# A Tribute to Bardhan and Sengupta

## Synthesisers of Phenanthrene and its Derivatives

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**Keywords**
Jogendra C Bardhan, Suresh C Sengupta, phenanthrene synthesis, Diels hydrocarbon.

**Jogendra C Bardhan and Suresh C Sengupta are two very common names to the undergraduate students of chemistry due to the classical Bardhan–Sengupta synthesis of phenanthrenes which is incorporated in all standard textbooks of organic chemistry and is one of the most convenient of approaches for constructing this ring system till date. Bardhan was a brilliant teacher and an outstanding synthetic chemist who enjoyed the essence of organic chemistry. Bardhan and Sengupta published their pioneering work in 1932. Bardhan modified his work later, as required. As students of chemistry, his work and memory inspire us.**

### Introduction

The two names, Jogendra Chandra Bardhan and Suresh Chandra Sengupta have their own signature in the world of chemistry for their outstanding contribution to the synthesis of phenanthrene and its derivatives from the University College of Science and Technology, Calcutta and Presidency College, Calcutta in 1932 [1]. Bardhan was an eminent, dedicated scientist and an exceptionally brilliant teacher. He completed his DSc from University of Calcutta (1924) under the supervision of R L Dutta and later under P C Mitter. Afterwards, he moved on to the Imperial College of London and was awarded a DSc from Oxford University (1928) for carrying out his research work under the supervision of Thorpe and Rosenheim at London University [2]. Bardhan was appointed lecturer in the chemistry department of the University of Calcutta in 1937. He became the Khaira Professor of Chemistry (1946), one of the most prestigious and coveted Chairs of the University of Calcutta that he adorned till 1962. He had many promising students working under his guidance. In the

highest sense of the word, all great scientists are great teachers. Bardhan had a brilliant research group and he was able to spread the fragrance of synthetic chemistry through his students, although the university setup was limited in many ways. The works of Bardhan have ignited interests in a number of students [3] in synthetic organic chemistry, especially in steroid systems.

Sengupta, demonstrator of Presidency College, was one of the bright students of Bardhan's early research group. He carried out his doctoral work on phenanthrene synthesis under the supervision of Bardhan from the University of Calcutta. Later on, he was engaged in teaching and research in the West Bengal Education Service. The Bardhan–Sengupta synthesis of phenanthrene, which is now included as a 'name reaction' in all standard textbooks of organic chemistry can be considered a classic even under modern standards and it is still one of the most convenient of methods for fabricating this ring system.

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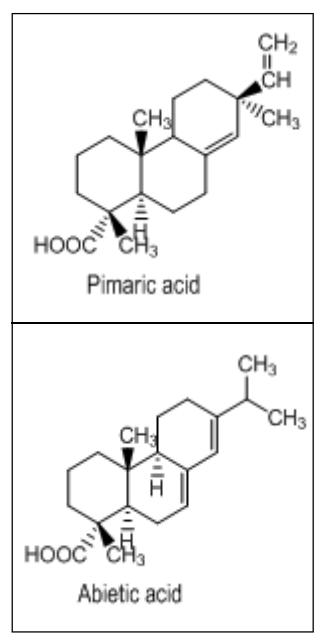
## Objective of Phenanthrene Synthesis

Bardhan made significant contributions in the field of resin acids with special reference to phenanthrene hydrocarbons [1, 4]. In the earlier part of his career Sengupta worked with him and developed a new method for the synthesis of phenanthrene. The available literature in a series of studies on the chemistry of resin acids indicates that the isolation and structure elucidation of several resin acids, such as pimaric acid and abietic acid (*Figure* 1), were established through Vesterberg–Diels dehydrogenation technique [1].

**Figure 1.** Isolated resin acids.




Other than this, in the early decades of the twentieth century, several derivatives of these acids were isolated by various chemists [5, 6]. The proposed structures of the phenanthrene derivatives were 2-methylphenanthrene, 1,4-dimethylphenanthrene, 1,7-dimethylphenanthrene (pimanthrene) and 1-methyl-7-isopropylphenanthrene (retene) (*Figure* 2) obtained from several resin acids through the Vesterberg–Diels dehydrogenation.

Determinations of complex substitution patterns of these phenan-

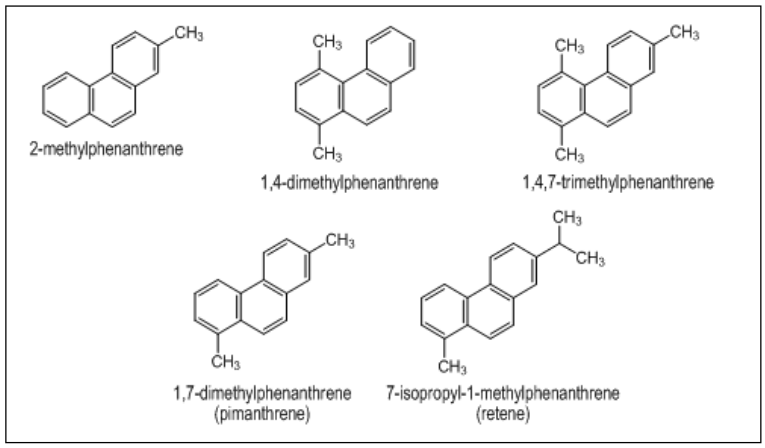



**Figure 2.** Isolated phenanthrene derivatives of resin acids.

threne derivatives were then essential to establish the locations of the substituents of *d*-pimaric acid, abietic acids and several resin acids. This prompted Bardhan and Sengupta to look into the locations of the substituents when no method was known by which substituted phenanthrenes could be obtained (see *Box* 1) [1].

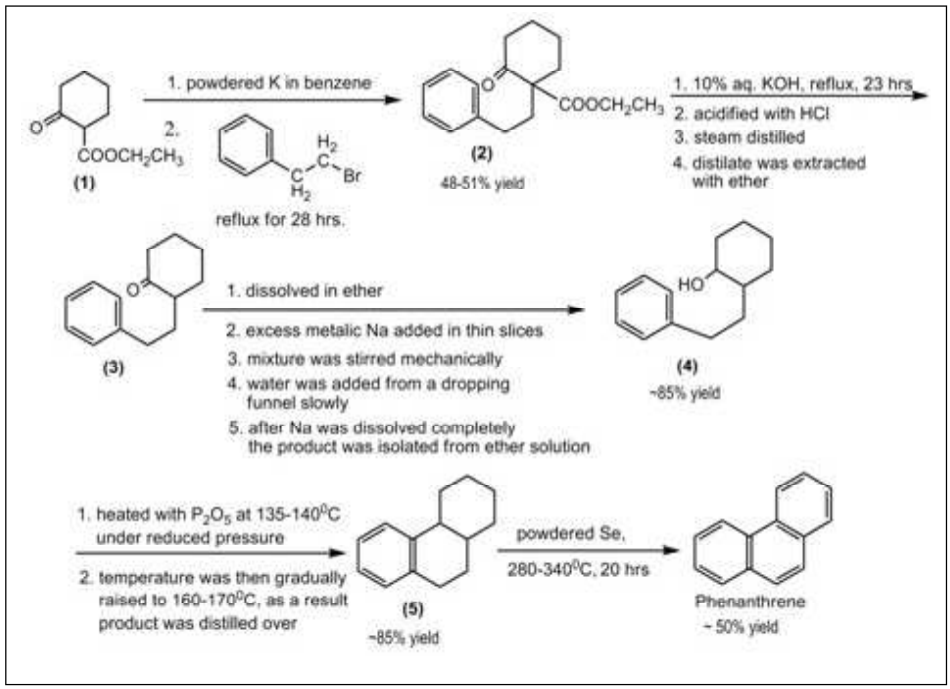
Bardhan–Sengupta synthesised all the phenanthrene derivatives shown in *Figure* 2 in an unambiguous manner and proved that these were indistinguishable from the corresponding phenanthrene derivatives isolated from the respective resin acids from which they were obtained. Thus, in the early thirties, it proved to be a very important contribution to establish the structure of abietic acid [4].

**Box 1.**

"For obvious reasons, the classical method of Pschorr and the modified method of Windaus and Eickel cannot be conveniently employed for the synthesis of the phenanthrene derivatives described above. On the other hand, Schroeter has recently indicated a new synthesis of phenanthrene starting from naphthalene. Owing to the difficulty of obtaining naphthalene derivatives with appropriate substituents and the difficult questions of orientation involved in the subsequent stages, this method cannot have any wide application. We therefore decided to devise a new synthesis of phenanthrene.

Whilst our work was in progress, the preliminary notice of work on similar lines by Haworth and his co-workers appeared. We, therefore, place on record the results which we have obtained independently and almost simultaneously by a method which, we believe, is quite different from that used by them."

*– Bardhan–Sengupta*

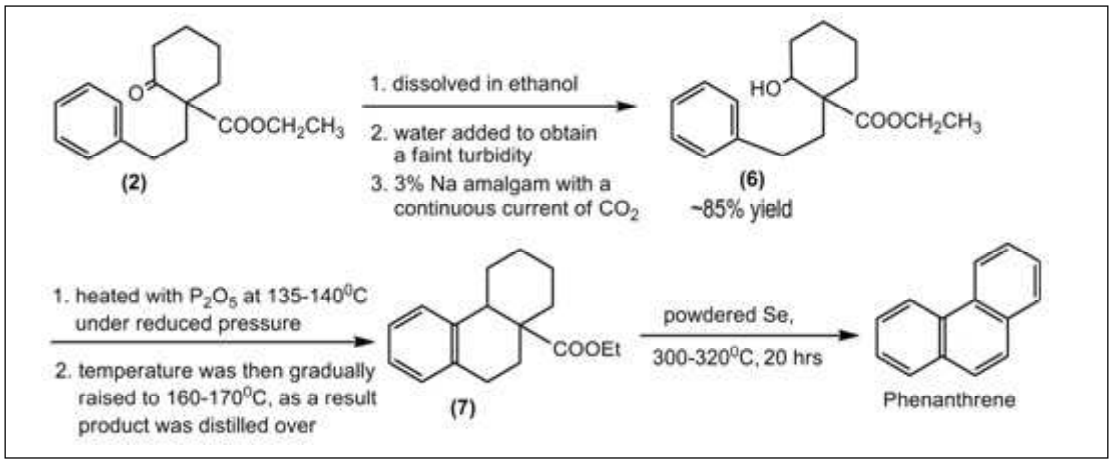



**Scheme 1.** Bardhan–Sengupta phenanthrene synthesis.

## Analysis of Bardhan–Sengupta Phenanthrene Synthesis

In the initial step, Bardhan-Sengupta condensed ß-phenylethyl bromide with the potassio-derivative of ethyl cyclohexanone-2-carboxylate (**1**) to obtain ethyl 2-*ß*-phenylethylcyclohexanone-2-carboxylate (**2**) which on alkaline hydrolysis followed by acidification and decarboxylation yielded 2-*ß*-phenylethylcyclohexanone (**3**). Then reduction of **3** by sodium in moist ether gave 2-*ß*-phenylethylcyclohexanol (**4**), which on cyclodehydration with phosphorus pentoxide readily furnished the desired condensation product, 1,2,3,4,9,10,11,12-octahydrophenanthrene (**5**). This was characterised from its physical properties and identified through rational synthesis from diketo-octahydrophenanthrene by Clemmensen's deoxygenation. The octahydrophenanthrene (**5**) was heated with selenium at 280–340 °C to furnish phenanthrene (*Scheme* 1) [1].

Bardhan and Sengupta confronted a problem during the hydrolysis of the intermediate *ß*-keto ester (**2**) as the reaction entailed long reaction times and low yields. They figured out a solution by reducing the *ß*-




**Scheme 2.** Modifications made by Bardhan–Sengupta.

keto ester (**2**) to the corresponding hydroxy ester by using sodium amalgam and moist alcohol [1] which on cyclodehydration using $P_2O_5$ yielded the cyclised ester (**7**) which was directly treated with selenium to obtain phenanthrene (*Scheme* 2) [1].

Later on, the eminent synthetic chemists, Amareshwar Chatterjee and Dilip Kumar Banerjee of Jadavpur University, Kolkata, studied this synthesis, phenomenal at that time, to rationalise each step and condition of the procedure and published their work in 1968 [7] and delivered a series of invited lectures on the topic. According to them, the observations may be categorised as:

Amareshwar Chatterjee and Dilip Kumar Banerjee of Jadavpur University, Kolkata, studied this synthesis, phenomenal at that time, to rationalise each step and condition of the procedure and published their work in 1968.

• In the first step, Bardhan-Sengupta condensed *β*-phenylethyl bromide with the potassio-derivative of ethyl cyclohexanone-2-carboxylate (*Scheme* 1). They reported that all attempts to bring about the interaction of *β*-phenylethyl bromide and sodio-derivative of ethyl cyclohexanone-2-carboxylate were unsuccessful [1].There was no explanation regarding the reason for this failure. Further study [7], however, indicated that the sodio-derivative was more or less insoluble in the reaction medium, whereas, potassium enolate was soluble in benzene. They also established that when DMF was added to the suspension of sodium derivative in benzene, the salt was found to be soluble and the alkylated product was obtained in good yield.

• Now, the yield of the condensation product ethyl 2-*β*-

phenylethylcyclohexanone-2-carboxylate (**2**) was very low (48–51 %) (*Scheme* 1). However, there was no account regarding such low yield. Later studies suggested that during such nucleophilic substitution by the bulkier nucleophile, elimination also proceeds to yield styrene through dehydrohalogenation.

• In the next step, the hydrolysis of ethyl 2-*β*-phenylethylcyclohexanone-2-carboxylate (**2**) (*Scheme* 1) required exceptionally long reaction time and that resulted in low yield. But there were no details for the requirement of such reaction conditions. Later studies pointed out that the ester was sterically congested and this explains why a long reaction time was required. In addition, the yield was low because of the side reaction such as reverse Claisen condensation. However, to obviate this problem, Bardhan–Sengupta modified their method later on [1] as depicted in *Scheme* 2.

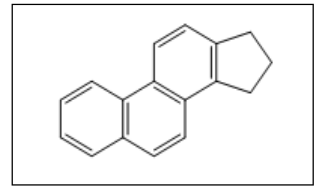
## Applications of Bardhan–Sengupta Synthesis

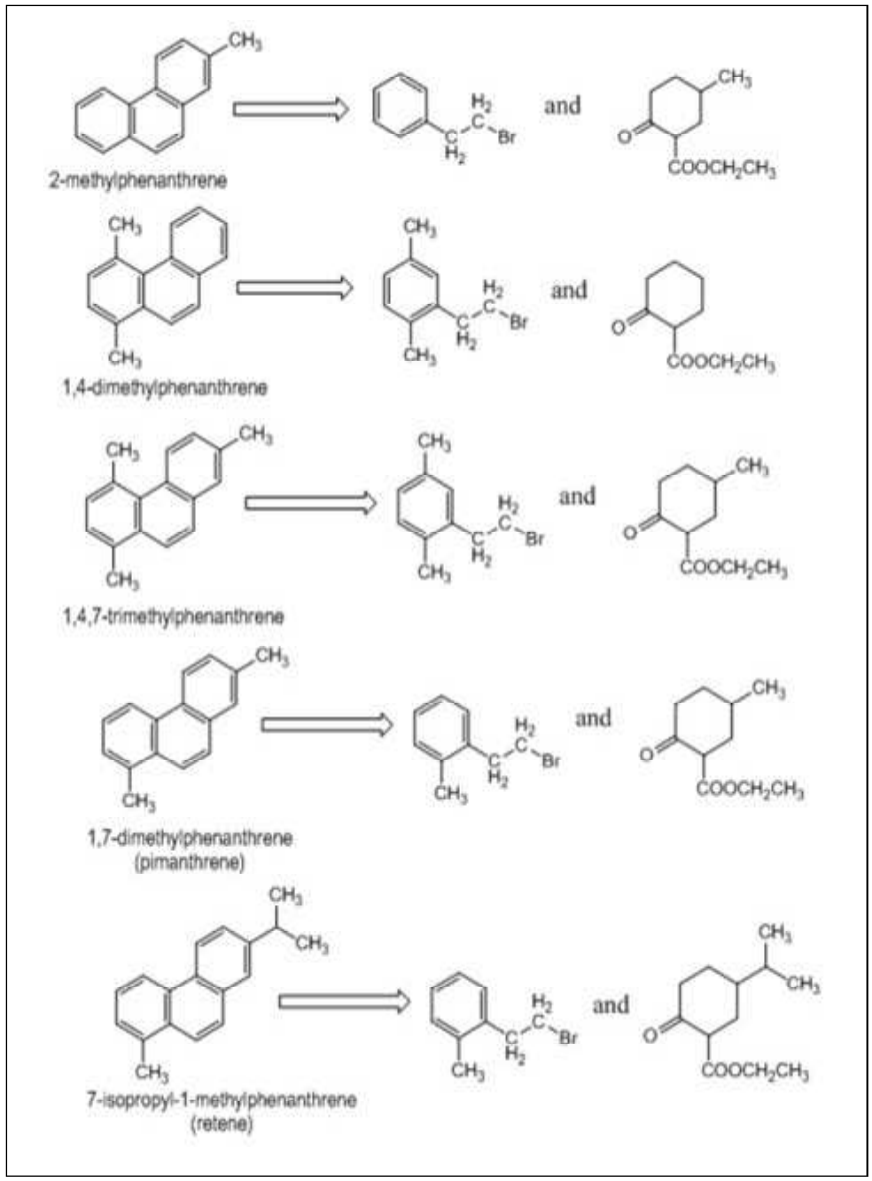
Bardhan–Sengupta very conveniently synthesised all the phenanthrene derivatives isolated from resin acids by their newly developed method. Among them, retene, pimanthrene, methylpimanthrene and methylretene are the most important ones (*Figure* 2).

The presence of additional methyl groups in the last two compounds led to the speculation of the probable position of carboxylic acid group in *d*-pimaric acid and abietic acid respectively [1]. Afterwards unambiguous synthesis of retene and methylretene based on Bardhan–Sengupta synthesis helped to establish the proper position of the methyl and isopropyl groups in retene and, thereby, in abietic acid [4]. The synthons for the synthesis of the above phenanthrene derivatives were as depicted in *Scheme* 3.

With the determination of the correct structural formulae for the bile acids and sterols, rapid advances were made in the knowledge of this group of natural products and various steroidal sex hormones [8]. The structures of the steroids are based on the 1,2-cyclopetanophenanthrene (**13**) (*Figure* 3) skeleton [9].

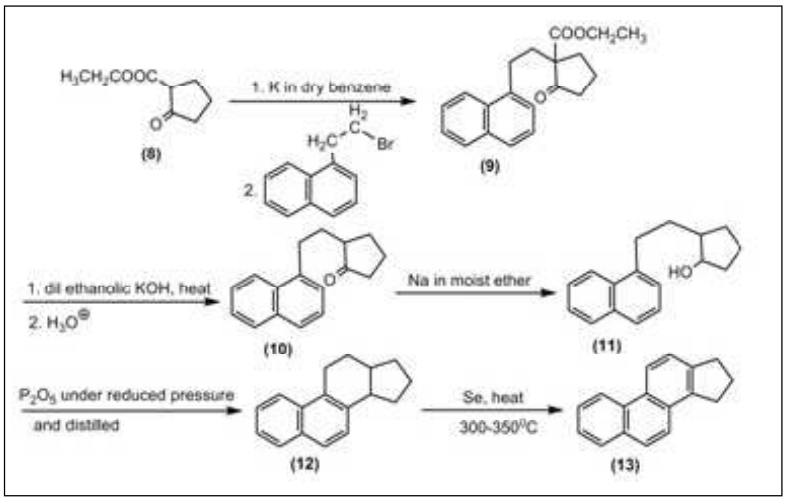
**Figure 3.** 1,2-cyclopentanophenanthrene (**13**).






**Scheme 3.** Synthons for the synthesis of phenanthrene derivatives obtained through Vesterberg–Diels dehydrogenation via Bardhan–Sengupta protocol.

Despite numerous attempts, however, this skeleton was not synthesised in the laboratory till 1933, pending development of suitable methods. The preparation of 1,2-cyclopentanophenanthrene was then achieved [10,11] utilising Bardhan–Sengupta protocol (*Scheme* 4).




**Scheme 4.** Synthesis of 1,2-cyclopentanophenanthrene utilising Bardhan–Sengupta protocol.

## Bardhan–Sengupta Synthesis of Diels Hydrocarbon: Limitation to Success

We are well aware of the fact that cholesterol is one of the most important ingredients of all animal tissues. In 1927, Otto Diels (NL) was responsible for introducing the use of selenium as a specific reagent for the dehydrogenation of hydroaromatic compounds; the hydrocarbon 3'-methyl-1,2-cyclopentenophenanthrene is now known as Diels' hydrocarbon. Diels obtained this skeletal steroid structure by dehydrogenating cholesterol, and other members of the series, with selenium (*Scheme* 5).

This proved to be a very useful tool in elucidating chemical structures in the complicated steroid series and many of them yielded Diels' hydrocarbon. Products of simpler structure, commonly derived, established structural relationships of biologically important steroid groups were shown to have the same

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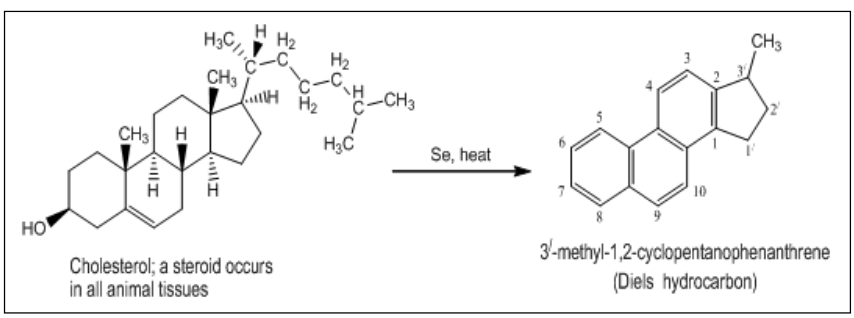
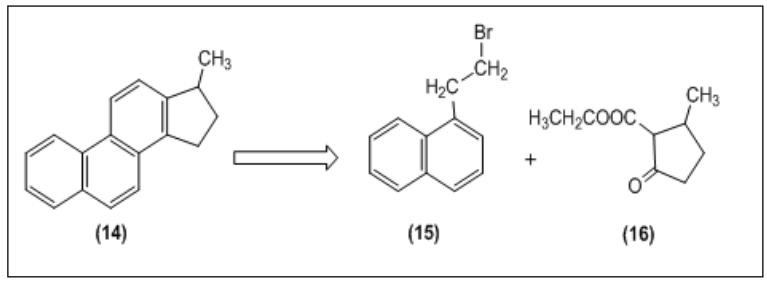



**Scheme 5.** Diels hydrocarbon from cholesterol.




**Scheme 6.** Synthons required for synthesis of Diels hydrocarbon via Bardhan–Sengupta method.

**Box 2.**

"After the publication of our preliminary communication (*Chem. and Ind.*, May 26th, 1933), describing the work now recorded, M T Bogert was good enough to send us a copy of his note (*Science*, March 17th, 1933) announcing the synthesis of this octahydrophenanthrene by a method apparently identical with our own, except that phenylethyl bromide was used where we used the chloride. No experimental details have been published by Bogert, and we, therefore, include an account of our own experiments in the present communication."

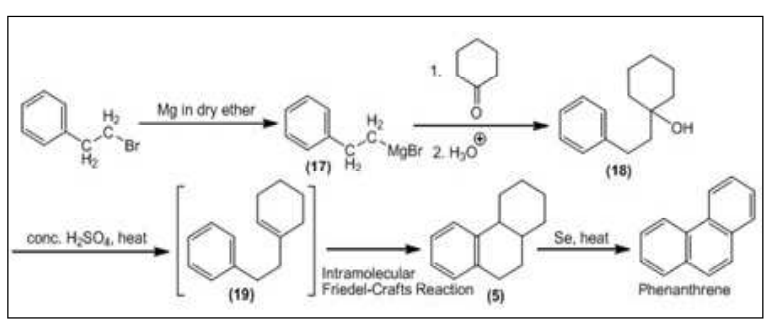
– *Cook*

carbon skeleton. Its structure was the critical clue that allowed other steroid structures to be assigned, all containing the four-ring skeleton of Diels' hydrocarbon, which became the defining feature of steroids. Thus, the synthesis of Diels' hydrocarbon was a very interesting challenge to the chemists at that time.

The synthons required for the synthesis of Diels hydrocarbon via Bardhan–Sengupta method are shown as in *Scheme* 6.

Now, the required $\beta$-ketoester **16** is undoubtedly difficult to obtain. Although Bardhan–Sengupta protocol was successfully utilised to synthesise [11] 1,2-cyclopentanophenanthrene (**13**), but there was no such report for the synthesis of Diels hydrocarbon till 1932. In the meantime (in 1933) M T Bogert and J W Cook individually developed a new process for the synthesis of phenanthrene using phenethyl magnesium halide (**17**) and cyclohexanone (*Scheme* 7).

Bogert carried out his work in Columbia University [12] whereas Cook completed his study at the research institute of the cancer hospital, London [13]. In this context, Cook referred to the work of Bogert in his publication (*Box* 2) [12].

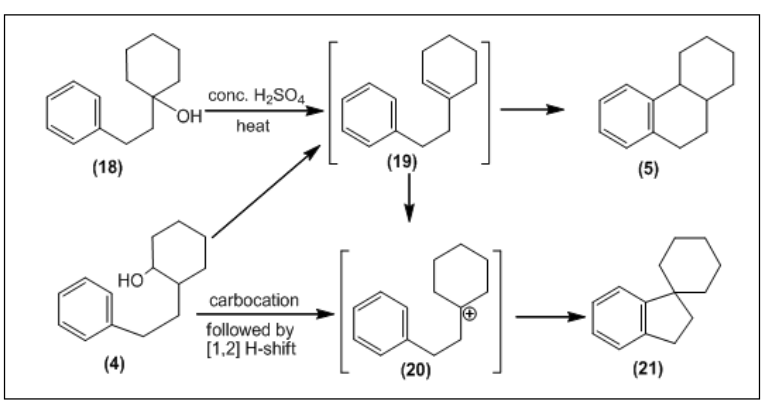



**Scheme 7.** Bogert–Cook synthesis of phenanthrene.

Regarding the Bardhan–Sengupta synthesis, Bogert pointed out in his paper that Bardhan and Sengupta 'appear' to assume a direct cyclodehydration between the OH of the alcohol and an H of the benzene nucleus. In addition, Bogert argued that such condensations, i.e., Bardhan–Sengupta and Bogert–Cook syntheses are expected to proceed through the formation of the olefin first, which then rearranges itself by cyclisation. Though this information was quite important in 1933, it appears to have little significance with respect to the modern standard of chemical science as the cyclisation undoubtedly takes place via the formation of carbocation followed by Friedel–Crafts alkylation in either case. However, during cyclisation to obtain octahydrophenanthrene (**5**), there is also a possibility of the formation of a spiro compound (**21**) via the formation of more stable carbocation **20** (*Scheme* 8) [9, 14].

There were no reports regarding the formation of olefin (**19**) or spiro compound (**21**) in their papers. However, they pointed out that the cyclisation of 4 leads to 1,2,3,4,9,10,11,12-octahydrophenanthrene (**5**) which was confirmed through its rationale synthesis.

This possibility and its outcome were not mentioned by the Indian authors and there were no reports regarding the formation of olefin (**19**) or spiro compound (**21**) in their papers. However, they pointed out that the cyclisation of **4** leads to 1,2,3,4,9,10,11,12-octahydrophenanthrene (**5**) which was confirmed through its rationale synthesis [1]. Although Bogert had speculated the formation of olefin **19** from the intermediate **4** in his earlier paper [12], he evidenced the formation of olefin **19** from **18** only (*Scheme* 8). In 1934, Cook and Hewett isolated spirans during their investigation of the cyclisation of naphthylethylcyclopentene with aluminium chloride and stannic chloride [10]. However,



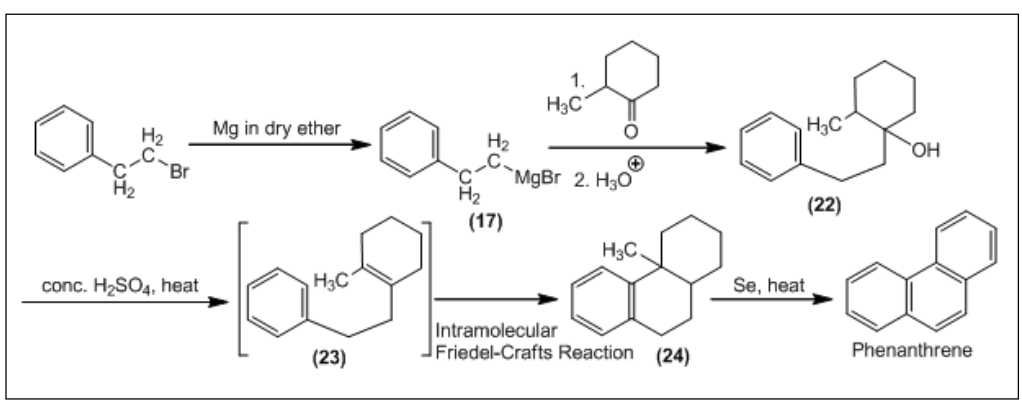

**Scheme 8.** Formation of spiro compound during cyclisation.

A closer scrutiny of Bardhan–Sengupta synthesis (June 29th, 1932) along with Bogert–Cook synthesis (November 18th, 1932 and July 11th, 1933), it appears that the idea behind the Bogert–Cook synthesis was rooted in the Bardhan–Sengupta synthesis.

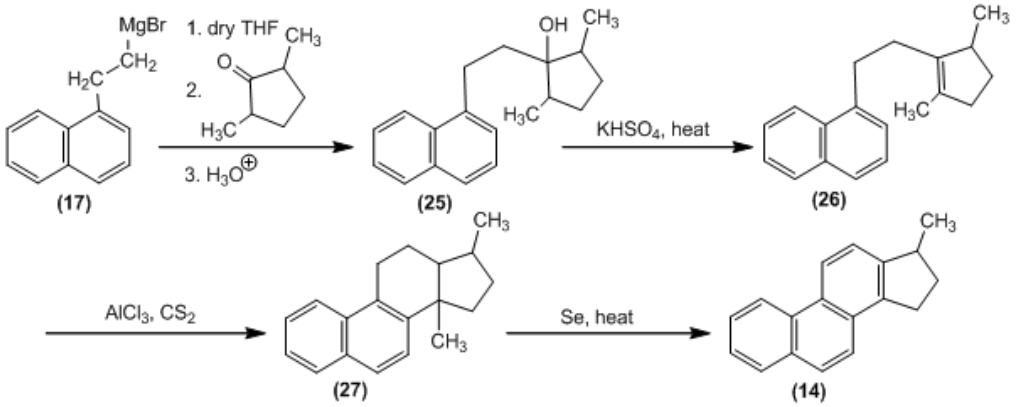
spiran formation was suppressed by placing a methyl group at the other end of the double bond. In addition, Bogert *et al* also isolated the spiro intermediate **21** from **18** in 1936 [15]. In this connection, it is worthwhile to mention that in the modified Bardhan–Sengupta synthesis, the presence of ester group in cyclohexanol moiety excludes the formation of spiro intermediate [14]. This problem was solved by Cook by the replacement of cyclohexanone with 2-methylcyclohexanone. Thus, the modified Bogert–Cook synthesis of phenanthrene can be illustrated as in *Scheme* 9.

The point to be noted here is that the presence of methyl group helps the Friedel–Crafts cyclisation in the correct orientation while the angular methyl group is knocked off during dehydrogenation. This modification undoubtedly guided the synthesis of 3'-methyl-1,2-cyclopentanophenanthrene (**14**), the Diels hydrocarbon (*Scheme* 10) in 1933 [16].

Based on this discussion and a closer scrutiny of Bardhan-Sengupta synthesis (June 29th, 1932) along with Bogert–Cook synthesis (November 18th, 1932 and July 11th, 1933), it appears that the idea behind the Bogert–Cook synthesis was rooted in the Bardhan–Sengupta synthesis. However, in this connection, Bogert as well as Cook individually claimed in their publications that they had the better synthetic approach to phenanthrene and its derivatives than that of the Indian authors (*Box* 3) [12, 13].




**Scheme 9.** Modified Bogert–Cook synthesis of phenanthrene.




**Scheme 10.** Bogert–Cook synthesis of Diels hydrocarbon.

Modern scientific knowledge dictates that statement of Cook regarding Bardhan–Sengupta synthesis in relation to the Howarth synthesis is undoubtedly irrelevant, as was pointed out by Bardhan in his publication (*Box* 1). In this connection, it is worthwhile to mention that Howarth's synthesis of phenanthrene involved the introduction of four carbon unit on the naphthalene moiety through succinoylation, a Friedel–Crafts acylation.

The apparent limitation of the Bardhan–Sengupta protocol in synthesising Diels' hydrocarbon was skilfully overcome by

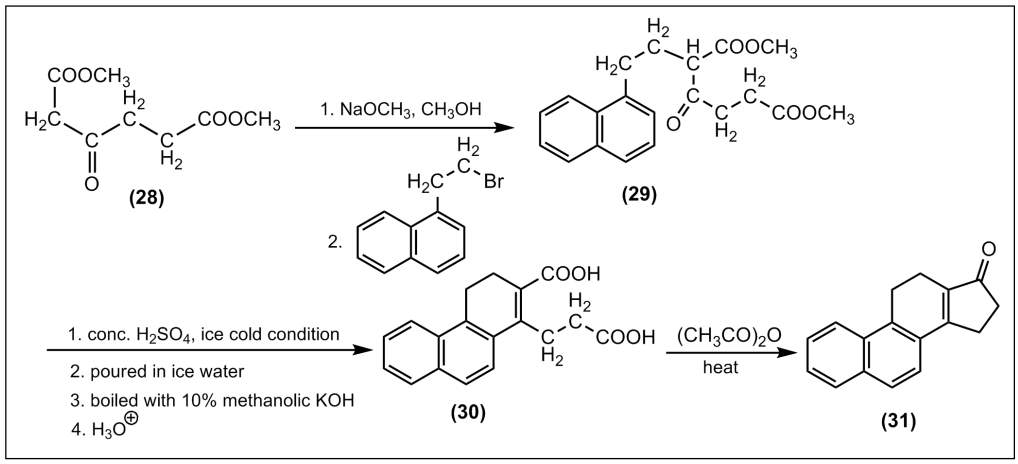
**Box 3. Statements of Bogert and Cook**

"We believe that this synthesis has certain advantages over that of Bardhan and Sengupta, in that it starts with a simpler initial material, cyclohexanone instead of the potassium derivative of its ethyl carboxylate, and involves fewer steps. The investigation, therefore, is being extended in various directions, by using other carbonyl compounds in place of cyclohexanone and other Grignard reagents instead of phenethyl magnesium halides."

– *M T Bogert* (1933)

"The octahydrophenanthrene had been obtained by Bardhan and Sengupta (*J. Chem. Soc.*, p.2520, 1932) by a somewhat similar method (we are indebted to R D Haworth for drawing our attention to this paper which we had overlooked), but as Bogert (*loc cit*) has pointed out, the present method is much simpler than that of Bardhan and Sengupta, and also demonstrates the true nature of the cyclisation process, which was apparently unsuspected by the Indian authors."

– *J W Cook* (1933)




**Scheme 11.** Synthesis of 3'-keto-3,4-dihydro-1,2-cyclopentenophenanthrene.

Bardhan himself through his brilliant logic in his 1936's publication from Imperial College of London where Bardhan efficiently synthesised 3'-keto-3,4-dihydro-1,2-cyclopentenophenanthrene (**31**) (*Scheme* 11). He was interested in the synthesis of the sterol derivatives or their stereoisomers and physiologically active ketones related to the sex hormones [8].

Bardhan ultimately prepared 1,2-cyclopentenophenanthrene (**13**) via the reduction of keto group. It is evident from the above synthesis (*Scheme* 11) that Diels' hydrocarbon can be obtained easily via functional group inter-conversion (FGI) on the synthesised ketone. In this connection, it can be informed that an alkyl group can be introduced at 3'-position with the aid of Grignard reaction. From this discussion, it may be assumed that the brilliant Bardhan took up a silent challenge of synthesising Diels' hydrocarbon without uttering any comment in this respect. Obviously, it appears that accepting Bogert and Cook's statements in any manner; he put forward a modified protocol of synthesising cyclopentano-phenanthrene moiety which may lead conveniently to the synthesis of Diels' hydrocarbon.

This vindicates the truism that the conflict in the scientific world always leads to a positive outcome and, thus, ultimately it is science that advances every day.

## Conclusion

Till date, the Bardhan–Sengupta phenanthrene synthesis is considered to be the most efficient, and justly famous synthetic route to phenanathrene and its derivatives. The Bardhan–Sengupta

synthesis is included as a 'name reaction' in the undergraduate curriculum of all universities. As students of the University of Calcutta, we feel proud of our avant-garde teachers and their excellent piece of work in 1932. Here, we have only discussed the most famous work of Bardhan–Sengupta. Besides this, they have a significant contribution to the synthetic world of chemistry with their classical approach of synthesis. The most inspiring fact to us is that Bardhan modified their syntheses as and when required and established his prominence through his outstanding knowledge and work to the chemical world silently. This vindicates the truism that the conflict in the scientific world always leads to a positive outcome and thus ultimately it is science that advances every day.

## Acknowledgement

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