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SCIENCE FOCUS 科言

Issue 033, 2026

School of 理學院 Science

香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

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Dear Readers,

As you look forward to your summer holidays, we hope that you will have time to explore ideas that are presented in this issue of *Science Focus*. After all, we have articles that are related to one of the biggest events this year, the World Cup.

Are you intrigued about the design of the football that will be used in this year's competition? You may want to take it into consideration when you cry about incredible goals scored against your favorite team. Interestingly, the tears you shed are going to be quite different from the ones triggered by pollutants. For those of you who are interested in chemistry, we treat you with a story on chirality beyond the textbook. Do you know what is in common between wine crystals and amino acids? While none of us can live in "seas within the sea" in the SpongeBob cartoon, can you imagine there are living things that can? Finally, we return from deep ocean to the lab and consider how organoids can be used to advance research and medical treatments.

We would like to thank those of you who participated in our recent "Science in Transportation" Design Competition. We were very happy to see your creativity and artistry. Please head over to our Instagram page to see the winning entries.

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

親愛的讀者：

在盼待暑假來臨的同時，希望您能善用假期了解今期《科言》探索的主題，當中的文章與今年最大盛事世界盃有關。

您對今年比賽用球的設計感興趣嗎？也許您為愛隊失球而痛哭時應該好好考慮這點，有趣的是那時的眼淚並不會與因污染物觸發的相同。對於喜愛化學的同學，我們會告訴您一個教科書沒有提及，關於手性的故事，而您又知道葡萄酒結晶與氨基酸之間的共通之處嗎？此外，雖然沒有人能在《海綿寶寶》中的「海中之海」存活，但您能想像竟然有生物可以？最後，我們從深海回到實驗室，探討類器官如何有助推進科研及疾病治療發展。

我們亦希望感謝最近參加過「交通工具的科學」設計比賽的同學，大家的創意和藝術才能令我們眼前一亮。請瀏覽我們的 Instagram 專頁查看得獎作品。

主編 麥晧怡教授
敬上

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What's Happening in Hong Kong? 香港科技活動

"Science in Transportation" Visual Explainer Challenge 2026 Result Announcement
圖解「交通工具的科學」設計比賽 2026 — 結果公佈

Champion 冠軍	Lee Jeannie On Kiu 李安翹
First Runner-Up 亞軍	Sun Fan Wan 孫凡匀
Second Runner-Up 季軍	Ho Tsz Yan Antonia 何祉欣
Best Effort Award 最佳努力獎	Lau Ya Lei 劉雅蕾

Visit our website for the winning entries.
請到《科言》網頁查看得獎作品。

Fun in Summer Science Activities 夏日科學好節目

Any plans for this summer? Check out the following event!
計劃好這個夏天的課餘節目了嗎？不妨考慮以下活動！

Hong Kong Science Museum 35th Anniversary Exhibition
香港科學館35周年展覽

To celebrate its 35th anniversary, the Hong Kong Science Museum presents "Enjoy Science, Infinite Fun," a special exhibition that takes you on a journey through its history. Visitors can explore a time tunnel of the museum's development, revisit classic exhibitions, and see the museum's first-ever robot. The exhibition also reveals the inner workings of the iconic "Energy Machine." Through interviews with special guests, you will hear precious memories and gain diverse perspectives on science. Don't miss the AI interactive photo booth, where innovative technology and playful experiences come together to capture your joyful moments of encountering science.

Period: Now – July 15, 2026
Venue: 1/F Lobby, Hong Kong Science Museum

香港科學館為慶祝成立 35 周年，呈獻「樂在科學．無限趣味」特別展覽，邀請大家回顧科學館歷史。觀眾將踏上介紹科學館發展的時光隧道，重溫經典展覽，以及認識科學館首部機械人。展覽亦會解構其「鎮館之寶」能量穿梭機的運作原理。透過特別嘉賓的訪談片段，觀眾將了解他們與科學館的珍貴回憶，並從不同角度欣賞科學。不要錯過結合創新科技和趣味體驗的 AI 互動照相亭，捕捉您與科學相遇的歡樂時刻。

展期： 現在至 2026 年 7 月 15 日
地點： 香港科學館一樓大堂

Organoids 類器官 –
An Alternative to Lab Rats?
實驗老鼠的替代方案？

By Ian Cheng 鄭朗健

The Problems of Using Lab Rats

People often jokingly say "you are a lab rat" when one is being experimented on something new. For decades, early stages of clinical trials use rodents like rats and mice before testing on human subjects. However, there are still two major issues around the use of animal models. First, the ethical dilemma: Does the benefit of drug testing outweigh the cost of animal suffering? Can we minimize the use of vertebrates in research? Second, the scientific dilemma: Can rats sufficiently represent human? Scientists have used rats and mice for modeling complex mammalian physiology and pathology. This is based on the notion that the making of the human body is instructed by a network of conserved proteins that are mostly found in rats and mice. Nevertheless, it remains challenging to accurately predict drug efficacy in animal models [1].

What if we can grow models of human organs, using real human cells instead?

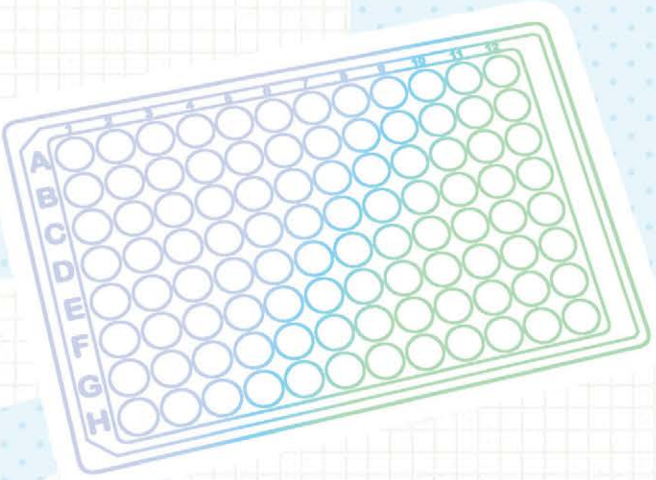
Organoids in a Nutshell

Enter organoids, self-assembling, 3D miniature cell clusters that mimic aspects of the real organ. The word “organoid” has two parts: “Organ” refers to a collection of cells and tissues that work together to perform specific functions, while the suffix “-oid” means the resemblance of a specified object – in this case an organ.

So ... is an organoid just an organ, with the same geometry but just smaller? Not exactly. Organs, as you may know, have a characteristic shape and internal structures. For example, the small intestine is a tubular structure. However, an organoid of a small intestine does not look like winding tubes under a microscope. In fact, the small intestine organoid, which is the first organoid to be developed, appeared as spherical hollow sacs, with small bud-like protrusions on their surface. These buds mimic intestinal crypts, pockets that house stem cells in real intestines, though the overall structure bears no resemblance to the winding tube shape [2].

The Story of the First Organoid

It is well known that the absorptive and secretory cells on the surface of our intestine are periodically replaced by new cells that are derived from stem cells. However, the exact identity of the stem cells remained elusive until 2007, when Hans Clevers' group made a pivotal advance [3]. They identified Lgr5, a marker unique to stem cells residing in crypts of small intestine. With these cells now identifiable and purifiable, it begs the question: Could they be grown outside the body? Toshiro Sato joined the lab as a postdoctoral fellow to answer precisely this question [2].



In the beginning of the study, Clevers and his team encountered a major problem – Intestinal stem cells would die when separated from the other cells in the intestine. Sato tried thousands of combinations of growth factors to arrive at the conditions suitable for "eternal growth." They used a cocktail of three growth factors: R-spondin, epidermal growth factor, and noggin [4]. Instead of working on a 2D surface, they used a soft, porous material called Matrigel, which provides the stem cells with a 3D space to grow, just like inside of the body [5].

The results were shocking.

"[Toshiro] realized what he had created was not just a lump of stem cells. It was a structure that recapitulates the normal structure of a gut and contains all the cell types of the epithelium, and even the cell types would be in the right location," Dr. Clevers recalled [2].

The stem cells did not simply multiply; they differentiated into multiple cell types and self-organized into unique spheroid structures.

Sato and Clevers were not the first to use the term "organoid." It had been applied without consistent definitions to various 3D cultures since mid-1960s. But their 2009 breakthrough launched a field explosion: Stomach, colon, liver, and pancreas organoids were created using the same principles – planting stem cells on a 3D culture supplemented with growth factors between 2010 and 2013 [5, 6]. This rapid expansion created a need for clarity. In 2014, Lancaster and Knoblich formally defined an organoid as "a collection of organ-specific cell types that develops from stem cells or organ progenitors and self-organizes through cell sorting and spatially restricted lineage commitment" – a definition that captured what Sato, Clevers and their colleagues had accidentally discovered five years earlier [5].

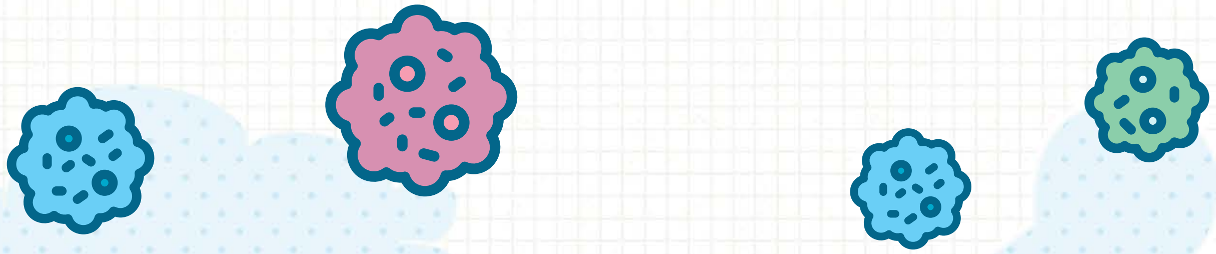
Why Do We Need Organoids?

In 2013, the Clevers and Watanabe labs published another pivotal research paper. They showed that intestine organoids transplanted to an injured area of the mice intestine could function normally [7]. The transplanted organoids integrated so well that they were indistinguishable from the host tissue when examined under the microscope [2].

The discovery opened a window for scientists to ponder the possibility of organoids in regenerative medicine. Patient-derived organoids enable autologous transplantation – transplanting one's own tissues back to the body to replace the function of failing organs – solving the host-versus-graft problem in transplantation (the patient’s immune system attacks the transplanted organ from donor). In 2024, a group of researchers transplanted patient-derived organoids of pancreas (islets) into a patient with type I diabetes. Seventy-five days after the transplantation, the patient achieved insulin independence [8], in a disease which is otherwise lifelong, highlighting the potential of organoids in autologous transplantation. The success in this single patient warrants further clinical studies.

Beyond regenerative medicines, researchers use animal models traditionally as an analogy to humans, and it has indeed provided us with ample insights about treating diseases. Yet there are features specific to humans that we cannot model with animal models like rats and mice [9].

Organoids derived from humans can act as a window to these features. A prime example is using organoids to understand the human brain – arguably the most complex object in the universe. Brain organoids are a simplified version of the brain,



making the task of understanding the organ more manageable [10]. For example, some researchers harness brain organoids to trace how brain cells develop and migrate in the fetus, while others connect a few brain organoids to investigate how pain signals travel from our skin to our brain [10].

More importantly, to be able to model a disease in rodents, scientists need to know the cause of it, and that takes about a year [9]. Patient-derived organoids can speed up the process significantly, allowing scientists to move faster when developing a model. In brain organoid research, scientists have already used brain organoids derived from patients to model Alzheimer's disease and Parkison's disease [6].

Perhaps a more exciting is the application of organoids in drug screening. For a long time, poor assessment of drug toxicity in the preclinical stage has been a major cause behind the failure of many drug developments [6]. This is particularly true for cancer therapies, which may have severe, sometimes lethal side effects. To this end, drug efficacy and toxicity can be better studied by comparing the response of organoids that are derived from normal and cancer cells from the same patients [6].

The End of Lab Rats?

So where does this leave us? Are organoids the end of "you're a lab rat?" Not yet. Model organisms still have unique value in the scientific community. With a large body of work and laboratory techniques already established, animal models allow a low-cost way for fundamental research [9]. While the potential for organoids in precision and regenerative medicine is widely recognized, the field of organoids is still in its infancy, with major technical bottlenecks ahead and limited clinical outcomes. However, regulatory progress has been made with the passing of the "FDA (Food and Drug Administration) Modernization Act 2.0" in the United States. It authorizes the use of "new approach methodologies," including organoids and AI-based computational models, as alternatives to the compulsory animal testing to support an investigational new drug application [11, 12]. This enables new drugs to be tested in a more effective and human-relevant way [12]. In April 2025, the FDA further announced a roadmap to phase out animal studies in the next three to five years [11]. The end of lab rats – in clinical trials – might not be that far away, after all.

使用實驗老鼠的弊病

當有人被迫參與試驗新事物時，人們常開玩笑說：「你被人拿來當白老鼠。」過往數十年，新藥在進行人體試驗前，都會先在大鼠和小鼠等囓齒動物上進行初步臨床測試。然而，以動物為模型仍有兩大難題。首先是道德上的取捨：藥物測試帶來的好處，是否抵得過動物承受的痛苦？我們能否在研究中減少使用脊椎動物？其次是科學上的難題：大鼠能充分模擬人類嗎？科學家一直用大小鼠模擬哺乳動物複雜的生理與病理過程，這是基於操控人類體內活動的蛋白質大多亦存在於大小鼠身上，它們都是在演化過程得以保留的蛋白質。可是，要準確地以動物模型預測藥物在人體上的效用仍然困難 [1]。

若我們能以人類細胞培養出人體器官模型，又會怎樣呢？

甚麽是類器官？

類器官（organoid）是可以自我成形的三維迷你細胞團，在某程度上能模擬真實器官。「類器官」一詞由兩部分組成：「器官」（organ）是指一群執行共同特定功能的細胞及組織，「類」（-oid）則表示與特定物件的相似性，在此即指「類似器官的東西」。

那麼，類器官就是具有正常器官形狀的迷你版器官嗎？這個描述並不準確。正如你可能知道，器官具有特定形狀和內部結構，就像小腸是管狀結構。然而，小腸類器官在顯微鏡下並不是彎曲的管道。事實上，作為史上第一個類器官，它是中空的球狀囊泡，表面帶有芽狀突出物。儘管整體結構與小腸彎曲的管狀外形毫不相似，但表面的芽狀結構類似於真實腸道中容納幹細胞的口袋 — 腸隱窩（intestinal crypts）[2]。

首個類器官的故事

研究界已知道腸道表面負責吸收和分泌的細胞會定期被由幹細胞分化而成的新細胞更替。然而，科學家一直未能找出識別這些幹細胞的方法，直到 2007 年 Hans Clevers 的研究團隊取得關鍵突破 [3]，發現了小腸隱窩內幹細胞獨有的生物標記 Lgr5，故此我們能識別並分離這些細胞。然後下一個問題是：我們能否在體外培養這些細胞？佐藤俊郎以博士後研究員的身份加入 Clevers 的團隊，嘗試解答這個問題 [2]。

在研究初期 Clevers 及其團隊面臨一個重大難題，就是腸道幹細胞一旦與腸道內其他細胞分離，就會死亡。佐藤嘗試了數以千計的生長因子組合，終於找到適合持續生長的培養條件。他們使用了由三種生長因子組成的混合配方：R- 脊椎蛋白 1、表皮生長因子和頭蛋白 [4]。此外，他們不只是在二維平面上培養細胞，而是選用一種名為基質膠的多孔柔軟材料，為幹細胞提供類似人體內的三維生長空間 [5]。

實驗結果令人震驚。

Clevers 博士回憶道：「......〔佐藤〕意識到自己創造出來的並不只是一團幹細胞，而是跟腸道正常結構相似的組織，當中不僅囊括上皮所有細胞類型，甚至連不同細胞也分佈在正確的位置 [2]。」因此這些幹細胞不僅自我複製，更分化成不同細胞類型，並自動組織成獨特的球狀結構。

佐藤和 Clevers 並非最早使用「類器官」一詞的人。自 1960 年代中期以來，這個詞已被人用來籠統描述各種三維組織，定義並不統一。然而，他們 2009 年的發現為整個領域的迅速發展打響頭炮，在 2010 至 2013 年間科學家運用相同原理，將幹細胞置於添加了生長因子的三維培養基中，成功培養出胃、結腸、肝和胰的類器官 [5, 6]。隨著類器官的快速發展，它需要一個清晰的定義。2014 年，Lancaster 和 Knoblich 正式將類器官定義為「源自幹細胞或器官前驅細胞（將會分化為器官細胞的細胞），並透過細胞分選和在特定位置下進行細胞特化，而自我成形的一群器官細胞」，這個定義正正概括了佐藤、Clevers 等人五年前意外發現的成果 [5]。

我們為何需要類器官？

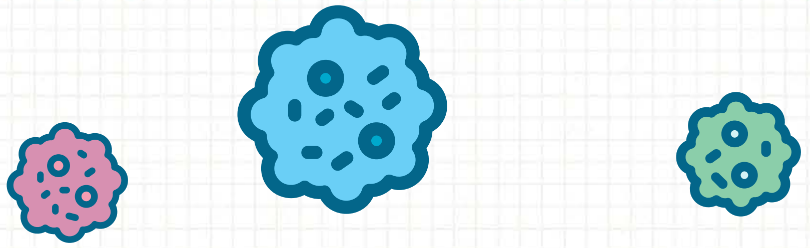
2013 年，Clevers 和渡邊的研究團隊發表了另一篇關鍵論文。他們的實驗證明，移植到小鼠腸道受損區域的腸道類器官仍然能夠正常運作 [7]，它們甚至與原來的身體組織融合得天衣無縫，以至在顯微鏡下幾乎無法與周圍組織區分 [2]。

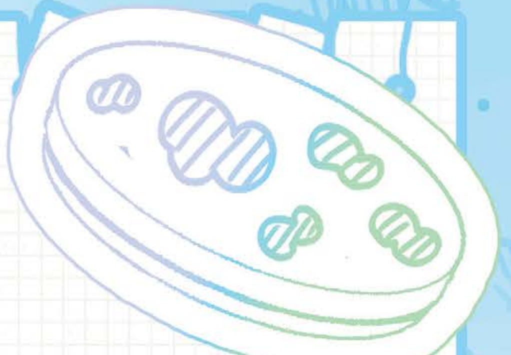
這項發現讓科學家思考將類器官應用於再生醫學（regenerative medicine）上的可能。使用患者自身細胞培養類器官使自體移植得以實現，因為將患者自身組織移植至其體內以取代功能衰竭的器官，就能避免傳統移植中排斥反應（即患者的免疫系統攻擊來自他人的移植器官）。2024 年，有研究團隊利用一名第一型糖尿病患者的身體組織培育出胰（島）類器官，然後移植回該名患者體內。在移植後 75 天，該名患者無需再依賴胰島素注射 [8]，治療了本為終生的疾病。這單一病例上的成功突顯了此方法的潛力，因此值得以臨床試驗進一步驗證。

除了再生醫學，研究人員傳統上一直使用動物模型代替人類。雖然這確實為治療疾病提供了不少啟發，但是人類仍有一些大小鼠等動物模型無法比擬的獨特之處 [9]。

從人類組織培育的類器官正好讓我們窺探這些獨特之處，典型例子是利用類器官研究被喻為可能是宇宙中最艱澀的人類大腦。腦的類器官較真正大腦簡單，讓我們更易理解這個像謎一樣的器官 [10]。有研究人員利用腦類器官追蹤胎兒腦細胞如何發育與遷移，也有研究人員將數個腦類器官連接，探究疼痛訊號如何從皮膚傳遞到大腦 [10]。

更重要的是，若要在囓齒動物上模擬疾病，科學家必須先了解病因，過程通常耗時一年 [9]。從患者組織培養



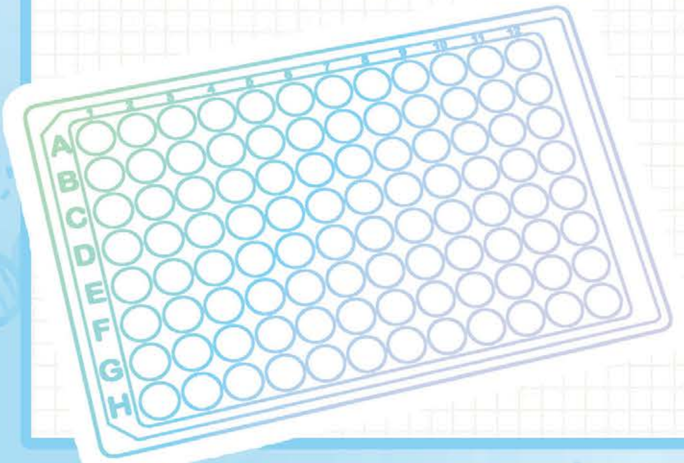


類器官能大幅縮短過程，讓科學家快速建立疾病模型。在腦類器官的研究中，科學家已利用來自患者的類器官模擬阿茲海默症和柏金遜症 [6]。

也許另一個更令人振奮的類器官應用是藥物篩選。一直以來，臨床試驗前對藥物毒性評估不佳，是許多新藥研發失敗的主因 [6]。這點在癌症藥物中尤為明顯，因為這類療法可能帶來嚴重，甚至致命的副作用。為此，研究人員透過比較源自同一患者的正常細胞和癌細胞所培育出的類器官對藥物的反應，就能更準確地評估藥物的功效和毒性 [6]。

再見實驗老鼠？

最後這一切到底意味著甚麼？類器官會終結「白老鼠」的時代嗎？目前還不會。模式生物在科學界仍有獨特價值，由於已有大量研究成果和成熟的實驗技術，動物模型提供了成本較低的方法進行基礎研究 [9]。雖然類器官在精準治療和再生醫學中的潛力已廣受認可，但這個領域仍處於起步階段，前方還有重大的技術瓶頸，臨床成果也相當有限。儘管如此，隨著美國通過《食品藥物管理局（FDA）現代化法案 2.0》，監管上的進程得以推進，因為法案授權使用類器官和人工智慧電腦模型等「嶄新方法」，取代新藥臨床試驗申請所需的強制動物測試 [11, 12]。這使新藥能以更有效，更能模擬人體反應的方式進行測試 [12]。2025 年 4 月，FDA 進一步宣布了在未來三至五年逐步淘汰動物實驗的路線圖 [11]。如此看來，可能在不久之後，至少在臨床試驗中，我們將能與實驗老鼠說再見。



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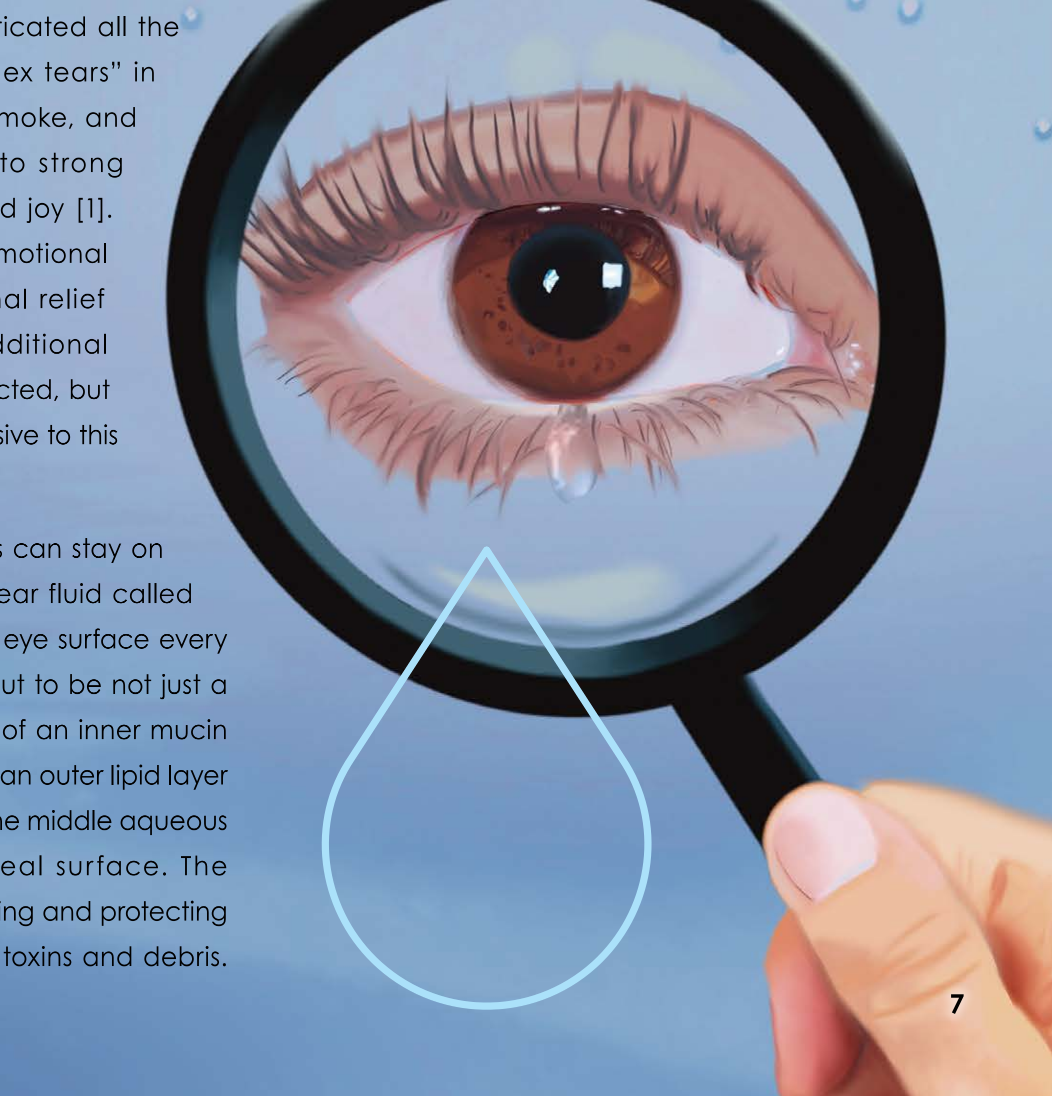
The Science of Tears 淚之科學

By Daria Zaitseva

Ever cried when watching a movie, chopping onions, or when dirt gets in your eye? The tears rolling down aren't just saline: They're a sophisticated biological fluid safeguarding your eyes, which contain metabolites, electrolytes, glucose, oxygen, and up to 1,500 proteins, including the most abundant ones associated with anti-inflammatory and antibacterial activity [1, 2]. Tears play a vital role in protecting and lubricating the eye surface. They can even offer insights about your health. Now let's unpack the science of tears!

What Makes a Tear?

First of all, tears can be classified into three types. "Basal tears" are for housekeeping purposes to keep the eye protected and lubricated all the time. Our eye also secretes "reflex tears" in response to irritants like dust or smoke, and "emotional tears" in response to strong emotions like sadness, anger, and joy [1]. Some scientists suspected that emotional tears could provide an emotional relief based on the discovery that additional proteins and hormones were detected, but current evidence remains inconclusive to this hypothesis [3].



Have you wondered why tears can stay on the eye surface? A thin layer of tear fluid called "tear film" is evenly spread on the eye surface every time we blink. The tear film turns out to be not just a layer of aqueous liquid; it consists of an inner mucin layer, a middle aqueous layer, and an outer lipid layer [1]. The inner mucin layer anchors the middle aqueous layer to the hydrophobic corneal surface. The aqueous layer is crucial for lubricating and protecting the eye surface by flushing away toxins and debris.

The outer lipid layer can maintain the thickness of the film by reducing the rate of tear evaporation. Only with these structures can the tear film be firmly attached to the eye surface.

Tear secretion is a carefully controlled process [4]. When sensory afferent nerves of the cornea and conjunctiva detect dryness and irritants [5], they will signal the efferent parasympathetic and sympathetic nerves connected to the lacrimal gland (Figure 1), to induce secretion of electrolytes, water, and proteins to the eye surface [4]. Notably, the sensory input can be modulated by the lacrimal nucleus of the brain, which integrates input from other centers as well, including emotional input, to produce a graded output. A stronger integrated input can induce the secretion of a greater volume of tear by the lacrimal gland. This can explain why tears overflow during emotional episodes, or in response to environmental irritants to flush away deleterious substances. In fact, low levels of nerve stimulation are already enough to produce basal tear to maintain the normal thickness of the tear film.

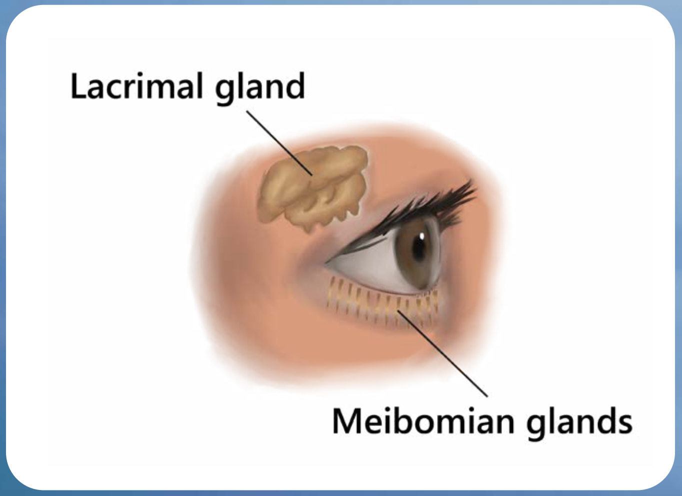


Figure 1 Lacrimal gland and meibomian glands.

Artificial Tears

The uncomfortable sensations of eye dryness can be distressing. Common causes of dry eye include eye strain from prolonged computer use, specific medical conditions, and exposure to smoky or windy environments [6].

To alleviate this discomfort, lubricating eye drops, often referred to as artificial tears, can be beneficial [7]. Most artificial tears consist of aqueous solutions with thickeners such as carboxymethyl cellulose, hyaluronic acid, hydroxypropyl guar, and polyethene glycol to enhance lubrication and prolong their stay on the eye. Natural tears are a non-Newtonian fluid whose viscosity temporarily reduces during each blink to protect the eye surface. Because of the resemblance to natural tears in terms of physical properties, hyaluronic acid is now under extensive research as a promising viscosity-enhancing agent. Other ingredients of artificial tears include electrolytes, pH buffers, antioxidants, and preservatives.

It is also worth noting that such aqueous-based artificial tears work by replenishing the aqueous layer of the tear film. However, lipid-based drops also become increasingly common as they can target the outer lipid layer, relieving dry eye symptoms in individuals whose meibomian gland (Figure 1) cannot properly secrete lipids to maintain the layer [7].

A Cry for Help: Tears in Disease Screening and Health Analysis

As a peripheral body fluid that can be collected in an easy and non-invasive manner, tears have been studied for their potential use in disease screening. By analyzing tear composition, it could be possible to diagnose a disease by quantifying certain biomarkers, in this case biological molecules associated with the disease in question. Scientists are exploring clinical applications for various diseases, from eye diseases like dry eye disease and allergic conjunctivitis, to neurological diseases like Alzheimer's disease.

For instance, in a subtype of dry eye disease caused by a deficiency in aqueous tear, inflammatory cytokines are synthesized and released to promote inflammation. Multiple studies reported that IL-6, IL-8, and IL-17 are three inflammatory cytokines that could potentially be the biomarkers for the diagnosis of aqueous-deficient dry eye disease [8].

Tear test, if successfully developed, could also help with the diagnosis of another eye disease, allergic conjunctivitis (AC). Type IV AC is associated with prolonged exposure to allergens, but it is often mistaken for seasonal type I AC in clinical practice. A quick test to quantify the amount of IgE in tear fluid could reliably differentiate the two conditions because low IgE levels are found to be indicative of type IV AC. The test will enable physicians to administer appropriate medication to the patients [9].

Non-invasive tear tests could also become an easy screening method for various neurological diseases because the elevated level of biomarkers in cerebrospinal fluid is also observed in tears in some cases. For example, TNF-alpha and alpha 1-antichymotrypsin are two such biomarkers for Parkinson's disease and multiple sclerosis, respectively [10]. Scientists are also making efforts to identify reliable biomarkers for Alzheimer's disease. If tear-based screening methods can be developed and commercialized eventually, we will be able to promote population screening in the community. Early diagnosis and treatment can improve the quality of life for both the patients and their caregivers [11].

As for tear-based biodevices, a recent study suggested the possibility for diabetic patients to continuously monitor their tear glucose level with a smart contact lens [12]. The previous challenge of using tear glucose level as an alternative indicator for blood glucose was that single measurement using conventional tear collection methods, such as filter paper strip and capillary tube, always undesirably induce the generation of reflex tears, which will interfere with the results. By embedding an antenna, a glucose sensor and an NFC chip in the soft contact lens, the research team could continuously monitor the glucose level in basal tears, with the ability to transfer real-time data to a mobile device.

While tears may contain a wide array of biomarkers that can reveal our health status, there is still a long way to go before relevant technologies can reach the clinic. With extensive research efforts working on the identification of biomarkers and the development of smarter biodevices, tears can one day become a powerful indicator of our health.

The Shape of Tears

One way to artistically study tears is to observe them under a microscope – by observing the air-dried salt crystals or the tear fluid compressed between a microscopic slide and a coverslip [13]. A photographer, Rose-Lynn Fisher, created a project called "The Topography of Tears," in which she captured the diverse morphology of tears shed by herself and her friends on various occasions.

More about the project:

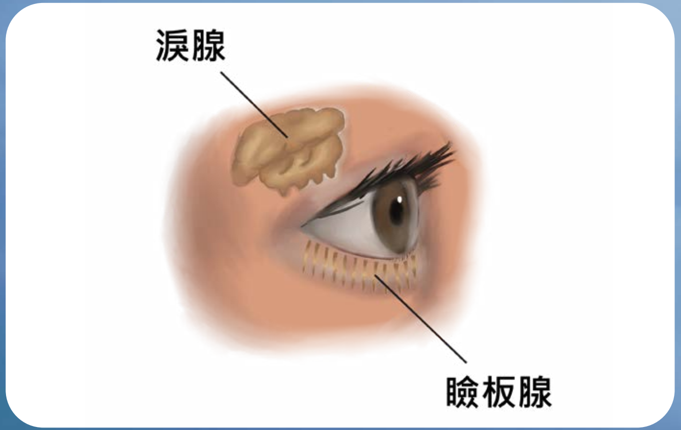
你曾在看電影、切洋蔥，或是有灰塵跑進眼睛時流過淚嗎？眼淚並不僅是鹽水：它是成分複雜的體液，能保護你的眼睛，當中包含代謝物、電解質、葡萄糖、氧，以及多達 1,500 種蛋白質，含量最高的蛋白質與消炎和抗菌息息相關 [1, 2]。淚液在保護和潤滑眼球表面上扮演至關重要的角色，甚至能讓你窺探自己的健康狀況。現在就讓我們揭開淚水的科學面紗吧！

淚水由甚麼構成？

首先，淚水可分為三類。「基礎眼淚」每分每刻都在保護眼睛及保持眼睛潤澤，而眼睛受塵埃或煙霧等刺激物刺激時會分泌「反射眼淚」，也會在悲傷、憤怒和喜悅等強烈情緒下分泌「情感眼淚」[1]。由於情感眼淚含有在其他眼淚中沒有發現的蛋白質和激素，有科學家猜測它能夠提供情感上的舒緩，儘管目前證據尚未能對此作出定論 [3]。

你有想過眼淚為何能停留在眼球表面嗎？每當我們眨眼，就能使稱為「淚膜」的淚液層均勻地分佈在眼球表面。淚膜不是單層水溶液，而是由底層的黏液層、中間的水性層和外層的脂質層這三層組成 [1]。底層的黏液層將中間的水性層固定在本為疏水的角膜表面。水性層對潤滑和保護眼球表面非常重要，皆因它能沖走毒素和碎屑。外層的脂質層則能降低淚液蒸發的速度，從而維持淚膜的厚度。只有具備這些結構，淚膜才能牢固地附著在眼球表面。

淚液分泌是受嚴密調控的過程 [4]，當角膜和結膜的感覺傳入神經偵測到乾燥和刺激物時 [5]，它們會向與淚腺（圖一）連接的傳出副交感神經和交感神經發出信號，使淚腺分泌電解質、水分和蛋白質至眼球表面 [4]。這些輸入信號可進一步被大腦的淚腺核調節，淚腺核會整合來自其他中樞的信號，包括情感輸入等，進而產生強度有別的輸出。換言之，經整合後強度較高的輸入能使淚腺分泌更多淚液，這解釋了為甚麼在情緒激動時眼淚會不斷流淌，以及在受到環境刺激時，眼睛能分泌大量淚水沖走有害物質。事實上，低水平的神經刺激就足以產生基礎淚液以維持淚膜的正常厚度。



圖一 淚腺與瞼板腺

人工淚液

眼乾所帶來的不適令人困擾，常見原因包括長時間使用電腦造成的眼睛疲勞，受某些疾病影響，或身處煙霧或大風中 [6]。

為了緩解不適，使用稱為「人工淚液」的滋潤眼藥水可能會有幫助 [7]。大多數人工淚液都由含有增稠劑的水溶液組成，以增強潤滑效果並延長其在眼球上的停留時間，添加的增稠劑可以是羧甲基纖維素、玻尿酸、羥丙基瓜爾膠或聚乙二醇等。天然淚液是非牛頓流體，黏度會隨每次眨眼暫時降低，以保護眼球表面。由於玻尿酸在物理特性上與天然淚液相似，因此科學家正對其進行深入研究，未來有望成為較廣為使用的增稠劑。人工淚液的其他成分還包括電解質、pH 緩衝劑、抗氧化劑和防腐劑。

值得提及的是，這類水性人工淚液是透過補充淚膜中的水性層發揮作用，然而脂質類眼藥水亦變得日益普及，因為它們能針對補充淚膜外層的脂質層，緩解因瞼板腺（圖一）無法正常分泌脂質而引起的乾眼症狀 [7]。

眼淚的秘密：淚液於疾病篩檢與健康分析中的應用

作為能以簡單、非侵入性方式收集的周邊體液，科學家正研究採用淚液作疾病篩檢用途。透過分析淚液成分，我們可以藉由量化當中的生物標記（即與特定疾病相關的生物分子）來診斷疾病。科學家正探索此技術在各種疾病中的臨床應用，涵蓋乾眼症和過敏性結膜炎，以至阿茲海默症等神經系統疾病。

譬如在因水性淚液分泌不足而引發的乾眼症中，身體會透過合成並釋放促炎性細胞因子引起發炎。多項報告因此指出，IL-6、IL-8 和 IL-17 這三種促炎性細胞因子就可能成為診斷淚液生成不足型乾眼症的生物標記 [8]。

如果淚液測試發展順利，亦可能有助診斷另一種眼疾：過敏性結膜炎。第四型過敏性結膜炎與長期接觸致敏原有關，但在臨床診斷上常被誤診為季節性的第一型。以快速測試量度淚液中免疫球蛋白 E（IgE）的含量，就能可靠地區分這兩種亞型，因為低 IgE 水平是第四型過敏性結膜炎的特徵。此測試將有助醫生為患者處方適當的藥物 [9]。

非侵入性的淚液測試亦可能成為各種神經系統疾病的簡易篩檢方法，因為在一些疾病中，腦脊髓液中生物標記含量上升的情況，亦出現在淚液中。舉例說，腫瘤壞死因子 α 和 α1 抗胰凝乳蛋白酶就分別是柏金遜症和多發性硬化症在淚液中可被觀察到含量上升的生物標記 [10]；科學家也正努力尋找阿茲海默症的可靠生物標記。如果淚液篩檢測試最終能成功開發並推出市場，我們將能在社區進行大規模篩檢，始終早期診斷和治療能改善患者及照顧者的生活質素 [11]。

在使用淚液的醫療裝置方面，最近一項研究提出糖尿病患者透過智能隱形眼鏡監測淚液葡萄糖水平的可能性 [12]。以往以淚液代替血液量度葡萄糖水平的挑戰在於淚液採集方法，使用傳統的單次淚液採集方法（如濾紙條和毛細管條等）總會刺激眼睛分泌反射眼淚，干擾量度結果。透過在軟式隱形眼鏡中嵌入天線、葡萄糖感測器和 NFC 晶片，研究團隊能夠持續監測基礎眼淚中的葡萄糖水平，並能實時將數據傳輸至行動裝置。

儘管淚液可能含有一系列能揭示我們健康狀況的生物標記，但在相關技術進入臨床應用之前仍有很長的路要走。隨著科學家更努力去尋找生物標記和研發更先進的醫療裝置，淚液有一天將能成為反映我們健康狀況的有力指標。

眼淚的形狀

其中一種研究眼淚的藝術方法是把其放在顯微鏡下觀看，鑑賞風乾後的晶體，或壓在蓋玻片下的淚液 [13]。攝影師 Rose-Lynn Fisher 因此展開了名為「眼淚拓撲學」的計劃，以顯微照片記錄她和朋友在不同場合下流過的眼淚。

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Do "Seas Within the Sea" Like in SpongeBob Really Exist?

《海綿寶寶》中的「海中之海」真的存在嗎？

By Jane Yang 楊靜悠

From Cartoon to Reality: The Mystery of Underwater Lakes

In the cartoon *SpongeBob SquarePants*, characters surf, sunbathe, and hang out at Goo Lagoon – a beach where the "goo" looks and acts like a separate body of water inside the ocean [1]. But wait – If they are all sea creatures which already live underwater, then why is there another pool? Isn't the whole ocean already water? This seems like pure cartoon nonsense...until you learn that "seas within the sea" actually exist on the ocean floor!

These strange underwater lakes are called deep-sea brine pools. They're not made of cartoon goo, but of extremely salty water. Because of this density difference, the brine doesn't mix with the ocean above [2–4]. Instead, it sits on the seafloor like a lake, with a visible surface you can even "float" a robot submarine on [5]. Just like in the cartoon, animals that wander too deep into the brine can die – because inside, there's almost no oxygen, and the water often contains high levels of hydrogen sulfide and methane, causing immediate suffocation and toxic shock for animals that enter it [2, 5, 6].

How Were Brine Pools Discovered?

One of the brine pool systems most frequently studied – the NEOM Brine Pools – was discovered in a 2020 expedition in the Gulf of Aqaba, between Saudi Arabia and Egypt [4, 5]. Located 1,770 meters below the surface, this site includes one large pool about the size of two football fields, and three tiny ones nearby [5].

The discovery of brine pools was made using a remotely operated vehicle (ROV) – basically an underwater robot with cameras. What they saw looked like something from another planet: a still, dark "lake" with an orange-to-gray rim, surrounded by shrimp and eels cautiously dipping in to grab stunned prey [4, 5].

How Do They Form?

Brine pools aren't filled by salt dumped from the sky. Instead, they form when ancient salt layers, buried under the seafloor for millions of years, dissolve into seawater that seeps down through cracks in the ocean crust [5, 6]. These massive salt deposits are leftovers from a time when the water body was partially cut off from the ocean and dried up [4]. In some regions, geothermal heating can enhance this circulation and dissolution process.

The resulting brine is so heavy that it flows downhill like syrup and collects in seafloor depressions. In the NEOM pools, the salinity within just 15 centimeters below the brine surface is four times greater than that of normal seawater above [5]. The oxygen levels crash to nearly zero within just 50 centimeters down the surface, killing most sea creatures inside [5].

A Pool of Death or An Underwater Oasis?

While the center of a brine pool may seem deadly, its edges are surprisingly alive. Researchers found a novel species of clam, *Apachecorbula muriatica*, in this mixing zone between normal seawater and brine [5, 7]. Shrimp, eels, and sharks also patrol the edges, using the brine like a trap: They watch as small animals drift in, get shocked and sink, then dart in to scavenge the easy meal [2, 4, 5]. This is what the BBC calls a "brine pool of death" – not because it's evil, but because its edges support life by harvesting death from its center [2].

Even more amazingly, life can also be found within the pool. The microbial communities vary significantly across different depths [5]. In the top layers, including the rim of the pool where microbes forming colorful "beaches," the microbes are primarily aerobic. However, in the deeper regions, anaerobic microbes that can survive without oxygen take over. Those microbes are equipped with diverse metabolic capabilities to generate energy in low-oxygen environments, such as sulfate reduction, methanogenesis and fermentation.

Why Do Scientists Care?

Brine pools aren't just weird – they're scientific treasure chests. Because of its inhospitability to animals, the seafloor remains undisturbed due to the lack of burrowing animals. The sediments at the bottom stay perfectly layered, like pages in a history book. In the NEOM pools, scientists pulled up a 1,200-year-old sediment core that records flash floods, underwater landslides, and even tsunamis – including the one possibly linked to the powerful 1995 Nuweiba earthquake [4, 5].

So next time you watch SpongeBob surf at Goo Lagoon, remember: The ocean is full of real wonders stranger than fiction. The “sea within the sea” isn’t just a cartoon joke – it’s a window into Earth’s hidden past and possibly life beyond our planet.

從動畫到現實：水底湖泊之謎

在動畫《海綿寶寶》中，角色在「酷樂湖」（Goo Lagoon）衝浪、曬太陽和玩耍；那是一片海灘，黏液在海洋世界裡構成了獨立的水體 [1]。等等，如果角色們本來就是活在水中的海洋生物，那為甚麼要另一個海洋呢？本來的海洋不就是水嗎？這看來純粹是動畫胡扯……直至你認識實際存在於海床上的「海中之海」！

這些奇怪的水底湖泊稱為深海鹽池，它們並不像動畫裡的由黏液形成，而是鹽度極高的鹹水。由於密度差異，這些鹽水不能與上方的海水混合 [2–4]，因此反而會像湖泊一樣停留在海床上，甚至可以在其可辨別的「水面」上放置一架漂浮潛艇 [5]。就像動畫裡一樣，誤闖鹽池的動物可能會性命不保，因為鹽池內幾乎沒有氧氣，並通常含有高濃度的硫化氫和甲烷，導致動物窒息及麻痺 [2, 5, 6]。

鹽池是如何被發現的？

經常被研究的鹽池包括 NEOM 鹽池群，它是在 2020 年於沙特阿拉伯和埃及之間的亞喀巴灣進行探險活動時被發現 [4, 5]，地點位於水底 1,770 米，由一個約兩個足球場大的大池，和附近三個小池組成 [5]。

這組鹽池是透過水底遙控載具發現的，亦即是帶攝影機的水底機械人。科學家看到的畫面彷彿來自另一個星球：靜止的「湖泊」顏色深沉，邊緣由橙色漸變成灰色，四周有蝦和鰻魚小心翼翼地探入其中，捕捉被麻痺的獵物 [4, 5]。

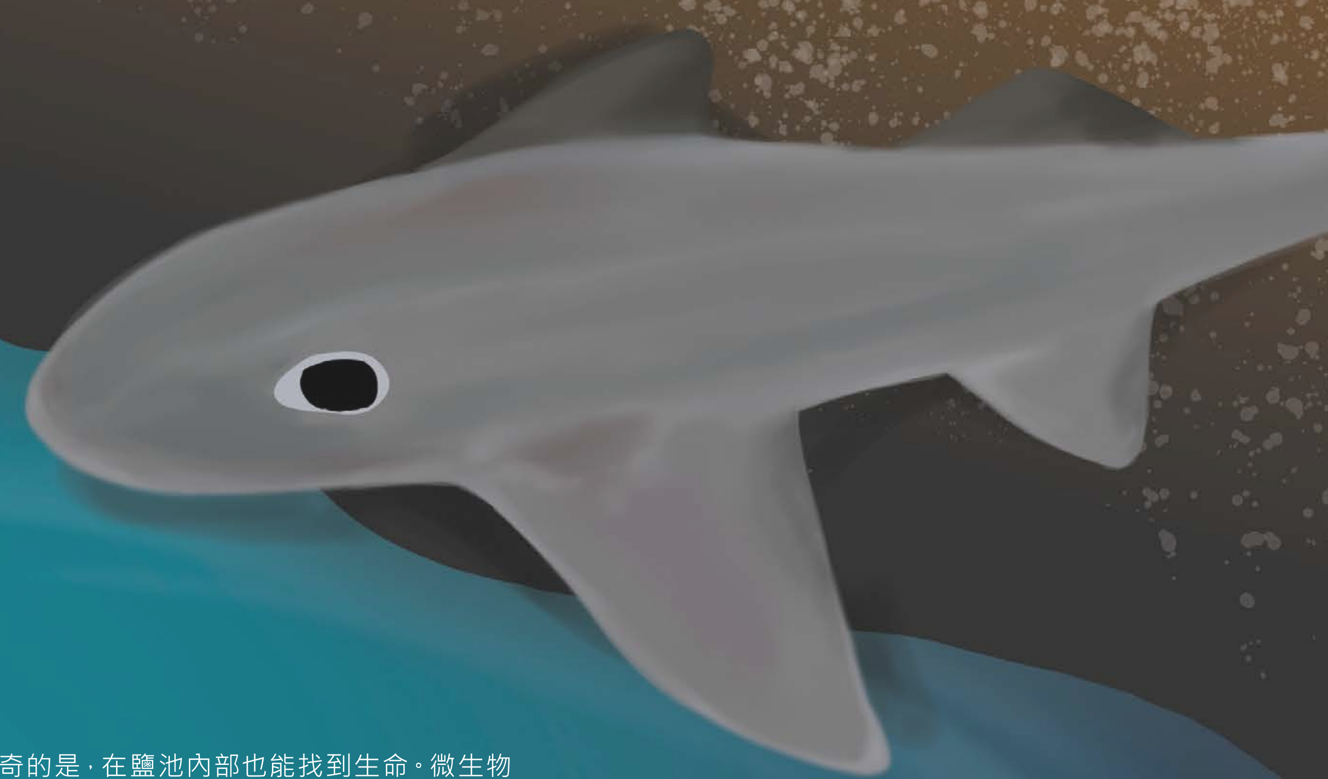
鹽池如何形成？

鹽池的鹽分並不是從天而來。過往部分海洋被分割成半獨立的水體，它們乾涸後留下巨大的沉積鹽 [4]。這些埋於海床下數百萬年的古老鹽層，再次被海水溶解後，從海洋地殼裂縫滲出，形成現在的鹽池 [5, 6]。在某些地區，地熱能加快這種流動和溶解的過程。

由此產生的鹽水密度非常高，會像糖漿般向下流動，積聚於海床的窪地中。在 NEOM 鹽池群，池下僅 15 厘米處的鹽度比上方一般海水高出四倍 [5]，而池下 50 厘米處的氧氣濃度就驟降至近乎零，足以殺死大部分海洋生物 [5]。

死亡之池還是水中綠洲？

雖然鹽池中心看似死氣沉沉，但邊緣卻出奇地充滿生機。研究人員在一般海水與鹽水交界的區域發現了一個新的蛤類物種 — *Apachecorbula muriatica* [5, 7]。蝦、鰻魚和鯊魚也在邊緣徘徊，把鹽池當作狩獵陷阱：牠們看著小動物闖進鹽池，麻痺然後下沉，就以迅雷不及掩耳的速度撿去這些垂手可得的食物 [2, 4, 5]。這就是英國廣播公司（BBC）稱之為「死亡鹽池」的原因：與其說是鹽池本身危機四伏，不如說這種以池中亡靈供養池邊生態的循環細想之下令人不寒而慄 [2]。



更令人驚奇的是，在鹽池內部也能找到生命。微生物群落隨深度不同會有顯著差異 [5]。頂層的微生物主要是好氧的，包括賦予「海灘」顏色的微生物所棲息的鹽池邊緣。然而，更深的區域轉為由可在無氧環境下存活的厭氧微生物佔據。這些微生物具有不同可在低氧環境下產生能量的特殊代謝能力，例如硫酸鹽還原、甲烷生成和發酵作用等。

科學家為何關注鹽池？

鹽池不僅奇特，更是科學寶庫。由於不宜動物居住，海床在沒有穴居動物干擾下保持了原貌，池底的沉積物就像一頁頁歷史書一樣分層完美。科學家從 NEOM 鹽池群提取了一塊具 1,200 年歷史的沉積物岩芯，當中記錄了歷史上的洪水、海底崩移（underwater landslides），甚至海嘯 — 包括可能與 1995 年努韋巴強烈地震相關的海嘯 [4, 5]。

所以，下次你看到海綿寶寶在酷樂湖衝浪時，請記住海洋充滿著比虛構故事更荒謬的奇觀。「海中之海」不僅是動畫裡的玩笑，亦是通往地球過去的窗口，也讓我們窺探可能存在於我們星球之外的生命模樣。

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Decoding the Aerodynamics of Incredible Shots Across the Sport Arena

劃過賽場上空的變幻球：空氣動力學

By Sam Fan 樊潤璋

Moments Made for Slow Motion

You must have seen the highlights: Lionel Messi's free kick curls around a wall of players as if it were being pulled by an invisible hand, bending perfectly into the top corner of the goal. This is the classic "banana kick." On the volleyball court, Japanese star Yuji Nishida strikes the ball with spin, causing it to bend sharply just before it reaches the receiver, often forcing a mistake in receive, or even scoring a clean ace. Then there are float serves, shots hit with almost no spin that can suddenly drift sideways in midair.

These tricks may seem very different, happening on different courts and fields, but they are all driven by the interaction between a moving ball and the air surrounding it. Whether a ball spins rapidly or barely at all, subtle changes in airflow can dramatically alter its path. This raises an interesting question: What exactly determines how a ball flies? Of course, the player's technique matters: the power of the kick, the angle of contact, and the amount of spin they apply. How about a ball that is perfectly round and completely smooth? Would it be easier to control and more predictable in flight? Uncovering what lies behind these factors reveals how players can control a ball's motion by changing the way it interacts with the air.

The Magnus Effect

Balls used in sports are rarely a perfect sphere but often with stitching and surface texture. When a ball is spinning, the friction drags the surrounding air along with the rotation, setting the nearby airflow into motion [1–3].

As shown in Figure 1, on the side of the ball where the surface motion works against the airflow, the air struggles to stay attached and breaks away from the surface much earlier (point A). On the opposite side where the surface rotation is aligned with the airflow, the rotation helps the air remain attached for longer and follows more of the ball's curved surface before it separates (point B). As a result, the airflow behaves differently on the two sides of the ball; the air on the side where the rotation is opposite to the direction of air motion is deflected more strongly than the other side [2, 4].

By Newton's third law, when the ball deflects the surrounding air more strongly to one side, say to the left, the air molecules push back with an equal and opposite force (Figure 1). This reaction force acts sideways on the ball causing the ball to curve in flight, an effect known as the Magnus effect. The direction of the curve depends on the direction of spin [2, 3, 5].

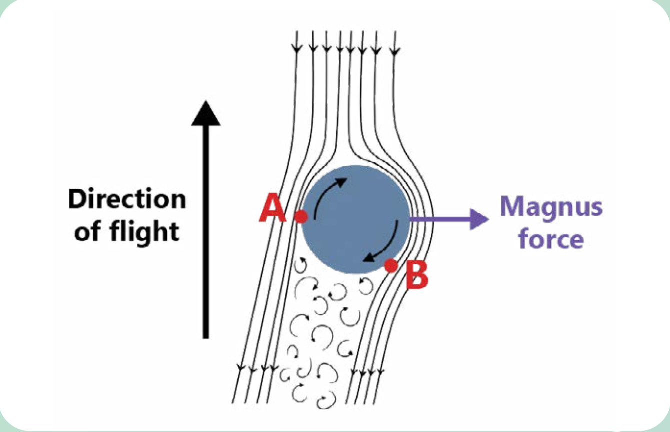


Figure 1 A diagram showing the airflow surrounding a ball in motion. Air separates from the ball surface at points A and B. On the side of the ball where the motion works against the airflow, the air struggles to stay attached, whereas the air remain attached for longer on the opposite side.

The Knuckleball Effect

How about Cristiano Ronaldo's signature knuckleball free kick with almost no spin? When such a ball moves through the air, it pulls some of the surrounding air along with it, but this air cannot always follow the ball's curvature all the way around. Eventually, it will separate from the surface. Without spin to stabilize this separation, the ball no longer experiences the smooth sideways force seen in the spinning case. But that doesn't mean it will fly straight; its motion actually becomes harder to predict [6, 7].

Ideally, if the airflow separated evenly on all sides, the wake would remain balanced and the ball would fly straight. In reality, without spinning to stabilize the flow, even small disturbances due to the seams on the ball [3], tiny changes in air speed, or turbulence in the surrounding air can cause the airflow to break away earlier on one side than the other randomly, with the separation point shifting from side to side during flight. When this happens, the force acting on the ball also becomes unbalanced and constantly changing [6–8].

This may cause the ball to wobble, dip, or suddenly veer off course while it is in the air, making it difficult for opponents to judge where it will go next. This is commonly seen in volleyball float serves that suddenly drop just before the bottom line and football knuckle shots that seem to hang in the air before dipping unexpectedly.

In the 2010 FIFA World Cup, the extra smooth match ball called "Jabulani" drew widespread criticism for its erratic flight. When a ball's surface texture is too smooth, it cannot "grip" or effectively drag the surrounding air by friction, making the airflow harder to maintain attached to its surface. As a result, the airflow tends to separate more easily and unpredictably, pushing the aerodynamics toward the knuckleball effect rather than a stable Magnus effect.

The Aerodynamicist's Toolkit: Applications Across Industries

To understand aerodynamics of "Jabulani," scientists conducted wind tunnel experiments, mounting the ball on a support rod and blowing air past it at controlled speeds to measure drag and lateral forces directly. The measured data were then applied to computer simulations, to predict and analyze its flight paths by solving complex equations of fluid motion [6]. These methods are not limited to sports but also applied to investigate aircraft wings to improve lift and control, vehicles to reduce air resistance, and buildings to understand how strong winds act on tall structures. In the 2026 World Cup, it will be interesting to see what new surprises the next generation of match balls may bring.

為慢動作而設的瞬間

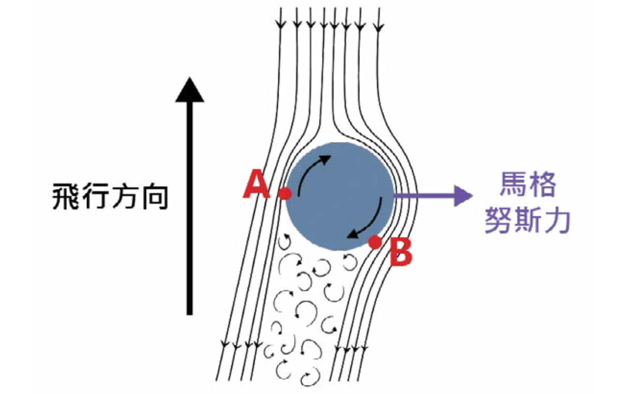
你一定看過的賽事精華：美斯（Lionel Messi）的罰球如同被一隻無形的手拉出一條弧線，完美地彎過人牆直飛球門上方死角 — 這就是所謂「香蕉球」。在排球場上，日本球星西田有志（Yuji Nishida）擊球時施加的旋轉，令球在接近接球員前突然轉向，常常迫使對方接發失誤，甚至直接得分。還有幾乎不帶旋轉的飄浮球，在空中突然橫向飄移。

這些出現在不同運動場上的招式看似大相逕庭，但全都源於飛行中的球與周圍空氣之間的相互作用。無論球是高速旋轉還是幾乎不轉，氣流的微妙變化都能大幅改變球的飛行軌跡。這引發了一個有趣的問題：究竟是甚麼決定球如何飛行？球員的技術固然重要：踢球的力道、擊球的角度，以及施加旋轉的多寡。如果用上一顆完美渾圓，且表面光滑的球又會怎樣呢？球會變得更易控制，飛行路徑更可預測嗎？深入了解這些因素背後的原理，便能知道球員是如何透過改變球與空氣的互動方式去掌控球的運動。

馬格努斯效應

由於體育用球很少是完美球體，通常帶有縫線和表面紋理，因此當球旋轉時，摩擦力會帶動周圍空氣隨之轉動，使附近空氣流轉 [1–3]。如圖一所示，在球旋轉方向與氣流相反的一側，空氣較難貼附在球上，因此會較早從表面分離（A 點）。而在另一側，球的旋轉方向與氣流一致，旋轉有助空氣貼附在球面更久，所以空氣會沿著球的彎曲表面流動更遠才分離（B 點）。因此，氣流在球兩側的表現並不相同，在旋轉方向與空氣流動方向相反的一側，空氣會被偏轉（反彈）得比另一側更多 [2, 4]。

根據牛頓第三定律，當球在其中一側把周圍空氣更強烈地偏轉時，譬如是左方，空氣分子會施加大小相等而方向相反的反作用力（圖一）。反作用力會橫向施加於球上，使球以弧線飛行 — 這種現象稱為馬格努斯效應。飛行路徑彎曲的方向取決於旋轉方向 [2, 3, 5]。



圖一 顯示運動中球體周邊氣流的示意圖。氣流在 A 和 B 點從球的表面分離。在球的旋轉方向與氣流相反的一側，空氣難以貼附；而在另一側，空氣能貼附更久。

蝴蝶球效應

C 朗拿度（Cristiano Ronaldo）幾乎不帶旋轉的招牌「落葉射球」又是怎麼回事？當球在空中移動時，它會帶動一些周圍的空氣前進，但空氣始終無法完全跟隨球的曲面流動，最終仍會從球面分離。由於沒有旋轉來穩定分離過程，球也不再像旋轉情況那樣感受到穩定的側向力，但這不代表它會筆直飛行，事實上運動路徑反而會變得更難預測 [6, 7]。

在理想情況下，如果氣流在各個方向都均勻分離，尾流就會保持平衡，球也會沿直線飛行。但現實上，在沒有旋轉穩定氣流時，即使只是球上的縫線造成的空氣擾動 [3]、微小的風速改變，或周圍空氣中的湍流，都能使氣流隨機在某一側比另一側更早分離，令分離點在飛行過程左右移動。在這種情況下，作用在球上的力也會變得不平衡，而且不停改變 [6–8]，令球在空中搖晃、下墜，或突然改變方向，使對手難以判斷去向。這種現象常見於排球中在接近底線前突然下墜的飄浮發球，以及足球中看似在空中飄浮，然後突然下沉的「落葉射球」。

回顧 2010 年 FIFA 世界盃，當時表面格外光滑的比賽用球「普天同慶」（Jabulani）就因飛行軌跡飄忽不定而備受批評。當球的表面過於光滑時，便無法有效地透過摩擦力「抓住」或帶動周圍空氣，令氣流難以穩定地附在球面。結果氣流更容易，而且不規則地分離，使球的空氣動力學行為偏向蝴蝶球效應，而非穩定的馬格努斯效應。

跨領域的應用：空氣動力學家的工具箱

為了研究「普天同慶」的空氣動力學特性，科學家進行了風洞實驗，將球固定在支撐桿上，再以特定的風速吹過球體，直接測量阻力和側向力。數據隨後被應用於電腦模擬之中，透過解開複雜的流體運動方程式來預測和分析球的飛行路徑 [6]。這套方法不僅用於體育範疇，也廣泛應用於飛機機翼的研究，以改善升力和操控性；亦應用於車輛設計，以降低空氣阻力；以及應用於建築，以了解強風對高樓結構的影響。在 2026 年世界盃賽場上，新一代比賽用球又會帶來甚麼驚喜？讓我們拭目以待吧。

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From Grapes to Diamonds:
The Fascinating World of Wine Crystals
從葡萄到鑽石：葡萄酒結晶的奇妙世界

By Roshni Printer

Wine Crystals Explained

At the bottom of some wine bottles or on the cork, you may notice small, clear crystals that winemakers call "wine crystals" or "wine diamonds (Figure 1)." Though they can resemble shards of glass, which sometimes surprise consumers, these crystals are completely harmless. They are a natural salt that forms from tartaric acid, an acid naturally present in grapes. In fact, crystals like these once helped unlock one of the most profound ideas in modern science: chirality.

Figure 1 Wine crystals on a cork.
Photo credit: Francesco Santini [1]

The Process of Crystallization: From Grapes to Diamonds

Let's first examine how these crystals form. Grapes contain several organic acids, but tartaric acid is the signature acid of grapes and wine [2]. During winemaking, depending on the wine's pH, tartaric acid can lose a hydrogen ion (H^+) and become bitartrate, also known as hydrogen tartrate. Meanwhile, wine contains potassium ions (K^+) derived from grapes as well. When potassium ions meet bitartrate, they combine to form a salt called potassium hydrogen tartrate (KHT).

Due to its relatively low solubility in water, KHT can "drop out" as crystals under certain conditions [3, 4]. Firstly, its solubility decreases with temperature, so chilling wine in a cold room, fridge, or cool climate encourages crystallization. Also, its solubility in aqueous ethanol drops as the ethanol content rises during alcoholic fermentation, causing KHT to precipitate during the winemaking process.

To avoid consumer's concerns about food safety, wineries use different ways to prevent post-bottling crystal formation [3]. A common technique is "cold stabilization," where the wine is chilled on purpose so that the salt crystallizes in storage tanks and can be filtered out before bottling. Other methods include the removal of compounds that involve KHT precipitation, and the introduction of additives to inhibit or decelerate the crystallization process.

Louis Pasteur and the Discovery of Chirality in Tartaric Acid

Although we now have extensive knowledge about tartaric acid and its salts, in the 1800s, tartaric acid presented an intriguing puzzle to scientists. To understand their early experiments, it helps to first understand polarized light. In unpolarized light – such as sunlight – the electric field vibrates in many random directions perpendicular to the light's direction. However, in plane-polarized light, the electric field vibrates in only one fixed direction (or on a single plane) as the light travels forward.

In early 1800s, scientists have already discovered that when plane-polarized light is passed through the solution of natural tartaric acid or its salts, the plane of polarization rotates clockwise [5]. One day, an industrial chemist, Phillippe Kestner, discovered a mysterious acid from the winemaking process [5]. The mysterious acid, later named paratartaric acid, appeared to share the same chemical composition with natural tartaric acid (at that time they didn't know the chemical structures) but showed no rotation [6]. This was perplexing because both acids should have behaved the same way.

A French chemist (later known as "the father of microbiology"), Louis Pasteur, approached this mystery from a novel angle. He examined the crystals formed by paratartaric acid under a magnifying glass, and observed that crystals occurred in two shapes that were mirror images of each other (Figure 2) [5, 7]. They were almost identical – but like left and right hands that could not be perfectly placed on top of the other. Pasteur separated these crystals with a tweezer and dissolved them to make two solutions. He found that one solution rotated polarized light to the left while the other rotated it to the right. When mixed in equal amounts, their rotations cancelled each other out.

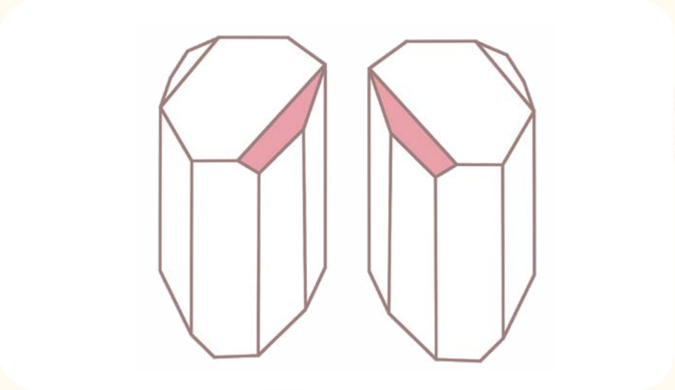


Figure 2 The two types of chiral crystals observed by Louis Pasteur [5].

This discovery introduced the concept of chirality to chemistry. Scientists further deduced that the chirality of tartaric acid crystals might stem from the dissymmetric structure of the molecules [5]. The hypothesis was not proved until 1940s; the structure of tartaric acid was revealed with the availability of rigorous X-ray diffraction analysis [7].

Why Chirality Matters

Intriguingly, chirality matters in nature. A classic example comes from amino acids, the building blocks of proteins. Most amino acids (except glycine) consist of four different atoms or groups of atoms bonded to the central carbon, so there are left-handed amino acids and right-handed amino acids (Figure 3), which rotate polarized light to left and right respectively. Interestingly, almost all proteins in mammals are constructed exclusively by left-handed amino acids [8]. This remarkable preference of handedness also applies to other molecules, like sugars. Enzymes and cell receptors bind strongly to their substrates only when their molecular handedness matches. This explains

why many modern medicines must be produced in a specific chiral form: One version may heal, while the mirror image could be ineffective or even harmful.

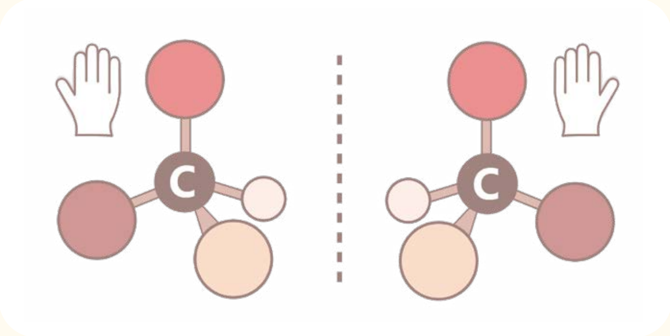


Figure 3 A left-handed and a right-handed amino acid with the central carbon bonded to four different atoms or groups of atoms.

Birefringent Beauty: The Artistic Inspiration from Wine Crystals

Another interesting property of wine crystals is their display of vivid colors when polarized light passes through them under a microscope [9]. When polarized light enters these "birefringent" crystals, it splits into two light waves that travel at different speeds and directions inside the crystal. The two waves can become out of phase with each other. When they recombine as they exit the crystal, they undergo interference – constructively or destructively depending on how their peaks and troughs align. This produces a resultant wave with an altered amplitude and wavelength – and therefore color. As the interaction with light varies with different orientation, the interference generates different bright colors that shift as the crystal is rotated. Contemporary artists and designers have occasionally drawn inspiration from this phenomenon; for instance, installations using polarizing films and birefringent materials create dynamic color displays that change with viewing angles, echoing the optical effects first observed in birefringent crystals.

From Observation to Insight: Pasteur's Scientific Legacy

Pasteur's work led to the discovery of the fact that nature distinguishes between left and right, and revealed the existence of a preference that shapes phenomena ranging from light behavior to the fundamental workings of living organisms. In this sense, wine crystals serve as a gentle reminder that profound scientific ideas can emerge from just careful observation of everyday life, and that even the smallest structures may carry clues to the deeper organization of the natural world.

Photo Gallery: The Art of Wine Crystals

These stunning photos of wine crystals were captured by a Canadian photographer, Dr. Robert Berdan, with a digital camera and a polarized light microscope [9]. One can definitively turn a science topic into a creative art project!

Stoneleigh Chardonnay crystals by polarizing microscopy 50X. Note the lack of smooth curves in these crystals.

Stoneleigh Chardonnay crystals by polarizing microscopy 50X. Note the lack of smooth curves in these crystals.

認識葡萄酒結晶

在葡萄酒瓶的底部或軟木塞上，你可能見過被釀酒師稱為「葡萄酒結晶」或「葡萄酒鑽石」的透明小晶體（圖一）。儘管它們像玻璃碎片的外貌也許會嚇怕消費者，但這些結晶完全無害。它們是由酒石酸（tartaric acid）形成的鹽，而酒石酸是天然存在於葡萄中的酸。事實上，這些晶體曾經幫助解開現代科學其中一個最影響深遠的概念：手性。

圖一 軟木塞上的葡萄酒結晶

圖片來源：Francesco Santini [1]

從葡萄到鑽石：結晶過程

讓我們看看這些晶體如何形成。葡萄含有多種有機酸，但酒石酸是葡萄和葡萄酒中最具標誌性的酸 [2]。在釀酒過程中，根據葡萄酒的 pH 值，酒石酸可以失去一個氫離子（H^+），形成酒石酸氫鹽（bitartrate 或 hydrogen tartrate）。與此同時，葡萄酒也含有來自葡萄的鉀離子（K^+）。當鉀離子與酒石酸氫鹽相遇時，會結合成一種稱為酒石酸氫鉀（potassium hydrogen tartrate）的鹽。

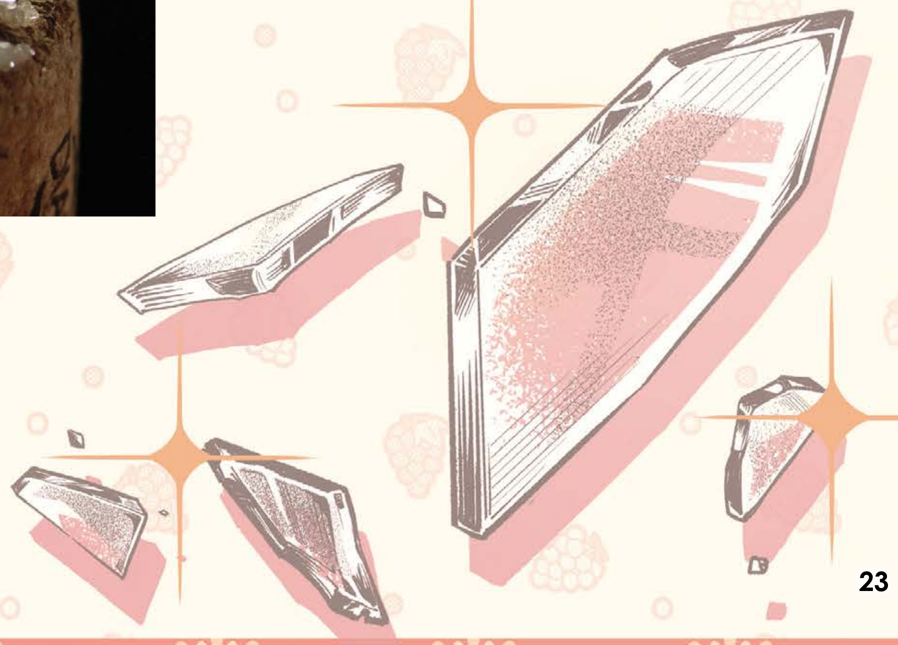
由於酒石酸氫鉀在水中的溶解度相對較低，在特定條件下它會結成晶體 [3, 4]。首先，其溶解度會隨溫度降低而下降，因此在冷藏室、冰箱或寒冷氣候中冷卻葡萄酒會促進結晶。此外，在酒精發酵過程中，隨著乙醇含量增加，酒石酸氫鉀在乙醇水溶液的溶解度會下降，導致酒石酸氫鉀在釀酒過程中沉澱出來。

為了減少消費者對食物安全的擔憂，酒莊採用不同方法防止葡萄酒在裝瓶後結晶 [3]。常見技術包括「冷穩定處理」（cold stabilization），即是刻意將葡萄酒冷卻，使酒石酸氫鉀在儲存罐內結晶，然後在裝瓶前將其過濾掉。其他方法包括去除有助酒石酸氫鉀沉澱的化合物，以及加入添加劑來抑制或減慢結晶過程。

Louis Pasteur 與酒石酸手性的發現

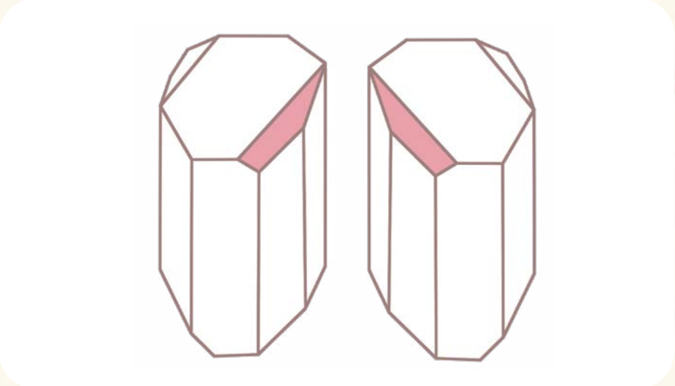
儘管我們現在對酒石酸及其鹽類已有深入了解，但在 19 世紀，酒石酸曾給科學家帶來過饒有趣味的難題。要理解早期的實驗，就要先認識偏振光。在包括陽光在內的非偏振光中，電場沿著與光前進方向垂直的許多隨機方向振動。然而，隨著光前進，平面偏振光中的電場只會向一個固定方向（在單一平面上）振動。

在 19 世紀初，科學家已經發現，當平面偏振光穿過天然酒石酸或其鹽類的溶液時，偏振平面會順時針旋轉



[5]。有一天，工業化學家 Phillippe Kestner 在釀酒過程中發現了一種神秘的酸 [5]。這種後來被命名為副酒石酸（paratartaric acid）的神秘物質，似乎與天然酒石酸在化學成分上相同（當時他們並不知道其化學結構），但卻沒有旋光性 [6]。這令人費解，因為兩種酸的表現理應相同。

法國化學家 Louis Pasteur（亦是後來的「微生物學之父」）選擇從新穎的角度探究這個謎團。他用放大鏡觀察副酒石酸形成的結晶，發現晶體呈現兩種互為鏡像的形狀（圖二）[5, 7]，兩個形狀幾乎相同，但就像左手和右手一樣無法完全重疊。Pasteur 用鑷子將晶體分類，並分別溶解成兩種溶液。他發現其中一種溶液使偏振光向左旋轉，而另一種則使其向右旋轉；當兩者等量混合時，旋光效應互相抵消。

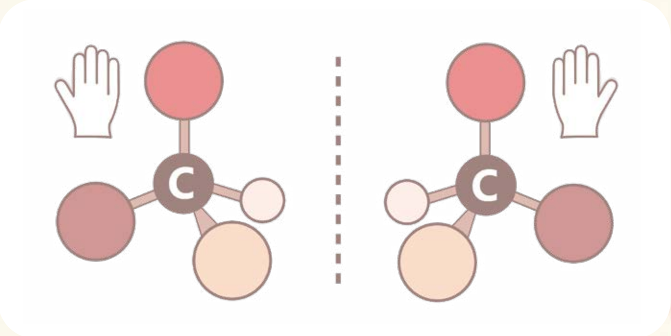


圖二 Louis Pasteur 觀察到的兩種手性晶體 [5]

這發現為化學界引入了「手性」的概念。科學家進一步推斷，酒石酸晶體的手性可能源於其分子不對稱的結構 [5]。隨著 X 射線繞射分析技術的出現，直到 20 世紀 40 年代，酒石酸的結構才得以揭示，證實這假說 [7]。

手性的重要性

手性在自然界至關重要，經典例子包括構成蛋白質的基本單位 — 氨基酸。大多數氨基酸（甘氨酸除外）的中心碳原子都連上四個不同的原子或原子團，因此氨基酸有左旋和右旋之分（圖三），分別使偏振光向左和向右旋轉。有趣的是，哺乳類動物中幾乎所有蛋白質都由左旋氨基酸構成 [8]。這種對特定手性的偏好也適用於其他分子，例如糖類。酶和細胞受體（本地課本譯作感受器）只有在手性匹配時，才能與基質牢固結合。這也解釋了為何許多現代藥物必須以特定的手性生產，因為其中一種手性可能有效，但其鏡像異構物則可能無效，甚至有害。



圖三 左旋和右旋氨基酸，其中心碳原子與四個不同的原子或原子團相連。

雙折射之美：葡萄酒結晶的藝術啟發

葡萄酒結晶的另一個有趣特性是，當偏振光穿過晶體時，晶體會在顯微鏡下展現鮮艷色彩 [9]。因為當偏振光進入這些雙折射晶體，光線會分裂成兩束在晶體內部以不同速度和方向傳播的光波，而兩束光波可能變成異相（out of phase），並在離開晶體時重新組合，發生干涉現象。根據波峰和波谷的對齊方式，光波會產生相長或相消干涉，形成振幅和波長都與原來不同的光波，因此顏色亦有所偏移。由於晶體與光的相互作用隨方向而異，因此旋轉晶體時干涉會使其產生不斷變化的明亮色彩。當代藝術家和設計師有時會從此現象汲取靈感，使用偏振膜和雙折射材料製作裝置藝術，創造隨觀看角度變化的動態色彩，這呼應了最初在雙折射晶體中觀察到的光學現象。

從觀察到見解：Pasteur 遺下的寶藏

Pasteur 的研究揭示了自然界會區分左右這一事實，並展現了一種從左右光的行為，到關乎生物基本運作的偏好。葡萄酒結晶的故事提醒我們，影響深遠的科學發現可能僅源於對日常生活的細心觀察，而即使是最小的結構，也能蘊含揭示大自然規律的線索。

相片集：葡萄酒結晶的藝術

這些驚艷的葡萄酒結晶照片由加拿大攝影師 Robert Berdan 博士以數碼相機和偏振光顯微鏡拍攝 [9]。誰說科學主題不能變成充滿創意的藝術項目？

偏振光顯微鏡以 50 倍拍攝的 Stoneleigh 灰皮諾葡萄酒結晶。

以偏振光顯微鏡拍攝的 Stoneleigh 霞多麗葡萄酒結晶，注意在 50 倍放大下晶體不平滑的細節。

More about Dr. Berdan's works:
了解更多關於 Berdan 博士的作品：

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