxis, the bacteria deposit small grains of the mineral magnetite in their cytoplasm. These grains aid the bacteria by acting as a compass and directing their movement to align them with the Earth's magnetic field. Magnetotactic bacteria are important to the environment as they can form symbiotic relationships with animals and can potentially prevent cancer tumors (1).

A magnetotactic bacterium and its chain of magnetosomes. (Various/Wikimedia Commons/CC BY-SA 3.0)

Figure 3. Image of a magnetotactic bacterium showing a line of magnetite particles (orange) (Via Science Alert/ Wikimedia Commons).

Gram Staining

Gram staining is an important procedure used to visualize the bacteria on the microscope. Gram-negative bacteria stain pink and gram-positive bacteria stain purple. To complete the stain, small aliquots of bacteria were heat fixed on a glass slide on a hot plate. Then, bacteria were stained through a sequence of crystal violet, iodine, alcohol decolorizer, and safranin.

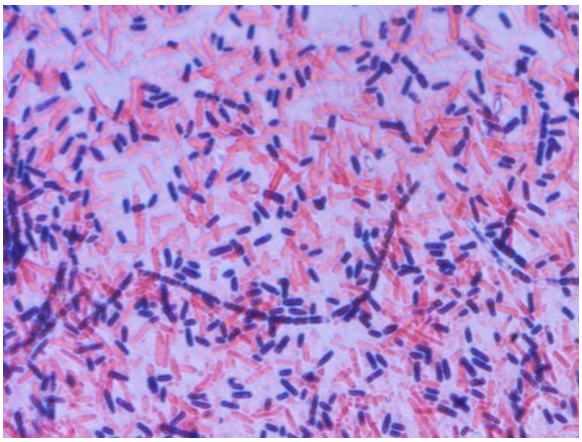


Figure 4. An image of Gram-stained, motile soil bacteria taken on a Zeiss Axiovert, 1000X microscope at Startup Sandbox.

Objective

The objective of this research is to better understand how magnetotactic bacteria first evolved. I propose the hypothesis that in populations composed of hundreds of species, a few may have been slightly affected by a local magnetic field. These may have later evolved the ability to produce the iron mineral particles in their cells, leading to magnetotactic bacteria. This hypothesis predicts that a mixed culture of motile soil bacteria may be affected by a magnetic field. If so, the bacteria most influenced by such a field could evolve towards magnetotactic species.

Methods and Materials

Creating Bacterial Cultures:

Bacterial cultures were prepared using soil samples collected from my backyard. Soil was added to water and shaken by hand to release the bacteria from the dirt. The soil-water mixture was filtered through layers of paper towels to remove large particles and a mixture of bacterial species was collected in the filtrate. 0.5 mL of the bacterial suspension was added to 10 mL of 2% LB broth nutrient solution, then incubated for 24 hours at room temperature. This process was repeated for each experiment. These ordinary soil bacteria were identified by 16s rRNA analysis and were therefore not unknown

microorganisms. All culturing was performed with overnight incubations in LB broth and small samples were examined after Gram staining with a Zeiss Axiovert microscope at Startup Sandbox.

Exposing Cultures to a Magnetic Field: Upward Motility Procedure:

A method was devised to expose motile bacterial species to magnetic fields by allowing them to swim upwards through the field. 3 mLs of fresh LB broth were floated on top of 1mL of mixed soil bacteria culture (motile and nonmotile) at the bottom of test tubes. This set up ensured that motile bacteria swam upward into the fresh culture medium. In two experimental tubes, bacteria were exposed to a magnetic field produced by strong, 1.25 Tesla field strength neodymium magnets (Figure 5). In two control tubes, no magnetic fields were present.

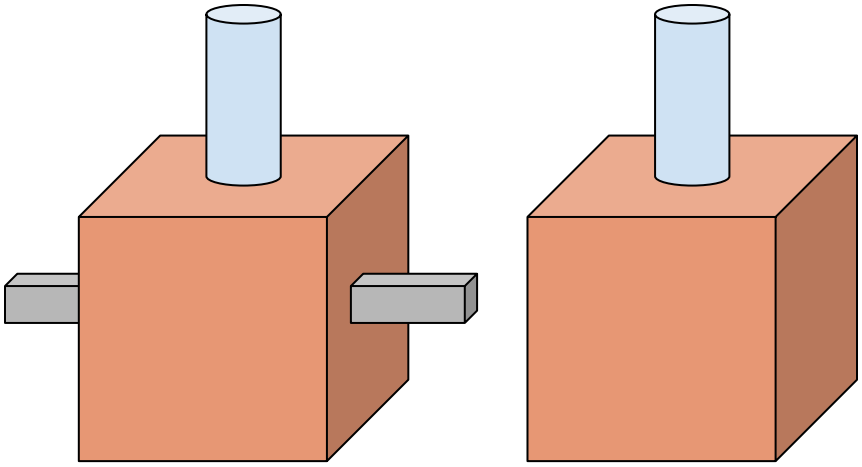


Figure 5. Experimental and control set up. Tubes were placed in wooden containers for 18 hours. Experimental tubes had slots for magnets on either side of the tubes.

It was important to separate motile bacteria from sedentary forms such as streptococcus in this protocol. Therefore, 3.4 grams of sucrose were dissolved in 5 mL of the 24-hour soil bacterial culture in order to bring the sucrose concentration up to 2.0 M. The bacterial cultures were intentionally made denser than the LB broth, so that when 3 mL of the LB broth was floated on top, there would be minimal mixing of the fresh broth and original bacterial culture. Because of this step, sedentary

bacteria were left behind in the dense culture medium, while motile bacteria were able to swim upward out of the sucrose-medium in the presence or absence of a magnetic field.

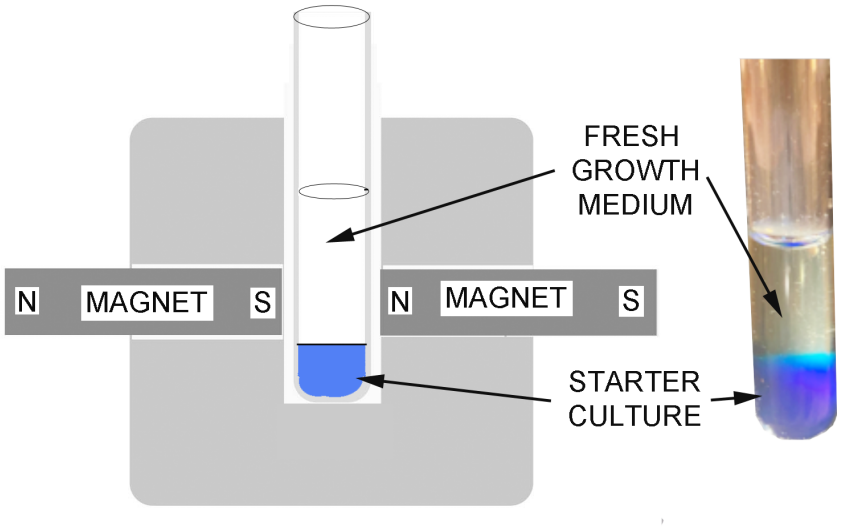


Figure 6. Bacterial solution in 2.0 M sucrose under 3 mL of fresh LB Broth growth medium. Blue dye was added to indicate demarcation between the starter culture and growth medium.

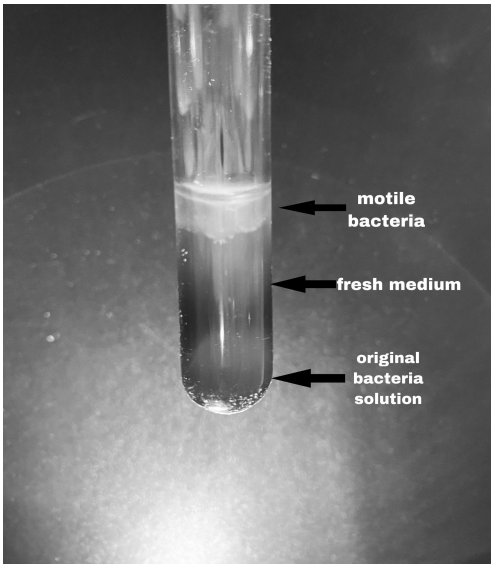


Figure 7. Separation of motile bacteria after 18 hour incubation.

After an overnight incubation for 18 hours, the top 0.5 mL of the solution containing motile bacteria was removed. 50 uLs of the sample were Gram stained and analyzed using a Zeiss Axiovert microscope. All photographs were taken at 1000x magnification using a 100x oil immersion lens. Sixteen individual trials were completed, with each trial containing two magnetic and control samples. After determining a visual difference between the control and magnet growth through microscopy, samples were submitted to CreativeBioGene, where 16s rRNA analysis was used to determine which species were present in the control and experimental samples.

16s rRNA Protocol:

After an overnight incubation, the top 0.5 mL aliquots from control and magnetic samples were centrifuged to form a pellet. The pellets were preserved in ethanol and then submitted to Creative BioGene: Microbiosci Inc., where 16s rRNA sequences were used to determine the species' identities and relative numbers of species present in the control and magnetic samples. Figure 8 demonstrates the steps taken to determine genetic makeup. After DNA was extracted from the pellets, it was amplified by polymerase chain reaction (PCR), and then sequenced. Bioinformatic methods were used to find sequences that code for 16s rRNA. Those sequences were compared with known bacterial sequences to determine the abundance of species present. This is a standard method for determining the composition of mixed bacterial populations.

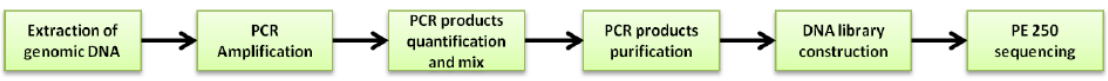


Figure 8. Method used by Creative BioGene to analyze bacterial pellets.

Results

Upward motility experiment and Microscopy of motile species:

The upper 0.5 mLs of solution were analyzed under 1000x oil immersion magnification, as described in the procedures. Microscopic analysis of the samples was repeated for each trial. In magnetic samples, the magnetic field tended to reduce the number of gram-positive species so that gram-negative species dominated the field. Figure 9 shows a typical example of microscopy. These results suggest that the magnetic field has a filtering effect on the movement of motile bacteria. See Discussion for another procedure completed that also indicated the magnetic filter on bacteria.

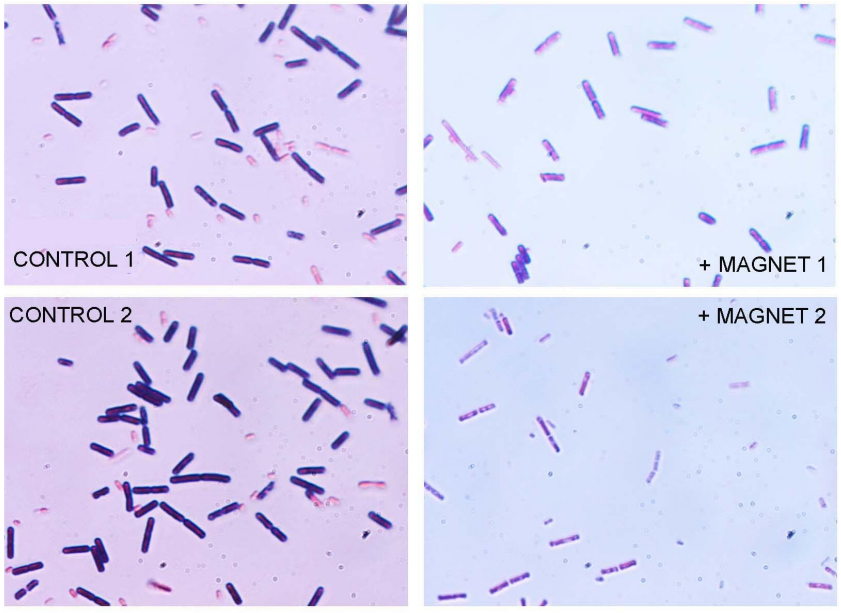


Figure 9. Microscopy analysis showing the filtration effects of the magnetic field. Samples exposed to the magnetic field contain mostly gram-negative bacteria.

Statistical Analysis of Microscopy Images:

Quantification of microscopy images was completed through statistical analysis based on bacterial counts in each image. Each control and magnet image was analyzed on ImageJ, and the number of bacteria present in the field was counted. A one-sample significance test for sample means was performed on the collected data at a α=.01 level. Conditions for Randomness, Independence, and Normality were checked. Conditions were deemed to be met: Normal distributions were assumed, all sample images accounted for less than 10% of the slides analyzed, and images were taken at random locations on the slide. The null hypothesis assumes no difference between the number of bacteria present in control and magnet samples. The alternate hypothesis test suggests that the number of bacteria in the magnetic samples is less than the controls.

	Mean ($\bar{x}$)	**Standard Deviation (σ)**	**P-value**
Control	51.5	18.26	
Magnet	26.3	10.95	.000445 (4.45E-4)

$$H_0: \bar{x}_{control} = \bar{x}_{magnet} = 51.5$$

$$H_a: \bar{x}_{magnet} < 51.5$$

Because the p-value was less than .01, the null hypothesis can be safely rejected, supporting the alternate hypothesis that the mean number of bacteria present in magnetic samples is statistically significantly less than the mean number of bacteria in the control samples. This statistically significant result is further supported by the following 16s rRNA analysis.

16s rRNA Analysis Results:

The four most abundant bacterial families in the samples were ordinary soil bacteria including *Enterobacteriaceae*, *Escherichia coli*, *Comamonas testosteroni* and *Pseudomonas*. These are all motile species, as expected. This confirmation is important because it confirms that the sucrose density separation method was successful at separating motile bacteria from the non-motile species of the soil mix. Furthermore, *Enterobacteriaceae, E. Coli, Comamonas testosteroni, and Pseudomonas* are all gram-negative species, which confirmed the results of microscopic analysis.

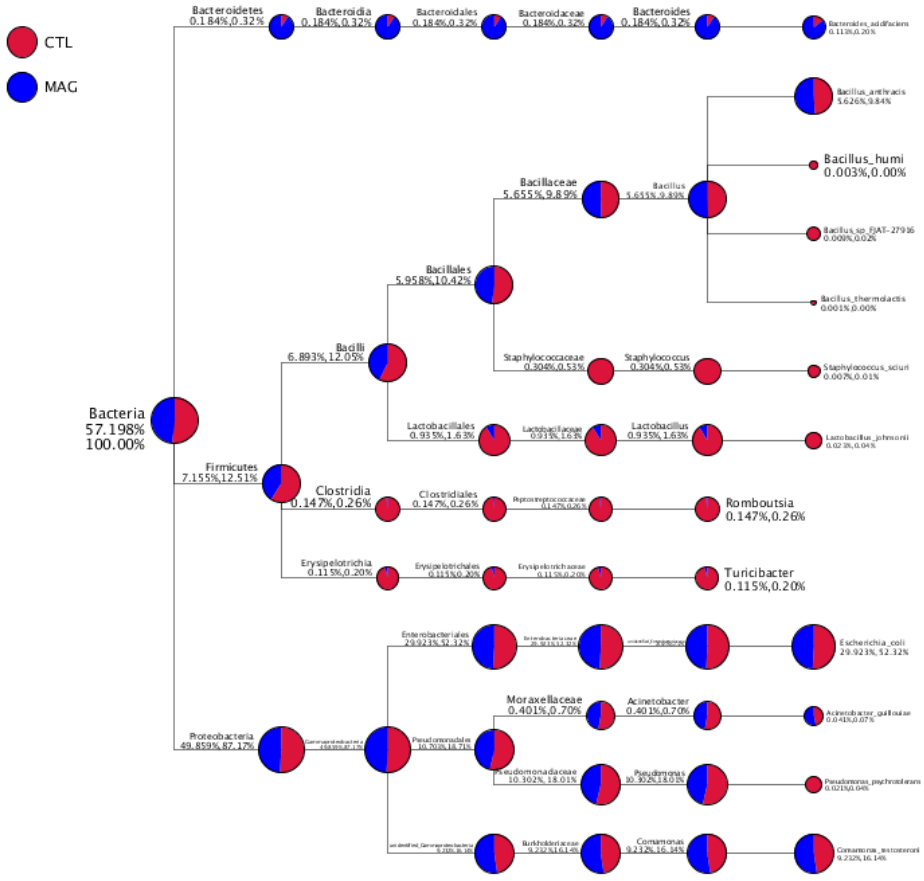


Figure 10. Comparison of relative abundance of species present between magnet and control samples.

Figure 10 illustrates the comparison of species present in the samples. The larger circles represent the more abundant species, and tend to be present in both the control and magnetic samples. However,

the smaller, mostly blue circles at the top of the diagram represent Bacteroidetes, a phylum much more represented in the magnetic sample than the controls. Bacteroidetes are gram-negative phylum, with species commonly found in soils and the gut. The diagram also displays bacterial families that are solely present in the control groups that have been filtered out by the magnetic field. These bacterial families include Staphylococcus, Clostridia, Erysipelotrichia, and some species of Lactobacillus. All of these families are gram-positive bacteria. Figure 10 demonstrates the clear filtration between gram-negative and gram-positive species due to the magnetic field. The results shown in Figure 10 and 11 are the clearest indication of this magnetic filtering effect.

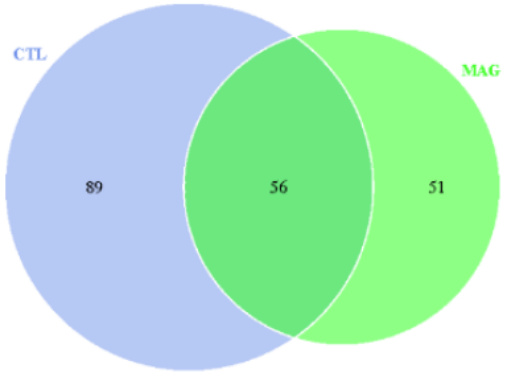


Figure 11. Venn diagram showing distinct differences in the populations of control motile species and those that swam through the magnetic field.

The venn diagram in Figure 11 summarizes the results of the study in terms of overlapping taxonomic units, or OTUs. These do not refer to species, but instead more generally to sequences in the 16s rRNA that are revealed to either overlap or not. The results confirm the microscopic differences that were observed and demonstrate that 89 sequences are exclusively present in the control samples, 51 are exclusively present in the magnetic samples, and 31 overlap. It became clear that the magnetic field

effectively filtered motile bacterial species into two populations that had significant compositional differences.

Conclusions

This research successfully determined that magnetic fields have a filtering effect on motile soil bacteria, simulating the evolution of magnetotactic bacteria. Both microscopy and 16s rRNA sequencing results demonstrate that a neodymium magnetic field filters out the majority of gram-positive bacteria, leaving mostly gram-negative motile species. Statistical analysis was performed on a series of microscopy images. The amount of bacteria present in magnetic samples was less than control groups by a statistically significant amount at the α=.01 level. Based on this research, there is a possibility that magnetotactic bacteria may have evolved through the magnetic field associated with magnetite. In addition, the field could have had a selective effect on populations of the first motile bacterial species, later amplified as they evolved the ability to deposit intracellular magnetite nodules.

Discussion

This research supports the conclusion that magnetic fields affect the motility of some common soil bacteria, and that magnetotactic bacteria could have evolved under strong magnetic fields.

Although my research supports this conclusion, an important question remains: what is the mechanism by which a magnetic field affects motility in bacteria that lack magnetite nodules? Guided by my mentor, I have come up with a possible answer in the form of a hypothesis that can be tested experimentally. The hypothesis involves the possible force acting on the protonic current created by a magnetic field (8).

Force of Magnetic Field on Protons (Biophysical explanation):

There is a biophysical explanation for the effects of the magnetic fields. The neodymium magnets used in this study are some of the strongest in the world. They are composed of a mixture of the elements neodymium, iron, and boron. Their dimensions are ½ x ½ x 2 inch and they have a strength of about 1.25 Teslas. These strong magnets were used to create a magnetic field that bacteria would traverse in order to reach fresh LB nutrient broth. The hypothesis involves a possible force acting on the protonic current by a magnetic field. The force can be calculated using the following equation, where the force equals the charge multiplied by the cross product of the velocity of the proton and magnitude of the magnetic field.

$$\vec{F} = Q(\vec{v} x \vec{\beta})$$

Equation for force on a proton.

The charge of a proton is 1.602×10^{-19} coulombs. The strength of the magnetic field, or β, is 1.25 teslas. The velocity of a proton can be calculated from the proton current, which has been measured as 1,200 protons flowing through a 5 nm thick membrane per second. This means that the velocity of one proton is $4.17 \text{ X } 10^{-6}$ meters per second. Because the protons move perpendicular to the magnetic field in three-dimensional space, the cross product can be accounted for by multiplying by sin(90). Plugging in the values, the force acting on a single proton equals 1.6 X 10-19 (417 X 10-6)(1.25)(sin 90^{o}) = **$8.35\text{X } 10^{-25}$ Newtons.**

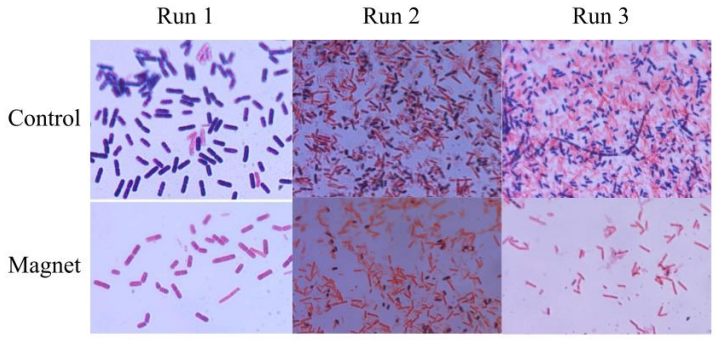
To calculate the total force acting on a flagellar motor of a bacterium, this value must be multiplied by $1.2 \text{ X } 10^{3}$ protons per second, which amounts to **10^{-21} Newtons.**

At first glance, this might seem negligible, but keep in mind that the force acts on a very small bacterial mass of approximately 10^{-15} kg. The Newtonian formula can be used to calculate the effect: force =

mass x acceleration (F = ma). Solving for acceleration, a = F/m = $10^{-21}/10^{-15}$ kg = 10^{-6} meters/s^2, equal to one micrometer (μm) s^2. A typical motile bacterium moves through the medium at a velocity of 50 μm/s, so it is clear that the force acting on a single flagellum would tend to accelerate it sideways at a rate of one μm/s^2, essentially making the bacterium do extra work to maintain its forward velocity. Furthermore, most motile bacteria have multiple flagella which would add to the braking effect. Because mixed soil bacteria will have varying sizes and numbers of flagella, this may account for the filtering effect of a strong magnetic field.

Selectively Filtering Magnetotactic Bacteria Using Magnets

Another experimental procedure was designed to determine if certain species in a bacterial culture would be drawn towards a magnetic force. A neodymium magnet was attached to a coverslip using a metal washer to hold it in place. About 40 uL of bacterial culture was pipetted onto the slip and dried on a heat plate for ten minutes. Bacteria were carefully rinsed off of the slip with distilled water, with the idea that the magnet would hold bacteria drawn to the field in place. Magnets were then removed from the coverslips and Gram stains were performed with crystal violet, iodine, alcohol decolorizer, and safranin. A control was conducted using the same procedure without the presence of the magnet. Coverslips were analyzed under 1000x magnification. A clear difference was observed between the control and magnet samples, where magnet samples contained much less gram-positive bacteria than



the controls. These results show that soil bacteria are clearly affected in the presence of magnetic fields. Gram-negative bacteria are drawn more towards magnetic fields and gram-positive bacteria typically

stay away. This could potentially mean that gram-negative bacteria were the ones that evolved into magneto-tactic bacteria, although further research is needed to make that conclusion.

Figure 12. Results of selectively filtering magnetic samples. Control groups contain an abundance of both gram-positive and gram-negative bacteria, while magnetic samples contain mostly gram-negative bacteria. Additionally, much less bacteria is present in the magnetic group. A clear filtering effect is shown.

Additional Medical Applications:

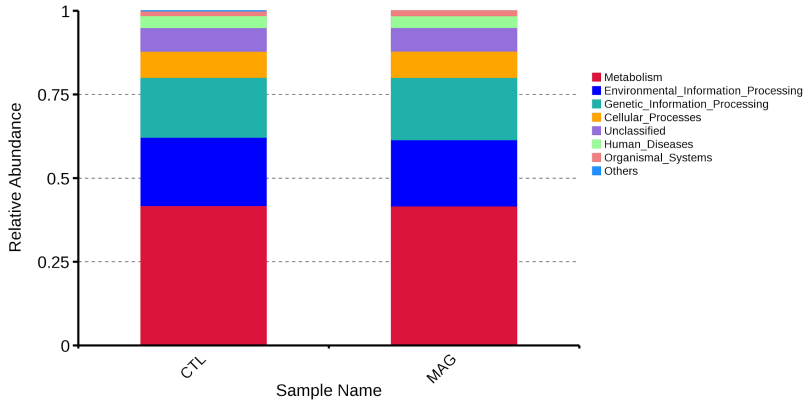


Figure 13. Bacterial function in samples. While the bacteria in both samples perform similar functions, about 20% of the bacteria are responsible for human diseases. The filtering effect could be potentially harnessed to slow down these bacterial infections in the human body.

Motile bacteria are important in our daily lives. Some are helpful bacteria related to digestion, such as *Lactobacillus*. However, other motile bacteria like *Salmonella* can cause disease. Our bodies have natural mechanisms such as the immune response to fight pathogenic bacteria, but when the bacteria overcome the protection they can cause infections. One example is *Vibrio*, the notorious "flesh eating" species. *Vibrio* is a motile species that can infect skin tissue, producing ulcers so serious that amputation is sometimes necessary. It's possible that magnetic fields can affect bacterial growth and the way that they cause disease. This could be extremely important when the diseased or infected area is easily accessible by external strong magnetic fields, such as skin ulcers caused by *Vibrio*. It would be

interesting to apply a neodymium magnetic field to both isolated bacterial cultures and the ulcer to see if it can slow or inhibit the disease process.

Further Experimentation:

Although 16s rRNA identification of bacterial populations is expensive, it must be repeated to further confirm the results reported here. Additionally, more experimentation will be done specifically on *Bacteroidetes*, which were only present in magnetic samples. Some species of this family are natural in the human gut, while others are pathogenic (9). It would be interesting to complete experimentation using HeLa cells to investigate which of the species of this family are amplified or slowed down under magnetic fields in human cells. Furthermore, research can be completed on other pathogenic species such as *Vibrio* to determine if the magnetic fields produce similar filtering effects.

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Analysis on Hill Cipher and RSA Cryptography

and the code implementation

Yuenan Huang

Abstract

In classical cryptography, the Hill cipher is a polygraphic substitution cipher based on linear algebra. Invented by Lester S. Hill in 1929, it was the first polygraphic cipher in which it was practical to operate on more than three symbols at once.[1] In this paper we explore the mechanisms of Hill cipher and improve its security by combining it with RSA public-key cryptosystem.

1 Hill Cipher

1.1 Encryption

In Hill cipher, each letter is represented by a number modulo 26. Let us assume the use of the usual 26 alphabet with A=0 and Z=25 (in the table below).

Table 1: conversion scheme mod 26

Letter	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Number	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

To encrypt a message, each block of n letters is multiplied by an invertible n by n matrix, against modulus 26. The matrix used for encryption is the cipher key, and it should be chosen randomly from the set of invertible $n \times n$ matrices (mod 26).

To illustrate this process, consider the plaintext message 'HELP', and the key below:

$$K = \begin{bmatrix} 1 & 5 \\ 7 & 2 \end{bmatrix}.$$

Since 'H'=7, 'E'=4, 'L'=11, 'P'=15, we can represent the text by two vectors:

$$\overset{\text{Text}}{\begin{bmatrix} H \\ E \end{bmatrix}} \rightarrow \begin{bmatrix} 7 \\ 4 \end{bmatrix}, \begin{bmatrix} L \\ P \end{bmatrix} \rightarrow \begin{bmatrix} 11 \\ 15 \end{bmatrix};$$

Then we compute

$$\begin{bmatrix} 1 & 5 \\ 7 & 2 \end{bmatrix} \begin{bmatrix} 7 \\ 4 \end{bmatrix} = \begin{bmatrix} 27 \\ 57 \end{bmatrix} \equiv \begin{bmatrix} 1 \\ 5 \end{bmatrix} \pmod{26}$$

$$\begin{bmatrix} 1 & 5 \\ 7 & 2 \end{bmatrix} \begin{bmatrix} 11 \\ 15 \end{bmatrix} = \begin{bmatrix} 86 \\ 107 \end{bmatrix} \equiv \begin{bmatrix} 8 \\ 3 \end{bmatrix} \pmod{26}$$

and thus

$$\begin{bmatrix} 1 \\ 5 \end{bmatrix} \rightarrow \begin{bmatrix} B \\ F \end{bmatrix}, \begin{bmatrix} 8 \\ 3 \end{bmatrix} \rightarrow \begin{bmatrix} I \\ D \end{bmatrix};$$

Therefore, we have HELP $\rightarrow$ BFID.

Now suppose our new message consists of same letters but in different order, let's say 'PHEL', then we have

$$\begin{bmatrix} P \\ H \end{bmatrix} \rightarrow \begin{bmatrix} 15 \\ 7 \end{bmatrix}, \begin{bmatrix} E \\ L \end{bmatrix} \rightarrow \begin{bmatrix} 4 \\ 11 \end{bmatrix};$$

This time, the ciphertext is given by:

$$\begin{bmatrix} 1 & 5 \\ 7 & 2 \end{bmatrix} \begin{bmatrix} 15 \\ 7 \end{bmatrix} = \begin{bmatrix} 50 \\ 119 \end{bmatrix} \equiv \begin{bmatrix} 24 \\ 15 \end{bmatrix} \pmod{26} \rightarrow \begin{bmatrix} Y \\ P \end{bmatrix};$$

$$\begin{bmatrix} 1 & 5 \\ 7 & 2 \end{bmatrix} \begin{bmatrix} 4 \\ 11 \end{bmatrix} = \begin{bmatrix} 59 \\ 50 \end{bmatrix} \equiv \begin{bmatrix} 7 \\ 24 \end{bmatrix} \pmod{26} \rightarrow \begin{bmatrix} H \\ Y \end{bmatrix};$$

Thus, *PHEL* $\rightarrow$ *YPHY*. This indicates that if the order of the plaintext changes, the entire ciphertext will change. Therefore, Hill cipher has achieved **Shannon's diffusion**, meaning that if we change a single bit of the plaintext or the

ciphertext, then the bits in the corresponding text would also change. The idea of diffusion is to hide the relationship between the ciphertext and the plain text. This will make it hard for an attacker who tries to find out the plain text and it increases the redundancy of plain text by spreading it across the rows and columns. It is also an important reason why Hill cipher is still in use in some cryptosystems today.[**2**]

1.2 Decryption

In order to decrypt, we have to turn the ciphertext back into a vector, then multiply by the inverse of the key matrix modulo n.

If the key matrix K is invertible, then there exists K^{-1} such that $KK^{-1} = K^{-1}K = I$, and the inverse of K can be computed by using the formula

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix}^{-1} = det(K)^{-1} \begin{bmatrix} d & -b \\ -c & a \end{bmatrix} = (ad - bc)^{-1} \begin{bmatrix} d & -b \\ -c & a \end{bmatrix}.$$

Therefore,

$$\begin{bmatrix} 1 & 5 \\ 7 & 2 \end{bmatrix}^{-1} = det(K)^{-1} \begin{bmatrix} 2 & -5 \\ -7 & 1 \end{bmatrix} = (-33)^{-1} \begin{bmatrix} 2 & -5 \\ -7 & 1 \end{bmatrix}.$$

Since our goal is to find the inverse of the key matrix modulo 26, we need to find the multiplicative inverse of 33 modulo 26 and multiply by our adjugate matrix.

By applying the **Euclidean algorithm**, we have:

$$\begin{aligned} 26 &= 19 + 7; \\ 19 &= 7 \times 2 + 5; \\ 7 &= 5 + 2; \\ 5 &= 2 \times 2 + 1; \end{aligned}$$

and

$$\begin{aligned} 1 &= 5 - 2 \times 2 \\ &= 5 - 2 \times (7 - 5) \\ &= 3 \times 5 - 2 \times 7 \\ &= 3 \times (19 - 7 \times 2) - 2 \times 7 \\ &= 3 \times 19 - 8 \times 7 \\ &= 3 \times 19 - 8 \times (26 - 19) \\ &= 3 \times 19 - 8 \times 7 \\ &= 11 \times 19 - 8 \times 26 \end{aligned}$$

Thus, we have

$$(-33)^{-1} \equiv 19^{-1} = 11 \pmod{26}.$$

Therefore,

$$\begin{bmatrix} 1 & 5 \\ 7 & 2 \end{bmatrix}^{-1} = (-33)^{-1} \begin{bmatrix} 2 & -5 \\ -7 & 1 \end{bmatrix} \equiv 11 \begin{bmatrix} 2 & -5 \\ -7 & 1 \end{bmatrix} = \begin{bmatrix} 22 & -55 \\ -77 & 11 \end{bmatrix} \equiv \begin{bmatrix} 22 & 23 \\ 1 & 11 \end{bmatrix} \pmod{26}.$$

We can multiply the inverse key to the ciphertext:

$$\begin{bmatrix} B \\ F \end{bmatrix} \rightarrow \begin{bmatrix} 1 \\ 5 \end{bmatrix}, \begin{bmatrix} I \\ D \end{bmatrix} \rightarrow \begin{bmatrix} 8 \\ 3 \end{bmatrix};$$

now we compute

$$\begin{bmatrix} 22 & 23 \\ 1 & 11 \end{bmatrix} \begin{bmatrix} 1 \\ 5 \end{bmatrix} = \begin{bmatrix} 137 \\ 56 \end{bmatrix} \equiv \begin{bmatrix} 7 \\ 4 \end{bmatrix} \pmod{26} \rightarrow \begin{bmatrix} H \\ E \end{bmatrix},$$

and

$$\begin{bmatrix} 22 & 23 \\ 1 & 11 \end{bmatrix} \begin{bmatrix} 8 \\ 3 \end{bmatrix} = \begin{bmatrix} 245 \\ 41 \end{bmatrix} \equiv \begin{bmatrix} 11 \\ 15 \end{bmatrix} \pmod{26} \rightarrow \begin{bmatrix} L \\ P \end{bmatrix};$$

Therefore, we have *BIFD* $\rightarrow$ *HELP*.

1.3 Two conditions exist in picking the key matrix

Two conditions must be satisfied in order for Hill cipher to work. They are:

1. The chosen matrix must be invertible ($det(K) \neq 0$)

   This one is easy to understand, because in order for Hill cipher to work we need to have a pair of inverse matrices to encrypt and decrypt the message.

2. The determinant of the encrypting matrix must not have any common factors with the modular base.

   From the formula of calculating the inverse of a modular matrix

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix}^{-1} = \begin{vmatrix} a & b \\ c & d \end{vmatrix}^{-1} \begin{bmatrix} d & -b \\ -c & a \end{bmatrix} = (ad - bc)^{-1} \begin{bmatrix} d & -b \\ -c & a \end{bmatrix}$$

   we can see that there must exist a modular inverse of the determinant of the original matrix.

Next we will prove that the modular inverse only exists if and only if the determinant of the encrypting matrix and the modular base are coprime.

Theorem 1 (Existence of modular inverses)**.** *Let $m \in \mathbb{Z}^+$ and $a \in \mathbb{Z}$. Then a has a multiplicative inverse, mod m, if and only if $GCD(a, m) = 1$.*

Proof. Firstly we will prove that if a has a multiplicative inverse mod m, then $GCD(a, m) = 1$. If there exists an inverse of a mod m, then we have a $x \in \mathbb{Z}$ such that $ax = 1 \pmod{m}$. Which is the same as $ax - 1 = my$ for some $y \in \mathbb{Z}$. Rearrange it, we have $ax - my = 1$ For any common divisor, d, of a and m, we will have $d \mid ax - my$, which gives us $d \mid 1$, that is $d = 1$. Therefore, $GCD(a, m) = d = 1$.

Next we will prove that if $\gcd(a, m) = 1$, then a has a multiplicative inverse mod m. In order to prove this, we will first prove an important lemma called **Bezout's Identity**, which states that

Lemma 1 (Bezout's Identity)**.** *Given distinct $a, m \in \mathbb{Z}$ with $\gcd(a, m) = d$, there exists integers x, y such that $ax + my = d$.*

Proof. Fix a and m. Consider the set $S = \{s > 0 : s = ax + my\}$ for some $x, y \in \mathbb{Z}$. We know that $\mid a \mid + \mid b \mid$ is in S, and this number is positive. Thus, S is nonempty. Also, all elements are greater than 0, so it has a smallest element. Let the smallest element be s_0, and let x_0 and y_0 be such that $s_0 = ax_0 + my_0$.

By the division algorithm there exists $q, r \in \mathbb{Z}$ such that $a = s_0 q + r$ and $0 \leqslant r < s_0$. Since $r < 0$, $r \notin S$. But

$$r = a - s_0 q = a - (ax_0 + my_0)q = a(1 - x_0 q) + m(-y_0 q),$$

so in order for it to not be in S, $r \notin \mathbb{N}$, but $r \geqslant 0$, so $r = 0$. Thus, $a = s_0 q$, and $s_0 \mid a$. Similarly, $s_0 \mid m$.

Let $\gcd(a, m) = d$. Since $s_0 \mid a$ and $s_0 \mid m$ we have $s_0 \mid d$. Additionally, we have that $d \mid a$ and $d \mid m$, so $d \mid ax_0 + my_0 = s_0$. Since s_0 and d divide each other, they must be equal. Thus, $d = ax_0 + my_0$, and we have found x, y such that $ax + my = d$. ■

According to Bezout's Identity, there exists $x, y \in \mathbb{Z}$ such that $ax + my = d = \gcd(a, m) = 1$.

Now we modulo m on both sides of the equation, we have

$$ax \equiv 1 \pmod{m}.$$

Therefore, a has a multiplicative inverse mod m. ■

Thus, to sum up, if we work modulo 26 as above, the determinant must be nonzero, and must not be divisible by 2 or 13. If the determinant is 0, or has common factors with the modular base, then the matrix cannot be used in the Hill cipher, and another matrix must be chosen.

However, the risk of the determinant having common factors with the modulus can be eliminated by making the modulus prime. Since the next prime to 26 is 29, it is useful to add 3 extra symbols to increase the modulus to 29.

1.3.1 Hill Cipher modulo 29

Assume the use of the usual 26 letter alphabet with A=0 and Z=25, and space=26, ?=27, and !=28.

Problem 1. *Encrypt "LINEAR ALGEBRA!" using key matrix*

$$K = \begin{bmatrix} 6 & 24 & 1 \\ 13 & 16 & 10 \\ 20 & 17 & 15 \end{bmatrix}.$$

Solution.

$$\begin{bmatrix} L \\ I \\ N \end{bmatrix} \to \begin{bmatrix} 11 \\ 8 \\ 3 \end{bmatrix}, \begin{bmatrix} E \\ A \\ R \end{bmatrix} \to \begin{bmatrix} 4 \\ 0 \\ 17 \end{bmatrix}, \begin{bmatrix} A \\ L \end{bmatrix} \to \begin{bmatrix} 26 \\ 0 \\ 11 \end{bmatrix}, \begin{bmatrix} G \\ E \\ B \end{bmatrix} \to \begin{bmatrix} 6 \\ 4 \\ 1 \end{bmatrix}, \begin{bmatrix} R \\ A \\ ! \end{bmatrix} \to \begin{bmatrix} 17 \\ 0 \\ 28 \end{bmatrix};$$

$$\begin{bmatrix} 6 & 24 & 1 \\ 13 & 16 & 20 \\ 20 & 17 & 15 \end{bmatrix} \begin{bmatrix} 11 \\ 8 \\ 3 \end{bmatrix} = \begin{bmatrix} 271 \\ 401 \\ 551 \end{bmatrix} \equiv \begin{bmatrix} 10 \\ 24 \\ 0 \end{bmatrix} \pmod{29} \to \begin{bmatrix} K \\ Y \\ A \end{bmatrix};$$

$$\begin{bmatrix} 6 & 24 & 1 \\ 13 & 16 & 20 \\ 20 & 17 & 15 \end{bmatrix} \begin{bmatrix} 4 \\ 0 \\ 17 \end{bmatrix} = \begin{bmatrix} 41 \\ 222 \\ 335 \end{bmatrix} \equiv \begin{bmatrix} 12 \\ 19 \\ 16 \end{bmatrix} \pmod{29} \to \begin{bmatrix} M \\ T \\ Q \end{bmatrix};$$

$$\begin{bmatrix} 6 & 24 & 1 \\ 13 & 16 & 20 \\ 20 & 17 & 15 \end{bmatrix} \begin{bmatrix} 26 \\ 0 \\ 11 \end{bmatrix} = \begin{bmatrix} 167 \\ 448 \\ 685 \end{bmatrix} \equiv \begin{bmatrix} 22 \\ 13 \\ 18 \end{bmatrix} \pmod{29} \to \begin{bmatrix} W \\ N \\ S \end{bmatrix};$$

$$\begin{bmatrix} 6 & 24 & 1 \\ 13 & 16 & 20 \\ 20 & 17 & 15 \end{bmatrix} \begin{bmatrix} 6 \\ 4 \\ 1 \end{bmatrix} = \begin{bmatrix} 133 \\ 152 \\ 203 \end{bmatrix} \equiv \begin{bmatrix} 17 \\ 7 \\ 0 \end{bmatrix} \pmod{29} \to \begin{bmatrix} R \\ H \\ A \end{bmatrix};$$

$$\begin{bmatrix} 6 & 24 & 1 \\ 13 & 16 & 20 \\ 20 & 17 & 15 \end{bmatrix} \begin{bmatrix} 17 \\ 0 \\ 28 \end{bmatrix} = \begin{bmatrix} 130 \\ 501 \\ 760 \end{bmatrix} \equiv \begin{bmatrix} 14 \\ 8 \\ 6 \end{bmatrix} \pmod{29} \rightarrow \begin{bmatrix} O \\ I \\ G \end{bmatrix};$$

Therefore, we have *LINEAR ALGEBRA!* $\rightarrow$ *KYAMTQWNSRHAOIG*.

We can also calculate the inverse key:

$$K^{-1} = (441)^{-1} \begin{bmatrix} 70 & -343 & 224 \\ 5 & 70 & -47 \\ -99 & 378 & -216 \end{bmatrix} \equiv 5 \begin{bmatrix} 70 & -343 & 224 \\ 5 & 70 & -47 \\ -99 & 378 & -216 \end{bmatrix} \equiv \begin{bmatrix} 2 & -25 & 18 \\ 25 & 2 & -26 \\ -27 & 5 & -22 \end{bmatrix} \pmod{29},$$

and use the decryption process we discuss above, we can decrypt the ciphertext back to the plaintext. ■

1.4 Key Space Size

The **key space** is the set of all possible keys, and the **key space size** is the number of possible keys. In this section, we will introduce the calculation of the key space size for the matrix of the given dimension under certain modulus. Let us take our usual 26 alphabet as an example. Theoretically, there are 26^{n^2} matrices of dimension n by n. However, it is only an upper bound because not every matrix is invertible, and for some non prime modulus not every matrix has a determinant that is coprime to the modulus, and thus not usable as a key.

Although it seems complicated to find the exact number of possible keys, it is actually possible by using the knowledge of number theory and group theory. Therefore, before we do the calculation, I will introduce the **Chinese Remainder Theorem** and the concept of **matrix groups**, which can help us calculate the key space size in a pretty elegant way.

Theorem 2 (Chinese Remainder Theorem)**.** *Let p, q be coprime. Then the system of equations*

$$x \equiv a \pmod{p}$$
$$x \equiv b \pmod{q}$$

has a unique solution for x modulo pq.

The reverse direction is trivial: given $x \in \mathbb{Z}_{pq}$, we can reduce x modulo p and x modulo q to obtain two equations of the above form.

Proof. Let $p_1 \equiv p^{-1} \pmod{p}$ and $q_1 \equiv q^{-1} \pmod{q}$. These must exist since p, q are coprime. Then we claim that if y is an integer such that

$$y \equiv aqq_1 + bpp_1 \pmod{pq}$$

then y satisfies both equations: Modulo p on both sides, we have $y \equiv aqq_1 \equiv a \pmod{p}$ since $qq_1 \equiv 1 \pmod{p}$. Similarly $y \equiv b \pmod{q}$. Thus, y is a solution for x.

It remains to show no other solutions exist modulo pq. If $z \equiv a \pmod{p}$ then $z - y$ is a multiple of p. If $z \equiv b \pmod{q}$ as well, then $z - y$ is also a multiple of q. Since p and q are coprime, this implies $z - y$ is a multiple of pq, hence $z \equiv y \pmod{pq}$. ■

This theorem implies we can represent an element of $\mathbb{Z}_{pq}$ by one element of $\mathbb{Z}_p$ and one element of $\mathbb{Z}_q$, and vice versa. In other words, we have a bijection between $\mathbb{Z}_{pq}$ and $\mathbb{Z}_p \times \mathbb{Z}_q$.

Therefore, according to the Chinese Remainder Theorem, a matrix is invertible modulo 26 if and only if it is invertible both modulo 2 and modulo 13, and we have converted the problem to finding the number of invertible matrices modulo 2 and modulo 13.

Now we will introduce some concepts in group theory.

Definition 1 (Group)**.** *A **group** is an ordered pair $(G, *)$ where G is a set and $*$ is a binary operation on G satisfying the following axioms:*

1. *$(a * b) * c = a * (b * c)$, for all $a, b, c \in G$, i.e. $*$ is associative.*
2. *There exists an element of e in G, called an identity of G, such that for all $a \in G$ we have $a * e = e * a = a$.*
3. *For each $a \in G$ there is an element a^{-1} of G, called an inverse of a, such that $a * a^{-1} = a^{-1} * a = e$.*

A simple example of a group is $G = \{\mathbb{Z}, +\}$. It is obvious that integer addition is a binary operation and associative. For every a belongs to G, $0 + a = a + 0 = a$, therefore, 0 is the identity of G. And for every a belongs to G, $a + (-a) = (-a) + a = 0$, therefore, $a^(- 1) = -a$ for every element in G. Therefore, $G = \{\mathbb{Z}, +\}$ is a group.

Definition 2 (Field)**.** *A **field** is a set F together with two binary operations $+$ and $*$ on F such that $\{F, +\}$ is an abelian group (call its identity 0) and $\{F - 0, *\}$ is also an abelian group, and the following distributive law holds:*

$$a * (b + c) = (a * b) + (a * c), \text{ for all } a, b, c \in F$$

Definition 3 (General Linear Group of Degree n)**.** *The set of all invertible $n \times n$ matrices is called the **general linear group of degree n**. For each $n \in \mathbb{Z}^+$ let $GL_n(F)$ be the set of all $n \times n$ matrices whose entries come from F and whose determinant is nonzero, i.e.,*

$$GL_n(F) = \{A \mid A \text{ is an n by n matrix with entries from F and det(A) is not equal to o}\}$$

where the determinant of any matrix A with entries from F can be computed by the same formula used when $F = \mathbb{R}$.

Now we prove that $GL_n(F)$ is a group.

Proof. For arbitrary $n \times n$ matrices A and B let AB be the product of these matrices as computed by the same rules as when $F = \mathbb{R}$. This product is associative. Also, since $\det(AB) = \det(A) * \det(B)$, it follows that if $\det(A)$ is not equal to o and $\det(B)$ is not equal to o, then $\det(AB)$ is not equal to o, so $GL_n(F)$ is closed under matrix multiplication. Furthermore, $\det(A)$ is not equal to o if and only if A has a matrix inverse, so each A belongs to $GL_n(F)$ has an inverse, A^{-1}, in $GL_n(F)$:

$$AA^{-1} = A^{-1}A = I,$$

Where I is the $n \times n$ identity matrix. Thus, $GL_n(F)$ is a group under matrix multiplication. ■

An important property of the general linear group that is related to the calculation of key space size: If F is a field and $\mid F \mid = q < \infty$, then

$$\mid GL_n(F) \mid = (q^n - 1)(q^n - q)(q^n - q^2)...(q^n - q^(n - 1))$$

Back to our problem, the goal is to find the number of invertible matrices modulo 2 and modulo 13. Based on the definition above, we can easily check that invertible n by n matrices modulo 2 and modulo 13 are general linear group $GL_n(\mathbb{Z}/2\mathbb{Z})$ and $GL_n(\mathbb{Z}/13\mathbb{Z})$, respectively. Thus, the number of invertible $n \times n$ matrices modulo 2 and modulo 13 are equal to the *order* (i.e. the number of elements in the group) of $GL_n(\mathbb{Z}/2\mathbb{Z})$ and $GL_n(\mathbb{Z}/13\mathbb{Z})$, respectively.

Thus, we have

$$\mid GL_n(\mathbb{Z}/2\mathbb{Z}) \mid = 2^{n^2} \left(1 - \frac{1}{2}\right)\left(1 - \frac{1}{2^2}\right) \dots \left(1 - \frac{1}{2^n}\right)$$

$$\mid GL_n(\mathbb{Z}/13\mathbb{Z}) \mid = 13^{n^2} \left(1 - \frac{1}{13}\right)\left(1 - \frac{1}{13^2}\right) \dots \left(1 - \frac{1}{13^n}\right)$$

According to the Chinese Remainder Theorem, the number of invertible matrices modulo 26 is the product of those two numbers. Hence it is

$$26^{n^2}\left(1-\frac{1}{2}\right)\left(1-\frac{1}{2^2}\right)\cdots\left(1-\frac{1}{2^n}\right)\left(1-\frac{1}{13}\right)\left(1-\frac{1}{13^2}\right)\cdots\left(1-\frac{1}{13^n}\right)$$

Similarly, since 29 is a prime, the number of invertible matrices modulo 29 is

$$29^{n^2}\left(1-\frac{1}{29}\right)\left(1-\frac{1}{29^2}\right)\cdots\left(1-\frac{1}{29^n}\right)$$

1.5 Limitation of Hill Cipher

The basic Hill cipher is vulnerable to a known-plaintext attack because it is completely linear. An opponent who intercepts n plaintext/ciphertext character pairs can set up a linear system which can be easily solved; if it happens that this system is indeterminate, it is only necessary to add a few more plaintext/ciphertext pairs. Calculating this solution by standard linear algebra algorithms then takes very little time.

While matrix multiplication alone does not result in a secure cipher it is still a useful step when combined with other non-linear operations, because matrix multiplication can provide diffusion.

Therefore, in order to improve the security level of the Hill Cipher, I decide to combine the Hill cipher process with the famous public-key cryptosystem known as **RSA**.

2 RSA Public-Key Cryptography

RSA is a public-key cryptosystem that is widely used for secure data transmission. In a public-key cryptosystem, the encryption key is public and distinct from the decryption key, which is kept secret. An RSA user creates and publishes a public key based on two large prime numbers, along with an auxiliary value. The prime numbers are kept secret. Messages can be encrypted by anyone, via the public key, but can only be decoded by someone who knows the prime numbers.

Before demonstrating this process, let us prove a lemma which is important for understanding the mechanism of RSA.

Lemma 2. *Let* $m \in \mathbb{Z}^+$, *and* $a \in \mathbb{Z}$ *such that* $\gcd(a, m) = 1$. *Let* $x, y \in \mathbb{N}$ *Then*

$$x \equiv y \pmod{\phi(m)} \textit{ implies } a^x \equiv a^y \pmod{m}$$

Proof. Assume without loss of generality that $x \geqslant y$, and let $t = x - y$. If $x \equiv y \pmod{\phi(m)}$, then $t = n\phi(m)$ for some $n \in \mathbb{N}$. Therefore, by the **Fermat's Little Theorem**,

$$a^t = a^{n\phi(m)} = {a^{\phi(m)}}^n \equiv 1^n = 1 \pmod{m}.$$

And thus

$$a^x = a^t a^y \equiv 1a^y = a^y \pmod{m}.$$

■

Now let us look at the process of RSA cryptography. Assume that Bob wants to send a message to Adam and Chris has tapped the wire.

To receive encrypted messages, Adam begins by coming up with two large prime numbers p and q (called Adam's private keys), which he keeps in private and never reveals to anyone, including Bob. But he multiplies them together to form $N = pq$ and makes the number N public to everyone. He also publicizes an auxiliary number called e, and the pair (N, e) is called Adam's public key.

When Bob wishes to send an encrypted message m (a small natural number) to Adam, he computes the ciphertext $c = m^e \pmod N$ using Adam's public key (N, e), and sends it to Adam over the wire.

To recover the message m from the ciphertext, Adam uses his private keys p and q to compute $\phi(N) = \phi(pq) = \phi(p)\phi(q) = (p-1)(q-1)$.

Then Adam computes a multiplicative inverse[1] d of e modulo $\phi(N)$, using the Euclidean algorithm

$$de = 1 \pmod{\phi(N)}$$

and keep d and $\phi(N)$ private as p and q.

When Adam receives the ciphertext, he computes c^d mod N. This remarkably recovers Bob's message m by Lemma 2:

$$c^d = (m^e)^d = m^{ed} \equiv m^1 = m \pmod N.$$

For Chris, breaking the code seems as hard as factoring the large number N, which provides a robust mechanism for short encrypted messages.[3]

3 Combined Cryptosystem with Hill Cipher and RSA

Let's assume that Adam wants to send the message "PICKLE" to Chris. They decide to use

$$K = \begin{bmatrix} 6 & 24 & 1 \\ 13 & 16 & 10 \\ 20 & 17 & 15 \end{bmatrix}$$

and

$$K^{-1} = \begin{bmatrix} 2 & 25 & 18 \\ 25 & 2 & 26 \\ 27 & 5 & 2 \end{bmatrix}$$

as their keys, and Chris announces his public key as $N = 9167$, $e = 13$ (his private keys are $p = 89$ and $q = 103$, but he will not reveal it to anyone!)

First of all, Adam will use the Hill cipher key to encrypt the plaintext:

$$\begin{bmatrix} P \\ I \\ C \end{bmatrix} \to \begin{bmatrix} 15 \\ 8 \\ 2 \end{bmatrix}, \begin{bmatrix} K \\ L \\ E \end{bmatrix} \to \begin{bmatrix} 10 \\ 11 \\ 4 \end{bmatrix}, \begin{bmatrix} K \\ L \\ E \end{bmatrix} \to \begin{bmatrix} 10 \\ 11 \\ 4 \end{bmatrix};$$

$$\begin{bmatrix} 6 & 24 & 1 \\ 13 & 16 & 20 \\ 20 & 17 & 15 \end{bmatrix} \begin{bmatrix} 15 \\ 8 \\ 2 \end{bmatrix} = \begin{bmatrix} 284 \\ 343 \\ 466 \end{bmatrix} \equiv \begin{bmatrix} 23 \\ 24 \\ 2 \end{bmatrix} \pmod{29}$$

$$\begin{bmatrix} 6 & 24 & 1 \\ 13 & 16 & 20 \\ 20 & 17 & 15 \end{bmatrix} \begin{bmatrix} 10 \\ 11 \\ 4 \end{bmatrix} = \begin{bmatrix} 328 \\ 346 \\ 447 \end{bmatrix} \equiv \begin{bmatrix} 9 \\ 27 \\ 12 \end{bmatrix} \pmod{29}.$$

Then Adam comes up with a number m, where he sends the number to Chris by RSA encryption. Let's assume that Adam chooses $m = 17$. Then he computes the ciphertext $c = m^e = 17^{13} = 1833 \pmod{9167}$ and sends to Chris, where Chris can recover the ciphertext by computing $\phi(N) = 8976$, $d = 1381$, and $m = 1833^{1381} = 17 \pmod{9167}$.

[1] When choosing e, it should be coprime to $\phi(N)$ for the purpose of finding a multiplicative inverse

After sending m, Adam uses the message to further encrypt his text by computing $x = a^m \pmod{29}$ for every Hill cipher encrypted letter:

$$\begin{aligned} 23^{17} &= 16 \pmod{29} \to Q; \\ 24^{17} &= 20 \pmod{29} \to U; \\ 2^{17} &= 21 \pmod{29} \to V; \\ 9^{17} &= 4 \pmod{29} \to E; \\ 27^{17} &= 8 \pmod{29} \to I; \\ 12^{17} &= 12 \pmod{29} \to M. \end{aligned}$$

Therefore, Adam gets *PICKLE* $\to$ *QUVEIM*, and he sends it to Chris.

To decrypt the message, Chris can use $a^m = x \pmod{29}$ to find the Hill cipher coded text a, and then apply Hill cipher decryption to get the plaintext.

For Eva who is tapping the wire between Adam and Chris, she can either factorize the large number N to decrypt the message m or simply list out all possible permutations, which is $29! = 8.842 * 10^{30}$ when we choose modulus 29. If we increase the number of symbols to some larger prime number n, the number of all the permutations would be $n!$, which has time complexity $O(n!)$ and thus can increase the difficulty of decryption by brute force.

4 Code Implementation

Here we use python to implement the preceding process of combining Hill cipher and RSA algorithm for cryptography. In the previous sections we discuss using 29 as our modulus. In fact, computers have their own number-character conversion mechanism via ASCII code. Since there are 256 ASCII characters available (including both standard and extended ASCII characters), we can take advantage of the increasing character choices to improve the security of the cryptosystem. Since the nearest prime number smaller than or equal to 256 is 251, we use 251 as our modulus in the code implementation process.

The following is the python code implementation:

```
import numpy as np
import math
import random
from numpy import matrix
from numpy import linalg


def modMatInv(A, p):  # Finds the inverse of matrix A mod p
    n = len(A)
    A = matrix(A)
    adj = np.zeros(shape=(n, n))
    for i in range(0, n):
        for j in range(0, n):
            adj[i][j] = ((-1) ** (i + j) * int(round(linalg.det(minor(A, j, i))))) % p
    return (modInv(int(round(linalg.det(A))), p) * adj) % p
```

```
def modInv(a, p):  # Finds the inverse of a mod p, if it exists
    for i in range(1, p):
        if (i * a) % p == 1:
            return i
    raise ValueError(str(a) + " has no inverse mod " + str(p))


def minor(A, i, j):  # Return matrix A with the ith row and jth column deleted
    #
    A = np.array(A)
    minor = np.zeros(shape=(len(A) - 1, len(A) - 1))
    p = 0
    for s in range(0, len(minor)):
        if p == i:
            p = p + 1
        q = 0
        for t in range(0, len(minor)):
            if q == j:
                q = q + 1
            minor[s][t] = A[p][q]
            q = q + 1
        p = p + 1
    return minor


# get a random prime number for encoding message:

def getRandomPrimeInteger(bounds):
    for i in range(bounds.__len__() - 1):
        if bounds[i + 1] > bounds[i]:
            x = bounds[i] + np.random.randint(bounds[i + 1] - bounds[i])
            if isPrime(x):
                return x

        else:
            if isPrime(bounds[i]):
                return bounds[i]

        if isPrime(bounds[i + 1]):
            return bounds[i + 1]

    newBounds = [0 for i in range(2 * bounds.__len__() - 1)]
    newBounds[0] = bounds[0]
    for i in range(1, bounds.__len__()):
        newBounds[2 * i - 1] = int((bounds[i - 1] + bounds[i]) / 2)
```

```
        newBounds[2 * i] = bounds[i]

    return getRandomPrimeInteger(newBounds)


def isPrime(x):
    count = 0
    for i in range(int(x / 2)):
        if x % (i + 1) == 0:
            count = count + 1
    return count == 1


# get the message prime between 100 and 10000:
bounds = [100, 10000]
mes = getRandomPrimeInteger(bounds)

n = 251

list = []  # Randomly generate an invertible key matrix
K_det = 0
while (K_det == 0):
    for x in range(0, 9):
        a = random.randint(1, n)
        list.append(a)
    K = np.array([[list[0], list[1], list[2]],
                  [list[3], list[4], list[5]],
                  [list[6], list[7], list[8]]])
    K_det = np.linalg.det(K)
K_modInv = modMatInv(K, n)  # Modular inverse of the key matrix

# Encryption Process


print("Key Marix: \n", K)
print("Determinant of the Key Marix: ", K_det)
print("Modular Inverse of the Key Matrix: \n", K_modInv)

letters = input("Please enter your text here: \n")  # input plaintext
print(" Encryption Process  \n")
len = len(letters)
numbers = []
for letter in letters:
    number = ord(letter)
    numbers.append(number)
```

```
while len % 3 != 0:
    numbers.append(ord(' '))
    len += 1
print("ASCII conversion: ", numbers)  # ASCII converted numbers

print("RSA encryption process: \n")
try:  # RSA message transfer
    input = raw_input
except NameError:
    pass
try:
    chr = unichr
except NameError:
    pass
p = int(input('Enter prime p: '))
q = int(input('Enter prime q: '))
print("Choosen primes:\np=" + str(p) + ", q=" + str(q) + "\n")
N = p * q
print("N = p * q = " + str(N) + "\n")
phi = (p - 1) * (q - 1)
print("Euler's function (totient) [phi(n)]: " + str(phi) + "\n")


def gcd(a, b):
    while b != 0:
        c = a % b
        a = b
        b = c
    return a


def modinv(a, m):
    for x in range(1, m):
        if (a * x) % m == 1:
            return x
    return None


def coprimes(a):
    l = []
    for x in range(2, a):
        if gcd(a, x) == 1 and modinv(x, phi) != None:
            l.append(x)
    for x in l:
        if x == modinv(x, phi):
```

```
            l.remove(x)
    return l


print("Choose an e from a coprime(s) array below:\n")
print(str(coprimes(phi)) + "\n")
e = int(input('Enter e: '))
d = modinv(e, phi)
print("\nYour public key is a pair of numbers "
      "(e=" + str(e) + ", N=" + str(N) + ").\n")
print("Your private key is a pair of numbers (d="
      + str(d) + ", p=" + str(p) + ", q=" + str(q) + ").\n")


def encrypt_block(m):
    c = pow(m, e, N)
    return c


def decrypt_block(c):
    m = pow(c, d, N)
    return m


print("\nPlain message: " + str(mes) + "\n")
enc = encrypt_block(mes)
print("Encrypted message: " + str(enc) + "\n")
dec = decrypt_block(enc)
print("Decrypted message: " + str(dec) + "\n")

ct = ""  # ciphertext
for x in range(0, len, 3):
    X = np.array([[numbers[x]], [numbers[x + 1]], [numbers[x + 2]]])
    M = K.dot(X)
    for i in range(3):
        val = np.int64(M[:][i])
        pyval = val.item()
        y = pow(pyval, mes, n)
        ct += chr(y)
print("Ciphertext: \n", ct)

# Decryption Process


print(" Decryption Process \n")
```

```
ct_numbers = []
for ct_letter in ct:
    ct_number = ord(ct_letter)
    ct_numbers.append(ct_number)

print("Ciphertext ASCII conversion: ", ct_numbers)  # ASCII converted ciphertext numbers

exp_table = []  # exponential ciphertext conversion table
for x in range(n):
    exp_element = pow(x, mes, n)
    exp_table.append(exp_element)
print("exp_table: ", exp_table)
pt_numbers = []
for ct_number in ct_numbers:
    for i in range(n):
        if exp_table[i] == ct_number:
            pt_numbers.append(i)

print("pt_numbers: ", pt_numbers)

pt = ""  # plaintext
for z in range(0, len, 3):
    Z = np.array([[pt_numbers[z]], [pt_numbers[z + 1]], [pt_numbers[z + 2]]])
    S = K_modInv.dot(Z)
    for i in range(3):
        val = np.int64(S[:][i])
        pyval = val.item()
        pt_number = pyval % n
        pt += chr(pt_number)
print("Plaintext: \n", pt)
```

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[3] Martin H. Weissman, *An Illustrated Theory of Numbers.* Providence, Rhode Island: American Mathematical Society, 2017, pp. 186-187.