

Time Crystal Synthon: The Way to Integrate Cascade Reactions for Advancing Multistep Flow Synthesis

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Abstract: Multistep flow catalytic reactions in organic chemistry integrate multiple sequential organic reactions to enhance cost-efficiency, time management, and labour resources, all while boosting effectiveness and environmental sustainability. Similar to how we select molecular synthons for reactions in retrosynthesis, we can employ time-crystal synthons to integrate catalytic reaction cycles in the development of a reaction pathway. This involves considering individual catalytic reaction steps of cycles as time-consuming events that can be topologically arranged like a clock. This results in a perpetual machine that violates time translational symmetry, leading to the production of a time crystal. This approach involves transferring a single product from one catalytic cycle to a neighbouring reaction cycle, connecting various reaction vessels vertically to establish a ‘cascade’ of reaction cycles. Additionally, catalytic cycles can be integrated by sharing common reaction steps or implementing a metathesis reaction at the junction zone of two neighbouring cycles. Here, the concept of time-crystal synthons facilitates the linear integration of heterogeneous catalytic cycles, step by step, to transfer products through the common reaction medium when modifying conventional flow synthesis. Significantly, this time-crystal synthon-driven multistep approach offers advantages over conventional flow synthesis, as the reaction vessels can be equipped with microwave and photosynthesis methodologies, allowing for the collection of specific products from their respective vessels as needed, providing more options to integrate reactions and enabling flow control using gravity.

Keywords: time crystal synthon; fractal time crystal; cascade of cascade reaction; supramolecular catalyst; chemical technology; circadian consciousness



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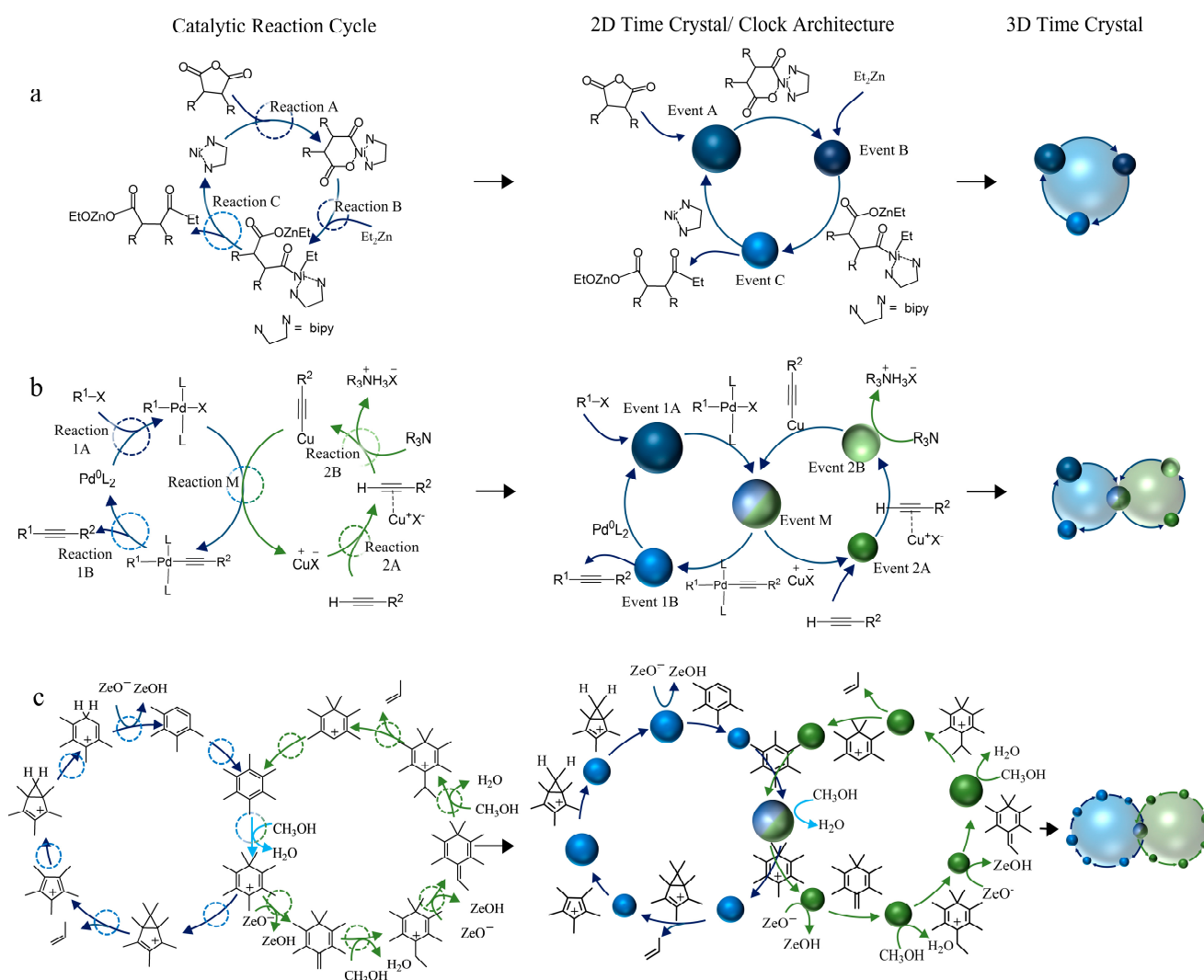


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1. Introduction

A multistep flow system in organic synthesis is gaining popularity over conventional batch systems for its rapid productivity, cost-effectiveness, safety, reproducibility [1–4], and control [5]. The purity in the flow system is becoming addressable with the online purification process in between the two reactions [6]. By packing the heterogeneous catalyst in the column, purification can also be carried out for some specific reactions [7]. The basic or acidic, as well as some other columns, can also separate chemicals with some functional groups like acid, amine, or other highly reactive groups. If we can connect the catalytic reactions by retrosynthetic [8] philosophy and pass only the product to the next reaction vessel, we can develop the scheme for carrying out the synthesis of a specific product. Multistep flow synthesis can even prepare highly purified pharma-grade products [5]. Once we use a heterogeneous catalyst to the reaction vessel and stick it to the vessel surface or on a grid surface, we can restrict the catalyst from entering the next vessel. Finally, we can carry out the continuous flow reactions by putting a specific semipermeable membrane [6] or a special column [9] between the two reactions. A catalytic reaction cycle occurs when a certain catalyst forms one or more temporary bonds with the substrate to convert it into a product under a few steps and repeats the mechanism until the reaction is finished or

forcefully stopped. By viewing each time-consuming step in a catalytic reaction cycle as an event and circularly linking them through the reagents or products, it is possible to transform the catalytic cycle into a time crystal, as depicted in Scheme 1a [10,11]. A time crystal is a clock-like structure that forms when the symmetry of time translation is broken, allowing for the sequencing of multiple sequential events. Remarkably, this clock can run perpetually without violating the second law of thermodynamics, meaning that no energy is required to maintain its motion. Time crystals can be nested when two or more reaction cycles occur under the same conditions, and their size can be modified by adjusting the time between events through a process known as time breathing [10]. We may create a complex reaction pathway that is similar to the biological system if we choose the reactions that use the same reaction medium (like water in a biological system), but identical or different temperatures and pH mediums.



Scheme 1. Schematic presentation of time crystal formation from catalytic reaction cycles. **(a)** A catalytic reaction cycle undergoes three individual reaction steps to complete the loop on the left side. Over the perimeter of the cycle in the left column, the reaction points are highlighted by dotted circles to denote them as events. We can construct the clocking topology [11] if we connect these events on a circle with blue spheres. These spheres represent the singularity points once we construct a 3D time crystal model on the right-hand side. **(b)** At the middle row, two reaction cycles are coupled through a metathesis reaction (Reaction M). All the reactions are converted into the event to construct a 3D time crystal at the right. The sharing event constructed by the metathesis reaction is depicted with a

bicoloured ball. (c) The row c represents a catalytic reaction for generating a single product but comes up with two probable mechanisms. It is sharing a complete reaction step, where a similar starting material is produced and a similar product is obtained. This reaction converts methanol into water. By converting all the time-consuming reactions into events, we can construct the time crystal of the coupled reaction cycles [10,11].

When two or more consecutive reactions under the same reaction conditions are integrated into executing a multistep reaction, known as a cascade, tandem, or domino reaction. Some of the cascade reactions [12,13] form a reaction loop under the presence of a catalyst known as a catalytic reaction cycle. In nature, all the reaction cycles [10] are integrated by sharing a product or some reaction steps in connecting the series of reaction cycles in both complex and linear pathways. Consequently, perturbing a single reaction cycle can exert influence along complex pathways. For instance, among the vast array of plants, approximately 8100 species (approximately 3%) utilize the C4 carbon fixation cycle. This cycle is remarkably efficient in converting CO₂ into carbohydrates, especially in arid conditions characterized by high temperatures and low CO₂ concentrations. C4 plants have evolved an adaptive mechanism where they close their stomata to conserve water during drought conditions. However, when an adequate water supply is available, the C4 cycle can be temporarily disrupted, and the plant reverts to the C3 cycle [10]. The sequential reaction pathways will have the advantage of creating a chemical system that is sustainable and versatile, requiring the least amount of time, money, and effort. Upon reviewing their integration pattern, we can discern how two consecutive reaction cycles might be interconnected. Drawing inspiration from this insight, the perspective will primarily delve into the development of the concept of time crystal synthons and the principles of fractal time crystals [14,15] within integrated reaction chambers. It will also explore a model fractal cascade reaction, aiming to pave the way for the evolution of futuristic chemical technology. From the literature, we can see that catalytic cycles can be integrated with other catalytic cycles by three basic modes: (i) by transferring a product as a reagent to the next cycle, (ii) by exchanging molecular parts through an exchange reaction between two cycles, and (iii) by sharing complete reaction steps in coupling two cycles. If we convert these kinds of catalytic reaction cycles into the time crystal, we can see how time-consuming events (reactions) are connected with each other in bridging the clocking topologies (Scheme 1b,c) [10,11]. As a single reaction takes a few milliseconds or femtoseconds to happen, the two neighbouring clocks may not be of the same size. For simplicity, the volumes of two neighbouring 3D time crystals at Scheme 1b,c are kept similar in volume. In reality, one of the cycles will be of a more time-consuming reaction to become the host of the final time crystal architecture. In Scheme 1b, the two cycles are sharing a metathesis reaction, and any one of the cycles can become a guest. Similarly, Scheme 1c shows the sharing of a common reaction, which implies the cycles are not dependent on each other. However, for connecting the reaction cycles, the approaches are important.

The method by which we can join two catalytic reaction cycles can aid in the development of the time-crystal synthon concept. Time-crystal synthon is the mutual sharing of an event or product between the two independent time crystals to develop a flow synthesis path [1–5] or fractal network of reaction cycles [13]. We can create a multistep flow synthesis pathway [1–5] once every catalytic reaction produces a single product to initiate the next catalytic reaction. When one reaction cycle has multiple products and supplies two or more reagents to the next reaction cycles, then the first reaction cycle gets connected to multiple reaction cycles and generates fractal reaction networks. This technique can also provide a sophisticated technique for selecting products according to our flexible requirements. It is important to note that, apart from Synthon A, catalytic reactions for Synthon B or Synthon C should also be conducted in the same reaction vessel.

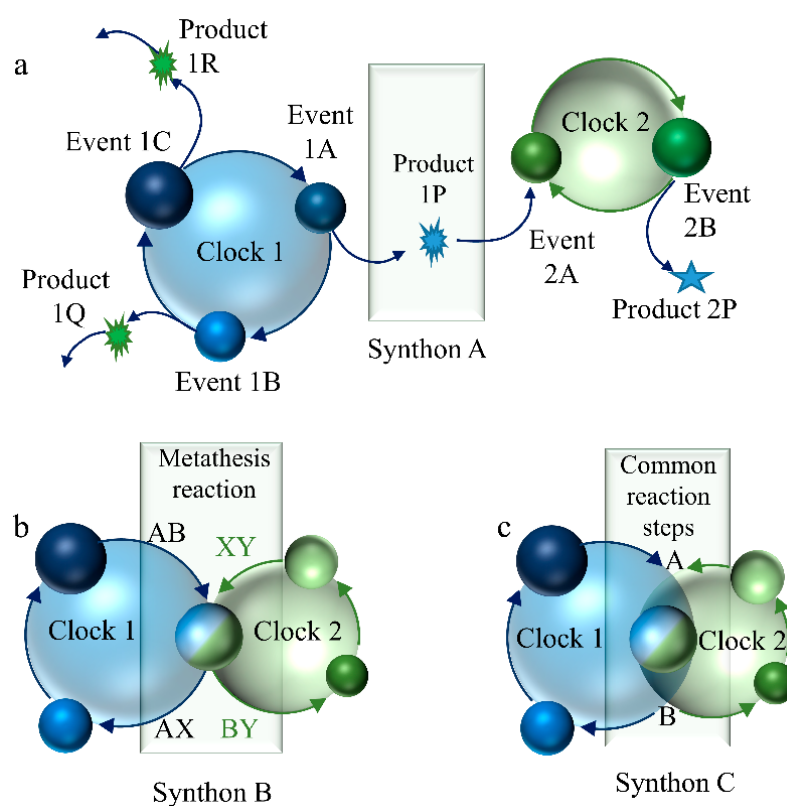
2. Time-Crystal Synthon (TCS)

In molecular synthesis, a molecular synthon [16] forms covalent bonds, while in supramolecular synthesis, a supramolecular synthon [17,18] recognizes the other [19–24],

but all do integrate the objects. Herein, the time crystal synthon concept is developed to recognize and integrate complementary catalytic reaction cycles in forming a fractal reactional pathway. In-time crystal engineering [10] time-crystal synthon can connect two cascade reactions by manoeuvring one product to the next reaction as a reagent in forming a cascade of cyclic reactions. The time-crystal synthon will be useful in developing futuristic chemical technology and artificial consciousness.

2.1. Types of Time-Crystal Synthons

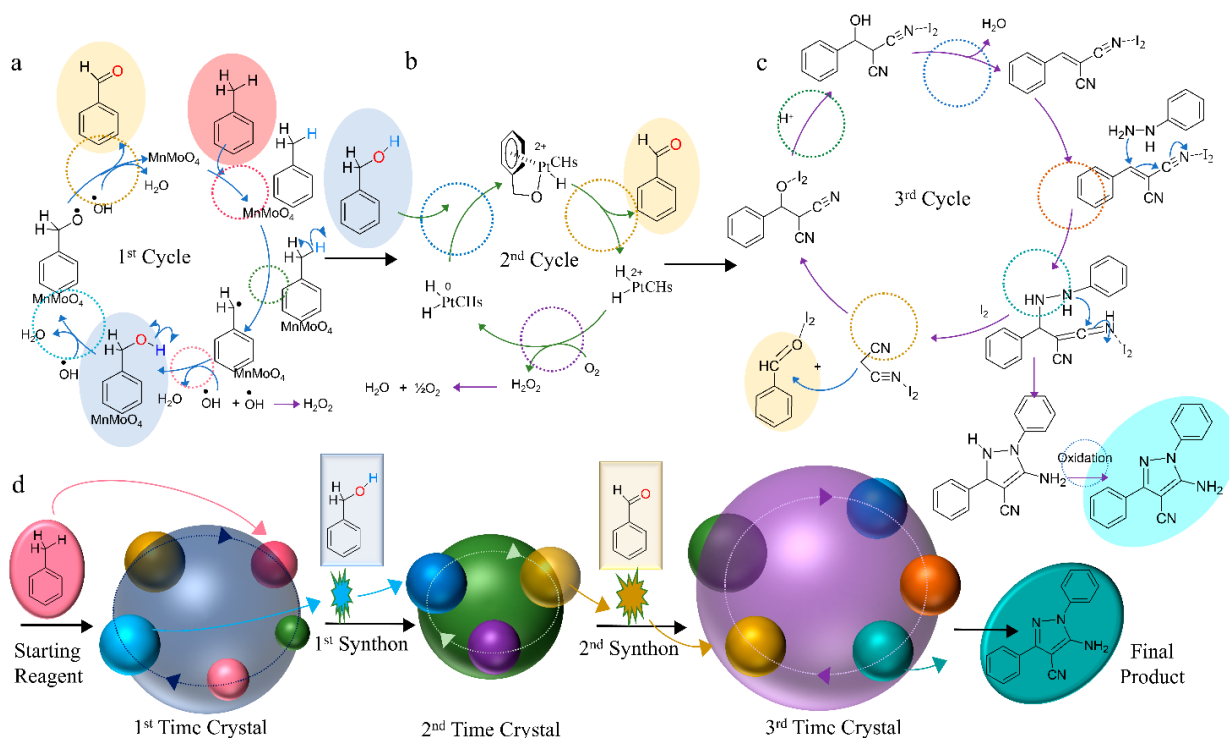
The three kinds of time-crystals in Scheme 1 can exhibit the corresponding three kinds of time-crystal synthons in Scheme 2. Like retrosynthesis [8] in the molecular synthesis approach, the selection of certain catalytic cycles is important for reaching the desired products. The synthons of coupling two reactions with the same interest are not useful, as we can consider them as a single reaction cycle for developing the fractal reaction path.



Scheme 2. Various Time-Crystal Synthons can be constructed from available reaction cycles in literature. All the synthons are shown in transparent boxes. (a) Linearly integrated TCS have their independent primary circles (depicted by clock 1 and clock 2). The product 1P becomes a reagent to clock 2 and behaves as a time-crystal synthon (Synthon A). If we can connect other reaction cycles through product 1R, 1Q then we can transform the one-way reaction path into fractal reaction cycles. (b) Two time-crystals (Clock 1 and Clock 2) can be coupled by a metathesis reaction at their junction zone. The common event in the metathesis reaction is denoted by a bicolour ball and designated as Synthon B. (c) When two reaction cycles share or few common reaction step/s, then they share one or few events and can form Synthon C. Here, the singularity point the junction zone reflects remains undefined, and the consequent reaction at the position B can turn either way.

Synthon A. In the first case, the product connecting the synthon (Scheme 2a) will be more common, as finding reactions with either producing a particular product or consuming that product will not be difficult. Herein, one product of the first cycle can be used as a substrate for the next catalytic reaction cycle. In Scheme 2a, we can see Cycle 1 produces product 1P and is getting used by Cycle 2. This product is used as a synthon

between two cycles. Thus, when synthon 2a is employed to form a closed loop of a circle to build a host time-crystal, all the individual catalytic cycles will be then converted into the events (Scheme 3). The connecting line between the two cycles for transferring the product from cycle 1 to cycle 2 will be converted into an event connecting arc to form the host time-crystals. Those catalytic circles should be placed in different reaction vessels.



Scheme 3. Three heterogeneous catalytic reaction cycles are nested here by the time-crystal synthon approach in developing a cascade of cyclic reactions. All the reaction points on the catalytic reaction cycles are highlighted by dotted circles to mark them as events for developing corresponding time-crystals at the end. (a) In the first step, toluene can be reduced by MnMoO_4 and can produce both $\text{Ph-CH}_2\text{OH}$ and Ph-CHO . (b) The $\text{Ph-CH}_2\text{OH}$ produced at the first reaction cycle can be further oxidized by Pt-derived catalyst at the second step in forming benzaldehyde. (c) The final cycle converts benzaldehyde to a pyrazole derivative. (d) All the reactions are converted to the events and highlighted on the catalytic reaction cycles (As Scheme 1). In transforming the reaction cycles to time-crystals in this step, the dotted circles are converted into the spheres of same colours. The arrows with distinct colours starting from one event to another event of two consecutive time-crystals represent the synthon connection to integrate the flow synthesis.

Synthon B. The second type of time-crystal synthon couples two reaction cycles by sharing a metathesis reaction step. Here, by running the cycles, the substrates of each ring undergo an exchange reaction and couple the two rings (Schemes 1b and 2b). In Scheme 2b, we can see AB and XY compounds at two reaction cycles undergo the exchange reaction and form AX and BY products. The exchange reaction couples two reaction cycles and can be demonstrated as an event-sharing synthon. Here the bicolour ball represents the common event. Under the same reaction conditions, all the cycle type 1 can form one class and cycle type 2 can form another class. Under the same reaction conditions, the reaction cycles with a similar side of the metathesis reaction are replaceable by exploiting this synthon. In this special case, both reaction cycles are complementary to each other.

Synthon C. In the third type of synthon, one or a few complete reaction steps can be shared by two reaction cycles to get coupled (Schemes 1c and 2c). In their corresponding catalytic cycle, we can see that a full reaction step, starting from reagent to product, is common to both of the reaction cycles. The reaction cycles with common one-two reaction

steps, available in the literature, can be coupled by exploiting the reaction step sharing the third time-crystal synthon. From Scheme 2c, we can see that a full reaction step, starting from the reagent A to its corresponding product B, is common for both cycles. This feature allows a substantial overlapping of the two time-crystal cycles. Herein, the event or the singularity point [10] of time-crystal can drive the reaction, then, at any of the two cyclic paths. By coupling two reaction cycles through a common reaction step, we can extract new products by using Synthon C.

Thus, going from Synthon A to C, the cycles will come close and finally overlap.

2.2. Formation of a Cascade of the Reaction Cycle

Homogeneous catalytic reaction cycles [25] are better to avoid developing the cascade of cyclic reactions or nested reaction cycles [10]. It will drag the catalyst to the next reaction vessel. In biological systems, the catalytic reaction cycles are nested with one or more reaction cycles in forming cascade reaction cycles [26] and use the products for other remote reactions. When one reaction cycle is entangled with three or more reaction cycles, then it can form the fractal of reaction cycles or fractal reaction cycles. Once a catalyst is soluble in the reaction medium, it is difficult to remove it from the medium, and pumping such a product to the next reaction vessel would bring impurity and undesirable reaction issues. To avoid such unwanted problems, it is always preferable to use heterogeneous catalysts for each reaction pot. Heterogeneous reactions with the different reaction chambers, connected with an aliquot tube, can develop the fractal network. As is needed, we can remove a certain product from the required reaction chamber/vessels. The reaction pots could contain the same or different solvent medium, depending on the reaction vessel-to-vessel connecting tube capability. Theoretically, if only the dry product can be isolated from one reaction pot, the next pot could be of any solvent. However, it would be impossible with the existing separation technology. Thus, any single reaction medium should be used throughout the fractal reaction series. However, the pH, temperature, and catalyst can change depending on the reaction condition.

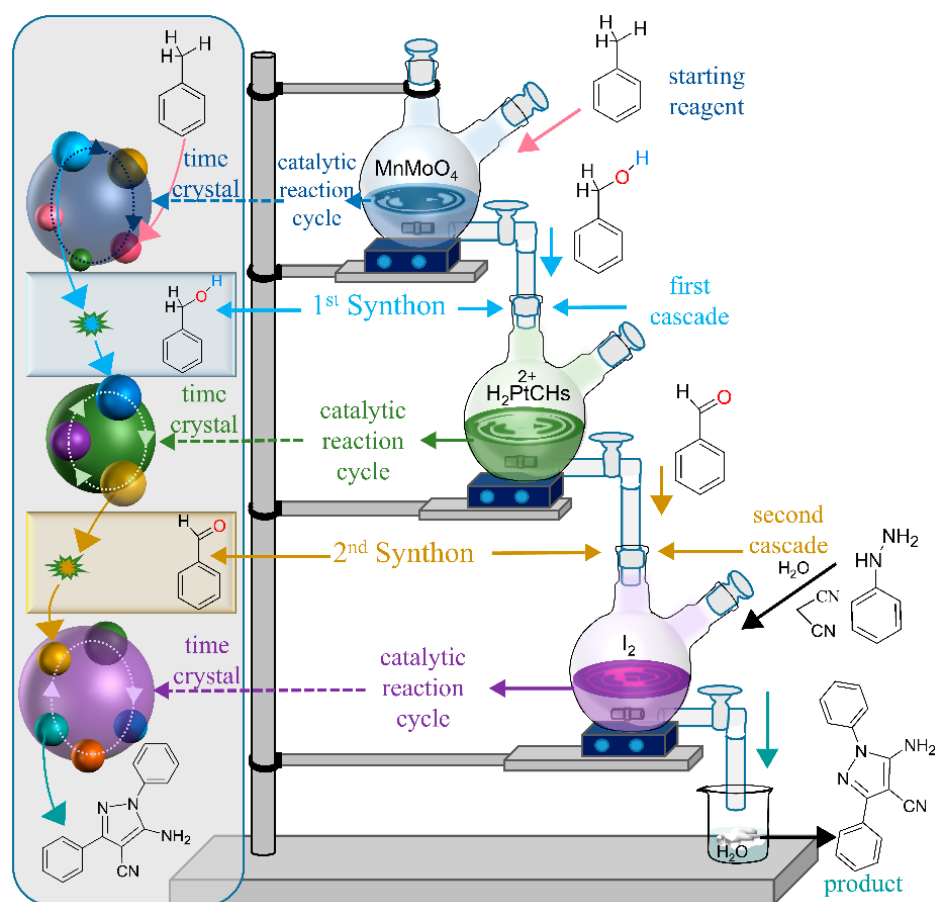
Here, all the reaction chambers will contain a specific heterogeneous catalyst to run a certain reaction but will retain their chamber while pumping the aliquot to the next chamber. Through scanning a wide range of catalytic reactions, we can determine the products of a certain reaction cycle that can be used as the reagent for the following reaction cycles. The time-crystal synthon can connect the two catalytic cycles of two neighbouring reaction pots by pumping one output (product) as a required input (reagent) to the next catalytic cycle. A compatibility by which a product that is generated by an event and consumed by another event of two different time crystals can be integrated is called TCS. All the heterogeneous reactions should possess their corresponding reaction vessels. Herein, the reactions can develop one or a few product(s) (Scheme 3). All the products of one cycle will be the substrate(s) for the next cycle(s) to move forward in building the fractal map. The reaction chambers can be of three categories, connected with a single line, double lines, and three or more lines. A reaction chamber with a single line can either initiate a cascade of reaction cycles (a cascade of cascades) or end up forming an end product. A chamber connected with a double line will form a cascade path for connecting two neighbour catalytic cycles. When a catalytic chamber is connected with three or more lines (inlet, outlet), it forms a junction zone in the fractal map. Once we start connecting the reaction pots and can return to the first pot, we can construct a host clock or develop continuity in a cascade of cyclic reactions (or cascade of cascades reactions) that can run autonomously.

3. Time-Crystal Synthons in Developing Model Cascade Reaction Cycles

After fixing the heterogeneous catalysts on the unreactive polymeric grids for every reaction vessel, and arranging it in a way to allow the magnetic bit free rotation inside the vessel, the common reaction medium can be driven to the next vessel. The first two catalysts are heterogeneous in nature with nano-dimensional sizes. These can be coated over the polymeric grids by the naffion binder [27]. This particular integration model of cascade

reaction is arbitrarily set upon Synthon A, as in this particular reaction set, Synthon B, and Synthon C are not available in the literature.

In the first catalytic cycle, toluene can be oxidized into both benzyl alcohol and benzaldehyde by using the molybdenum-combined manganese oxide (MnMoO_4) nanoparticle (Scheme 3) [28]. The catalyst activates the C–H bond at the methyl functionality and oxidises alcohol or aldehyde by the use of H_2O_2 . The solution should be heated at 80°C for 18 h, and then the solution should be sent to the next vessel. The presence of aldehyde will behave as the product at the final stage and will not interfere with the second reaction cycle. In the second stage, the Pt nanocatalyst was coated over the active carbon [29], which should be coated again on the unreactive grid to pass the product at the third stage without any catalyst. This second stage reaction also runs at 80°C but can be completed after 3 h only. However, it needs a trace amount of KOH (1.5 mmol) solution and oxygen. Fewer substitutions at the benzene ring drive the reaction to go near 100% conversion. After 3 h, the reaction can be sent to the final stage. As both these two initial reactions do not need any external solvent, in principle, we can get the freedom of selecting the solvent for the third reaction. In the third or final stage, we should use water to run the reaction as the reaction medium [30]. To the final solution, 20 mol% iodine, malononitrile (1 mmol), and phenylhydrazine (malononitrile) against 1 mmol aldehyde at 60°C Iodine behaves as the catalyst but can be easily separated from the medium by using a small amount of $\text{Na}_2\text{S}_2\text{O}_3$. It converts the iodine to water-soluble NaI to wash it out from the final product. If we arrange the reactions vertically to run the solution downwards using gravity, we can avoid the pumping effort to run the reaction. Importantly, by using RB, we can use light or microwave [31–33], which is not possible under conventional flow synthesis (Scheme 4).



Scheme 4. A model flow synthesis in the cascade of cyclic reaction mode by exploiting Synthon A. On the left side, the time crystals of corresponding reactions are connected by the time crystal synthons

to produce pyrazole derivative from toluene. On the right, catalytic reaction cycles are performed at the corresponding double neck round bottom (RB) flasks. The corresponding catalysts are shown inside the RB and the required reagents are shown to be added through the side necks of the flasks. All the catalysts are heterogeneous in nature and cannot fall to the lower RB. Only I2 can come but can be removed easily (see supra). As soon as a reaction is complete, its product is gravitationally allowed to fall to the next RB. We can collect any product from any RB as per our requirements.

4. Advantages of Time-Crystal Synthon Concept

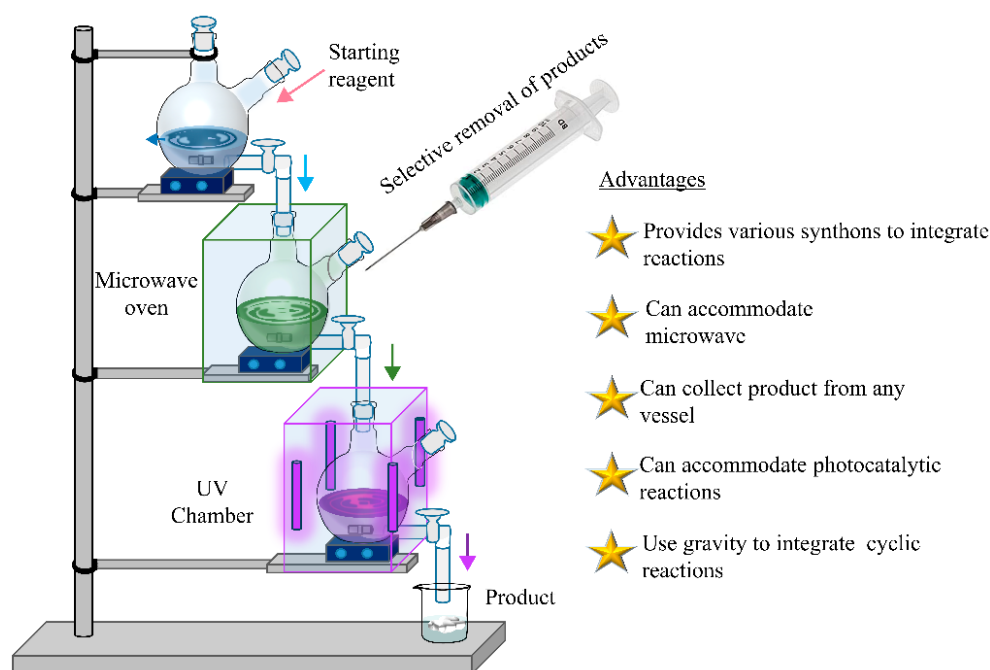
All the biological reactions are connected with other reactions to minimize the byproducts, develop circadian consciousness, and minimize the reaction complexity. In living systems, the products of cyclic reactions are connected to other reactions and cyclic reactions. We see that, most of the time, the chemicals are becoming the reagents for the next associative cycles. The components that cannot be used as reagents become excretory substances. We can minimize the byproduct, and as water is the 'universal solvent' for all the reactions, the body becomes susceptible to carrying out all the reactions in a single solvent and reduces the complexity. Once we can tune the product by exploiting different catalysts, we can extract two different products, even from a single reaction vessel [11]. By exploiting this concept, the medicinal compounds can also be prepared similar to the flow synthesis [6]. A frequently prescribed drug mesalazine for treating Crohn's disease and colitis can be synthesized by flow synthesis [5]. An optically active anti-inflammatory drug rolipram was synthesized by Tsubogo et al. in 2015 [7]. The final molecular drug, the drug precursor like 1-(m-benzyloxyphenyl)-ethylamine, was also synthesized by Porta et al. in 2017 [31].

4.1. Hybridized Facilities of Multistep Flow Synthesis and Step-by-Step Synthesis

Step-by-step synthesis needs more reaction solvents, time, and manpower but flow synthesis minimizes the cost and pollution [6]. However, in flow synthesis, we do not have the option to always collect the product according to our requirements. This cascade of reaction cycle style synthesis provides us with a flexible opportunity to collect any product of our choice from the corresponding reaction vessels. Moreover, we can use light for running photoreaction and can provide microwave as the energy source. It is difficult to use microwaves in flow synthesis [32–34]. Microwave-assisted syntheses are generally pollution-free in nature [35]. Thus, we should always have the provision for carrying out the microwave-assisted synthesis in the flow synthesis protocol. Like step-by-step synthesis, we can obtain any product from the corresponding reaction vessels. For carrying out microwave-assisted synthesis, we need to have two small holes on the top and the bottom of the reaction chamber to maintain options for the inlet and the outlet in connecting the steps. We also can arrange UV lamps around certain UV assisting reaction vessels and shield the light to conduct the heterogeneous photocatalytic reactions (Scheme 5).

4.2. Extracting Specific Products as per Requirements

Once we implement the time-crystal synthon concept in developing a cascade of cyclic reactions, we can obtain any product without wasting too many chemicals. In each reaction pot, a separate reaction is occurring in the water medium. As the catalyst is heterogeneous, it will not come to the reaction medium. Thus, running a reaction for just a few minutes/hours will provide any product as per the requirement. A flexible choice of product will always be assured in this process. The last reaction can help split water into oxygen and hydrogen to make a room more pleasant and hydrogen to use the medium as well. Fresh oxygen can help breathe the air, and the produced hydrogen [11] can be used for curing a series of diseases [36–40].



Scheme 5. The advantages of the Time-Crystal Synthon approach for multistep flow reactions.

4.3. Rhythm That Sustains the Cascade of Cyclic Reaction

Converting reaction cycles into time-crystals will include the reaction times of every individual reaction step. When all the time-crystals of individual catalytic cycles at the sequential reaction-vessel are synchronized in a horizontal arrangement, then they can form a host time-crystal, and the overall rhythm can be developed. This technique may need additional purification techniques, as some unreacted compounds can go to the next step, but an overall rhythm can be developed. In the biological system, the circadian rhythm develops a special kind of consciousness by which the body synchronizes the metabolism with the diurnal motion of the earth. Once we carry out one photochemical reaction, such as sunlight-based water oxidation, then synchronize it with the photochemical reaction, the horizontally arranged cascade of the cascade reaction will gain the circadian rhythm and circadian consciousness like a plant. We can control time-crystal breathing by controlling the time to pass the reaction medium to the next reaction cycle [10].

4.4. Application of TCS in Other Fields

Besides integrating the cascade reactions in forming a cascade of cyclic reactions, other time-crystals of different fields can also be artificially integrated to form the polytime-crystal [15,41–43]. However, we must ensure that one product of the system (time-crystal) can be consumed by another system (time-crystal) without any external effort. The coupling of two (spin-1/2 systems) or more (ultracold atoms or trapped ions) time-crystals can be found in the atomic or subatomic systems' [41] Kitaev chain [42]. Fractal time-crystals can also be found in various biological systems like the brain [15], protein, microtubule, and neurons [43]. By extrapolating the concept of coupling timecrystals [15,41–43], we can construct the cascade reaction cycle or fractal reaction cycles.

5. Challenges

In this process, we needed to learn about proper cascade reactions such as synthetic chemists picking up certain synthons in molecular synthesis. However, with time linking of cascade reactions by exploiting time-crystal synthons, this will be a common practice. To develop this technology, we need to restrict the choices as follows.

5.1. Heterogeneous Catalysis

As heterogeneous catalysts are important in carrying out the cascade of cascades, the organic reactions producing stereoisomer will not be very convenient in selecting the normal heterogeneous catalysts. All the biological catalysts such as proteins, hormones, and enzymes are extremely selective in nature and always produce certain enantiomers selectively [44]. Thus, carrying out any stereoisomers by normal heterogeneous catalysts will produce enantiomers with enantiomeric excess. Even if a supramolecular catalyst cannot produce 100%, it will not be useful for running a cascade of cascades unless a special column can absorb and separate the byproducts.

5.2. Complete Conversion

At present, the purification of the compound is very tricky, and cannot always be done instantaneously. We can exploit reactions to create a cascade of cascades once we use all the heterogeneous reaction cycles that have common reaction media and highly effective catalysts for 100% conversion. The way the cell membrane selectively passes a specific chemical has yet to develop compound-specific similar semipermeable membrane in a laboratory. However, some unwanted compounds can be removed by passing the reaction aliquot through a certain reaction pot-to-pot, connecting a tube-based column through very simple reactions. For example, a basic alumina column can be used to absorb and separate the acid component. Incorporating purifying machines with specific product separating abilities also necessitates labour and time and removes autonomy.

5.3. Solvent Similarity

As the cascade of cascades technique will pass the reaction aliquot directly, all the reactions in the cascade of cascades should be the same in principle. We can change the pH by exploiting buffer tablets and temperature by adding external heating resources. Once we use water, we can generate oxygen and hydrogen at the bottommost reaction vessel, if we do not pump up the water from the bottommost to the topmost reaction vessel.

5.4. Specific Product Carrier Channel in the Reaction Chamber Joining Tubes

If the reaction does not produce a pure product, then we need to introduce a purification system. There are several purification techniques like chromatography [45], phase separation, [46] selectively reacting out other products [47], or passing the reaction medium through a certain semipermeable membrane [48]. Unless we are equipped with such particular separation techniques for every single catalytic reaction cycle, we need to restrict ourselves only to the aforementioned techniques.

6. Conclusions

A multistep organic synthesis under continuous flow is becoming increasingly popular for its environmental sustainability, fast production rate, and ability to produce high-quality pharmaceutical products. By applying the concept of connecting catalytic reaction cycles and developing time-crystals with clocking topology, we can revolutionize the industrial synthesis of a variety of organic compounds. Time-crystals can be connected using time-crystal synthons, which may involve using a product as a reagent for the next reaction cycle, coupling different classes of cyclic reactions through a common exchange reaction, or merging two catalytic cycles through a common reaction. We can connect the time-crystals by time-crystal synthons to continue the multistep flow synthesis. The time-crystal synthon can be from several categories. A product from a reaction cycle can be used as a reagent for the next reaction cycle. By sharing a common exchange reaction between two reaction cycles we can couple different classes of cyclic reactions. Sometimes, one or few reaction steps can be similar under the same reaction conditions for two catalytic reactions but may produce similar or different products. Such a common reaction can merge the two catalytic cycles to continue the flow synthesis. Machine learning can assist in identifying and integrating time-crystal synthons into the flow technique. All the reaction cycle nesting candidates, such as

supplying a product as a reagent to the next cycle, exchange reactions between two cycles, or the common reactions between two cycles can be classified into various time-crystal synthons. Carrying the reaction cycles in a glass RB can be useful for microwave-assisted or photocatalytic synthesis, which is not possible in the conventional multistep flow synthesis. Once we carry these reactions vertically, we can connect the cascade reactions (catalytic reaction cycles) in multi-cascade steps, which can provide us with any product from the multistep, as per our requirement. If all reactions are brought together horizontally to close a loop, we can develop host time crystals that generate artificial consciousness similar to circadian consciousness.

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