THE FUTURE OF CHEMISTRY

Dr. S. Sivaram,
National Chemical Laboratory,
Pune-411 008, INDIA

Tel : 0091 20 2590 2614
Fax : 0091 20 2590 2615
Email : s.sivaram@ncl.res.in
Visit us at : http://www.ncl-india.org

National Science Day Lecture
Indian Institute of Technology,
Kharagpur

April 9, 2012

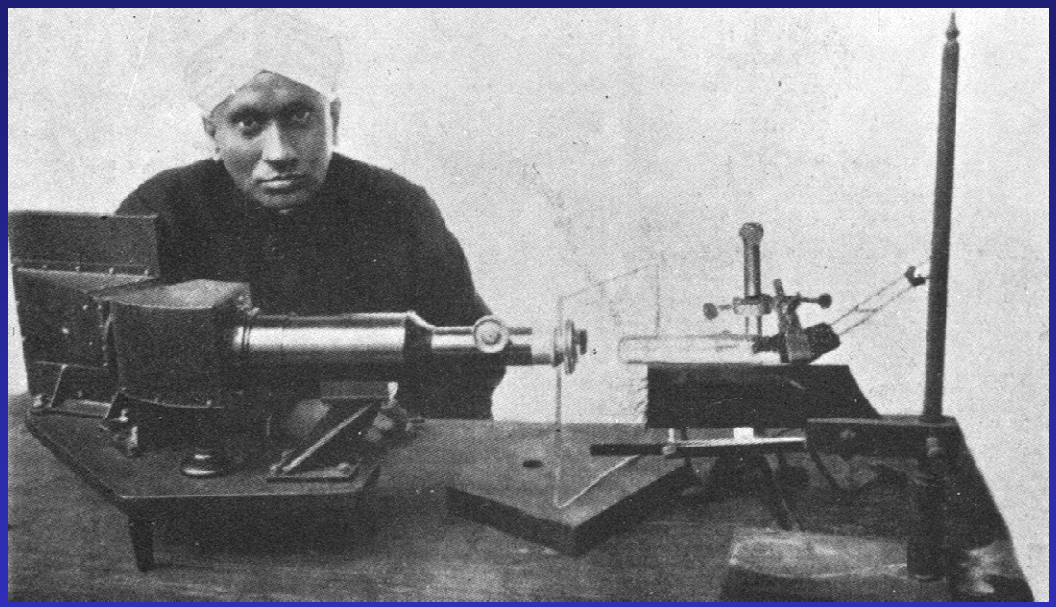
- *Bidhan Chandra Roy*
- *Jawaharlal Nehru*
- *Nalini Ranjan Sarkar*

Congratulations on a Glorious Sixty Years

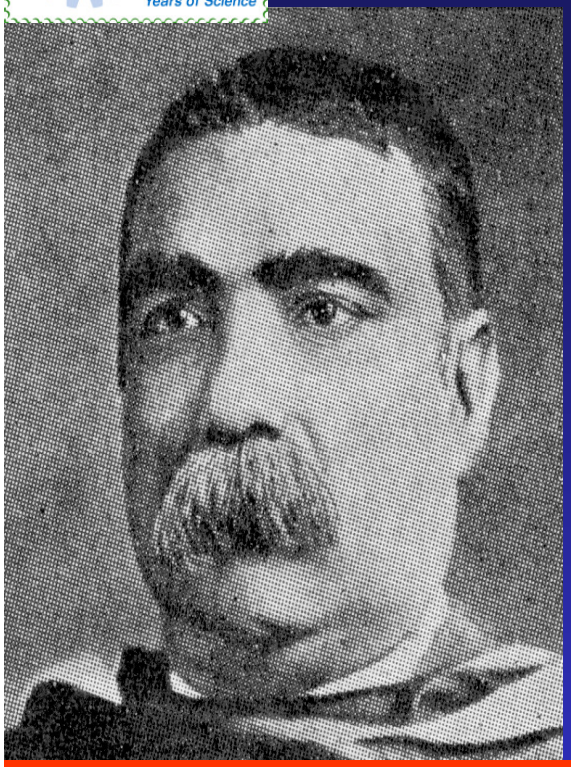
Here in the place of that Hijli Detention Camp stands the fine monument of India, representing India's urges, India's future in the making. This picture seems to me symbolic of the changes that are coming to India.

Nehru, First Convocation of IIT, Kharagpur, 1956

C. V. Raman
1888-1970



1906 Published first paper at the age of 18
1907 Asst. Auditor General ; starts research at IACS
1917 Palit Professor of Physics, Calcutta University
1928 Raman Effect announced on 28 Feb, used sunlight & eyes
1930 Raman receives the Nobel Prize ; bought tickets before announcement !
1998 International Historic Chemical Landmark of ACS at IACS



Asutosh Mukherjee (1864-1924)

Dr. Mahendralal Sircar (1833-1904) Founder,Indian Association for the Cultivation of Science,1876

" The sole function will be science-learning and science-teaching. I want freedom for the institution. I want it to be solely native and purely national ".

We have got a young student with fine intellect, doing research in our laboratory. A side issue of his work has been published in *Nature* , 24 October 1907. The prophecy of the great man is now going to be fulfilled. If circumstances do not go against us, Raman will be the brightest ornament of IACS.

- *A. L. Sircar, 21 November 1907*

I admire the courage and spirit with which Raman exchanged a lucrative official appointment for a University professorship. This instance encourages me to entertain the hope that there will be no lack of seekers of truth in the Temple of Knowledge which it is our ambition to erect.

- Asutosh Mukherjee (1864-1924)

Sir Asutosh ventured to ask an young and unknown official to devote himself to the pursuit of knowledge under the aegis of the Calcutta University. This, on his part, was an act of courage. But for the action of Sir Asutosh, my scientific career would long ago suffered an abrupt termination

- Sir C. V. Raman

I would like to stress the practical value of scientific researches to be carried out at in the National Chemical Laboratory, although I do not believe that utility is the main incentive to scientific work. It is in man's attempts to study nature and to understand her secrets that science finds its best motive. For this reason, I believe that good laboratories alone are not sufficient to produce scientific work but it is the ability of the individuals who work in the laboratory that counts.

I am sure that individuals of exceptional ability will work in the NCL and work for the advancement of science

Sir C.V. Raman , January 3, 1950

ACHARYA P.C.RAY

P.C.Ray (1861-1944)

- India's first chemist and entrepreneur
- Ph D from Edinburgh (1882-87) ; the first Indian scientist to practice chemistry
- A staunch nationalist who understood the power of manufacturing for India's economy
- Established Bengal Chemicals and Pharmaceuticals Works Ltd in 1901 with a capital of Rs 700, drawn from his personal wealth
- Today , Bengal Chemicals and Pharmaceuticals Ltd is a public sector company with a turn over of over 100 crores, having survived many upheavals
- Author of over 100 original scientific papers and a book titled, *A History of Hindu Chemistry (1902)*

Acharya Ray has become many in his pupils and made his heart alive in the hearts of many; and this would not have been possible had he not unreservedly made a gift of himself : Tagore

ACHARYA P.C. RAY

- **His discovery of mercurous nitrite (1895) received wide recognition world wide**
- **Great institution builder; created an internationally recognized school of chemistry at Presidency College**
- **Explored the problem of adulteration of ghee and mustard oil, produced sodium phosphate from locally available resources, and attempted to place traditional Indian medicine on a sound scientific footing**
- **A contemporary of J.C.Bose, yet they were like chalk and cheese. Ray was a pedestrian down to earth chemist whereas Bose was an aristocrat, who abhorred creation of wealth through science and sought repeated western approval of his science**

Acharya Ray remarked (1940) that he set up BCPWL to wipe out the idea that the Bengalees were good for nothing in business affairs !

International Year of CHEMISTRY 2011

- Celebrate the achievements of chemistry
- Improve public understanding of chemistry
- Champion the role of chemistry in addressing the critical challenges of our society
  - Food and nutrition
  - Clean water
  - Sustainable energy
  - Climate change
- Broader outreach and engagement
- Get younger people more interested in chemistry

Chemistry is the central, useful and creative science : Ronald Breslow

Madame Curie, Nobel Prize in Chemistry , 1911

Earnest Rutherford, The Structure of the Atom. 1911

MARIE SKLODOWSKA CURIE
(7 November 1867 – 4 July 1934)

- **The first woman to get a PhD in Europe**
- **The first woman to be appointed a full Professor in Sorbonne in 1906 , but only after the death of her husband and after having won a Nobel Prize**
- **The first woman to win a Nobel Prize , in 1903 for Physics based on her PhD thesis**
- **The only woman to have won two Nobel Prizes**
- **The only person to have won two Nobel Prizes for two different branches of science, Physics and Chemistry (1911)**
- **The only mother and daughter pair to win Nobel Prizes in Chemistry; the only family that produced four Nobel Laureates**

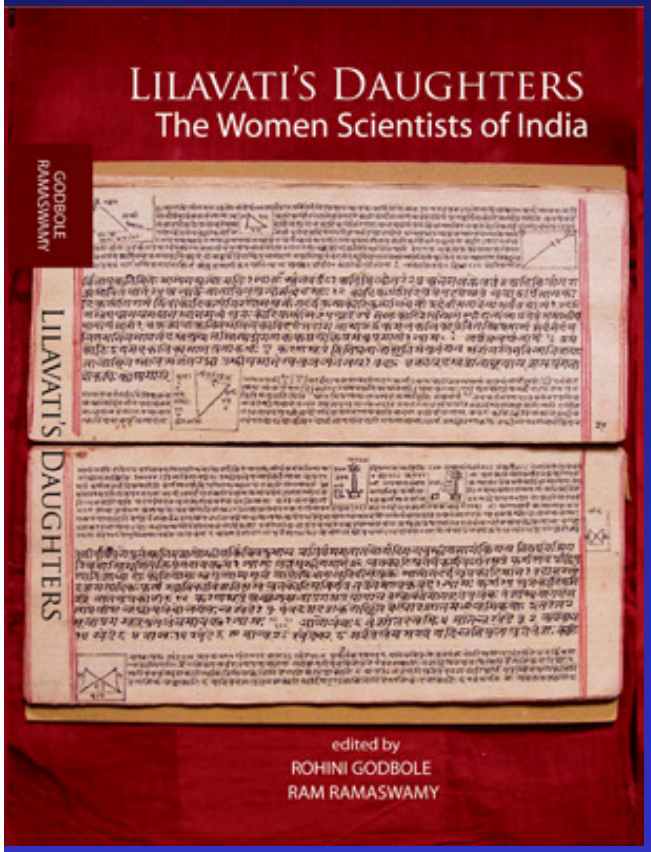
You cannot hope to build a better world without improving the individuals; To that end , each one of us must work for our own improvement, and at the same time share a responsibility for all humanity. Our particular duty being to aid those to whom we think we can be most useful" : Marie Curie

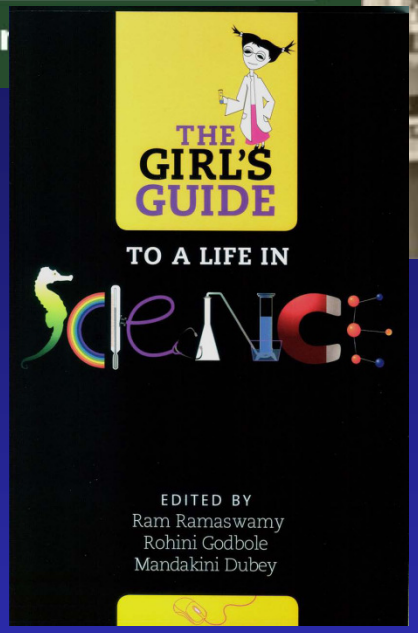
CHALLENGES FOR WOMEN IN SCIENCE (AND CHEMISTRY)

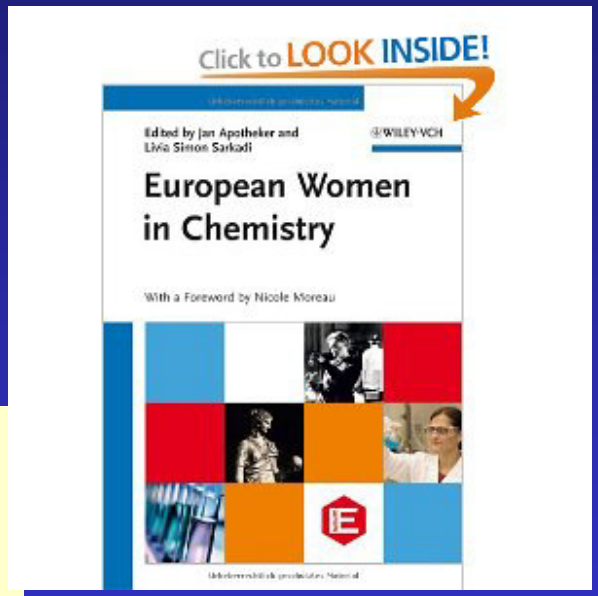
- **High attrition; In UK and USA about 50% of PhDs awarded to women , but they are under represented in the faculty**
- **Experimental research adversarial**
- **Difficulty in combining a career and family**
- **Lack of adequate role models**
- **Chemistry is competitive and male dominated; women are assumed to be less competitive than men**
- **Social biases and gender prejudices downplay women`s accomplishments in science**
- **Can chemistry make all its leaps it could without the contribution of half of its finest minds ?**

Women in Science

An Indian Academy of Scien







European Women in Chemistry, Ed., J. Apotheker, L. S. Sarkadi and N. Moreau, Wiley - VCH, 2011

M. Francl, Sex and the Citadel of Science, Nature Chemistry, 3, 670 (2011) ; C. V. Robinson, Women in Science, In pursuit of Female Chemists, Nature, 476, 273 (2011); Women in Chemistry: Triumphs and Opportunities, Eur. J . Chem., 3541 (2011)

OUTLINE

- What is Chemistry ?
- The Beginning of Chemistry and the Chemical Industry
- Chemistry in the 20 th Century
- The Structure of Chemistry Enterprise : Teaching and Research
- Education of Chemistry: The Emergence of Integrative Science
- Future of Chemistry

WHAT IS CHEMISTRY ?

- **Chemistry is primarily a qualitative and intuitive science. Many of the discoveries are characterized by audacity of imagination rather than evidence based reductionism**
- **Advances in chemistry has been propelled by human needs and wants- in peace and war (eg, Indigo, Bakelite, Ammonia, Penicillin)**
- **Chemistry is uniquely utilitarian; Many famous chemists have been and are preoccupied with concerns of the society**
- **The utilitarian aspect of chemistry has probably contributed to it being less romantic than other branches of natural science. Human mind is often more fascinated by the unreachable-exploding stars, contracting universe, cure for cancer or understanding human cognition and conscience**

CHEMISTRY : STATUS

- **Chemistry is an old subject . Its practice has been known for over three centuries**
- **The ancient heritage is both a strength and a burden**
- **Difficult to change mindsets, often frozen under the weight of tradition**
- **It is always difficult to teach an old dog new tricks**
- **Its transformation to a new order poses innumerable challenges**

- structure and organization of teaching departments in universities
- Teaching pedagogy and learning resources
- Integration of research and training
- Regulatory frameworks, occupational health and safety, product safety
- Resource based science : sustainability issues
- Integrating learning with practice; research in undergraduate curricula
- converting knowledge to wealth and decline of corporate R&D

HISTORY OF CHEMISTRY : 20TH CENTURY

- **Nineteenth century marked the end of vitalism and beginning of the reductionism in science (Bertholet)**
- **The belief became prevalent that all problems can be solved by breaking them into parts**
- **Evolution of quantum mechanics and their applications to chemistry gave rise to the belief that one can understand chemical and physical states of matter ab initio, based on the electronic theory**
- **This led Paul Dirac to state that " all problems in chemistry are problems in applied mathematics "**

TIMELINES IN THE HISTORY OF CHEMISTRY

- **1900 : Ernest Rutherford / J J Thompson : Nothing left to discover in physics**
- **1915 : Niels Bohr : Chemistry is solved**
- **1928 : G.N.Lewis : The concept of a bond – ionic, covalent and coordinate- electron sharing and pairing**
- **1930: Linus Pauling : H Bond, van der Walls forces, Resonance, Hybridization of Orbitals, The Nature of the Chemical Bond**

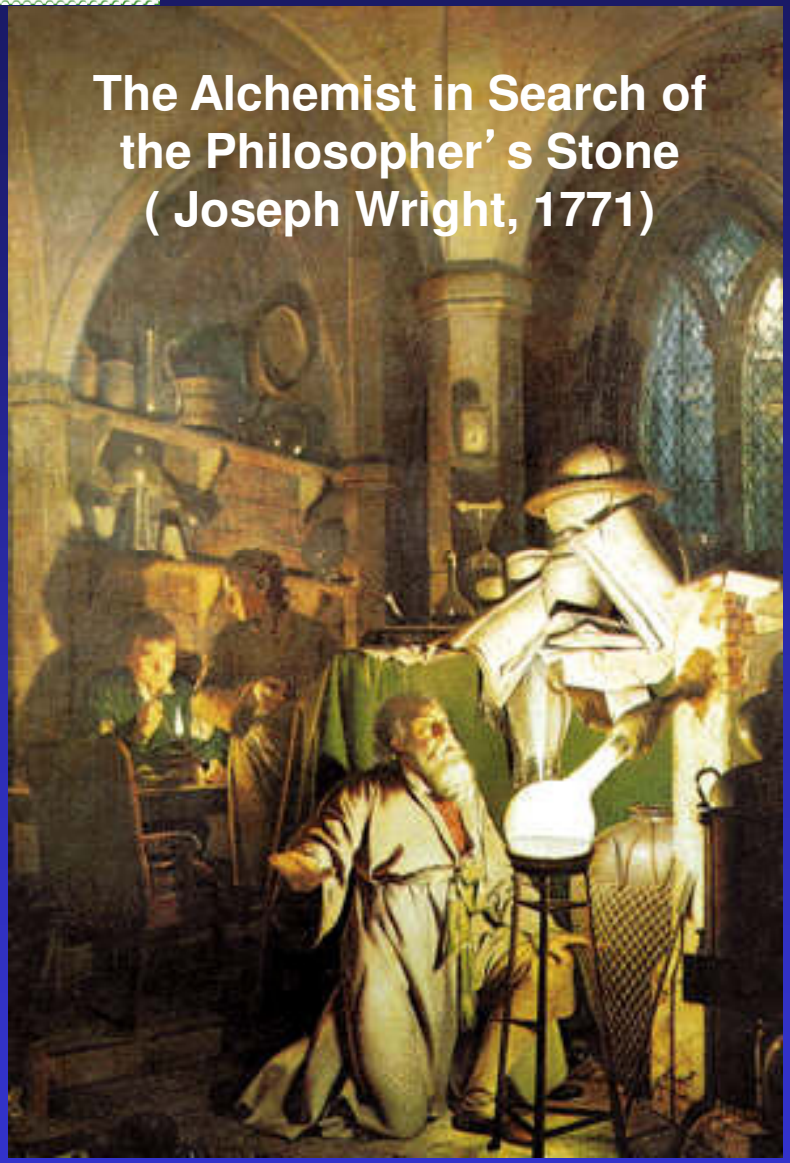
TIMELINES IN THE HISTORY OF CHEMISTRY

- **1930 : Quantum chemistry, the first book written; valence bond and molecular orbital concepts**
- **1920-30 : Mark, Staudinger, Carothers , Flory, Ziegler, Natta: The Concept of Macromolecules, Tacticity in polymers**
- **1930-40 : Hammet, Whitmore, Ingold : The Birth of Physical Organic Chemistry**
- **1950-60 : R.B Woodward : Total Synthesis**
- **1970 : The Grammar of Chemistry: The Woodward- Hoffman Orbital Rules**
- **1990 : Allotropes of Carbon**

CHEMISTRY AND INDUSTRY: THREE PHASES OF EVOLUTION

- **Post Industrial Revolution (1760-1915)**
- **World War I and II (1915-1950)**
- **The Era of inexpensive Petroleum (1950- 2000)**

CARBON CENTERED CHEMISTRY



The Alchemist in Search of the Philosopher's Stone (Joseph Wright, 1771)

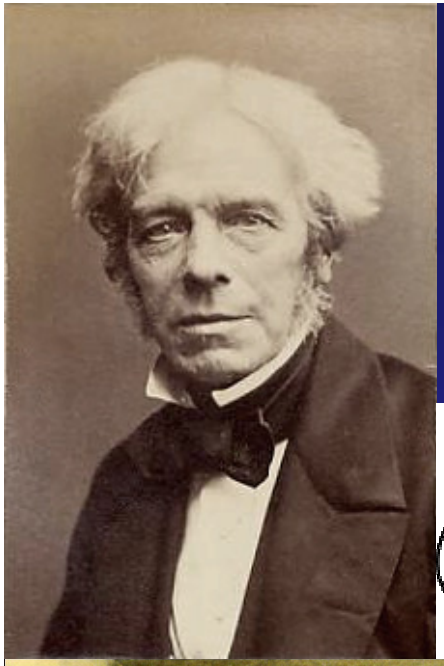
Hennig Brandt of Hamburg (1630 -1710)

Discoverer of Phosphorous

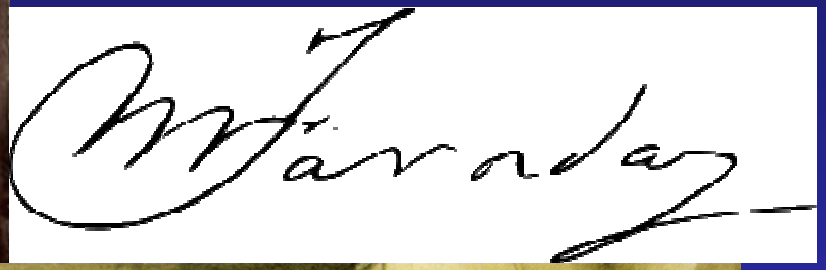
The chemical reaction Brandt stumbled on was as follows. Urine contains phosphates PO_4^{3-}, as sodium phosphate (i.e. with Na^+), and various carbon-based organics. Under strong heat the oxygens from the phosphate react with carbon to produce carbon monoxide CO, leaving elemental phosphorus P, which comes off as a gas. Phosphorus condenses to a liquid below about 280° C and then solidifies (to the white phosphorus allotrope) below about 44° C (depending on purity).

This same essential reaction is still used today (but with mined phosphate ores, coke for carbon, and electric furnaces).

The phosphorus Brandt's process yielded was far less than it could have been. The salt part he discarded contained most of the phosphate. He used about 5,500 litres of urine to produce just 120 grams of phosphorus. If he had ground up the entire residue he could have got 10 times or 100 times more (1 litre of adult human urine contains about 1.4 g phosphorus).



MICHAEL FARADAY
(1791- 1867)



The most influential scientist in the history of science

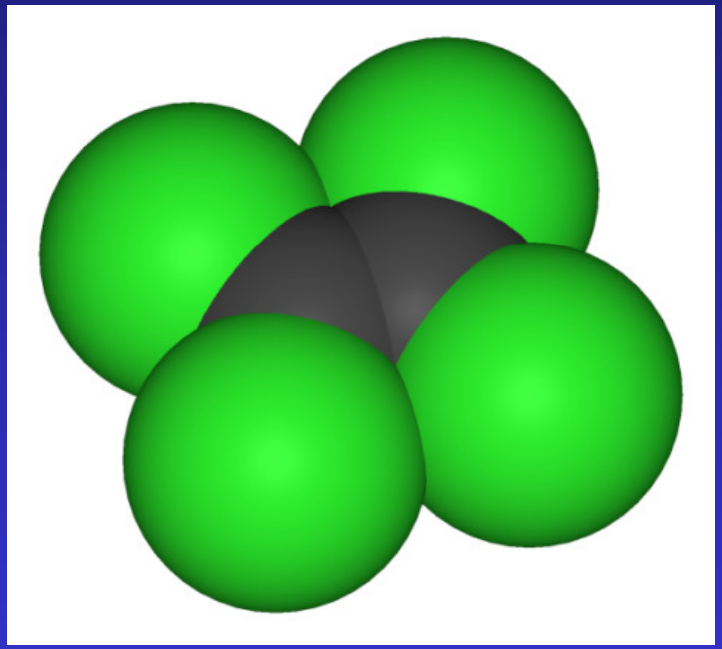
Faraday's Laboratory

- **One of the first scientists in the post – industrial revolution who established the methods of evidence based proof of hypothesis**

- **Contributed to both science and its applications; Studied pollution of river Thames, developed the first optical glass, studied the chemistry of flames and established that fine dust of coal can combust spontaneously**

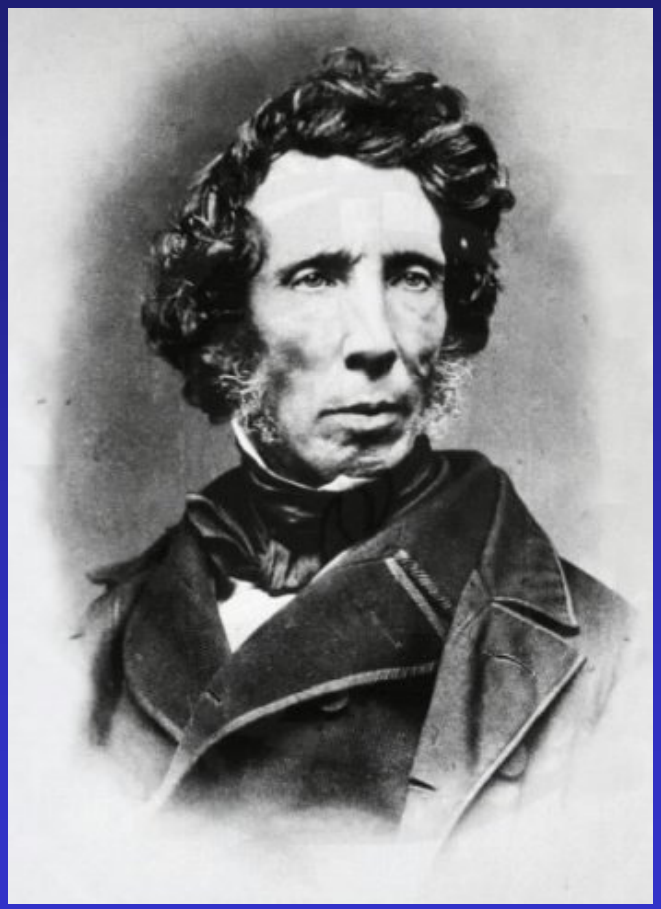
MICHAEL FARADAY : A PIONEER IN CHEMISTRY

- **Discovery of Benzene**
- **Laws of electrolysis; concept of anode, cathode, electrode and ions**
- **First demonstration of decomposition of magnesium sulfate by applying electrical potential; Design of a voltaic pile consisting of seven half penny pieces, seven discs of zinc and filter paper soaked in salt water (1812)**
- **First synthesis of hexa-chloroethane and tetrachloro-ethylene (1820)**
- **Identification of isoprene as a constituent of natural rubber , now known as poly(isoprene) (1826)**



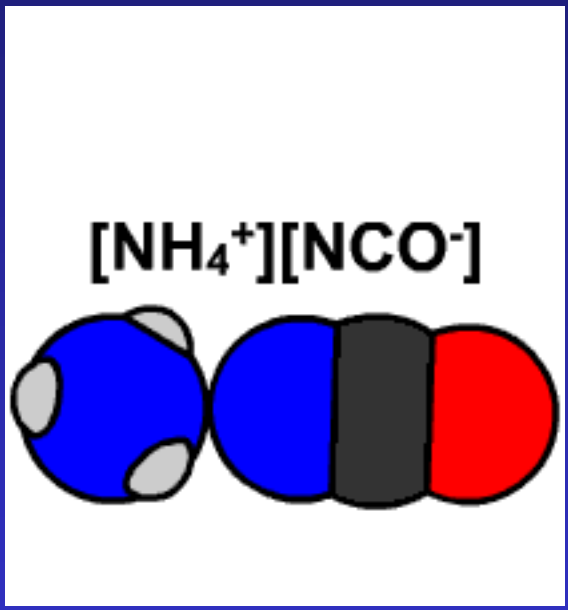
Tetrachloroethylene

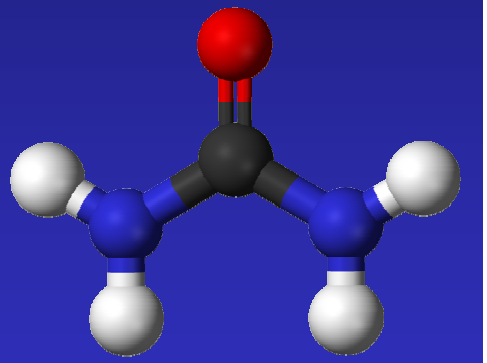
CHEMICAL REVOLUTION : EARLY BEGINNINGS



Freidrich Wohler (1800 – 1882)

$[NH_4^+][NCO^-]$





Annalen der Physik und Chemie, 88(2), 253-256 (1828)

Chemistry creates its own object. This creative power, similar to that of arts distinguishes it fundamentally from the other natural and historical sciences

Marcellin Bertholet, 1860

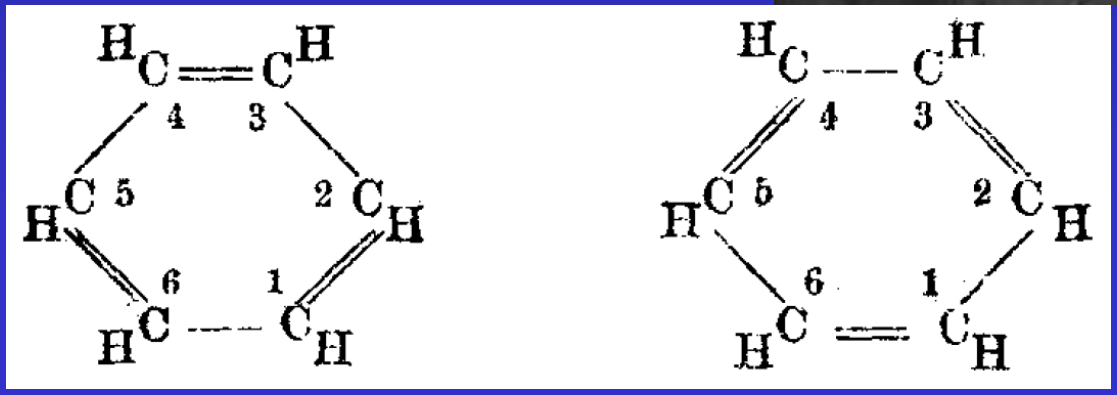
(1827- 1907)

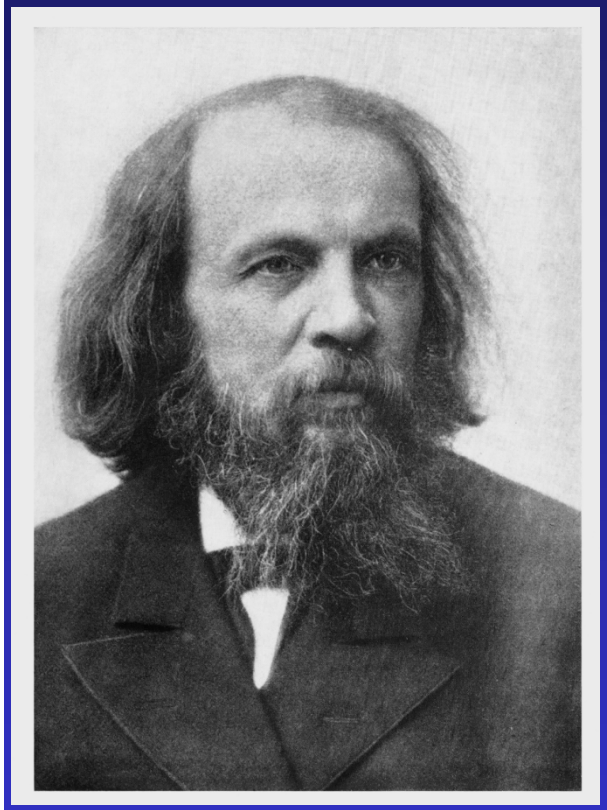
CHEMICAL REVOLUTION : UNDERSTANDING CHEMICAL STRUCTURES

- **The Theory of Chemical Structure (1857-58)**

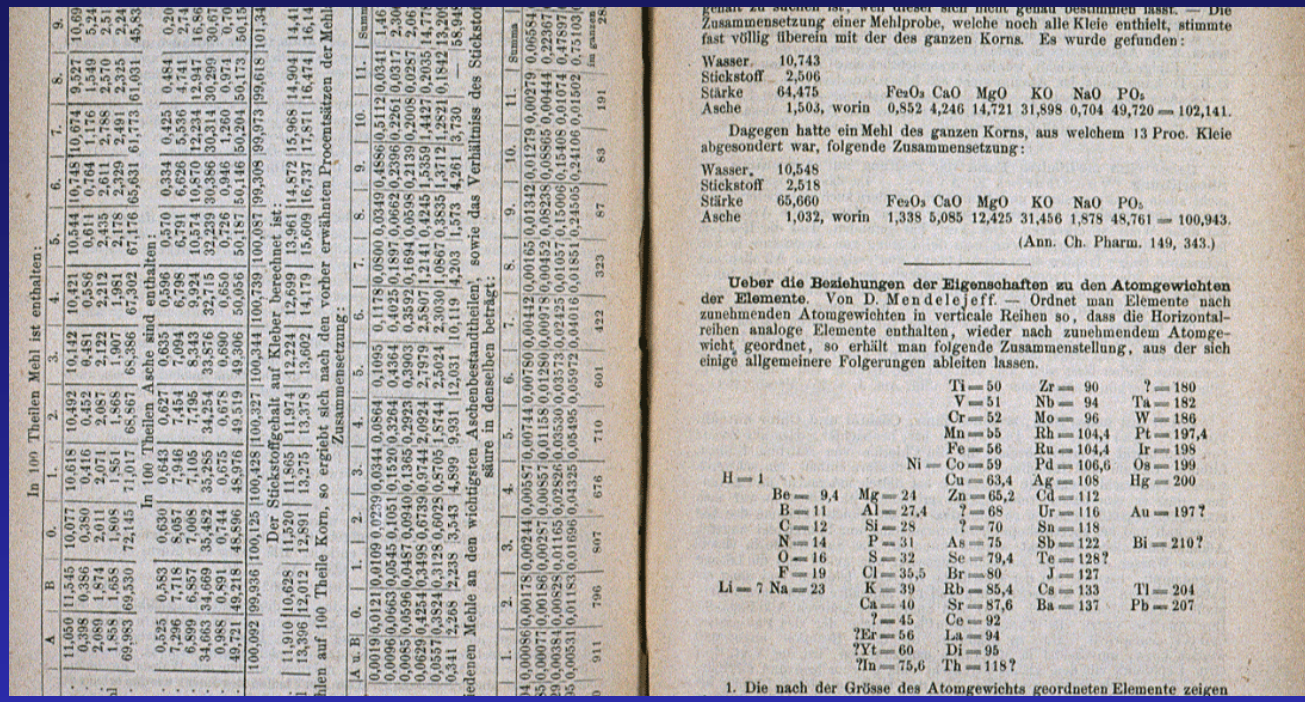
- **Structure of Benzene published in *Bulletin de la Society Chimique de Paris, 3(2), 98-110 (1865)***

Auguste Kekule (1829 -1896)





Dimitri MENDELEJEFF
1834-1907



In 100 Theilen Mehl ist enthalten:

	A	B	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
	11,050	11,545	10,077	10,618	10,492	10,142	10,421	10,544	10,745	10,674	9,527	10,69
	0,398	0,386	0,380	0,416	0,452	0,481	0,456	0,611	0,764	1,176	1,549	5,24
	2,089	1,874	2,011	2,071	2,087	2,122	2,212	2,435	2,611	2,788	2,570	2,51
	1,858	1,658	1,808	1,561	1,505	1,907	1,981	2,178	2,329	2,491	2,325	2,24
	69,983	69,530	72,145	71,017	68,567	68,386	67,302	67,176	65,631	61,773	61,031	45,83
					In 100 Theilen Asche sind enthalten:							
			0,525	0,583	0,630	0,643	0,627	0,635	0,596	0,570	0,334	0,425	0,484	0,20
			7,296	7,718	8,057	7,946	7,454	7,094	6,798	6,791	6,626	5,536	4,741	2,74
			6,599	6,857	7,008	7,105	7,195	8,343	9,924	10,574	10,870	12,234	12,947	16,88
			34,663	34,669	35,482	35,285	34,254	33,876	32,715	32,239	30,386	30,314	30,299	30,67
			0,988	0,891	0,744	0,675	0,678	0,690	0,550	0,726	0,946	1,260	0,971	0,70
			49,721	49,218	48,596	48,596	49,519	49,306	50,056	50,187	50,146	50,204	50,173	50,15
			100,092	99,936	100,125	100,128	100,327	100,344	100,739	100,087	99,309	99,973	99,618	101,34

Der Stickstoffgehalt auf Kleber berechnet ist:

	11,910	10,628	11,520	11,565	11,974	12,224	12,699	13,961	14,572	15,965	14,904	14,41
	13,396	12,012	12,891	13,275	13,378	13,602	14,179	15,609	16,737	17,871	16,474	16,14

Zusammensetzung:

	A u. B	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Summa
	0,0019	0,0121	0,0109	0,0239	0,0344	0,0564	0,1095	0,1178	0,0800	0,0349	0,4886	0,5112	0,0341	1,46
	0,0096	0,0663	0,0545	0,1051	0,1520	0,3264	0,4364	0,4025	0,1897	0,0662	0,2396	0,2261	0,0317	2,30
	0,0055	0,0596	0,0487	0,0940	0,1365	0,2923	0,3903	0,3592	0,1694	0,0598	0,2139	0,2008	0,0287	2,06
	0,0629	0,4254	0,3495	0,6739	0,9744	2,0924	2,7979	2,5807	1,2141	0,4245	1,5359	1,4427	0,2035	14,77
	0,0557	0,3824	0,3125	0,6025	0,8705	1,8744	2,5024	2,3030	1,0867	0,3835	1,3712	1,2821	0,1842	13,20
	0,341	2,268	2,238	3,543	4,599	9,931	12,031	10,119	4,203	1,573	4,261	3,730	—	58,94
														In grammen
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	Summa		
	0,00086	0,00178	0,00244	0,00557	0,00744	0,00780	0,00442	0,00165	0,01342	0,01279	0,00279	0,06584		
	0,00077	0,00186	0,00287	0,00567	0,01158	0,01280	0,00978	0,00452	0,05238	0,05865	0,00444	0,22367		
	0,00384	0,00828	0,01165	0,02826	0,03530	0,03573	0,02425	0,01057	0,15006	0,15408	0,01074	0,47897		
	0,00531	0,01183	0,01696	0,04325	0,05495	0,05972	0,04016	0,01851	0,24505	0,24106	0,01502	0,75103		
	911	796	807	676	710	601	422	323	87	83	191	25		

gehalt zu suchen ist, weil dieser sich nicht genau bestimmen lässt. — Die Zusammensetzung einer Mehlprobe, welche noch alle Kleie enthielt, stimmte fast völlig überein mit der des ganzen Korns. Es wurde gefunden:

Wasser.	10,743							
Stickstoff	2,506							
Stärke	64,475		Fe_2O_3	CaO	MgO	KO	NaO	PO_5
Asche	1,503, worin		0,852	4,246	14,721	31,898	0,704	49,720 = 102,141.

Dagegen hatte ein Mehl des ganzen Korns, aus welchem 13 Proc. Kleie abgesondert war, folgende Zusammensetzung:

Wasser.	10,548							
Stickstoff	2,518							
Stärke	65,660		Fe_2O_3	CaO	MgO	KO	NaO	PO_5
Asche	1,032, worin		1,338	5,085	12,425	31,456	1,878	48,761 = 100,943.

(Ann. Ch. Pharm. 149, 343.)

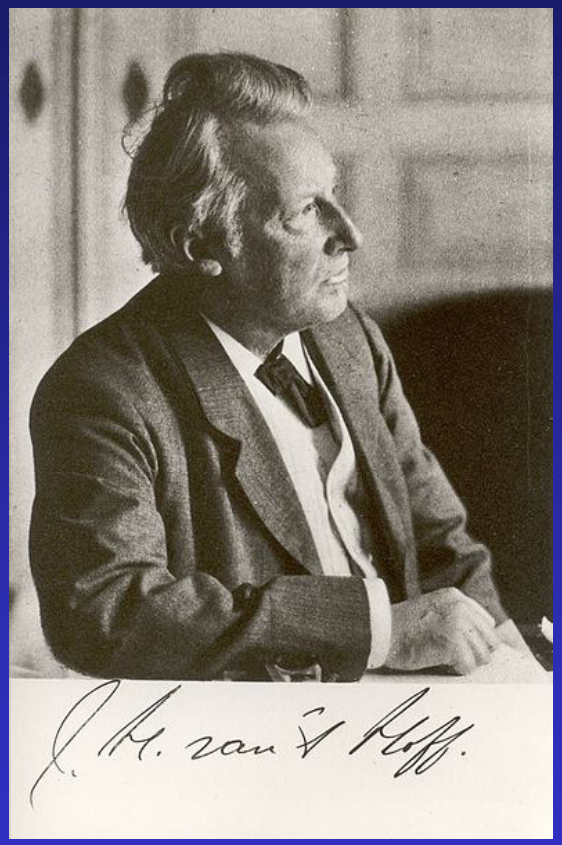
Ueber die Beziehungen der Eigenschaften zu den Atomgewichten der Elemente. Von D. Mendelejeff. — Ordnet man Elemente nach zunehmenden Atomgewichten in verticale Reihen so, dass die Horizontalreihen analoge Elemente enthalten, wieder nach zunehmendem Atomgewicht geordnet, so erhält man folgende Zusammenstellung, aus der sich einige allgemeinere Folgerungen ableiten lassen.

			Ti = 50	Zr = 90	? = 180	
			V = 51	Nb = 94	Ta = 182	
			Cr = 52	Mo = 96	W = 186	
			Mn = 55	Rh = 104,4	Pt = 197,4	
			Fe = 56	Ru = 104,4	Ir = 198	
			Ni = Co = 59	Pd = 106,6	Os = 199	
H = 1			Cu = 63,4	Ag = 108	Hg = 200	
	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112		
	B = 11	Al = 27,4	? = 68	Ur = 116	Au = 197?	
	C = 12	Si = 28	? = 70	Sn = 118		
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?	
	O = 16	S = 32	Se = 79,4	Te = 128?		
	F = 19	Cl = 35,5	Br = 80	J = 127		
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204	
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207	
		? = 45	Ce = 92			
		?Er = 56	La = 94			
		?Yt = 60	Di = 95			
		?In = 75,6	Th = 118?			

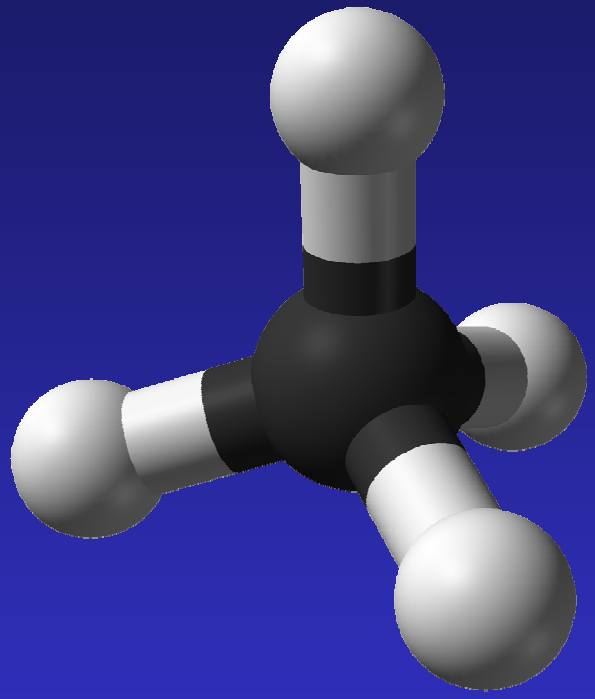
1. Die nach der Grösse des Atomgewichts geordneten Elemente zeigen

On the Relationships of the Properties to the Atomic Weights of the Elements
D. Mendelejeff,
Zeitschrift für Chemie 12,405-406(1869)

CHEMICAL REVOLUTION : UNDERSTANDING CHEMICAL STRUCTURES



Jacobus van't Hoff (1852-1911)

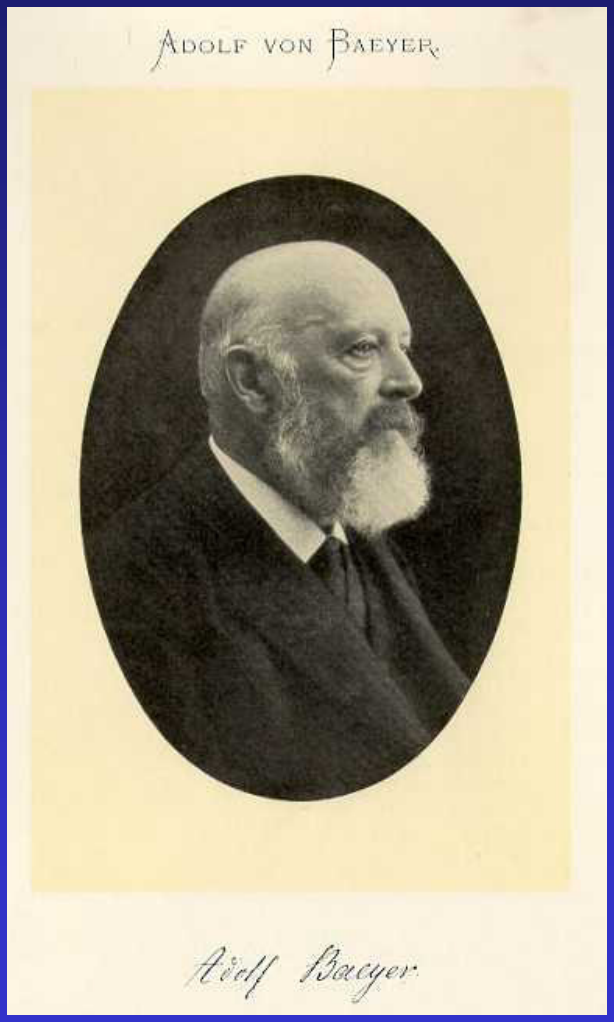


The Tetrahedral Nature of Carbon

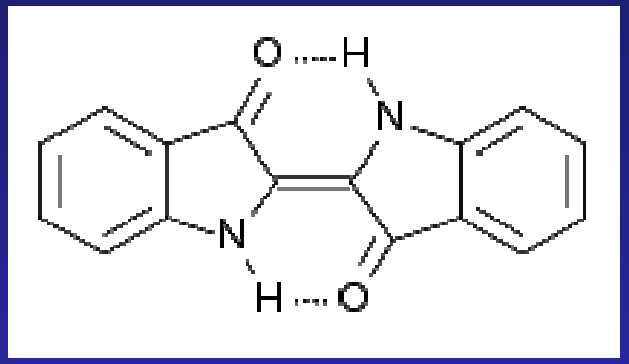
(La Chimie dans l'espace, 1874)

First Nobel Prize in 1901

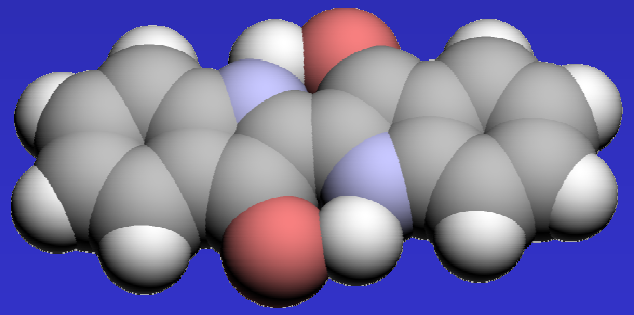
BEGINNING OF INDUSTRIAL CHEMISTRY : THE INDIGO SYNTHESIS



Adolf von Baeyer (1835-1917)



Synthesis of a plant derived natural product, from Isatin and 2-Nitrobenzaldehyde (1878-80)



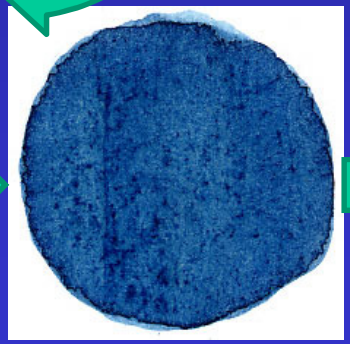
Nobel Prize , 1905

THE DAWN OF THE CHEMICAL INDUSTRY: THE MANUFACTURE OF INDIGO

BASF commences manufacture of synthetic Indigo (1897)

BASF develops a more economic route based on N-2-carboxyphenyl glycine, derived from aniline, which had become just then available from coal tar distillation

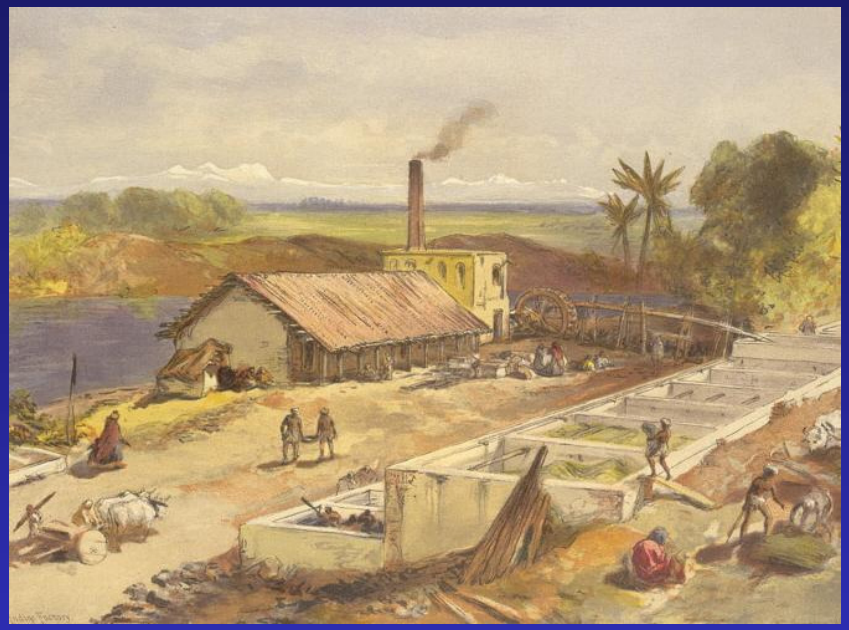
Indigofera Tinctoria



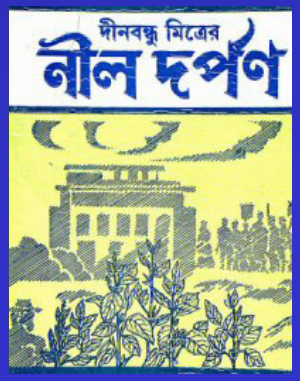
Indigo dye

Blue denim

THE DAWN OF THE CHEMICAL INDUSTRY: THE BENGAL CONNECTION



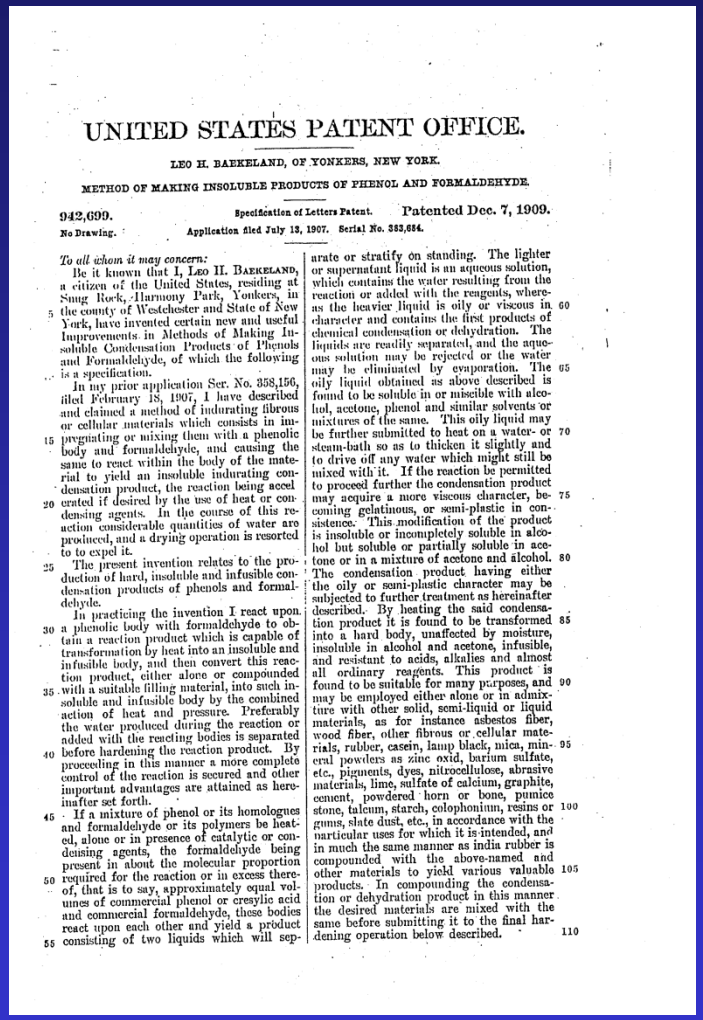
Indigo dye factory in Bengal, circa 1867



Nil Darpan by Dinabandhu Mitra (1860)

- Indigo plantation in Bengal dates back to 1777
- The Indigo Riots (Nil Bidroho) began in Nadia in 1859, an uprising of the farmers against the exploitation by the planters and later spread to Champaran in Bihar in 1868
- There was an anger against the British traders, fresh after the Sepoy Mutiny of 1857
- Regarded as the first non violent passive resistance in Indian history
- India's exports of over 20,000 tons of Indigo to Europe ceases; by 1914 synthetic Indigo completely replaces natural Indigo

THE DAWN OF THE CHEMICAL INDUSTRY: THE MANUFACTURE OF BAKELITE



UNITED STATES PATENT OFFICE.

LEO H. BAEKELAND, OF YONKERS, NEW YORK.

METHOD OF MAKING INSOLUBLE PRODUCTS OF PHENOL AND FORMALDEHYDE.

942,699. Specification of Letters Patent. Patented Dec. 7, 1909.

No Drawing. Application filed July 13, 1907. Serial No. 383,884.

To all whom it may concern:

Be it known that I, LEO H. BAEKELAND, a citizen of the United States, residing at Snug Rock, Harmony Park, Yonkers, in the county of Westchester and State of New York, have invented certain new and useful Improvements in Methods of Making Insoluble Condensation Products of Phenols and Formaldehyde, of which the following is a specification.

In my prior application Ser. No. 358,156, filed February 18, 1907, I have described and claimed a method of indurating fibrous or cellular materials which consists in impregnating or mixing them with a phenolic body and formaldehyde, and causing the same to react within the body of the material to yield an insoluble indurating condensation product, the reaction being accelerated if desired by the use of heat or condensing agents. In the course of this reaction considerable quantities of water are produced, and a drying operation is resorted to to expel it.

The present invention relates to the production of hard, insoluble and infusible condensation products of phenols and formaldehyde.

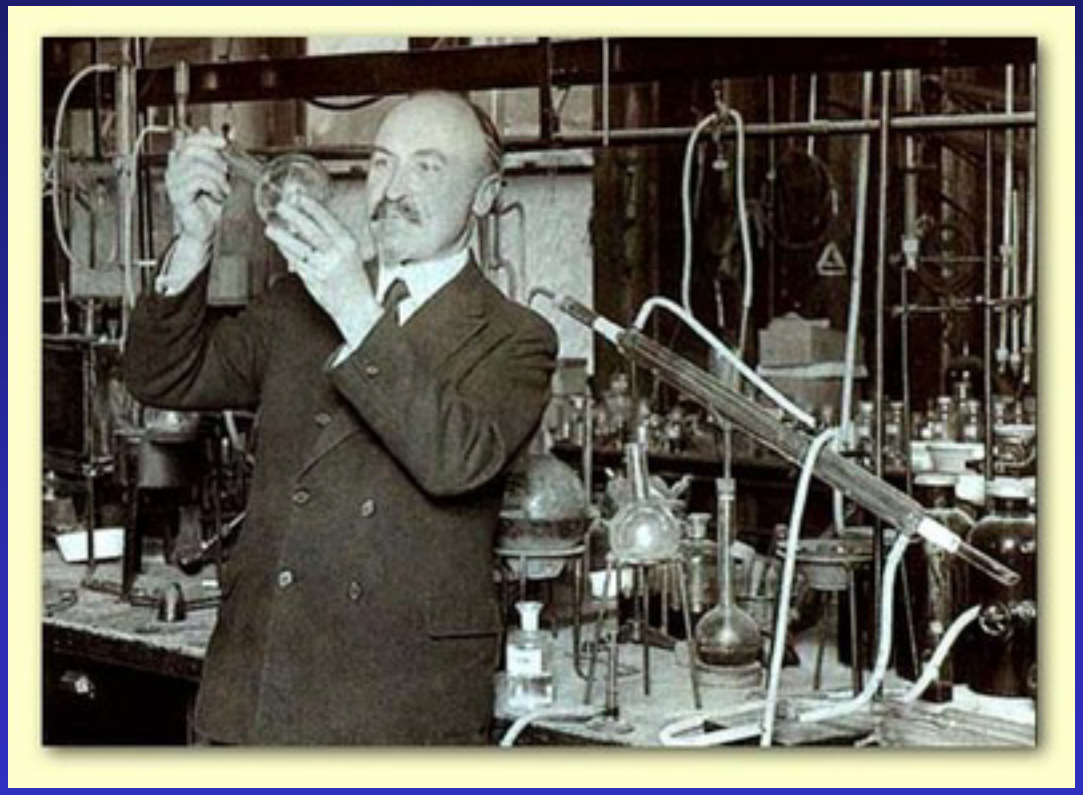
In practicing the invention I react upon a phenolic body with formaldehyde to obtain a reaction product which is capable of transformation by heat into an insoluble and infusible body, and then convert this reaction product, either alone or compounded with a suitable filling material, into such insoluble and infusible body by the combined action of heat and pressure. Preferably the water produced during the reaction or added with the reacting bodies is separated before hardening the reaction product. By proceeding in this manner a more complete control of the reaction is secured and other important advantages are attained as hereinafter set forth.

If a mixture of phenol or its homologues and formaldehyde or its polymers be heated, alone or in presence of catalytic or condensing agents, the formaldehyde being present in about the molecular proportion required for the reaction or in excess thereof, that is to say, approximately equal volumes of commercial phenol or cresylic acid and commercial formaldehyde, those bodies react upon each other and yield a product consisting of two liquids which will separate or stratify on standing. The lighter or supernatant liquid is an aqueous solution, which contains the water resulting from the reaction or added with the reagents, whereas the heavier liquid is oily or viscous in character and contains the first products of chemical condensation or dehydration. The liquids are readily separated, and the aqueous solution may be rejected or the water may be eliminated by evaporation. The oily liquid obtained as above described is found to be soluble in or miscible with alcohol, acetone, phenol and similar solvents or mixtures of the same. This oily liquid may be further submitted to heat on a water- or steam-bath so as to thicken it slightly and to drive off any water which might still be mixed with it. If the reaction be permitted to proceed further the condensation product may acquire a more viscous character, becoming gelatinous, or semi-plastic in consistence. This modification of the product is insoluble or incompletely soluble in alcohol but soluble or partially soluble in acetone or in a mixture of acetone and alcohol. The condensation product having either the oily or semi-plastic character may be subjected to further treatment as hereinafter described. By heating the said condensation product it is found to be transformed into a hard body, unaffected by moisture, insoluble in alcohol and acetone, infusible, and resistant to acids, alkalies and almost all ordinary reagents. This product is found to be suitable for many purposes, and may be employed either alone or in admixture with other solid, semi-liquid or liquid materials, as for instance asbestos fiber, wood fiber, other fibrous or cellular materials, rubber, casein, lamp black, mica, mineral powders as zinc oxid, barium sulfate, etc., pigments, dyes, nitrocellulose, abrasive materials, lime, sulfate of calcium, graphite, cement, powdered horn or bone, pumice stone, talcum, starch, colophonium, resins or gums, slate dust, etc., in accordance with the particular uses for which it is intended, and in much the same manner as india rubber is compounded with the above-named and other materials to yield various valuable products. In compounding the condensation or dehydration product in this manner the desired materials are mixed with the same before submitting it to the final hardening operation below described.

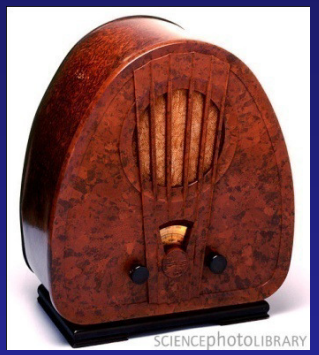
US Patent 942, 699, December 7, 1909

- Baekland set out to discover a substitute for Shellac, then wholly supplied by India to the world
- In the process he made the first man made material, heralding the age of plastics, a discovery considered as revolutionary
- Heat resistant and insulating
- Baekland named his new material Novolak
- He founded a company called Bakelite Corporation in 1910 to manufacture the product

THE DAWN OF THE CHEMICAL INDUSTRY: THE MANUFACTURE OF BAKELITE



Leo Baekland (1863-1944)



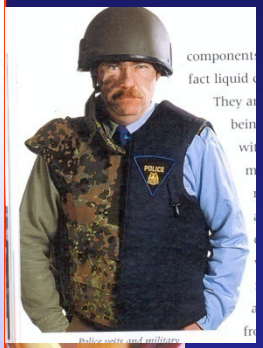
When asked why he chose to work in the field of synthetic resins, he replied " to make money "

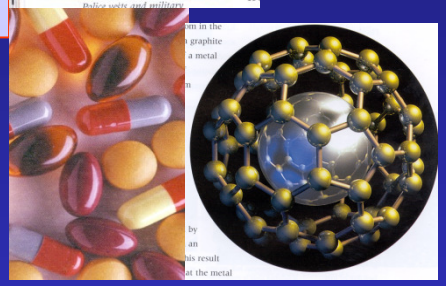
CHEMISTRY CREATES MATTER THAT NEVER EXISTED BEFORE eg. PLASTICS, DETERGENTS, DRUGS, INSECTICIDES, ETC.

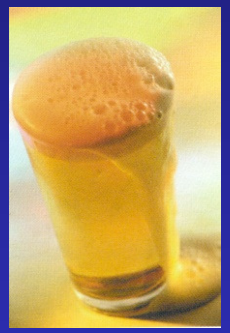
Central

Underpins many other scientific disciplines

Biology, geology, material science

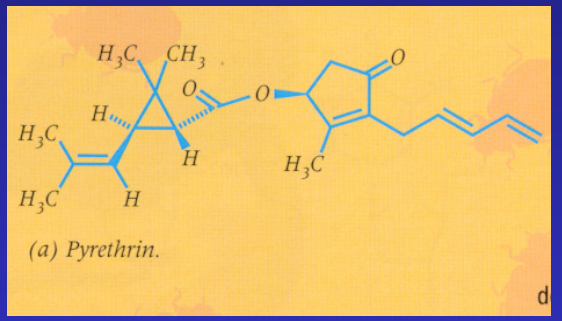




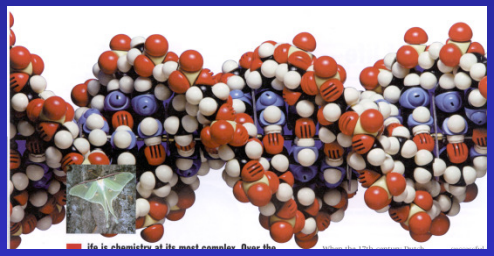


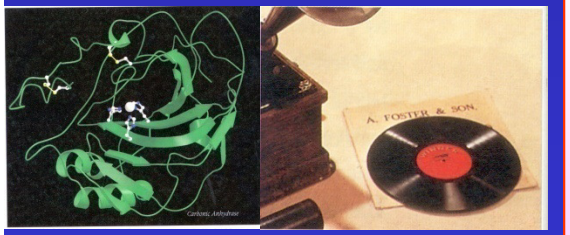
Creative

Designs structures with new and unique properties



(a) Pyrethrin.

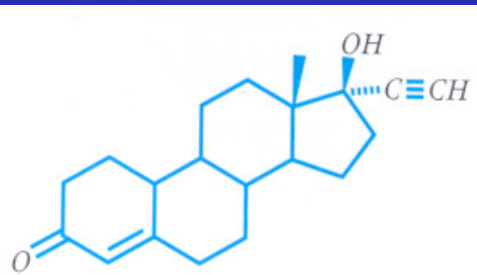




Useful

Provides many materials essential to everyday life,

knowledge to better human, veterinary and plant care, better food, environment



Norethindrone (Norlutin)

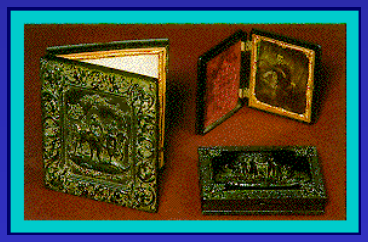
Figure 14. Norlutin, the first contraceptive pil

POLYMERS FULFILLING MATERIAL NEEDS OF SOCIETY…

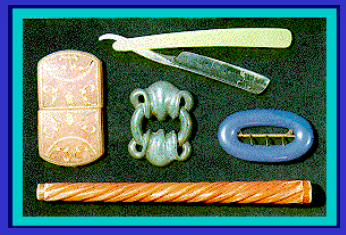
Precursor 19th Century → Semi Synthetics

1839 : Natural Rubber
1843 : Vulcanite / Gutta Percha
1856 : Shellac / Bois Durci
1862 : Parkesine
1863 : Celluloid
1894 : Viscose Rayon
1898 : Poly Carbonate

Natural Polymers



Semi Synthetics



1900 – 1950 → Thermoplastics

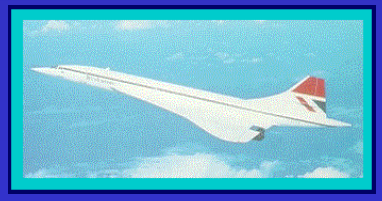
1908 : Cellophane
1909 : Bakelite
1926 : Vinyl or PVC
1927 : Cellulose Acetate
1933 : Polyvinylidene chloride
1935 : Low density polyethylene
1936 : Polymethyl Methacrylate
1937 : Polyurethane
1938 : Polystyrene
1938 : Teflon
1939 : Nylon and Neoprene
1941 : PET
1942 : LDPE
1942 : Unsaturated Polyester

1950 onwards → Growth Phase

1951 : HDPE
1951 : PP
1954 : Styrofoam
1960 : PC, PPO
1964 : Polyamide
1970 : Thermoplastic Polyester
1978 : LLDPE
1985 : Liquid Crystal Polymers

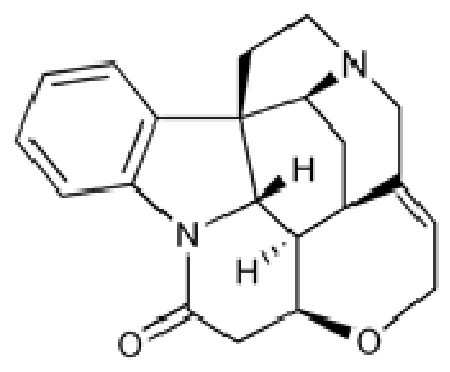
Plastics in Packaging

Hi Tech Plastics

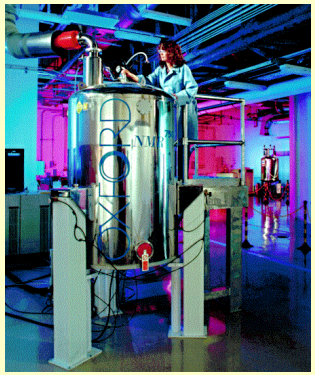


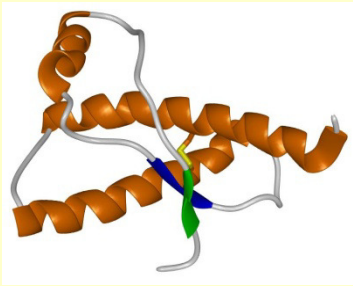
Source : British Plastic Federation Website

CHEMICAL SCIENCE AND INDUSTRY : GREAT SUCCESSES

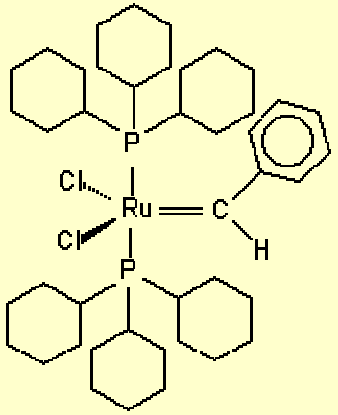


strychnine

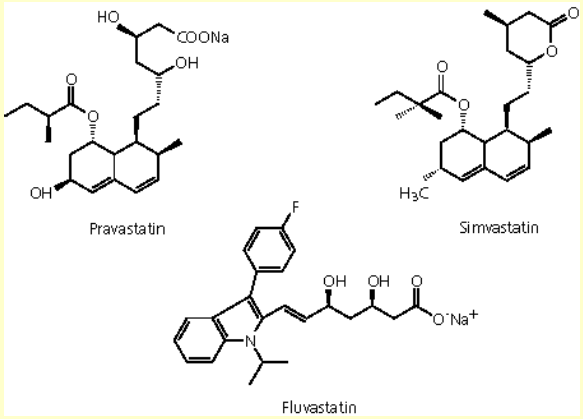




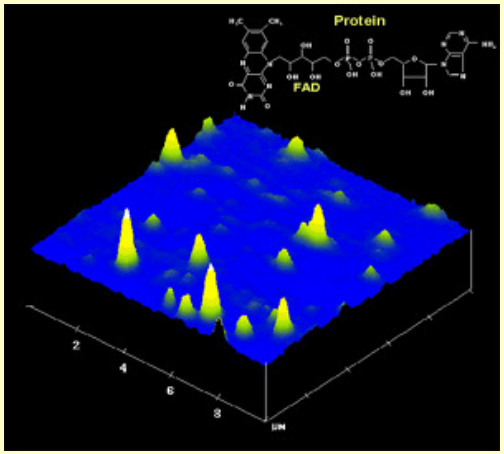
protein NMR



ROMP catalyst



statins

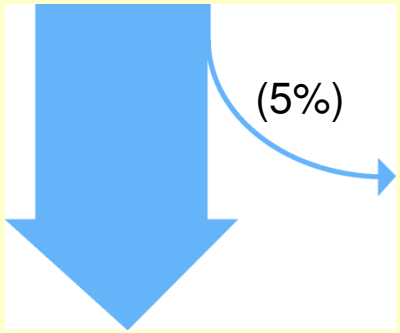


single-molecule spectroscopy

CH_y, NO_x ⟶ CO_2 + N_2

CHEMICAL INDUSTRY : POST WAR STRUCTURE

crude oil



fuel
(energy)

transportation,
heating

petrochemicals
(materials)

commodities

specialties

biological
sources

(synthesis)

pharma

Total Size - 3 trillion USD (2010)
~ 5.3% of global GDP

CHEMISTRY'S HOARY PAST

- **Aspirin, Indigo, ammonia, Antibiotics, Lipitor, Nylon, Teflon, Polyethylene, rayon, synthetic rubber, fuels**

- **Nylon stockings, Hula Hoop, Packaged Foods, Bullet Proof Vests**

Is Chemistry today capable of capturing the public imagination ?

Can you recollect the last major impact making discovery in chemistry ?

C 60 and Graphene ?

Element carbon was once the monopoly of the chemist; it is no more !

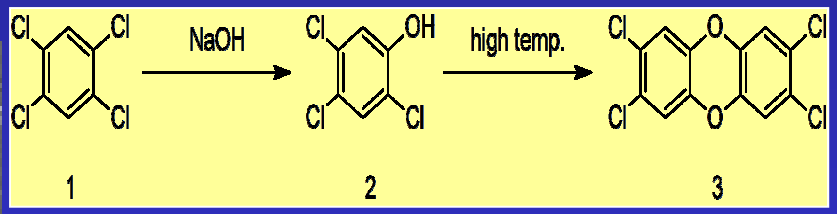
PUBLIC AND GOVERNMENT PERCEPTION OF CHEMISTRY

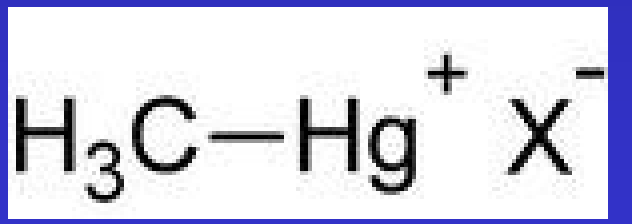
- **Chemistry is invisible to the public**
- **Chemistry is considered "mature" economically**
- **Chemistry is associated with pollution/global warming**
- **"Good" and "Bad" are not balanced in perceptions of chemistry**

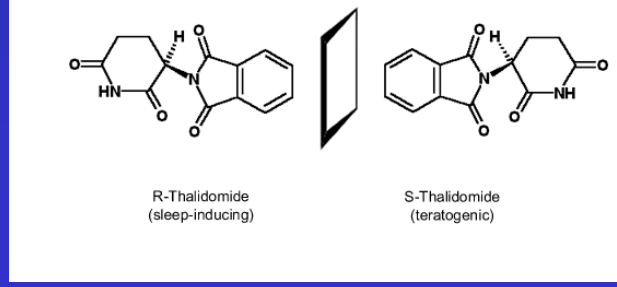
THE UGLY SIDE OF CHEMISTRY

A child victim of the Bhopal gas disaster.

- Minamata
- Love Canal
- Seveso
- Bhopal
- Thalidamide
- DDT







Bill Bryson, "A Short History of Nearly Everything", Random House, 2003 p. 137:

When the wife of the great Austrian physicist Wolfgang Pauli left him for a chemist, he was staggered with disbelief. "Had she taken a bullfighter I would have understood," he remarked in wonder to a friend. "But a *chemist*. . ."

CHEMISTRY AT CROSSROADS

- **Chemistry is at the end of one wave of development and struggling to begin another; perceptible shift in the centre of gravity of the discipline**
- **There are still many important opportunities in both fundamental and applied science**
- **Chemistry offers fewer puzzles to solve; What confronts are number of problems**
- **Longer term curiosity driven research is more important than in the past, but harder to justify**

In the future, functions will be more important than molecules. Molecules are no longer enough (they never really were)

IS CHEMISTRY SCIENTIFICALLY MATURE? CAN WE...

… *really* understand molecules / reactions?

… engineer functions?

… design drugs?

… make materials by design?

… rationalize the origin of life?

… understand life / thought?

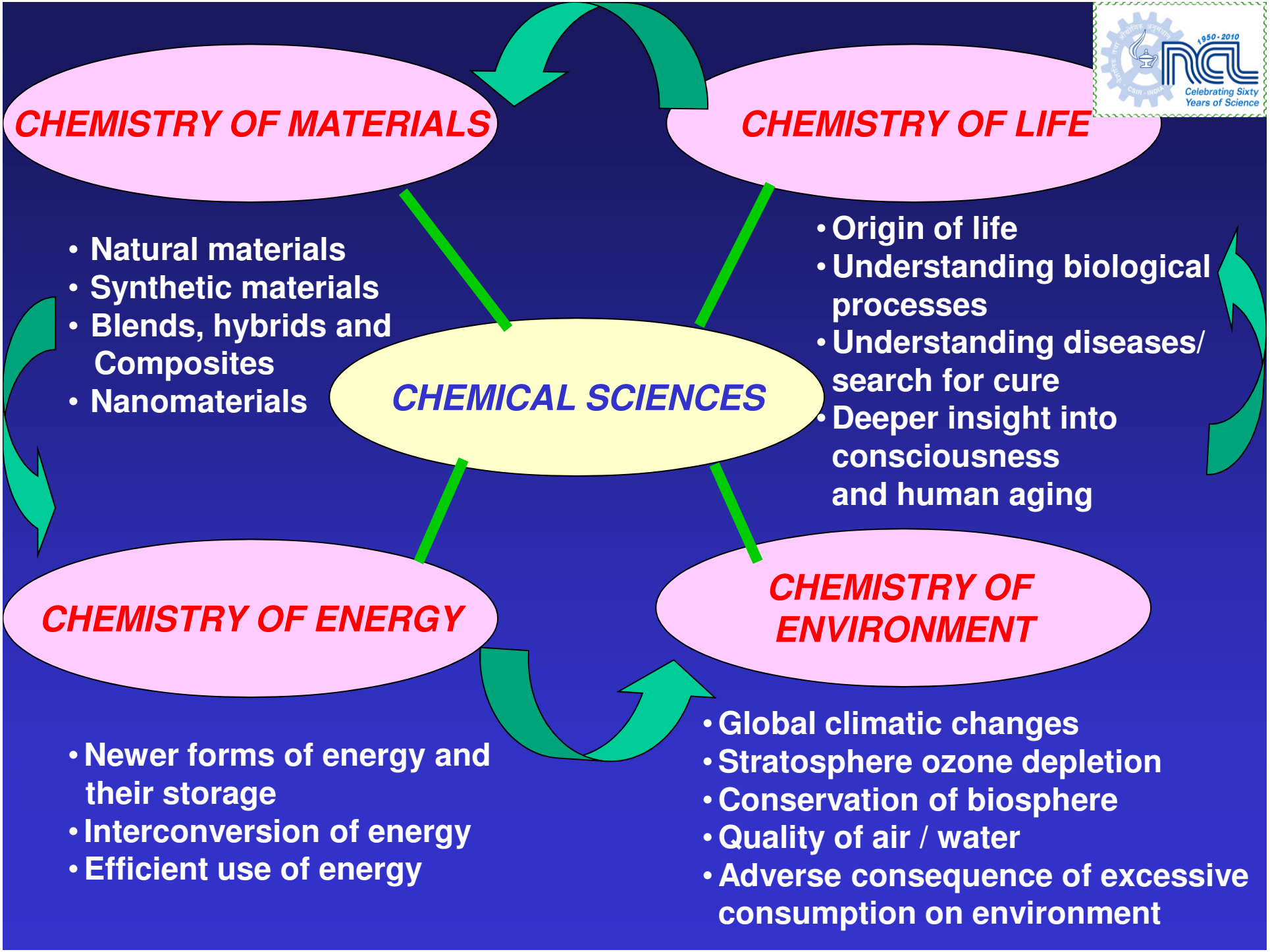
… build a cell?

Chemistry is still in its infancy!

CHEMISTRY : CENTRAL SCIENCE

- **Central to the sustenance of civilization on earth**
- **Key to management of resources on this planet**
- **Key to understanding the mysteries of life**

Chemistry is the science of the real world; the world today is searching for innovative solutions for many of its vexing problems. Chemistry must become part of this solution and dispel the image that it is the cause of the problem


CHEMISTRY OF MATERIALS
• Natural materials
• Synthetic materials
• Blends, hybrids and Composites
• Nanomaterials
CHEMISTRY OF LIFE
• Origin of life
• Understanding biological processes
• Understanding diseases/ search for cure
• Deeper insight into consciousness and human aging
CHEMICAL SCIENCES
CHEMISTRY OF ENERGY
• Newer forms of energy and their storage
• Interconversion of energy
• Efficient use of energy
CHEMISTRY OF ENVIRONMENT
• Global climatic changes
• Stratosphere ozone depletion
• Conservation of biosphere
• Quality of air / water
• Adverse consequence of excessive consumption on environment
1950-2010
Celebrating Sixty Years of Science

IS CHEMISTRY ON THE THRESHOLD OF A NEW REVOLUTION ?

- **Responsibility for solving some of the most interesting problems in science and technology**
- **Exceptionally wide range of tools**
- **Chemistry offers a balance of skills; synthetic, computational, ability to handle complexity**
- **Existing body of knowledge insufficient**

FUTURE OF CHEMISTRY

- **Systems, not molecules**
- **Functions, not molecular structure**
- **Problems, not puzzles**

No longer "What is it?" but "What does it do?
Chemistry must move beyond molecules and learn to solve the entire problem. Only then the flow of ideas, problems and solutions between chemistry and society will become more animate and visible

CHALLENGE OR CRISIS OF CHEMISTRY

- **Inadequacies of theory ; eg: Complex and coupled networks, protein- ligand binding, catalysis, non-equilibrium systems, non-covalent interactions**

- **Peer Review Systems: Encourages safe science at the cost of risky science**

- **Demise of industrial R&D Centres : No longer great source of innovation and discovery as well as providers of jobs (DuPont Central R&D, GE Corporate Research, BASF etc)**

- **Teaching Pedagogy , departmental structure and textbooks**

- **Academic Social Systems : Diversity is rejected, conformity is rewarded**

STRUCTURE OF CHEMICAL SCIENCE

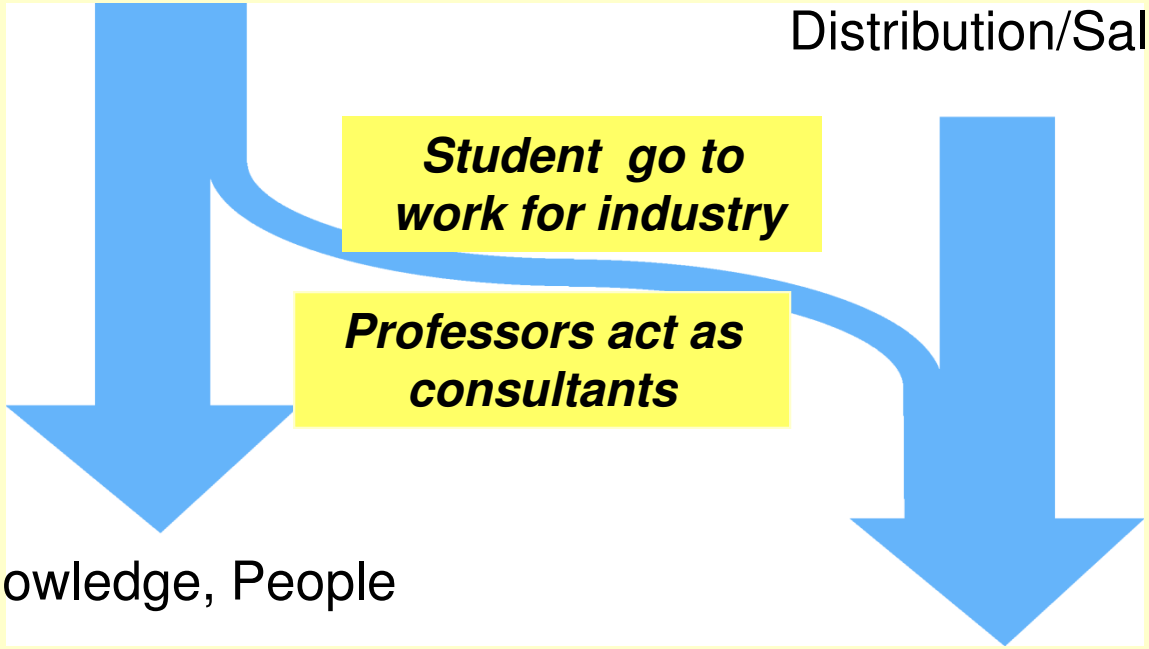
Money

University **Government** Laws, Regulation

Industry

("Liebig" Model:
Professor/Student/Problem/Thesis)

(Development, Manufacturing,
Distribution/Sales)



Knowledge, People

Products/Solutions for Problems

LINEAR MODEL OF IMPACT OF SCIENCE

Money → Institutions

→ Research → Papers and PhD's →

Greater prosperity and wealth creation in society

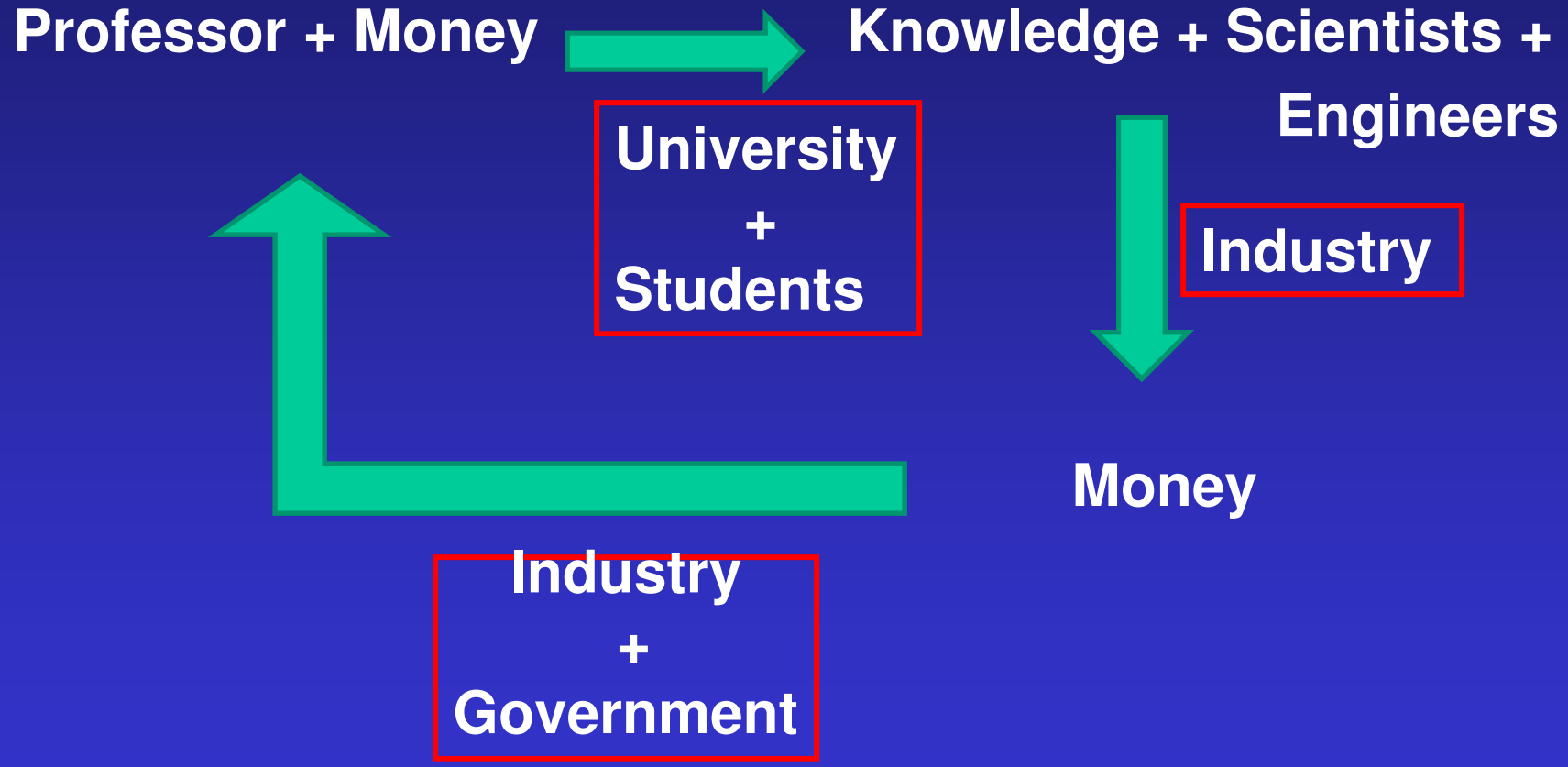
Basic research → Applied research → Development

Basic research performed in academia

Applied research and commercialization in industry

Vannevar Bush, Science : The Endless Frontier, 1945

LEIBIG´S MODEL



LEIBIG MODEL OF RESEARCH TRAINING

Professor assigns a problem to a student

The student solves the problem , gets his Ph D; the professor becomes famous

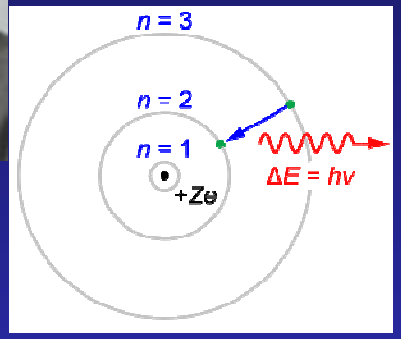
The student goes on to become a professor and repeats the process all over again

RE-EXAMINE THE MODELS

- **Is the "Liebig Model" obsolete?**
- **Is the current model of the university ("a collection of semi-isolated experts") still workable?**
- **Can curiosity-driven basic research survive?**
- **Should research be driven by large missions ?**
- **Should translational research be funded by the state or should be left to industry ?**

Pasteur's Quadrant

Bohr



Pasteur

Edison

Fundamental Research

Use Inspired Research

R.E.Stokes

Goethe once said about science: "To one man it is the highest thing, a goddess; to another it is a productive cow who supplies them with butter. We must honor the goddess and feed the cow.

REDEFINING CHEMISTRY

(S.Ritter, C&EN, November 29, 2004, p.31)

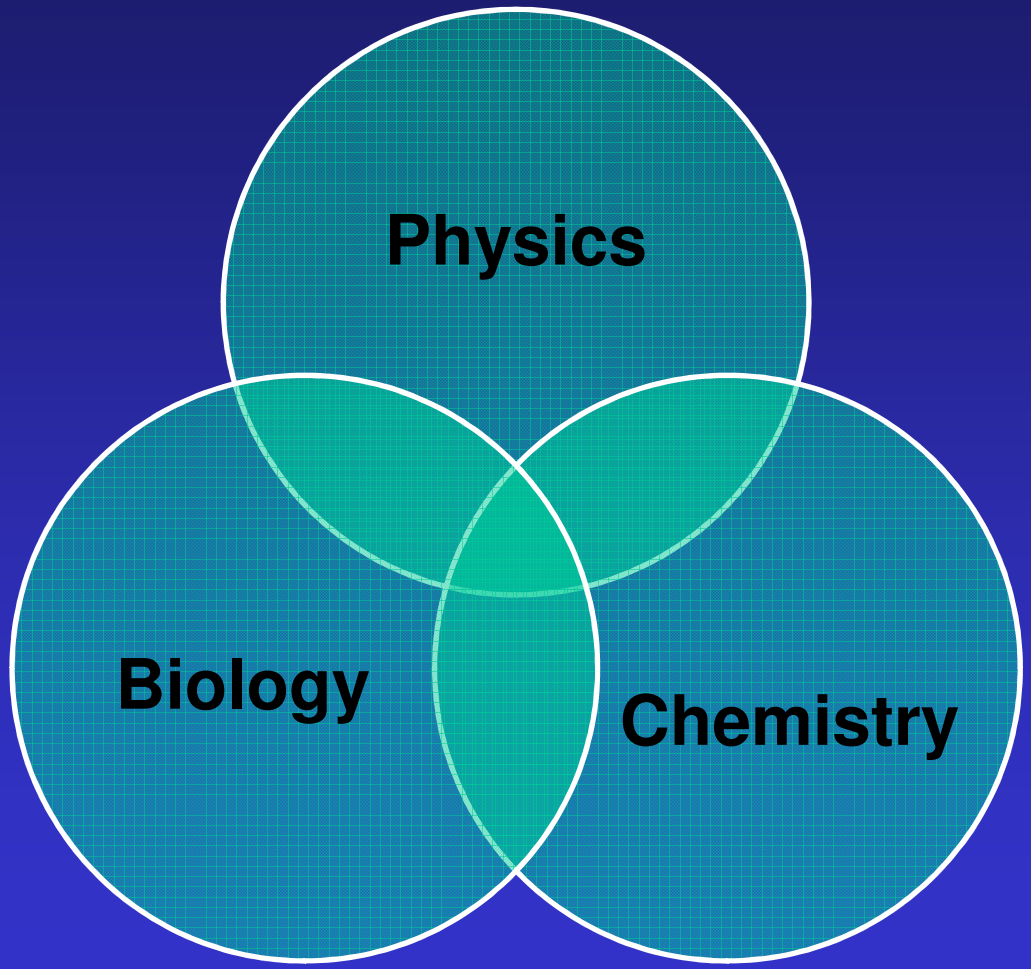
- Chemistry will continue to be a body of knowledge essential for science to function
- But chemistry as a discipline is noticeably in trouble
- Changing nature of chemistry is an evolution, not a paradigm shift
- Science began centuries ago as a unitary discipline and included mathematics, astronomy, anatomy and alchemy
- During the 1700's, in the Age of reason, scientific disciplines as we broadly understand today took shape
- Now science is evolving again, back into a multidisciplinary endeavor with key focal points as the interface between chemistry and physics, chemistry and biology and biology and physics.
- From a study of elements to molecules to the current time to the study of molecular interactions and functions , leading to the creation of many sub disciplines, semingly away from the core discipline of chemistry and into increasingly multidisciplinary space that has made chemistry vulnerable.

CHANGING FACE OF CHEMISTRY

- Chemistry is becoming more and more an interdisciplinary pursuit
- However, students usually learn chemistry in isolation
- Is there a case for teaching science in an integrative fashion ?
- Can principles of chemistry be illustrated using familiar biological phenomena or ecosystem behavior or semiconductor physics ?
- Structure and function constitute the central theme of chemistry. All chemistry must be taught in the context of this theme
- We tend to teach chemistry in the chronological order of its evolution. This is unnecessary
- We should teach chemistry in the context of contemporary knowledge. The origins of chemistry must be covered in a module called "History of Science"

Why don't we teach chemistry the way it is practiced ?

INTEGRATIVE SCIENCES : THE IMPORTANCE OF OVERLAP BETWEEN DISCIPLINES



INTEGRATIVE SCIENCE IS NOT NEW

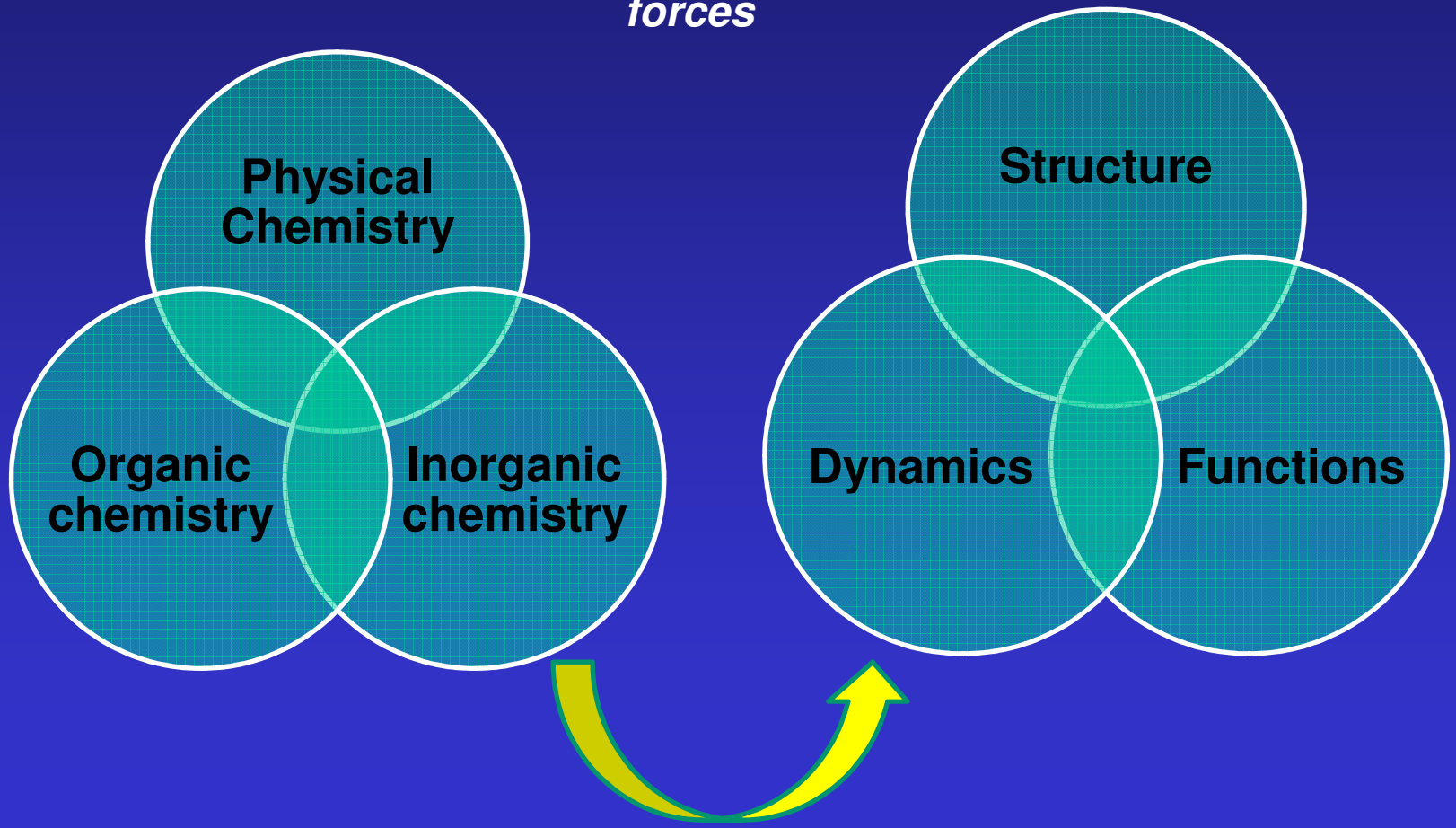
- **Science, when it began as an organized body of knowledge was essentially integrated or holistic.**
- **Science was part of a larger domain of knowledge called Natural Sciences, that included the study of chemistry, biology, physics, mathematics, logic and philosophy**
- **Most departments of sciences in the nineteenth century and early twentieth century were called Department of Natural Sciences**
- **As science expanded during the second half of twentieth century, fragmentation of disciplines became more prevalent**
- **Integrative Science recognizes the absence of borders between sciences. Science finds its strengths in the unity of its diverse disciplines**

WHAT IS INTEGRATED SCIENCE ?

- Integrated Science is an attempt to break down traditional disciplinary barriers
- A series of courses taken in the first and second years provides students with first-rate preparation for a major in any of the core scientific disciplines and in such a way that helps retain the connections to the other disciplines.
- The curriculum is founded on the expectation that much of the most important science of the future, though based on the classical disciplines, will lie in areas that span two or more of them.
- Any budding researcher needs a foundation in several fields to be able to work on the most important problems confronting society today.

INTEGRATION WITHIN CHEMISTRY

Molecules can be organic, inorganic or biologically derived, small or big, single or assemblies and involving a range of inter and intra -molecular forces



CHEMISTRY EDUCATION IN THE INTERNET ERA

- Information and facts abound in the world wide web; era of distributed teaching and learning
- Information retrieval no longer a rate limiting step
- However, one needs higher order skills to get the true value of available information
- Interpretation, making creative connections between data from different sources and spot the needles in the ever expanding information haystacks
- Shift from acquiring knowledge to sharpening the cognitive skills
- Providing facts to students no longer relevant; need to reinvent the classroom.
- The objective should be to make a student active and independent learner
- From “chalk and talk” to “ learn to connect and create”

Connexions : An open source website for college textbooks

PhET : Use of interactive computer simulations to teach physics, chemistry, biology and earth sciences

KHAN ACADEMY

Not for Profit Organization

- **2700 lectures on YouTube**
- **Every conceivable subject**
- **Translated into ten languages**
- **Funded by Google and Bill and Melinda Gates Foundation**
- **Watched by over 4 million students world wide**

CHEMISTRY EDUCATION IN THE INTERNET ERA

- Classroom lectures followed by homework followed by exams is a recipe for educational failure
- From " teach a syllabus" and "teach to test" to " teach to learn"
- From " factual " to " analytical"
- From " fill the mind with facts" to "open the mind with empty spaces"
- From "teacher centric" to "student centric"
- Teach to understand why chemistry is critical to their everyday life

➢ *Nature Publishing Group has launched its first of its kind digital book "Principles of Biology"*

➢ *Pay for access on internet; available on Laptop, Tablet or Smart Phone*

➢ *Interactive, dynamic illustrations, audio and video clips*

➢ *A book aimed at learning not reading*

➢ *Introduces students to primary literature summaries, explains how biology impacts the quality of life, introduces real world skills and talks about careers*

➢ *Teachers in the classroom will have to compete with "teachers" in the cyberspace .*
➢ *Are teachers becoming an endangered species?*

DATA AND ACCESS WILL NOT BE LIMITING

- ***Data*** **: from one billion terrabyte in 2010 to 35 billion terrabyte in 2020**
- ***Access*** **: from 120 million to 500 million**
- ***Devices*** **: Over a billion mobile and smart phones and low cost Tablets and Laptops**

Access to facts and information will no longer be a challenge; the question will be what do we do with all the information ?

What then will be the challenge to education ?

The most important thing in science is not so much to obtain new facts as to discover new ways of thinking about them

William Bragg

SOME UNSOLVED PROBLEMS IN CHEMISTRY

- **How many molecules can you make from a given set of elements, say C,H,O,N etc**
- **Is there a limit to the number of elements in the Periodic Table**

  (106, now; is 136 the limit , Feynman's answer)
- **What is the origin of chirality in nature ?**
- **Why does nature have a preference to L-Amino acids and D-Sugars**
- **Why do many organic reactions proceed faster in water?**
- **Why does water plays a central role in the chemistry associated with biological processes?**
- **How many elements have allotropic forms? What do we know of the properties of allotropes, other than those of carbon ?**

SOME UNSOLVED PROBLEMS IN CHEMISTRY

- **Why is nature carbon centric ?**
- **Can we mimic photo-synthesis with 10X efficiency?**
- **Can we make energy molecules from carbon dioxide, water hydrogen and methane?**
- **Can carbon-dioxide and methane, two of the most stable organic molecules, be made reactive ?**
- **How can we create purposeful motion in molecular objects ?**
- **Can we create "informed matter" from molecules ?**
- **How can we make materials with impossible properties ?**
- **Can we synthesize life from atoms? What are the consequences? Can , in the future, chemistry make biology ?**
- **What is the "chemical" basis of human consciousness ?**

Chemistry has not lost its identity; it has instead gained important footholds within the domains of other sciences – albeit rarely at the initiative of chemists

D. Seebach

CHEMISTRY BACK TO BASICS

- **Emphasize function**
- **Take control of the systems**
- **Reengineer the transition from university to industry; generate a “new chemical industry”**
- **Reinvent teaching / objectives**
- **Consider the balance between single investigator and collaborative research**
- **Modify/supplement peer review**
- **Focus resources on change**

I believe chemistry can be everywhere, if chemistry so chooses or that it can contract into an invisible part of the infrastructure of society

G. M. Whitesides


1950 - 2010
CSIR - INDIA
Celebrating Sixty
Years of Science
THANK YOU