
二十世纪
天然产物化学的伟大成就
～第一部分～
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河北医科大学药学院
天然药物化学教研室
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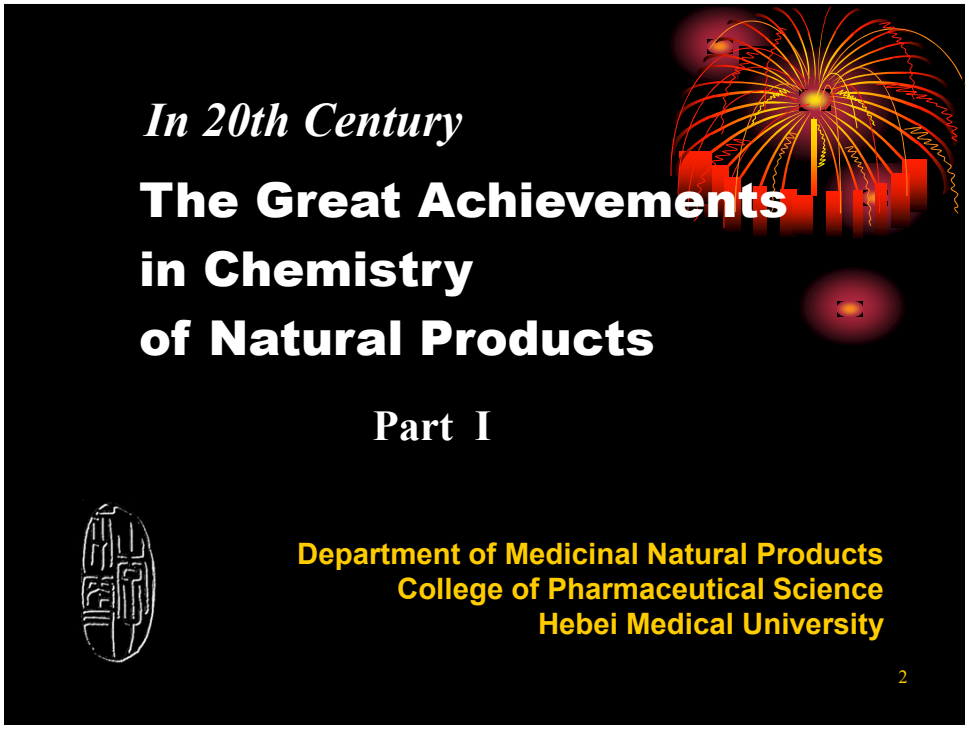
In 20th Century
The Great Achievements
in Chemistry
of Natural Products
Part I
Department of Medicinal Natural Products
College of Pharmaceutical Science
Hebei Medical University
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Who is he ?

His achievements in organic synthesis were:

Cholesterol（胆固醇），Cortisone（可的松,皮质酮），Lanosterol（羊毛甾醇），Strychnine（士的宁），Lysergic acid（麦角酸），Reserpine（利血平），Chlorophyll（叶绿素），Tetracycline（四环素），Colchicine（秋水仙碱），Cephalosporin C（头孢子菌素C）and Vitamin B_{12}（维生素B_{12}）.

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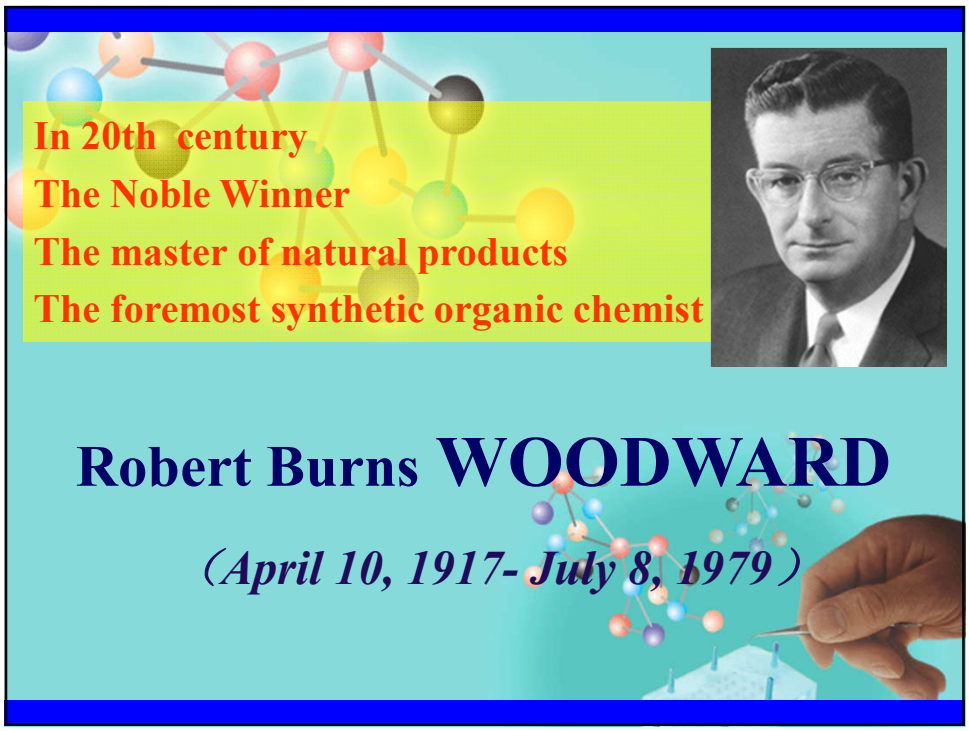
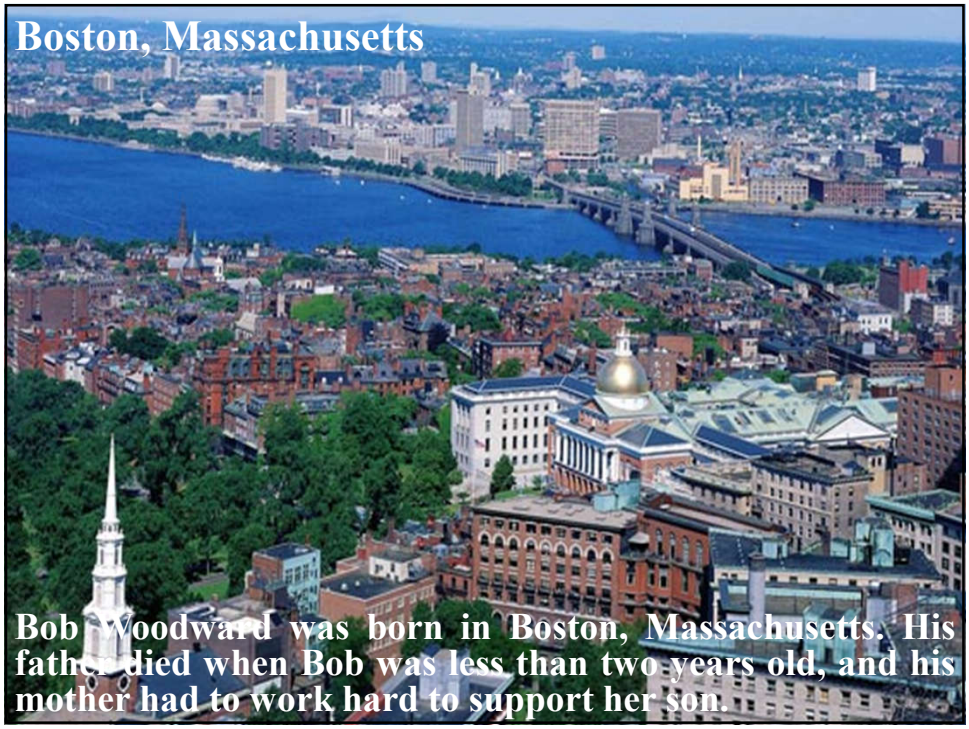
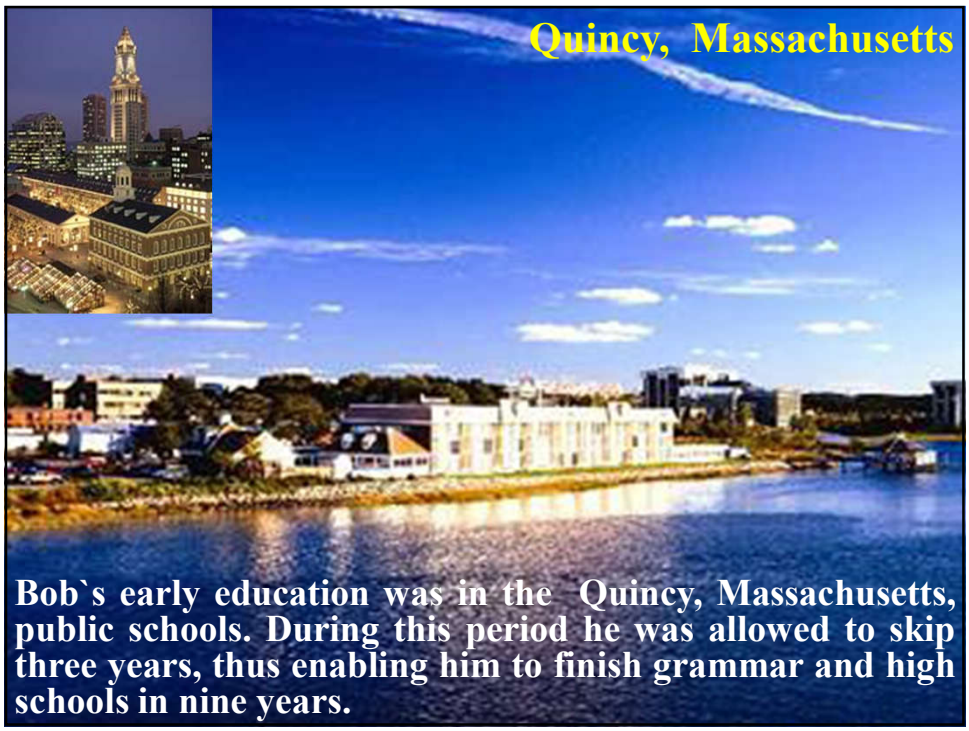
Who is he ?

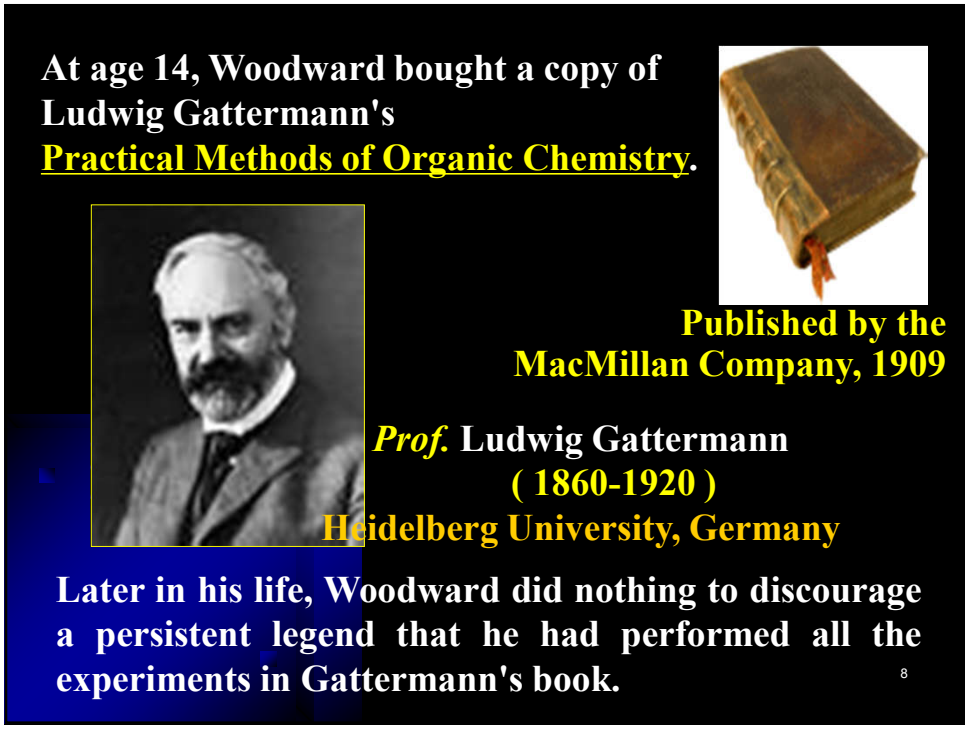
And his breathtaking catalog in structure determination includes:

Penicillin（青霉素），Strychnine（士的宁），Patulin（棒曲霉素），Terramycin（土霉素），Aureomycin（金霉素），Cevine（沙巴达碱），Magnamycin（碳霉素），Gliotoxin（胶霉毒素），Oleandomycin（竹桃霉素），Streptonigrin（链黑菌素），Tetrodotoxin（河豚毒素）.


In 20th century
The Noble Winner
The master of natural products
The foremost synthetic organic chemist
Robert Burns WOODWARD
(April 10, 1917- July 8, 1979)


Boston, Massachusetts
Bob Woodward was born in Boston, Massachusetts. His father died when Bob was less than two years old, and his mother had to work hard to support her son.


Quincy, Massachusetts
Bob`s early education was in the Quincy, Massachusetts, public schools. During this period he was allowed to skip three years, thus enabling him to finish grammar and high schools in nine years.


At age 14, Woodward bought a copy of Ludwig Gattermann's Practical Methods of Organic Chemistry.
Published by the MacMillan Company, 1909
Prof. Ludwig Gattermann
(1860-1920)
Heidelberg University, Germany
Later in his life, Woodward did nothing to discourage a persistent legend that he had performed all the experiments in Gattermann's book.
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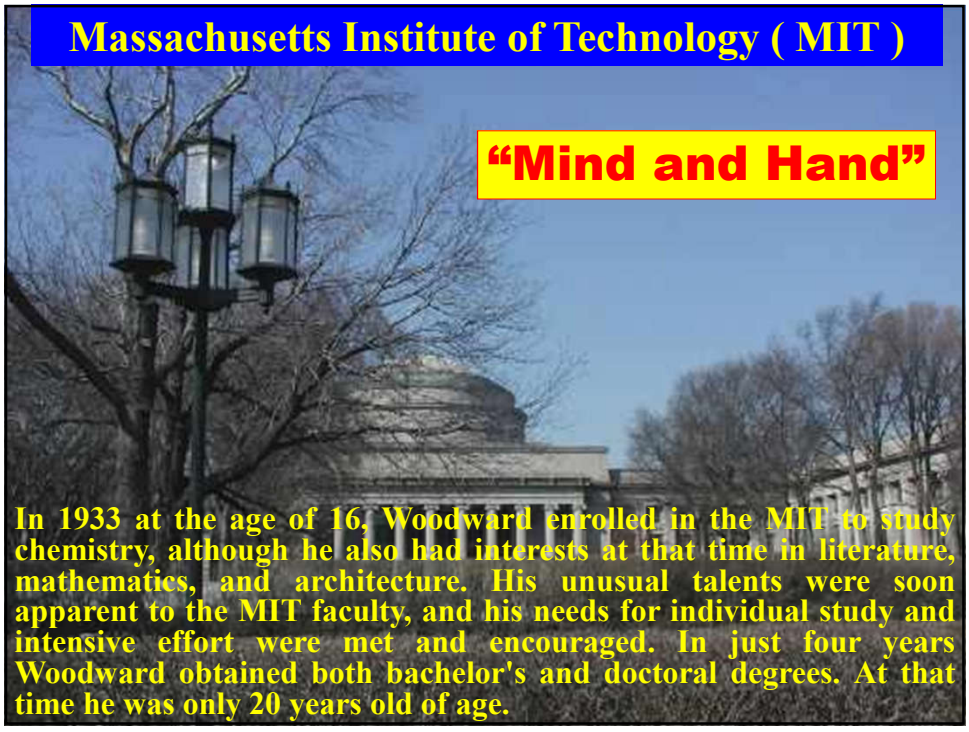
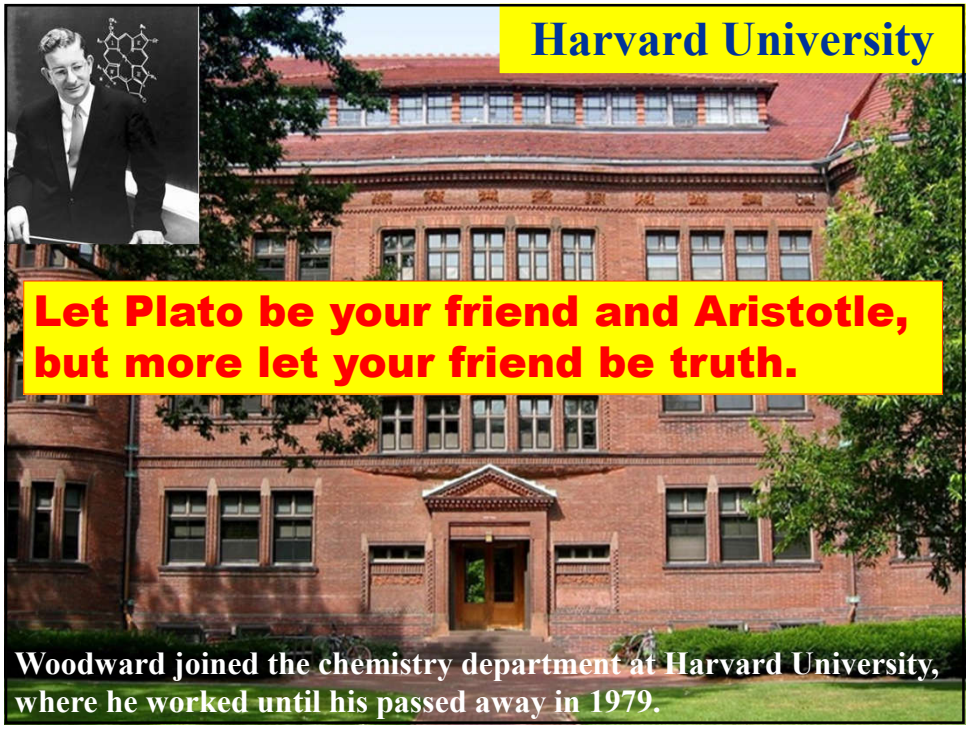
Massachusetts Institute of Technology (MIT)

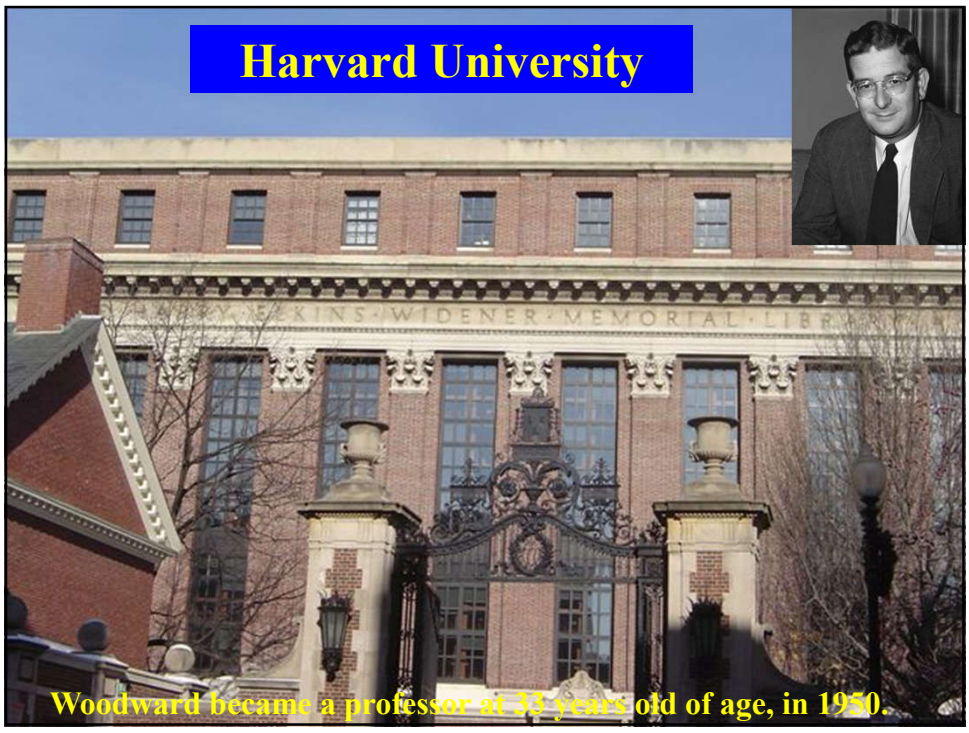


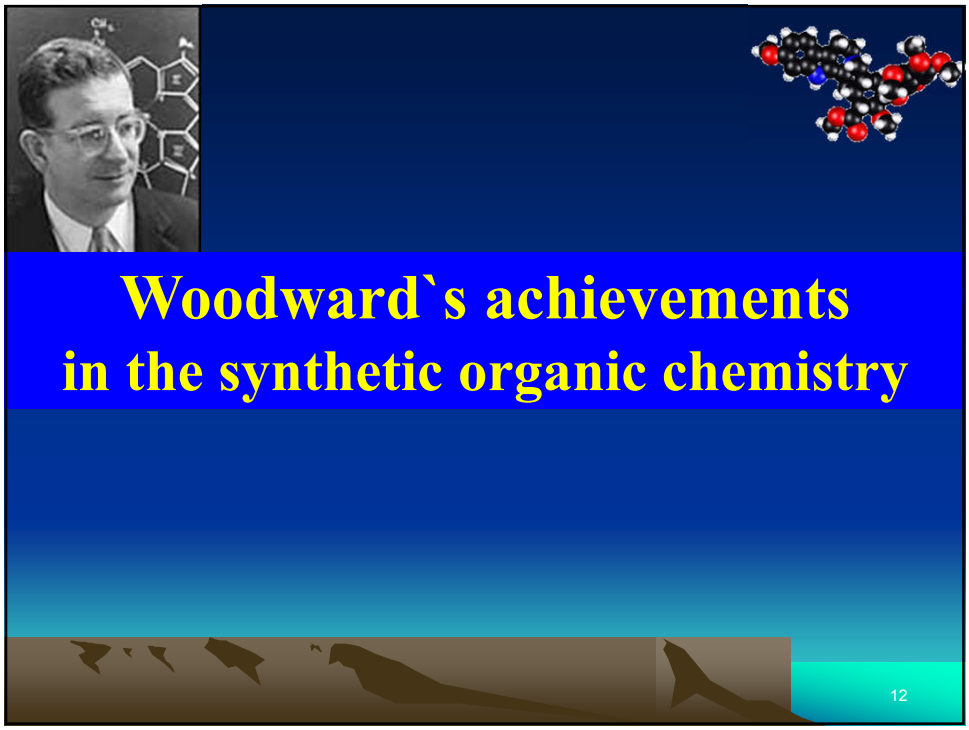
In 1933 at the age of 16, Woodward enrolled in the MIT to study chemistry, although he also had interests at that time in literature, mathematics, and architecture. His unusual talents were soon apparent to the MIT faculty, and his needs for individual study and intensive effort were met and encouraged. In just four years Woodward obtained both bachelor's and doctoral degrees. At that time he was only 20 years old of age.

Harvard University



Woodward joined the chemistry department at Harvard University, where he worked until his passed away in 1979.


Harvard University
Woodward became a professor at 33 years old of age, in 1950.


Woodward`s achievements
in the synthetic organic chemistry
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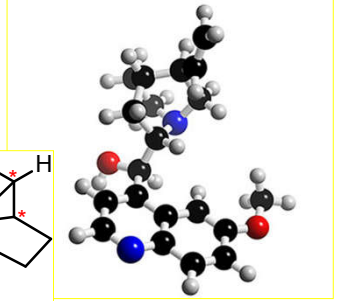
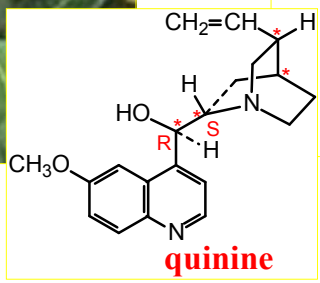
In 1944, Woodward with W. Doering finished the total synthesis of quinine when he was 27 years old.





⊙ **The total synthesis of quinine.** ***J. Am. Chem. Soc.*** **1944, 66:849.**

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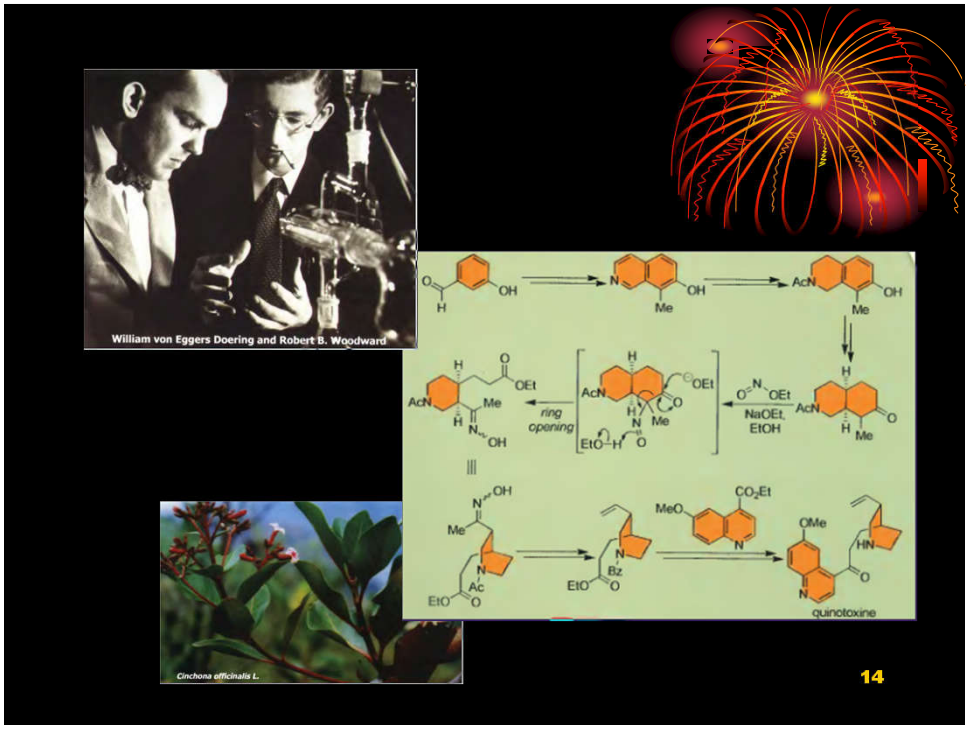
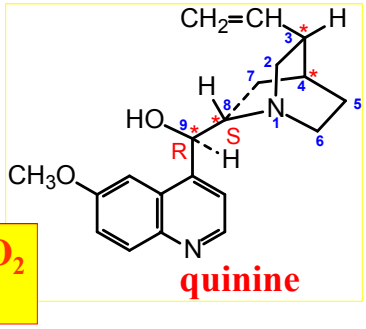


The First Stereoselective Total Synthesis of Quinine

The molecule is optically active with four stereogenic groups making synthesis potentially difficult because it is one of 16 stereoisomers.



MF: $C_{20}H_{24}N_2O_2$
MW: 324

In total synthesis, the Quinine total synthesis describes the efforts in synthesis of quinine over a 150 year period. The development of synthetic quinine is considered a milestone in organic chemistry although it has never been produced industrially as a substitute for natural occurring quinine.

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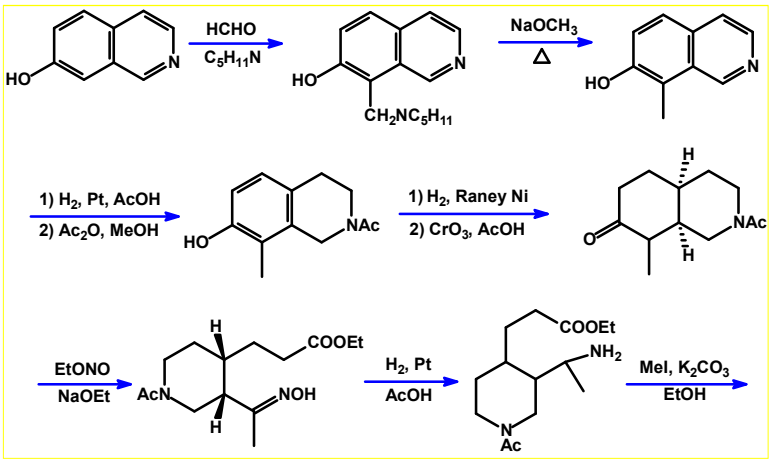
Woodward`s total synthetic quinine route:



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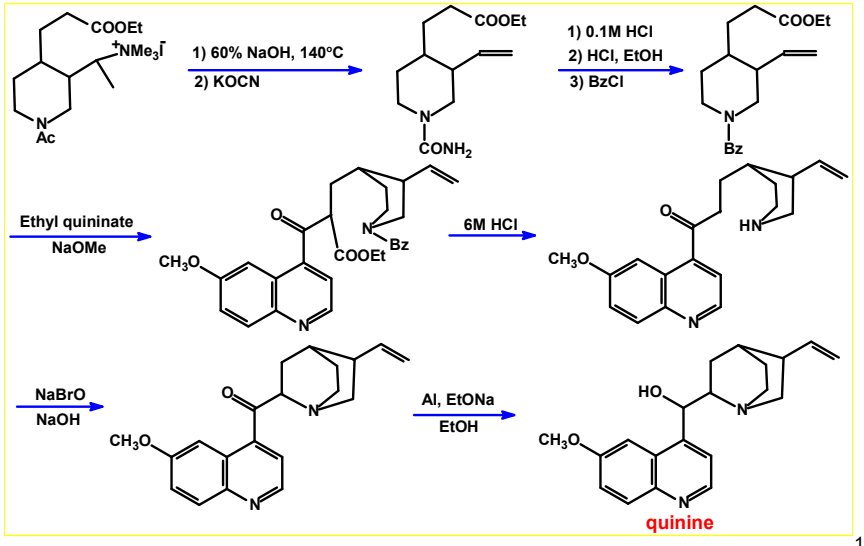
Woodward`s total synthetic quinine route:



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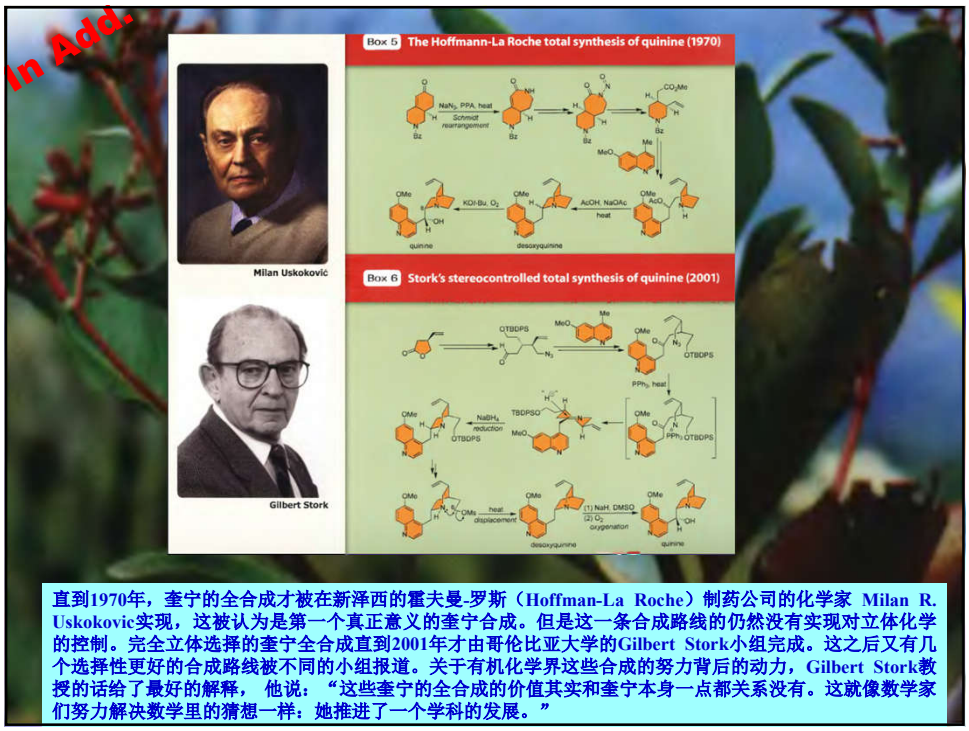
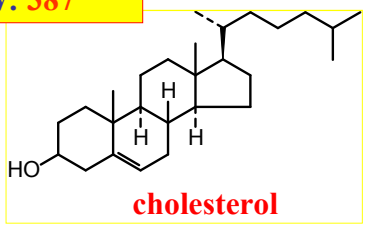


直到1970年，奎宁的全合成才被在新泽西的霍夫曼-罗斯（Hoffman-La Roche）制药公司的化学家 Milan R. Uskokovic实现，这被认为是第一个真正意义的奎宁合成。但是这一条合成路线的仍然没有实现对立体化学的控制。完全立体选择的奎宁全合成直到2001年才由哥伦比亚大学的Gilbert Stork小组完成。这之后又有几个选择性更好的合成路线被不同的小组报道。关于有机化学界这些合成的努力背后的动力，Gilbert Stork教授的话给了最好的解释， 他说：“这些奎宁的全合成的价值其实和奎宁本身一点都关系没有。这就像数学家们努力解决数学里的猜想一样：她推进了一个学科的发展。”

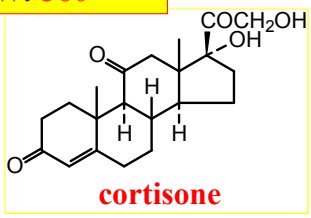
Woodward undertook and completed the total syntheses of the steroids cholesterol and cortisone in 1951.

MF: $C_{27}H_{46}O$
MW: 387



cholesterol
(胆固醇)

MF: $C_{21}H_{28}O_5$
MW: 360



cortisone
(可的松)

⊙The total synthesis of cholesterol. *J. Am. Chem. Soc.* 1951, 73:3548.
⊙The total synthesis of cortisone. *J. Am. Chem. Soc.* 1951, 73:4057.

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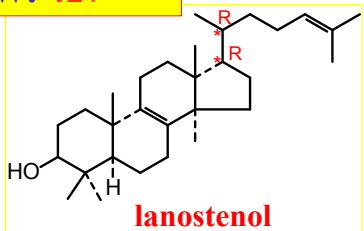
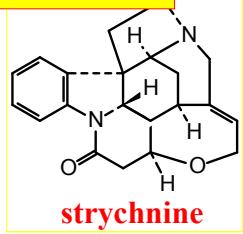
Then, in 1954 Woodward completed the total syntheses of lanosterol and strychnine.

MF: $C_{30}H_{50}O$
MW: 427



lanostenol
(羊毛甾醇)

MF: $C_{21}H_{22}O_2N_2$
MW: 334



strychnine
(士的宁,番木鳖碱)

⊙ The synthesis of lanostenol. *J. Am. Chem. Soc.* 1954, 76:2852-53.
⊙ The total synthesis of strychnine. *J. Am. Chem. Soc.* 1954, 76: 4749 -51.

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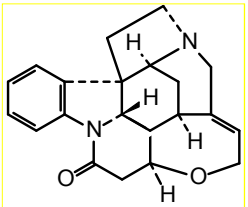
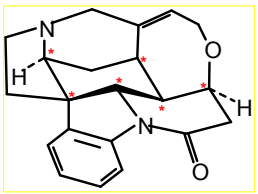
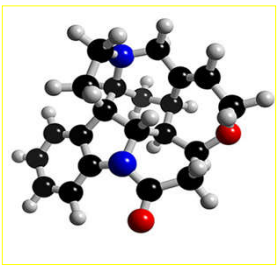
The stereo structure & 3D model of strychnine:



$C_{21}H_{22}N_2O_2$





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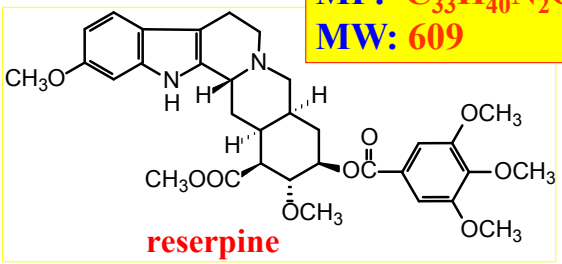
In 1956 the synthesis of reserpine has become a model of elegant technique and has been used for the commercial production of this tranquilizer.

rauvolfia serpentina L.

MF: $C_{33}H_{40}N_2O_9$
MW: 609



reserpine

⊙ The total synthesis of reserpine. *J. Am. Chem. Soc.* 1956, 78: 2023-2025, 2057.

⊙ The total synthesis of reserpine. *Tetrahedron.* 1958, 2:1-57.

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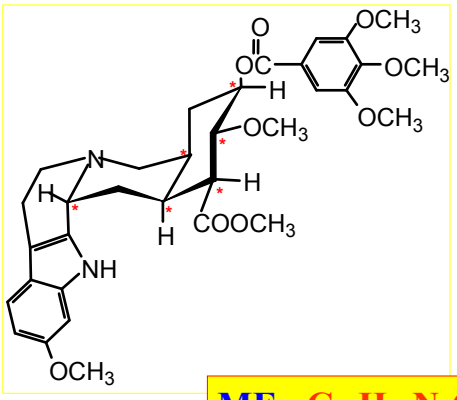
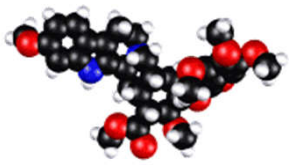
The stereo structure of reserpine:

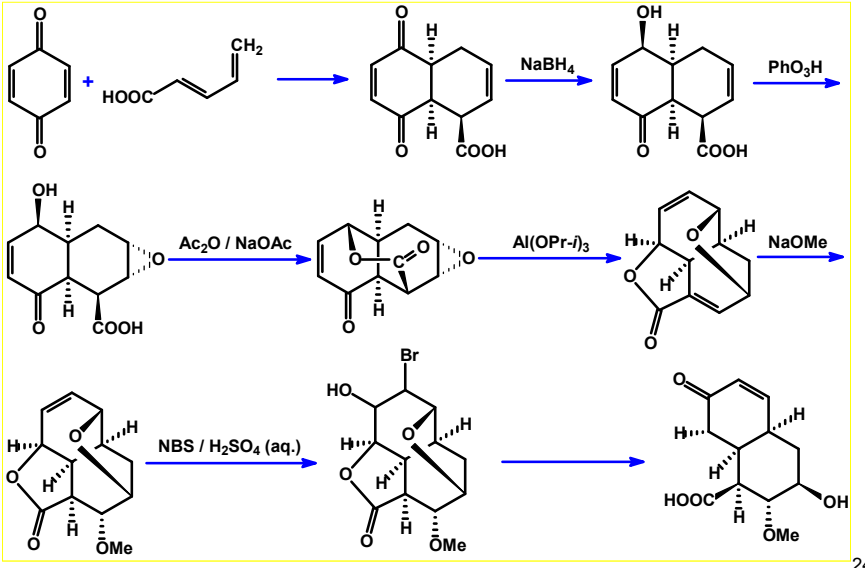




MF: $C_{33}H_{40}N_2O_9$
MW: 609

23

Woodward`s total synthetic route of reserpine:



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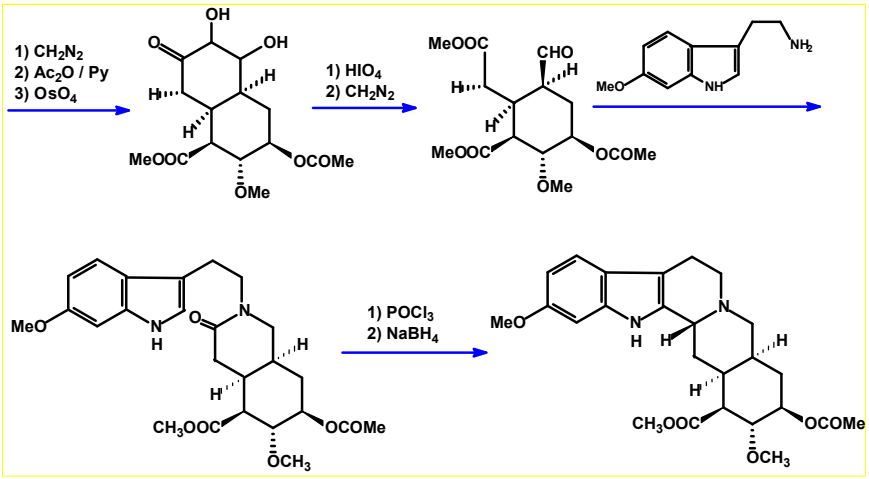
Woodward`s total synthetic route of reserpine:



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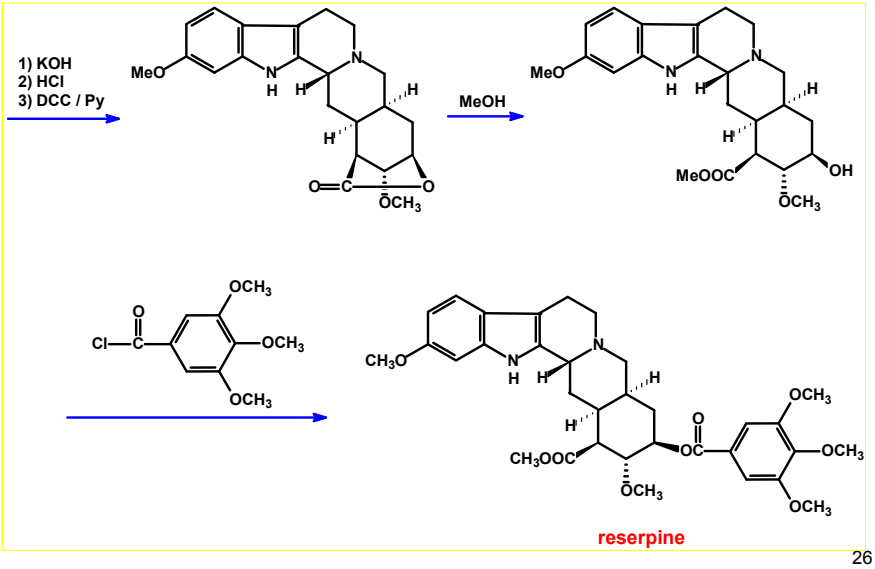
Woodawrd`s total synthetic route of reserpine :



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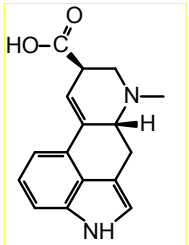
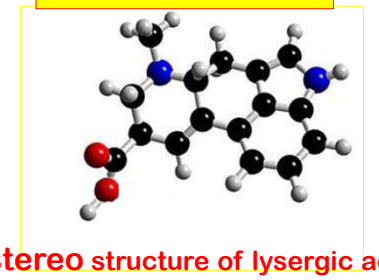
Woodward finished the total synthesis of lysergic acid in 1956, too .

（麦角酸）

MF: $C_{16}H_{16}N_2O_2$
MW: 268



lysergic acid
（麦角酸）



stereo structure of lysergic acid

⊙ **The total synthesis of lysergic acid. *J. Am. Chem. Soc.* 1956, 78: 3087-3014.**

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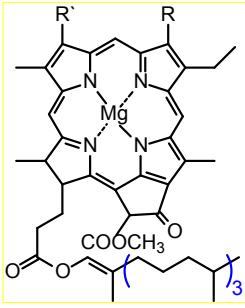
Woodward`s subsequent achievements included the syntheses of chlorophyll (1960), tetracycline (1962), colchicine (1963), and cephalosporin C (1966).

Chlorophyll A
MF: $C_{55}H_{72}O_5N_4Mg$
MW: 893.5



chlorophyll A R= $-CH_3$ R`= $-CH=CH_2$
chlorophyll B R= -CHO R`= $-CH=CH_2$
chlorophyll D R= $-CH_3$ R`= -CHO

（叶绿素）

⊙**The total synthesis of chlorophyll. *J. Am. Chem. Soc.*, 1960, 82: 3800-3802.**

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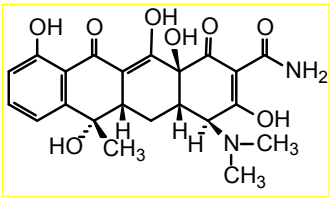
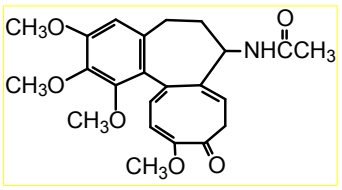
1962：tetracycline



MF: $C_{22}H_{24}O_8N_2$
MW: 444

（四环素）

1963：colchicine



MF: $C_{22}H_{25}O_6N$
MW: 399

（秋水仙碱）

⊙The total synthesis of tetracycline. *J. Am. Chem. Soc.*, 1962, 84:3222-3224.

⊙The total synthesis of colchicine. *Harvey Lectures*, 1963, 59: 31.

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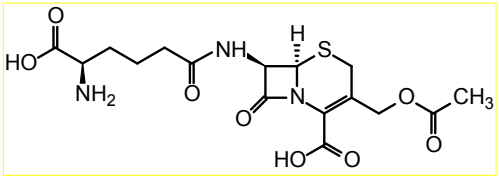
1966：cephalosporin C



MF: $C_{16}H_{21}O_8N_3S$
MW: 415

（头孢菌素 C）

⊙The total synthesis of cephalosporin C. *J. Am. Chem. Soc.*, 1966, 88:852-53.

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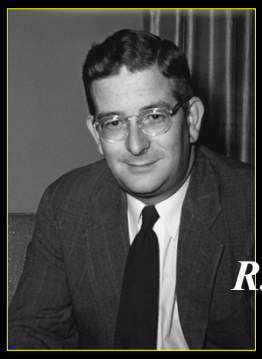
"For his outstanding achievements in the art of organic chemistry."



R. B. WOODWARD

R. B. WOODWARD was awarded the **Nobel Prize for Chemistry** in 1965.

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R.B. Woodward upon receipt of the Nobel Prize in Stockholm, 1965.

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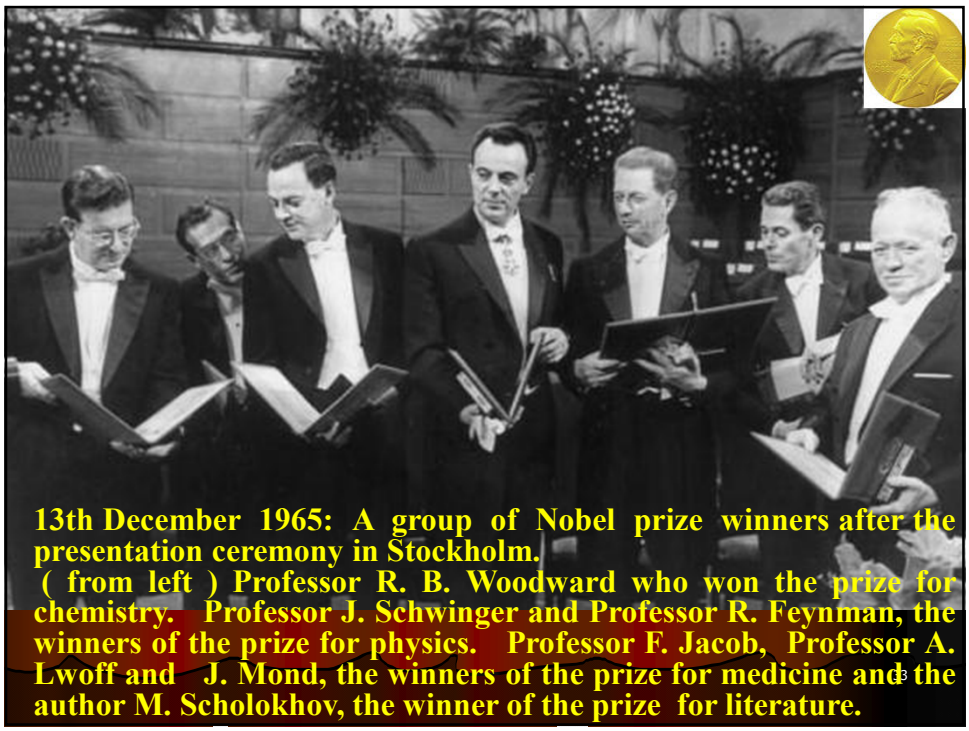

13th December 1965: A group of Nobel prize winners after the presentation ceremony in Stockholm.
(from left) Professor R. B. Woodward who won the prize for chemistry. Professor J. Schwinger and Professor R. Feynman, the winners of the prize for physics. Professor F. Jacob, Professor A. Lwoff and J. Mond, the winners of the prize for medicine and the author M. Scholokhov, the winner of the prize for literature.

Woodward` team completed in 1973 the synthesis of the complicated coenzyme Vitamin B12 (cyanocobalamin) by a sequence of more than 100 reactions.

The formula of vitamin B_{12} :

MF: $C_{63}H_{90}CoN_{14}O_{14}P$ MW: 1356

Chiral centres: 15 Complex rings: 9

- The total synthesis of vitamin B12. *Pure Appl. Chem.*, 1973, 33: 145-177.
- Natural product synthesis and vitamin B12. *Science.* 1977, 24: 1410-1420

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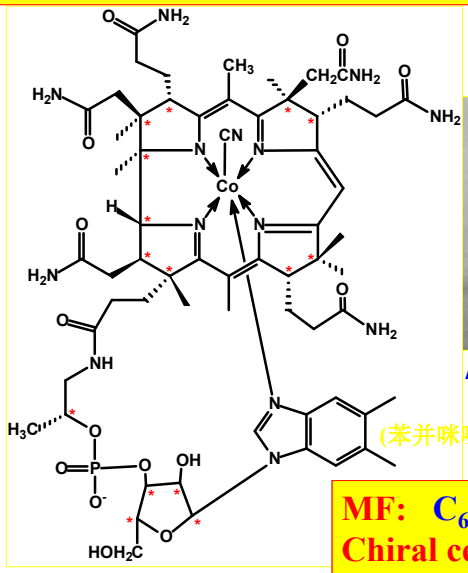
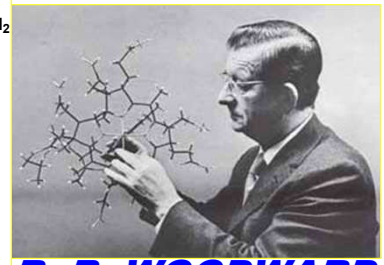
Vitamin B12 Chemical Structure, $C_{63}H_{90}CoN_{14}O_{14}P$

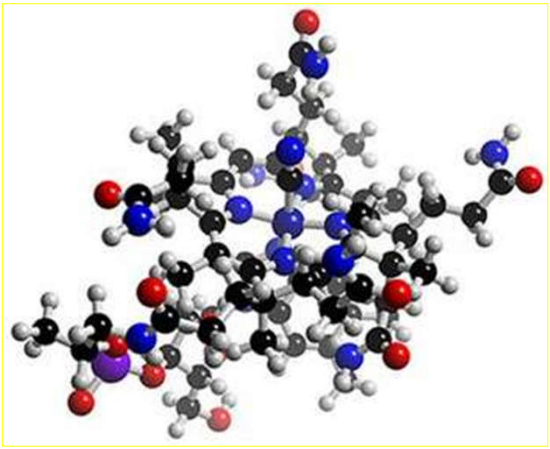




R. B. WOODWARD

MF: $C_{63}H_{90}CoN_{14}O_{14}P$ MW: 1356
Chiral centres: 15
Complex rings: 9

Crystal structure model of Vitamin B12 made for the X-ray crystallographer



Winner of Nobel Prize for Chemistry in 1964 :

"For her determinations by X-ray techniques of the structures of important biochemical substances".

Dorothy Crowfoot-Hodgkin
(Oxford University, Great Britain)

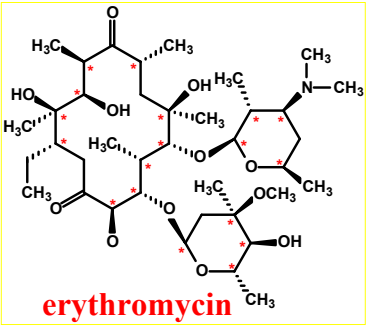
Completing the determination of the structures of VB_{12}.

37

At the time of his death, Woodward was working on the synthesis of erythromycin.

(红霉素)

There could were 2^{18} = 262144 stereoisomers at least, but only one is true.



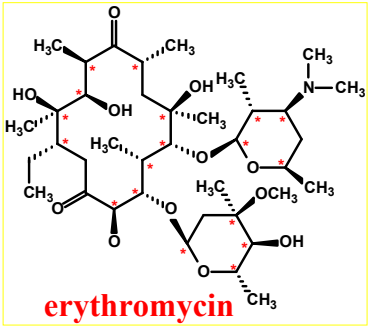
erythromycin

Woodward once thought "it is a impossible compound to be synthesized".

38

But in 1981, the total synthesis of "the impossible compound" was completed by the team of Woodward.

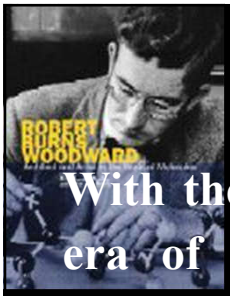
M F: $C_{37}H_{67}O_{13}N$
MW: 734
Chiral centres: 18



erythromycin

⊙Total synthesis of erythromycin. *J. Am. Chem. Soc.*, 1981, 103: 3215-3217.

39

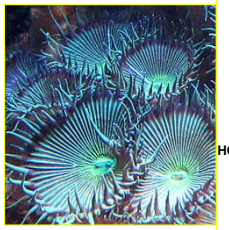


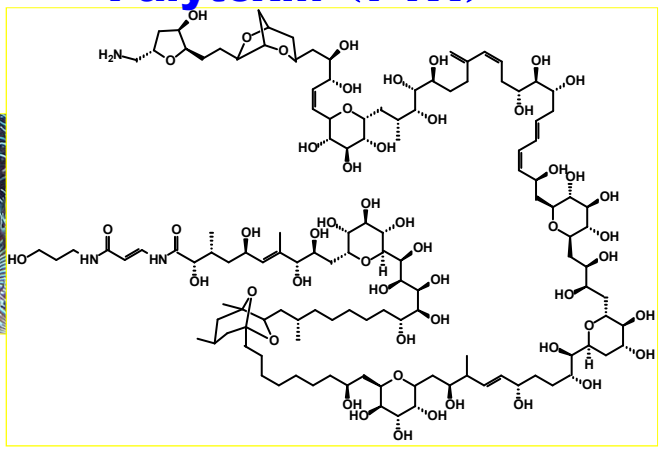
With these, Woodward opened up a new era of synthesis, sometimes called the "*Woodwardian era*" in which he showed that natural products could be synthesized by careful applications of the principles of physical organic chemistry, and by meticulous planning.

40

In Add.

Palytoxin（PTX）



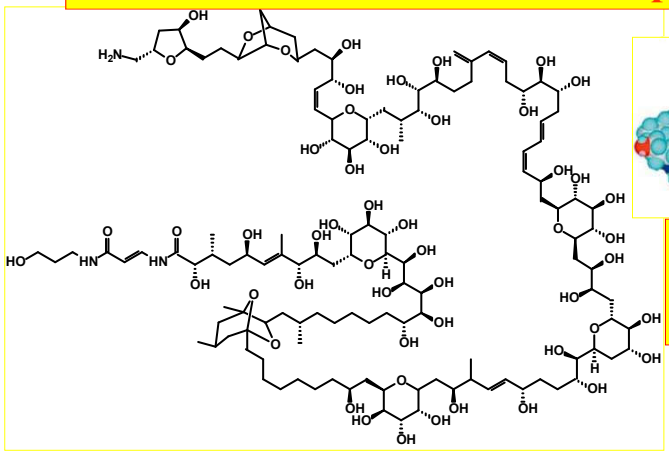


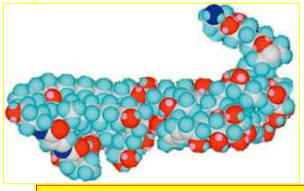
Palytoxin was originally isolated in 1971 in Hawaii from the seaweed-like coralis, one of the most potent toxins known. Later, in 1981 its full chemical structure was published by R. E. Moore and G. Bartolini at University of Hawaii.

41

岩沙海葵毒素

The stereo molecular model of palytoxin:





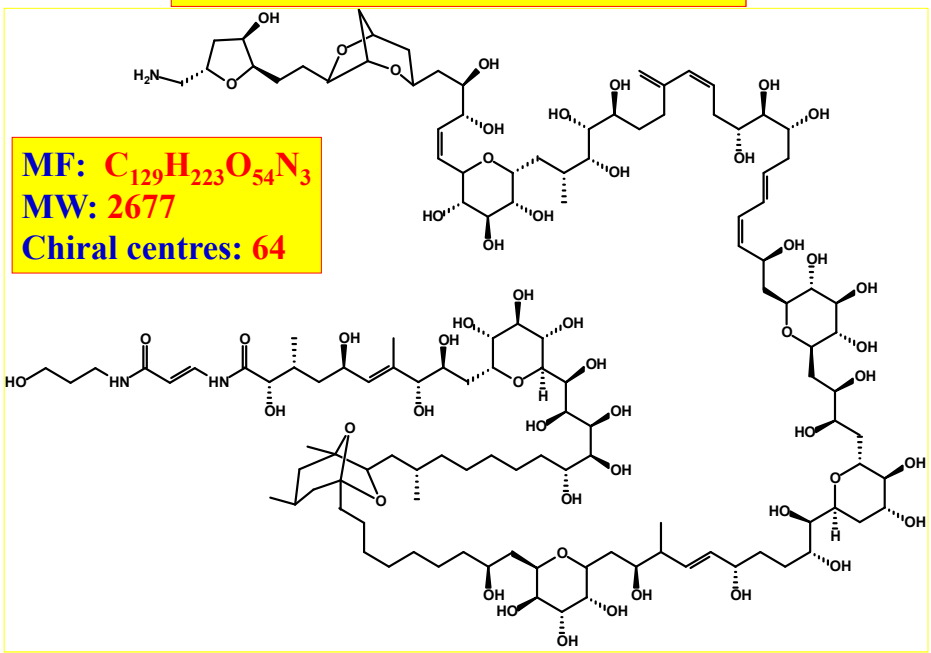
MF: $C_{129}H_{223}O_{54}N_3$
MW: 2677
Chiral centres: 64

Despite palytoxin is relatively large molecular size, it does not contain repeating units, such as sugars and amino acids. There are 71 stereochemical elements (64 chiral carbons and 7 *cis-trans* double bonds), so that there could exist 2^{71} isomers!

42

(next page)

Chemical structure of PTX



MF: $C_{129}H_{223}O_{54}N_3$
MW: 2677
Chiral centres: 64

"The Everest in organic synthetic chemistry"

Yoshito Kishi`s group (28 persons), took 8 years to finish the total synthesis, at Harvard University, in 1989.

This feat is still considered today by many to be the greatest synthetic accomplishment ever, due to its complexity in structure.

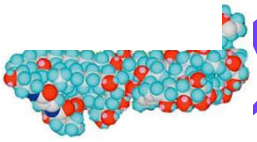
⊙Total synthesis of palytoxin carboxylic acid and palytoxin amide. *J. Am. Chem. Soc.*, 1989, 111:7525-7530.
⊙Synthesis of palytoxin from palytoxin parboxylic acid. *J. Am. Chem. Soc.;* 1994, 116: 11205-11206.

44

Yoshito Kishi
（Harvard University）

Both of the structural determination and total synthesis of palytoxin created scientific and social sensation.

Palytoxin compound was included as a new milestone in history of organic chemistry.

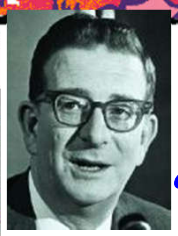


"The structure known, but not yet accessible by synthesis, is to the chemist what the unclimbed mountain, the uncharted sea, the untilled field, the unreached planet."

R. B. Woodawrd

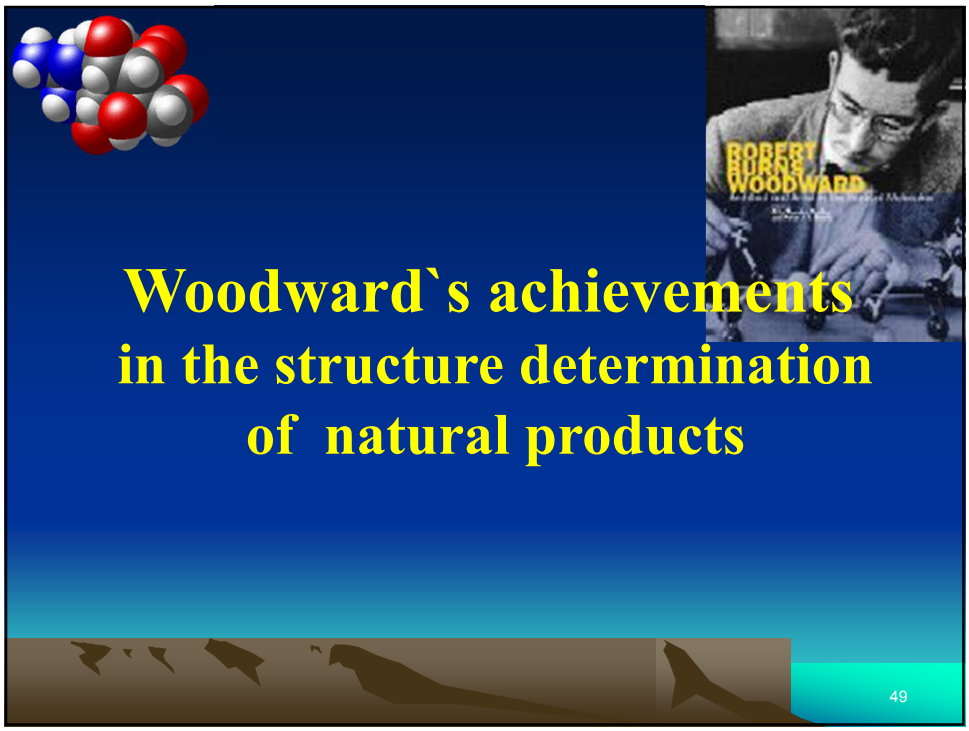
"A new natural world is being built up beside the old natural world because organic chemistry has greatly improved the life of human beings."

R. B. Woodawrd



"有机化学极大地改善了人类的生活，使人类在古老的自然界旁边建立起一个崭新的自然界。"

R. B. Woodawrd



Woodward's analytical skill and mechanistically oriented approach allowed him to solve many of the great structural problems of his day.

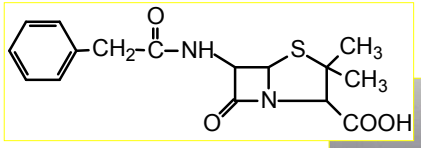
Woodward's breathtaking catalog in structural determination includes penicillin (1945), strychnine (1948), patulin (1949), terramycin (1953), aureomycin (1954), cevine (1954), magnamycin (1956), gliotoxin (1958), oleandomycin (1960), streptonigrin (1963), and in 1964, the famous puffer-fish derived tetrodotoxin.

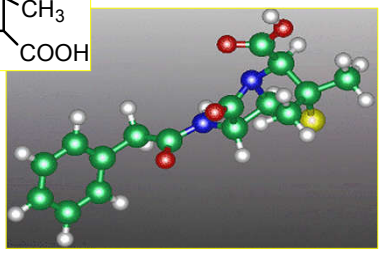
（青霉素，士的宁，棒曲霉素，土霉素，金霉素，沙巴达碱，碳霉素，胶霉毒素，竹桃霉素，链黑菌素，河豚毒素）

50

1945：Penicillin

β-lactam



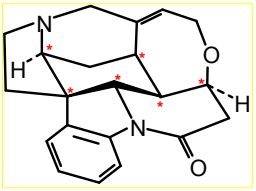


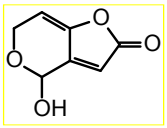
MF: $C_{16}H_{18}N_2O_4S$
MW: 334

⊙The structure of penicillin. *J. Am. Chem. Soc.*, 1945, 67:860-874.

51

1948：Strychnine　　1949：Patulin





MF: $C_{21}H_{22}O_2N_2$
MW: 334

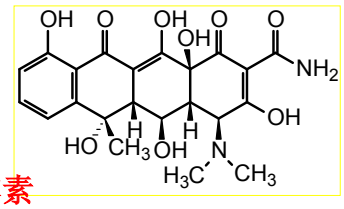
MF: $C_7H_6O_4$
MW: 154

⊙The structure of strychnine. *J. Am. Chem. Soc.*, 1948, 70:2107-2115.

⊙The structure of patulin. *J. Am. Chem. Soc.*, 1949, 71:758-759.

52

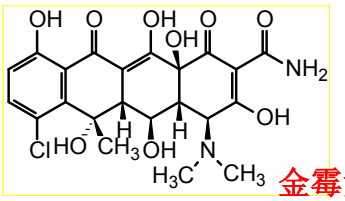
1953：Terramycin



土霉素

MF: $C_{22}H_{24}O_9N_2$
MW: 460

1954：Aureomycin



金霉素

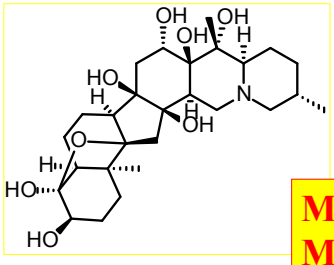
MF: $C_{22}H_{23}O_8N_2Cl$
MW: 479

⊙The structure of terramycin. *J. Am. Chem. Soc.*, 1953, 75: 5455-75.

⊙The Structure of aureomycin. *J. Am. Chem. Soc.*, 1954, 76: 3568-3575.

53

1954：Cevine



MF: $C_{27}H_{43}NO_8$
MW: 510

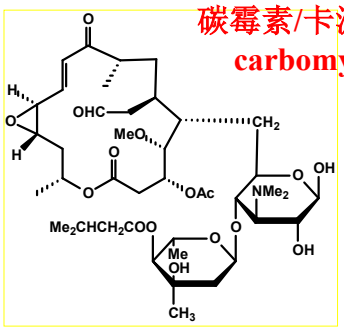
西芬胺

⊙The constitutions of cevine and some related alkaloids. *J. Am. Chem. Soc.*, 1965, 87:4662-3

54

1956：Magnamycin

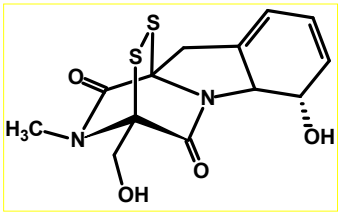
碳霉素/卡波霉素
carbomycin



MF: $C_{42}H_{67}NO_{16}$
MW: 842

1958：Gliotoxin

胶霉毒素

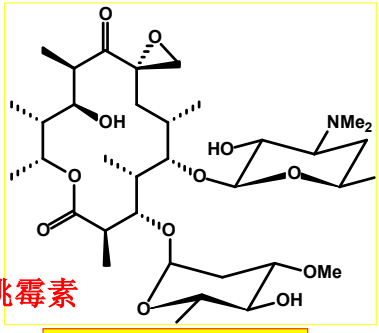


MF: $C_{13}H_{14}N_2O_4S_2$
MW: 326.4

⊙The structure of magnamycin. *J. Am. Chem. Soc.*, 1954, 76: 5256.
⊙Structure of gliotoxin. *J. Am. Chem. Soc.*, 1958, 80:1001.

55

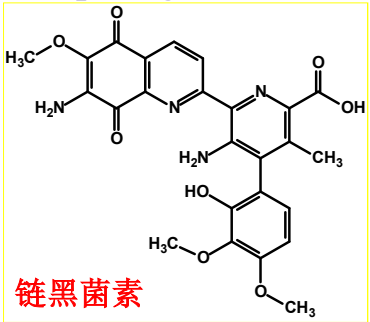
Oleandomycin（1960）



竹桃霉素

MF: $C_{35}H_{61}NO_{12}$
MW: 688

Streptonigrin（1963）

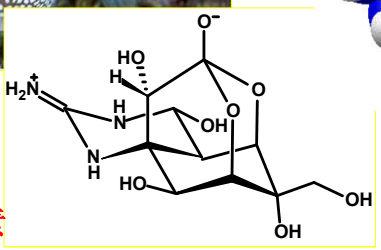


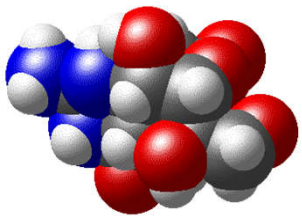
链黑菌素

MF: $C_{25}H_{22}N_4O_8$
MW: 506.5

⊙The structure of oleandomycin. *J. Am. Chem. Soc.*, 1960, 82: 3225-3227.
⊙The structure of streptonigrin. *J. Am. Chem. Soc.*, 1963, 85: 2532-2533.

56





河豚毒素

MF: $C_{11}H_{17}N_3O_8$
MW: 319

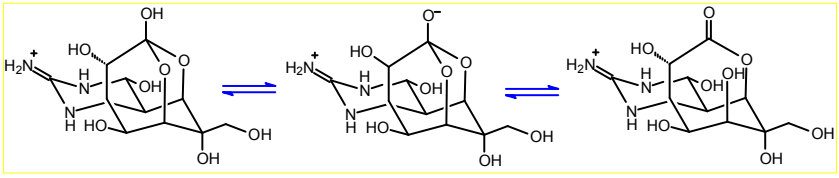
Tetrodotoxin（1964）

⊙The structure of tetrodotoxin. *Pure. Appl. Chem.*, 1964, 9:49-74.

57

河豚毒素（TDX）特殊的结构和性质

- ☞ 含有胍基、笼形原酸酯类生物碱。
- ☞ 在有机溶剂、水中都不溶解，仅溶于乙酸等酸性溶剂。
- ☞ 在强碱性、强酸性溶剂中不稳定。
- ☞ 在溶液中以下平衡体存在：



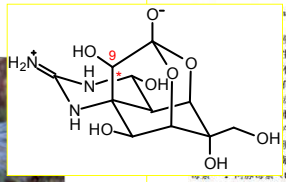
58

课外阅读：

郭瑞霞, 李力更, 王磊, 吴一兵, 史清文*.

天然药物化学史话：河豚毒素

[J].中草药, 2014, 45(9): 1330-1335.



作者单位：河北医科大学药学院

Though synthesis and structure determination were the main focus of Woodward's research, he also made other major contributions.

Woodward`s achievements in the theory of organic chemistry

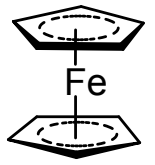
The **Woodward Rules**, published when he was only 23, correlate structures of *α,β*-unsaturated ketones with their ultraviolet absorption spectra and saturated ketones with their optical rotatory dispersion .

Relational papers:

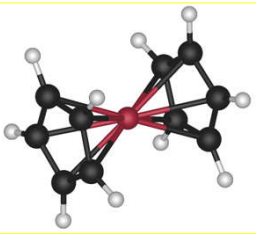
- Structure and absorption spectra of*α,β*-unsaturated ketones. *J. Am. Chem. Soc.*, 1941, 63:1123-26.
- Structure and absorption spectra. II. 3-acetoxy-$\Delta^{5(6)}$ -*nor*-cholestene-7-carboxylic acid. 1941, *J. Am. Chem. Soc.*, 63:2727.
- Structure and absorption spectra. IV. Further observations on *α,β*-unsaturated ketones. *J. Am. Chem. Soc.*, 1942, 64:76-77.
- Structure and the optical rotatory dispersion of saturated ketones. *J. Am. Chem. Soc.*, 83:4013-18.

61

Woodward`s deduction of the ferrocene structure opened a new area of organometallic chemistry.



ferrocene



Relational paper:

- The structure of iron bis-cyclopentadienyl. *J. Am. Chem. Soc.*, 1952, 74: 2125 - 2126.

62

In Add.

E. O. Fischer and G. Wilkinson won the Nobel prize for chemistry, in 1973.

Ernst Otto Fische
Munich Technical University, Germany（1918~2007）

Geoffrey Wilkinson
London Imperial College, United Kingdom（1921~1996）

"For their pioneering work, performed indepe nd-ently, on the chemistry of the organometallic, so called sandwich compounds."

63

Woodward proposed correctly biogenetic schemes for the conversion of squalene to cholesterol, and for the biosynthesis of indole alkaloids and macrolides.

(大环内酯类)

Relational papers:

- The cyclization of squalene in cholesterol synthesis. *J. Am. Chem. Soc.*, 1953, 75: 2023-2024.
- The biosynthesis of indole alkaloids. *Angew. Chem*. 1956, 68:13-20.
- The biosynthesis of macrolides. *Angew. Chem*. 1957, 69:50-58.

64

Finally, as a consequence of certain unusual stereochemical results encountered during the Vitamine B_{12} synthesis, Woodward collaborated with Roald Hoffmann to develop the theory for The conservation of orbital symmetry in chemical reactions, explicating a broad group of fundamental reactions.

These Woodward-Hoffman rules were probably the most important theoretical advance of the 1960s in organic chemistry.

65

Relational papers:

- **Stereochemistry of electrocyclic reactions. *J. Am. Chem. Soc.*, 1965, 87:395-97.**
- **Selection rules for concerted cycloaddition reactions. *J. Am. Chem. Soc.*, 87:2046-48.**
- **Selection rules for sigmatropic reactions. *J. Am. Chem. Soc.*, 87:2511-2513.**
- **Orbital symmetries and *endo-exo* relationships in concerted cycloaddition reactions. *J. Am. Chem. Soc.*, 87:4388-89.**
- **Orbital symmetries and orientational effects in a sigmatropic reaction. *J. Am. Chem. Soc.*, 87:4389-90.**
- **The conservation of orbital symmetry. *Angew. Chem. Int. Ed.*, 8:781-853.**
- **The Conservation of Orbital Symmetry. 1970, *Verlag Chemie Academic Press.***

66

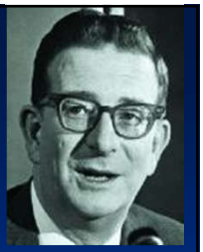
In 1981, the *Nobel Prize* was awarded jointly to:

Roald Hoffmann
Cornell University,
New York, USA.

Kenichi Fukui
Kyoto University,
Kyoto, Japan.

"For their theories, developed independently, concerning the course of chemical reactions".

67



Woodward`s honours and awards in his time

68

Prof. Woodward held honorary degrees:

★ A member of the National Academy of Sciences;

★ A member of the American Academy of Arts and Sciences;

★ Honorary Member of the German Chemical Society;

★ Honorary Fellow of the Chemical Society;

★ Foreign Member of the Great Britain Royal Society;

★ Honorary Member of the Royal Irish Academy;

next page
69

Prof. Woodward held honorary degrees:

★ Corresponding Member of the Austrian Academy of Sciences;

★ Member of the American Philosophical Society;

★ Honorary Member of the Belgian Chemical Society;

★ Honorary Fellow of the Indian Academy of Sciences;

★ Honorary Member of the Swiss Chemical Society;

★ Member of the Deutsche Akademie der Naturforscher (Leopoldina);

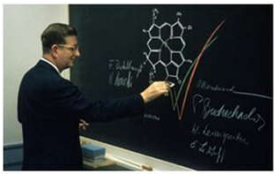
next page
70

Prof. Woodward held honorary degrees:

★ **Foreign Member of the Accademia Nazionale dei Lincei;**

★ **Honorary Fellow of the Weizmann Institute of Science;**

★ **Honorary Member of the Pharmaceutical Society of Japan.**



71

The awards presented to Woodward are the following:

♠ **1945：John Scott Medal (Franklin Institute and City of Philadelphia).**

♠ **1955：Backeland Medal (North Jersey Section of the American Chemical Society).**

♠ **1959：Davy Medal (Great Britain Royal Society) .**

♠ **1961：Roger Adams Medal (American Chemical Society).**

next page

72

Among the awards presented to Woodward are the following:

- ♠ 1964：National Medal of Science (USA).
- ♠ 1965：Nobel Prize for Chemistry.
- ♠ 1967：Willard Gibbs Medal (Chicago Section of the American Chemical Society).
- ♠ 1968：Lavoisier Medal (Societe Chimique de France).
- ♠ 1969：Pius XI Gold Medal (Pontifical Academy of Sciences).

next page
73

Among the awards presented to Woodward are the following:

- ♠ 1970：The Order of the Rising Sun, Second Class (His Majesty the Emperor of Japan).
- ♠ 1970：Hanbury Memorial Medal (The Pharmaccutical Society of Great Britain).
- ♠ 1970：Pierre Brnylants Medal (Université de Louvain).
- ♠ 1978：Copley Medal (Great Britain Royal Society) .

74

Besides his unfailing personal courtesy and wry sense of humor, R. B. Woodward's most characteristic attributes were precision in style, evident in all he said, *wrote or did*.

Those who heard him lecture relished his meticulous choice of words, his dramatic sense of timing, and his seemingly leisurely and deliberate writing of structural formulae and reaction schemes.

75

He accomplished much in several diverse areas (e.g., the correlation of various physical methods with organic structures, determination of the structures of complex compounds, the syntheses of many naturally occurring biological compounds, and devising beautiful and concise synthetic pathways for complicated molecules).

During his lifetime he authored or coauthored 196 publications, of which 85 are full papers, the remainder comprising preliminary communications, the text of lectures, and reviews.

76

In his time Woodward brought up more than 200 doctors or postdoctors and other researchers.

His famous students included ***Yoshito Kishi*** (professor of Harvard university), ***Stuart L. Schreiber*** (professor of Harvard university), ***Christopher S. Foote*** (professor of UCLA) and ***Kendall Houk*** (professor of UCLA), etc.

77

"Architect and Artist in the World of Molecules!"

----This opinion is shared by other distinguished chemists

R. B. WOODWARD

78

Professional Chronology of R. B. Woodward

1934

Publishes first scientific paper

1940-1942

Publishes four papers on rules for the correlation of ultraviolet spectroscopy with molecular structure; known as the **Woodward Rules**

1942

Writes early paper on the Diels-Alder reaction

1944

Completes synthesis of quinine

79

Professional Chronology of R. B. Woodward

1945-1956

Determines the structure of penicillin, patulin, strychnine, terramycin, aureomycin, and magnamycin

金霉素

碳霉素

1951

Synthesis of the steroids cholesterol and cortisone

1954

Synthesis of strychnine and lysergic acid

1956

Synthesis of reserpine

80

Professional Chronology of R. B. Woodward

1960

Completes synthesis of chlorophyll, which took 4 years

1963

Synthesis of cephalosporin C

1965-1969

Development of the laws of the conservation of orbital symmetry, with Roald Hoffman

1972

Synthesis of VB12 completed with A. Eschenmoser

81

We will remember the man forever:

A preeminent organic chemist in the 20th century.

R. B. WOODWARD

(April 10, 1917- July 8, 1979)

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Thanks for your attention!
Thanks everybody !
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