MATERIALS IN EVERYDAY LIFE

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

Tel : 0091 20 2589 3030
Fax : 0091 20 2589 3355
Email : s.sivaram@ncl.res.in
Visit us at : http://www.ncl-india.org

Lecture delivered at
SCIENCE OUTREACH PROGRAMME,
EXCITING SCIENCE GROUP
Venture Center, Pune
AUGUST 21, 2011

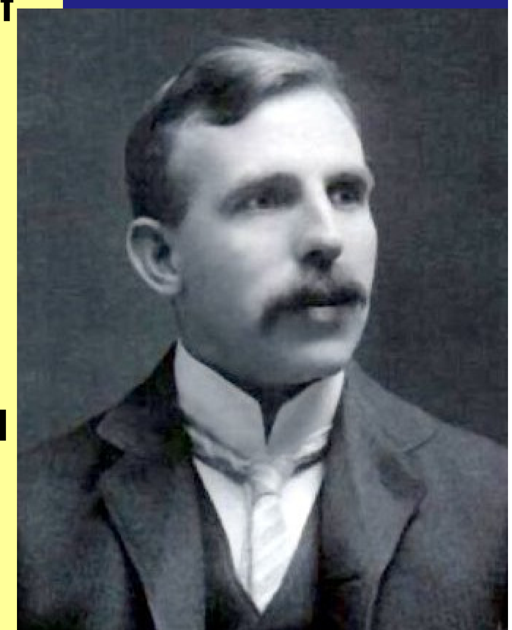
International Year of CHEMISTRY 2011

1950-2010 NCL Celebrating Sixty Years of Science

Madame Curie, Nobel Prize in Chemistry , 1911

- **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



Earnest Rutherford, The Structure of the Atom. 1911

THE AGES OF HUMAN KIND

Human Civilization has been marked by several ages, which are all material based:

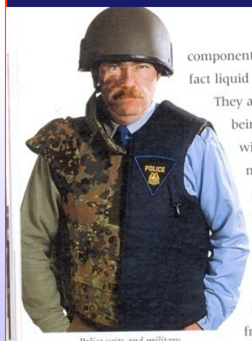
- *Stone Age*
- *Bronze Age*
- *Iron Age (Steel. Aluminum)*
- *Polymer Age (Carbon based materials)*
- *Age of Elements (Lithium, Platinum, Tellurium, Cadmium, Gallium, Indium, Silicon, Rare Earths, such as, Lanthanum, Cerium, Neodymium and Ytterbium, Nuclear Elements, such as, Uranium, etc)*

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

Central

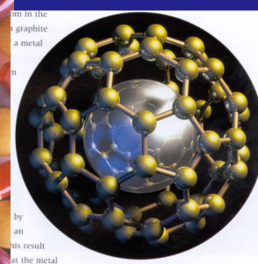
Underpins many other scientific disciplines

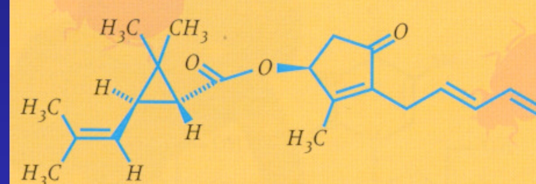
Biology, geology, material science



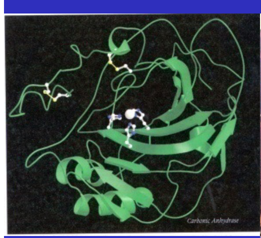
Creative

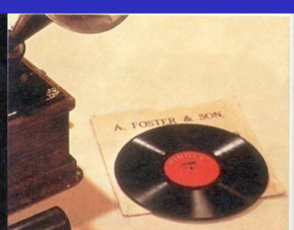
Designs structures with new and unique properties





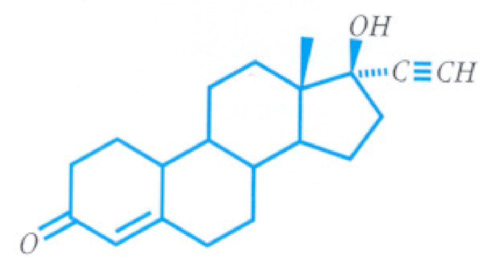
(a) Pyrethrin.





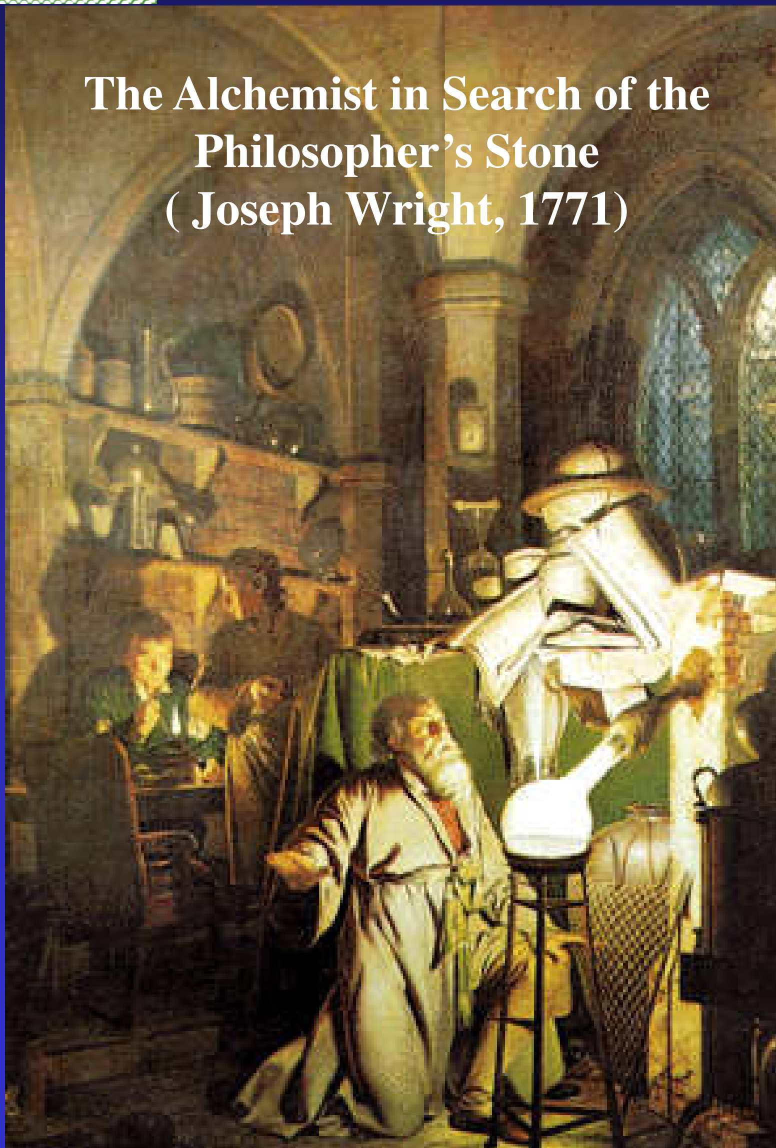
Useful

Provides many materials essential to everyday life, knowledge to better human, veternary and plant care, better food, environment



Norethindrone (Norlutin)

Figure 14. Norlutin, the first contraceptive pil



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

Hennig Brandt of Hamburg (1630 -1710)

Discoverer of Phosphorous

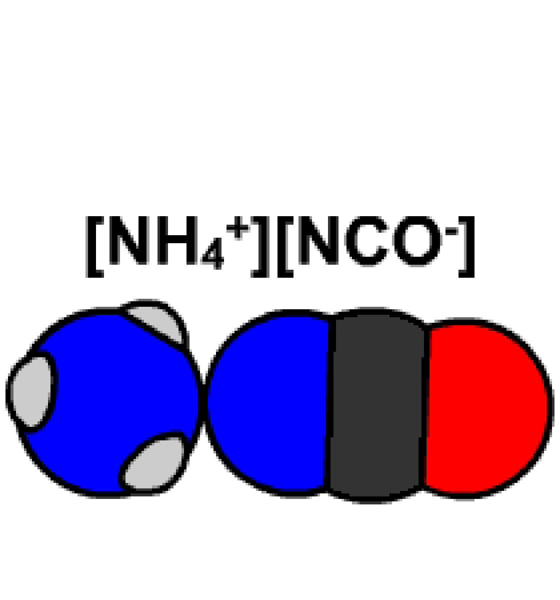
The chemical reaction Brandt stumbled on was as follows. Urine contains phosphates PO_4^{3-}, as sodium phosphate (i.e. with Na^+), and various carbon-based organics. Under strong heat the oxygens from the phosphate react with carbon to produce carbon monoxide CO, leaving elemental phosphorus P, which 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).

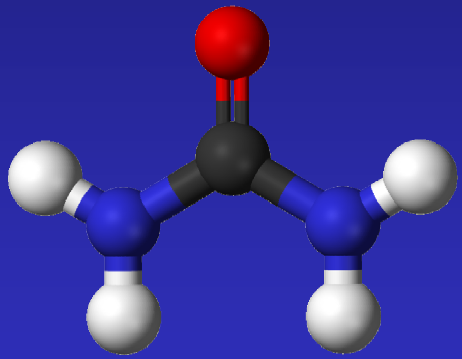
This same essential reaction is still used today (but with mined phosphate ores, coke for carbon, and electric furnaces).

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).

CHEMICAL REVOLUTION : EARLY BEGINNINGS

Freidrich Wohler (1800 – 1882)





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

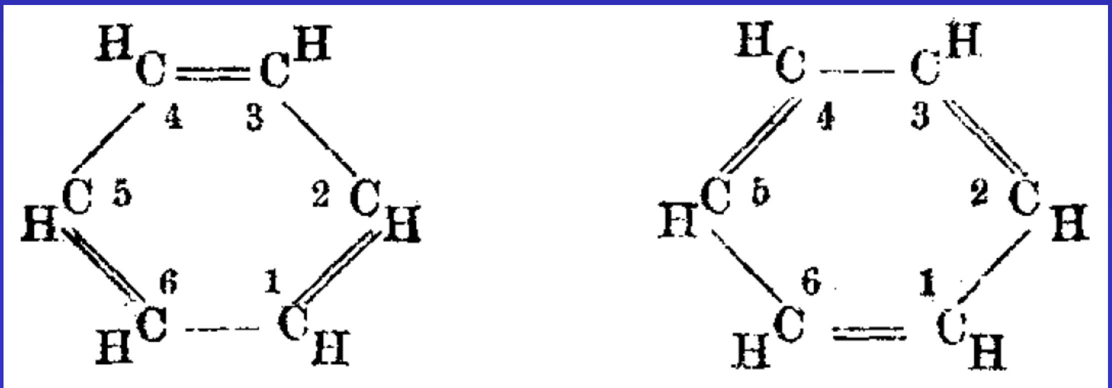
Marcellin Bertholet, 1860

(1827- 1907)

CHEMICAL REVOLUTION : UNDERSTANDING CHEMICAL STRUCTURES

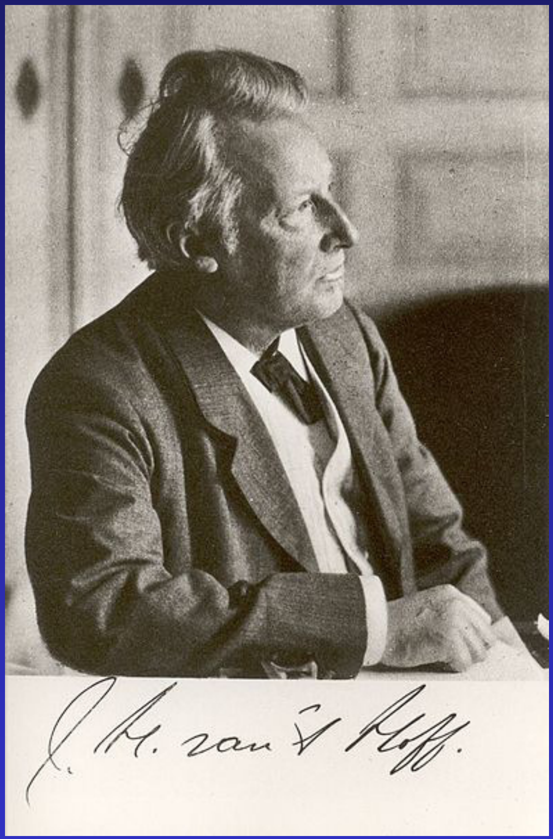
- **The Theory of Chemical Structure (1857-58)**
- **Structure of Benzene published in *Bulletin de la Society Chimique de Paris, 3(2), 98-110 (1865)***

Auguste Kekule (1829 -1896)

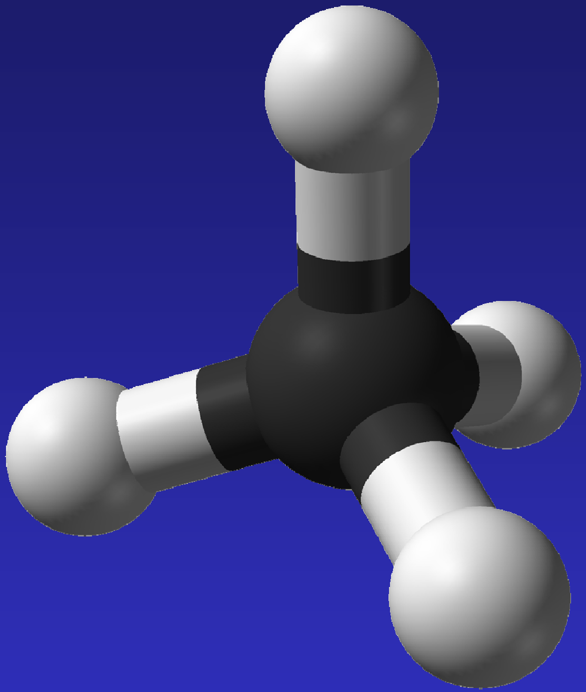


" If you want to become a chemist, so Liebig told me, when I worked in his laboratory, you have to ruin your health. Who does not ruin his health by his studies, now a days, will not get anywhere in chemistry"

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

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. 383,684.

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.

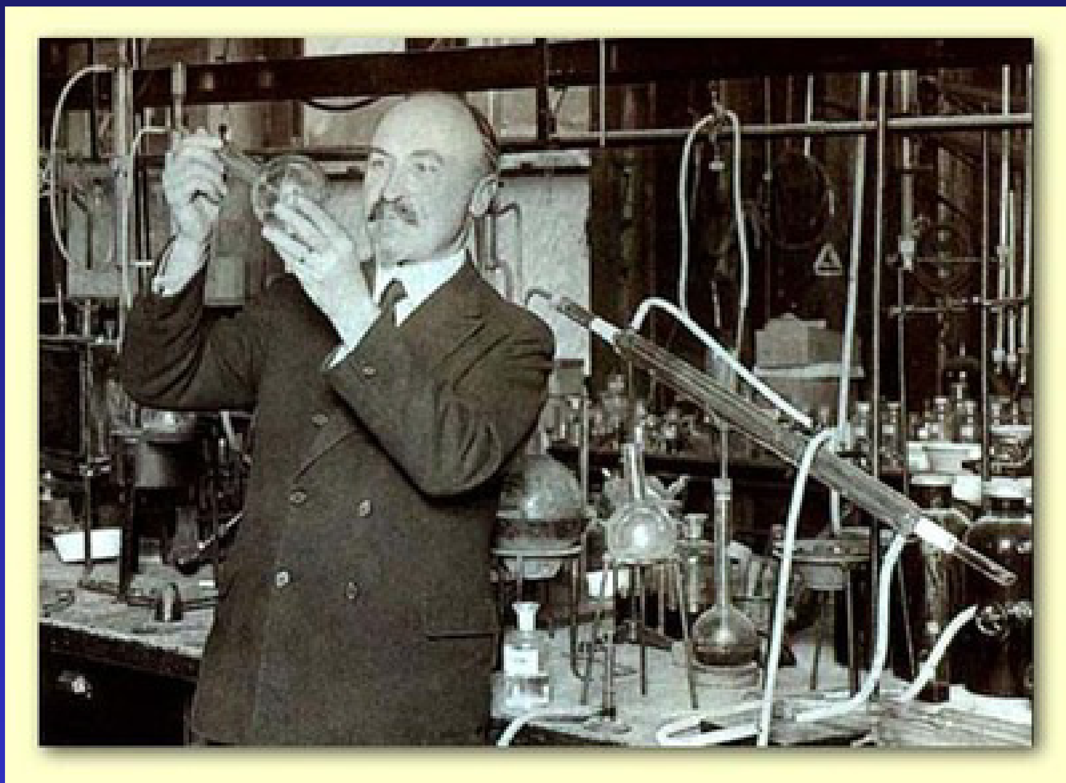
In practicing the invention I react upon a phenolic body with formaldehyde to obtain a reaction product which is capable of transformation by heat into an insoluble and infusible body, and then convert this reaction product, either alone or compounded with a suitable filling material, into such insoluble 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, these 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.

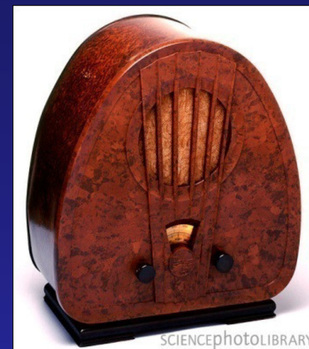
US Patent 942, 699, December 7, 1909

- 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)



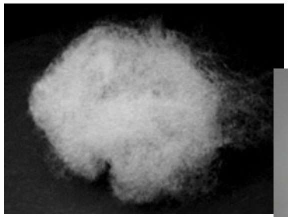
When asked why he chose to work in the field of synthetic resins, he replied" to make money"

SYNTHETIC POLYMERS

- ***Plastics***
  - Water bottles
  - Packaging materials
  - Tote bag / luggage

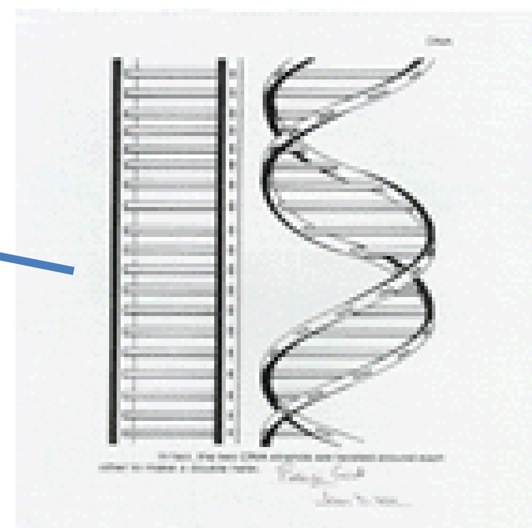
- ***Rubbers (elastomers)***
  - Tires
  - Latex Gloves
  - Chewing gum

- ***Fibers***
  - Fillings in Pillows
  - Apparels
  - Stockings

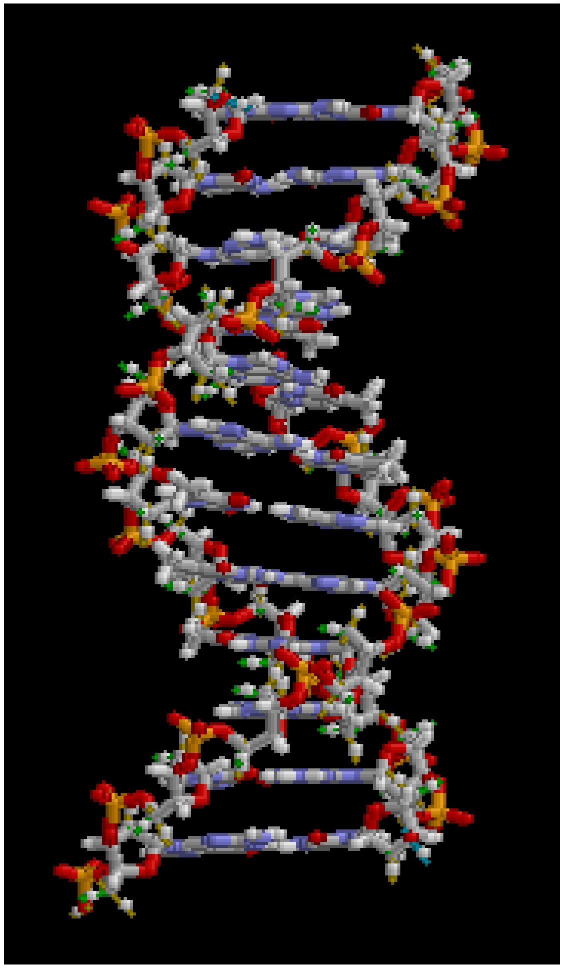


Natural Polymers

- Collagen
- Gelatin
- Keratin
- Silk
- Wool
- Cellulose
- Natural Rubber
- DNA



THE POLYMER MOLECULE OF LIFE : DNA



What are Polymers?

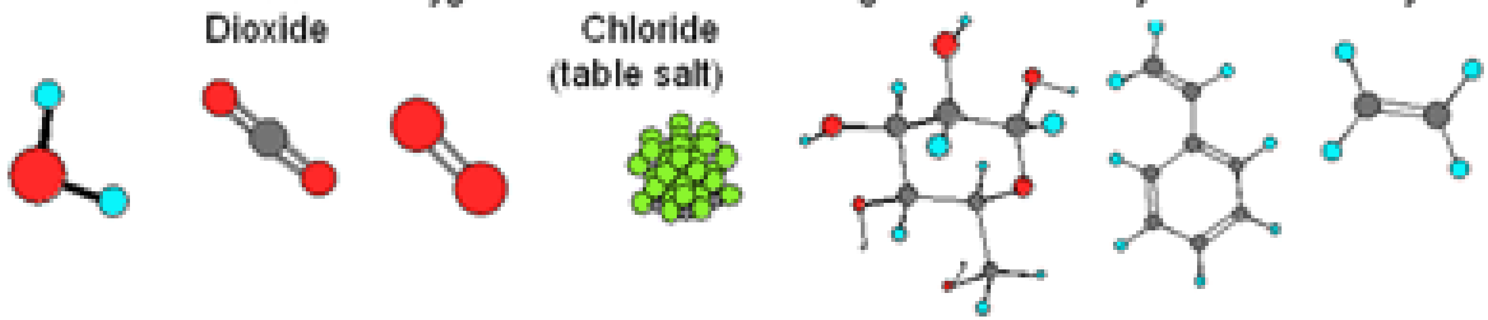
Poly mers *are made up of many* **Mono mers**

Poly → Many; mers → Units

Mono → One; mer → Unit

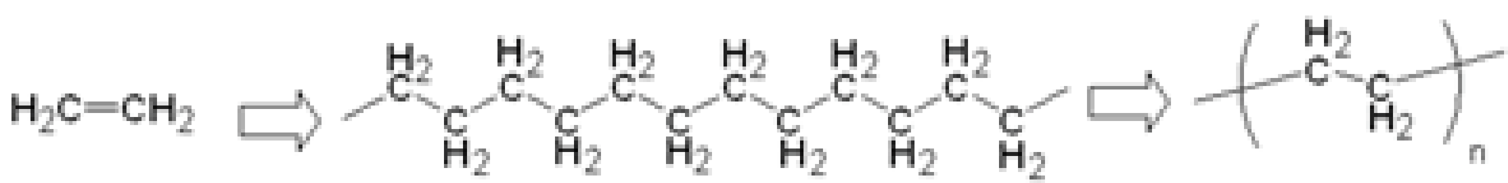
Small Molecules and Monomers:

H_2O	CO_2	O_2	NaCl	$C_6H_{12}O_6$	C_8H_8	C_2H_4
Water	Carbon Dioxide	Oxygen	Sodium Chloride (table salt)	Sugar	Styrene	Ethylene



Macromolecules (Polymers):

Ex: Polyethylene



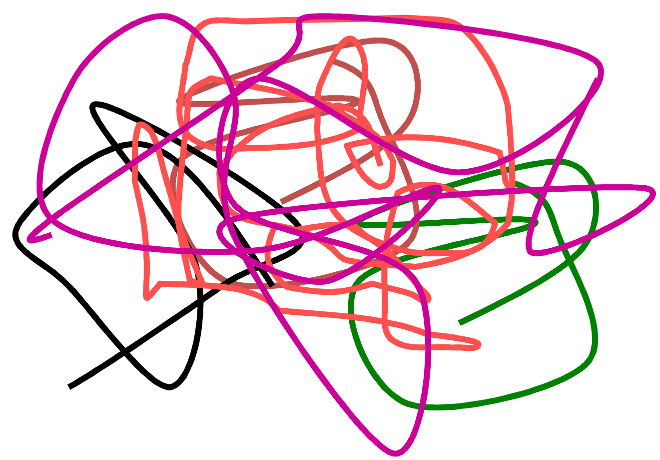
Length + Flexibility Make it Happen...

Short Molecules

- Can separate easily
- Too short to entangle
- Behave independently

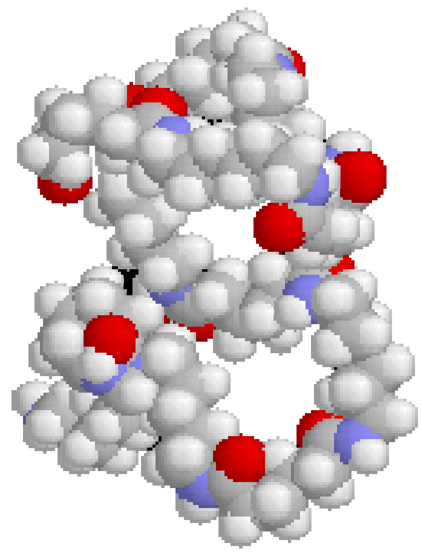
Bowl of Rice

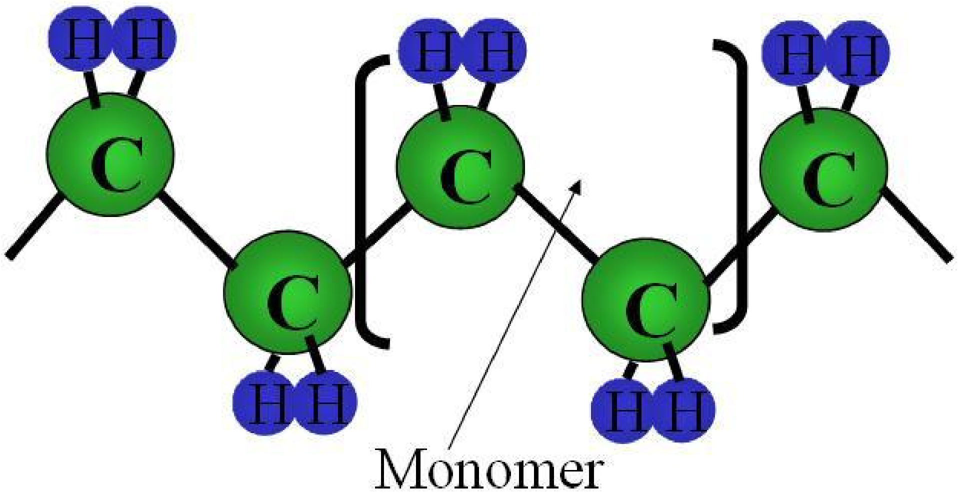
Long Molecules

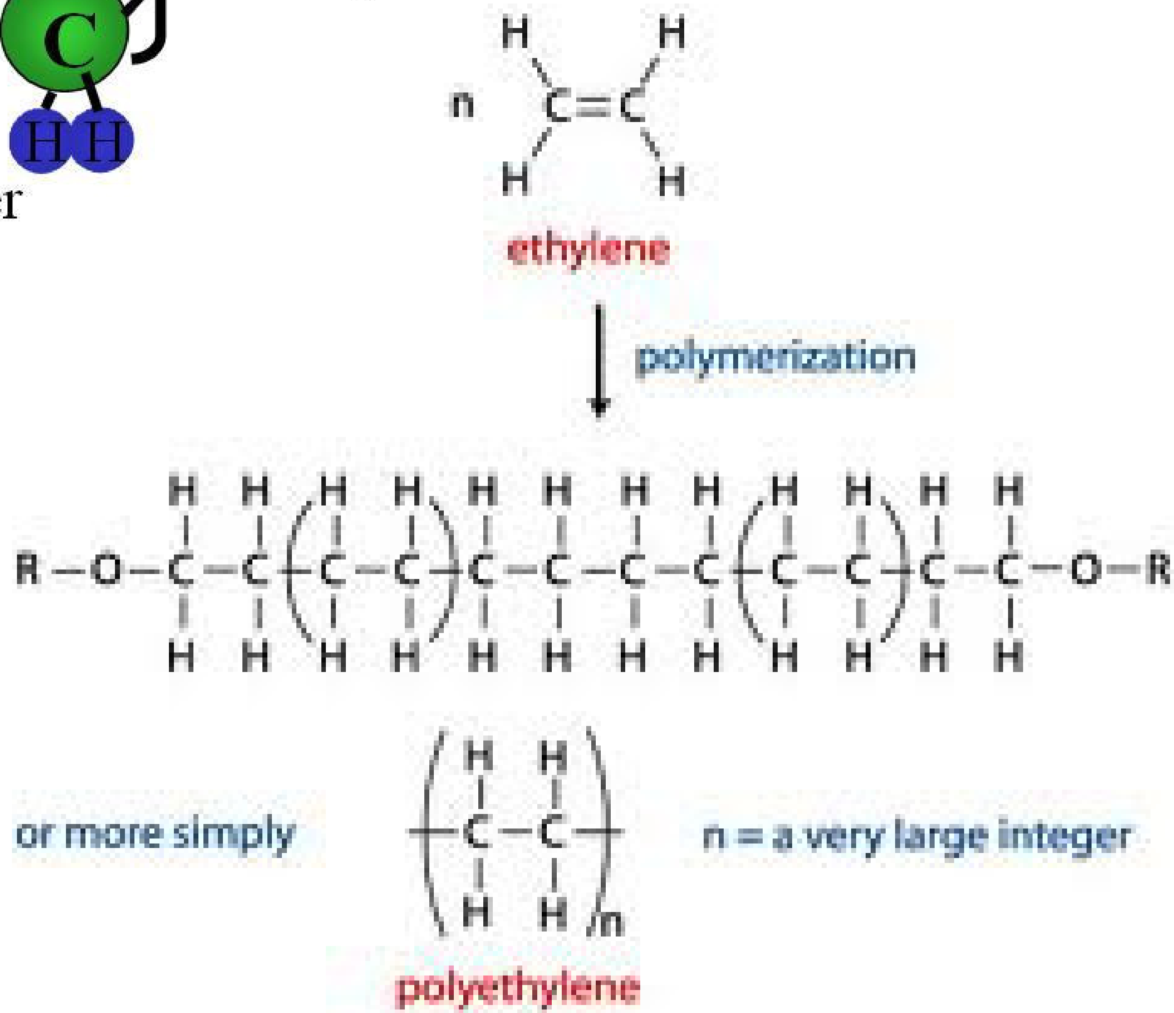


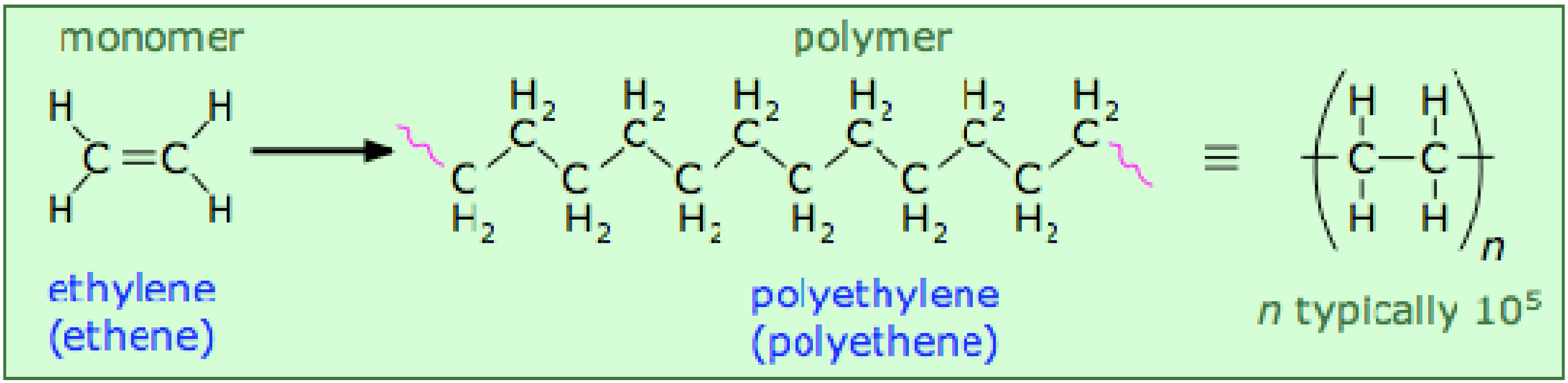
- Completely entangled
- Molecules do not easily move independently

Bowl of Spaghetti



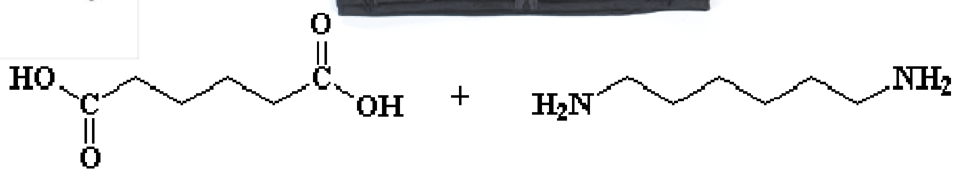

Monomer


ethylene
polymerization
or more simply
n = a very large integer
polyethylene

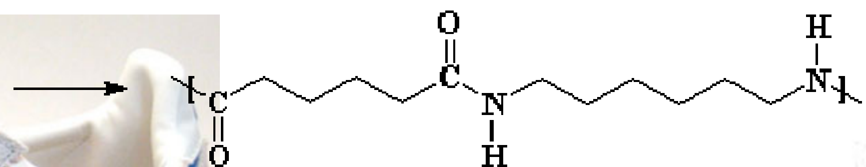

monomer
polymer
ethylene
(ethene)
polyethylene
(polyethene)
n typically 10^5

Ox's Bone for handles
Pig's hair for bristles

Polypropylene for handles
Nylon 6,6 for bristles
Synthetic rubber for grip



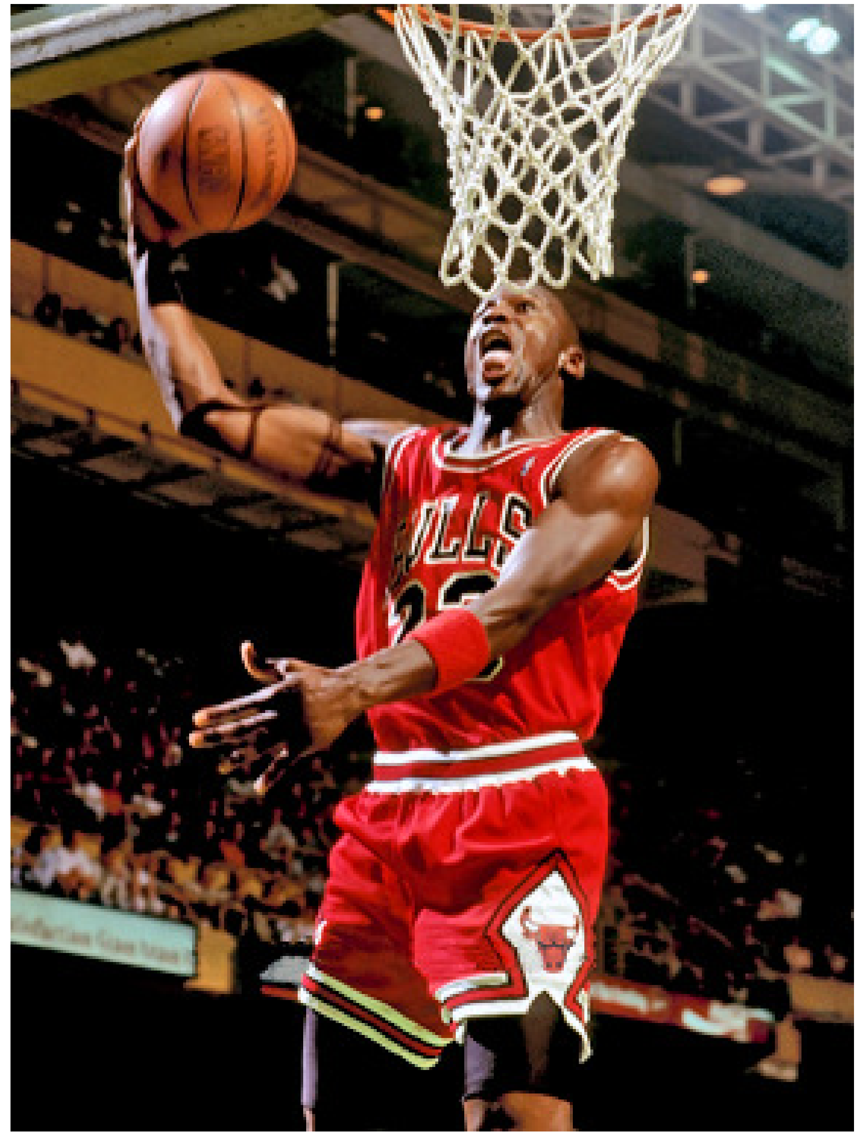
adipic acid hexamethylene diamine



nylon 6,6

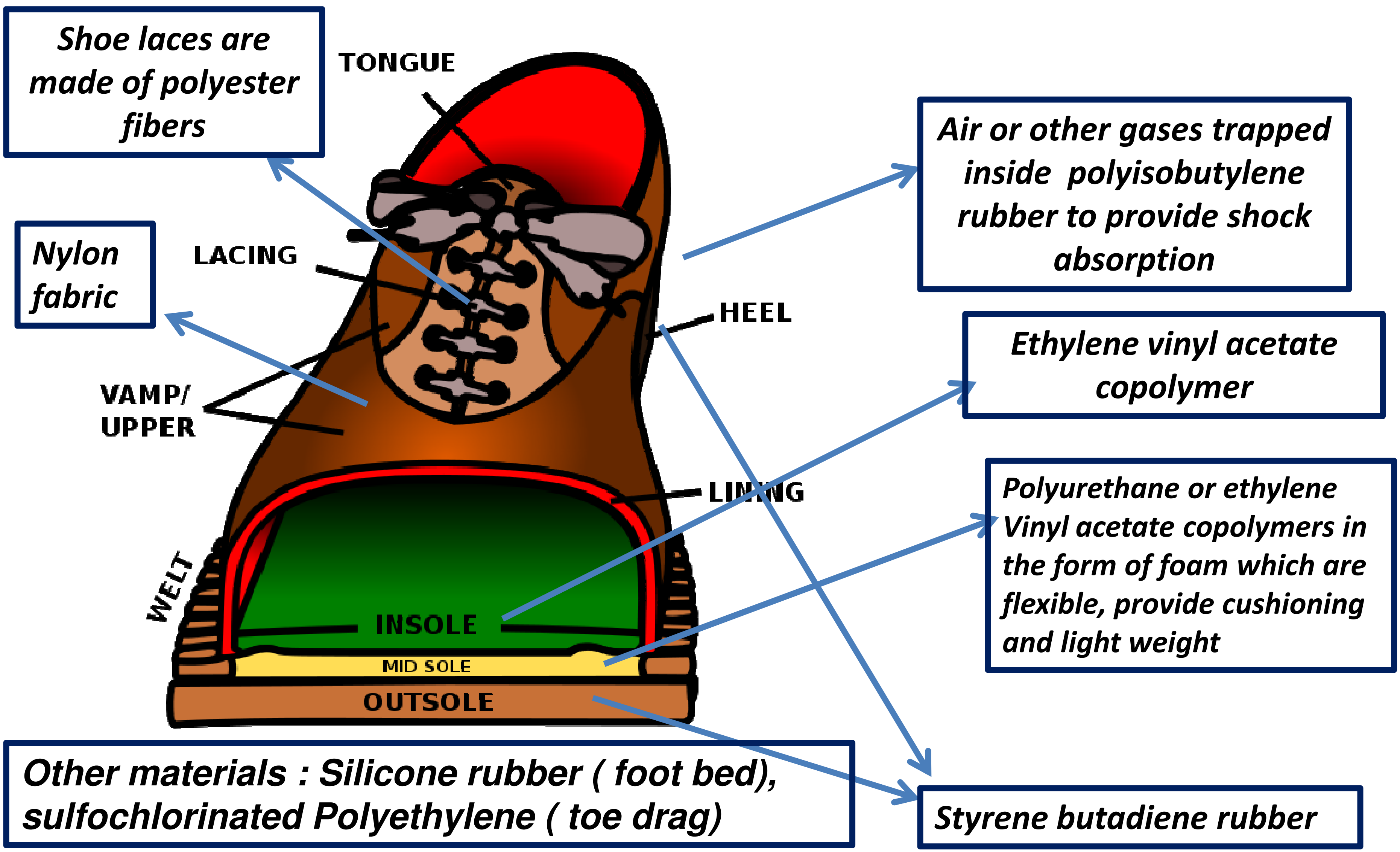
NYLONS ARE ALSO FOUND IN MANY ARTICLES OF EVERY DAY USE


CSSR



HOW MANY MATERIALS CAN YOU FIND IN YOUR ATHLETIC SHOES ?

- ***When you jump, run and play, your body weight can put 3-6 times the force on your feet. So you want your shoe to absorb the shock***
- ***You want your shoe to last***
- ***You want your shoes to be light on your feet***
- ***You want your shoes to be flexible, assuming the contours of your feet as you walk, run, and bend***


Shoe laces are made of polyester fibers
TONGUE
Air or other gases trapped inside polyisobutylene rubber to provide shock absorption
Nylon fabric
LACING
HEEL
VAMP/ UPPER
Ethylene vinyl acetate copolymer
LINING
Polyurethane or ethylene Vinyl acetate copolymers in the form of foam which are flexible, provide cushioning and light weight
WELT
INSOLE
MID SOLE
OUTSOLE
Other materials : Silicone rubber (foot bed), sulfochlorinated Polyethylene (toe drag)
Styrene butadiene rubber

Synthetic Polymers

- Poly (ethylene terephthalate) {PET}
  - Soda bottles, laundry detergent containers
- High Density Polyethylene {HDPE}
  - Milk jugs, shampoo bottles, landfill liners
- Poly (Vinyl Chloride) {PVC}
  - Shower curtains, siding, piping
- Low Density Polyethylene {LDPE}
  - Garbage bags, tape, disposable diapers
- Polypropylene {PP}
  - Chip and cookie bags, tupperware
- Polystyrene {PS}
  - Packing foam, disposable cups

The Periodic Table of the elements by Medvedev was a historic achievement in chemistry and enabled chemists to see the relationship between structure and properties of the basic elements.

Polymers also have a strong relationship between structure and properties and this 'Periodic Table of Polymers' is a first attempt to provide a simple codification of the basic polymer types and structures.

The diversity of polymer types makes it impossible to include all of the variations in one simple table and this table only includes the most common polymers.

Tangram Technology
Periodic Table of Thermoplastics

TANGRAM TECHNOLOGY Consulting Engineers

Increasing performance →

Commodity — **Engineering** — **Performance**

Increasing crystallinity ↓

Amorphous

Random molecular orientation in both molten and solid phases.

General Characteristics
- Soften gradually.
- Generally transparent.
- Lower Tensile Strength and Tensile Modulus.
- Lower Density.
- Low Creep Resistance.
- High Dimensional Stability.
- Low fatigue resistance.
- Easy to bond using adhesives and solvents (high surface energy).

Semicrystalline

Random molecular orientation in molten phase, densely packed crystallites in solid phase.

General Characteristics
- Sharp melting point.
- Generally translucent or opaque.
- Higher Tensile Strength and Tensile Modulus.
- Higher Density.
- High Creep Resistance.
- Low Dimensional Stability.
- High fatigue resistance.
- Difficult to bond using adhesives and solvents (low surface energy).

Amorphous	**PS-HI** High Impact Polystyrene	**PS-GP** General Purpose Polystyrene	**ABS** Acrylonitrile Butadiene Styrene (Copolymer)	**SAN** Styrene Acrylonitrile (Copolymer)		**PMMA** Polymethyl methacrylate (Acrylic)	**PPO** (Modified) Polyphenylene Oxide	**PC** Polycarbonate		**PAR** Polyarylate	**PSU** Polysulphone	**PES** Poly-ethersulphone	**PPSU** Poly-ethersulphone (Block copolymer)	
Amorphous	**PVC-P** Plasticised Poly-vinylchloride	**SBS** Styrene-Butadiene-Styrene (Copolymer)	**SMA** Styrene-Maleic Anhydride (Copolymer)	**ASA** Acrylonitrile Styrene Acrylate (Copolymer)	**SB** Styrene-Butadiene (Copolymer)						**PEI** Polyetherimide	**PAI** Poly-amideimide	**PI** Polyimide	**PBI** Polybenzimide azole
Amorphous	**PVC-U** Unplasticised Poly-vinylchloride	**CA** Cellulose Acetate	**CAB** Cellulose Acetate Butyrate	**CAP** Cellulose Acetate Propionate	**CP** Cellulose Propionate	**PET-G** Glycolised Polyethylene terephthlate	**PVC-UX** Crosslinked Unplasticised PVC	**PVC-C** Chlorinated PVC						
Amorphous	**PVC-U** High-Impact Unplasticised PVC								**PA 6/3/T** Amorphous polyamide	**PPA** Poly-phthalamide (Amorphous)	**PARA** Polyaryl amide			
Semicrystalline	**PE-LD** Low Density Polyethylene	**PE-LLD** Linear Low Density Polyethylene	**PE-MD** Medium Density Polyethylene	**PMP** Polymethyl pentene	**EVA** Ethylene-vinyl Acetate (12% VA)	**PE-X** Crosslinked Polyethylene	**PB** Polybutene-1 (Polybutylene)	**PE-UHMW** Ultra-high Molecular Weight PE	**PA 11** Polyamide 11 (Nylon 11)	**PA 12** Polyamide 12 (Nylon 12)	**PPA** Poly-phthalamide	**PA 46** Polyamide 46 (Nylon 46)	**PEK** Poly-etherketone	**PEEK** Polyetherether ketone
Semicrystalline			**PE-C** Chlorinated Polyethylene	**PE-VLD** Very Low Density Polyethylene	**EMA** Ethylene-methyl Acrylate	**PBT** Polybutylene-terephthlate	**PA 6** Polyamide 6 (Nylon 6)	**PA 66** Polyamide 66 (Nylon 66)		**LCP** Liquid Crystal Polymer (Aromatic copolyester)	**PFA** Perfluoroalkoxy	**ECTFE** Ethylene-chlorotrifluoro-ethylene	**PCTFE** Polychloro-trifluoro-ethylene	**PTFE** Poly-tetrafluor-ethylene
Semicrystalline		**PP** Polypropylene (Homopolymer)	**PP** Polypropylene (Copolymer)			**PET** Crystalline Polyethylene-terephthlate	**PA 6/10** Polyamide 6/10 (Nylon 6/10)	**PA 6/12** Polyamide 6/12 (Nylon 6/12)	**POM** Poly-oxymethylene (Acetal Copolymer)	**EVOH** Ethylene-vinyl Alcohol	**PPS** Polyphenylene Sulphide	**FEP** Fluorinated ethylene-propylene	**ETFE** Ethylene-tetrafluoro-ethylene	**PVDF** Poly-vinylidene-fluoride
Semicrystalline	**PE-HD** High Density Polyethylene								**POM** Poly-oxymethylene (Acetal Homopolymer)					

KEY TO MAJOR POLYMER FAMILIES: Styrenes · Polyolefins · Vinyls · Cellulosics · Polyesters · Polyamides · Acrylics · Polycarbonates · Acetals · Polysulphones · Imides · Fluoropolymers

Reduced Version. Issue 2: February 2008