Assignment #1: Envisioning Sustainability Through Art

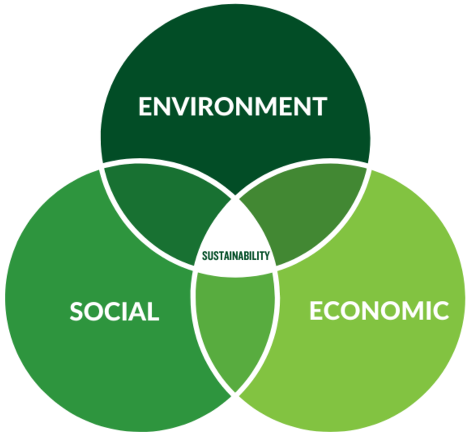
Due TODAY!

Please let me know if you have any questions or if you need any assistance.

Final Project Guidelines

Key Objective

Develop an innovative solution to a current challenge using sustainable materials. Your project should focus on designing or improving a material system that addresses an environmental, economic, or social issue.



Evaluation Criteria

- **Innovation and creativity**: Originality of the solution and its potential to address the identified problem. (20%)
- **Feasibility and practicality**: Practicality of implementation and scalability of the proposed material system. (20%)
- **Sustainability impact**: Environmental, economic, and/or social impact of the solution. (20%)
- **Research and analysis**: Depth of research, thoroughness of presentation and analysis. (20%)
- **Presentation and communication**: Clarity, organization, and effectiveness of both midterm and final presentations. (20%)

Find your "**Why**"

- I always find it easier to **think of a problem first**, and then consider some potential solutions
- Examples may include:
  - Waste management—electronic, textile, packaging, microplastics, agricultural, pollution
  - Critical material scarcity—Rare earths, cobalt, lithium, etc.
  - Wasteful construction materials—concrete, steel, single use plastics, drywall, asphalt, etc.
  - Fast fashion
  - Water-intensive manufacturing processes
  - Energy-intensive material production—aluminum, steel, cement, glass, bricks, ceramics, etc.
  - Depleting natural resources—metals, minerals, fossil fuels, freshwater, arable land, etc.
  - Carbon emissions/climate change
  - Environmentally harmful batteries—EVs, lithium-ion batteries
  - Material toxicity—human toxicity, animal, marine, plant
  - Marine debris and harmful fishing
  - Harmful thermally insulating materials

Materials solutions: your "**How**"

- Now that you have selected a "why" let's think how we can address the issue using a materials-focused approach
- Examples:
  - Biodegradable packaging
  - Circular economy in construction
  - Sustainable textile development
  - Biomaterials for medical applications
  - Renewable polymers for 3D printing
  - Upcycling waste for construction
  - Bio-inspired material design
  - Sustainable electronics
  - Self-healing materials
  - Energy harvesting materials
  - Water filtration using sustainable materials
  - Sustainable adhesives
  - Bioplastics
  - Concrete alternatives
  - Bamboo for construction
  - Sustainable battery materials
  - Mycelium-based insulation
  - Sustainable packaging from ag byproducts
  - Ocean plastic capture and reprocessing

Checkpoints

September 18: Project checkpoint #1: Pick your groups and pick your problem—**deliverable: email Logan <u>first come first serve</u>**

- groups should consist of 2-3 members.

October 2: Project checkpoint #2: Send one slide introduction to your project. Will be reviewed by the team to ensure that it is a reasonable selection—**deliverable: upload slide**

October 16: Project checkpoint #3: Written portion of the midterm (1-2 Pages)—**deliverable: upload doc**

- Think of this as your "trial run". We will look to challenge your ideas in this stage to prepare for the final presentation

Checkpoints

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Checkpoints

October 30: Project checkpoint #4: Literature review—collect resources to support your proposed sustainable material design. Delve into the research. What are some things you had not thought about yet? (minimum 5 articles)—**deliverable: upload list of references and brief synopsis of how each relate to your design**

November 13: Project checkpoint #5: Materials management and life cycle analysis for your proposed project—**deliverable: upload your analysis with full details on the calculations**

Presentations

Midterm: 5 minute in class presentation. I recommend 5 slides:

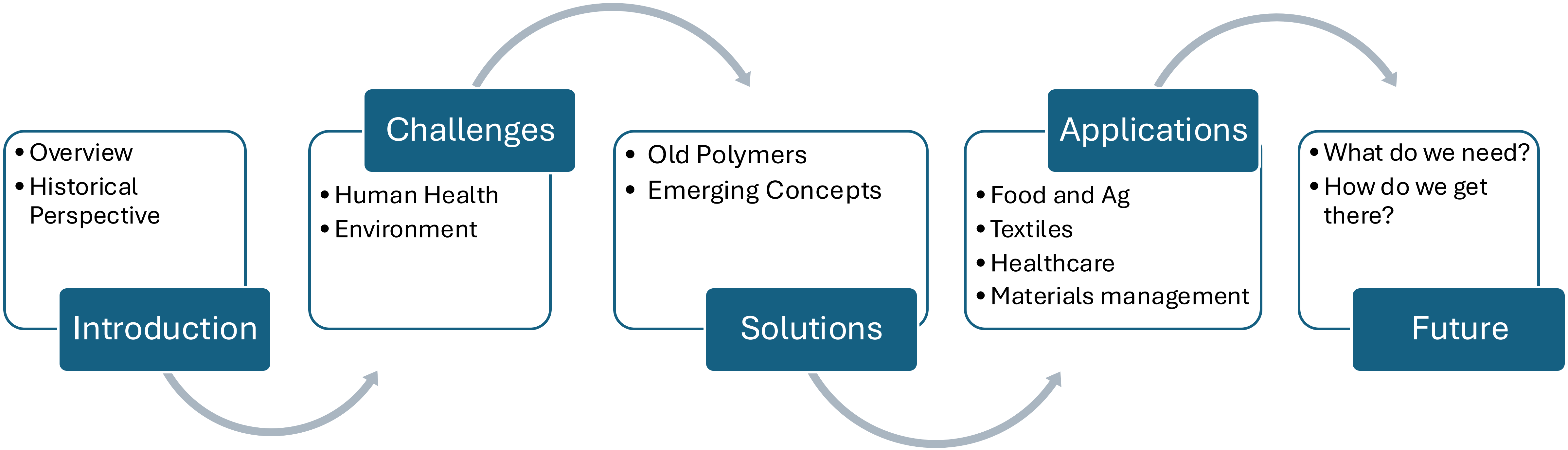
1. Background and context
2. Introduction to the proposed solution
3. Conceptual framework and theoretical basis
4. Expected impact and feasibility
5. Next steps: What would it look like to try this? Has anyone tried something similar? Did they have success?

Presentations

Final: 20 minute in class presentation

- More free-form: make it your own
- Make sure to give sufficient background. Identify the problem clearly.
- Do your research: Cite sources. Show data to support your claims.
- Incorporate what we talk about in class
- Life cycle analysis, materials management should be included
- Ensure that the timing is tight. Do not go way under or over time.
- Remember the evaluation criteria

Course Overview



Course Overview

Introduction
- Overview
- Historical Perspective

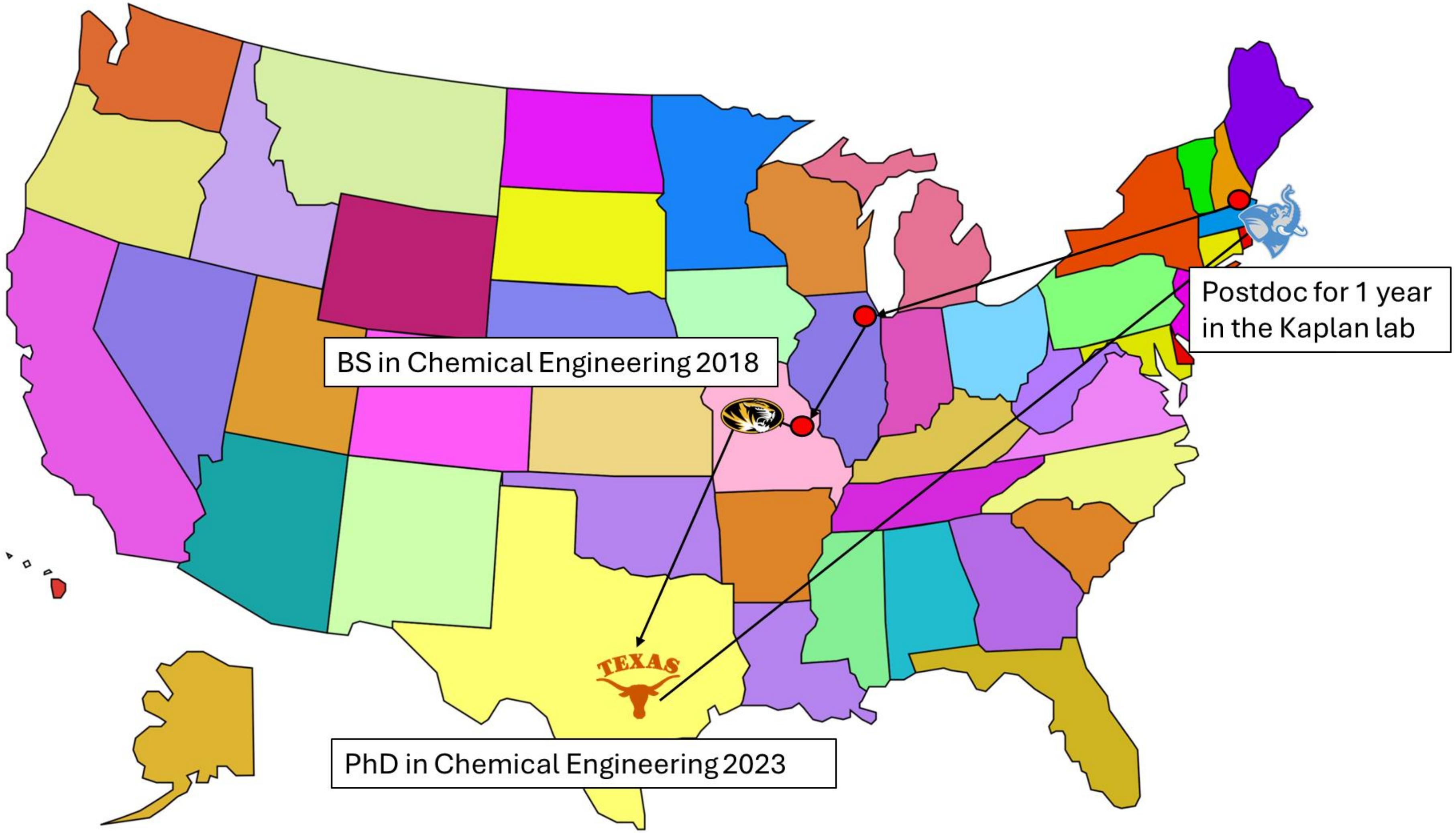
Challenges
- Human Health
- Environment

Solutions
- Old Polymers
- Emerging Concepts

Applications
- Food and Ag
- Textiles
- Healthcare
- Materials management

Future
- What do we need?
- How do we get there?

Logan Morton, PhD.

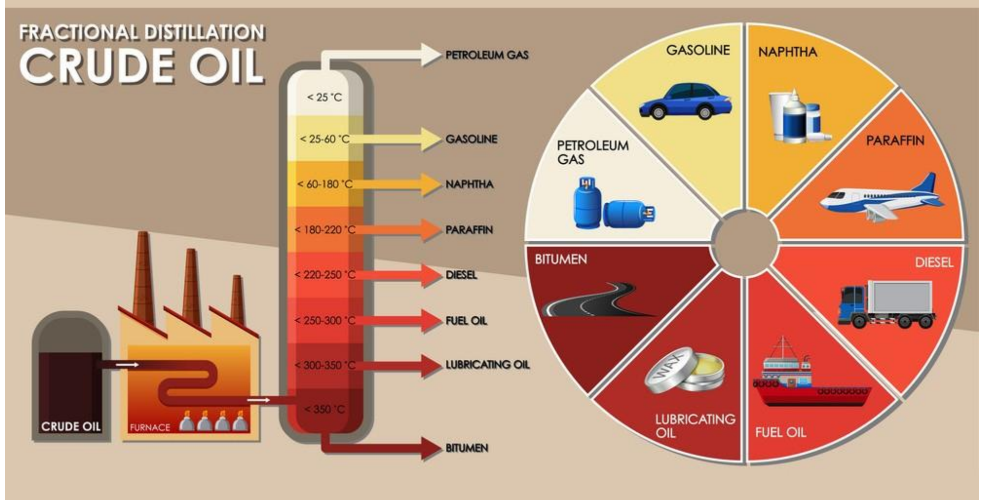


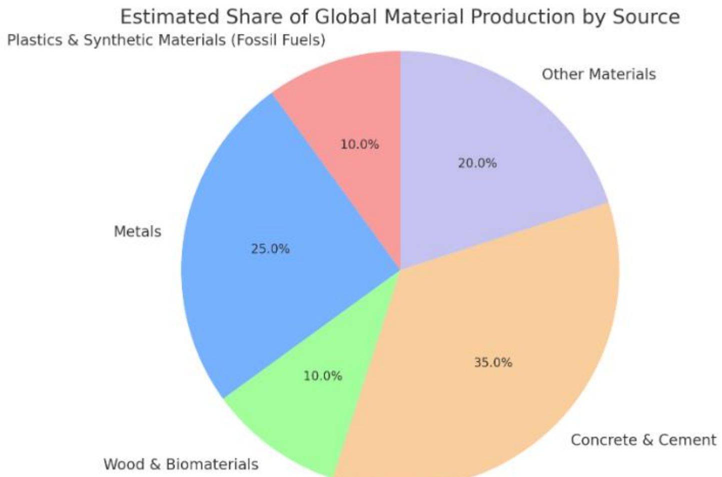
What do these have in common?

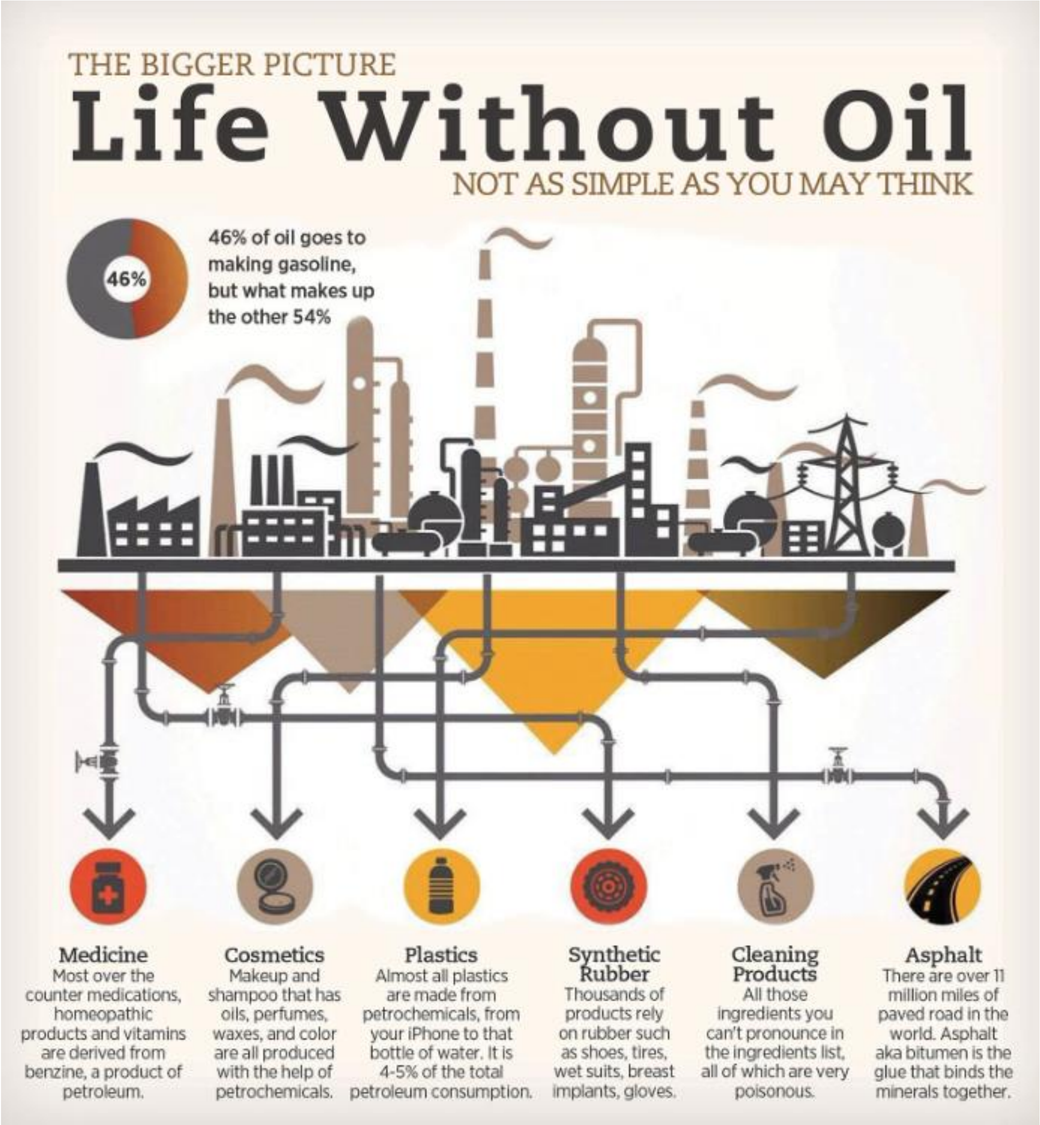
They all use synthetic polymers—a relatively new invention.

Fossil fuel contribution to material production

What percentage of oil is used in gasoline?



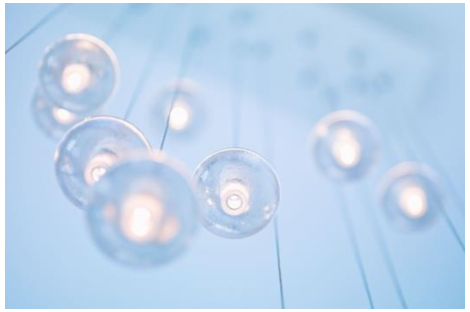




Materials Engineering…

- Prior to the invention of plastic, what moldable substances did we have?

1. Glass
2. Clays/Pottery










Materials Engineering…

- Prior to the invention of plastic, what moldable substances did we have?

1. Glass
2. Clays/Pottery

- What are some issues with glass and clay as materials?
- Why did plastic become so universal?

Synthetic polymers are only 117 years old!

- It might sound like a lot, but modern humans lived without it for thousands of years
- So how did we make stuff?
- Natural materials like Shellac!

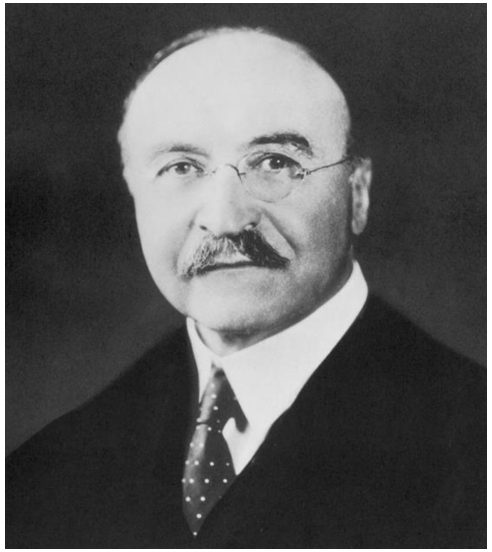
Lac insect cocoons

dissolved in ethanol

dried into a film/flakes

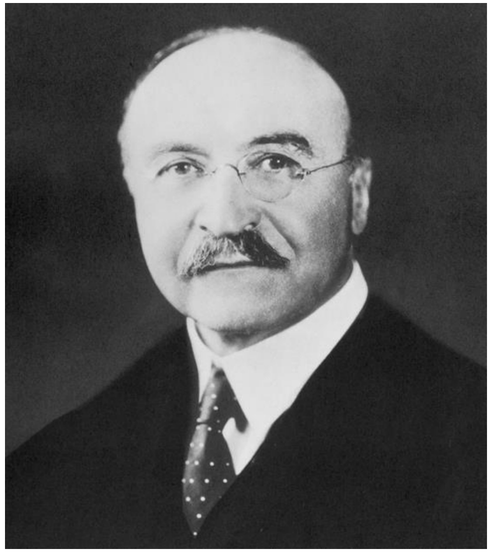
Synthetic polymers are only 117 years old!

- It might sound like a lot, but modern humans lived without it for thousands of years
- So how did we make stuff?
- Natural materials like Shellac!
- But…this is a bit of a pain right?
- What gives these materials such interesting properties?
- Welcome back to the stage: Leo Hendrik Baekeland



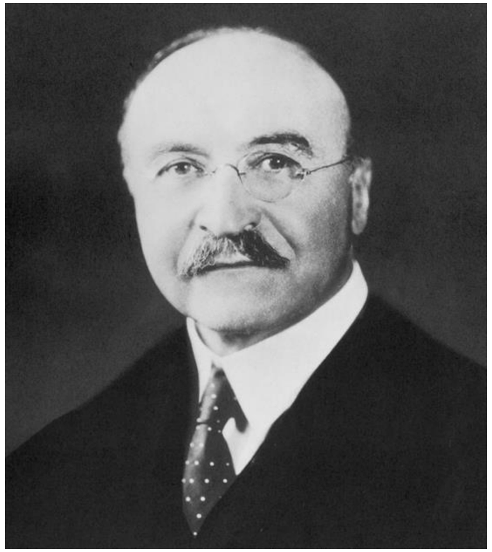
The Beauty of Bakelite

Anybody know what these are?



The Beauty of Bakelite

Ivory Billiards Balls

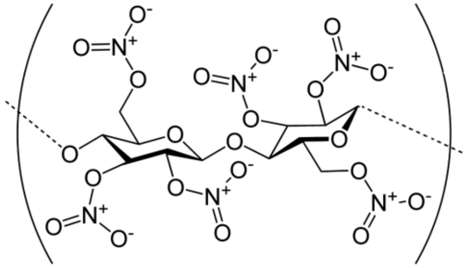


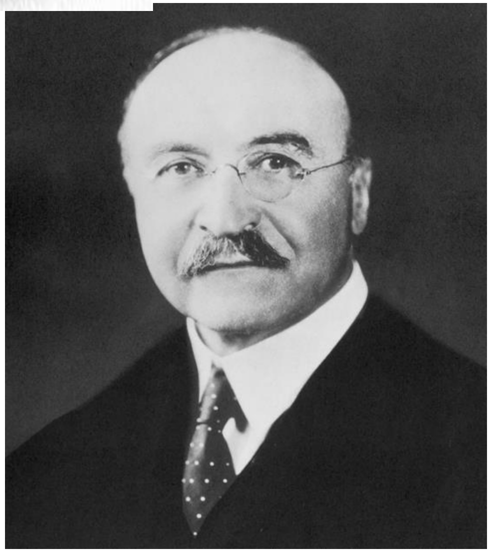
This singular company alone harvested **>1,100 elephants a YEAR** for their ivory
Bakelite may well be the reason that elephants still walk the planet today.

- in 1863, pool table manufacturer Phelan and Collender announced a $10,000 prize to any innovator who could invent a pool ball not made of ivory (nor wood).

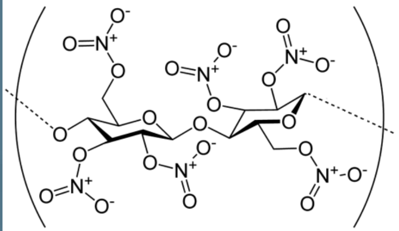
The Beauty of Bakelite

The first substitute (and potential prize winner) was John Wesley Hyatt's invention: Nitrocellulose

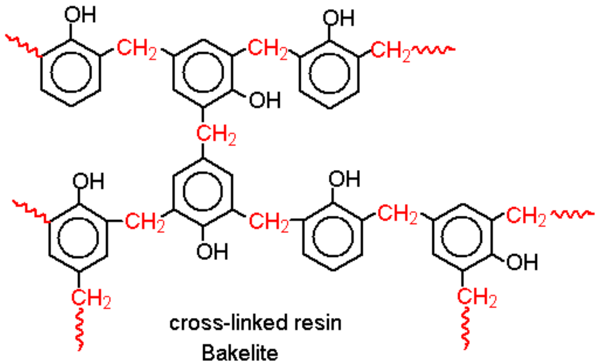




There was just one minor problem...any ideas?



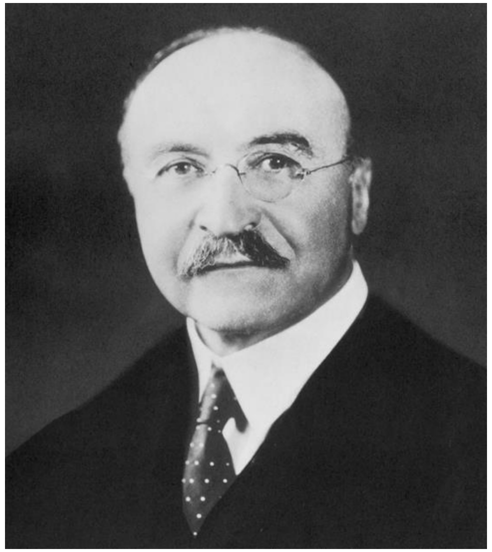
The Beauty of Bakelite



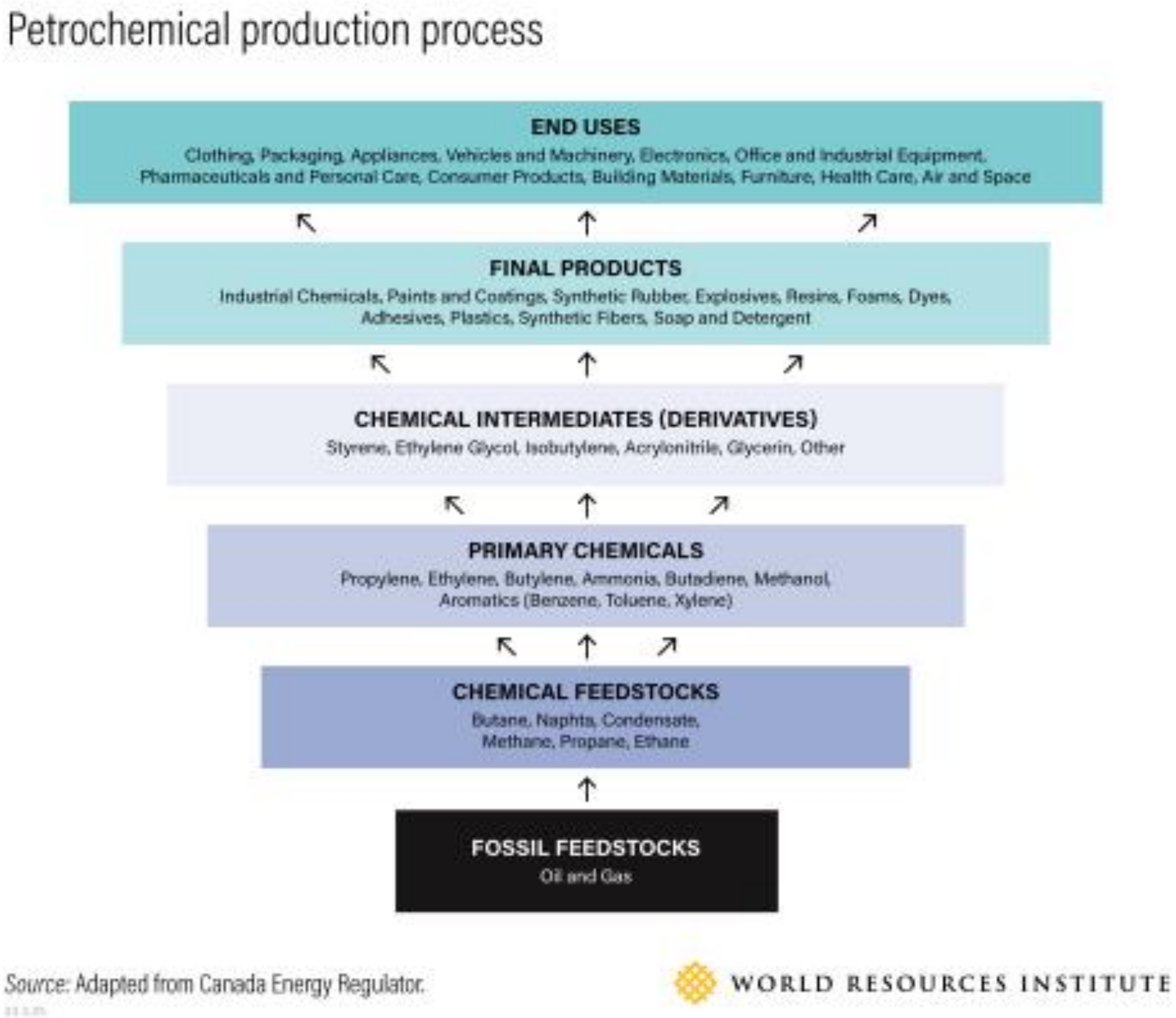
cross-linked resin
Bakelite

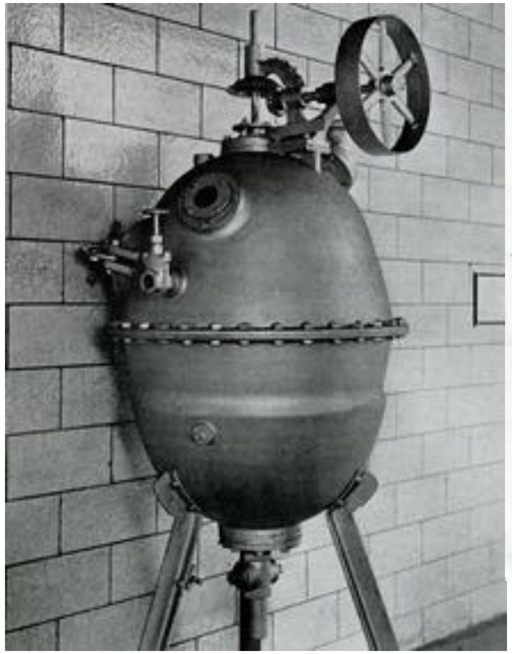
Introducing **Polyoxybenzylmethyleneglycolanhydride** (or Bakelite)

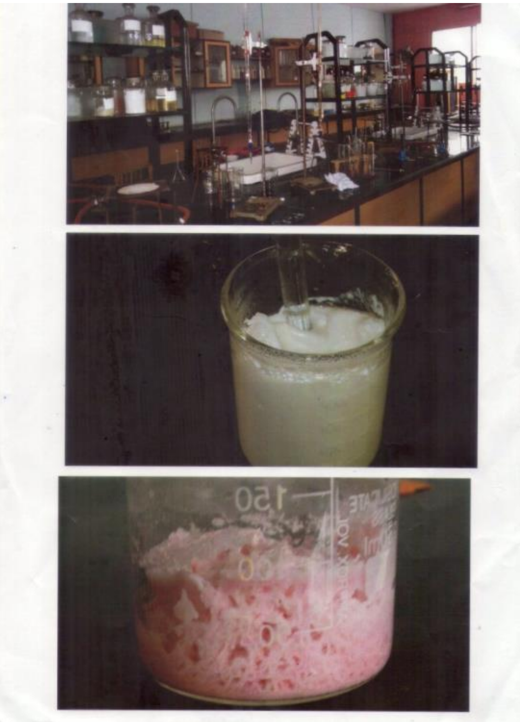
Interestingly, it was an inventor's imagination, not an activist's persuasive arguments, that spared tens of thousands of elephants from becoming pool ball. Go Jumbos!



The Beauty of Bakelite



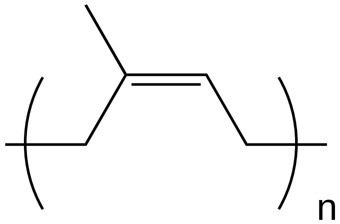




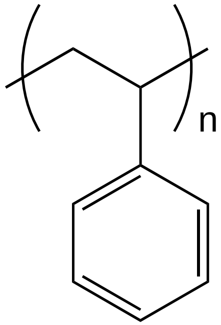
Bakelite: the material of a thousand uses!

- Baekeland invented the first synthetic plastic:
- But what IS a polymer?

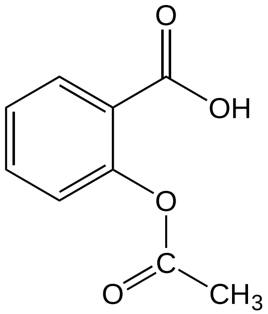
Which is NOT a polymer?



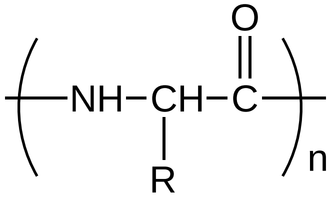
Rubber



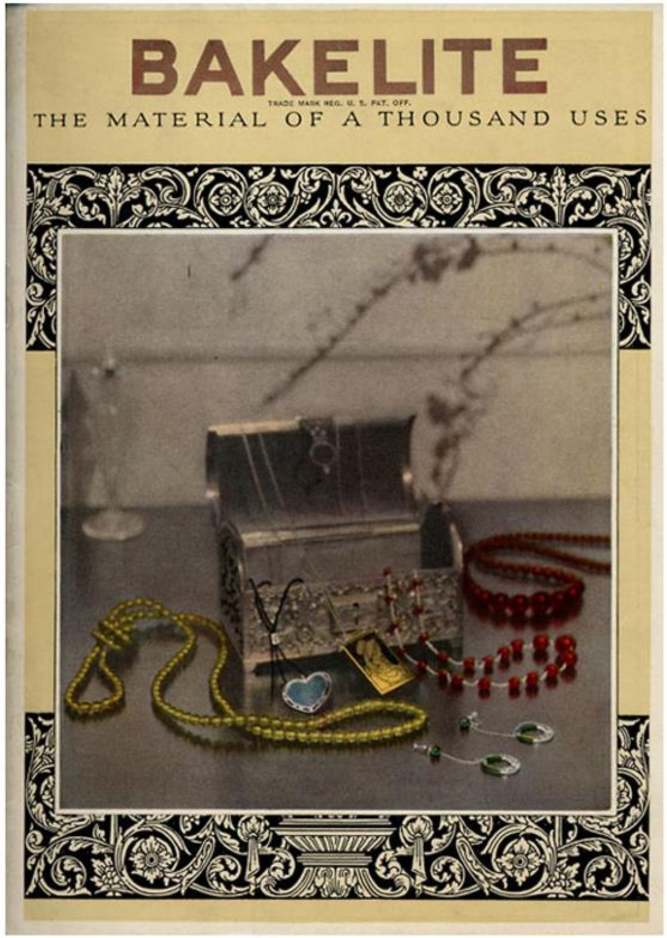
Styrofoam



Aspirin



Polypeptide



Polymers have unique properties due to their structure

- Polymers are extremely versatile materials
- What are some parameters we can tune to change their properties?

Molecular Weight

MW Distribution

Degree of polymerization

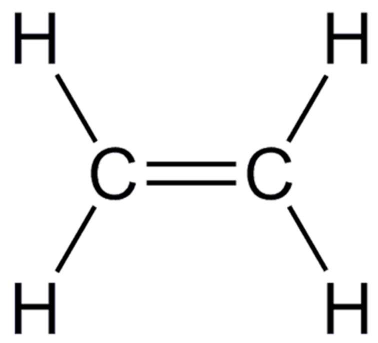
Chemical Structure

Tacticity

Conformation

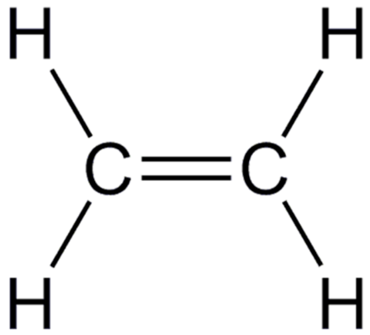
Polymerization method

Molecular weight of polymers



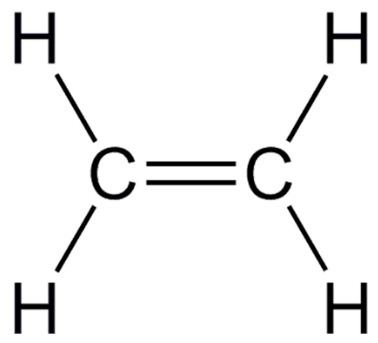
Does anyone know what this molecule is?

Molecular weight of polymers



Does anyone know what this molecule is?
It's ethylene. How do we calculate its molecular weight?

Molecular weight of polymers



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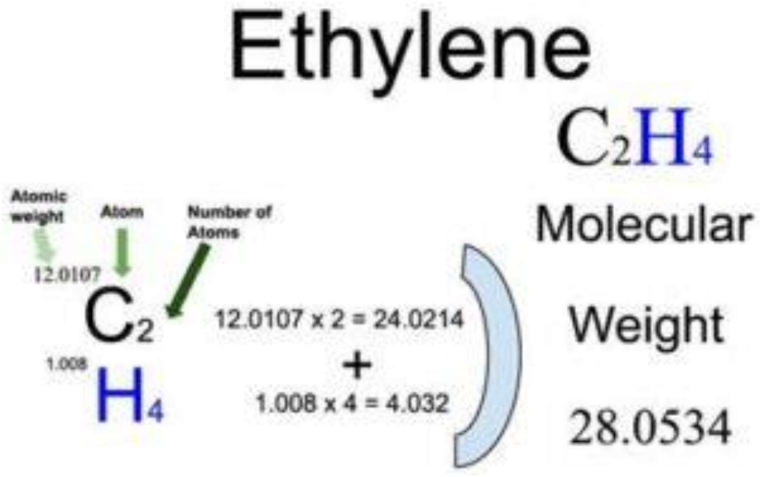
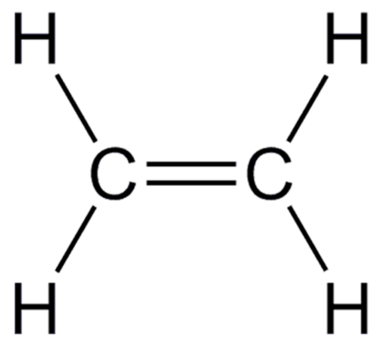
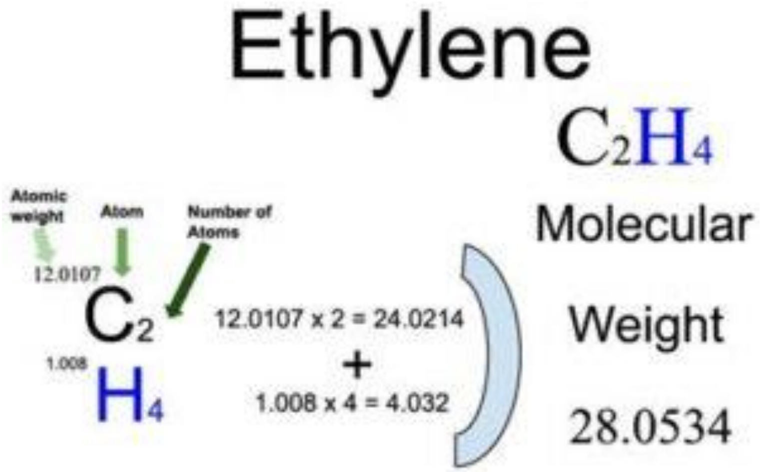
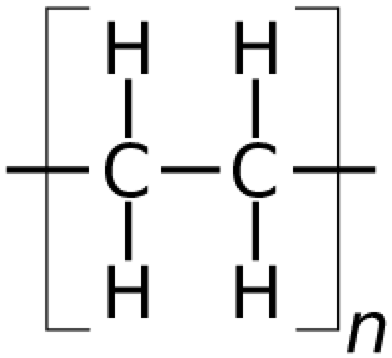


Molecular weight of polymers

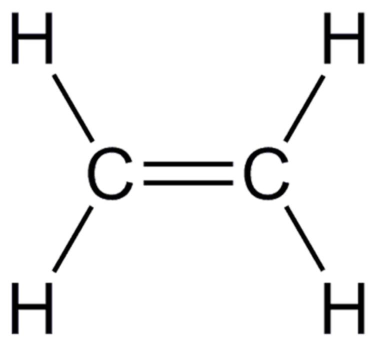


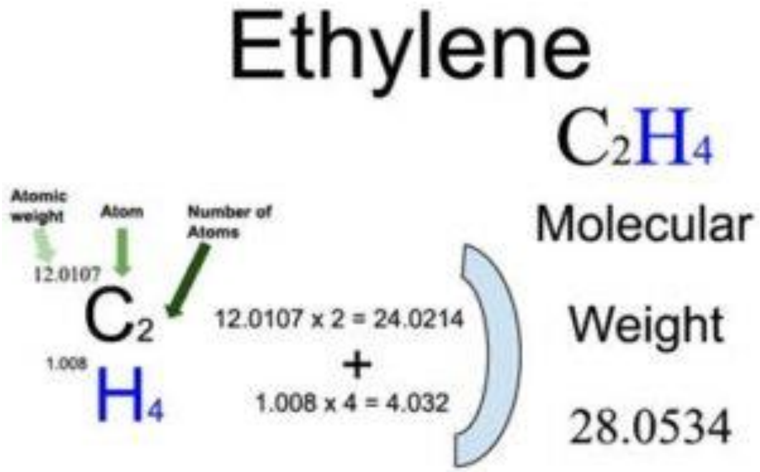


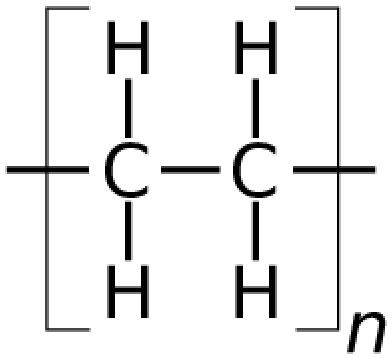


What is this molecule called?

Molecular weight of polymers

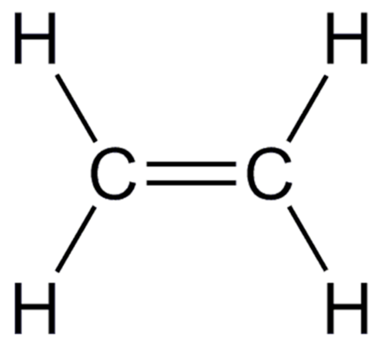


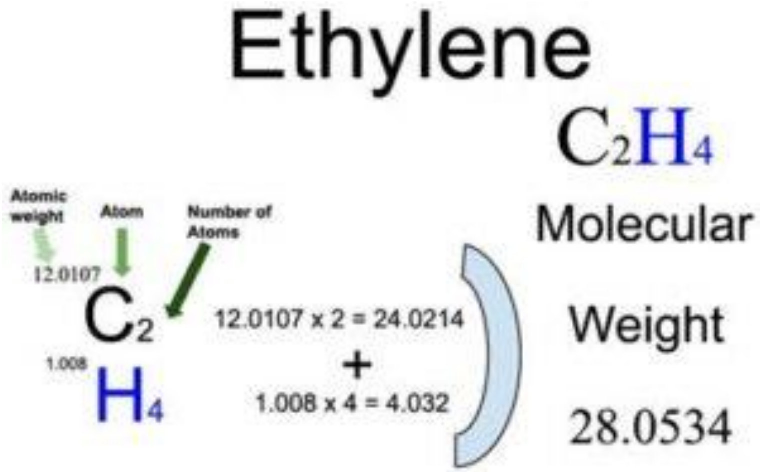


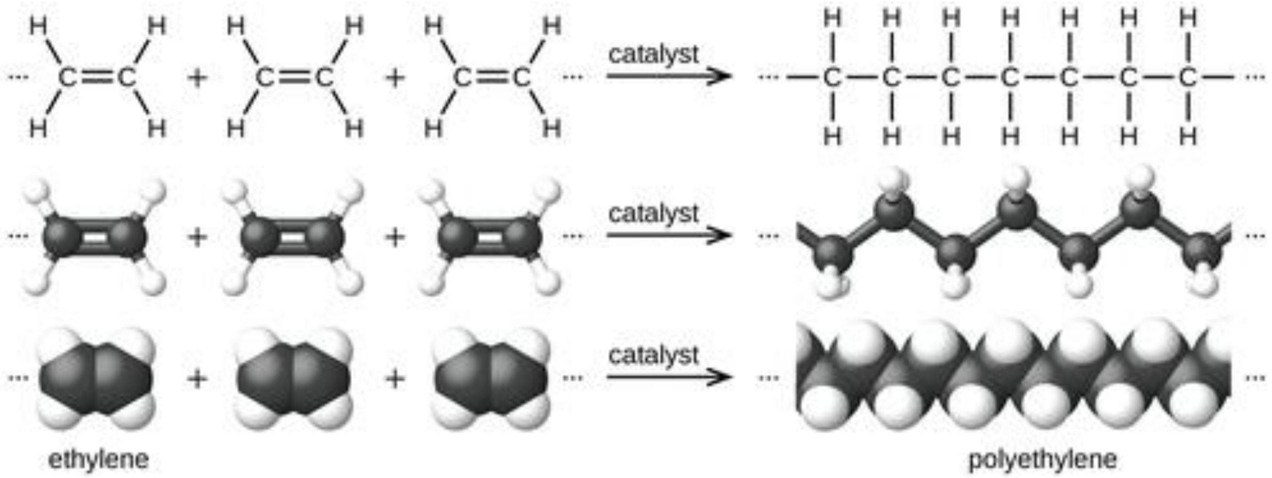


What is this molecule called?
Polyethylene…anyone know why it’s called that?

Molecular weight of polymers

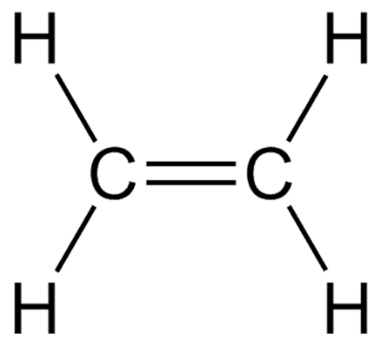


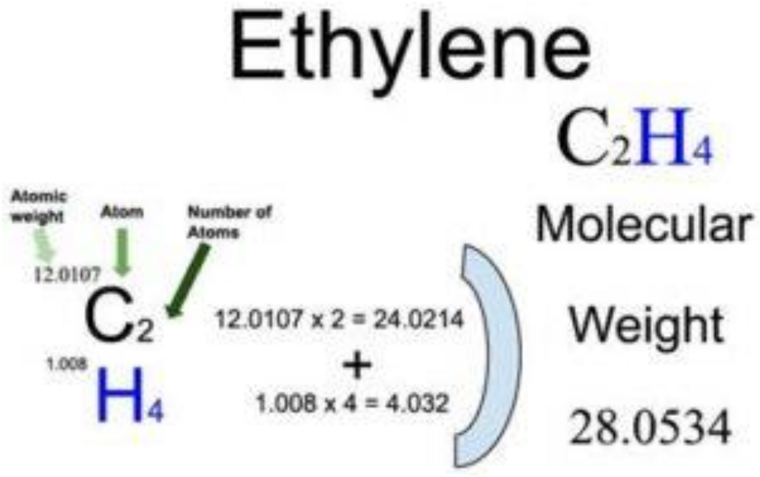


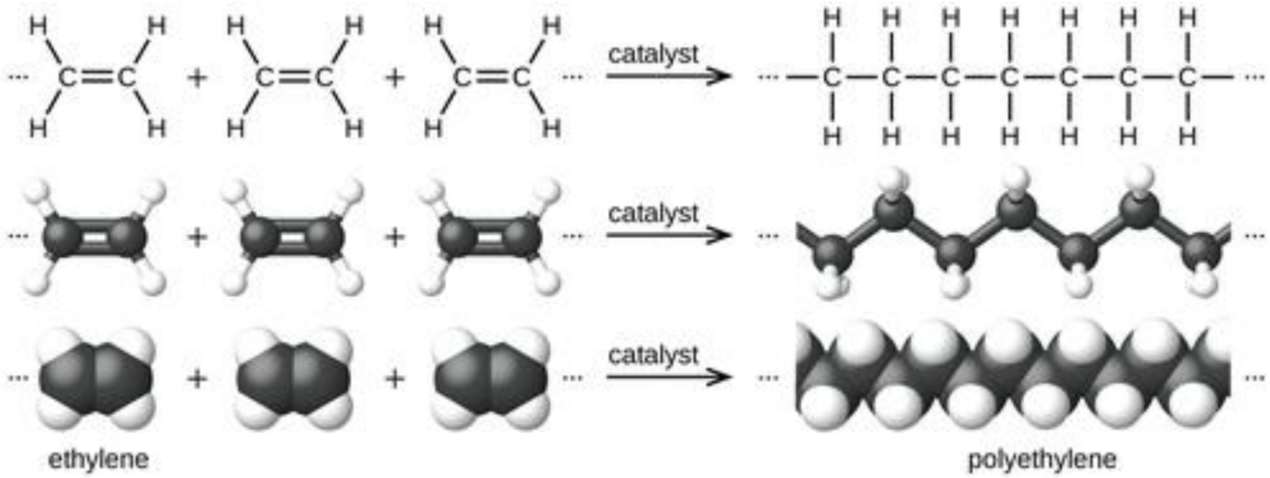


What is the molecular weight of polyethylene?

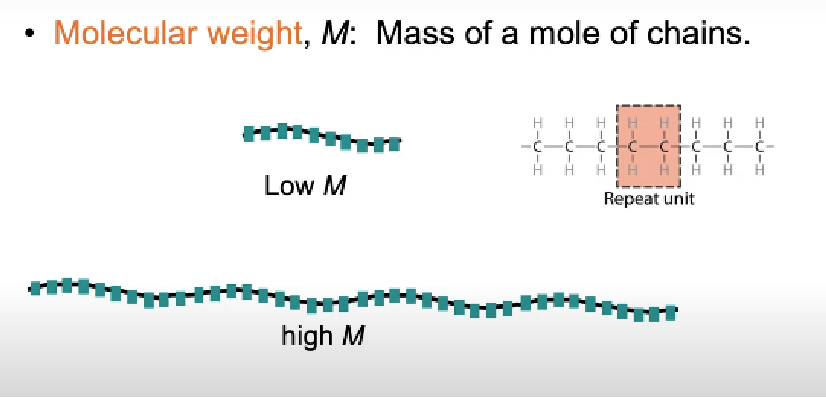
Molecular weight of polymers







What is the molecular weight of polyethylene?
Trick question—I know. The answer is it depends.



Not all chains in a polymer are of the same length: **Molecular weight distribution**

$$M_n = \frac{\sum M_i N_i}{\sum N_i}$$

$$M_w = \frac{\sum M_i^2 N_i}{\sum M_i N_i}$$

$$Đ = \frac{M_w}{M_n}$$

$$Đ = \frac{\sigma^2}{M_n^2} + 1$$

Number average MW

Weight average MW

Dispersity

Think: what number of chains are a certain molecular weight?

Think: what weight of chains are a certain molecular weight?

Gentekos D, Sifri R, Fors B, *Nature Reviews Materials* volume 4, pages 761–774 (2019)

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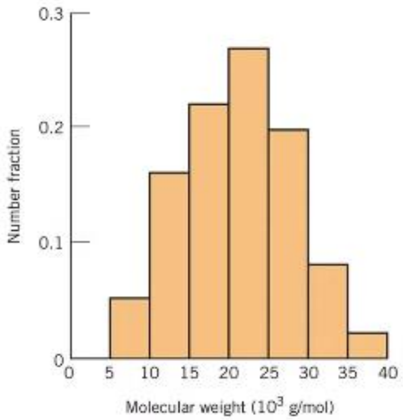
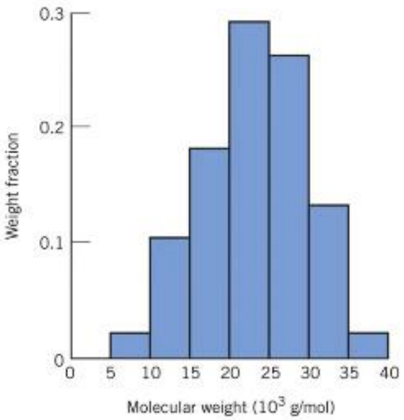
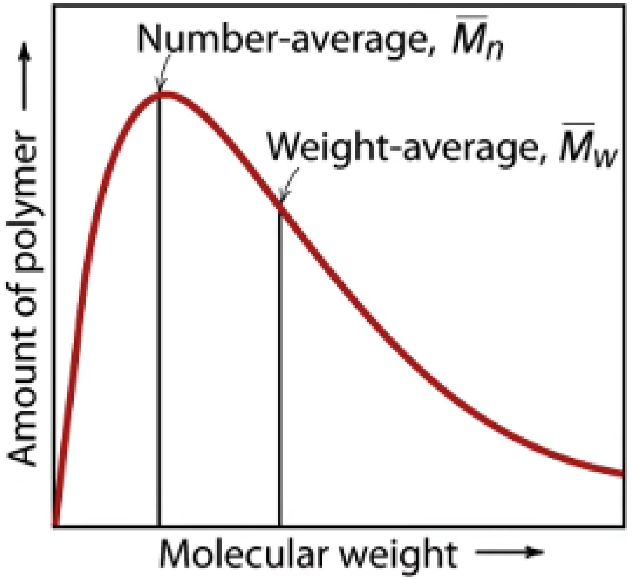
Number average MW | **Weight average MW** | **Dispersity**

Average based on **number fraction** in each molecular weight range



Average based on **weight fraction** in each molecular weight range





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Dispersity

# of chains	MW (kg/mol)
20	10
25	15
20	20
5	50

How would we calculate $\sum N_i$?

Gentekos D, Sifri R, Fors B, *Nature Reviews Materials* volume 4, pages 761–774 (2019)

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$$Đ = \frac{\sigma^2}{M_n^2} + 1$$

Dispersity

	# of chains	MW (kg/mol)
	20	10
	25	15
	20	20
	5	50
total	70	

How would we calculate $\sum M_i N_i$?

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Weight average MW

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$$Đ = \frac{\sigma^2}{M_n^2} + 1$$

Dispersity

	# of chains	MW (kg/mol)	Mi*Ni
	20	10	200
	25	15	375
	20	20	400
	5	50	250
total	70		1225

How would we calculate $\sum M_i^2 N_i$?

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$$Đ = \frac{\sigma^2}{M_n^2} + 1$$

Number average MW

Weight average MW

Dispersity

	# of chains	MW (kg/mol)	Mi*Ni	Mi^2*Ni
	20	10	200	2000
	25	15	375	5625
	20	20	400	8000
	5	50	250	12500
total	70		1225	28125

What is M_n?
What is M_w?
What is Đ?

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Weight average MW

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Dispersity

	# of chains	MW (kg/mol)	Mi*Ni	Mi^2*Ni
	20	10	200	2000
	25	15	375	5625
	20	20	400	8000
	5	50	250	12500
total	70		1225	28125

What is M_n? 17.5 kg/mol
What is M_w? 23 kg/mol
What is Đ? 1.31

Gentekos D, Sifri R, Fors B, *Nature Reviews Materials* volume 4, pages 761–774 (2019)

Polymers have unique properties due to their structure: Molecular weight distribution

$$M_n = \frac{\sum M_i N_i}{\sum N_i}$$

Number average MW

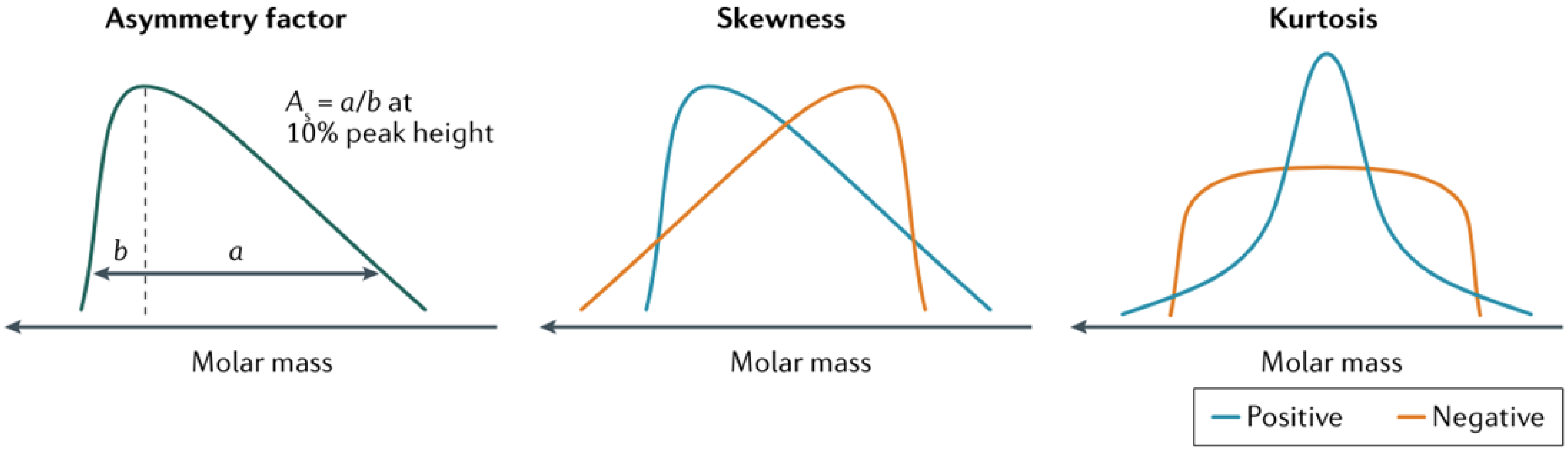
$$M_w = \frac{\sum M_i^2 N_i}{\sum M_i N_i}$$

Weight average MW

$$Đ = \frac{M_w}{M_n}$$

$$Đ = \frac{\sigma^2}{M_n^2} + 1$$

Dispersity



Gentekos D, Sifri R, Fors B, *Nature Reviews Materials* volume 4, pages 761–774 (2019)

Polymers have unique properties due to their structure: Molecular weight

Table III Mechanical Properties of the Annealed Poly(L-Lactide) Specimens

Sample	Ann. PLLA I	Ann. PLLA II	Ann. PLLA III	Ann. PLLA IV
$\bar{M}_v$	20,000	33,500	47,000	71,000
Tensile properties				
Yield strength (MPa)	—	63	68	70
Tensile strength (MPa)	47	54	59	66
Yield elongation (%)	—	1.8	2.2	2.0
Elongation at break (%)	1.3	3.3	3.5	4.0
Modulus of elasticity (MPa)	4100	4100	4050	4150
Flexural properties				
Flexural strength (MPa)	51	83	113	119
Maximum strain (%)	1.6	2.3	4.8	4.6
Modulus of elasticity (MPa)	4200	4000	4150	4150
Impact resistance				
Notched strength (J/m)	32	55	70	66
Unnotched strength (J/m)	180	360	340	350
Heat resistance				
HDT (°C)	66	60	—	61
Vicat penetration (°C)	157	159	163	165
Hardness				
Rockwell hardness (HR)	84	82	84	88

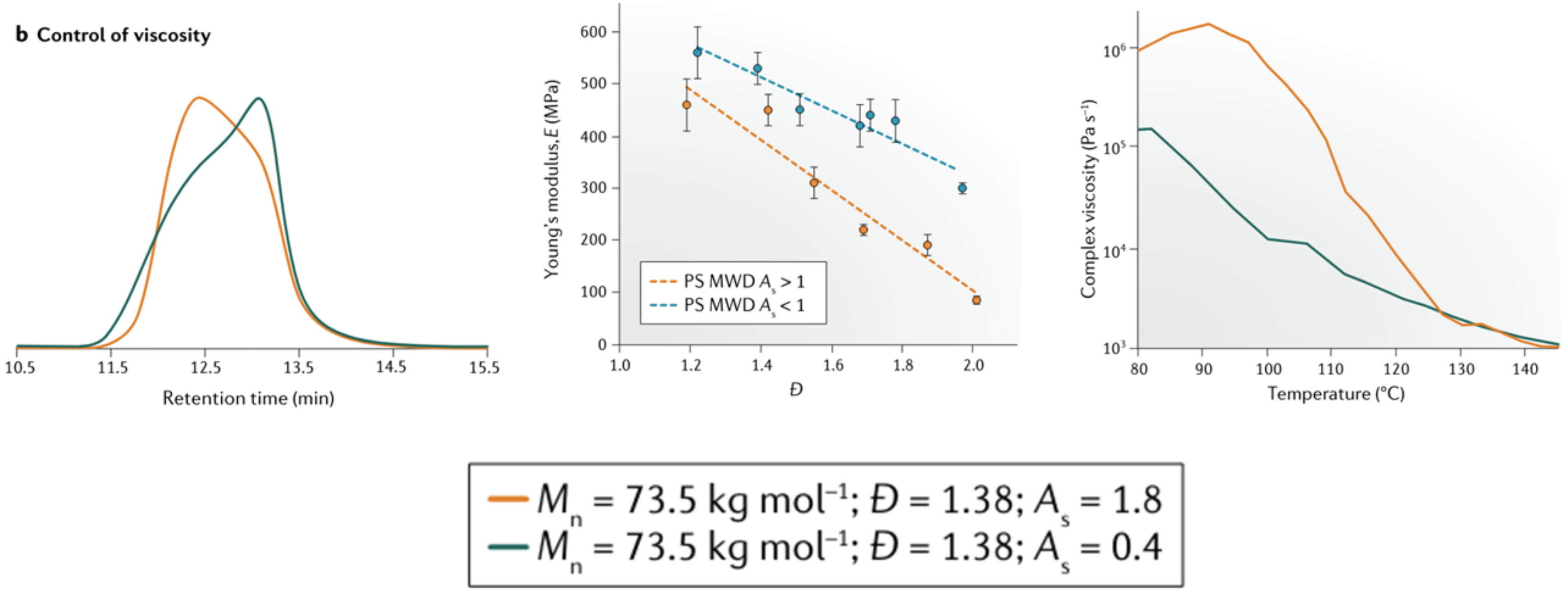
Perego, G., Cella, G.D. and Bastioli, C. (1996), *J. Appl. Polym. Sci.*, 59: 37-43.

Polymers have unique properties due to their structure: Molecular weight distribution

a Control of Young's modulus

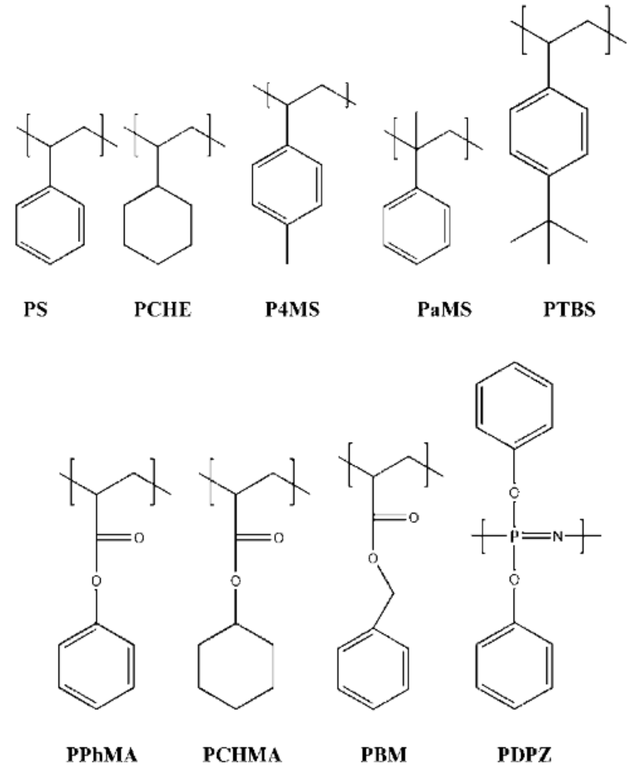
Entry	M_n (S) (kg mol^{-1})	Đ (S)	A_s	M_n (SI) (kg mol^{-1})	Đ (SI)	E (MPa)
1a	14.1	1.19	1.85	35.6	1.14	460
1b	14.2	1.22	0.52	35.1	1.16	560
2a	14.9	1.42	3.52	36.8	1.21	450
2b	14.1	1.39	0.37	33.6	1.22	530
3a	15.2	1.69	4.48	36.3	1.25	220
2b	14.1	1.71	0.31	36.5	1.28	440
3a	14.4	2.01	4.97	37.2	1.28	85
2b	13.8	1.97	0.26	34.4	1.29	300

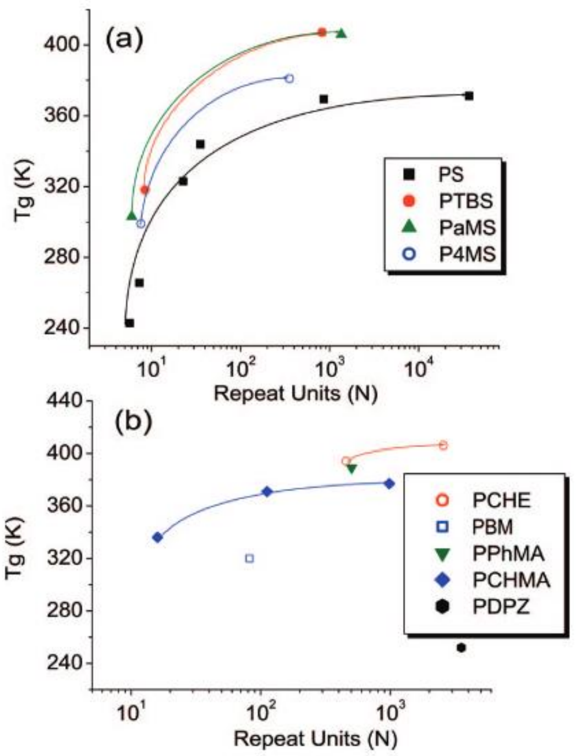
b Control of viscosity

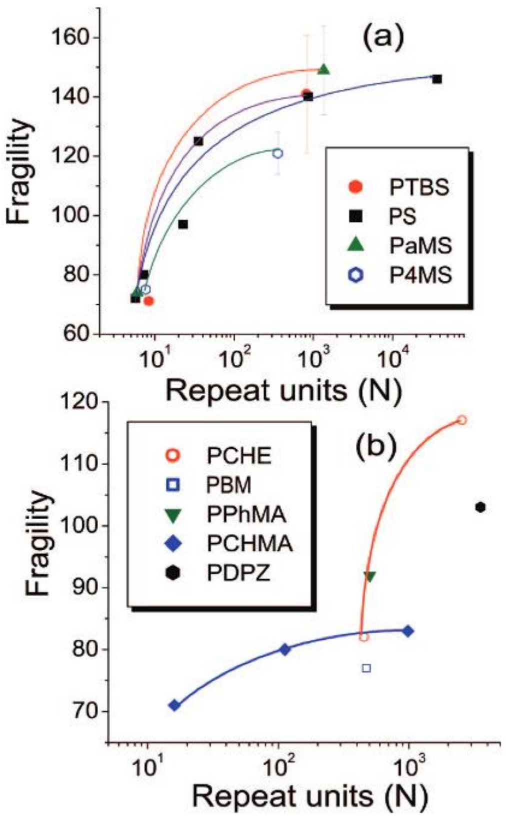


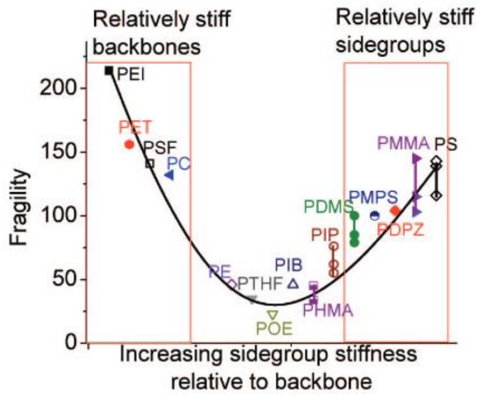
Gentekos D, Sifri R, Fors B, *Nature Reviews Materials* volume 4, pages 761–774 (2019)

Polymers have unique properties due to their structure: chemical structure







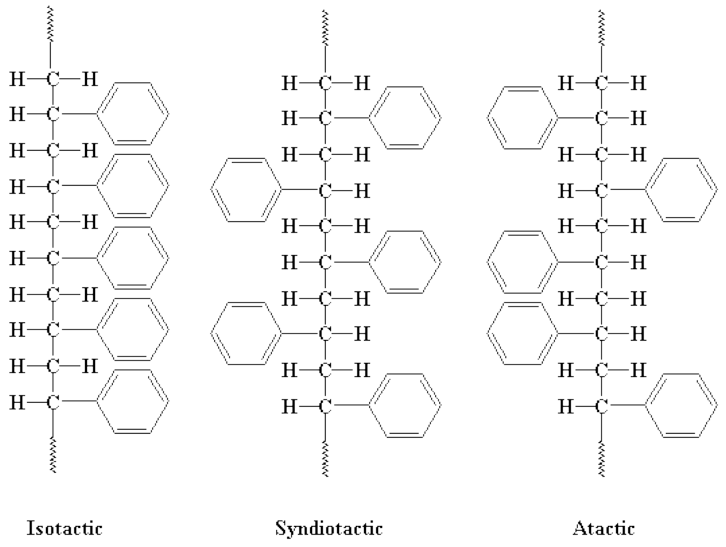


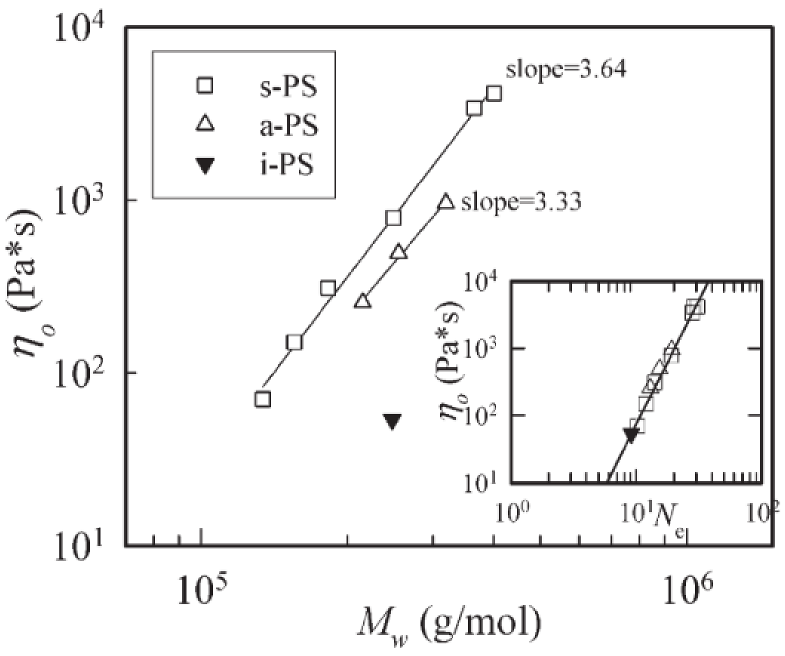
polymer	fragility	T_g (K)
polyoxyethylene (POE)	23[16]	232[16]
polytetrahydrofuran (PTHF)	35[16]	189[16]
polyethylene (PE)	46[16]	237,[16] 231[13]
polyisobutylene (PIB)	46[16]	201,[16] 205,[13] 200[4]
polyhexylmethacrylate (PHMA)	45,[16] 34[16]	280.5[16]
polyisoprene (PIP)	55,[13] 62,[16] 76[16]	199,[13] 200[16]
polydimethylsiloxane (PDMS)	79,[4] 85,[13] 100[16]	143,[13] 146[16]
polymethylpheynylsiloxane (PMPS)	100[16]	243[15]
polymethylmethacrylate (PMMA)	103,[16]115,[17] 145[12]	367,[16] 373[13]
polystyrene (PS)	116 [4]139,[16] 143[17]	375,[16] 373[4]
polycarbonate(PC)	132[16]	423.5,[16] 418[5]
polyethyleneterephthalate (PET)	156[16]	342[16]
polysulfone (PSF)	141[4]	459[4]
polyetherimide (PEI)	214[16]	480.6,[16] 478.5[4]

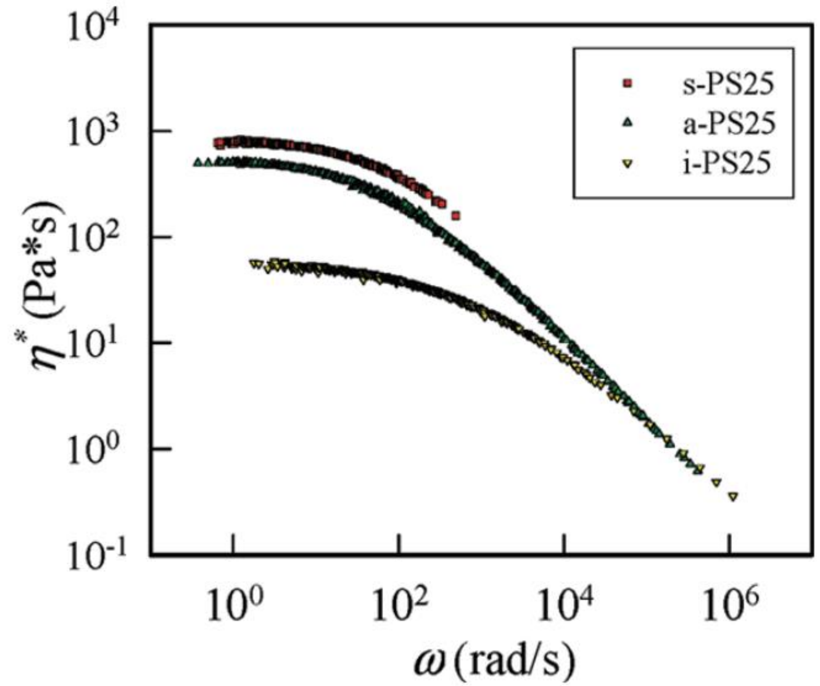
Kunal K, Robertson CG, et al. *Macromolecules* 2008, 41, 19, 7232–7238

Polymers have unique properties due to their structure: tacticity

s-PS: syndiotactic polystyrene
a-PS: atactic polystyrene
i-PS: isotactic polystyrene

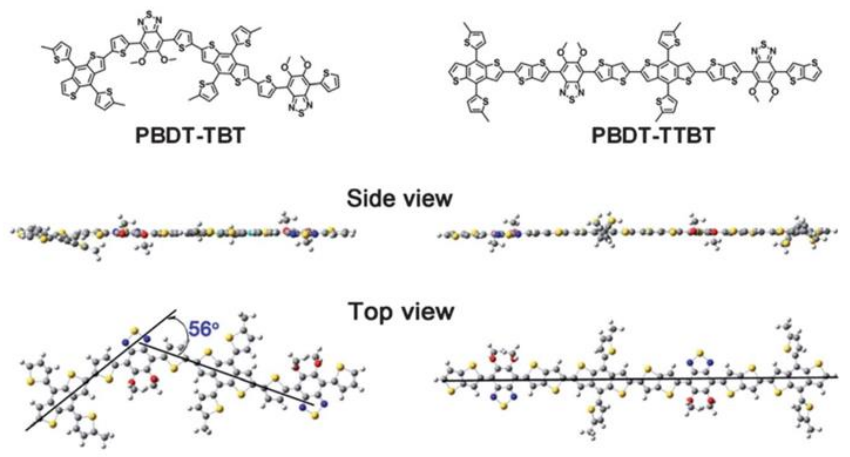


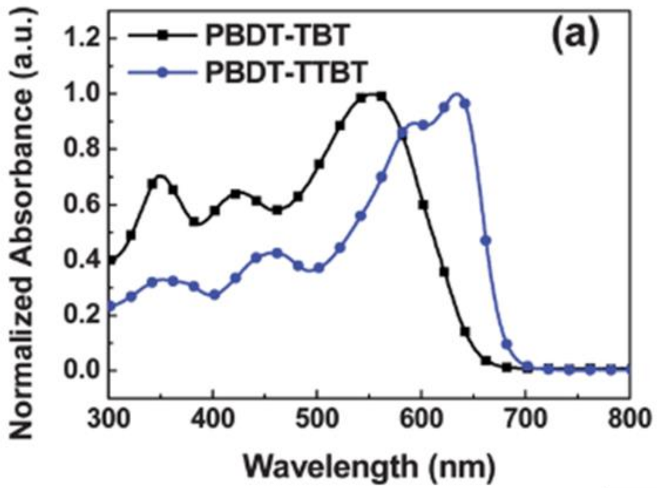


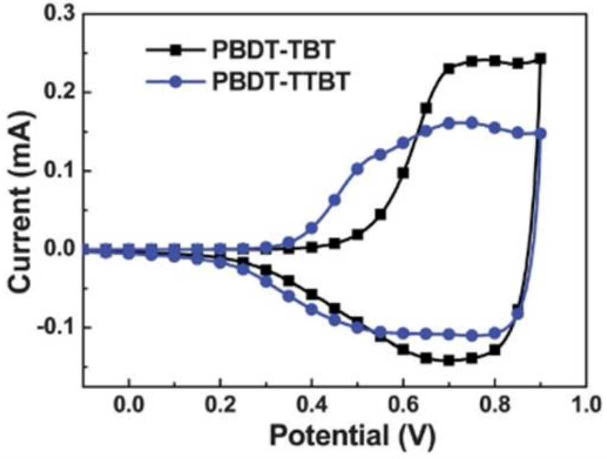


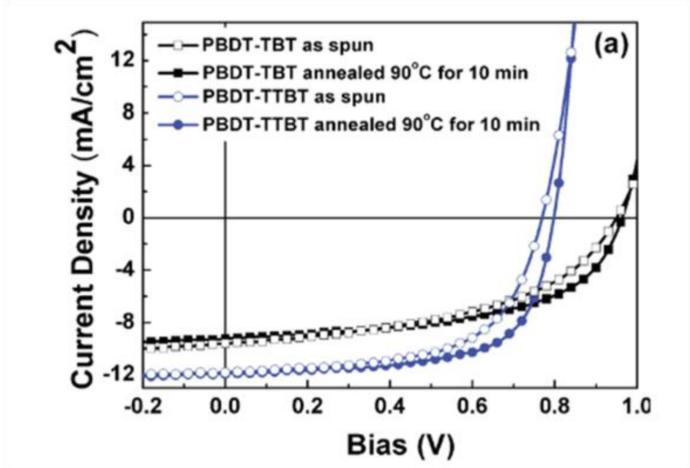
Huang CL, Chen YC, et al. *Macromolecules* 2011, 44, 15, 6155–6161

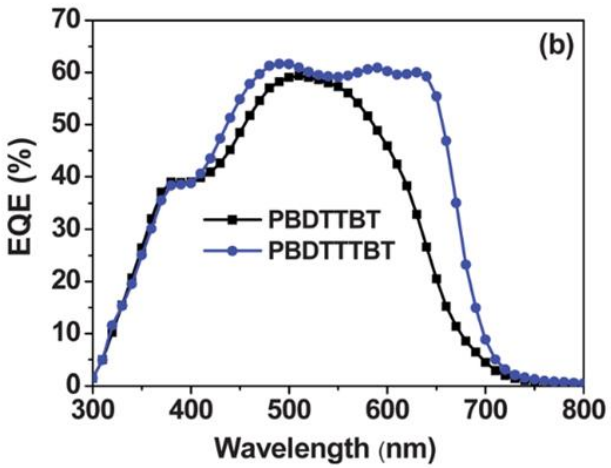
Polymers have unique properties due to their structure: backbone conformation

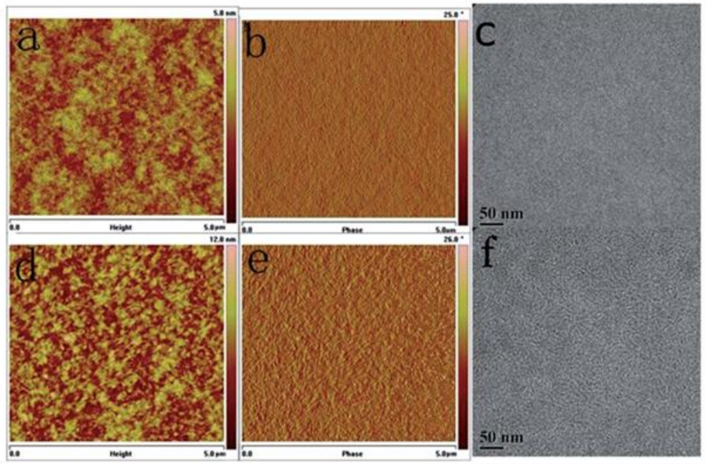






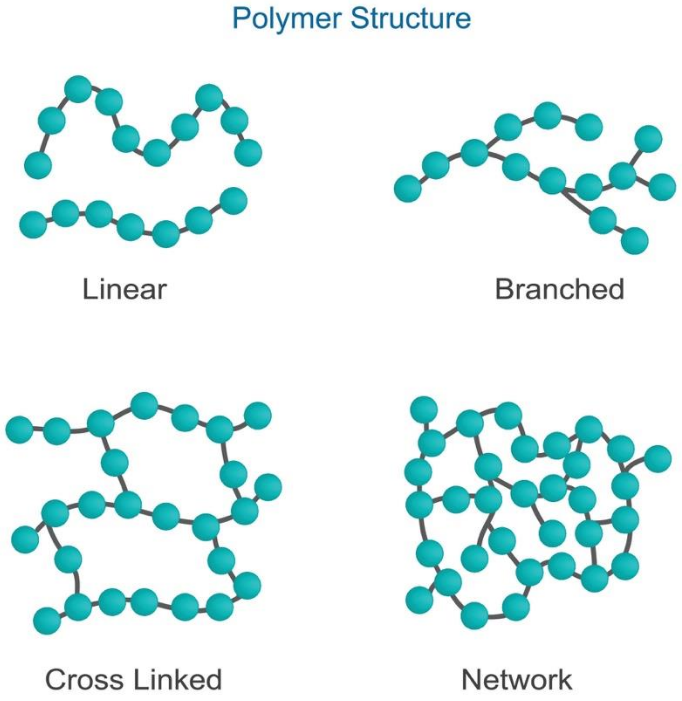






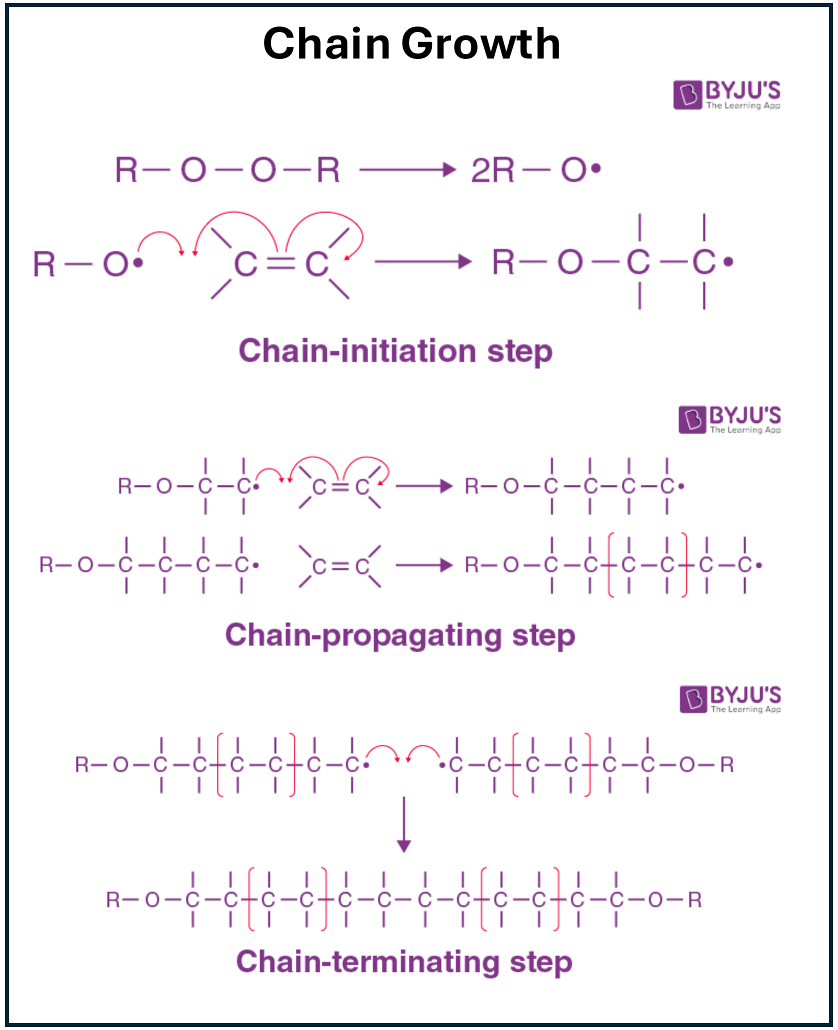
Zou G, Li Z, et al. *Polym. Chem.*, 2014,5, 1976-1981

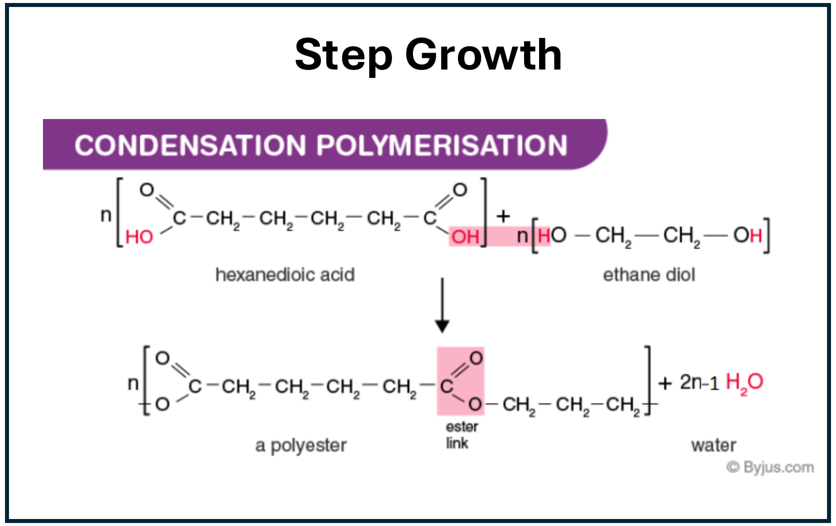
If that wasn't enough knobs to tune…

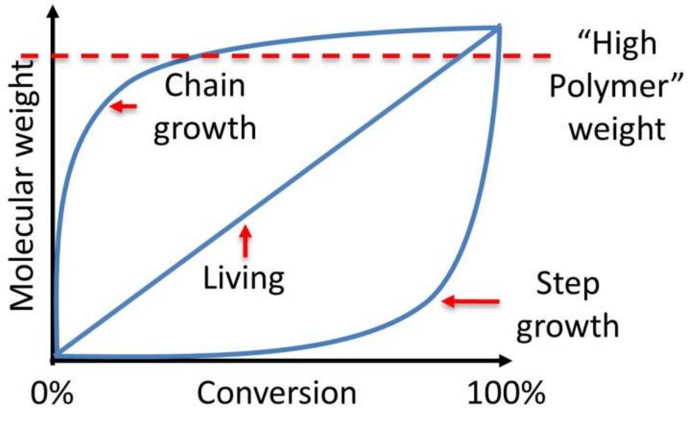


Anybody know the most famous copolymer?

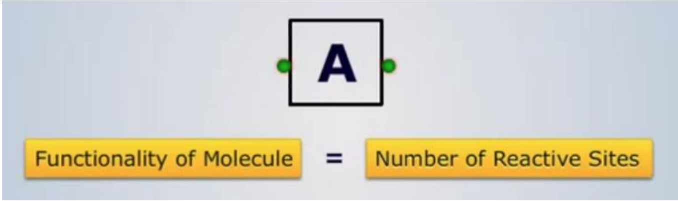
Polymers have unique properties due to their structure: polymerization method

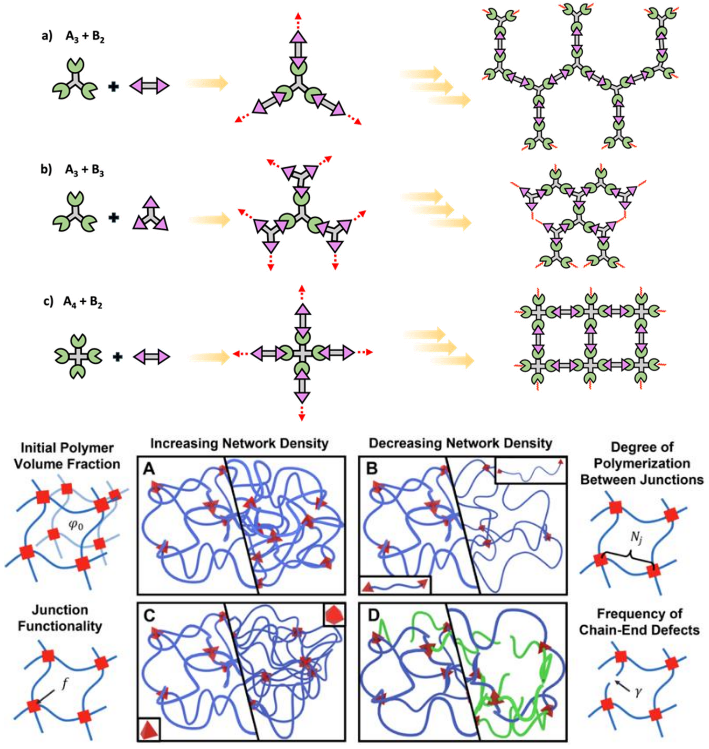






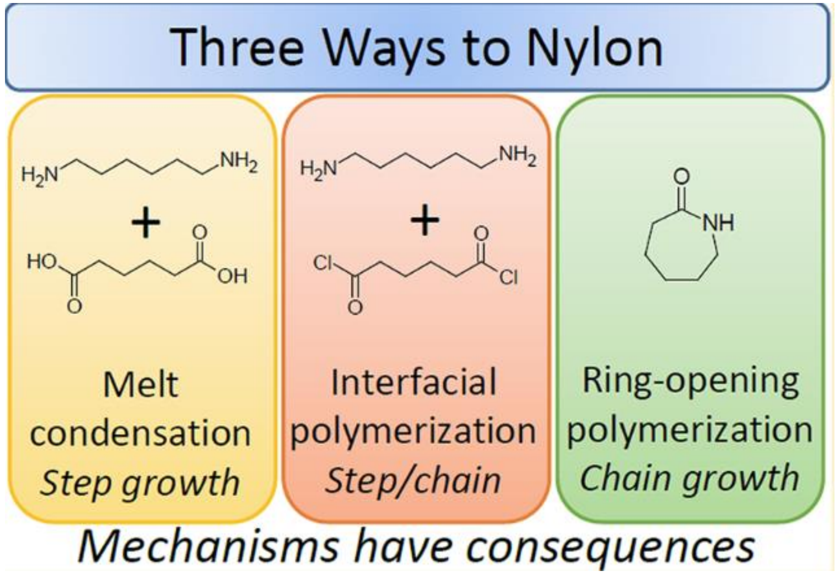
https://hydrogeldesign.org/the-model/

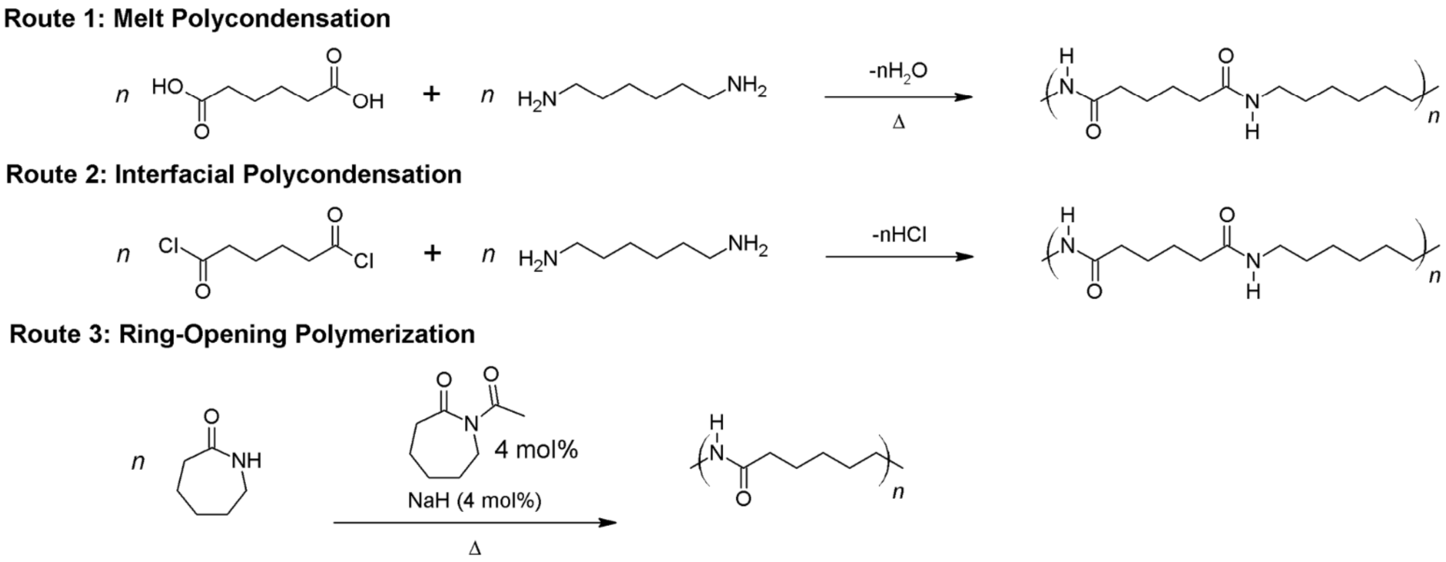


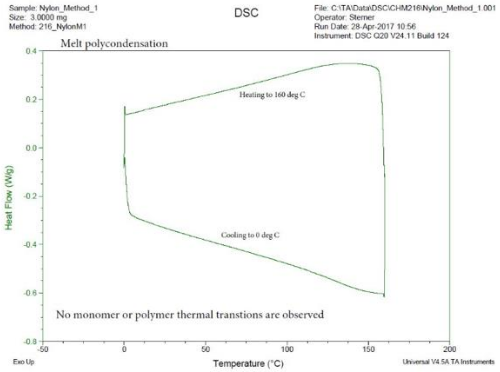


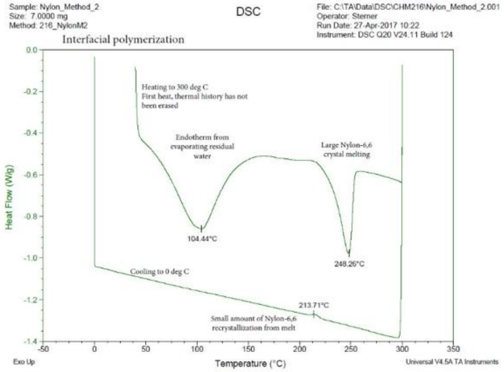
Polym. Chem., 2023, **14**, 4503-4514

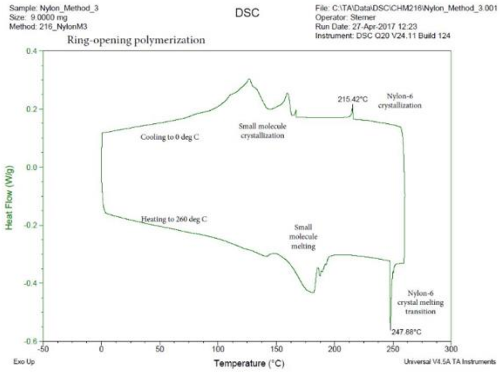
Polymers have unique properties due to their structure: polymerization method







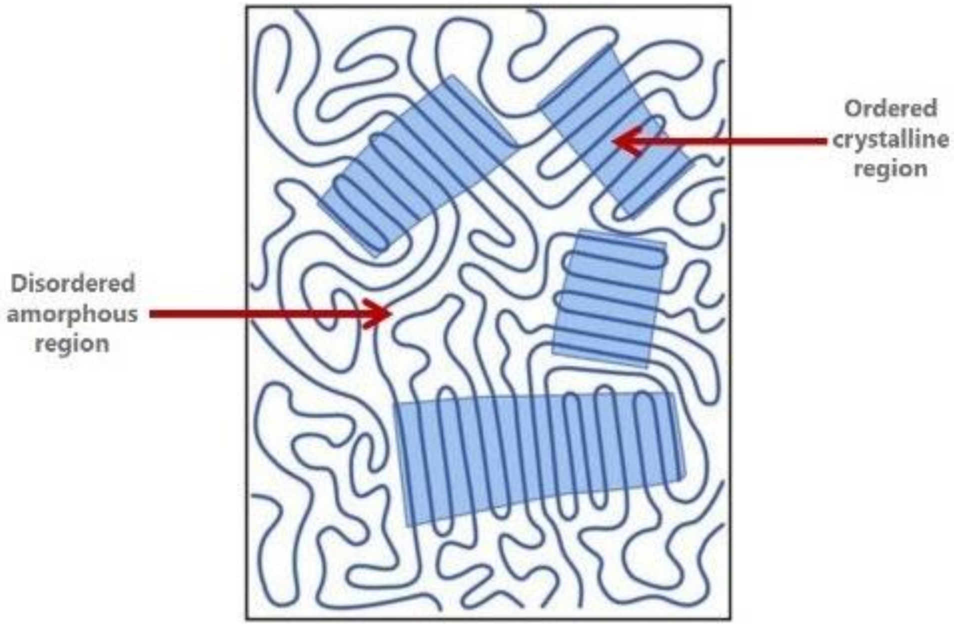




Sterner E, *Journal of Chemical Education* **2019** *96* (9), 2003-2008

Polymer crystallinity may be the MOST important property to consider

Almost no polymer is 100% crystalline and, in fact, most polymers are only around 10-30% crystalline



Methods for measuring polymer crystallinity:

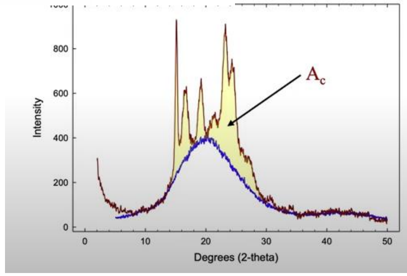
- Density

$$\%C = \frac{\rho_c}{\rho_s}\left(\frac{\rho_s - \rho_a}{\rho_c - \rho_a}\right) \times 100$$

ρ(c) = crystalline density
ρ(a) = amorphous density
ρ(s) = polymer density

- X-ray diffraction

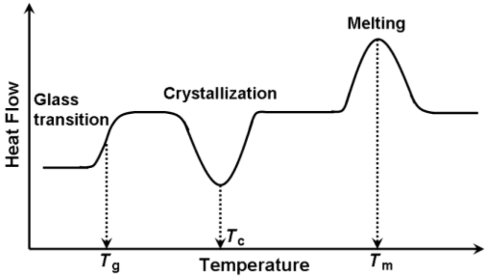
Area under the curve of the crystalline pattern



$$X_c = \frac{A_c}{A_c + A_a}$$

Total area

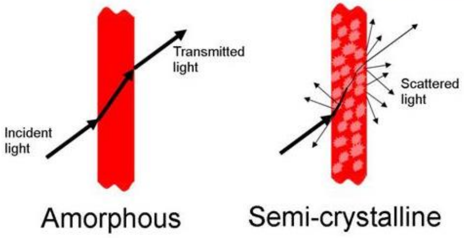
- Thermal transitions



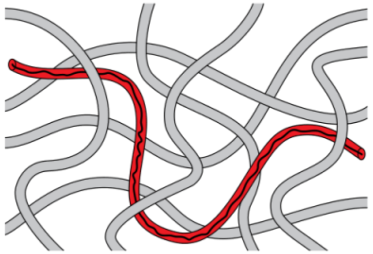
Kaliappan, Senthil Kumar. (2007). Characterization of physical properties of polymers using AFM force-distance curves.

The Impacts of Polymer Crystallinity

- Mechanical properties-the more crystalline the **stronger**, but more **brittle**. The more amorphous the **tougher**
- Thermal properties-the more crystalline the **higher the melting temperature**, the **narrower the melting transition**, and generally the more **thermally stable**
- Optical properties-anyone have a guess?



Bonus question: how do you think polymer molecular weight impacts crystallinity? And why?

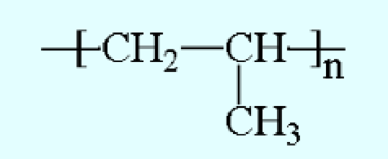


Chain entanglement
Chain mobility
Steric hindrance

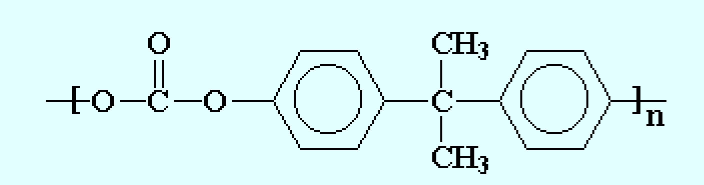
Which are crystalline? Which are amorphous?

Use your intuition! Try to imagine these molecules fitting together, would they be able to densely pack?

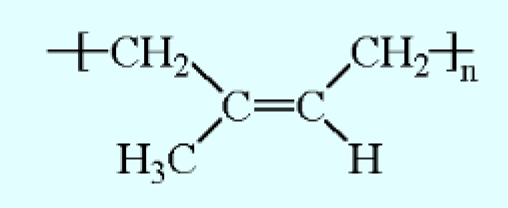
polypropylene



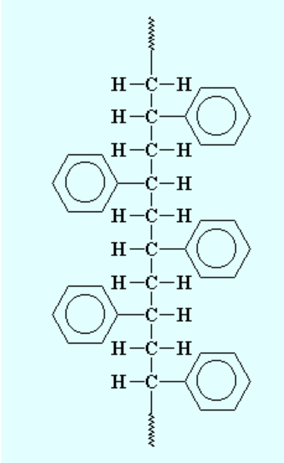
polycarbonate



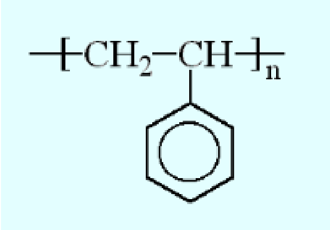
polyisoprene



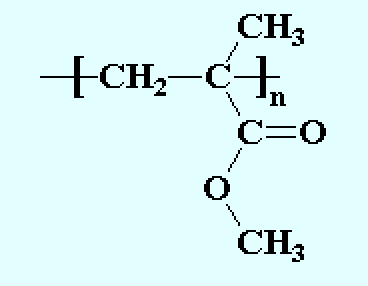
Syndiotactic polystyrene



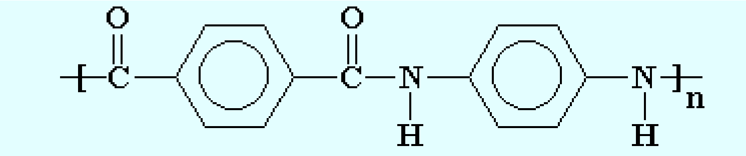
atactic polystyrene



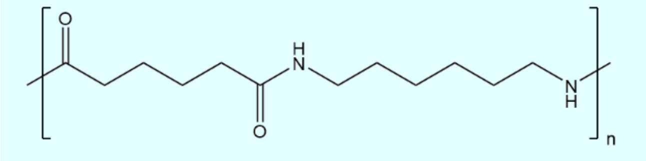
Poly(methyl methacrylate)



Aramids (Kevlar)



Nylon



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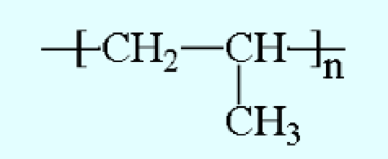
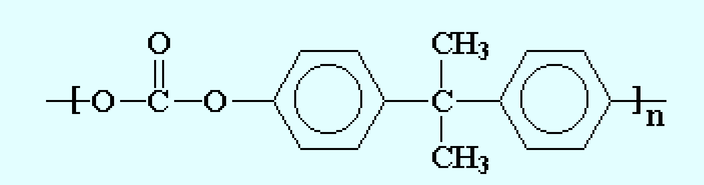
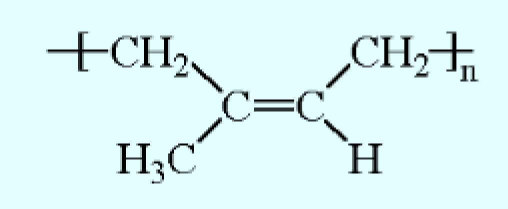
polypropylene



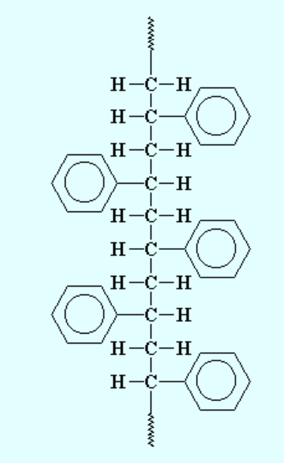
polycarbonate



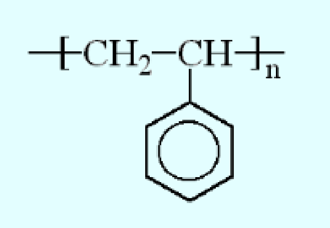
polyisoprene



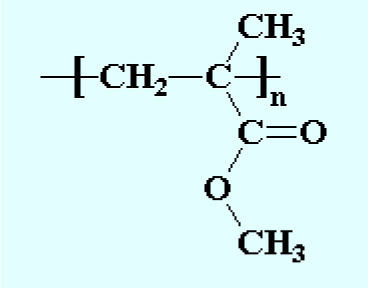
Syndiotactic polystyrene



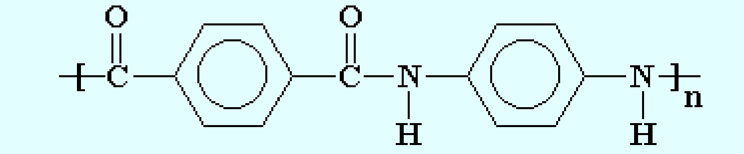
atactic polystyrene



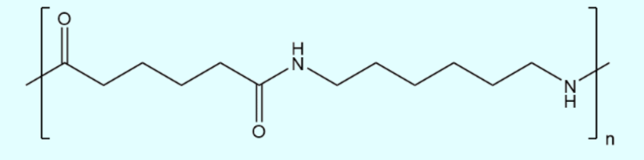
Poly(methyl methacrylate)



Aramids (Kevlar)



Nylon



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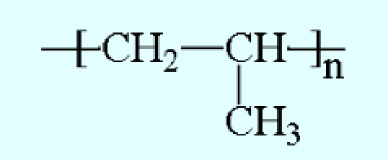
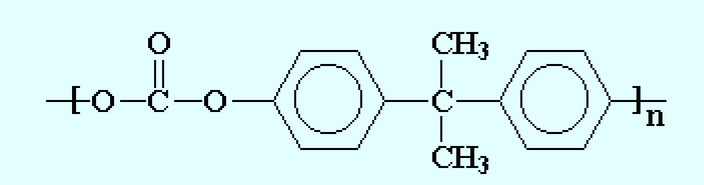
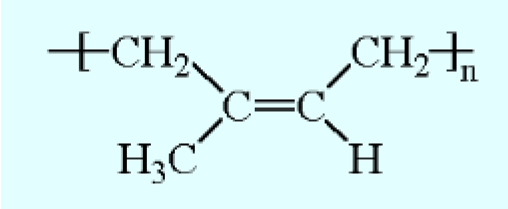
polypropylene



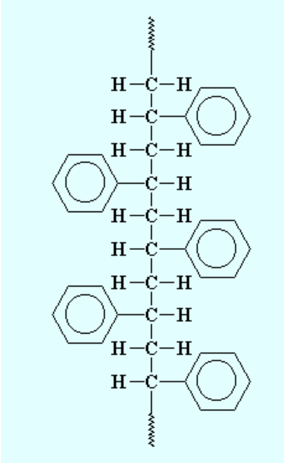
polycarbonate



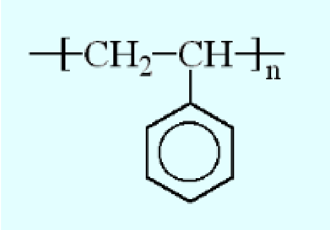
polyisoprene



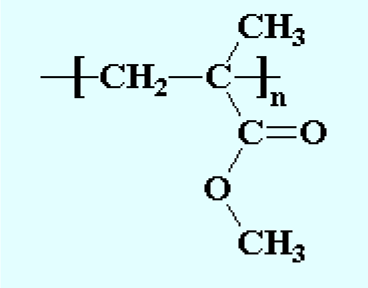
Syndiotactic polystyrene



atactic polystyrene



Poly(methyl methacrylate)



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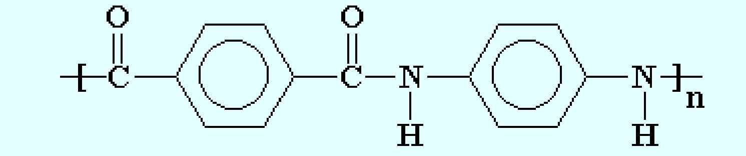
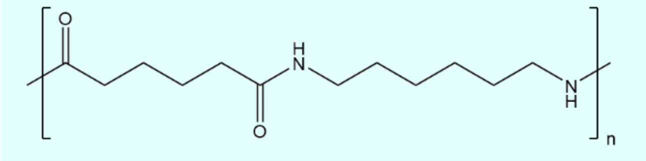


Nylon



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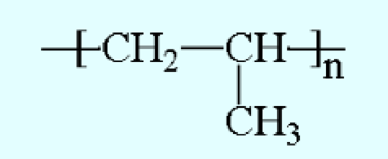
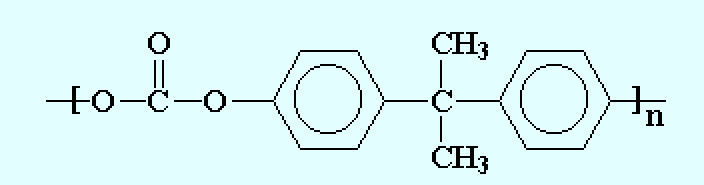
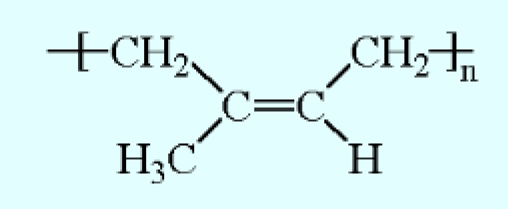
polypropylene



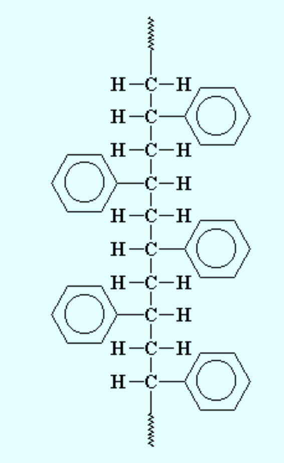
polycarbonate



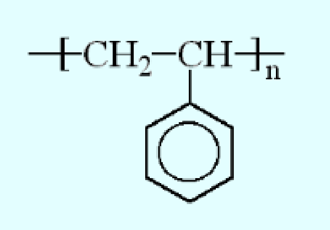
polyisoprene



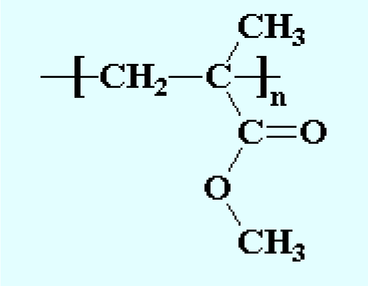
Syndiotactic polystyrene



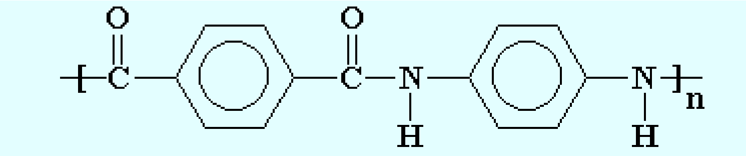
atactic polystyrene



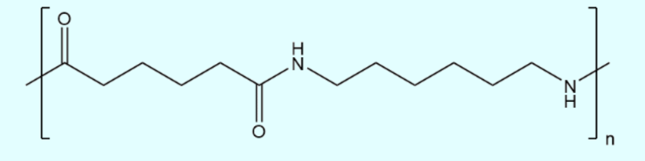
Poly(methyl methacrylate)



Aramids (Kevlar)



Nylon



Which are crystalline? Which are amorphous?

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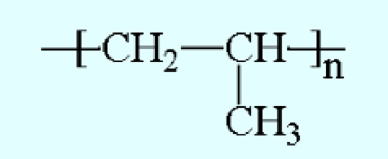
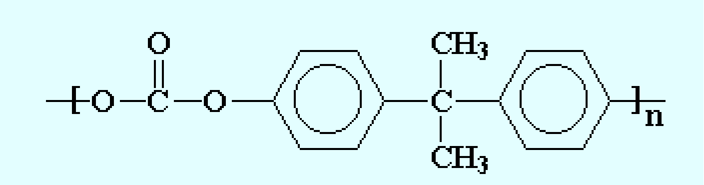
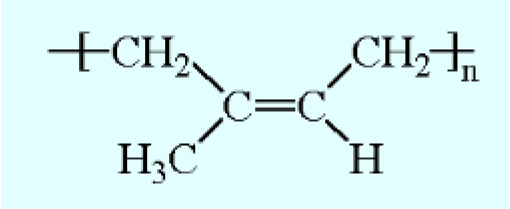
polypropylene



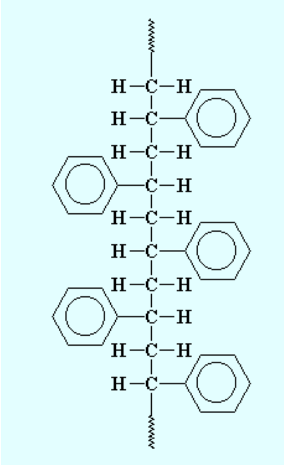
polycarbonate



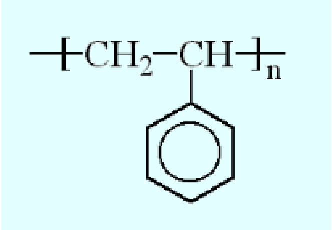
polyisoprene



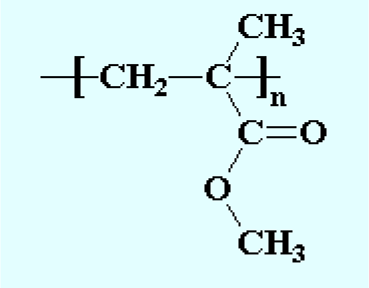
Syndiotactic polystyrene



atactic polystyrene



Poly(methyl methacrylate)



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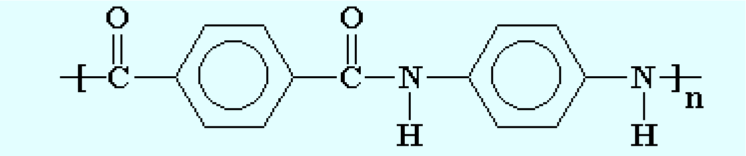

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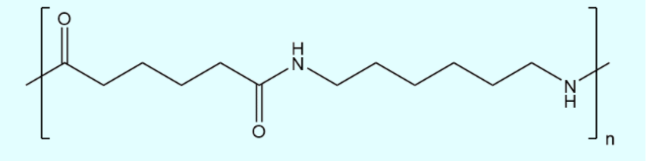

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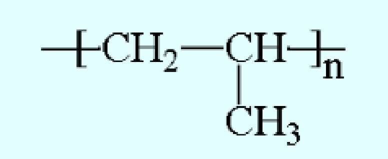
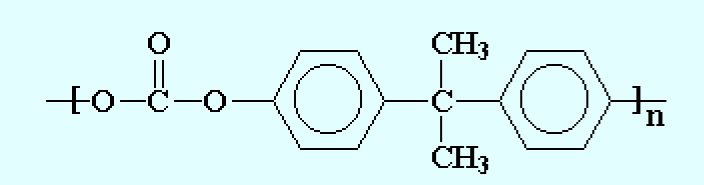
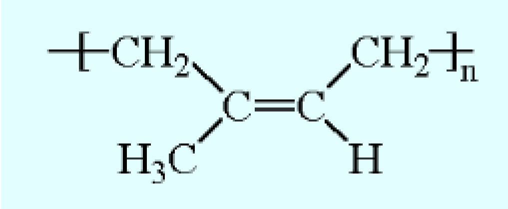


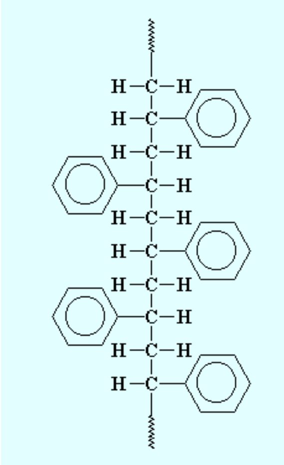
polycarbonate



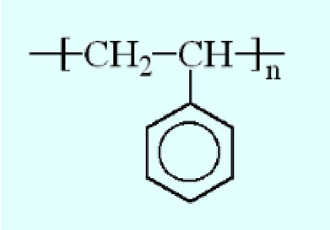
polyisoprene



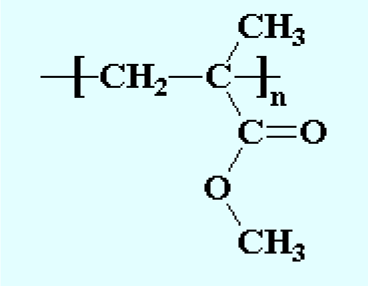
Syndiotactic polystyrene



atactic polystyrene



Poly(methyl methacrylate)



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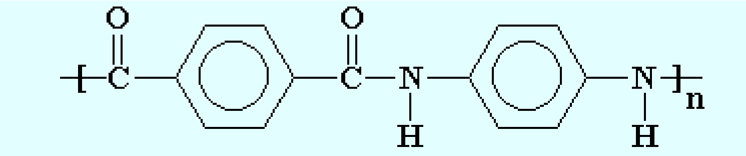
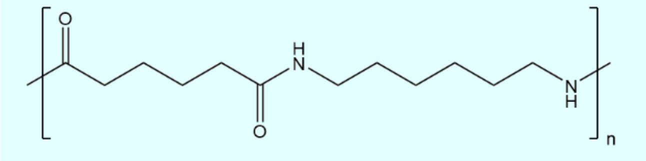


Nylon



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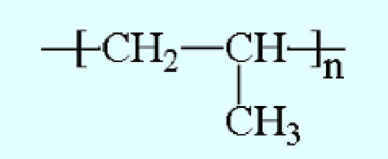
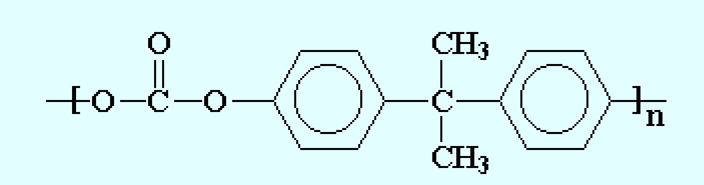
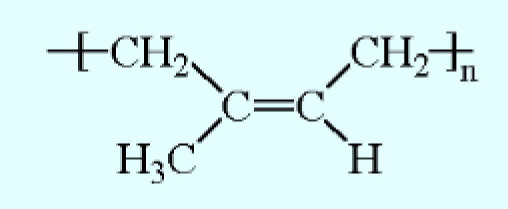


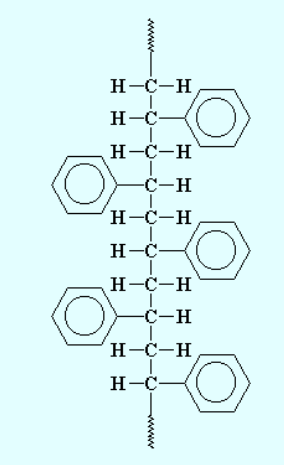
polycarbonate



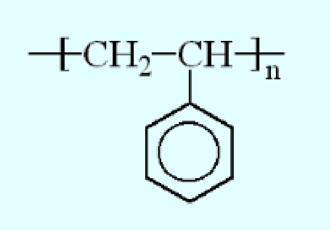
polyisoprene



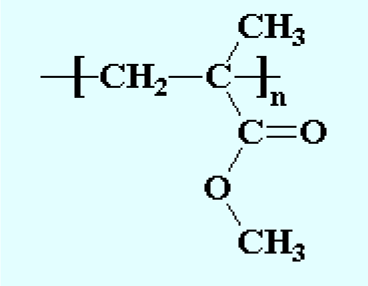
Syndiotactic polystyrene



atactic polystyrene



Poly(methyl methacrylate)



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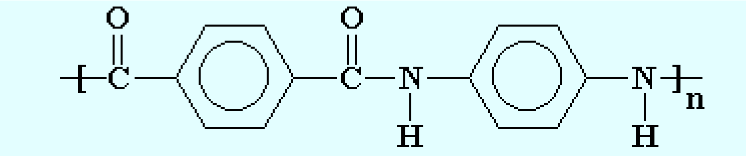
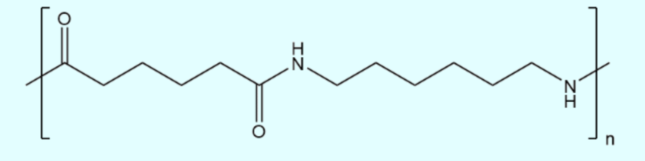


Nylon



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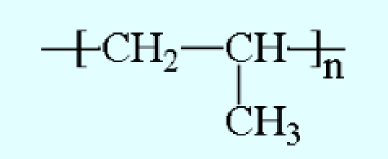
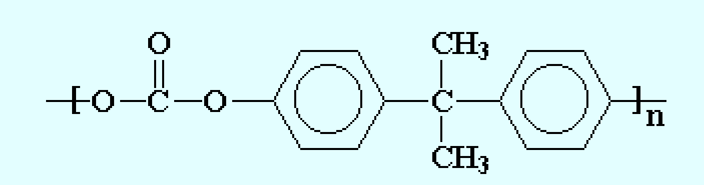
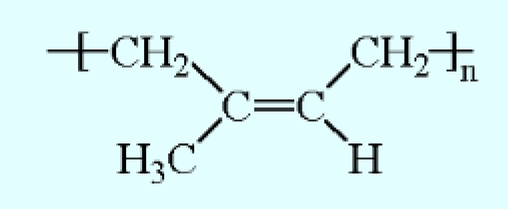


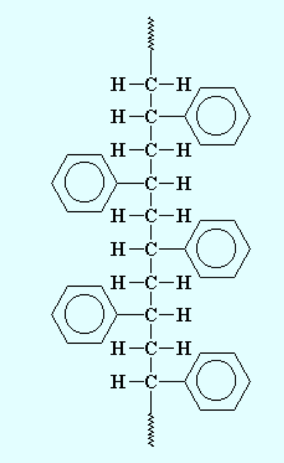
polycarbonate



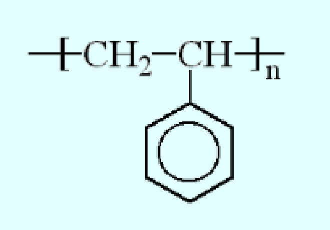
polyisoprene



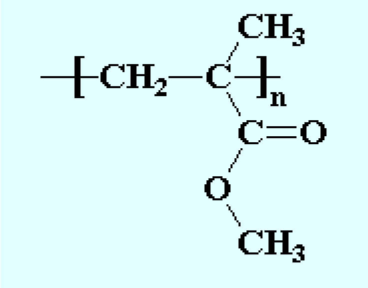
Syndiotactic polystyrene



atactic polystyrene



Poly(methyl methacrylate)



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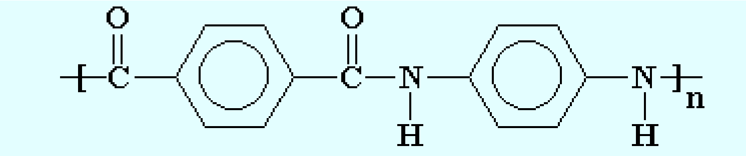
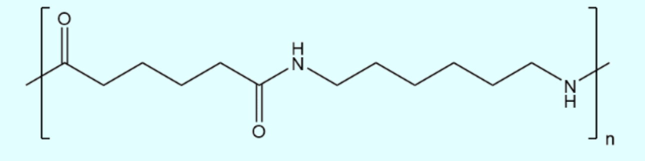


Nylon



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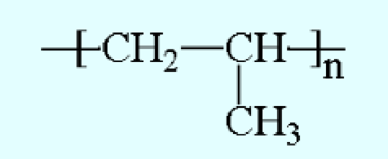
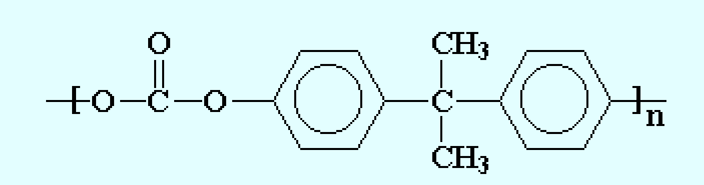
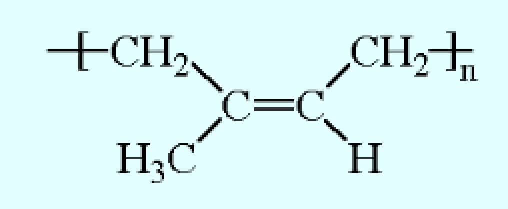


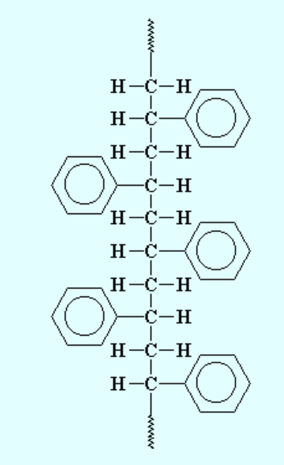
polycarbonate



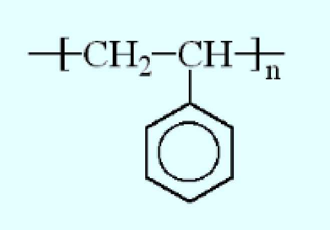
polyisoprene



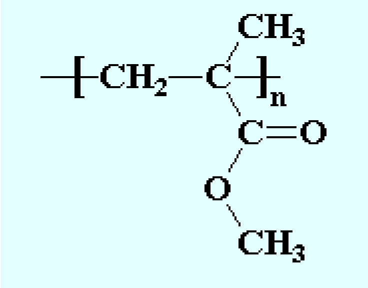
Syndiotactic polystyrene



atactic polystyrene



Poly(methyl methacrylate)



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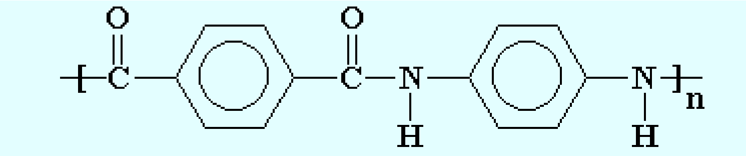
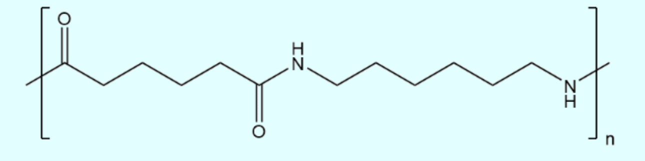


Nylon



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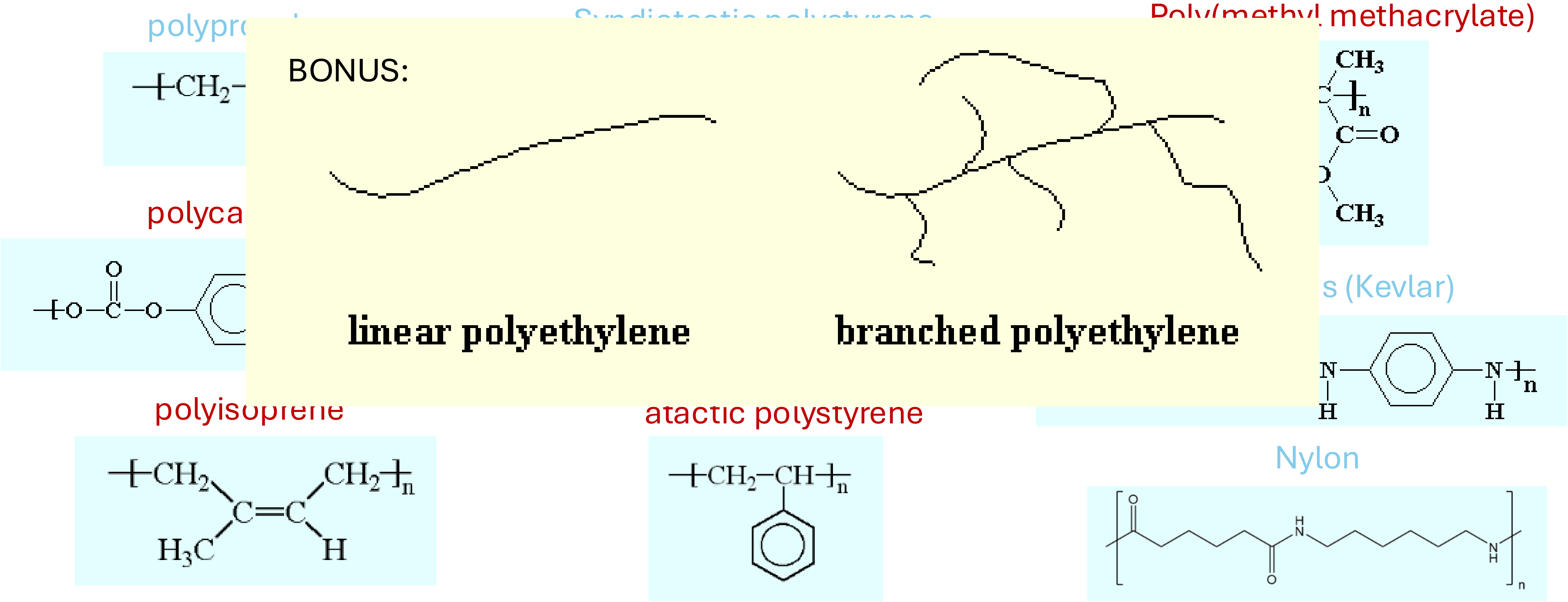
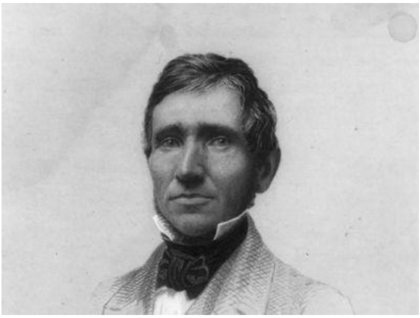


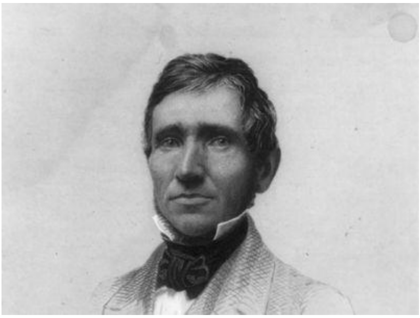
The history of vulcanization



Charles Goodyear

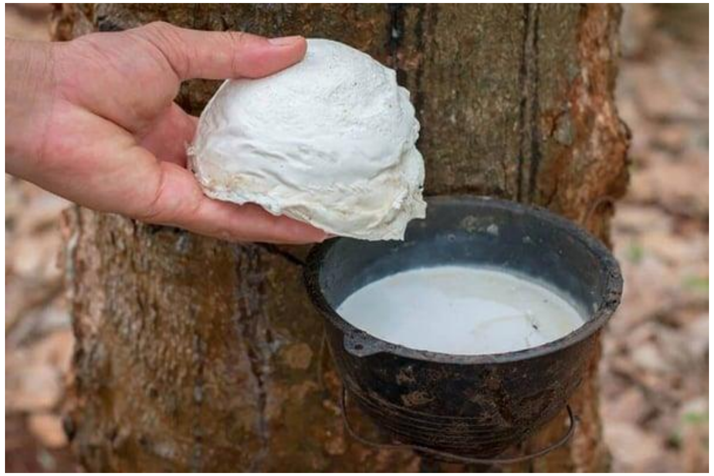
Anybody recognize that name?

The history of vulcanization



Charles Goodyear

What is natural rubber? Anyone know?



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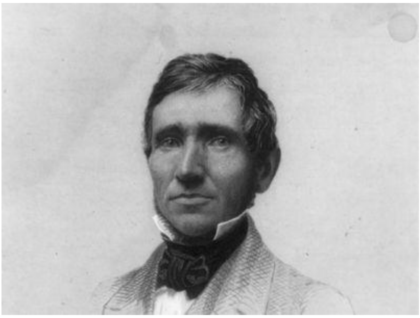

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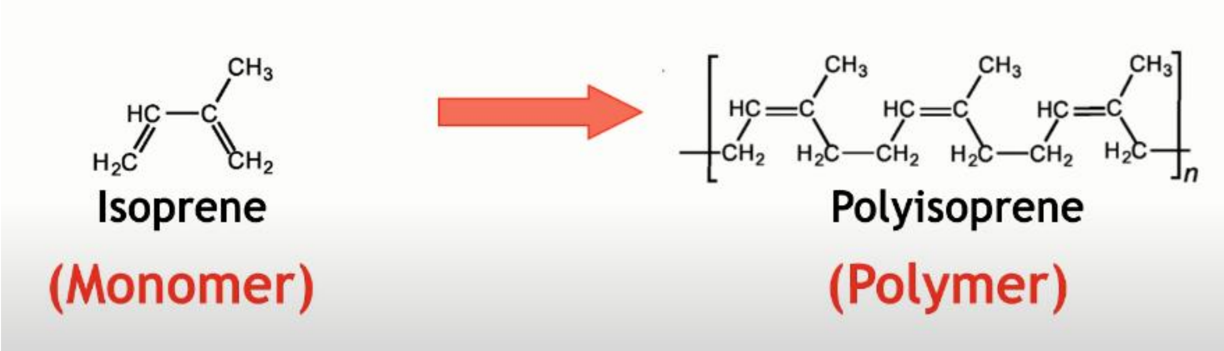

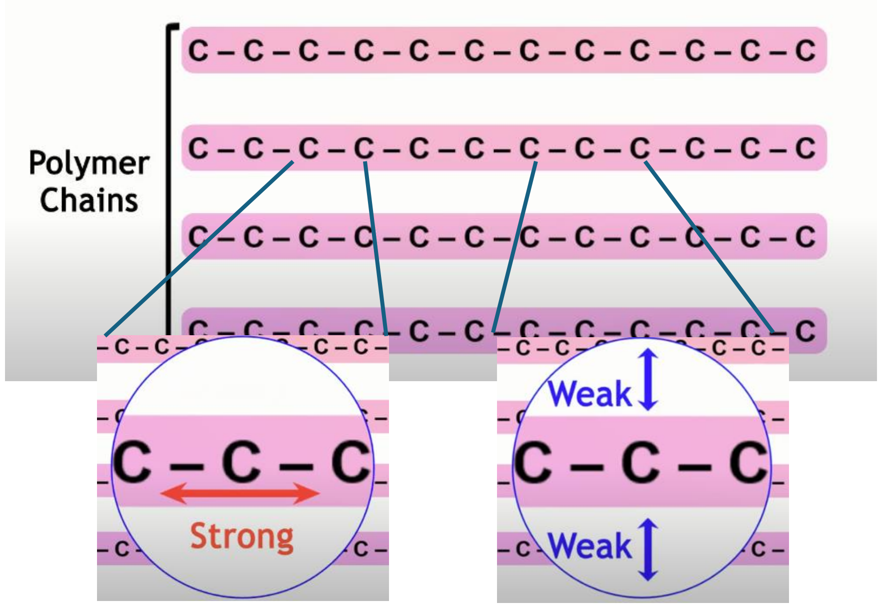

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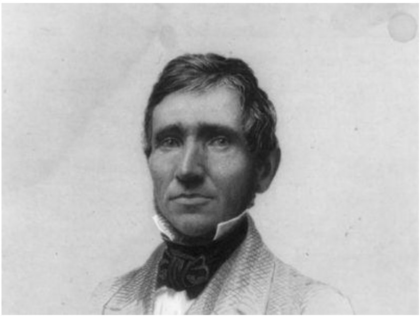
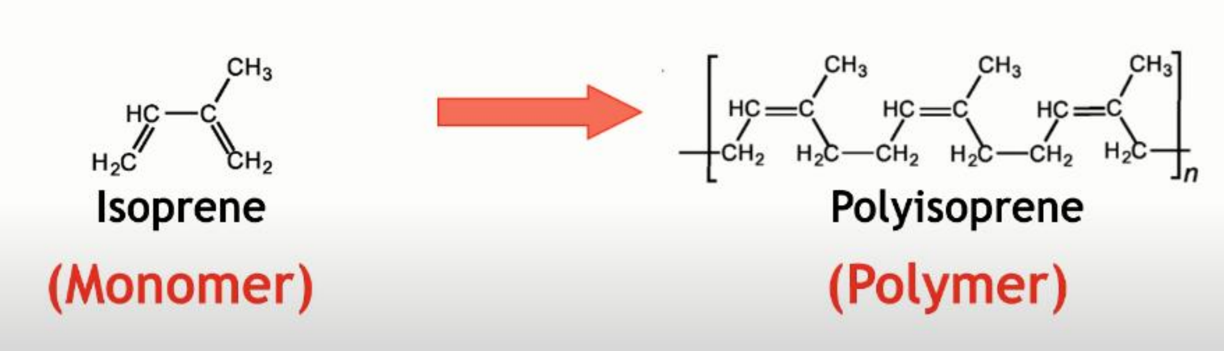


Charles Goodyear



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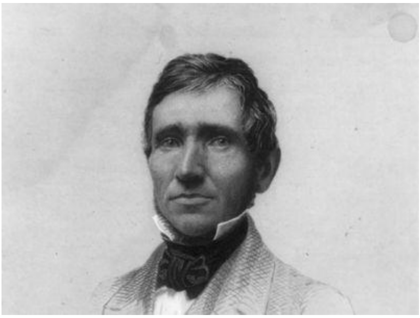
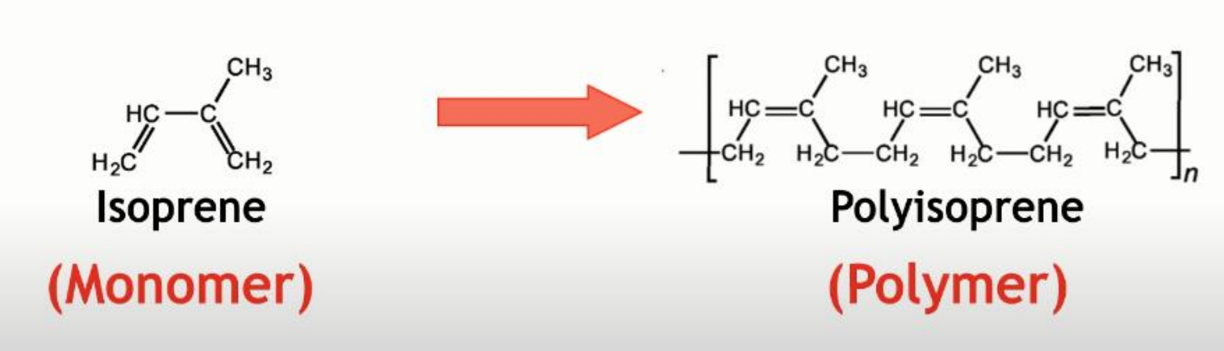
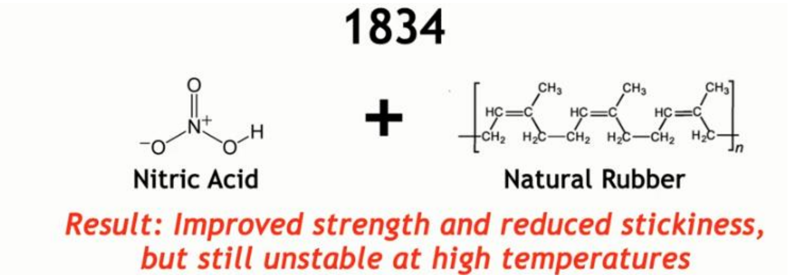
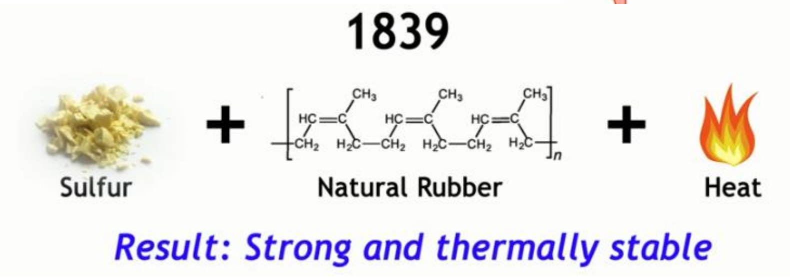

Charles Goodyear







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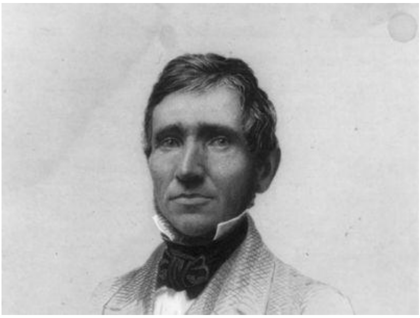

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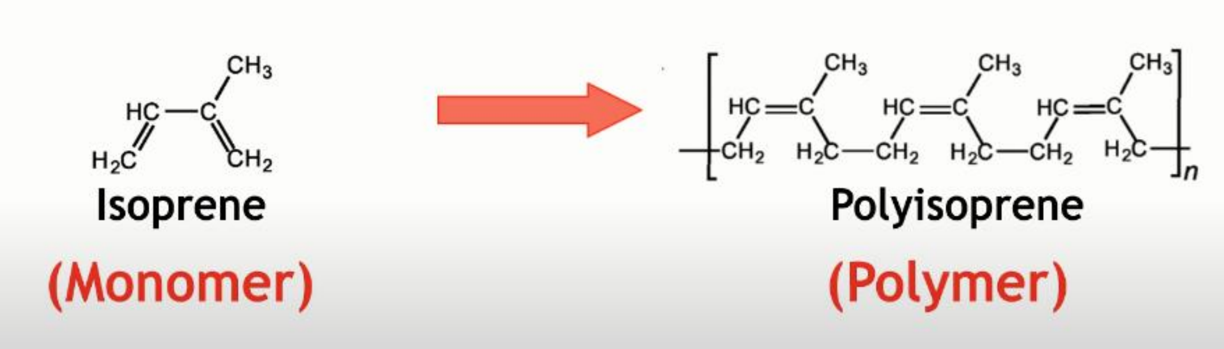

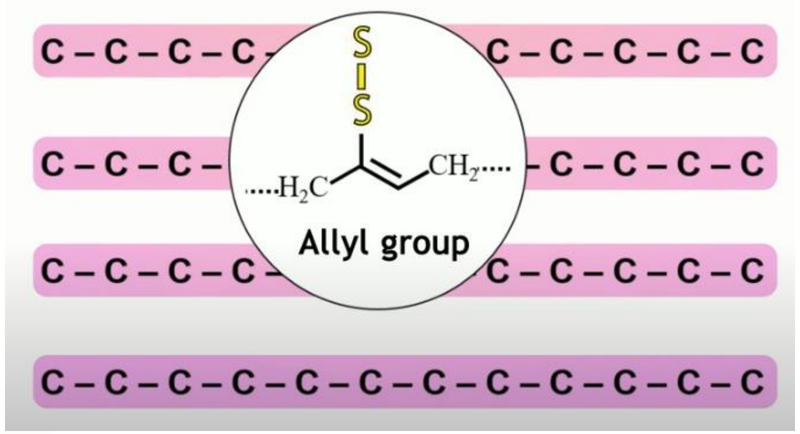

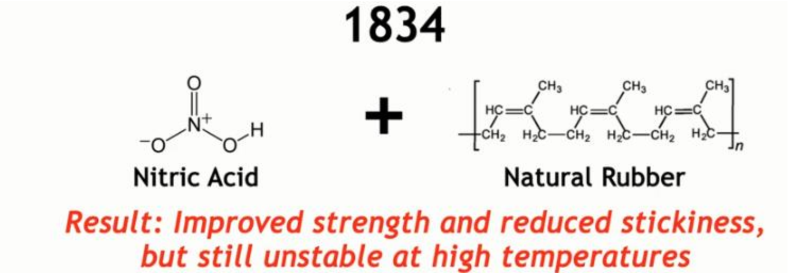

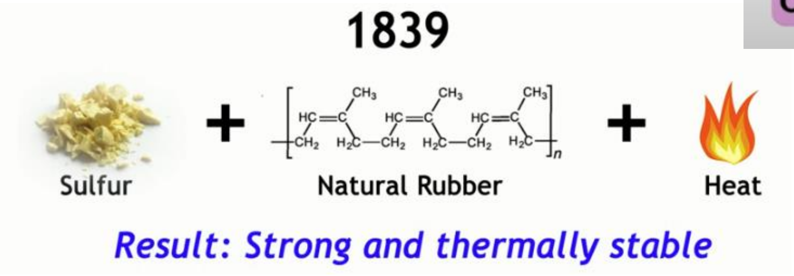

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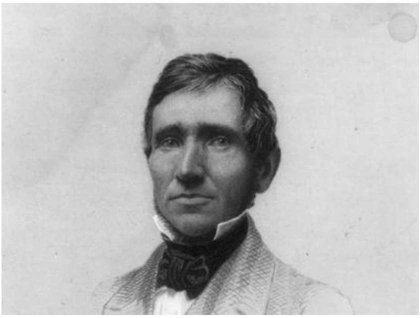

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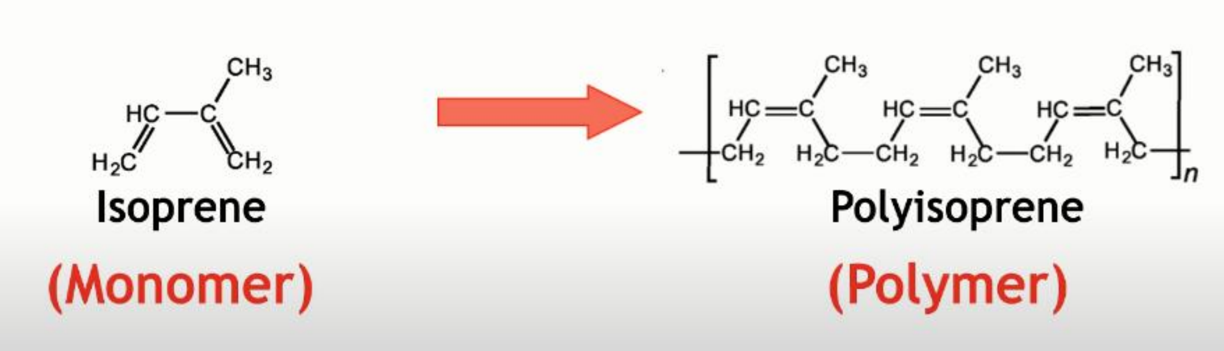
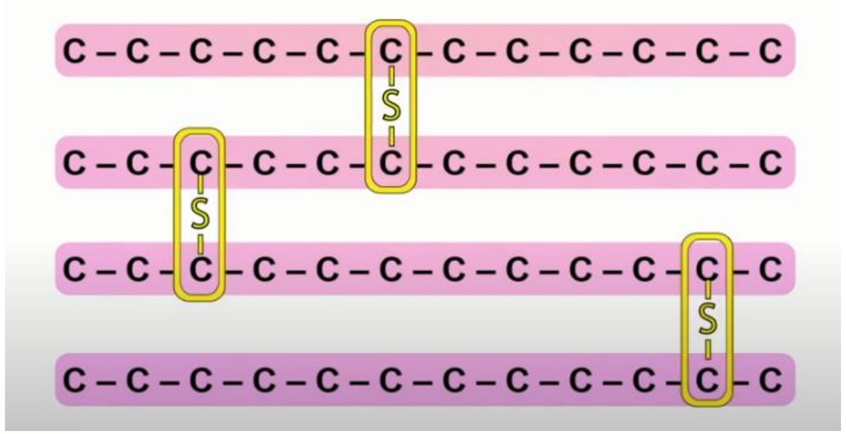
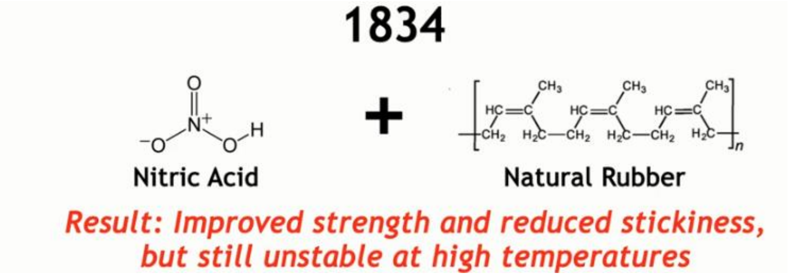
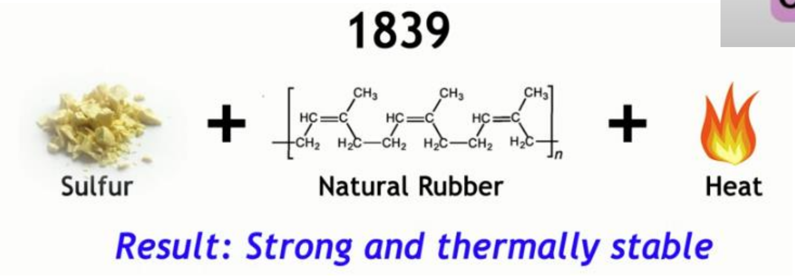




Crosslinking





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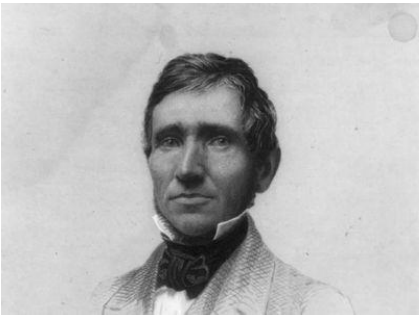

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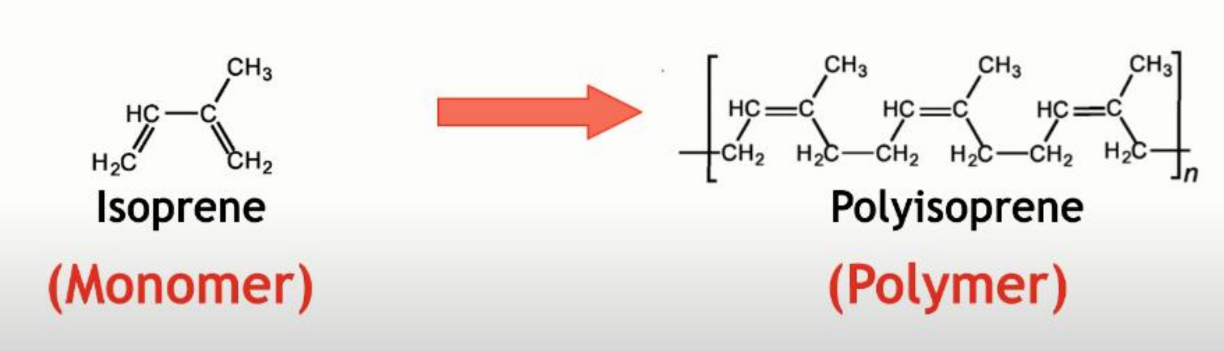
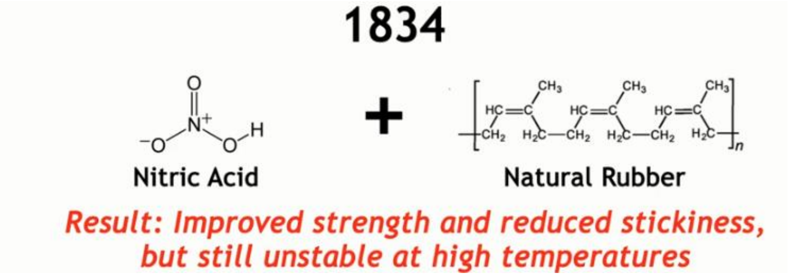
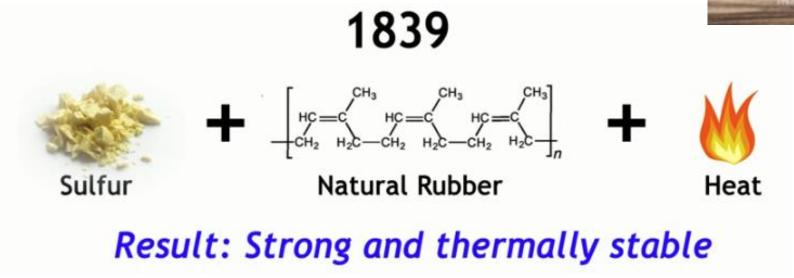
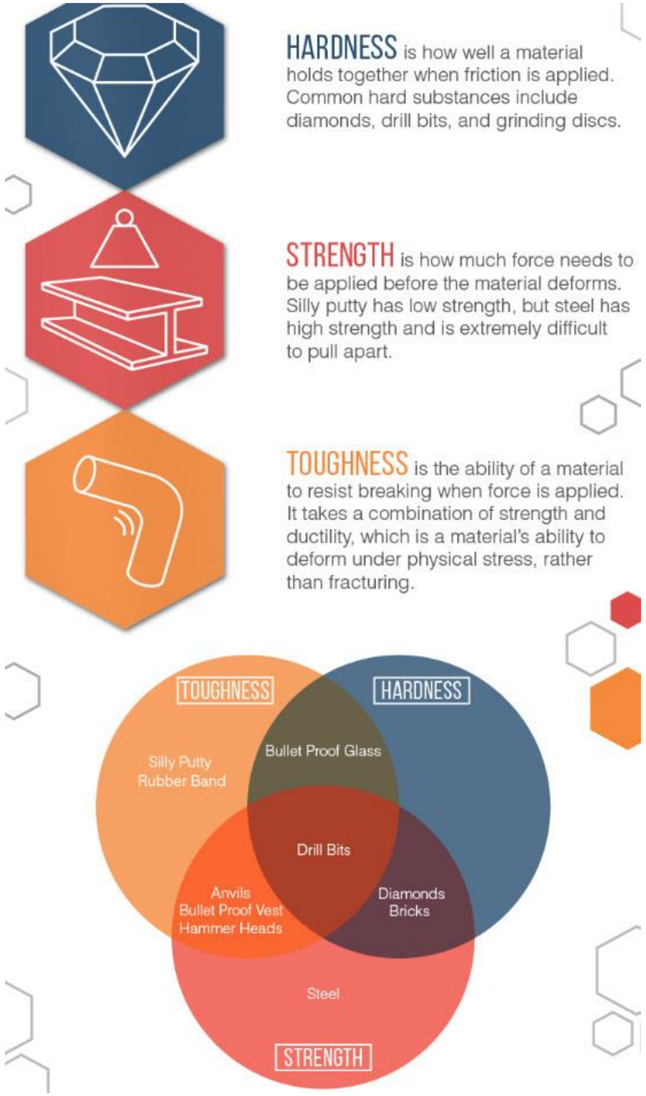


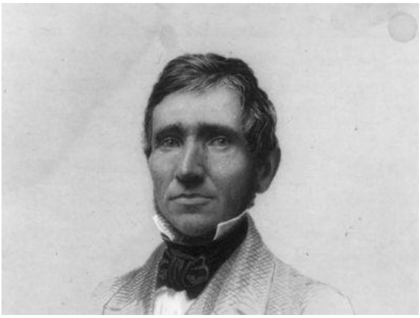




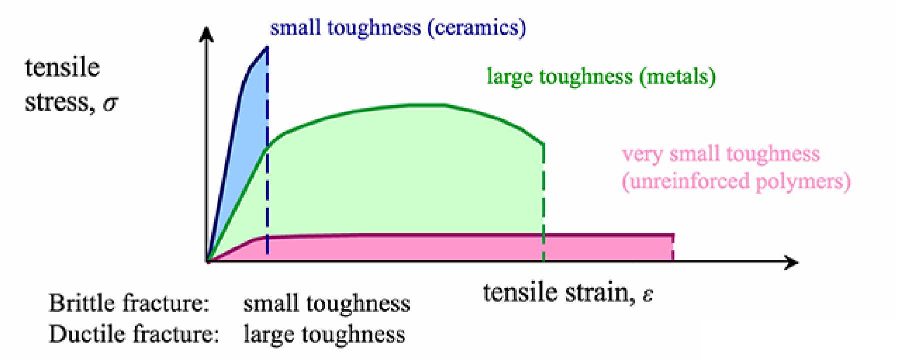
The history of vulcanization

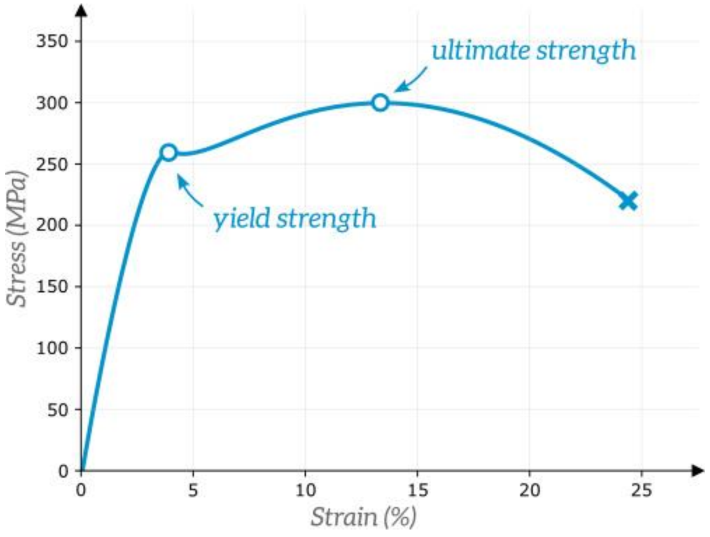


Crosslink density

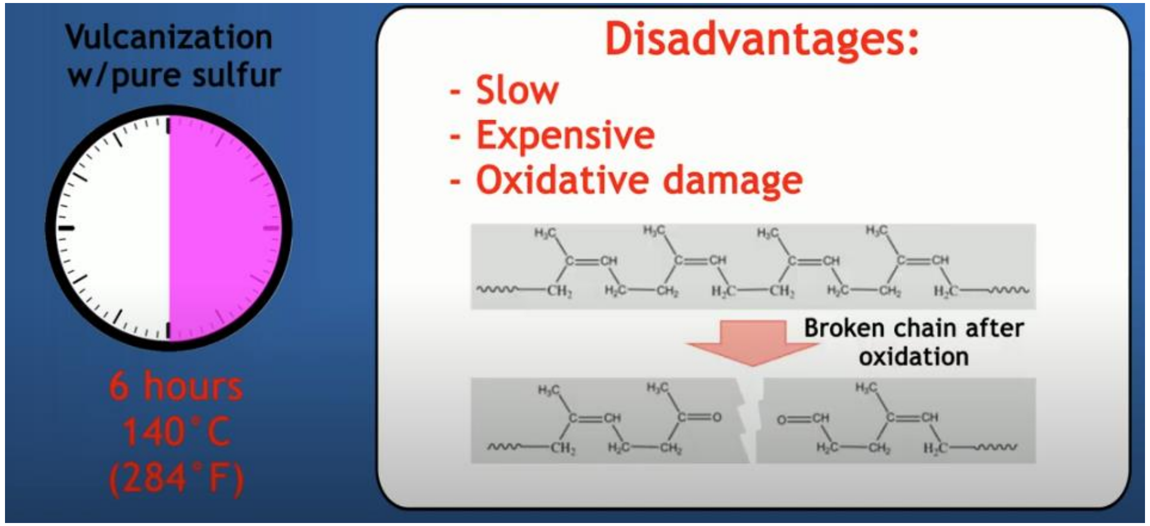


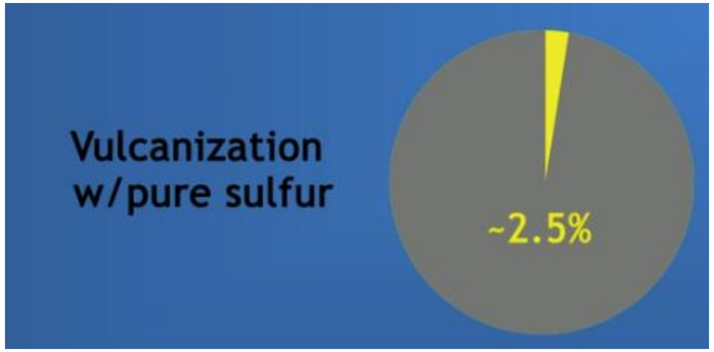
Charles Goodyear

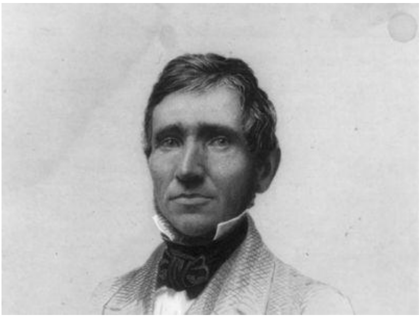




The history of vulcanization







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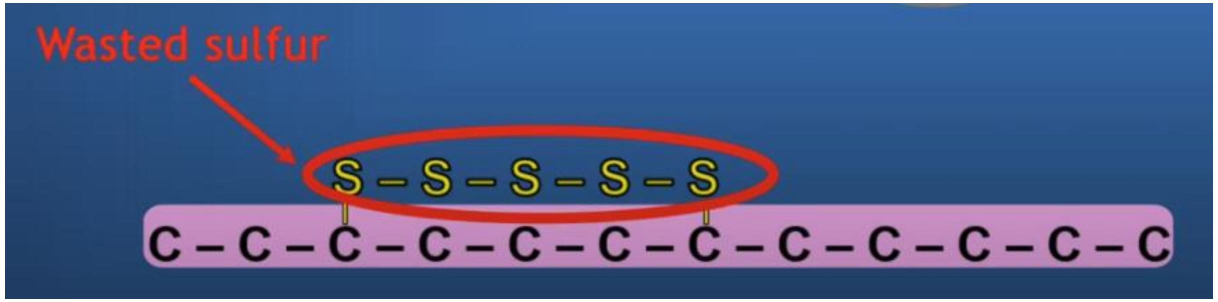
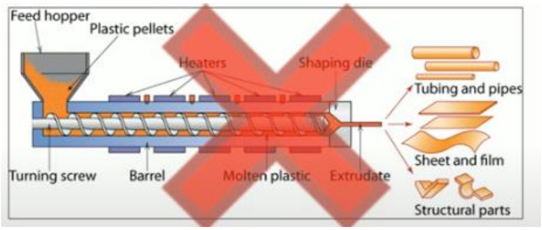


	Vulcanization w/pure sulfur	Vulcanization w/accelerator	Modern vulcanization
Sulfur per crosslink	40-50	10-15	<5
Time	6 hours	1 hour	< 30 min
Temperature	140°C+	120-140°C	<100°C

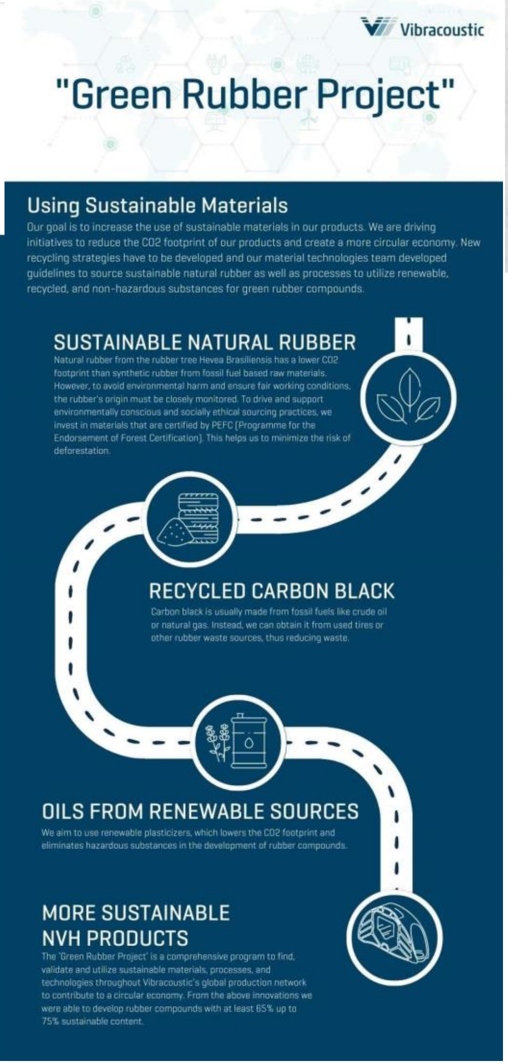
Drawbacks of Crosslinking

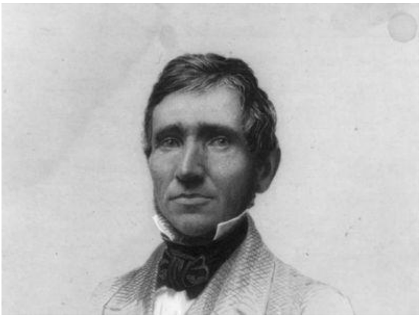
- Not easily shaped



- Not easily recycled

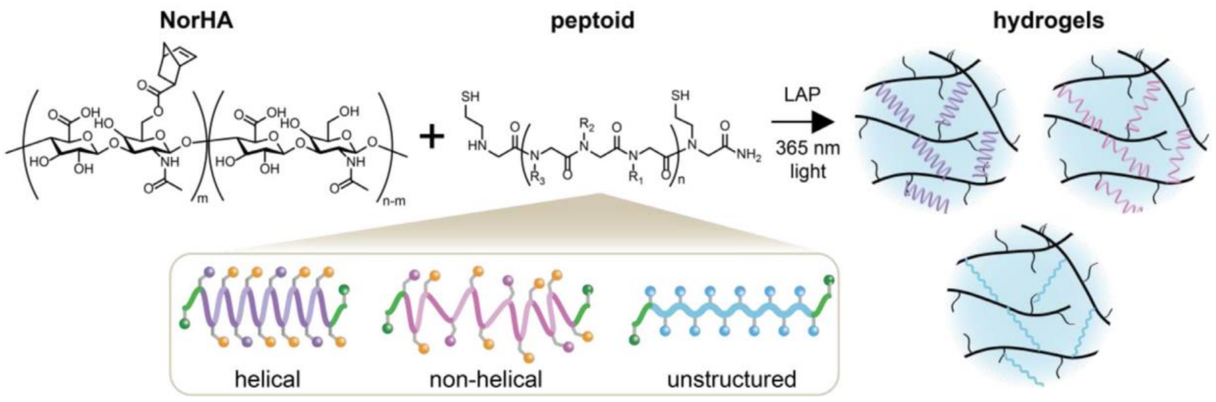
- Environmental hazard

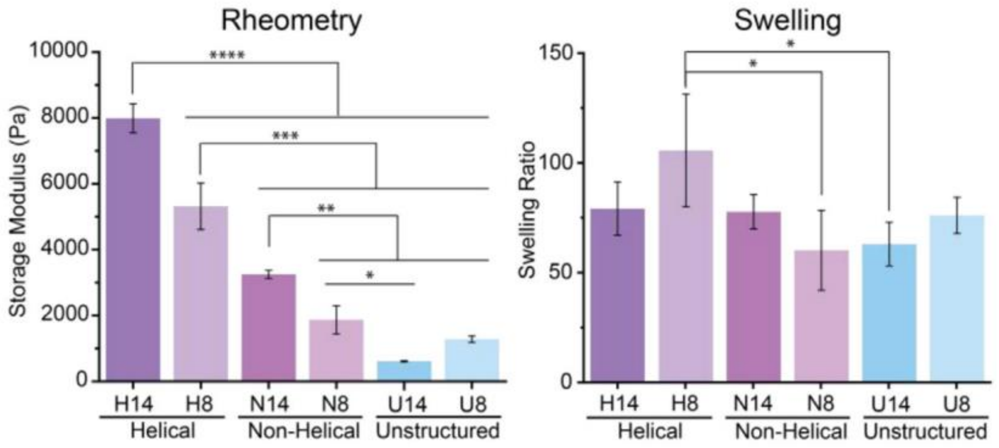


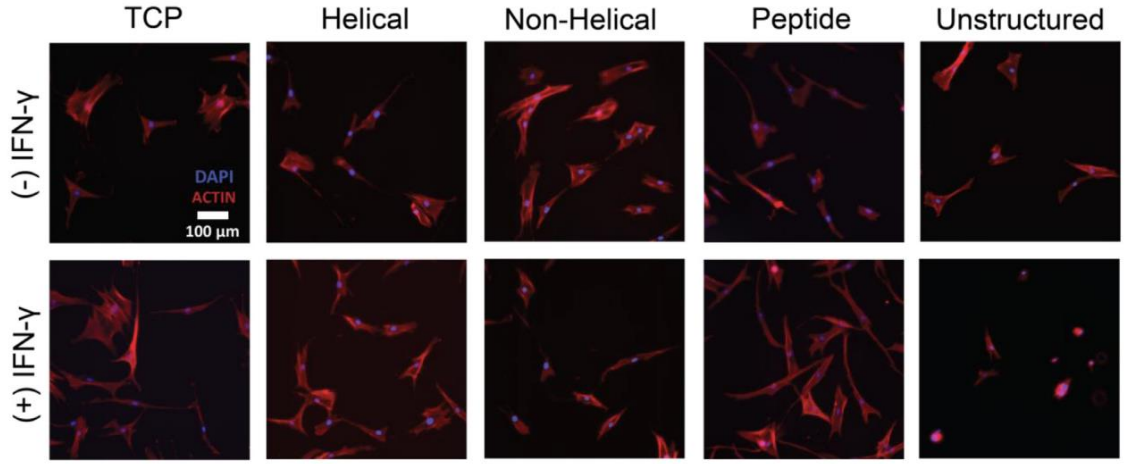


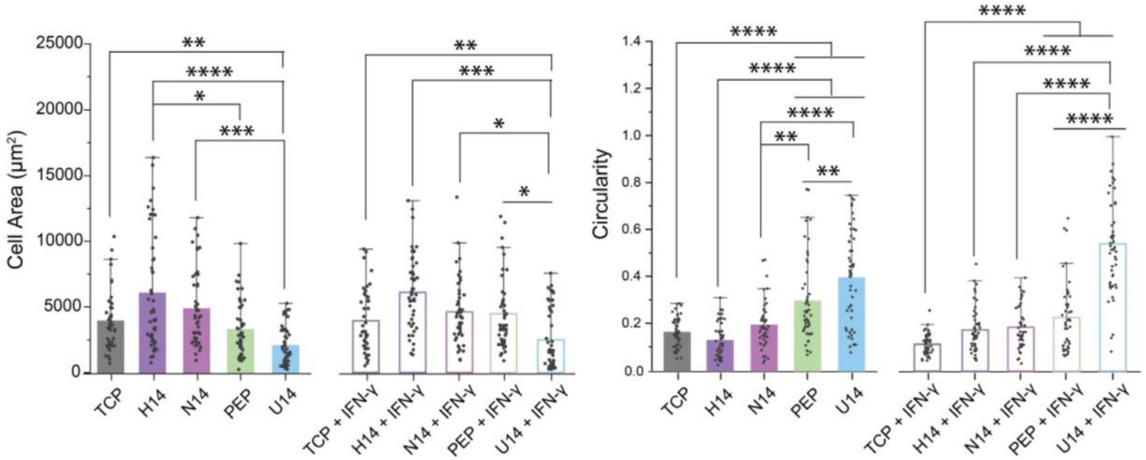
Charles Goodyear

Innovations in polymer crosslinking and crosslinker chemistry



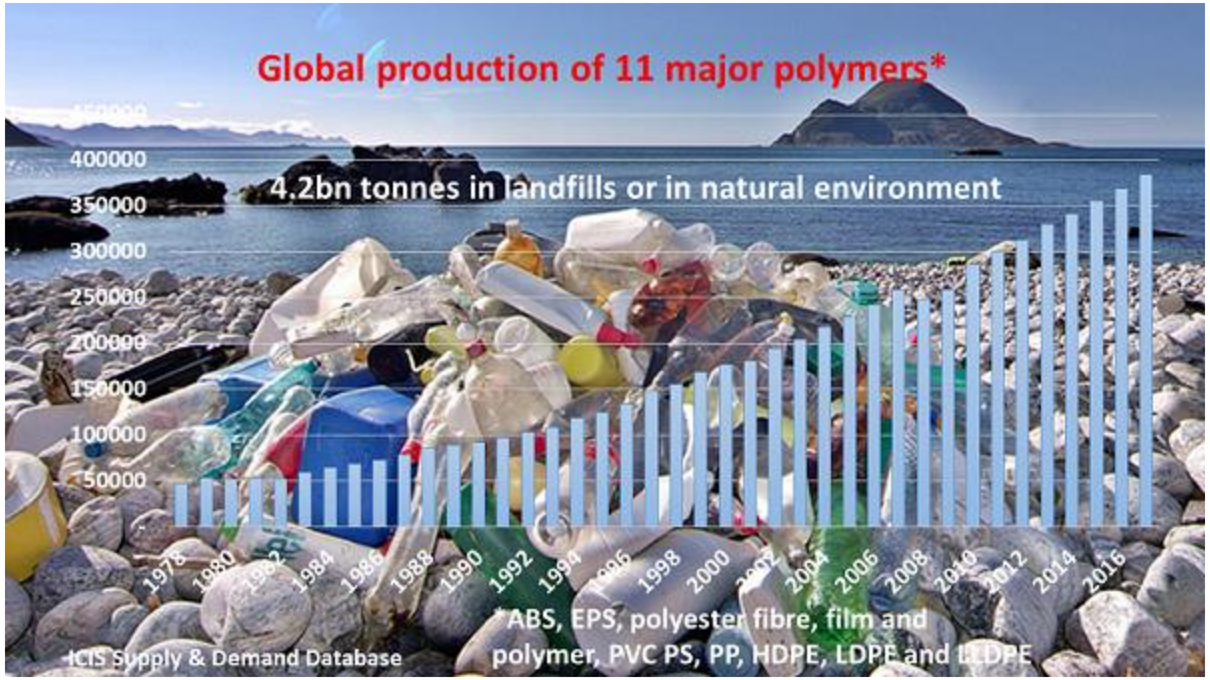




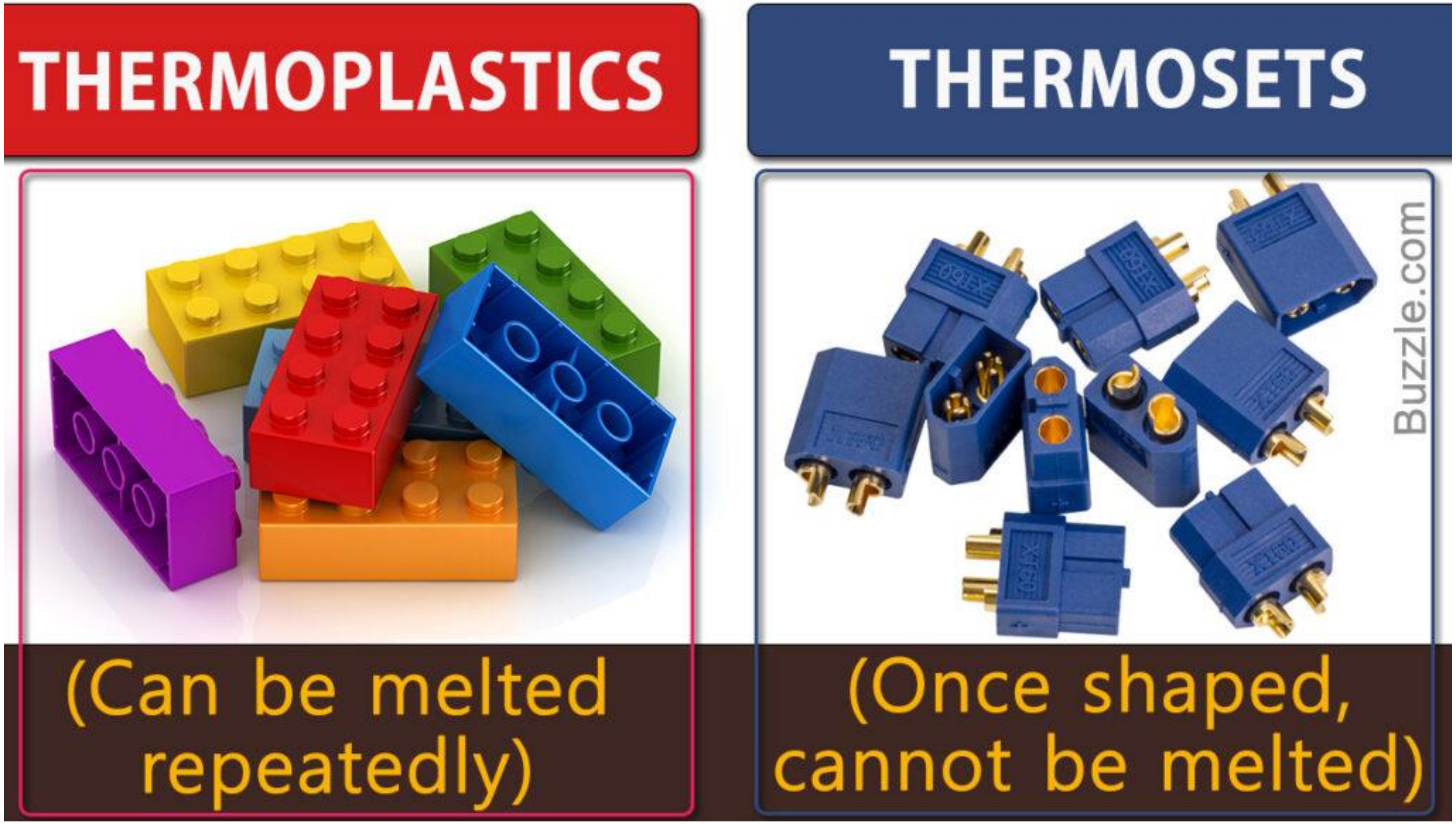


Morton et al. *Acta Biomaterialia* 155 (2023) 258–270

Wow polymers are amazing! Hopefully there isn’t some huge downside!

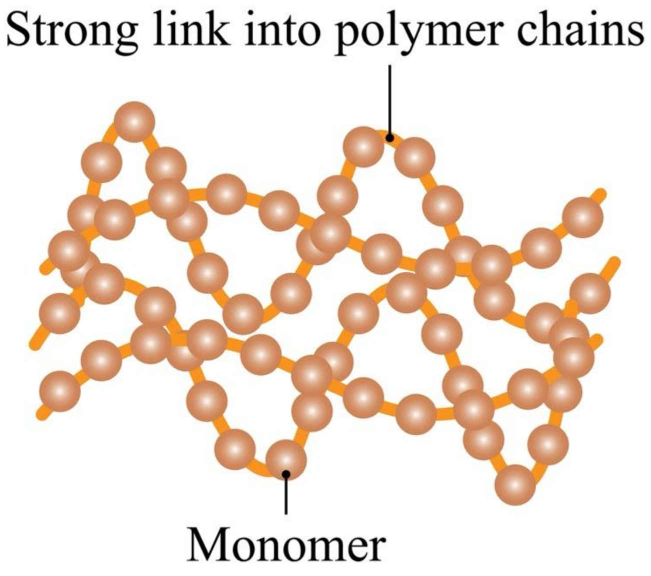


One other materials note:



The chemistry of polymer manufacturing

Thermoplastic

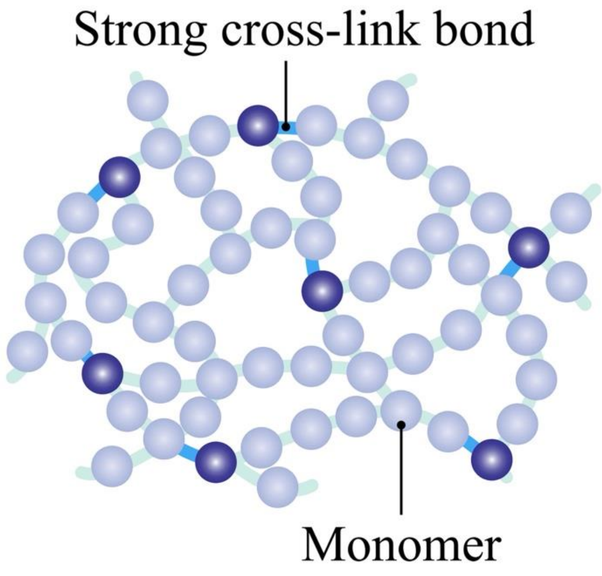


Weak intermolecular forces between polymer chains

No cross-links between chains

Softens when heated

Thermosetting



Strong covalent bonds between polymer chains

Remains hard when heated

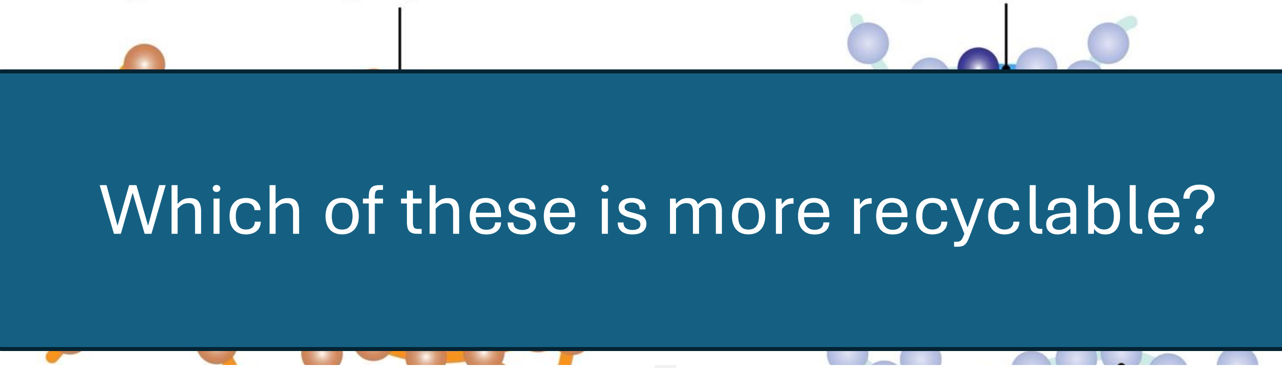
The chemistry of polymer manufacturing

Thermoplastic

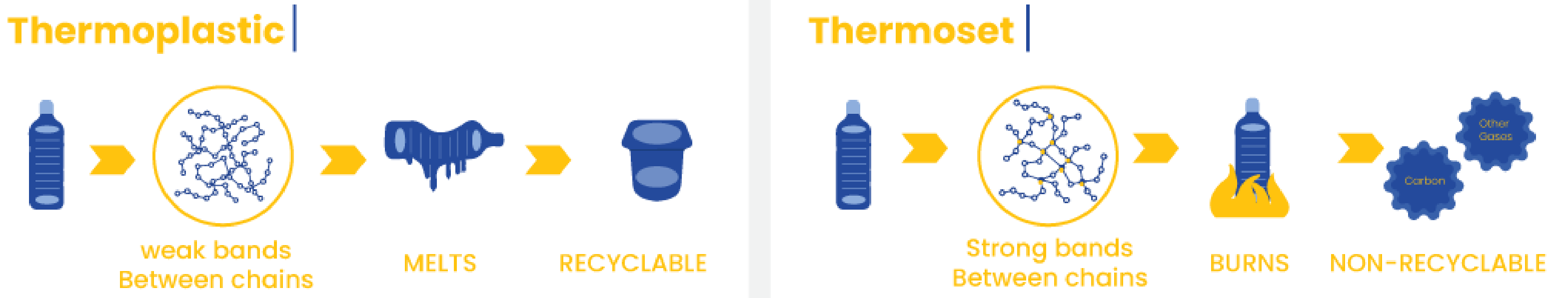
Thermosetting

Strong link into polymer chains

Strong cross-link bond



Which of these is more recyclable?



No cross-links between chains

Softens when heated

Remains hard when heated

Types of thermoplastics—are they recyclable?

1 PETE	2 HDPE	3 PVC	4 LDPE	5 PP	6 PS	7 OTHER
Polyethylene Terephthalate	**High-density Polyethylene**	**Polyvinyl Chloride**	**Low-density Polyethylene**	**Polypropylene**	**Polystyrene**	**Other plastics,**
Soft drink bottles, mineral water, fruit juice containers, cooking oil	Milk jugs, cleaning agents, laundry detergents, bleaching agents, shampoo bottles, washing and shower soaps	Trays for sweets, fruit, plastic packing (bubble foil) and food foils to wrap the foodstuff	Crushed bottles, shopping bags, highly-resistant sacks and most of the wrappings	Furniture, consumers goods, luggage, toys as well as bumpers, lining and external boarders for cars	Toys, hard packing, refrigerator trays, costume jewelry, cd cases, vending cups	including acrylic, polycarbonate, nylon, fiberglass

Types of thermoplastics—are they recyclable?

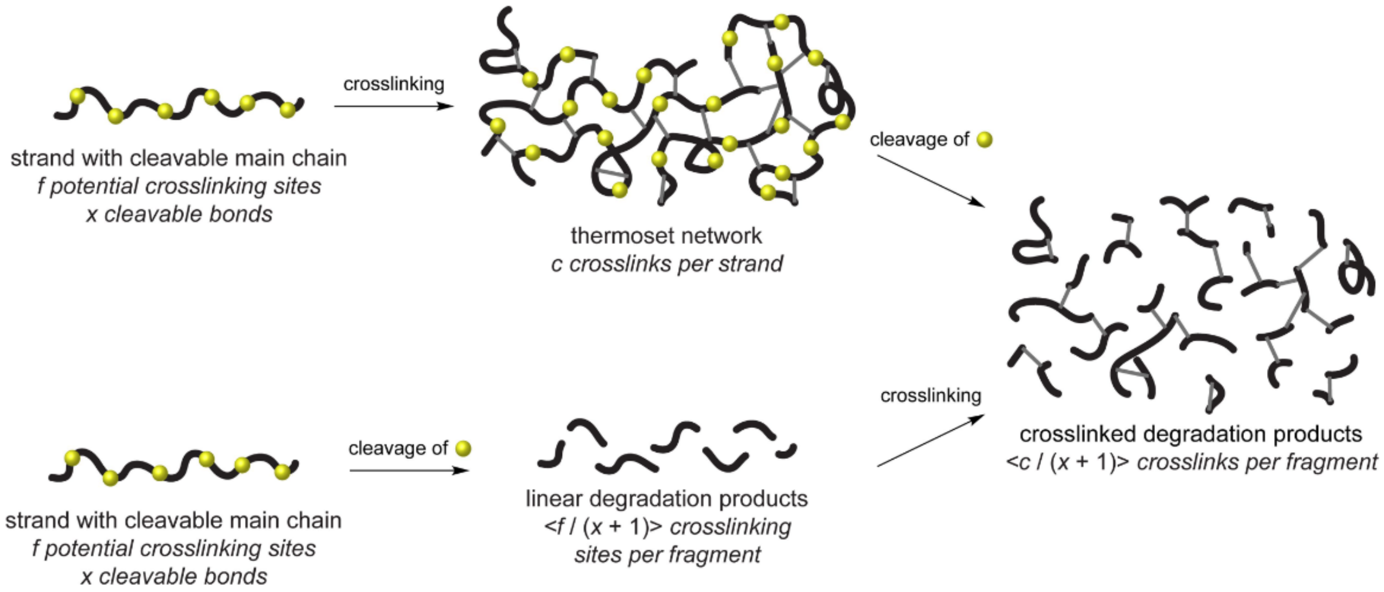
Plastic Type	♻️ Recyclable?	Reason Why / Why Not Recyclable
#1 PET (Polyethylene Terephthalate)	✅	Easy to process, can be remade into fibers, containers, and other products. Most recycling programs accept it.
#2 HDPE (High-Density Polyethylene)	✅	Strong, durable, easy to recycle. Often remade into bottles, piping, and plastic lumber.
#3 PVC (Polyvinyl Chloride)	❌	Contains toxic additives, hard to process without releasing harmful chemicals. Recycling is complicated and expensive.
#4 LDPE (Low-Density Polyethylene)	⚠️	Not commonly accepted in curbside programs due to difficulty in processing, but can be recycled at specific collection points (e.g., plastic bag recycling).
#5 PP (Polypropylene)	⚠️	Less commonly accepted than PET and HDPE, but some programs do recycle it. Can be remade into products like packaging or automotive parts.
#6 PS (Polystyrene)	❌	Difficult to recycle due to low density and contamination risks. Often ends up in landfills; specialized facilities can process it, but they're not widespread.
#7 Other (Miscellaneous plastics)	❌	Includes a wide range of materials, making recycling complicated. Some bioplastics or mixed materials cannot be recycled in standard facilities.

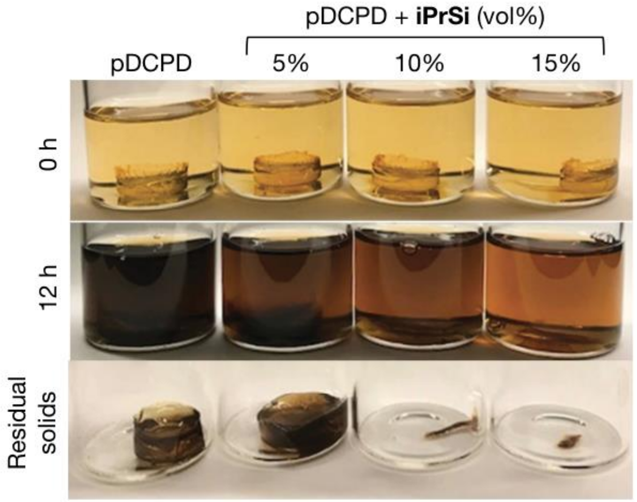
How do polymers break down?

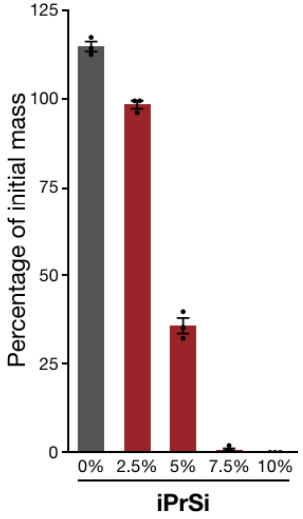
- Most polymers do NOT biodegrade
- They degrade by UV-light, oxygen, water, etc.
- They break down into smaller and smaller pieces until they are **microplastics**
- Whether it's our bloodstream, brain, or lungs, microscopic fragments of plastic seem to turn up every time scientists scour a new corner of the human body.
- Recent work has found microplastics in the testicles of in 23/23 men and 47/47 dogs tested*

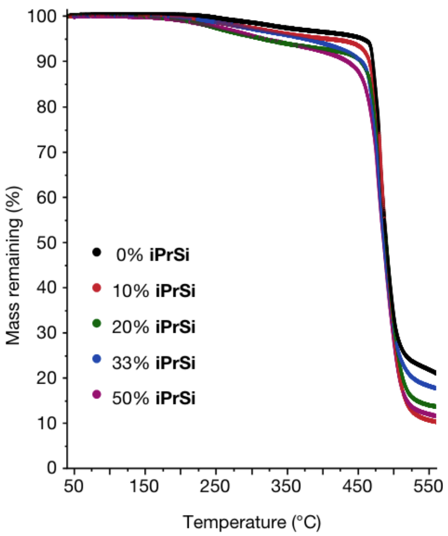
Toxicological Sciences, kfae060, May 15, 2024

Recycling thermoset polymers







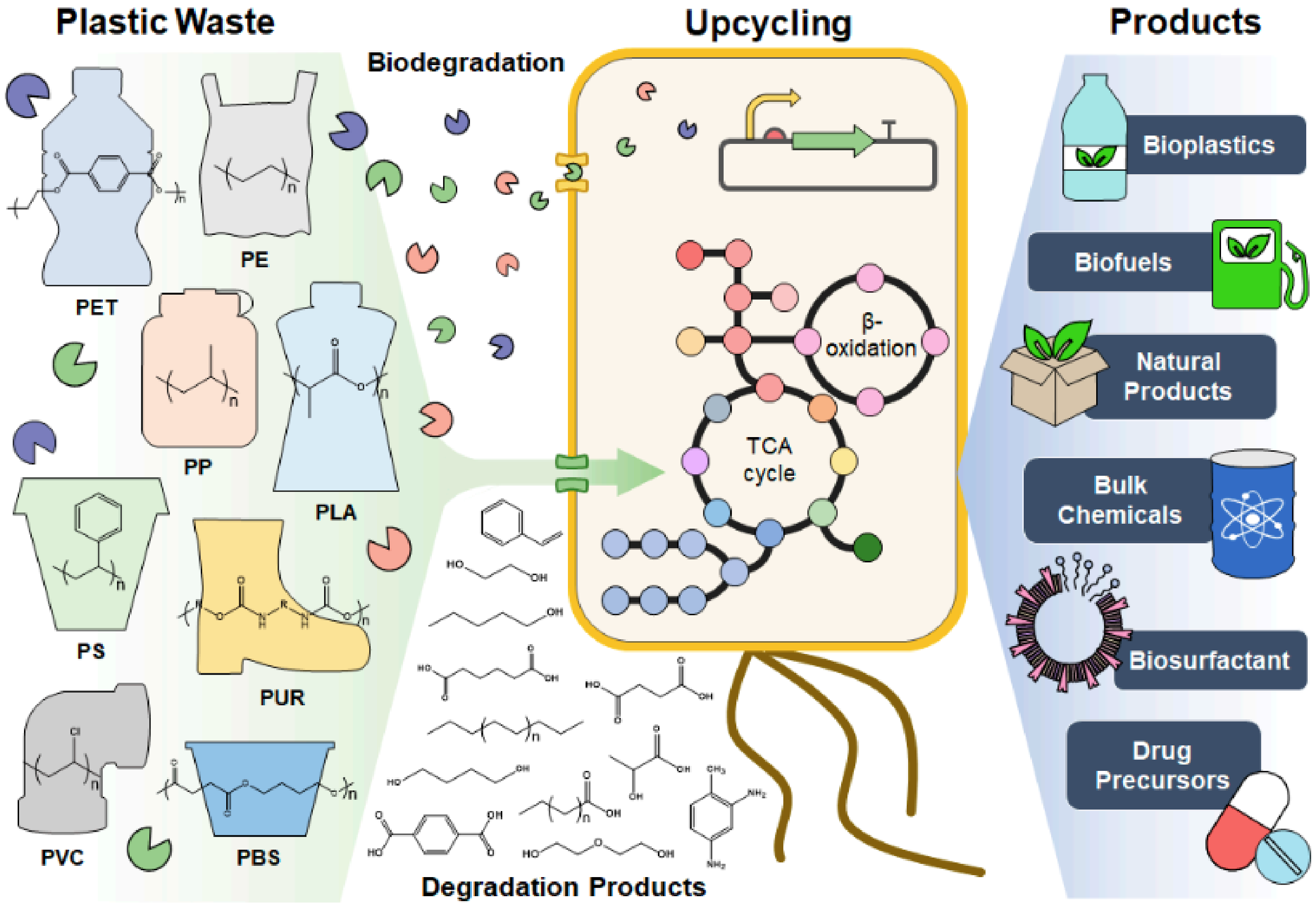


LOTS of people are working on these problems, but no solution has proven sufficient for the real-world issues we are dealing with

Shieh P, Zhang W, et al. *Nature* **volume 583**, pages542–547 (2020)

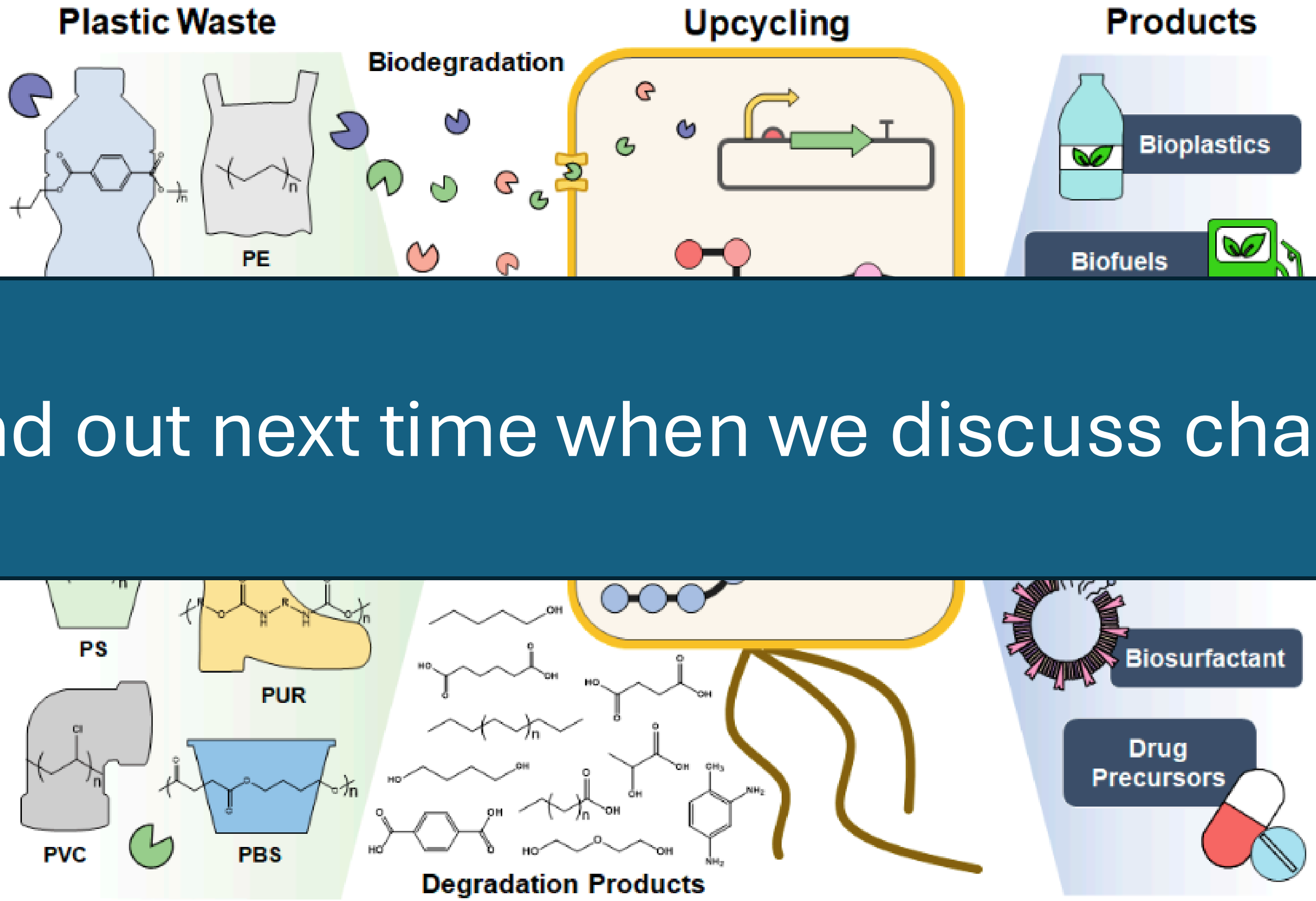
200 years	**6 weeks**	**2 months**	**10-20 years**
ALUMINIUM CAN	NEWSPAPER	FRUIT CARDBOARD	PLASTIC BAG
3 months	**600 years**	**1-5 years**	**2-5 months**
COTTON T SHIRT	FISHING LINE	WOOLLEN SOCK	WAXED CARTON
450 years	**2-4 weeks**	**50 years**	**1-3 years**
NAPPY / DIAPER PLASTIC BOTTLE	PAPER TOWEL	TIN CAN FOAM CUP	PLYWOOD

These papers are a dime a dozen…so why do we still struggle with plastic waste?



Lee G.H., Kim D.W., et al. *Int. J. Mol. Sci.* **2023**, *24*(20), 15181

These papers are a dime a dozen…so why do we still struggle with plastic waste?



Find out next time when we discuss challenges!

Lee G.H., Kim D.W., et al. *Int. J. Mol. Sci.* **2023**, *24*(20), 15181

First Checkpoint Due Next Week!

September 18: Project checkpoint #1: Pick your groups and pick your problem—**deliverable: email Logan first come first serve**

- groups should consist of 2-3 members.