Science Focus 科言

Issue 020, 2021

Helium and Why It Makes You Sound Like Mickey Mouse
氦氣 — 為何它使您的聲音像米奇老鼠

The Serendipitous Invention of Teflon™: An Appreciation of Unexpected Results
欣賞不一樣的實驗結果：鐵氟龍™的意外發明

A New Body Part to Keep One Salivating
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The Twin Prime Conjecture and the Polymath Project
孿生質數猜想與博學者計劃

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Acknowledgements 特別致謝

Message from the Editor-in-Chief 主編的話

Dear Readers,

As I write, the COVID pandemic appears to be under control in Hong Kong. Have you enjoyed your return to school? With the precious in-person interactions with your classmates and teachers restored, I hope you are as motivated as ever to learn.

Mask-wearing, social-distancing and vaccination are three prominent elements in our fight against COVID. Perhaps you have already heard much about the COVID vaccines that are being offered. In this issue, we delve into the history of vaccines and share the stories of heroes who made significant contributions in the past. Although you may strive to obtain a "perfect" set of data for your school-based assessments, have you ever thought that great scientific progress could come from not-so-perfect or unexpected results? Let us illustrate with the discovery of Teflon and a new salivary gland. For those of you who are intrigued by our cover, please check out the article on the study of twins, not in biology, but in mathematics!

We have finally reached the landmark of 1000 followers for our Instagram page. Thank you very much for those of you who interacted with us on our social media platforms. Do look out for our Instagram exclusive content, which is updated regularly. Finally, I wish you a fruitful summer and beyond. I hope we can all boldly say "I'm Fine, Thx."

Yours faithfully,
Prof. Ho Yi Mak
Editor-in-Chief

親愛的讀者：

執筆之時，本港疫情似乎已經受控。您享受回校上課的時光嗎？在能與同學和老師再一次親身見面的寶貴機會下，希望您會得到前所未有的學習動力。

配戴口罩、保持社交距離和接種疫苗可能是解決疫情的終極方法。您可能已經聽過很多關於可供接種肺炎疫苗的資訊。今期我們會介紹疫苗的歷史和分享對疫苗作出偉大貢獻科學家的故事。在校本評核中，您可能努力地嘗試獲取「完美」的數據，但您有沒有想過不太完美或意想不到的實驗結果也可以在科學上帶來極大的進展？讓我們把發現鐵氟龍和新唾腺的故事娓娓道來，向大家細說這些不平凡的二三事。另外，如果您被我們的封面深深吸引，不妨翻閱一下後頁關於孿生雙子研究的文章，那可不是一篇生物文章，而是一篇關於數學的文章！

《科言》Instagram 的訂閱數最終達到 1000 的里程碑，謹此感謝在社交平台與我們有過互動的各位。除了記得要「讀多啲書、飲多啲水」，還要繼續留意我們 Instagram 定期更新的內容。最後我祝大家有一個充實的暑假。希望大家在怎樣的逆境下都能自信地說出「I' m Fine, Thx.」。

主編 麥晧怡教授
敬上

What's Happening in Hong Kong? 香港科技活動

Fun in Summer Science Activities 夏日科學好節目

Any plans for this Summer? Check out these science activities!

計劃好這個夏天的好去處了嗎?不妨考慮以下活動!

The Science Behind Pixar 彼思動畫的科學秘密

In 1995, Pixar Animation Studios was the first in the world to produce an entirely computer-animated feature movie, Toy Story. Since then, Pixar has created many other blockbuster movies that are filled with mind-blowing imagery, bringing artists' vision to life. In this exhibition, you can discover how lively characters and realistic scenes are created through more than 50 interactive exhibits. Let's check it out and take photos with your favorite Pixar characters like Buzz Lightyear and Dory!

Date: July 30, 2021 – December 1, 2021

Venue: G/F Exhibition Hall, Hong Kong Science Museum

Remarks: Please refer to the museum's website for the admission fee for this special exhibition.

由彼思動畫製作室在1995年製作出全球首部全電腦動畫製作電影《反斗奇兵》開始,他們不斷推出票房大賣的經典電影,當中一幕幕引人入勝的場景使藝術家構想中的奇妙世界活現在觀眾眼前。在這個展覽中,您可以從超過50組互動展品中了解到彼思動畫製作室如何創造出電影中生動的角色和真實的場境。如此吸引的展覽當然不容錯過,巴斯光年和多莉等多個彼思動畫角色正等著和您拍照!

展期:2021年7月30日至2021年12月1日

地點:香港科學館地下展覽廳

備註:此專題展覽的票價請參閱科學館網頁。

Perseid Meteor Shower – August 13, 2021 英仙座流星雨 — 2021年8月13日

This year, the Perseids is expected to peak on August 13 (Fri), 03:00. You may observe the meteor shower during the entire night of August 12, and there could be up to 110 meteors per hour (subject to light pollution level, weather conditions, etc.). The moon phase will be 21% and the Hong Kong Space Museum has rated the observation condition as "excellent".

Places with wide view of the sky and low light pollution are suitable for the observation, such as the East Dam of the High Island Reservoir, Tai Tau Chau in Shek O, and Tai Au Mun (near HKUST). Please observe the "stargazing etiquette" — use a red light torch and don't point it to others. To take photos of the starry sky, don't forget to bring a tripod and a camera with a wide-angle lens. The summer Milky Way will never disappoint you, too!

今年英仙座流星雨的高峰期預計是8月13日(五)上午三時。您可以在12日的整個晚上觀賞,預計每小時最多會有約110顆流星在夜空劃過(亦受光害、天氣等因素影響);當晚月齡初六(農曆初六),觀測條件被香港太空館評為極佳。

天空視野廣闊和光害較少的地方都適宜觀測是次流星雨,本港的觀星熱點有萬宜水庫東壩、石澳大頭洲以及離科大不遠的大坳門等。觀星時記得遵守「觀星禮儀」,包括使用紅光手電筒,及不要把光照向別人。想嘗試天文攝影的朋友記得攜帶三腳架和廣角鏡頭。夏季銀河也絕對不會令人失望!

Helium and Why
It Makes You Sound Like Mickey Mouse
氦氣 - 為何它使您的聲音像米奇老鼠

By Henry Lau 劉以軒

Have you ever thought that it was cool to have a really deep and husky voice like Darth Vader or Batman? What if we could temporarily change our voice for fun? Listen closely – I am going to let you in on a little not-so-secret secret...the power of helium. Being the first in a group of elements dubbed the noble gases, you'd think that helium would be a dignified sort of element. Indeed, helium is well known for its inertness, a property unique to noble gases, which is essential for its use in industry. However, helium can also be used for comic effect: upon inhaling helium, one's voice becomes squeaky and seemingly higher pitched. This phenomenon is called "helium speech". So, I guess I lied; you won't sound like Batman, but you will sound like a Mickey Mouse impersonator! You may have seen people do this in parties or on TV, or even during classes, for its great entertainment value. Next time you want to go incognito, you could try this out. Now, what exactly is it with helium that produces this property?

Before we delve into the mechanism of helium speech, here's some background information about helium. Helium was first discovered in 1868, when scientists were studying the Sun [1]. When light from the Sun was resolved into a spectrum, a previously undocumented line in the spectrum was observed. Scientists then pursued this further and proved the existence of helium in 1895. Denoted by the chemical symbol "He", helium is the second lightest element known to humans. Subsequently, helium was found to be very inert, which means it rarely undergoes chemical reactions with other substances.

If you've heard someone speak after inhaling helium, you may describe their voice as "squeaky". But in reality, helium doesn't change the pitch of your voice; rather it messes with the timbre (or quality) of your voice [2]. In order to speak, your vocal cords have to vibrate, which causes the air nearby to vibrate at the same frequency, termed the fundamental frequency. This also creates a set of weaker harmonics (or overtones), at frequencies which are the integral multiples of the fundamental frequency with lower amplitudes. As those frequencies pass through the vocal tract, they are all amplified (in terms of amplitude, or loudness) due to the vocal tract resonances, but to different extents. Some frequencies tend to be amplified more, which make up spectral peaks called formants, if shown in a power-frequency graph. It is the profile of the set of sound waves produced at multiple frequencies with different amplitudes (and hence the resultant waveform) that make up the quality of one's voice, known as timbre.

Since sound travels much faster in helium than it does in normal air, when we inhale helium and speak, the resonances and formants shift towards higher frequencies [2]. In other words, the frequencies of the fundamental and harmonics remain unchanged because the vocal cords still vibrate at the same frequency, but the harmonics at higher frequencies are preferentially amplified to a greater extent. On the other hand, if one inhales sulfur hexafluoride and speaks, their voice will sound very deep. This is because sulfur hexafluoride, a heavier gas when compared to atmospheric air, will cause the lower frequencies to resonate more, producing an opposite effect [3].

The production of human speech is a very complex process. But now, we know we can mess with our timbre simply by inhaling gas. Notwithstanding its entertainment value, inhaling helium can also be dangerous. Firstly, helium should not be directly inhaled from gas canisters, as the high pressure can be dangerous [4]. Instead, you can breathe it in safely through a balloon. And while sounding squeaky can be fun, it's also not advisable to inhale too much helium in one go or for too long as your body needs oxygen to survive. So if you do decide to play with helium, be sure to take necessary precautions and stay safe.

您有沒有覺得黑武士和蝙蝠俠低沉而沙啞的聲線聽起來很吸引？如果我們可以暫時改變自己的聲音搞笑一下，您會想試嗎？聽好了，我將會跟您說一個不太秘密的秘密......氦氣的力量！排列在貴氣體的第一位，您可能會認為氦氣是一種像謙謙君子的元素。事實上，氦氣也因其惰性（inertness）而廣為人知，貴氣體這個獨有的特性對工業應用至關重要；而氦氣亦可以用來製造搞笑效果：吸入氦氣後，人的聲音會變得像「經過處理」一樣，音調聽起來似乎被提高 — 這就是「氦氣變聲（helium speech）」現象了。所以我想我騙了您，氦氣並不能令您的聲音像蝙蝠俠般磁性，而您只會像個米奇老鼠配音員而已！您可能在派對、電視節目，甚至課堂上見過別人因其娛樂價值而用氦氣變聲。下次您想隱身作怪時，亦不妨一試。那氦氣變聲究竟是什麼，什麼原因令氦氣有這種特性呢？

在探討氦氣變聲的原理之前，以下是一些關於氦氣的基本知識。氦氣於 1868 年在科學家研究太陽時被首次發現 [1]。當科學家把太陽光折射並分散成光譜後，他們觀察到光譜中出現了一條之前沒有記載的光譜線。經過進一步研究後，科學家在 1895 年證明了氦的存在。被冠以化學符號「He」的氦是人類已知第二輕的元素，科學家亦發現氦的惰性，意味著它很少與其他物質發生化學反應。

如果您聽過有人吸入氦氣後說話，您或許會描述他們的聲音為「雞仔聲」，但實際上氦氣並不會改變您的音調；相反，它會改變您的音色（timbre/quality）[2]。說話時，您的聲帶必須振動使附近的空氣亦以相同的頻率振動，這頻率被稱為基頻（fundamental frequency）。過程還會產生一系列振幅（amplitudes）較弱的諧音（harmonics；又稱泛音（overtones）），它們的頻率是基頻乘以整數後倍數。當這些不同頻率的聲波通過聲帶時，由於聲帶共振（resonances）的緣故，它們在振幅上會被放大，不過是不同程度地放大，這會反映在響度（loudness）上。某些頻率會傾向被放大得更多，如果用功率 – 頻率圖來顯示的話，那些被放大得更多的頻率的棒就會在圖表上構成共振峰（formants）。正是這些在多個頻率下有著不同振幅的聲波（或者說是它們疊加後形成的波形（waveform））定義我們每個人獨特的聲線，稱為音色。

由於聲音在氦氣中的傳播比在正常空氣中快得多，因此當我們吸入氦氣並說話時，產生的共振和共振峰會移向較高的頻率 [2]。換句話說，由於聲帶仍然以相同的頻率振動，所以基頻和諧音的頻率保持不變，而較高頻的諧音就會被選擇性地放得更大。另一方面，如果一個人吸入六氟化硫並說話時，他們的聲音聽起來就會很低沉。這是因為六氟化硫是一種比大氣重的氣體，會導致較低頻的聲音產生更大程度的共振，從而產生相反的效果 [3]。

人類發出不同聲音的過程本身就非常複雜；但是現在，我們知道僅通過吸入氣體就可以使我們的音色作出明顯的改變。儘管這樣的行為極具娛樂價值，但吸入氦氣也可以很危險。首先，我們不應直接從壓縮氣體罐吸入氦氣，因為其極大的壓力可以構成危險 [4]；相反，您可以從氦氣球安全地吸入氦氣。另外，發出尖銳的奇怪聲音雖然很有趣，但我們不建議您一次吸入過多或長時間不停吸入氦氣，畢竟您的身體需要氧才能生存。所以如果您決定使用氦氣變聲，請務必採取必要的安全措施，以策安全。

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[2] Wolfe, J. (n.d.). Speech and helium speech (and very brief notes about the physics of the voice). Retrieved from *https://newt.phys.unsw.edu.au/jw/speechmodel.html*

[3] Harvard University. (n.d.). Helium and Sulfur Hexafluoride. Retrieved from *https://sciencedemonstrations.fas.harvard.edu/presentations/helium-and-sulfur-hexafluoride*

[4] Josefson D. (2000). Imitating Mickey Mouse can be dangerous. *BMJ, 320(7237), 732.*

The Mathematics of Trust – Why We Are Generally Uncooperative Creatures at Our Core

從數學看「信任」：為何人們通常不願和別人合作

By Sonia Choy 蔡蒨珩

People are, in a nutshell, quite depressing. Even though when we know we need to cooperate with each other in order to do something, from an assignment to stopping global warming, people just can't help but act out of their self-interest and prevent the best case scenario from happening. But why is this the case? Game theory, a branch of mathematics, might give you a few answers.

We first look at a one-off game which goes like this; imagine you are a prisoner with a prison guard baiting you to tell on your good friend (who is also in prison). If you both stay silent, then they do not have enough evidence, and you both get your sentence of a year; if only one of you confesses, the other gets punished with three years in prison, while the teller walks free; if both of you confess, you go to prison for two years. The catch: you cannot communicate with your friend throughout this process. In this scenario, what will you do?

This is the infamous prisoner's dilemma, in which if you act to protect your self-interest, you prevent the best case scenario. Any sane person will betray their friend, because if your friend cooperates and you cheat, you walk free; if your friend cheated, it is definitely better for you to cheat, since at least you get out of prison a year earlier. The best scenario here, however, is if both of you stay silent and get out of prison together after a year. But your fear of being betrayed (or rather, your desire to walk free) prevents this from happening.

	They cooperate	They cheat
You cooperate	You get: 1 year	You get: 3 years
	Opponent gets: 1 year	Opponent gets: freedom
You cheat	You get: freedom	You get: 2 years
	Opponent gets: 3 years	Opponent gets: 2 years

These games always have an "equilibrium point", known as the Nash equilibrium (footnote 1) – the point where both players are satisfied with their outcome, enough to stop them from switching to another strategy [1]. In that situation, the game has arrived at its optimal outcome, known as the value of this particular game. So here we will actually have a certain "best" solution to the game – we say that the dominant strategy here is to cheat. However, it does not give the best outcome.

But in life, we constantly make decisions; what happens to this game if it happens more than once? When the game is repeated, the optimal strategy might not be always cheating. For example, you could alternate between cheating and cooperating, at random, or repeat what your opponent does to you in the next round. You have the choice of pure-strategy (sticking to a certain plan on what to do) or mixed-strategy (i.e. using a bit of probability) tactics [2]. For the sake of our sanity, we'll reword the game by asking players to bet points and awarding marks to each player instead – prison terms don't really add up properly, and we are now able to deduct points.

	They cooperate (bet 1)	They cheat (bet 0)
You cooperate (bet 1)	You get: +2	You get: -1
	Opponent gets: +2	Opponent gets: +3
You cheat (bet 0)	You get: +3	You get: 0
	Opponent gets: -1	Opponent gets: 0

If you don't want to dive into the math, we can chuck this scenario into a computer program (footnote 2) and repeat it multiple times to see what happens: what ultimately emerges as the victor in this game is the strategy of repeating your friend's last play. The ancient Chinese wisdom of "do unto others as you would have done to you" seems to hold up here – if you want to win, cooperate since you want your opponent to cooperate as well, and if your opponent follows the strategy of repeating your friend's last play, you two will always cooperate and achieve the best outcome.

This, though, is quite an idealized model. In the real world, people make mistakes, and blunders occur. What happens when you follow a strategy that is bound to make you win in theory (that is, repeating your friend's last play), but your opponent occasionally makes mistakes on which option they choose? Now we go back to our simulator – among a crowd of generally distrusting opponents who have a 5% chance of making a mistake (50% will always cheat, and the rest are a mix of different strategies), we realize that the strategy of cheating only if your opponent cheats twice in a row will win you the game. However, as distrust increases, the winner of the game will be the character that always cheats no matter what – the sad truth. This shows the importance of clear and accurate communication; a little bit of miscommunication will lead to forgiveness; however, more and more mistakes will lead to widespread distrust [3].

You might think life is quite far from being a confession or coin-betting game, but game theory is remarkable in that it straddles the boundaries between math and social sciences – theorists have studied decisions made in history using game theory. A notable example is, unsurprisingly, from World War II, where there is often no room for collaboration between enemies, and so war is the perfect textbook example in looking for an equilibrium. This results in a zero-sum game, when your opponent's gain is your loss, and vice versa. Here, unlike in the prisoner's dilemma above, cooperation is simply not an option.

In the Battle of the Bismarck Sea, a Japanese admiral was forced to choose between two different routes, North and South [4]. The American general, George Kenney, tried to predict which route the Japanese would take, so that they could coordinate a more persistent bomb attack on the Japanese Navy. Basically, the Japanese aimed at minimizing the number of days of being bombed; but the American would like to maximize the duration of the attack. Both routes would take three days but American's action was restricted by various limitations, such as poor visibility on the North route. The table for the scenario looks like this:

Possible days for attack	Japanese: North	Japanese: South
American: North	2 days	2 days
American: South	1 day	3 days

From this table, we know that the Japanese will take the North route to minimize the days of possible attack from the Americans (footnote 3); while no routes seem particularly advantageous, the better route for the American navy, therefore, is also the North route based on the inference above. In fact, this is exactly what happened; the Allied forces sustained an air attack on the Japanese over two days, and ended up resisting the Japanese invasion into New Guinea. Game theory is powerful in this way – it extends far beyond just numbers, into the realms of disciplines such as history and biology.

Then, you might ask, what should we do in situations like this? In truth, life is almost never a zero-sum game, although the zero-sum game mindset is a common belief among people [3]. You don't have to win at the expense of others – there is always a win-win solution. As much as I sound like an old person, look for these win-win situations. There is almost always room to compromise, and you don't need to put people down in order to pull yourself up.

1 The Nash equilibrium is named after John Nash (1928–2015), a mathematician who made important contributions to game theory and geometry; the former won him the Nobel Prize for Economics in 1994. He was also portrayed in the film, A Beautiful Mind.

2 You may want to try out the simulator itself; the prisoner's dilemma simulator that inspired this article is *https://ncase.me/trust/*.

3 If we think from the Japanese's perspective, both routes are equally risky if the American chooses the North route, but the North route will become less dangerous if the American picks the South route. As a result, the North route is more favorable for the Japanese.

人類總是令人失望。無論是做分組作業還是解決全球暖化問題，我們心裡雖然知道要跟別人合作才能做好一件事情，但是最後總是會為了一己私利，令最理想的情況無法出現。可是為什麼人類會這樣做呢？數學中的博弈論也許能解答你的問題。

要介紹博弈論，就讓我們先來看看一個只有一回合的的遊戲。假設你是一名囚犯，獄警為了取得情報，不斷引誘你告發另一個同樣被關在獄中的朋友。如果你和朋友都保持緘默，他們就不會有足夠證據，你和朋友都只會面臨一年刑期；只要你們其中一個招供，對方就得面臨三年刑期，而告密者則會被釋放；如果你們互相告發對方，你們都會被監禁兩年。壞消息是：在獄中，你無法和朋友商量決定。這時候，你會怎樣做呢？

這就是著名的囚犯困境（prisoner' s dilemma）：如果你一味只顧保護自己利益，最好的結局將不會發生。任何渴望得到自由的人都會選擇背棄朋友，因為如果朋友沒有告發你而你告發他，你將會馬上得到自由；如果朋友告發你的話，那你更應該要告發他，因為至少你可以早一年出獄。然而，這遊戲最理想的情況是你們都保持緘默，然後大家在一年後重獲自由。你擔心朋友會出賣你的這份恐懼（又或是你打從心底對自由的渴望）會驅使你背叛你親愛的朋友。

	朋友：合作	朋友：背叛
你：合作	你：1年刑期	你：3年刑期
	朋友：1年刑期	朋友：獲得自由
你：背叛	你：獲得自由	你：2年刑期
	朋友：3年刑期	朋友：2年刑期

博弈論中的遊戲有著一個均衡點（equilibrium point），又名納許均衡（Nash equilibrium；註一）：那發生在兩名玩家都對遊戲結果感到滿意，而不會改變他們策略的時候 [1]。在這情況下，遊戲已經自然而然地達到了最適的（optimal）結果，這結果也稱為這局遊戲的價值（game value）。所以在囚犯困境裡的確存在著一個「最好」的解決方法，也就是說，這遊戲的優勢策略（dominant strategy）是「背叛」；可是，它並不會帶來最好的結果。

但是在現實生活中，我們每天都需要作出不同的決定。如果「遊戲」不止得一局，將會發生什麼情況？可以告訴你的是，當「遊戲」多於一回合時，不停地背叛對手未必是「遊戲」的優勢策略，而我們有著不少新的策略，譬如在不同回合中隨機選擇「合作」和「背叛」，或者重複朋友上一回合的選擇；你可以選擇純策略（根據一個預先制定的計劃行事）或混合策略（涉及利用機率去選擇策略）[2]。為了方便解說，我們可以把上面的遊戲重整一下，將刑期變成一場賭博分數的遊戲 — 因為胡亂調整刑期有點奇怪，而且我們現在能夠扣減分數。

	朋友：合作（付出：1）	朋友：背叛（付出：0）
你：合作（付出：1）	你：+2	你：-1
	朋友：+2	朋友：+3
你：背叛（付出：0）	你：+3	你：0
	朋友：-1	朋友：0

如果你不想自己著手計算的話，我們可以將這個情境輸入電腦程式（註二），然後讓它運行數回合，看看會發生什麼事情。我們會發現，這次遊戲的最終贏家採用的致勝策略是重複對方上一回合的選擇。古語有云：「己所不欲，勿施於人」 — 它似乎能簡潔地總結這場遊戲。如果你想贏的話，最好第一回合就選擇「合作」，因為你也希望朋友會

跟你「合作」；如果朋友採用的策略也是重複對方上回合選擇的話，你們倆就能一直「合作」，實現遊戲中最理想的結局。

然而，這情境未免過份理想化；畢竟在現實世界中，人總會犯錯。假設你繼續使用能令你致勝的策略（即是重複對方上回合的選擇），但對方不時會因為不小心搞錯而在某些回合作出錯誤的選擇，那你仍能勝出遊戲嗎？現在讓我們回到模擬器，如果遊戲中普遍都是不太靠譜的對手，他們有百分之五的機會會在每回合犯錯，而一半人的策略是只會背叛對手，其他人則採取其他不同策略的話，那麼你的致勝策略將會是：在被對手連續兩次背叛後選擇「只會背叛」。可是隨著對手犯錯的機率提升，殘酷的現實是，最後的贏家將會是永遠背叛對手的玩家。如果你細心想想，這個故事暗示了現實世界上溝通的重要性，溝通最好是清晰準確的；少許誤會也許會得到原諒，但重重的誤解卻會引起人與人之間廣泛的猜疑 [3]。

看到這裡，你可能認為現實生活根本和這些遊戲沒有關係 — 我們不會每天被拷問，也不需要每天押下賭注 — 但博弈論厲害的地方是它能夠跨越數學和社會科學，不少理論學者嘗試過利用博弈論分析歷史上的重大決定。值得關注的例子當然有第二次世界大戰，因為在戰爭中，往往不是你死就是我亡，交戰雙方沒有折衷的餘地，因此戰爭是教科書中典型分析均衡點的例子。我們通常稱這種情形為零和遊戲（zero-sum game），當中一方的得益將無可避免地造成對方的損失，這與文初提及的囚犯困境有所不同，因為現在「合作」並不是一個選項。

在二戰中的俾斯麥海海戰，一位日本上將被迫選擇北邊或南邊其中一條航道 [4]。美國上將 George Kenney 嘗試預測日軍的路線，以便盟軍能對日本海軍進行更持續的轟炸。簡單而言，日軍希望減少被轟炸的日數，而美軍則希望進行最持久的轟炸。兩條航道的航程均為三天，但美軍的攻擊計劃受不同因素限制，例如北航道的低能見度等。下表總結了雙方走不同路線下美軍可以進行襲擊的日數：

可以進行襲擊的日數	日軍：北航道	日軍：南航道
美軍：北航道	2天	2天
美軍：南航道	1天	3天

根據以上列表，我們知道日軍會採取北航道，以儘量減少受襲的日數（註三）；另一方面，對美軍而言兩條航道都沒有一條有特別優勢，因此如果純粹考慮上述推論，在日軍可能會走北航道的情況下，同樣選擇北航道是較明智的選擇。現實上，兩軍也的確走了北航道，盟軍對日軍進行了兩天的持續空襲，成功阻止了日軍佔領新畿內亞。這就是博弈論的精彩之處：它不只是數字上的分析，而是能應用至歷史或生物學的層面。

你可能會問，在這樣的情況下，我們應該怎樣是好？事實上，我們在現實生活中面對的往往都不是零和遊戲，雖然不少人的認知仍然停留在零和遊戲的層面上 [3]，但是你的快樂的確不需要建構在別人的痛苦上，因為事情總有著雙贏的辦法。這可能聽起來像陳腔濫調：我們應該去尋找能達致雙贏的辦法，事情往往有協商的餘地，你也不用為了抬高自己而貶低別人。

1 納許均衡以數學家John Nash（1928–2015）命名。John Nash是一位對博弈論和幾何學影響深遠的數學家，前者使他贏得1994年諾貝爾經濟學獎；電影《有你終生美麗》中的主角亦是以他作為藍本。

2 你可能會想自己親手操作一下模擬器，另外亦正是它啟發了本文的創作：*https://ncase.me/trust/*

3 從日軍的角度考慮，如果美軍選擇北航道的話，南北兩條航道都一樣危險；可是如果美軍走南航道的話，日軍選擇北航道會比較安全。因此整體而言，走北航道對於日軍而言是上策。

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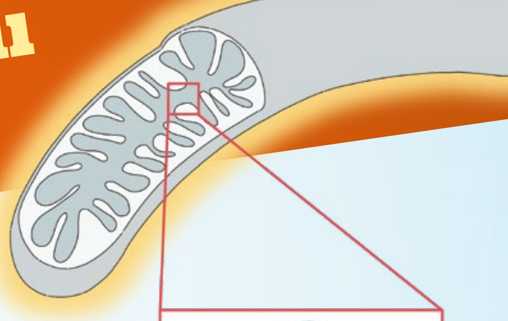
Mitochondria: So Much More Than the Powerhouses of the Cell
線粒體：遠不只是細胞的發電站

By Kit Kan 簡迎曦



Powerhouse and Suicide Bomb

For those of you who have some basic understanding of biology, you may already know the mitochondria as the powerhouses of the cell. These double-membrane structures serve as sites for cellular respiration, in which sugar and oxygen are used to produce adenosine triphosphate (ATP), the energy currency that our cells use. Sperms have plenty of mitochondria for their long distance swim in search of an egg. Muscle cells need mitochondria to contract and bring about movement. Neurons use the energy generated by mitochondria to send electrical and chemical signals. However, powering the cell is not all that the mitochondria do.

Our cells engage in a process called apoptosis, which is essentially suicide for cells. During embryonic development, some cells have to die to carve out the body structures that we now have. For instance, our hands and feet would be webbed like frog's if the cells between our fingers and toes did not undergo apoptosis. As apoptosis is also a way for our body to eliminate cells that are potentially cancerous, defective apoptosis can result in cancer. One pathway of apoptosis involves mitochondria. Mitochondria contain a protein called cytochrome c, which when released to the cytoplasm, binds to other proteins to form apoptosomes and facilitate apoptosis. In short, mitochondria are not just powerhouses, but also suicide bombs.

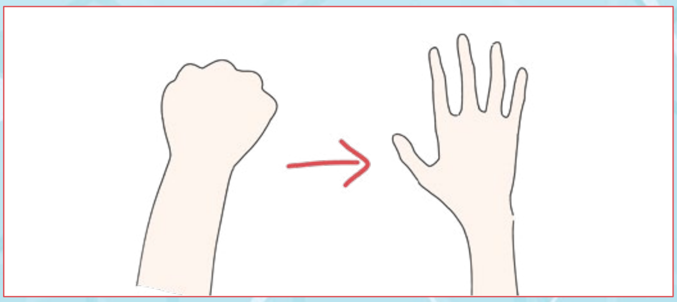
Origin and Inheritance

Mitochondria are not only interesting in the functions they serve, but also their origin. The mitochondria came from a process named endosymbiosis. More than 1.45 billion years ago [1], a unicellular organism is believed to have engulfed another unicellular organism, and they formed a symbiotic relationship. The endosymbiont (the one being engulfed) became the mitochondria. There are two different theories as to whether the host was a prokaryote or a more full-fledged eukaryote, but the hypothesis that the host was a prokaryote is more widely accepted because the ubiquity of mitochondria in eukaryotes can then be explained, providing that eukaryotes were evolved from the mitochondrial endosymbiosis in a prokaryote [1]. Mitochondria are similar to bacteria in many ways. One major feature and evidence of endosymbiosis is that mitochondria contain their own DNA that is organized in circular chromosomes.

Unlike nuclear DNA, the inheritance of mitochondrial DNA is strictly maternal. During fertilization, mitochondria from the sperm are actively removed. Therefore, no one inherits mitochondrial DNA from his or her father. Mitochondrial DNA encodes for genes that are essential to the oxidative phosphorylation process in the mitochondria. Since the mitochondria mainly generate energy by oxidative phosphorylation, the mutation in mitochondrial DNA can lead to disorders in tissues with high energy demands, such as muscles and brain [2].

Mitochondrial DNA is not just clinically important, but also provides a convenient way for ancestry tracing. Since mitochondrial DNA is only inherited from the mother, scientists can trace our maternal ancestry using this feature. In a study published in 1987, taking 147 samples from different populations, scientists mapped the samples onto an evolutionary tree based on the similarity of their mitochondrial DNA sequence. They found proof that all current mitochondrial DNA originated from one woman in Africa, supporting the popular "out-of-Africa" model [3]. The matrilineal most recent common ancestor of all living humans is often called the Mitochondrial Eve in human genetics. However, it is not to say that Mitochondrial Eve was the only woman alive at the time; our nuclear DNA suggests that we do have other female ancestors [4]. In other words, we all share a common maternal great-great...grandmother, but we also have female ancestors, just not in the direct female line.

After you use the energy generated by your mitochondria to read this article and marvel at the beauty of these complex structures, maybe you can go thank your mother, grandmother and great grandmother for the functional mitochondria that they passed on to you!



發電站和自殺式炸彈

如果你對生物學有基本了解，你可能已經知道線粒體是細胞的發電站（註一）。這些擁有雙層薄膜的結構是細胞進行呼吸作用的地方，在過程當中糖和氧被用於生產腺苷三磷酸（ATP），亦即是我們細胞使用的「能量貨幣」。精子含有大量線粒體產生能量來支持長距離游泳以尋找卵子，肌肉細胞需要線粒體生產的 ATP 來收縮並引起運動，神經元利用線粒體產生的能量來發送電和化學信號，但其實線粒體的功能並不只是為細胞提供能量。

我們的細胞有時會進行稱為細胞凋亡（apoptosis）的過程，簡單來說就是細胞的自殺。在胚胎發育過程中，一些細胞必須死亡才能形成我們現在擁有的身體結構，例如如果我們的手指和腳趾之間的細胞不發生凋亡，那麼我們的手和腳就會像青蛙的掌一樣有蹼。由於凋亡也是我們身體消除潛在癌細胞的一種方法，故不正常的凋亡可導致癌症。細胞凋亡的其中一種途徑涉及線粒體。線粒體含有一種叫做細胞色素 c（cytochrome c）的蛋白質，當被釋放到細胞質時，它將與其他蛋白質結合形成凋亡小體（apoptosome）並促進細胞凋亡。簡而言之，線粒體不僅是發電廠，而且亦是自殺式炸彈。

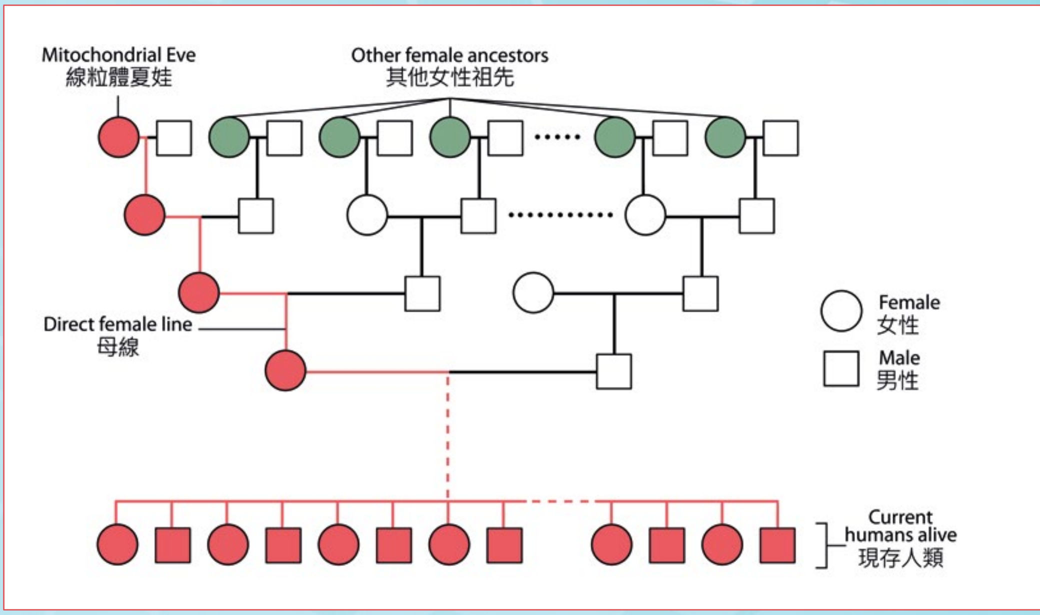
起源與遺傳

線粒體的有趣之處不僅在於其功能，它們的來歷更是稀奇。線粒體來自稱為內共生的過程（endosymbiosis）。科學家相信在超過 14.5 億年前 [1]，一種單細胞生物吞噬了另一種單細胞生物，然後它們形成了共生關係，當中內共生體（被吞噬的單細胞生物）變成了線粒體。關於宿主是原核生物還是發展得較成熟的真核生物，學術界存在兩種不同的理論，但是宿主是原核生物的假說被更廣泛地接受，因為在真核生物是從原核生物的線粒體內共生進化而來的前提下，這種說法可以解釋為何線粒體普遍存在於真核生物中 [1]。線粒體在許多方面與細菌相似。內共生的其中一個主要特徵和證據是線粒體含有自己的環狀 DNA 染色體。

與細胞核內的 DNA 不同，線粒體 DNA 是母系遺傳的。在受精過程中，來自精子的線粒體會被移除，因此沒有人能遺傳父親的線粒體 DNA。線粒體 DNA 包含了線粒體中氧化磷酸化過程必不可少的基因。由於線粒體主要通過氧化磷酸化產生能量，因此線粒體 DNA 的突變可以導致一些與肌肉和大腦等能量需求較高的組織相關的病症 [2]。

線粒體 DNA 不僅在臨床上很重要，而且還提供了一種方便的方法追踪祖先。由於線粒體 DNA 僅是從母親那裡繼承，因此科學家可以使用此特點追踪我們的母系血統。在 1987 年發表的一項研究中，科學家從不同族群採集了 147 個樣本，並根據其線粒體 DNA 序列的相似度畫成了一棵演化樹。他們找到了證據證明目前所有的線粒體 DNA 均源自非洲的一名婦女，這發現正正支持受普遍認同的非洲起源說 [3]。在人類遺傳學中，所有活著的人類的母系最近的共同祖先通常被稱為「線粒體夏娃」。然而，這並不是說線粒體夏娃是當時唯一活著的女性；我們的細胞核內的 DNA 表明我們確實還有其他女性祖先 [4]。換句話說，我們都有一個共同的母系曾......曾祖母，但同時我們也有其他女性祖先，只是不在母線（direct female line）而已。

在你使用線粒體產生的能量閱讀本文，並驚嘆於這些複雜的結構之後，也許你可以去感謝你的母親，祖母和曾祖母，因為她們把健康的線粒體遺傳給你！



1 編按：在英文中，線粒體通常被比喻為「the powerhouse of the cell（細胞的發電站）」，外國網民甚至創作了不同迷因來揶揄這個一成不變的比喻，有人覺得它代表了學校裡會教授但在現實生活上不太實用的知識。但無論如何，教育局似乎沒有把這個比喻帶進香港中學的中文課程裡。

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氣凝膠 —
由空氣構成的物質及其特性

AEROGEL –
An Air-Based Material and Its Exciting Properties

By Randy Stefan Tanuwijaya

Overview

In 1931, an American chemical engineer, Dr. Samuel Stephens Kistler bet his colleague, Dr. Charles Learned, that they could replace the liquid inside a jelly with gas without shrinking it. Dubbing this concept "aerogel", they managed to make the first aerogel with silica [1]. Afterwards, other materials, such as alumina, cellulose, egg albumin, rubber and agar, were also used to produce aerogels [1, 2]. Do you know how aerogel is made? Let's discover more about the science of aerogel and its wide range of applications thanks to its density and thermal insulating properties.

How to Make Aerogel

In order to understand how aerogel is produced, we first need to understand the structure of jelly – yes, the chewy, sweet jelly that everyone loves. Imagine cooking jelly in your kitchen, there are three main ingredients you need: jelly powder, water and sugar. In this case, sugar can be taken out of the equation because it provides only the sweet taste. The resulting jelly, which is 95% water with a small amount of porous solid support, is defined as one of the hydrogel structures. To make aerogel, you want to replace the water in hydrogel with air.

Swapping water for air in hydrogel sounds simple, but it's actually very complex. If you simply vaporize the liquid by heating the jelly, it shrinks as its solid network collapses due to capillary action caused by the attractive forces between the liquid molecules. Imagine when solvent molecules constantly vaporize from the gel, the intermolecular forces between the remaining liquid molecules keep pulling the molecules together to fill the vacancy produced in order to maintain the density of the gel. This also induces an inward stress on the delicate network of the gel, causing the network to collapse and shrink.

In Dr. Kistler's paper, he proposed a method called "supercritical drying", which consists of two steps [2]. First, a water-based hydrogel can be submerged in alcohol to substitute the water in the jelly with alcohol via diffusion. Then, the hydrogel is subjected to a high temperature and pressure beyond its critical point in a machine called autoclave. The alcohol inside the now alcohol-based hydrogel is induced to reach its "supercritical fluid" phase, in which the adhesive forces between the fast moving molecules become insignificant due to the overwhelming kinetic energy gained. If we hold the temperature above the critical temperature but depressurize the autoclave at this stage, all the fluid inside the hydrogel becomes gas (Figure 1). By converting the liquid alcohol into gas via this intermediate supercritical fluid phase, the solid jelly structure is preserved due to the absence of the capillary action brought by intermolecular attractions. Voilà – you have produced aerogel from hydrogel.

What is a supercritical fluid?

You are probably familiar with the concepts of boiling point and melting point (at a given pressure), and the three states of matter. However, a substance can also exist as "supercritical fluid" when subjected to high temperature and pressure above its "critical point", beyond which the molecules are completely vaporized but compressed to the extent that is as dense as those in the liquid. A supercritical fluid therefore shows the properties of both states, and the clear distinction, including the visual boundary, between the liquid and gas phases disappears. For methanol (an alcohol), the critical pressure and temperature are 8.1035 x 10^6 Pa (around 80 atm, i.e. 80 times atmospheric pressure) and 512.6 K (239.45°C) respectively [6].

The Exciting Properties and Applications

Hooray – we have discovered how to produce aerogel, now what? Let's look at some of the most interesting properties, namely the density and thermal insulation. In fact, aerogel can even be made with up to around 99.9% air [3], which makes the aerogel very light, while allowing it to maintain a sturdy structure. Naturally, the lightest known solid is also an aerogel, called graphene aerogel, or aerographene, which is 7.5 times lighter than air in vacuum [3]. Another interesting property is its excellent thermal insulation ability. Air itself is a poor thermal conductor, but it can still transfer heat by convection. However, in aerogel, the narrow space in the nanostructure hinders air molecules from moving freely and effectively, and hence prevents convection of the air trapped inside [4], which enables aerogel to be an even better thermal insulator than air.

One of the most popular applications of aerogel is the use by NASA in some of their space missions [5]. In the Stardust mission, aerogel was used to collect samples of interstellar dust because the rapidly moving dust particles can decelerate gradually and embed itself in the sponge-like porous structure of aerogel. In addition, in the Mars Rover mission, aerogel is used as a layer of insulation to protect electronic circuits inside the Mars rover against the huge diurnal temperature variation on Mars.

From the story of aerogel, we can see that a groundbreaking invention may just stem from a simple and fun idea. Who knows – perhaps your idea can make a breakthrough in science and technology one day!

簡介

在 1931 年，美國化學工程師 Samuel Stephens Kistler 博士與同事 Charles Learned 博士打賭，說他們可以把啫喱內的液體換成氣體而不會使它塌陷。他們把這個概念稱為「氣凝膠」，並最終使用二氧化矽造出史上第一塊氣凝膠 [1]。此後，其他材料，譬如氧化鋁、纖維素、卵白蛋白、橡膠和瓊脂都被用於製作氣凝膠 [1, 2]。你知道氣凝膠是怎樣製造的嗎？讓我們探索一下氣凝膠的科學和它一系列的應用，這全都要歸功於它的密度和隔熱特性。

如何製造氣凝膠

要明白如何製造氣凝膠，我們首先要了解果凍的結構 — 對，是香甜有彈性，大家都喜愛的果凍啊！想像你正在廚房準備果凍，你需要用上三種材料：果凍粉、水和糖。我們可以暫且忽略糖，因為它只為果凍提供甜味。製作出來的果凍含有 95% 水份和少量的多孔固體結構，這樣的結構被定義為水凝膠（hydrogel）。要製作氣凝膠，我們會希望把水凝膠當中的水轉換成氣體。

要把水凝膠中的水換走這個步驟聽起來很簡單，但其實非常複雜。如果你僅是把凝膠加熱令當中的液體汽化，液體分子之間的吸引力會令凝膠的固體網狀結構因毛細管作用塌陷，令整塊凝膠收縮。試想像溶劑分子不斷從凝膠汽化，剩下的液體分子藉著分子間的吸引力不停把餘下的分子拉在一起，以彌補分子流失所產生的空位以維持凝膠的密度。這會在纖巧的凝膠骨架產生一股向內收縮的壓力，令網狀結構塌陷並收縮。

在 Kistler 博士的論文中，他提出了一種名為「超臨界乾燥（supercritical drying）」的方法，過程涉及兩個步驟 [2]。首先，把水凝膠浸進酒精裡，凝膠中的水可以通過擴散作用被換成酒精。然後，把水凝膠放進一部名為高壓釜（autoclave）的機器裡，並把溫度和壓力提高至其臨界點（critical point）以上，令水凝膠中的酒精處於「超臨界流體（supercritical fluid）」的狀態，當中獲得極大動能的分子會高速移動，分子間的吸引力因而變得微不足道。如果我們在這時把溫度維持在臨界溫度以上，但把高壓釜減壓，水凝膠內的所有流體都會變成氣體（圖一）。透過超臨界流體這個相把液體變成氣體，固體的凝膠結構能得以保存，因為我們避免了分子間吸引力所帶來的毛細管作用。瞧，你已經成功從水凝膠製造出氣凝膠了。

有趣的特性和應用

好耶！我們知道怎樣製造氣凝膠了，然後呢？讓我們認識一下其有趣的特性，分別是密度和隔熱能力。事實上，氣凝膠最多可以含有高達 99.9% 的空氣 [3]，這使氣凝膠擁

有穩妥的結構之餘亦非常輕巧。理所當然地，世界上已知最輕的固體亦是一種氣凝膠，名為石墨烯氣凝膠（graphene aerogel）或空氣石墨（aerographene），它在真空下比空氣輕 7.5 倍 [3]。另一個有趣的特性是其絕佳的隔熱能力。空氣本身是一個差勁的熱導體，但它仍然可以透過對流傳熱。然而，氣凝膠中狹窄的奈米結構能阻礙空氣分子自由和有效地流動，令裡面的空氣不能透過對流傳熱 [4]，使氣凝膠成為甚至比空氣更佳的熱絕緣體。

氣凝膠其中一個最受大眾歡迎的應用，大概是美國太空總署在多次太空任務上的應用了 [5]。在星塵任務中，氣凝膠被用於收集星際塵埃，因為高速移動的塵埃分子能在氣凝膠像海棉般的多孔結構中逐漸減速並嵌入其中。此外，在火星探索任務中，氣凝膠被用作保護火星探測器中的電子電路，確保其能在火星極大的日夜溫差下正常運作。

從氣凝膠的故事，我們可以了解到一個突破性的發明最初可能只來自一個簡單而有趣的想法。誰知道你的想法有一天可能亦會帶來科技上的突破呢？

甚麼是超臨界流體？

你應該對（在某一壓力下的）沸點和熔點，以及物質三態的概念非常熟識。可是，當物質處於其「臨界點」以上的高溫和高壓下，它也可以以「超臨界流體」的狀態存在，當中的分子完全氣化，但被壓縮至像液體分子一樣高的密度。因此，超臨界流體能同時展示以上兩個物態的特性，液相和氣相之間的區別變得模糊，包括視覺上的分界。酒精甲醇的臨界壓力和溫度分別為8.1035 x 10^6 Pa（大約80 atm，即是大氣壓力的80倍）和512.6 K（239.45℃）[6]。

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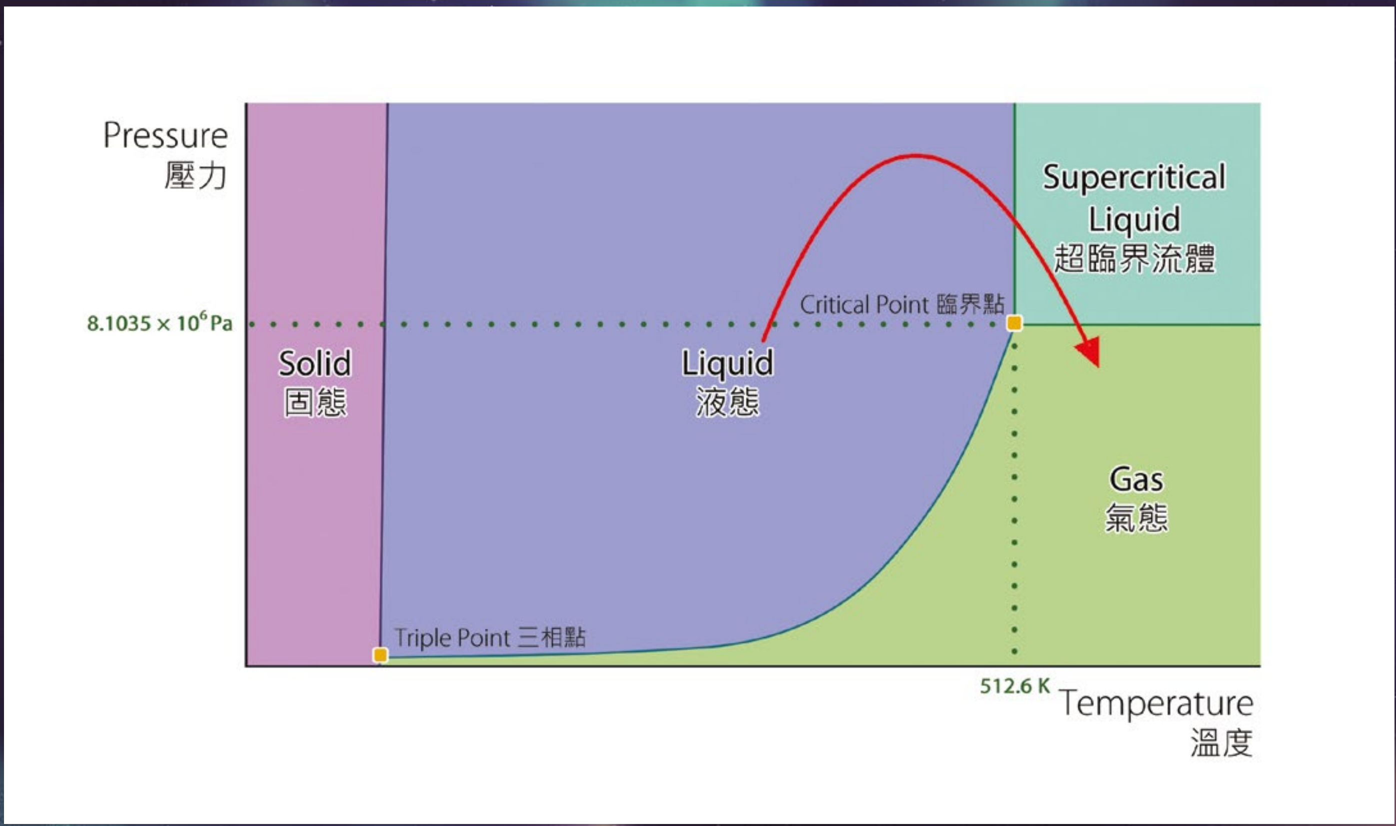


Figure 1. *Phase diagram of methanol and the phase change in supercritical drying (see the red arrow).*
圖一 *甲醇的相圖和超臨界乾燥時的物態改變（見紅色箭頭）*

** The graph is not necessary drawn to scale.*
** 圖未必依比例畫。*

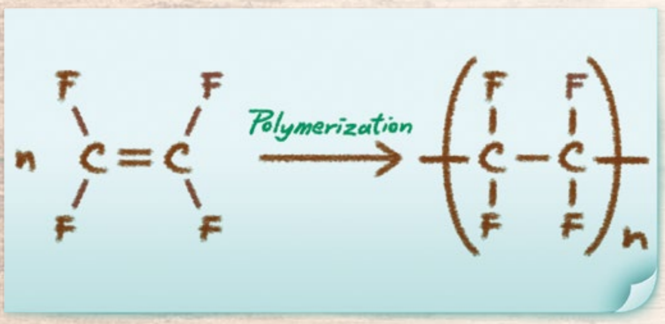
The Serendipitous Invention of Teflon™: An Appreciation of Unexpected Results

欣賞不一樣的實驗結果：鐵氟龍™的意外發明

By Henry Lau 劉以軒

Life rarely goes according to plan. The same can be said for science. As scientists have painfully learned (and will continue to learn), more often than not, it takes a few tries to get your expected experimental results. But sometimes, unexpected results turn out to be the best results. Such is the case of one Dr. Roy J. Plunkett, the inventor of Teflon™, which you may know to be a key component of non-stick frying pans. This is the story of how an experimental blunder turned into a scientific wonder. Stick around to find out more!

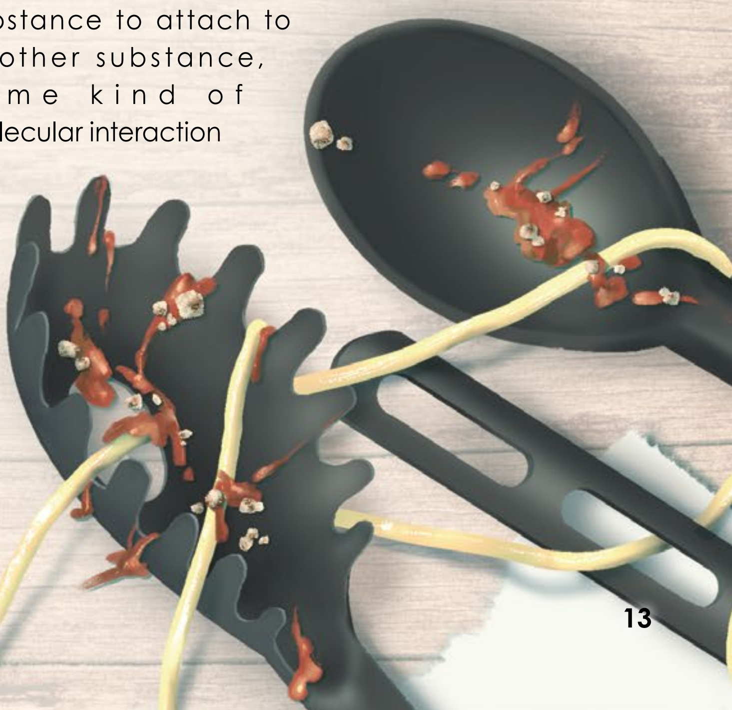
You may have heard of Teflon™ before. Scientifically called polytetrafluoroethylene (PTFE), it is a polymer made up of identical repeating "monomer" units joined together. The monomer in question is called tetrafluoroethylene. While that sounds like a mouthful, it's actually a simple structure: "-ethylene" (IUPAC name: "-ethene") implies that the monomer has a backbone of two carbons, joined together by a carbon-carbon double bond. The breaking of one such bond allows monomeric tetrafluoroethylene to join with one another, forming polymers. "Tetrafluoro-" refers to the four fluorine atoms attached to the two carbon atoms, substituting the hydrogen atoms in regular ethylene.



Now that we've covered the chemical nature of Teflon™, we can delve into the accidental invention of Teflon™ [1]. In 1938, Roy J. Plunkett, a recent PhD graduate, was working on creating new forms of non-toxic refrigerants. In a study, a considerable amount of tetrafluoroethylene gas was needed to synthesize novel compounds. He produced the gas and stored them in small containers. One day, while retrieving the gas, one container released less gas than it previously contained while the same container weighed as much as it did before. Puzzled by this mystery, Plunkett sawed open the container and found a white powdery substance, which explained the missing gas. After conducting some chemical tests, Plunkett confirmed that the substance is in fact polytetrafluoroethylene created from the polymerization of the "missing gas".

Upon further examination, Plunkett discovered the material to be highly resistant to heat and corrosive chemicals. The most unique property was that polytetrafluoroethylene was very slippery. Marketed as Teflon™ since 1945, a French engineer, Marc Grégoire, attempted to coat his aluminum pan with the material at his wife's suggestion and created the first non-stick pan in 1954 [2]. To this day, non-stick pans are still made by coating the metal cooking surfaces with Teflon™.

The slipperiness of Teflon™ is made possible thanks to the high electronegativity of fluorine along the polymer chain [3]. For a substance to attach to another substance, some kind of molecular interaction



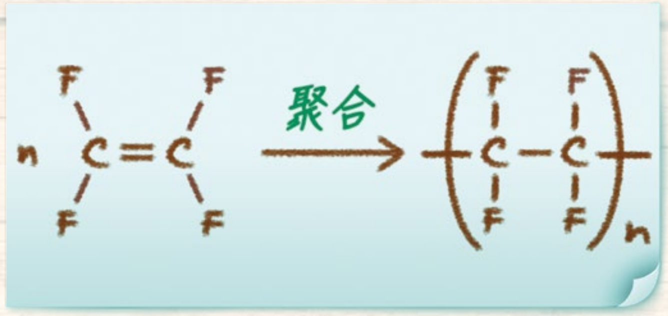
is needed. In the case of Teflon™, the predominant attraction is instantaneous dipole-induced dipole interactions, a type of van der Waal's force. This requires an instantaneous uneven distribution of electrons in a molecule to produce a temporary net charge (or more accurately a dipole). However, the fluorine atoms, being able to strongly draw electrons towards itself as it is the most electronegative element, create a permanent negative charge on the polymer and hence prevent the formation of the said molecular interaction between Teflon™ and other substances. This essentially prevents all kinds of materials from adhering to it, making it one of the most slippery substances known to humans.

Now, wait a second. How could Teflon™ be adhered to a pan then, for instance? The best answer [4]: you can only force its pure form to attach temporarily onto another surface, or modify its structure slightly such that the modified version can adhere to substances. The method of forced temporary attachment is known as "sintering", in which the Teflon™ is heated to high temperatures and pressed onto the surface of a material. Upon cooling down, the Teflon™ will adhere to said surface, but it may peel off eventually. The alternative method is to modify the chemical structure of Teflon™. As fluorine atoms are responsible for Teflon™'s "non-stickiness", removing a few of them will allow it to adhere to substances better. This can be achieved by colliding the Teflon™ polymer with ions at high speeds or by treating the Teflon™ with reducing agents, such that the fluorine atoms are broken away from the polymer. And that's how one of the most slippery substances can be utilized to coat various materials, including your trusty non-stick frying pan.

From blunder to wonder, the story of Teflon™ will be remembered through the ages. Mind you, this article is not encouraging students to commit as many blunders on their projects as possible. Rather, this story comes to show that unexpected results can still be useful. It also highlights the importance of observation even in the most mundane steps in science. As Dr. Plunkett himself said, it was his training that enabled him to recognize that something unique had occurred [5]. Had he neglected to take it a step further, who knows when polytetrafluoroethylene would have been discovered.

世事難料，人生也往往並不會按照計劃進行。科學亦是如此。儘管科學家從痛苦的經歷中才領悟到實驗有些時候需要重覆多次才能獲得預期的結果（當然還有更多失敗的經歷等著他們！），但有時候，始料不及的結果才是最理想的結果。易潔鑊物料鐵氟龍™的發明者 Roy J. Plunkett 博士正是親歷這段奇妙過程，把一個實驗失誤變成了科學奇蹟。「黏著」我們一起聽聽這個關於易潔鑊的故事吧！

您可能曾經聽過鐵氟龍™，它的科學名稱為聚四氟乙烯（polytetrafluoroethylene/PTFE），是由相同的「單體（monomer）」重複連接而成的聚合物（polymer）。當中的單體被稱為四氟乙烯（tetrafluoroethylene）。雖然讀起來好像很拗口，但實際上它只是一個簡單的結構：「乙烯」表示該單體的碳骨架具有兩個碳原子，通過碳碳雙鍵（carbon-carbon double bond）連接在一起。其中一個鍵的斷裂可讓四氟乙烯單體彼此結合，形成聚合物。「四氟」是指與兩個碳原子連接的四個氟原子，它們取代了一般乙烯分子中的氫原子。



既然我們已經了解到鐵氟龍™ 的結構，我們可以探究一下它的意外發明了 [1]。在 1938 年，剛取得博士學位的 Roy J. Plunkett 正研發新款的無毒製冷劑。在一項研究中，由於他需要用上大量的四氟乙烯氣體來合成一款新的化合物，因此他生產了大量的四氟乙烯，並把氣體儲存在多個小容器中。有一天在提取氣體時，他發現其中一個容器釋放的氣體比之前存入的量少，可是容器的總重量與之前比並沒有任何改變。面對這個令人困惑的謎團，Plunkett 選擇鋸開容器，然後發現當中有一些白色粉末，這解釋了消失氣體的蹤影。經過一些化學測試後，Plunkett 確認該物質是由「消失氣體」經聚合反應生成的聚四氟乙烯。

在進一步測試後，Plunkett 發現這種物質具有很高的耐熱和耐腐蝕性，最獨特之處在於聚四氟乙烯是一種非常順滑的物料。自 1945 年開始以鐵氟龍™ 的品牌名稱銷售以後，法國工程師 Marc Grégoire 在妻子的建議下，嘗試把這種材料塗在鋁造的平底鍋上，在 1954 年製造了第一個易潔鑊 [2]。時至今日，易潔鑊仍然是透過在金屬製的烹飪用具表面上塗上鐵氟龍™ 而製成的。

鐵氟龍™ 順滑的特性來自聚合物鏈上電負性很高的氟 [3]。使一種物質能附著到另一種物質之上，少不了要靠分子間的某種相互作用或吸引力來達成。對於鐵氟龍™ 而言，主要作用的引力是一種名為瞬時偶極—誘發偶極力（instantaneous dipole-induced dipole interactions）的范德華力（van der Waal' s force）。這種引力需要分子內電子霎時間不均勻的分佈以產生短暫的淨電荷，更準確地說是產生偶極（dipole）。然而，作為電負性最大的元素，氟原子有把電子拉向自己的強烈傾向，使聚合物上產生永久的負電荷，從而防止鐵氟龍™ 與其他物質之間產生以上所說的吸引力。這基本上可以防止各種物料黏附在其表面，使它成為已知的最滑的物質之一。

且慢 — 那麽鐵氟龍™ 是怎樣黏附到平底鍋等的廚具上呢？答案如下 [4]：您只可以強行把鐵氟龍™ 暫時固定在一個表面上，或是輕微改變其化學結構使它可以附著在物件上。強行把鐵氟龍™ 臨時固定的方法稱為「燒結（sintering）」，過程是將鐵氟龍™ 加熱至高溫並壓在其他物質的表面。冷卻後，鐵氟龍™ 會黏附在物質表面，但最終可能會剝落。另一種方法是改變鐵氟龍™ 的化學結構。由於氟原子是鐵氟龍™ 不具黏性的原因，因此除去當中的一些氟原子可使其較有效地黏附於物質表面，具體方法包括利用離子高速碰撞鐵氟龍™ 聚合物，或利用還原劑處理鐵氟龍™，這兩種方法都能使氟原子從聚合物中脫落。這就是如何把最滑物料之一的鐵氟龍™ 塗覆在各種表面上的奧秘了，包括您最信賴的易潔鑊。

從慨嘆到驚歎，鐵氟龍™ 的故事大概會被一直流傳下去。儘管如此，本文不是鼓勵學生在自己的實驗中儘可能多犯錯誤；反而，這個故事說明了意料之外的結果可能仍有其價值。它也強調了觀察在科學上的重要性，即使在最平凡的步驟中也是如此。正如 Plunkett 博士本人所說，正是他多年以來的歷練和得來的知識才使他意識到所發生事情的獨特性 [5]。如果他僅把問題忽略而止步，誰知道何時才會有人會發現聚四氟乙烯呢？

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A New Body Part to Keep One SALIVATING

令人「垂涎」的新發現

By Kit Kan 簡迎曦

Anatomy is one of the oldest fields in biology. Ever since ancient Egypt, people have been dissecting the human body to understand how it works. Along the millennia, the understanding of our own bodies has gone from the primitive sketches by ancient Egyptians and Greeks, to the detailed drawings by Leonardo da Vinci, and to the famous reference book *Gray's Anatomy*. However, in the past two centuries, nothing much has changed in the field of anatomy. Just when everyone, including medical professionals, is convinced that we have fully mapped out all the body structures, a team of Dutch scientists discovered a new pair of salivary glands.

Salivary glands, as the name implies, secrete saliva, which contains enzymes to break down starch and acts as a lubricant to help us swallow food. Before this groundbreaking discovery, it was known that humans have three pairs of major salivary glands, one in front of the ears (parotid glands), one under the jaw (submandibular glands), and one under the tongue (sublingual glands); and around 1000 minor glands in the head and neck region. This new pair of salivary glands are located right in the middle of the head, near the nose [1, 2].

As unlikely as it sounds, the discovery of these new structures in the head began with some prostate cancer scans. To screen for metastasis in prostate cancer patients, the Dutch doctors performed a PSMA PET/CT scan from the upper leg to the skull [2]. PSMA stands for prostate-specific membrane antigen, a protein presents on the surface of almost all prostate cancer cells [3]. A radioactive dye was used to label PSMA during the scan to detect cancer cells, but the dye also unexpectedly lit up a structure in the middle of the head, an observation that perplexed the doctors [1].

Although they were initially convinced that it was just an aberration, they decided to look into it. Reading through some more detailed anatomy textbooks, they saw that the region that showed abnormal signals is made up of salivary gland tissues but was never labeled as such [2]. They also looked at scans from other prostate cancer patients. To their surprise, all the other 100 scans they examined displayed an area that lit up near the nose, with an average length of 4 cm [1].

More interestingly, the scientists confirmed that the same structure can also be observed in females, from the scan of a female patient [2]. While females do not have a prostate, there is a small tissue near the urethra, named the Skene's gland, which is the female version of the prostate and can also develop cancer. Therefore, the scientists could obtain such a scan for their investigation.

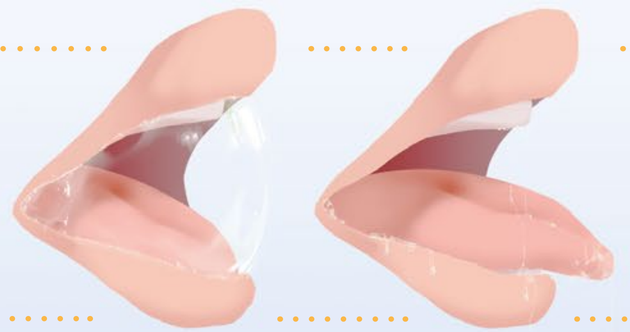
By now, you are probably wondering why people could miss a 4-cm tissue right in the middle of the head despite millennia of dissection. While the gland is impossible to miss if exposed, it is not very accessible. Endoscopy is needed to reach that deep into the head. Also, the gland does not show up in MRI or CT scan, but only PET scan [2].

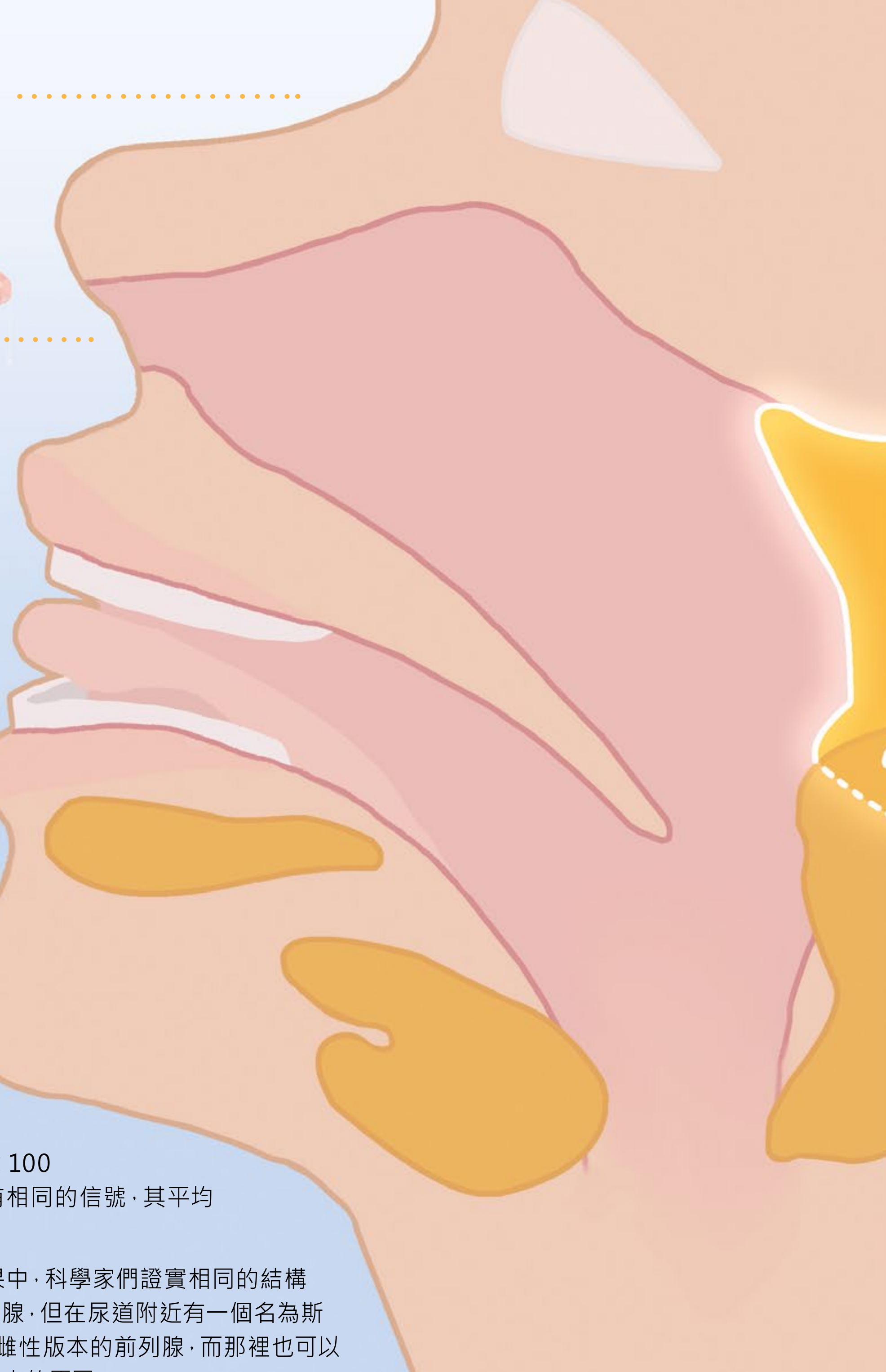
The discovery of the new pair of salivary glands does not just change the textbook description of the glands, but may also change the way doctors treat head and neck cancer. The salivary glands are important for swallowing and speaking, so doctors always try to avoid damaging them in radiotherapy. However, many head and neck cancer patients still experience mouth dryness after the treatment. The new pair of salivary glands that used to be unnoticed and possibly damaged in radiotherapy might explain the phenomenon. In a cohort of over 700 patients, the doctors discovered a correlation between the dose applied to the newly discovered glands and the complaint of dry feeling in the mouth, suggesting the new pair of salivary glands are still functional [1]. From now on, doctors may try to avoid those salivary glands in radiotherapy.

While the discovery may not change the way most people live, there is a takeaway message for everyone – keep an open mind when you encounter something unexpected. It might turn out to be a groundbreaking discovery.

解剖學是生物學中歷史最悠久的領域之一。自古埃及以來，人們就開始解剖人體以了解其運作方式。幾千年來，我們對自己身體結構的理解日益加深，從古埃及人和古希臘人原始的素描，到達文西詳細的圖紙，再進化到著名的參考書《格雷氏解剖學》，都可以使我們對這個進程略知一二。但是，在過去的兩個世紀，解剖學領域的知識並沒有發生太大的變化。當所有人，包括醫學專業人士，都相信我們已經完全了解所有身體結構時，一組荷蘭科學家卻發現了一對新的唾腺。

唾腺，顧名思義，功能是分泌唾液。唾液含有分解澱粉的酶，而唾液本身可以作為潤滑劑幫助我們吞嚥食物。在這個突破性發現之前，人類已知有三對主要的唾腺，一對在耳朵前面 (腮腺)，一對在下顎底下 (頜下腺)，另一對在舌頭底下 (舌下腺) ; 頭部和頸部周圍大約有 1000 個小腺體。這次發





現的新唾腺位於頭部中央，靠近鼻子的位置 [1, 2]。

雖然聽起來似乎不太可能，這對新結構是在前列腺癌掃描中被發現的。為了篩查前列腺癌患者的癌細胞擴散，這組荷蘭醫生為病人進行了從大腿到顱骨的 PSMA 正電子電腦斷層掃描（PSMA PET/CT scan）[2]。PSMA 是前列腺特異性膜抗原（prostate-specific membrane antigen），一種存在於幾乎所有前列腺癌細胞表面的蛋白質 [3]。在掃描過程中，醫生會使用放射性染料標記 PSMA 以檢測癌細胞，但令他們感到困惑的是染料亦使頭部中央的結構在掃描中亮起來 [1]。

儘管醫生們最初相信這只是一種誤差，但還是決定對其進行研究。通過閱讀一些較詳細的解剖學參考書，他們發現顯示異常信號的區域的確由唾腺組織組成，但在文獻中從未被如此標記 [2]。他們還查看了其他前列腺癌患者的掃描結果，令他們驚訝的是，其餘 100 張掃描結果都顯示出一個靠近鼻子的區域有相同的信號，其平均長度為四厘米 [1]。

更有趣的是，從一個女性患者的掃描結果中，科學家們證實相同的結構也出現在女性身體內 [2]。儘管女性沒有前列腺，但在尿道附近有一個名為斯基恩氏腺（Skene’s gland）的小組織，它是雌性版本的前列腺，而那裡也可以生癌。這正是科學家能獲得女性掃描結果作調查的原因。

讀到這裡，你可能不明白為什麼經過了數千年的解剖，人們還是會遺漏在頭部中間長達四厘米的組織。若腺體暴露在外頭那就很容易會被發現，但因為這腺體位於頭部深處，要深入到頭部中央一般需要使用內窺鏡檢查。另外，磁力共振（MRI）或電腦斷層（CT）掃描不能偵測到這對腺體，僅在正電子掃描（PET）掃描中才能被發現 [2]。

這對新唾腺的發現不僅改變了教科書中有關腺體的描述，而且還可能改變醫生治療頭頸癌的方法。唾腺對於吞嚥和說話很重要，因此醫生總是試圖避免在放射治療中對其造成損害，但是許多頭頸癌患者在治療後仍會感到口乾。這對曾經不為人知的唾腺可能就是箇中原因，因為它們很可能在我們不知道其存在的情況下在放射治療中被破壞。在一個超過 700 名患者參與的研究中，醫生發現在治療中對該唾腺使用的放射劑量與口乾感有關聯，說明這對新唾腺仍然有分泌唾液的功能 [1]。從現在開始，醫生可能會嘗試避免在放射治療中損害到這對唾腺。

雖然這項發現可能不會改變大多數人的生活方式，但它提醒了我們在遇到出乎意料的事情時要保持開放的態度，因為這說不定會帶來開創性的發現。

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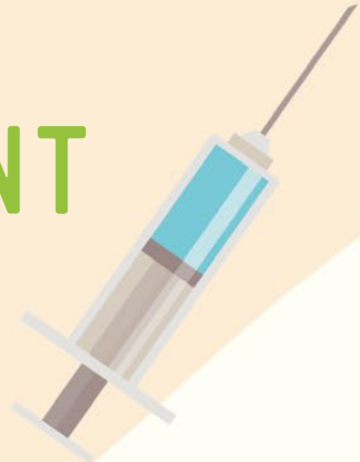
Vaccine DEVELOPMENT
疫苗研究的發展



By Paolo Miguel Magallanes Mallorca

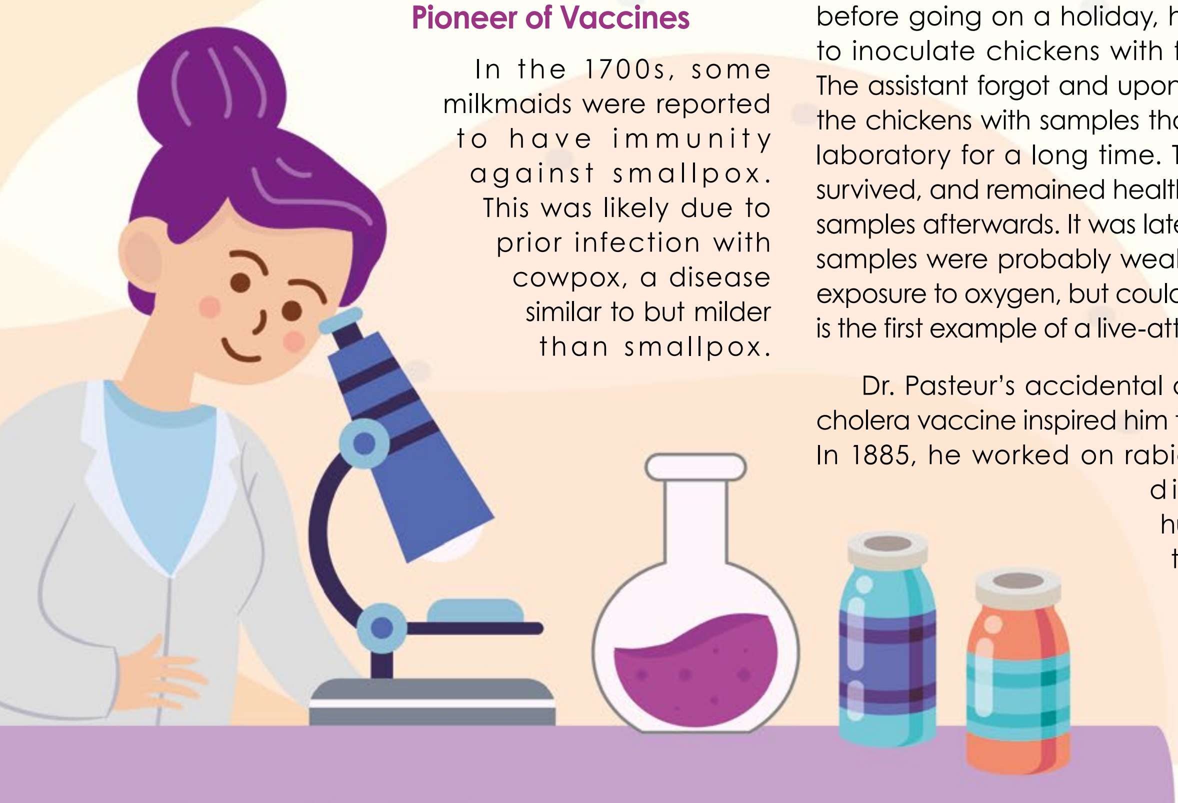
Vaccines! Everyone is talking about it lately. We may see them as the way out of this dreadful pandemic that made 2020 a mess. The good news is that some COVID-19 vaccines are approved and now being distributed to billions of people on this planet. With the vaccines making headlines, have you ever wondered where and how do vaccines originate?

"Vaccination" Before Dr. Edward Jenner

The earliest sign of "vaccination" was documented in ancient China and India, in the 10th Century [1]. The idea was to collect smallpox samples from blisters of a sick individual and inoculating minute amounts on healthy individuals. This practice wasn't called vaccination but "variolation" (after the smallpox virus *Variola major*). It spread across some countries in Asia and Africa, eventually reaching Britain and other parts of Europe in 1721 [2]. While it was quite effective at protecting people from smallpox and controlling outbreaks, inoculated individuals still have a small risk of developing smallpox or other diseases transmitted by this procedure [2].

Dr. Edward Jenner: The Pioneer of Vaccines

In the 1700s, some milkmaids were reported to have immunity against smallpox. This was likely due to prior infection with cowpox, a disease similar to but milder than smallpox. In 1796, English physician Dr. Edward Jenner proved this observation by inoculating an eight-year-old boy with cowpox. The boy only developed fever and minor symptoms. After his sickness subsided, the boy was exposed to smallpox samples but did not developed the disease. After publishing the results of the experiments, Dr. Jenner called this procedure "vaccination" (derived from the latin word *vacca*, meaning cow) and it became more popular than variolation [2]. Countries in Europe began to enforce vaccination and saw significant decline in mortality rate [1].



Dr. Louis Pasteur: The Father of Immunology

While Dr. Louis Pasteur is well known for pasteurization, a method to reduce the load of microbial pathogens in food by heat, little attention is given to his other contribution: live-attenuated vaccines. Inspired by Dr. Jenner's works, he suggested that there can be vaccines for other diseases as well.

In 1877, positing that vaccines could be found for all virulent diseases, Dr. Louis Pasteur attempted to work on chicken cholera [3], a bacterial disease that was devastating chicken populations. One time before going on a holiday, he instructed his assistant to inoculate chickens with fresh bacterial samples. The assistant forgot and upon returning, he inoculated the chickens with samples that had been sitting in the laboratory for a long time. The inoculated chickens survived, and remained healthy upon exposure to fresh samples afterwards. It was later discovered that the old samples were probably weakened due to prolonged exposure to oxygen, but could still induce immunity. This is the first example of a live-attenuated vaccine.

Dr. Pasteur's accidental discovery of the chicken cholera vaccine inspired him to work on other diseases. In 1885, he worked on rabies, a fatal neurological disease in dogs and humans. It was discovered that growing rabies virus in other hosts like rabbits where the microbe does not normally propagate for more than several generations (scientifically termed serial passage), could weaken their virulence to the original host [3]. Through this method, weakened viral strains were collected and tested on dogs. After they successfully induced immunity in dogs, Dr. Pasteur tested the same strains on a boy who was bitten by a rabid dog. The boy did not show rabies symptoms.

Dr. Pasteur's work shows that weakened pathogens may induce immunity against the disease they cause. This treatment was also named vaccination, which was originally referring to only smallpox, to honor Dr. Jenner's previous work [3].

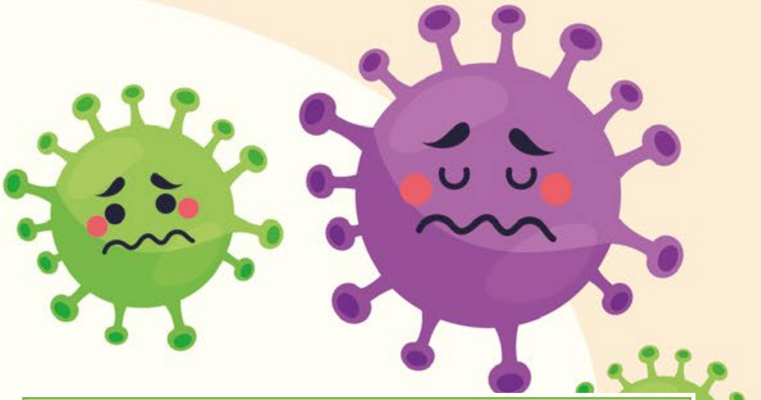
Modern Vaccine Development

Breakthroughs in microbiology and molecular biology in the 20th century drove the development of more vaccines. Not only there were vaccines available for more diseases, but there were new methods of creating vaccines and new types of vaccines as well.

It was discovered that pathogens carefully killed by heat or chemical treatment can induce immunity, creating inactivated vaccines. The first successful inactivated vaccines were created in the 1890s against typhoid fever and plague. This technique was expanded to viruses as well, and by 1936, a vaccine for influenza was invented [4].

Inactivated vaccines and live-attenuated vaccines are referred to as first-generation vaccines. The second-generation vaccines are subunit vaccines. Unlike the former generation, which uses whole pathogens, subunit vaccines use components of the pathogen that can be targeted by the immune system to develop immunological memory [4]. With the recent advances in genetic engineering, one variant of subunit vaccines uses recombinant DNA technology to mass-produce these components in other organisms or cells, such as yeast, animal cells and insect cells [4].

Then is the relatively new, third generation of vaccines. Instead of administering patients with whole pathogens or their components, genetic materials coding for those components in the form of DNA or mRNA are used. These genetic materials will be read by cells as instructions to produce viral components for the immune system to target. Due to the COVID-19 pandemic, both DNA and mRNA vaccines are receiving a lot of attention lately, which are the first of their kind to be approved for emergency use in humans. The development of DNA and mRNA vaccines was spurred unprecedentedly by the race to develop vaccines against COVID-19. Besides their application in the pandemic, research is being done for the potential use of such nucleic-acid based vaccines against cancer and HIV [5].

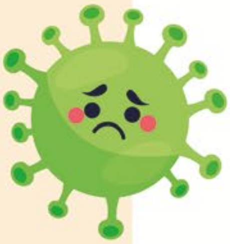


Types of vaccine summarized:

1. First-generation vaccine = whole pathogen (live-attenuated, inactivated)
2. Second-generation vaccine = pathogen pieces (subunit, recombinant)
3. Third-generation vaccine = DNA based; mRNA based

The Future of Vaccine Research

Looking back at how vaccines developed, we have come a long way in protecting people from deadly diseases. In 1980, the W.H.O. declared smallpox's eradication, the complete removal of a disease from the human population. More diseases like malaria and polio may face the same fate in the future. We have even managed to create a vaccine against COVID-19 within a short period of time. As more vaccines become available and as more research is done, the containment or the eradication of certain deadly diseases is now a possibility, thanks to scientists like Dr. Jenner and Dr. Pasteur.



疫苗，最近人人都在談論它。肺炎疫情把你我的 2020 年生活都搞得一團糟，因此我們可能會視疫苗為平息疫情的唯一出路。好消息是一些新型冠狀病毒肺炎疫苗已獲准使用，並正分發予全球數十億人。在疫苗成為每天頭條的今天，你有想過最早的疫苗是在哪裡以及怎樣被發明嗎？

在金納之前的「疫苗接種」

有記錄以來最早的「疫苗接種（vaccination）」跡象出現在 10 世紀的古代中國和印度 [1]，概念是從天花病人的水疱中抽取樣本，然後接種少量樣本在健康的人身上。這個做法當時被稱為「人痘接種法（variolation）」而不是疫苗接種，英文「variolation」一詞的源自天花病毒 *Variola major*。人痘接種法傳遍亞洲和非洲多個國家，並在 1721 年流傳至英國及其他歐洲地方 [2]。它對於預防天花和控制疫情傳播頗為有效，但已接種的人仍會有輕微染上天花的風險，亦可能會經接種過程染上其他疾病 [2]。

愛德華 • 金納：疫苗的發明者

在 1700 年代，據悉一些負責擠牛奶的牧場女工對天花有免疫力，這很可能是因為她們之前感染過牛痘的緣故，而牛痘是與天花相似但比其輕微的一種病。1796 年，英國醫生愛德華 • 金納（Edward Jenner）透過在一名八歲男孩身上接種牛痘證實了這個傳聞。那個男孩在接種後只出現發燒和其他輕微症狀。在不適消退後，男孩被安排接觸天花病毒樣本，但並沒有染病。在發表這次實驗結果後，金納醫生稱這個程序為「疫苗接種」（英文「vaccination」一詞來自拉丁文中表示牛的「vacca」）。疫苗接種在當時變得比人痘接種法更為流行 [2]，而歐洲國家亦開始強制疫苗接種，死亡率也有明顯的下降 [1]。

路易 • 巴斯德：免疫學之父

路易 • 巴斯德（Louis Pasteur）博士以透過加熱來減少食物中微生物病原體的巴斯德殺菌法（pasteurization）聞名，但是他對減活疫苗（live-attenuated vaccines）的貢獻卻往往被受忽視。在受到金納醫生的研究啟發下，他估計我們也應該能夠研發針對其他疾病的疫苗。

1877 年，在假設我們可以為所有致命疾病找到相應疫苗的前提下，路易 • 巴斯德博士嘗試為雞霍亂找出疫苗 [3]，那是一種能摧毀雞群的細菌性疾病。在某個長假期前，他吩咐助手為雞隻注射剛準備好的細菌樣本，可是他的助手卻忘記了，所以從假期回來後才為雞隻注射放置了在實驗室很久的樣本。結果經過接種的雞隻都活著，又在其後重新接種新鮮樣本後也依然健康。他們發現舊樣本中的細菌大概因為長時間與氧氣接觸而削弱了其致病能力，但仍能提供免疫力。這就是減活疫苗誕生的故事了。

巴斯德博士在雞霍亂上的意外發現啟發了他，使他向其他疾病著手。1885 年，他進行與狂犬病相關的研究，那是影響犬隻和人類的致命神經疾病。他發現如果把狂犬病毒在其通常不會寄生的宿主內（例如兔子）培養上數代的話（科學上稱為連續傳代（serial passage）），便有可能減低病毒對原來宿主的致病能力 [3]。通過這種方法，他們取得減弱了的病毒株並在犬隻上進行測試。成功令犬隻獲得免疫力後，巴斯德博士利用相同的病毒株在一個剛被狂犬病犬隻咬過的男孩上進行測試，男孩最終並沒有出現狂犬病的症狀。

巴斯德博士的研究展示出經減弱的病原體也能激發對該疾病的免疫力。這個接種過程也被命名為「疫苗接種（vaccination）」以紀念金納醫生之前的貢獻，令這個詞語不再只是用於牛痘接種上 [3]。

現代疫苗發展

二十世紀微生物學和分子生物學上的突破推動了疫苗的發展。我們不僅有疫苗對抗更多的疾病，還有新方法製造疫苗以及新種類的疫苗。

科學家發現經熱力或化學方法小心處理而被殺滅的病原體也能帶來免疫力，因此製造出滅活疫苗(inactivated vaccines)。首批成功的滅活疫苗在 1890 年代被用於對抗傷寒和鼠疫。這項技術亦被擴展至用於病毒上，流感疫苗就在 1936 年面世 [4]。

滅活疫苗和減活疫苗都被歸類為第一代疫苗，而第二代疫苗是次單元疫苗(subunit vaccines)。與前者用上完整的病原體不同，次單元疫苗只使用病原體的一部分，它能被免疫系統識別而帶來免疫記憶 [4]。有賴近年基因工程上的進步，有一種次單元疫苗利用重組 DNA 技術於其他生物或細胞(例如酵母、動物細胞和昆蟲細胞)上大量製造那些病原體的構成部分 [4]。

然後有相對上較新的第三代疫苗。這代疫苗並不會把完整的病原體或病原體的一部分注射到體內，而是使用以 DNA 或 mRNA 形式編碼著病原體構成部分的遺傳物質。細胞會閱讀這些像指令一樣遺傳物質，並製造出病毒組件讓免疫系統識別。新冠肺炎的大流行使 DNA 和 mRNA 疫苗最近被受關注，這兩類疫苗都是首次被批准作緊急用途用於人類身上。DNA 和 mRNA 疫苗的發展都在研發新冠肺炎疫苗的競賽中被前所未有地加速。除了在這次大流行上的應用外，核酸疫苗也被研究用於癌症和愛滋病上 [5]。

疫苗分類總結：

1. 第一代疫苗 = 完整病原體（減活、滅活）
2. 第二代疫苗 = 病原體的一部分（次單元、重組）
3. 第三代疫苗 = DNA; mRNA

疫苗研究的未來

回顧過往的疫苗發展，我們經過很多努力來保護人類免受致命疾病的折磨。1980 年，世界衛生組織宣佈天花被完全根除，即是這種疾病完全在人類中消失，例如瘧疾和小兒麻痺症等更多的疾病也可能在未來有被根除的一天。我們現在甚至能在短時間內製造出對抗新冠肺炎的疫苗。更多疫苗的推出和相關研究的進行為有效控制或根除某些致命疾病帶來了新的可能性，這要感謝包括金納醫生和巴斯德博士在內的一眾科學家。

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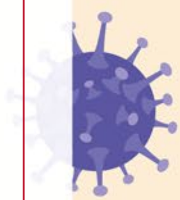
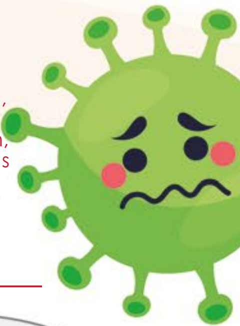




The Twin Prime Conjecture and the Polymath Project

孿生質數猜想與博學者計劃

By Sonia Choy 蔡蒨珩

There are math problems that are thoroughly incomprehensible to the layman – the Riemann hypothesis needs a fair amount of sophisticated math to explain, for example. And then there are those that even a ten-year-old could understand. The famous Twin Prime Conjecture (footnote 1) is definitely in the latter category – conjectured by Alphonse de Polignac in the 19th century, it states that there are infinitely many pairs of prime numbers that differ by two – hence the name "twin" prime. For example, 3 and 5 are twin primes, and so are 71 and 73. As we get to larger numbers, prime numbers show up less frequently. However, we have also found ridiculously big twin primes [1] – the current record being $2996863034895 \times 2^{1290000} - 1$ and $2996863034895 \times 2^{1290000} + 1$, with 388,342 decimal digits – which leads us to believe that there might be an infinite number of twin primes; no matter how large you go, you might always expect a pair of twin primes ahead.

There isn't very much to say about the problem, but more interesting is how progress has been made in recent years. People might think of math research as a solitary affair, imagining a mathematician locking himself/herself up in a room until they find a solution. And certainly there are two remarkable people involved in this story – Yitang Zhang and James Maynard – but at the heart of a lot of progress sits a huge collaborative project called the Polymath Project.

Yitang Zhang's life story is certainly worthy of a movie. He was born in China, and was sent to a labor camp with his mother during the Cultural Revolution, which interrupted his education for about eight years [2]. He later went to graduate school in the U.S., but parted ways extremely unhappily with his supervisor. Unable to find a job in academia after graduation, he worked a number of odd jobs for seven years, including a stint as an accountant at his friend's Subway franchise, before becoming a lecturer at the University of New Hampshire in 1999 [2]. No one had heard of him before his breakthrough, which makes his pioneering work even more remarkable. Before Zhang's breakthrough and subsequent work built on that by others, there was no real upper bound on the maximum gap between primes; efforts were, of course, made on the problem, but it largely refused to budge. In April 2013, Zhang published his results, showing that there were infinitely many primes with a gap less than 70 million – a large number, but a finite one. This was news that set the math community ablaze. Amidst a flurry of interest in the new result, Polymath8 began.

The Polymath Project was founded by mathematician Timothy Gowers, who started the first project on his blog in 2009 [3]. It is a massive mathematical collaborative project, with a goal set out at the beginning, and different mathematicians contributing to the goal through online discussions open to everyone. Usually a mathematician serves as a host, with their blog becoming the project's discussion forum, and allowing all people to participate as long as they could chip in with some insight [4]. The results were usually published in academic journals under the pseudonym D.H.J. Polymath. Polymath8, the eighth project in the series, was started by Terence Tao, arguably the world's most famous mathematician, in June 2013 [5]. The project set out to improve Zhang's work and give a more accurate upper bound of the prime gap. A good number of mathematicians joined in, and the project generated a lot of excitement. The bound was reduced every day, eventually falling to 4680 in July 2013, where the project momentarily came to an end [6].

In a dramatic development, James Maynard, now a professor at Oxford, published another result in November 2013. Fresh off a PhD, he had been working independently of Zhang and the Polymath Project, but gave a bound of 600 using an entirely different method [7]. Had he published his result earlier, it would have been him who made the headlines – 600, after all, is a far more headline-worthy bound than 70 million. Maynard's result was a better bound than that from the Polymath Project, and soon the project's participants turned their attention to Maynard's new methods, hoping that the conjecture could be solved once and for all.

Thus began Polymath8b, a continuation of the previous project, which now involved James Maynard; together, the mathematicians tried to push the gap down further, but this time they were met with other forms of resistance. After all, one could only improve bounds for so long – nevertheless, the results were quite encouraging. In April 2014, just one year after Zhang published his results, the bound stood at 246; assuming an additional result on the distribution of primes, known as the Elliott-Halberstam conjecture, the bound can be reduced to 6 (footnote 2) [8, 9]. However, to lower the bound to 2 for the Twin Prime Conjecture, new methods have to be invented in order for further progress.

The Polymath Project has always been an interesting exposition in mathematical research – the open-sourced nature of the project causes results to come extremely quickly, at a speed far greater than regular mathematical collaborations, which often involve just a few mathematicians corresponding with each other. It is often likened to drinking out of a fire hose – the speed at which breakthroughs happen is simply thrilling. On the flip side, some may be hesitant to participate, as all their mistakes will be left open on the discussion forum permanently; others argue that the speed doesn't allow mathematicians to dwell on some things for a longer period of time, perhaps yielding more results [10]. The question is, in this age of the internet, are Polymath Projects the way forward in mathematical research?

Perhaps time will tell. The Polymath projects so far have tackled tasks that were easily divided into parts, so different people could work on different components before piecing the details together. But if there is one moral from the story of the Twin Prime Conjecture, it is that breakthroughs come in different forms, from a lone mathematician working alone for years, to the rapid-fire breakthroughs of a group think tank. There are still numerous mathematical questions waiting for us to solve, and you, dear reader, might solve one of those some day!

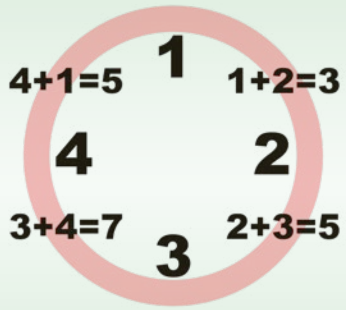
1 Conjecture: A proposed statement waiting to be proved. A proved conjecture becomes a theorem.

2 A small aside: primes that have a difference of six are, somewhat hilariously, known as "sexy primes" ("sex" is the Latin prefix for "six", so the label is as in twin primes).

As is now customary for these articles, we will end with a problem, this time about prime numbers [11]:

Let n be an integer ≥ 4.

Our goal is to arrange the numbers 1, 2, ..., n in a circle, so that any two neighboring numbers add up to a prime number. For example, (1, 2, 3, 4) is a valid arrangement for $n = 4$:



However, this proves to be impossible for odd n. Why?

(As a bonus question, if $n + 1$ and $n + 3$ are twin primes, then can you construct an arrangement for n?)

Solution 答案

Interested and mathematically advanced readers may wish to read Terence Tao's blog (but be warned that you will need a lot of mathematical background!):
如果你對以上的數論有興趣，又學過一點大學數學的話，可以看一看陶哲軒的網誌（但是他寫的東西比較深，看不懂也不要緊！）：
https://terrytao.wordpress.com/

Timothy Gowers, the founder of Polymath, also has a blog, which is more accessible to the layman:
博學者計劃的創辦人Timothy Gowers也有寫網誌，裡面有不少比較容易看懂的內容：
https://gowers.wordpress.com/

James Maynard, one of the main contributors to this problem, also talks about the Twin Prime Conjecture on Numberphile:
為問題帶來重大突破的 James Maynard 也有在著名Youtube頻Numberphile上和主持討論孿生質數猜想：
https://youtu.be/QKHKD8bRAro

Terence Tao's blog
陶哲軒的網誌

Timothy Gowers' blog
Timothy Gowers的網誌

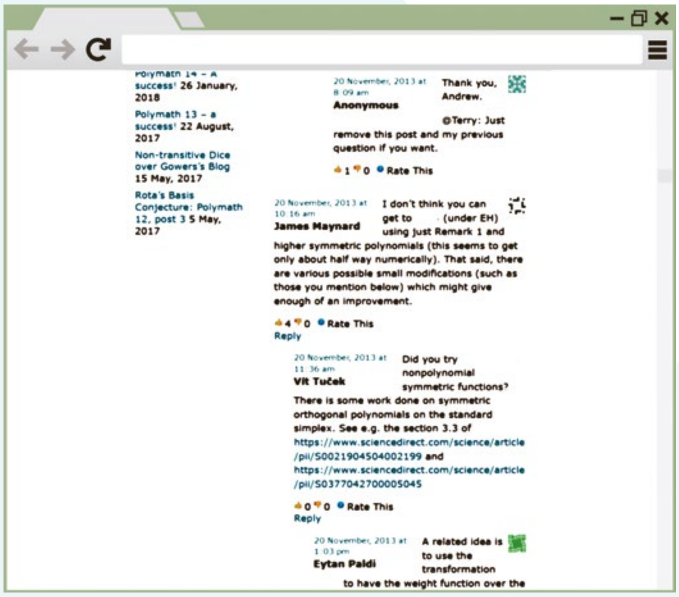
The Numberphile video on the twin prime conjecture
Numberphile的孿生質數猜想影片

有些數學問題是常人完全不能理解的，譬如黎曼猜想（Riemann hypothesis）需要用到不少高等數學知識才能解釋；可是也有些問題是十歲小孩也能明白的。著名的孿生質數猜想（Twin Prime Conjecture；註一）絕對能被歸類為後者。它由 Alphonse de Polignac 在 19 世紀提出，指世界上存在著無限多對相減之差為二的質數，而這些質數因此被稱為「孿生」質數（twin primes），例如 3 和 5 是一對孿生質數，71 和 73 也是。當數字越來越大，質數出現的頻率越來越低。即使如此，我們也能找到一些大得驚人的孿生質數 [1]，現時紀錄是一對在十進制下有著 388,342 位的質數 $2996863034895 \times 2^{1290000} - 1$ 和 $2996863034895 \times 2^{1290000} + 1$。這不禁讓人猜想數字裡面可能包括無限對孿生質數，即是無論我們找到的孿生質數有多大，都總有一對會比它們大。

這猜想本身其實也沒什麼好說的，但是比較有趣的是近年在這個問題上作出突破所用的方法。大家對數學研究的印象可能是一位數學家坐在房間裡獨自與問題搏鬥，一直把自己鎖在房間裡直至找到解決方法為止。對孿生質數提出突破性理論的兩位數學家 — 張益唐和 James Maynard 的確都是分別獨自進行研究，可是另一方面的突破則來自一個公開的大型合作計劃 — 博學者計劃（Polymath Project）。

張益唐的人生故事絕對值得拍成一部電影。他在中國出生，文革期間和母親被送到勞改營，使其教育中斷長達八年 [2]。他之後到了美國念研究院，可惜最後和導師不歡而散。畢業後，張益唐在學術界找不到工作，結果到處做著零零散散的工作，包括曾經在朋友開的 Subway 三文治店裡做會計，直到 1999 年才在新罕布什爾大學裡擔任講師 [2]。在他取得突破之前，幾乎沒有人聽過他的名字，這使他具開創性的研究結果更為受人注目。此前，以及在其他數學家建基於他的結果作出更多發現之前，數學家並不知道兩個質數之間的差距（或間隙）最大可以有多大。不少人當然嘗試過著手解決這個問題，但是基本上都沒有進展。在 2013 年 4 月，張益唐出版了他的研究結果，論文裡指出在間隙小於 7000 萬之下存在著無限多個質數。7000 萬是個很大的數字，但至少是一個有限的數字。這個消息令數學界為之一振，在掀起了一輪關注後，計劃「博學者八號難題（Polymath8）」正式誕生。

博學者計劃是一個由數學家 Timothy Gowers 創立的大型數學合作計劃，最初在 2009 年於其網誌展開 [3]，建立計劃的時候會訂出研究的目標，然後由不同數學家在公開的網上討論中發表自己相關的研究結果，同心協力地使研究一步一步向目標推進。每個計劃通常都由一位數學家作為主辦人，並以自己的網誌作為計劃的討論區，任何對問題有見解的人都可以在討論中貢獻自己的想法 [4]，成果通常都以筆名 D.H.J. Polymath 投稿到學術期刊。Polymath8 是這個系列的第八個計劃，由可能是世界上最有名的數學家陶哲軒在 2013 年 6 月展開 [5]，計劃的目標是希望能夠對張益唐的研究結果加以改善，得出一個更準確的質數間隙。不少數學家都參與了這次計劃，當中喜訊一個接一個，間隙一天比一天減少，在 2013 年 7 月 Polymath8 暫時完結時已經降到 4680 [6]。



更戲劇化的是，在同年 11 月，現時為牛津大學教授的 James Maynard 取得了新的突破。他當時只是剛完成博士課程不久，在完全沒有和張益唐或博學者計劃合作的情況下使用了一個截然不同的方法得出了 600 這個最大間隙 [7]。

如果 Maynard 能更早發表這個突破的話，登上報紙頭條的一定會是他，畢竟 600 比 7000 萬是一個更令人驚嘆的上限數字。Maynard 的結果甚至比博學者計劃的更為準確，因此計劃的參與者開始把目光轉移到 Maynard 的新方法，希望可以得到更大的突破，甚至一舉解決孿生質數猜想的問題。

於是，他們決定延續上一個計劃，展開 Polymath8b。這次計劃亦邀請得 James Maynard 參與，他們嘗試合力把上限再次降低，可惜卻遇到其他阻力。最後，雖然他們只能把上限再降低一點，但這已經算是十分鼓舞的成績了。在張益唐發表結果後一年的 2014 年 4 月，上限數字止住了在 246；在假設另一條關於質數分佈的 Elliott-Halberstam 猜想是正確的情況下，上限可以被降至 6 (註二) [8, 9]。可是，如果要證明孿生質數猜想，我們要把上限降至 2，因此我們必須發明新的方法才能使問題有所進展。

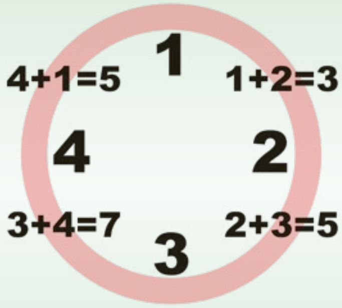
其實博學者計劃一直是數學研究裡面一個有趣的課題。由於這是任何人都能參與的開源 (open-sourced) 計劃，因此一切突破都來得很快，進展速度與通常只涉及幾個人的普通數學研究相比之下快得多。很多人曾經打過一個比喻，說如果普通研究是喝水杯裡的水的話，那麼博學者計劃就好比嘗試從消防喉裡喝水，因為突破湧現的速度可謂前所未見。另一方面，也有一些人會因抗拒在公開討論區發言而不願意參與，因為參加者犯過的所有錯誤都會永久地被留在互聯網上；也有人指計劃進展速度之快令人不能花上更長的時間反覆思考和消化結果，放慢步伐也許反而能得來更多成果 [10]。但問題是，在這速食文化通行的互聯網世紀，博學者計劃會不會是數學研究未來的趨勢呢？

這問題，也許要經過時間的洗禮才能解答。直到現時，博學者計劃都在解決一些能夠分拆成許多細小部分的數學問題，讓參與者可以分工完成不同部分，再把結果整合。不過，孿生質數猜想的故事告訴了我們一件事：突破可以來自大相逕庭的形式。從獨自與問題搏鬥數年的隱世數學家到大型數學智庫的光速突破，都能帶來各種各樣的新發現。世界上還有很多數學問題等著大家去探索和解答，可能有朝一日，親愛的讀者，你將會是解決那些難題的其中一人呢！

像以往一樣，就以一道小小的挑戰題完結本文，今次的問題與質數有關 [11]：

設 n 為大於或等於 4 的整數。

我們的目標是把數字 1, 2, ..., n 排成一個圓圈，令所有相鄰的數字加起來都是一個質數。譬如 n = 4 的話，我們可以用 (1, 2, 3, 4) 這個組合：



可是，如果 n 是單數的話，排列就會變得不可行。為什麼？

(加分題：如果 n + 1 和 n + 3 為孿生質數，你可以就數字 n 寫出一個排列方法嗎？)

Solution 答案

1 猜想：還沒有得到證明的數學論述；如果猜想得到證明就會變成定理。

2 題外話：相減之差為六的質數對在英文被稱為「sexy primes (性感質數)」，就像孿生質數被稱為「twin primes」一樣，名字由來是因為「sex」在拉丁文中是代表「六」的前綴。在中文，「sexy primes」只是平平無其地被叫作「六質數」，並沒有任何幽默感可言。

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