Polymers in Biomedical and Pharmaceutical Systems

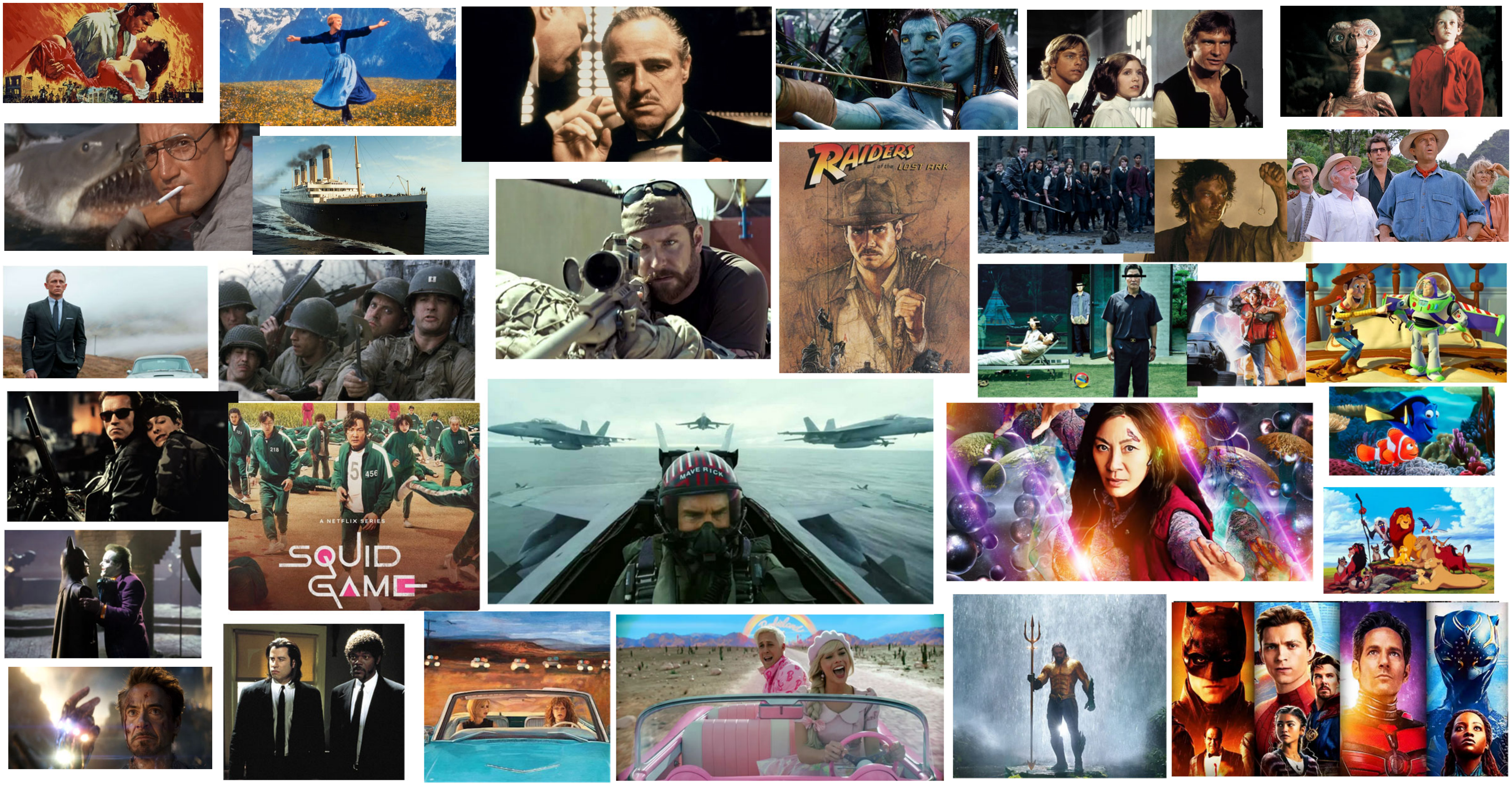
Purdue University
Biomedical Engineering

2024

Professors Kinam Park & Andrew Otte

Purdue Boilermaker

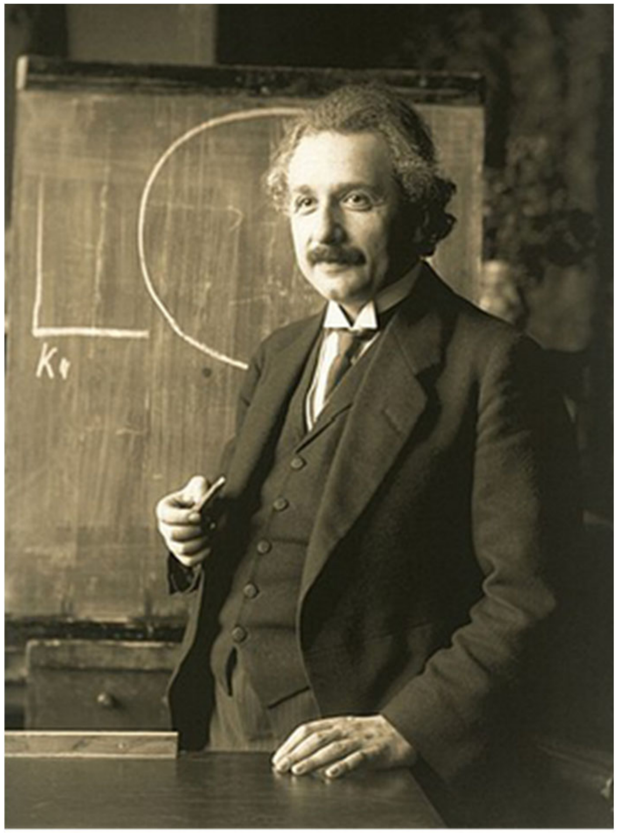
Storytelling



The Value of Education

"The value of a college education is not the learning of many facts but the training of the mind to think."

Albert Einstein

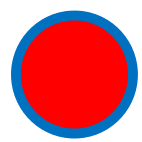


"College isn't just about learning facts — it's about social growth and how to function in society. College teaches you how to be independent and accepting of ideas that may be different than your own, so if you're able to go to college, use your time there wisely."

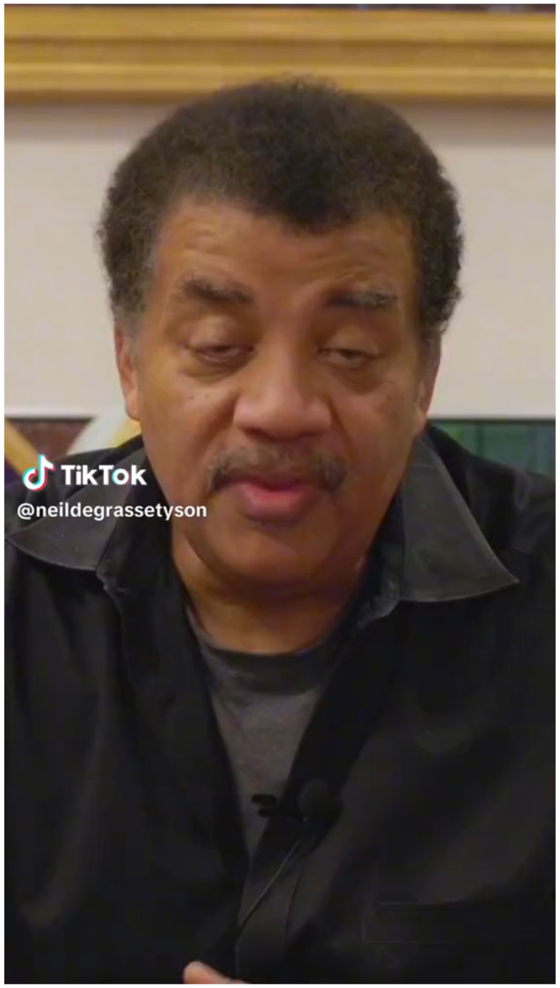
—Michele Meyer, 57

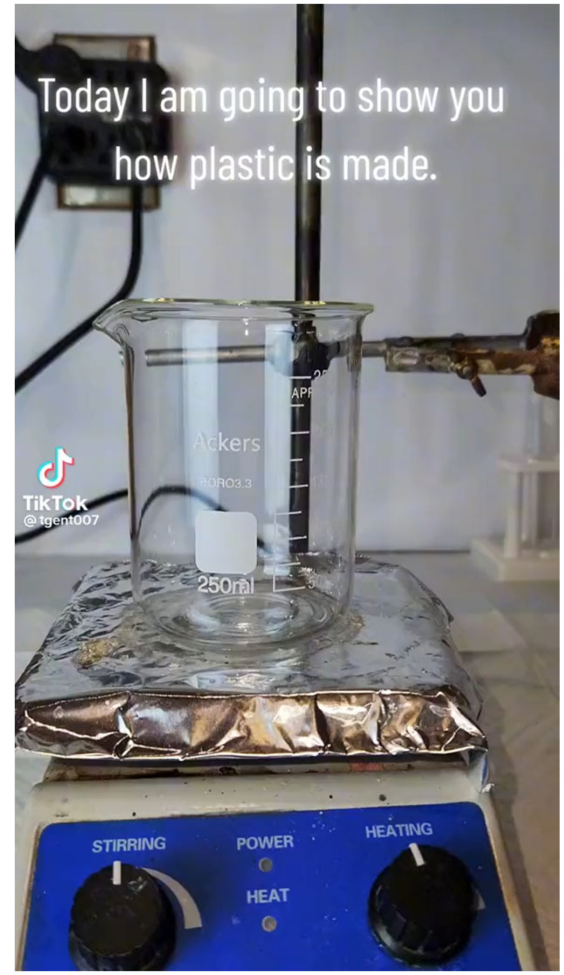
https://www.buzzfeed.com/dannicaramirez/older-adults-share-advice-with-younger-generations

What Do You See?



How do you know whether the information you find is right or wrong?





99 Brilliant Charlie Munger Quotes

https://www.inc.com/bill-murphy-jr/99-brilliant-charlie-munger-quotes-that-explain-why-warren-buffett-trusted-him-so-much.html

99 Brilliant Charlie Munger Quotes That Explain Why Warren Buffett Trusted Him So Much

"It is remarkable how much long-term advantage people like us have gotten by trying to be consistently not stupid, instead of trying to be very intelligent."

By Bill Murphy Jr., Founder of Understandably and contributing editor, Inc.@BillMurphyJr

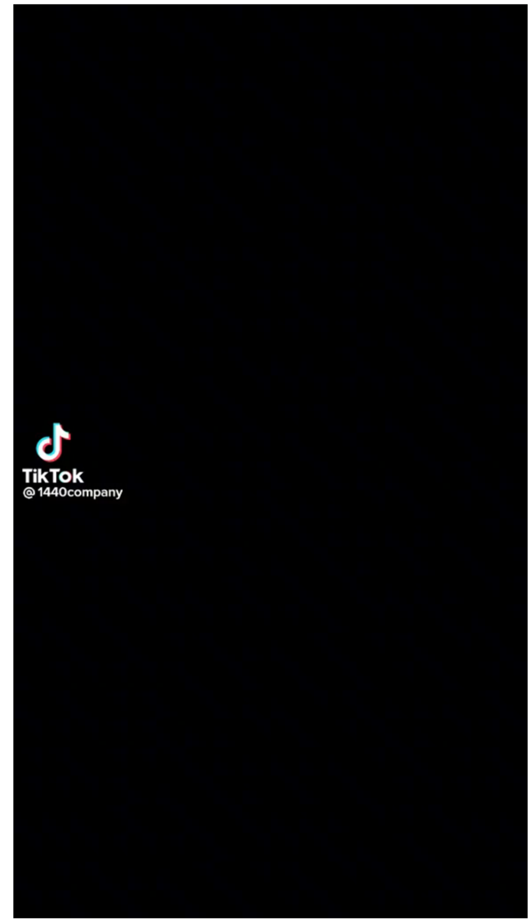
We lost some lions in 2024. Among them, Charlie Munger, the irreverent billionaire who was Warren Buffett's right-hand man.

Munger lived to be 99 years old, and so I've compiled a list of 99 of the smartest and most entertaining quotes attributed to him. If you didn't follow Munger while he was alive, I think you'll find some of these poignant and even hilarious now.

1. "Being rational is a moral imperative. You should never be stupider than you need to be."
2. "It takes character to sit there with all that cash and do nothing. I didn't get to where I am by going after mediocre opportunities."
3. "Whenever you think something or some person is ruining your life, it's you. A victimization mentality is so debilitating."
4. "If you want to understand science, you have to understand math. ... The good thing about business is that you don't have to know any higher math."
5. "In my whole life, I have known no wise people ... who didn't read all the time. ... You'd be amazed at how much Warren reads, at how much I read. My children laugh at me. They think I'm a book with a couple of legs sticking out."
6. "We look for a horse with one chance in two of winning and which pays you three to one."
7. "Knowing what you don't know is more useful than being brilliant."
8. "Recognize reality even when you don't like it. Especially when you don't like it."
9. "A business model that relies on trickery is doomed to fail."
10. "We have to have a special insight, or we'll put it in the 'too tough' basket. All of you have to look for a special area of competency and focus on that."
11. "Those of us who have been very fortunate have a duty to give back. Whether one gives a lot as one goes along as I do, or a little and then a lot as Warren [plans to], is a matter of personal preference."
12. "You don't have to be brilliant, only a little bit wiser than the other guys, on average, for a long, long, time."
13. "**Remember that reputation and integrity are your most valuable assets, and can be lost in a heartbeat**."
14. "There's no way that you can live an adequate life without making many mistakes."
15. "Anytime anybody offers you anything with a big commission and a 200-page prospectus, don't buy it. Occasionally, you'll be wrong if you adopt 'Munger's Rule.' However, over a lifetime, you'll be a long way ahead, and you will miss a lot of unhappy experiences."
16. "Forgetting your mistakes is a terrible error if you are trying to improve your cognition."
17. "Is there such thing as a cheerful pessimist? That's what I am."
18. "I have a black belt in chutzpah. I was born with it."
19. "The best armor of old age is a well-spent life preceding it."
20. "It never ceases to amaze me to see how much territory can be grasped if one merely masters and consistently uses all the obvious and easily learned principles."
21. "Choose clients as you would friends."
22. "It's not the bad ideas that do you in, but the good ones."
23. "Acknowledging what you don't know is the dawning of wisdom."
24. "Our job is to find a few intelligent things to do, not to keep up with every damn thing in the world."
25. "If you don't allow for self-serving bias in the conduct of others, you are, again, a fool."
26. "For some odd reason, I had an early and extreme multidisciplinary cast of mind. I couldn't stand reaching for a small idea in my own discipline when there was a big idea right over the fence in somebody else's discipline. So I just grabbed in all directions for the big ideas that would really work."
27. "The big money is not in the buying and selling, but in the waiting."
28. "Spend each day trying to be a little wiser than you were when you woke up. Day by day, and at the end of the day, if you live long enough ... you will get out of life what you deserve."
29. "Everybody engaged in complex work needs colleagues. Just the discipline of having to put your thoughts in order with somebody else is a very useful thing."
30. "I always knew from when I was a little boy that the opportunities that were important that were going to come to me were few and that the trick was to prepare myself for seizing the few that came. This is not the attitude that they have at a big investment council. They think that if they study a million things, they can know a million things."
31. "The first chance you have to avoid a loss from a foolish loan is by refusing to make it. There is no second chance."
32. "I never allow myself to have an opinion on anything that I don't know the other side's argument better than they do."
33. "A foreign correspondent, after talking to me for a while, once said: 'You don't seem smart enough to be so good at what you're doing. Do you have an explanation?'"
34. "If it is wisdom you're after, you're going to spend a lot of time on your ass reading."
35. "I don't have too much interest in teaching other people how to get rich."
36. "Once you get into debt, it's hell to get out. Don't let credit card debt carry over. You can't get ahead paying eighteen percent."
37. "Bull markets go to people's heads. If you're a duck on a pond, and it's rising due to a downpour, you start going up in the world. But you think it's you, not the pond."
38. "Capitalism is a pretty brutal place."
39. "If you have competence, you know the edge. It wouldn't be a competence if you didn't know where the boundaries lie. Asking whether you've passed the boundary is a question that almost answers itself."
40. "I regard it as very unfair. But capitalism without failure is like religion without hell."
41. "A rough rule in life is that an organization foolish in one way in dealing with a complex system is all too likely to be foolish in another."
42. "Assume life will be really tough, and then ask if you can handle it. If the answer is yes, you've won."
43. "It's a rare business that doesn't have a way worse future than it has a past."
44. "We're emphasizing the knowable by predicting how certain people and companies will swim against the current. We're not predicting the fluctuation in the current."
45. "You have to learn to be a follower before you become a leader."
46. "Opportunity comes to the prepared mind."
47. "If you always tell people why, they'll understand it better, they'll consider it more important, and they'll be more likely to comply."
48. "I try to get rid of people who always confidently answer questions about which they don't have any real knowledge."
49. "Mankind invented a system to cope with the fact that we are so intrinsically lousy at manipulating numbers. It's called the graph."
50. "I don't invest in what I don't understand. And I don't want to understand Facebook."
51. "Good businesses can survive a little bad management."
52. "Intense interest in any subject is indispensable if you're really going to excel in it."
53. "Trying to prioritize among things we're unlikely to do is pretty fruitless."
54. "I believe in the discipline of mastering the best that other people have ever figured out. I don't believe in just sitting down and trying to dream it all up yourself. Nobody's that smart."
55. "If the value of a company doesn't just scream out at you, it's too close."
56. "You don't have to have perfect wisdom to get very rich. Just a bit better than average over a long period of time."
57. "When you locate a bargain, you must ask, 'Why me, God? Why am I the only one who could find this bargain?'"
58. "Show me the incentive and I will show you the outcome"
59. "It's a good habit to trumpet your failures and be quiet about your successes."
60. "Just avoid things like racing trains to the crossing, doing cocaine, etc. Develop good mental habits."
61. "Acquire worldly wisdom and adjust your behavior accordingly. If your new behavior gives you a little temporary unpopularity with your peer group, then to hell with them."
62. "There must be some wisdom in the folk saying, 'It's the strong swimmers who drown.'"
63. "It's dishonorable to stay stupider than you need to be"
64. "If you turn on the television, you'll find the mothers of the most obvious criminals that man could ever diagnose, and they all think their sons are innocent. That's simple psychological denial. The reality is too painful to bear, so you just distort it until it's bearable. We all do that to some extent, and it's a common psychological misjudgment that causes terrible problems."
65. "Let me know what your problem is, and I will try to make it more difficult for you."
66. "When I run into a paradox I think either I'm a total horse's ass to have gotten to this point, or I'm fruitfully near the edge of my discipline. It adds excitement to life to wonder which it is."
67. "Strategic plans cause more dumb decisions than anything else in America."
68. "For years I have read the morning paper and harrumphed. There's a lot to harrumph about now."
69. "In engineering, people have a big margin of safety. But in the financial world, people don't give a damn about safety. They let it balloon and balloon and balloon. It's aided by false accounting."
70. "You're looking for a mispriced gamble. That's what investing is. And you have to know enough to know whether the gamble is mispriced. That's value investing."
71. "The way to win is to work, work, work, work and hope to have a few insights. And you're probably not going to be smart enough to find thousands in a lifetime. And when you get a few, you really load up. It's just that simple."
72. "It is remarkable how much long-term advantage people like us have gotten by trying to be consistently not stupid, instead of trying to be very intelligent."
73. "We tend to buy things--a lot of things--where we don't know exactly what will happen, but the outcome will be decent."
74. "Failure to handle psychological denial is a common way for people to go broke: You have made an enormous commitment to something. You have poured effort and money in. And the more you put in, the more that the whole consistency principle makes you think, 'Now it has to work. If I put in just a little more, then it will work.'"
75. "People calculate too much and think too little."
76. "We don't train executives. We find them. If a mountain stands up like Everest, you don't have to be a genius to figure out that it's a high mountain."
77. "Those who will not face improvements because they are changes, will face changes that are not improvements."
78. "It's stupid the way people extrapolate the past. And not slightly stupid, but massively stupid."
79. "In my life there are not that many questions I can't properly deal with using my $40 adding machine and dog-eared compound interest table."
80. "If you don't keep learning, other people will pass you by. Temperament alone won't do it. You need a lot of curiosity."
81. "The harder you work, the more confidence you get. But you may be working hard on something that is false."
82. "I did not succeed in life by intelligence. I succeeded because I have a long attention span."
83. "It's not a competency if you don't know the edge of it."
84. "The game of life is the game of everlasting learning. At least it is if you want to win."
85. "We have a passion for keeping things simple."
86. "The tax code gives you an enormous advantage if you can find some things you can just sit with."
87. "We have found in a long life that one competitor is frequently enough to ruin a business."
88. "I'd rather throw a viper down my shirt front than hire a compensation consultant."
89. "Suppose you were a real estate investor with a 1/3 interest in the best apartment complex in town, the best mall, and the best office building. Would you feel like a poor, undiversified investor? No! But as soon as you get into stocks, people feel this way. Partly, people need to justify their fees."
90. "We have the same problem as everyone else: It's very hard to predict the future."
91. "Why should it be easy to do something that, if done well, two or three times, will make your family rich for life?"
92. "There are worse situations than drowning in cash and sitting, sitting, sitting. I remember when I wasn't awash in cash, and I don't want to go back."
93. "If you took our top 15 decisions out, we'd have a pretty average record. It wasn't hyperactivity, but a hell of a lot of patience. You stuck to your principles and when opportunities came along, you pounced on them with vigor."
94. "We both insist on a lot of time being available almost every day to just sit and think. That is very uncommon in American business. We read and think."
95. "Go to bed smarter than when you woke up."
96. "A great business at a fair price is superior to a fair business at a great price."
97. "Avoid working directly under somebody you don't admire and don't want to be like."
98. "Mimicking the herd invites regression to the mean."
99. "All I want to know is where I'm going to die, so I'll never go there."

We Choose to Go to the Moon Because It is Hard

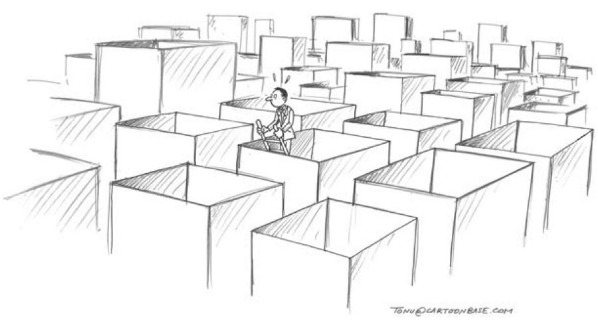
President John F. Kennedy's "We choose to go to the Moon" speech on September 12, 1962 in Rice Stadium.
We shall send to the moon 240,000 miles away, a giant rocket, more than 300 feet tall on an untried mission to an unknown celestial body, and then return it safely to Earth. But why some say the moon? Why choose this as our goal? And they may well ask, why climb the highest mountain? Why 35 years ago fly the Atlantic? We choose to go to the moon. We chose to go to the moon. We choose to go to the moon in this decade and do the other things not because they are easy, but because they are hard. Because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we're willing to accept. One we are unwilling to postpone. And therefore, as we set sail, we ask God's blessing on the most hazardous and dangerous and greatest adventure that man has ever gone.



What If?

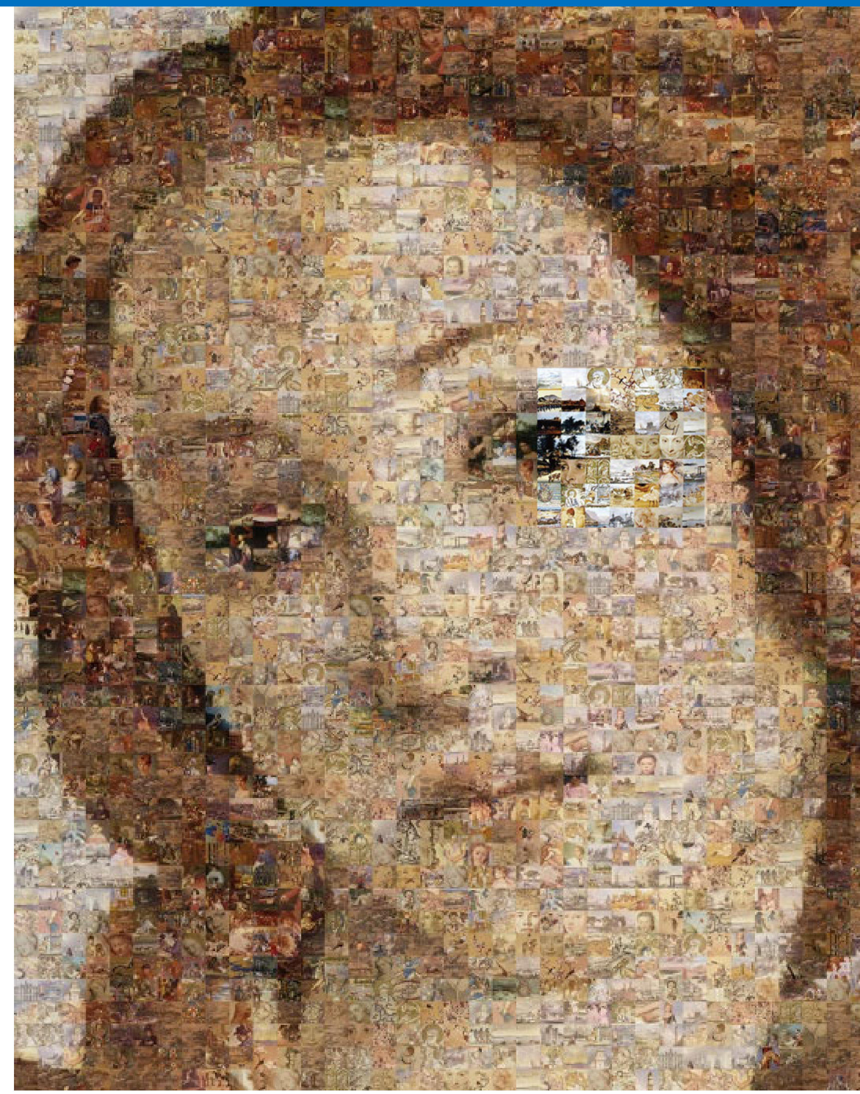
See the Big Picture

Thinking outside the box



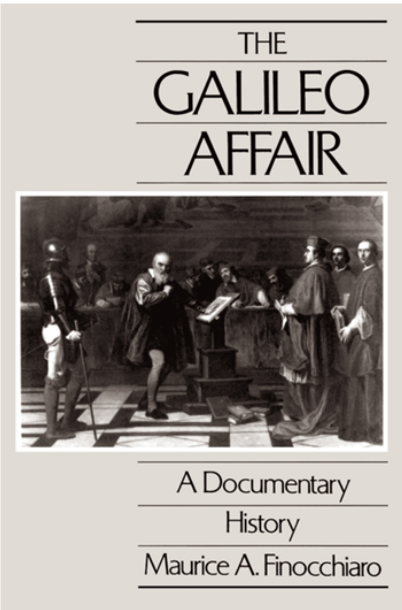
Source: Tonu of CartoonBase

THE FIRST "OUTSIDE THE BOX" BOX



The Galileo Affair

Galileo Galilei: the Father of Modern Science



sketch of a philosophical approach to its study. By the "Galileo affair"[1] is meant the sequence of developments which began in 1613 and culminated with the trial and condemnation of Galileo Galilei by the Roman Catholic Inquisition in 1633. Galileo Galilei is the Italian scientist and philosopher whose contributions to astronomy, physics, and scientific instrumentation and methodology in general were so numerous and crucial that, of the several founders of modern science, he is usually singled out as the "Father of Modern Science." The approach to be

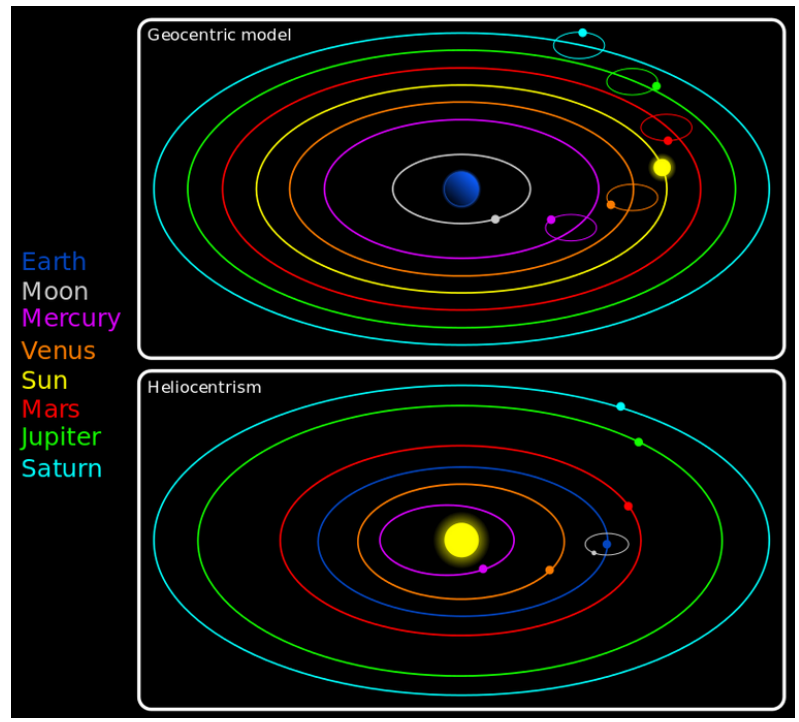
Copernicus's challenge to traditional ideas. Copernicus was able to demonstrate that the known details about the motions of the heavenly bodies could be explained more simply and more coherently if the sun rather than the earth is assumed to be at the center and the earth is taken to be the third planet circling the sun. --- Copernicus was able to explain many phenomena in detail by means of his basic assumption of a moving earth, without having to add artificial and ad hoc assumptions; the phenomena in question were primarily the various known facts about the motions and orbits of the planets.

On the other hand, in the previous geostatic system, the thesis of a motionless earth had to be combined with a whole series of unrelated assumptions in order to explain what is observed to happen.

Galileo believed not only that the geokinetic theory was simpler and more coherent than the geostatic theory (as Copernicus had shown), not only that it was more physically and mechanically adequate, but also that it was empirically superior in astronomy.

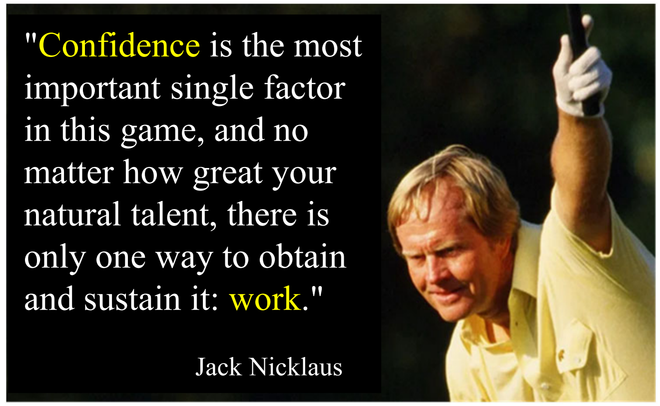
Discovered a new instrument called the spyglass in 1609

An 1857 painting of Galileo being investigated for his heliocentric beliefs. (How It Works, Issue 179, 2023)



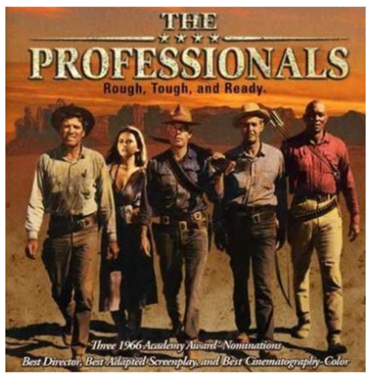
http://origins.osu.edu/milestones/february-2016-400-years-ago-catholic-church-prohibited-copernicanism

A True Professional: Get the job done!



We don't have to be superstars or win championships… All we have to do is learn to **rise to every occasion, give our best effort**, and make those around us better as we do it. (John Wooden, UCLA basketball coach)

Integrity. Integrity means doing the right thing, even when nobody's watching. A true professional won't take shortcuts just because they know they can get away with it. They give their best effort to every task set before them and can always feel proud about their day's work. https://www.zippia.com/advice/professionalism/



A professional is someone who can do his best work when he doesn't feel like it. (Alistair Cooke, British Journalist and Broadcaster)

Your Priorities in Life

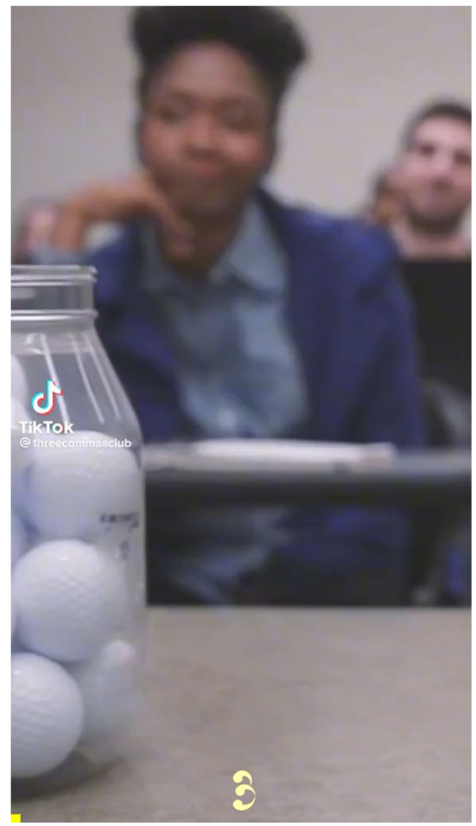
ZeFrank is the executive vice president of video at BuzzFeed and a pioneer in "vlogging."

The average American will live approximately 28,835 days. From the first 365 days of being alive to the average 8,477 days we will spend sleeping. The thousands of days that the average American spends watching television, eating and sleeping is juxtaposed with the mere 564 days we will spend caring for our family and friends. As the video nears its end, 2,740 Jelly Beans remain unaccounted for. These Jelly Beans remain after all necessary tasks have been finished. Many students are nearing graduation next spring and are just about to enter the 3,202 Jelly Beans jellybean days that they will spend working in the professional world. The graduating students who have yet to find a job are placed in a new pile of Jelly Beans, whether it be the Jelly Bean pile of sleeping and errands or a pile of community obligations. As winter break looms, those of us still unemployed and not attending winter session could put our free 2,740 Jelly Bean days into use. Rather than tossing the 2,740 Jelly Bean days aside and stressing about an unknown future, students should try to make every Jelly Bean count.

The biggest tragedy in our 20s would be throwing our Jelly Beans away by worrying about external variables outside of our control. These external variables change from person to person but can include financial hardship or not having a job. Say 100 of the 2,740 Jelly Bean days will be used to learn a new trade or skill. Those 100 Jelly Beans will affect the rest of the Jelly Beans from that point on. Each Jelly Bean will carry a little more weight because you, the Jelly Bean holder, can put more emphasis on each Jelly Bean.

As college students lost in the stress of the unknown in our 20s, we may forget how valuable each Jelly Bean is. While being 20-somethings, hundreds of the 2,740 of the unaccounted Jelly Beans can become the basis for how we use the rest of our Jelly Beans after graduation. If you had one more day or Jelly Bean, how would you use it?

https://daily49er.com/opinions/2013/12/02/jelly-bean-inspired-video-should-inspire-young-people-to-live/
https://www.cbc.ca/strombo/news/amazing-video-maps-out-your-whole-life-in-jellybeans.html

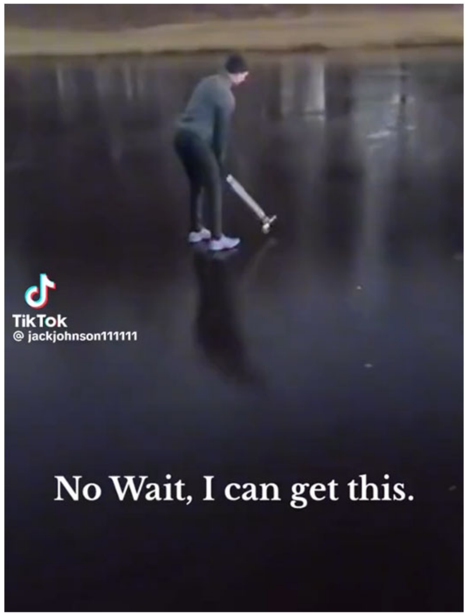


Set your priorities

Live a little

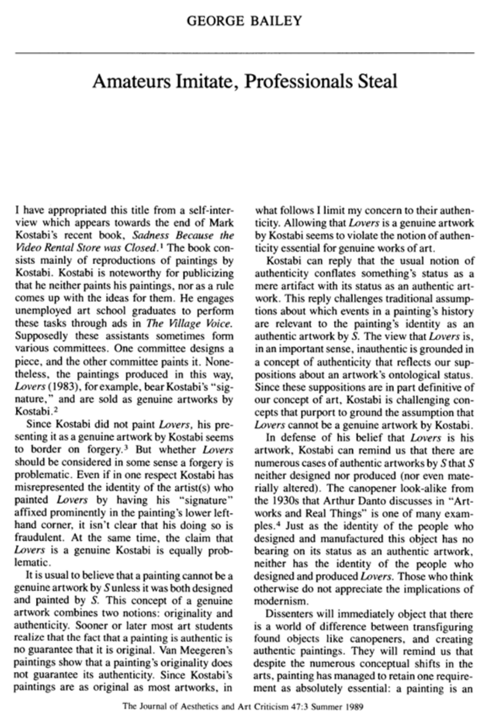
Amateurs vs. Professionals

Amateurs



Professionals

Amateurs imitate, Professionals steal



GEORGE BAILEY

Amateurs Imitate, Professionals Steal

I have appropriated this title from a self-interview which appears towards the end of Mark Kostabi's recent book, *Sadness Because the Video Rental Store was Closed*.[1] The book consists mainly of reproductions of paintings by Kostabi. Kostabi is noteworthy for publicizing that he neither paints his paintings, nor as a rule comes up with the ideas for them. He engages unemployed art school graduates to perform these tasks through ads in *The Village Voice*. Supposedly these assistants sometimes form various committees. One committee designs a piece, and the other committee paints it. Nonetheless, the paintings produced in this way, *Lovers* (1983), for example, bear Kostabi's "signature," and are sold as genuine artworks by Kostabi.[2]

Since Kostabi did not paint *Lovers*, his presenting it as a genuine artwork by Kostabi seems to border on forgery.[3] But whether *Lovers* should be considered in some sense a forgery is problematic. Even if in one respect Kostabi has misrepresented the identity of the artist(s) who painted *Lovers* by having his "signature" affixed prominently in the painting's lower left-hand corner, it isn't clear that his doing so is fraudulent. At the same time, the claim that *Lovers* is a genuine Kostabi is equally problematic.

It is usual to believe that a painting cannot be a genuine artwork by *S* unless it was both designed and painted by *S*. This concept of a genuine artwork combines two notions: originality and authenticity. Sooner or later most art students realize that the fact that a painting is authentic is no guarantee that it is original. Van Meegeren's paintings show that a painting's originality does not guarantee its authenticity. Since Kostabi's paintings are as original as most artworks, in what follows I limit my concern to their authenticity. Allowing that *Lovers* is a genuine artwork by Kostabi seems to violate the notion of authenticity essential for genuine works of art.

Kostabi can reply that the usual notion of authenticity conflates something's status as a mere artifact with its status as an authentic artwork. This reply challenges traditional assumptions about which events in a painting's history are relevant to the painting's identity as an authentic artwork by *S*. The view that *Lovers* is, in an important sense, inauthentic is grounded in a concept of authenticity that reflects our suppositions about an artwork's ontological status. Since these suppositions are in part definitive of our concept of art, Kostabi is challenging concepts that purport to ground the assumption that *Lovers* cannot be a genuine artwork by Kostabi.

In defense of his belief that *Lovers* is his artwork, Kostabi can remind us that there are numerous cases of authentic artworks by *S* that *S* neither designed nor produced (nor even materially altered). The canopener look-alike from the 1930s that Arthur Danto discusses in "Artworks and Real Things" is one of many examples.[4] Just as the identity of the people who designed and manufactured this object has no bearing on its status as an authentic artwork, neither has the identity of the people who designed and produced *Lovers*. Those who think otherwise do not appreciate the implications of modernism.

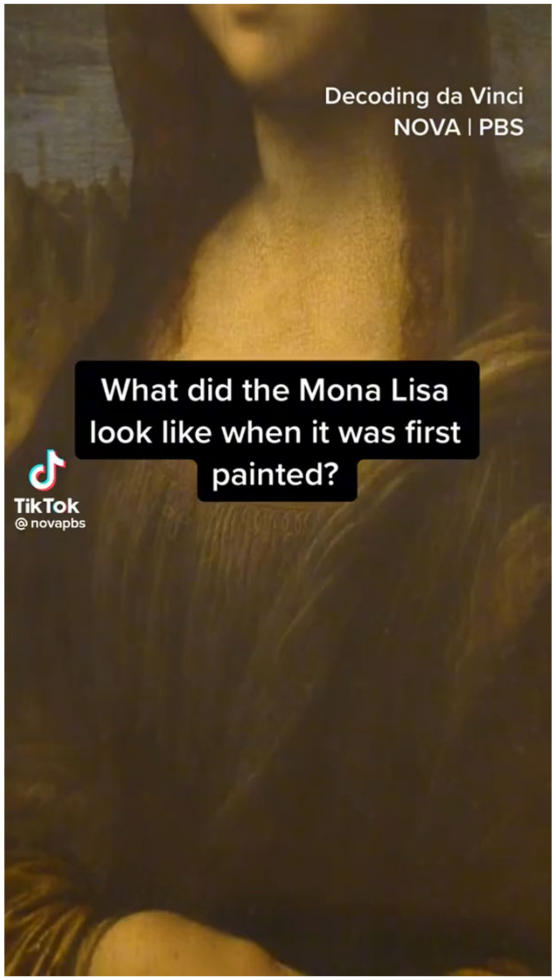
Dissenters will immediately object that there is a world of difference between transfiguring found objects like canopeners, and creating authentic paintings. They will remind us that despite the numerous conceptual shifts in the arts, painting has managed to retain one requirement as absolutely essential: a painting is an

The Journal of Aesthetics and Art Criticism 47:3 Summer 1989

Bailey 1989, Amateurs imitate, professionals steal
https://www.theartstory.org/artist/kostabi-mark/

James Brown: The father of funk, the godfather of soul.
https://www.theguardian.com/music/musicblog/2015/oct/28/james-brown-10-of-the-best

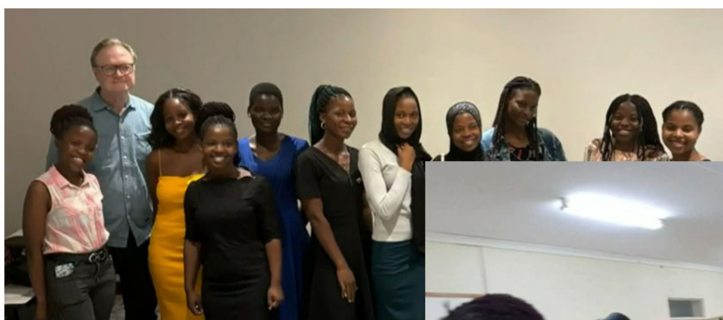
The True Boilermaker



"When I let go of what I am, I become what I might be."

"Watch your thoughts, they become your words; Watch your words, they become your actions;
Watch your actions, they become your habits; Watch your habits, they become your character;
Watch your character, it becomes your destiny." Lao Tzu

Little by Little (Joyce Chisale)



Little by little we'll go…
No matter how far the distance is…
We are not shaken…

Little by little we'll go and reach our destination…

Little by little we'll go…
No matter how bumpy the road gets…
We're not going to turn back…

Little by little we'll go no matter how narrow the path is…
We are going to force ourselves to pass…

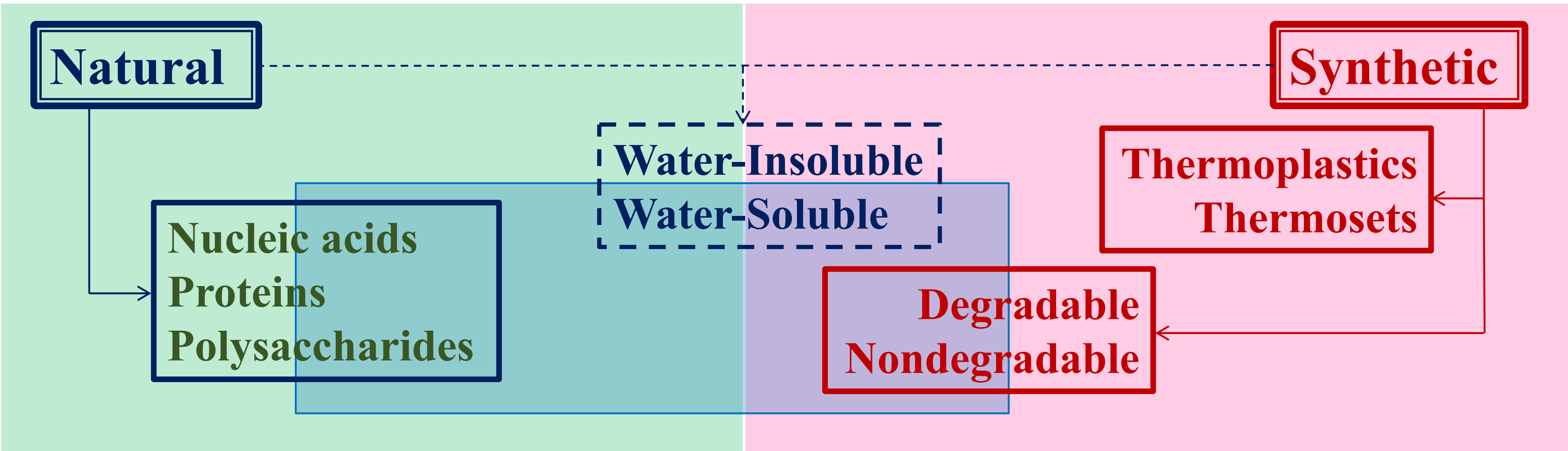
Little by little we'll go and reach the promised land…
Don't be shaken…Don't turn back…

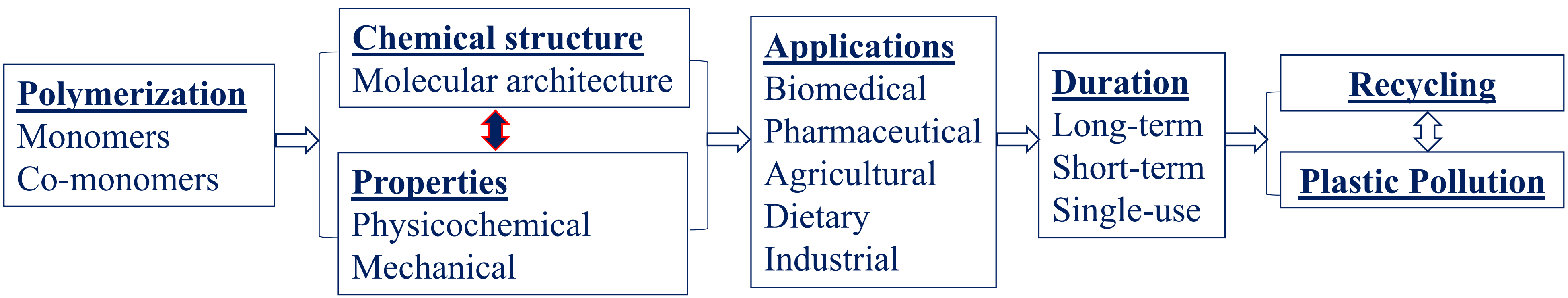
Little by little we'll go and reach our destination…

Lawrence O'Donnell in Malawi " Little by Little" (11/29/2016)
The KIND Fund (kids in need of desks) sponsored by UNICEF USA & MSNBC
https://www.youtube.com/watch?v=OlVUwLSFUd8
https://medium.com/@unicef_malawi/little-by-little-malawian-school-girl-follows-her-dreams-752e1931b324
https://artsalazar.wordpress.com/2016/12/04/little-by-little/
https://www.msnbc.com/the-last-word/watch/joyce-chisale-i-couldn-t-have-been-in-medical-school-without-k-i-n-d-198352965720

1. Introduction to Polymers

Polymers: The Big Picture





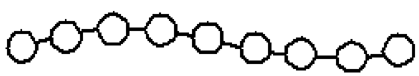
Polymers: Definitions

Monomer

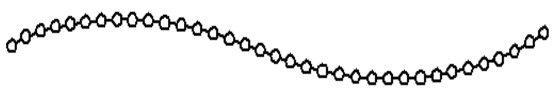
Dimer

Trimer

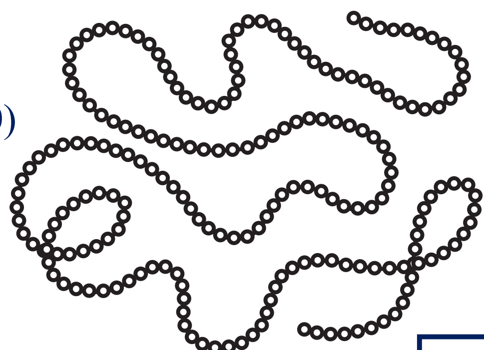
Multimer



Oligomer
(N = 30~200)



Polymer
(N = >200)



Polymer: A substance whose molecules consist of many parts (or units)
(Polymeros = Manyparts) ↔ (Macromolecule)

Long chain molecular structure
→ Many unique and useful properties

Light but stiff, strong, and tough,
Resilient,
Resistant to chemicals & corrosion,
No conductivity (temp & electricity)
Transparent or opaque
Easily processible and cheap

Molecular Weight: M_n, M_w
Number-average, Weight-avergage

Polymer Names

Polyhuman = Poly(human being)

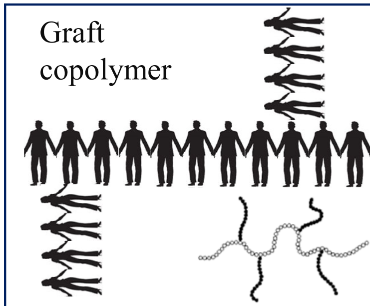
Poly(red man) = polymer of red man

Polychild = Polykid = Polymer of kids

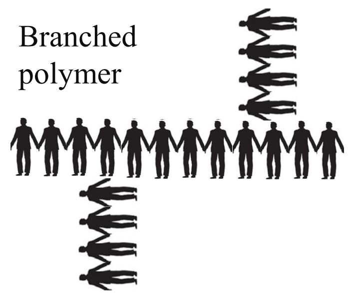
Poly(boy-co-girl), Poly(girl-co-boy),
Copolymer of boy and girl

Poly(father-co-daughter),
Copolymer of father and daughter

Graft copolymer

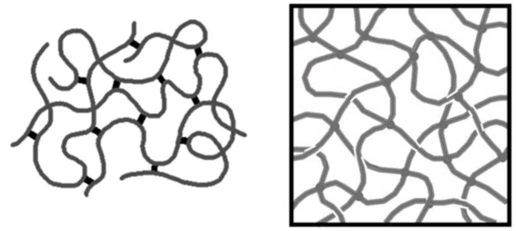


Branched polymer

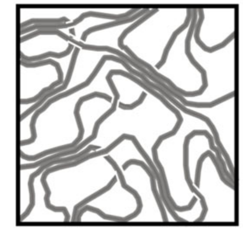


Poly(man-co-woman), Random copolymer

Poly(man-co-woman), Block copolymer

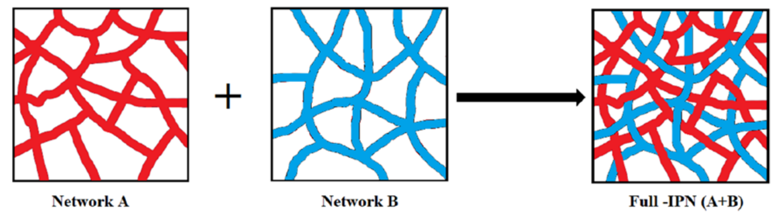


Chemically crosslinked Gel
= Chemical Gel

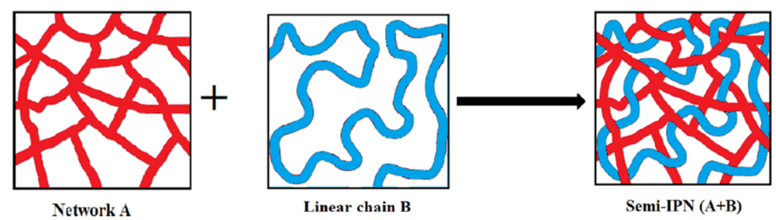


Physically crosslinked Gel
= Physical Gel

Interpenetrating Polymer Network (IPN)

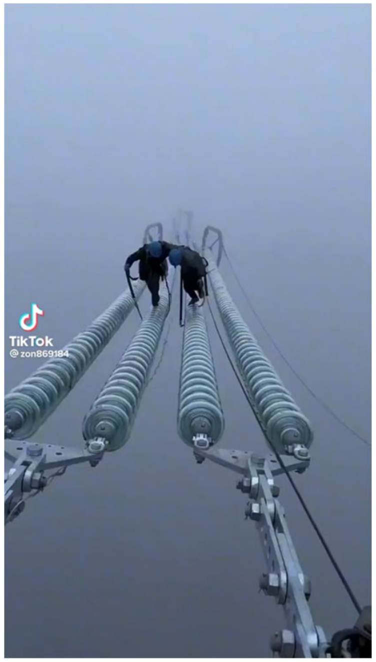


Semi-Interpenetrating Polymer Network (semi-IPN)



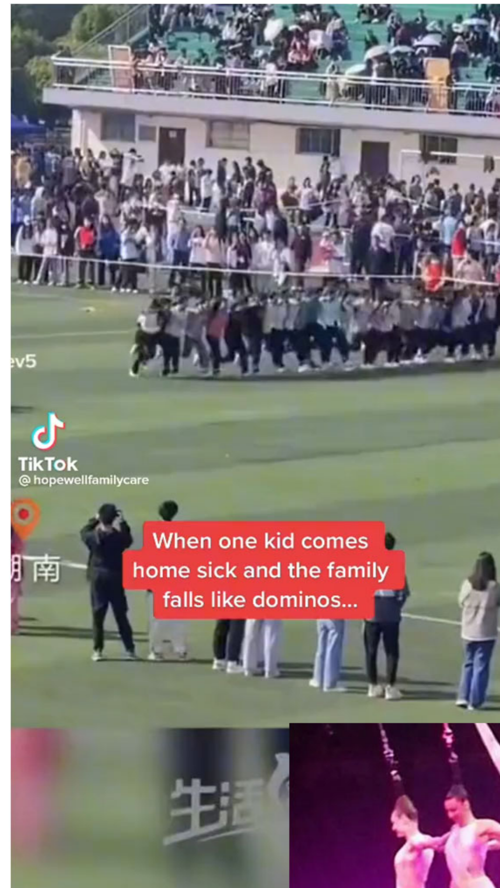
Inamdar 2018, Thermoplastic-toughened high-temperature cyanate esters and their application in advanced composites

Polymers: Unique Properties that the Monomers Do Not Have



Multiple contacts → Stronger contacts (higher affinity)

DNA:
Individual hydrogen bonding is trivial, but millions of hydrogen bonding is significant.



Hair Suspension Artists

https://www.usatoday.com/story/news/nation-now/2014/05/05/hair-hang-circus-ringling/8719429/

Polymers: Definitions

Monomer

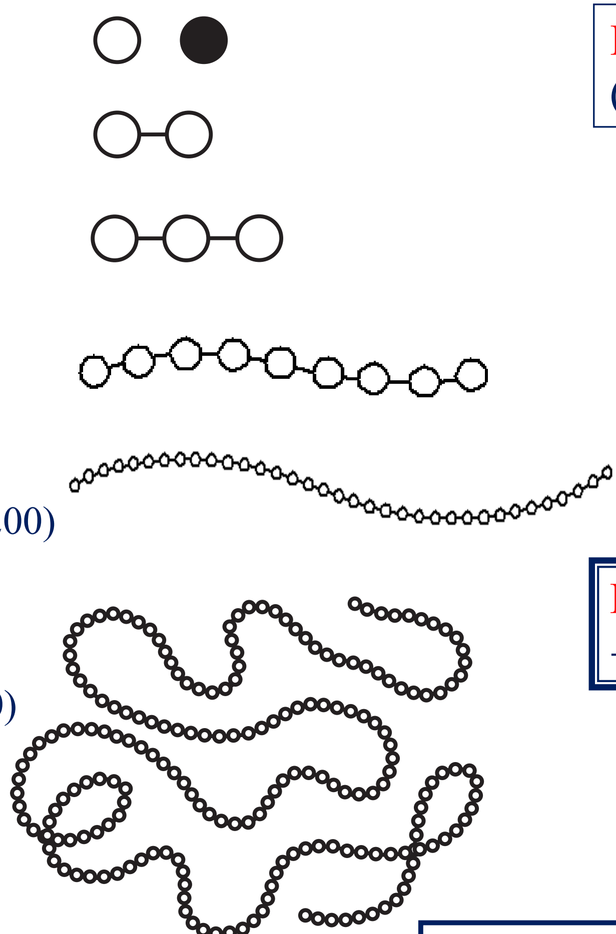
Dimer

Trimer

Multimer

Oligomer (N = 30~200)

Polymer (N = >200)



Polymer: A substance whose molecules consist of many parts (or units) (Polymeros = Manyparts) ↔ (Macromolecule)

Polymer ⊃ Plastics

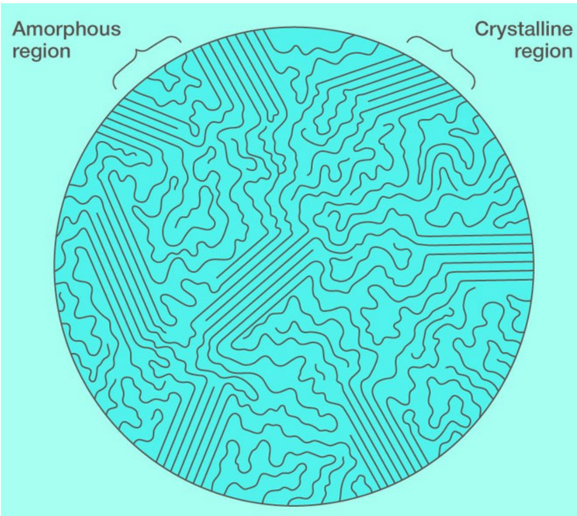
Plastic (plastikos = fit for molding, or shaping by heating): A polymer-based material that can be molded, cast, extruded, drawn, or laminated into objects, films, or filaments. (Pliable & easily shaped)

Long chain molecular structure
→ Many unique and useful properties

- Light but stiff, strong, and tough,
- Resilient,
- Resistant to chemicals & corrosion,
- No conductivity (temp & electricity)
- Transparent or opaque
- Easily processible and cheap

Molecular Weight: M_n, M_w
Number-average, Weight-avergage

Thermoplastic Polymer: Amorphous and Semicrystalline Regions

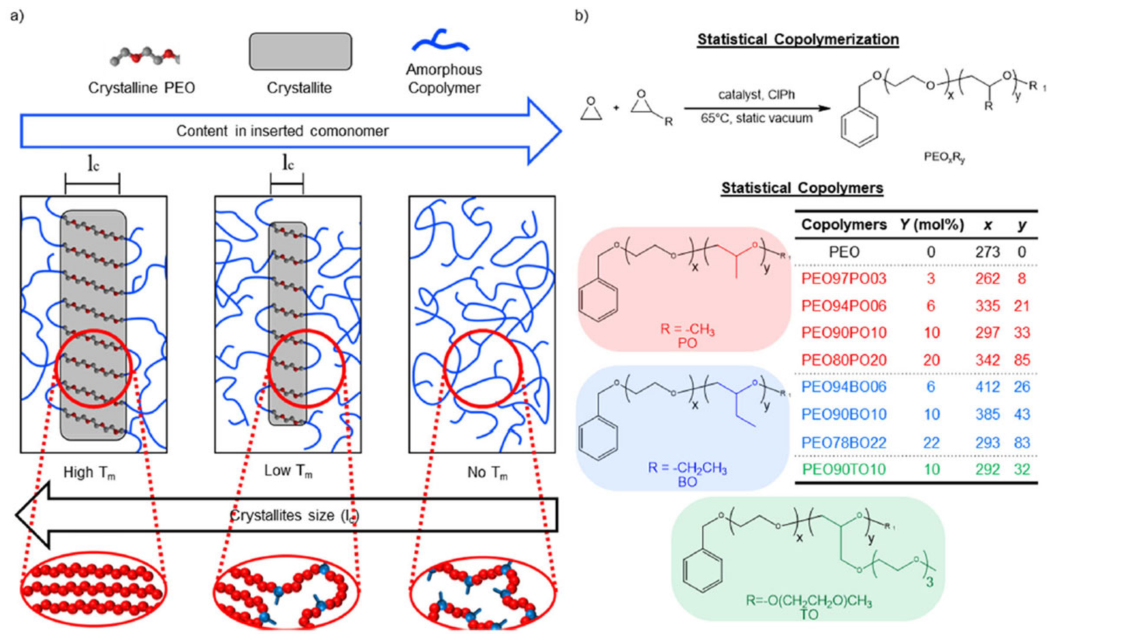


https://phys.org/news/2018-12-physicists-x-ray-polymers.html

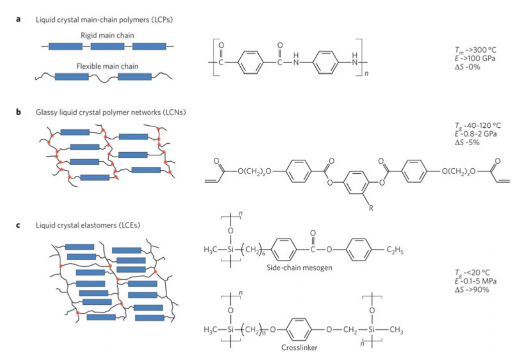
Amorphous thermoplastic materials are usually clear and stiff material with low shrinkage (e.g., polystyrene, polycarbonate, and poly(methyl methacrylate)).

Semicrystalline thermoplastic materials are generally tougher and less fragile than amorphous thermoplastics. They are translucent, or opaque, and have a high shrinkage and a high specific heat (e.g., polyethylene, polypropylene, poly(ethylene terephthalate), polyamides

https://www.azom.com/article.aspx?ArticleID=17477



St-Onge 2021, Reducing crystallinity in solid polymer electrolytes for lithium-metal batteries via statistical copolymerization



White 2015, Programmable and adaptive mechanics with liquid crystal polymer networks and elastomers

Plastics

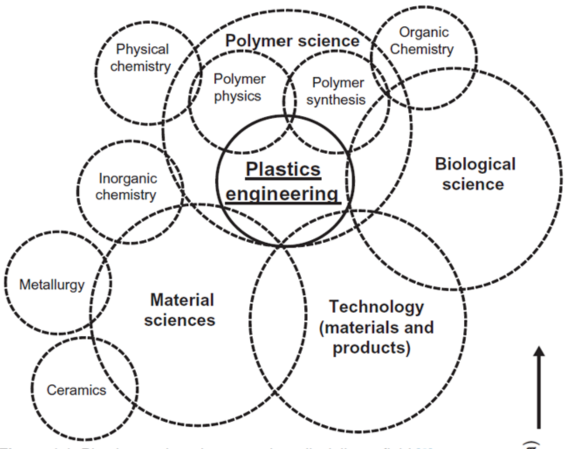
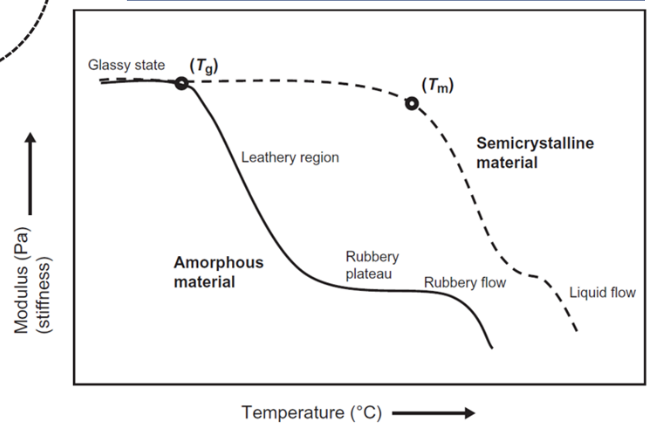


Figure 1.1 Plastics engineering as an interdisciplinary field [3].

Figure 1.5. Melting and softening behavior of semicrystalline and amorphous materials.



Temperature Dependency of Polymers

Most thermoplastics in normal room temperatures are in some sort of solid state. In the solid form, the molecular chains have limited energy available to move around. During the application of heat, the molecular chains gain energy allowing them to move farther than initially possible, and the plastic begins to expand. As the molecular chains continue to receive more energy, at some point, they gain sufficient energy to move around freely in the form of a viscous fluid also known as melt. The melt can then be shaped into various structures.

Upon cooling as the energy is extracted out from the molecular chains, the gap between the chains shrinks and the materials hardens to retain the shape. Amorphous material only indicates glass transition temperature, whereas semicrystalline temperatures indicate both glass transition and melting temperature. Melting temperature is represented by T_m.

Shrivastava 2018, Introduction to plastic engineering

Glass Transition Temperature (T_g) and Melting Temperature (T_m)

Glass transition temperature is described as **the temperature at which 30-50 carbon chains start to move**. At the glass transition temperature, the amorphous regions experience transition from rigid state to more flexible state making the temperature at the border of the solid state to rubbery state. It is also said that at this temperature **the free volume** (gap between the molecular chains) increases by 2.5 time. Glass transition temperature, T_g, is a property of the amorphous materials or the amorphous portion of a semicrystalline materials. When the ambient temperature is below T_g, the molecular chains of amorphous materials are frozen in place and behave like solid glass. Plastic materials with flexible backbone show lower T_g, whereas plastic materials whose molecular structure is stiff, rigid, and inflexible show a higher T_g. Glass transition temperature helps determine various flexible and rigid applications for a material.

Melting point also known as melt temperature is the critical temperature above which the crystalline regions in a semicrystalline plastic are able to flow. Semicrystalline polymers begin to soften above T_g, however, they do not demonstrate fluid behavior until the T_m range is achieved. In general, T_m for a semicrystalline polymer is higher than its T_g. At temperature above T_g but below T_m, there is a "rubbery region," where the material can exhibit large elongations under relatively low load. Plastic materials are made up of uneven chain lengths and require different amount of energy to move which means that T_g or T_m for amorphous and semicrystalline polymers is not one definite temperature but a range of temperature during which all the chains start to move and experience complete flow. Fig. 1.5 illustrates the melting and softening phenomenon of amorphous materials. At temperature above melting point, semicrystalline plastics exhibit a rapid phase change from solids to viscous liquids that can be molded or given shapes. Even though, amorphous material starts transitioning into leathery region at T_g and continues to soften over a wide range of temperature. Fig. 1.5 also illustrates that as temperature increases above T_g, amorphous materials quickly lose their strength and the semicrystalline materials continue to maintain their mechanical properties until the temperature increases to reach T_m.

Glass Transition Temperature (T_g) & Winter Tires

Engineering High-Performance Winter Tires

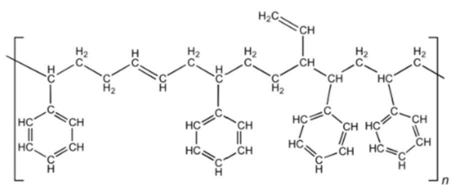
Natural rubber - cis-1,4 polyisoprene $(C_5H_8)_n$ is an organic compound that exhibits stretchy properties from weak C-H bonds. It is collected as latex from rubber trees and refined into rubber. Sensitive to both temperature and atmospheric oxidation, engineers often vulcanize natural rubber to crosslink the polymer chains.

Synthetic rubber - formulators make styrene-butadiene rubber by thermally cracking naphtha from petroleum. More chemically consistent than the natural material, synthetic rubber augments the raw material taken from rubber trees to provide the base for the tire material.

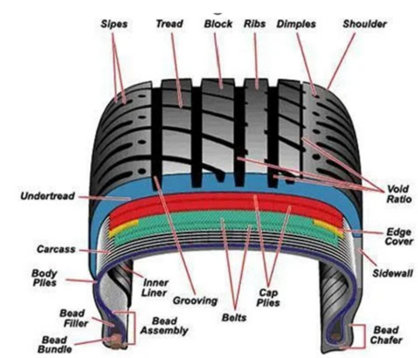
Sulfur - a critical component in rubber vulcanization, formulators mix sulfur with rubber and heat to between 140-160 °C to form crosslinks between isoprene polymers. Natural rubber has low intermolecular strength, and the vulcanization process improves the rubber's resistance to oxidation and reduces its thermal sensitivity.

Carbon black - used to optimize handling, reduce friction wear and hysteresis, and improve abrasion resistance, carbon black is a powder form of carbon that reinforces the tire rubber. It also offers UV resistance to prevent tire rot.

https://www.engineering.com/story/engineering-high-performance-winter-tires



Styrene-Butadiene Rubber (SBR)



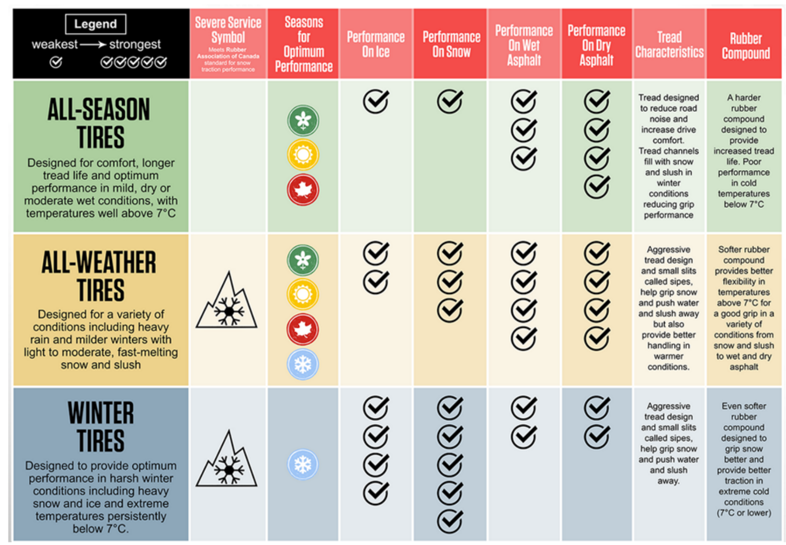
Snow Tires Are Designed for Winter: Snow tires are uniquely designed to improve traction in snowy and icy conditions. Regular tires are not. There are three main features that set winter tires apart from regular tires: rubber composition, tread depth and pattern, and biting edges.

Rubber Composition: Winter tires are made with a special rubber that works best in cold temperatures. The rubber is designed to stay soft and pliable when the weather cools so your tires can maintain adequate grip and traction. The rubber in regular tires (even all-season tires) stiffens in the cold, which reduces traction.

Tread Depth and Pattern: Winter tires have deeper tread depths than regular tires, especially performance tires. Deeper tread depths improve traction in the snow and lessen snow buildup. In addition to deep treads, winter tires also have unique tread patterns, or grooves. These special grooves help prevent hydroplaning by efficiently pumping water through the tread. Moisture is essentially pushed out and away from the tire so your wheel can make solid contact with dry ground.

Biting Edges: Winter tires have a series of zig-zag grooves covering their tread. And you guessed it! Regular tires do not. These grooves act as biting edges to grip the road in snow or ice. Watch this video about Blizzak winter tire technology to learn more about biting edges!

https://www.firestonecompleteautocare.com/blog/tires/difference-between-snow-tires-regular-tires/

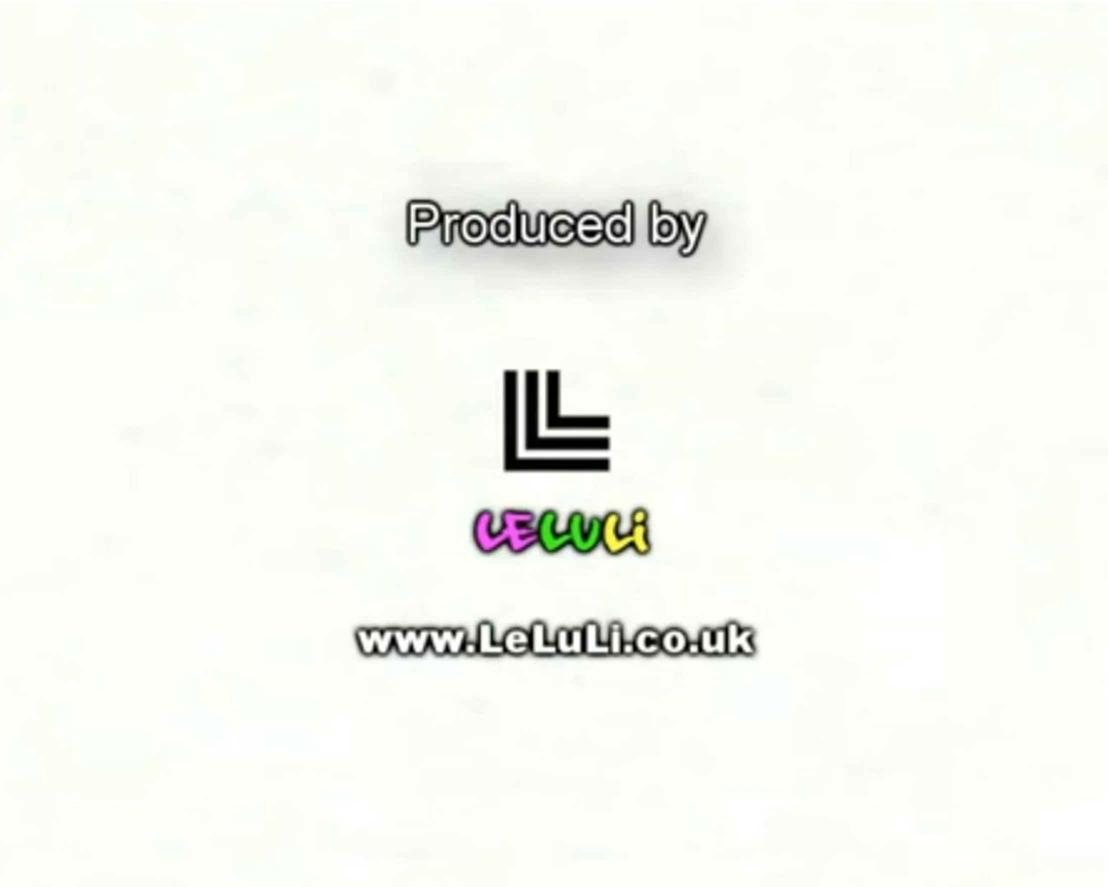


Legend: weakest ✓ → strongest ✓✓✓✓✓	Severe Service Symbol (Meets Rubber Association of Canada standard for snow traction performance)	Seasons for Optimum Performance	Performance On Ice	Performance On Snow	Performance On Wet Asphalt	Performance On Dry Asphalt	Tread Characteristics	Rubber Compound
ALL-SEASON TIRES Designed for comfort, longer tread life and optimum performance in mild, dry or moderate wet conditions, with temperatures well above 7°C			✓	✓	✓✓✓	✓✓✓✓	Tread designed to reduce road noise and increase drive comfort. Tread channels fill with snow and slush in winter conditions reducing grip performance	A harder rubber compound designed to provide increased tread life. Poor performamce in cold temperatures below 7°C
ALL-WEATHER TIRES Designed for a variety of conditions including heavy rain and milder winters with light to moderate, fast-melting snow and slush			✓✓	✓✓✓	✓✓✓✓	✓✓✓✓	Aggressive tread design and small slits called sipes, help grip snow and push water and slush away but also provide better handling in warmer conditions.	Softer rubber compound provides better flexibility in temperatures above 7°C for a good grip in a variety of conditions from snow and slush to wet and dry asphalt
WINTER TIRES Designed to provide optimum performance in harsh winter conditions including heavy snow and ice and extreme temperatures persistently below 7°C.			✓✓✓✓	✓✓✓✓✓	✓✓	✓✓	Aggressive tread design and small slits called sipes, help grip snow and push water and slush away.	Even softer rubber compound designed to grip snow better and provide better traction in extreme cold conditions (7°C or lower)

https://www.draytonvalleyford.com/2021/09/14/do-winter-tires-really-make-a-difference.html

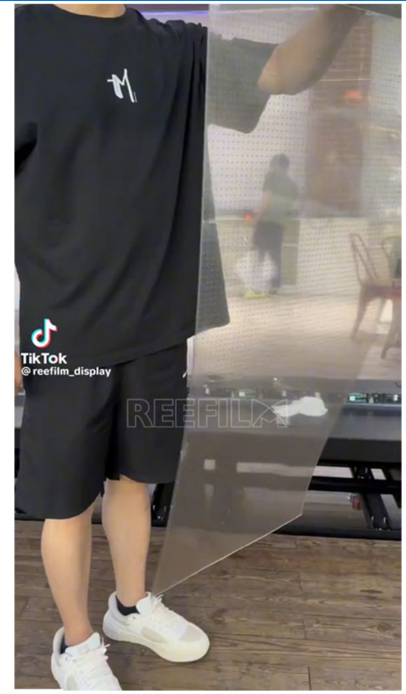
https://gobigo.ca/all-season-vs-winter-vs-all-weather-tires/

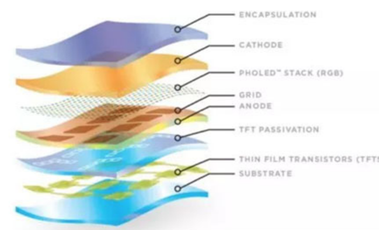
Polymers & Plastics

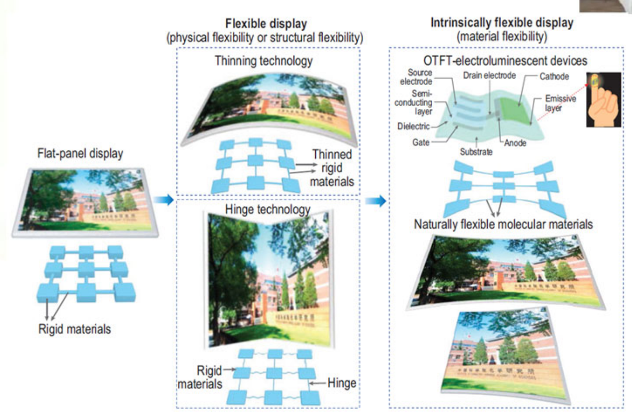


http://www.bpf.co.uk/plastipedia/plastics_history/default.aspx

Sabrina. 1954

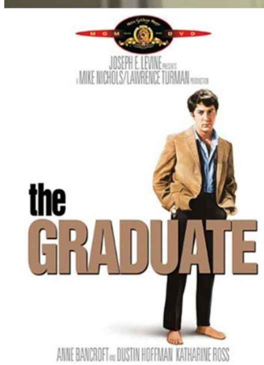






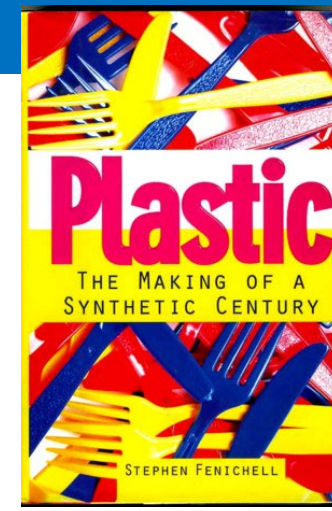
Zhao 2022, Intrinsically flexible displays- Key materials and devices

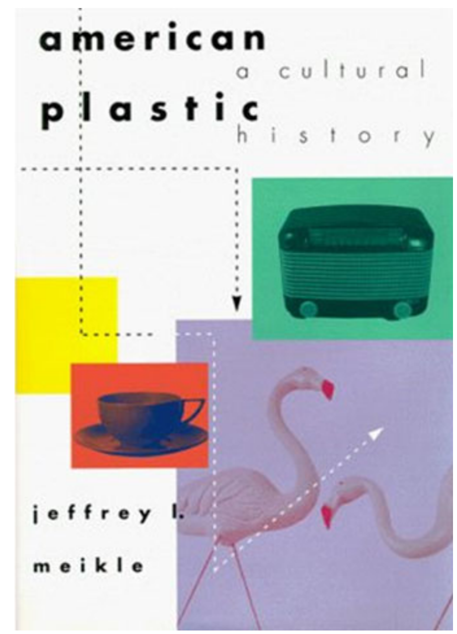
Plastics



The Graduate. 1967

“One word. Just one word: Plastics. There’s a great future in plastics.”





Natural Polymers

5 Chapter Review

SUMMARY OF KEY CONCEPTS

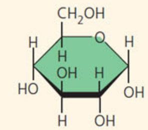
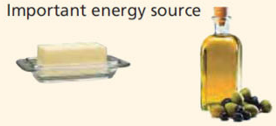
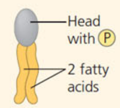
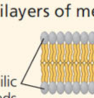
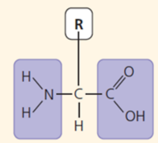
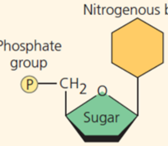
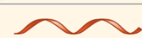
CONCEPT 5.1

Macromolecules are polymers, built from monomers *(pp. 67–68)*

VOCAB SELF-QUIZ goo.gl/6u55ks

- Large carbohydrates (polysaccharides), proteins, and nucleic acids are **polymers**, which are chains of **monomers**. The components of lipids vary. Monomers form larger molecules by **dehydration reactions**, in which water molecules are released. Polymers can disassemble by the reverse process, **hydrolysis**. An immense variety of polymers can be built from a small set of monomers.

? *What is the fundamental basis for the differences between large carbohydrates, proteins, and nucleic acids?*

Large Biological Molecules	Components	Examples	Functions
CONCEPT 5.2 **Carbohydrates serve as fuel and building material** *(pp. 68–72)* ? *Compare the composition, structure, and function of starch and cellulose. What role do starch and cellulose play in the human body?*	 Monosaccharide monomer	**Monosaccharides:** glucose, fructose **Disaccharides:** lactose, sucrose	Fuel; carbon sources that can be converted to other molecules or combined into polymers
		Polysaccharides: ▪ Cellulose (plants) ▪ Starch (plants) ▪ Glycogen (animals) ▪ Chitin (animals and fungi)	▪ Strengthens plant cell walls ▪ Stores glucose for energy ▪ Stores glucose for energy ▪ Strengthens exoskeletons and fungal cell walls
CONCEPT 5.3 **Lipids are a diverse group of hydrophobic molecules** *(pp. 72–75)* ? *Why are lipids not considered to be polymers or macromolecules?*		**Triacylglycerols** (fats or oils): glycerol + three fatty acids	Important energy source 
		**Phospholipids:** glycerol + phosphate group + two fatty acids	Lipid bilayers of membranes 
	 Steroid backbone	**Steroids:** four fused rings with attached chemical groups	▪ Component of cell membranes (cholesterol) ▪ Signaling molecules that travel through the body (hormones)
CONCEPT 5.4 **Proteins include a diversity of structures, resulting in a wide range of functions** *(pp. 75–83)* ? *Explain the basis for the great diversity of proteins.*	 Amino acid monomer (20 types)	▪ Enzymes ▪ Defensive proteins ▪ Storage proteins ▪ Transport proteins ▪ Hormones ▪ Receptor proteins ▪ Motor proteins ▪ Structural proteins	▪ Catalyze chemical reactions ▪ Protect against disease ▪ Store amino acids ▪ Transport substances ▪ Coordinate organismal responses ▪ Receive signals from outside cell ▪ Function in cell movement ▪ Provide structural support
CONCEPT 5.5 **Nucleic acids store, transmit, and help express hereditary information** *(pp. 84–86)* ? *What role does complementary base pairing play in the functions of nucleic acids?*	 Nucleotide (monomer of a polynucleotide)	**DNA:**  ▪ Sugar = deoxyribose ▪ Nitrogenous bases = C, G, A, T ▪ Usually double-stranded	Stores hereditary information
		RNA:  ▪ Sugar = ribose ▪ Nitrogenous bases = C, G, A, U ▪ Usually single-stranded	Various functions in gene expression, including carrying instructions from DNA to ribosomes

Urry 2021, The structure and function of large biological molecules

Natural Polymers: Deoxyribonucleic acid & Ribonucleic acid

Nucleic acids are composed of monomers known as nucleotides (= polynucleotides)
Each nucleotide consists of a phosphate, a pentose sugar (deoxyribose for DNA and ribose for RNA), and a nitrogenous base.

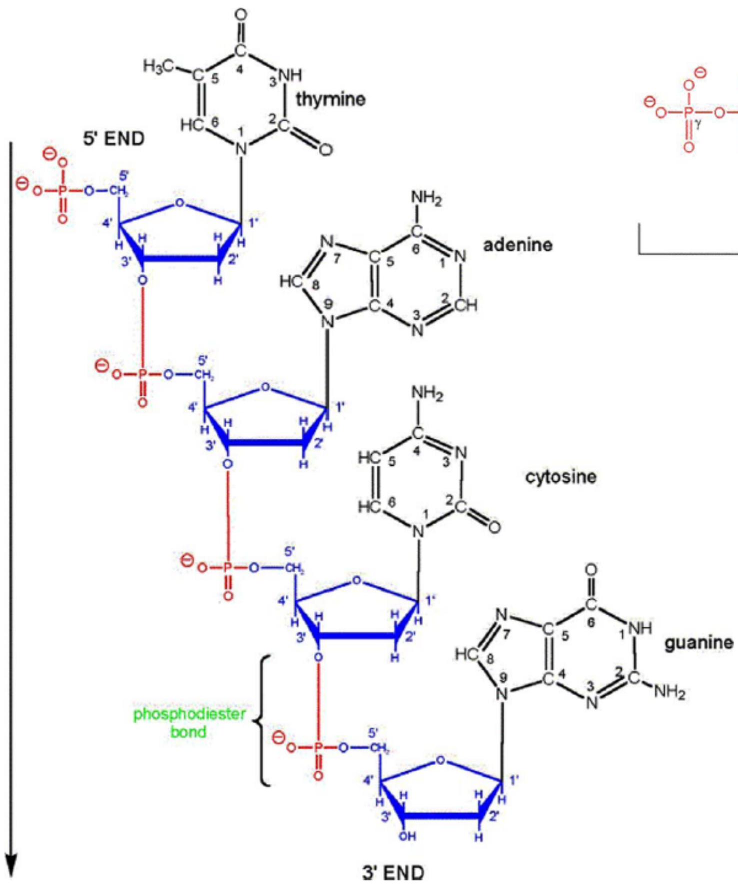
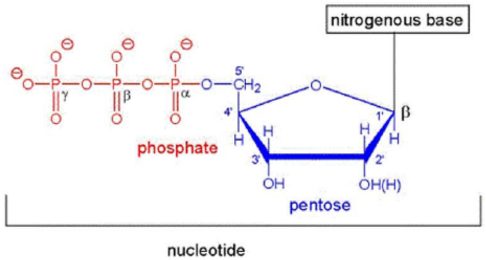
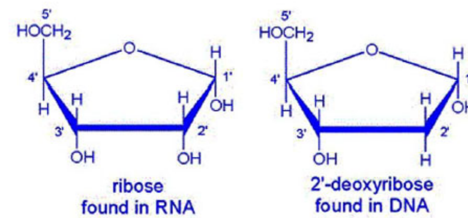
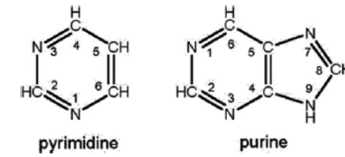
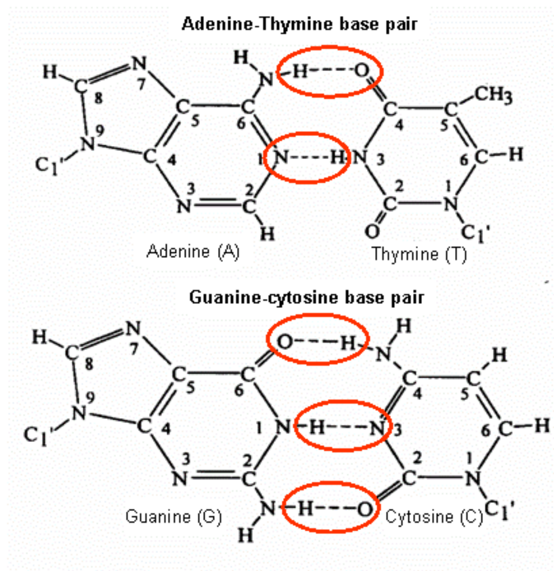


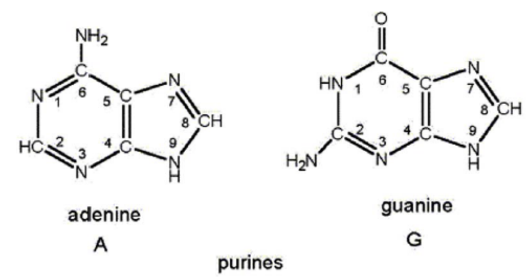
Fig. 13 DNA polarity. A single-stranded DNA molecule of the sequence TACG as written in the direction of the arrow, from the 5′ to 3′ end of the molecule.

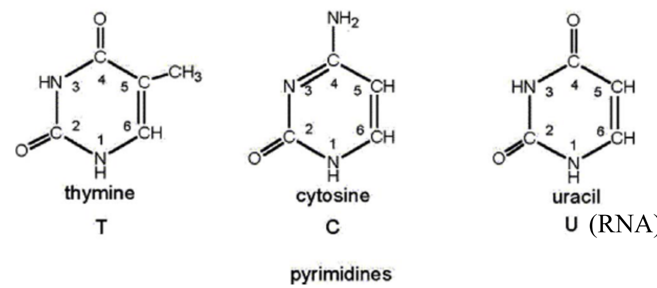












Scofield 2007, Nucleic acids

DNA

MOLECULAR STRUCTURE OF NUCLEIC ACIDS

A Structure for Deoxyribose Nucleic Acid

WE wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A.). This structure has novel features which are of considerable biological interest.

A structure for nucleic acid has already been proposed by Pauling and Corey[1]. They kindly made their manuscript available to us in advance of publication. Their model consists of three inter-twined chains, with the phosphates near the fibre axis, and the bases on the outside. In our opinion, this structure is unsatisfactory for two reasons: (1) We believe that the material which gives the X-ray diagrams is the salt, not the free acid. Without the acidic hydrogen atoms it is not clear what forces would hold the structure together, especially as the negatively charged phosphates near the axis will repel each other. (2) Some of the van der Waals distances appear to be too small.

Another three-chain structure has also been suggested by Fraser (in the press). In his model the phosphates are on the outside and the bases on the inside, linked together by hydrogen bonds. This structure as described is rather ill-defined, and for this reason we shall not comment on it.

We wish to put forward a radically different structure for the salt of deoxyribose nucleic acid. This structure has two helical chains each coiled round the same axis (see diagram). We have made the usual chemical assumptions, namely, that each chain consists of phosphate di-ester groups joining β-D-deoxyribofuranose residues with 3',5' linkages. The two chains (but not their bases) are related by a dyad perpendicular to the fibre axis. Both chains follow right-handed helices, but owing to the dyad the sequences of the atoms in the two chains run in opposite directions. Each chain loosely resembles Furberg's[2] model No. 1; that is, the bases are on the inside of the helix and the phosphates on the outside. The configuration of the sugar and the atoms near it is close to Furberg's 'standard configuration', the sugar being roughly perpendicular to the attached base. There is a residue on each chain every 3·4 A. in the z-direction. We have assumed an angle of 36° between adjacent residues in the same chain, so that the structure repeats after 10 residues on each chain, that is, after 34 A. The distance of a phosphorus atom from the fibre axis is 10 A. As the phosphates are on the outside, cations have easy access to them.

The structure is an open one, and its water content is rather high. At lower water contents we would expect the bases to tilt so that the structure could become more compact.

The novel feature of the structure is the manner in which the two chains are held together by the purine and pyrimidine bases. The planes of the bases are perpendicular to the fibre axis. They are joined together in pairs, a single base from one chain being hydrogen-bonded to a single base from the other chain, so that the two lie side by side with identical z-co-ordinates. One of the pair must be a purine and the other a pyrimidine for bonding to occur. The hydrogen bonds are made as follows: purine position 1 to pyrimidine position 1; purine position 6 to pyrimidine position 6.

If it is assumed that the bases only occur in the structure in the most plausible tautomeric forms (that is, with the keto rather than the enol configurations) it is found that only specific pairs of bases can bond together. These pairs are: adenine (purine) with thymine (pyrimidine), and guanine (purine) with cytosine (pyrimidine).

In other words, if an adenine forms one member of a pair, on either chain, then on these assumptions the other member must be thymine; similarly for guanine and cytosine. The sequence of bases on a single chain does not appear to be restricted in any way. However, if only specific pairs of bases can be formed, it follows that if the sequence of bases on one chain is given, then the sequence on the other chain is automatically determined.

It has been found experimentally[3,4] that the ratio of the amounts of adenine to thymine, and the ratio of guanine to cytosine, are always very close to unity for deoxyribose nucleic acid.

It is probably impossible to build this structure with a ribose sugar in place of the deoxyribose, as the extra oxygen atom would make too close a van der Waals contact.

The previously published X-ray data[5,6] on deoxyribose nucleic acid are insufficient for a rigorous test of our structure. So far as we can tell, it is roughly compatible with the experimental data, but it must be regarded as unproved until it has been checked against more exact results. Some of these are given in the following communications. We were not aware of the details of the results presented there when we devised our structure, which rests mainly though not entirely on published experimental data and stereochemical arguments.

It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.

Full details of the structure, including the conditions assumed in building it, together with a set of co-ordinates for the atoms, will be published elsewhere.

We are much indebted to Dr. Jerry Donohue for constant advice and criticism, especially on interatomic distances. We have also been stimulated by a knowledge of the general nature of the unpublished experimental results and ideas of Dr. M. H. F. Wilkins, Dr. R. E. Franklin and their co-workers at King's College, London. One of us (J. D. W.) has been aided by a fellowship from the National Foundation for Infantile Paralysis.

J. D. WATSON
F. H. C. CRICK

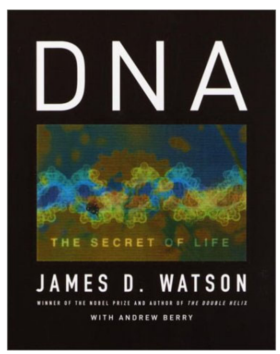
Medical Research Council Unit for the Study of the Molecular Structure of Biological Systems,
Cavendish Laboratory, Cambridge.
April 2.

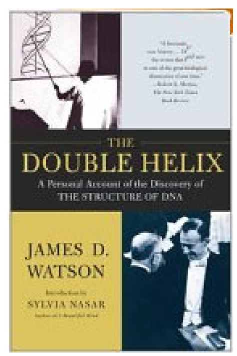
[1] Pauling, L., and Corey, R. B., *Nature*, 171, 346 (1953); *Proc. U.S. Nat. Acad. Sci.*, 39, 84 (1953).
[2] Furberg, S., *Acta Chem. Scand.*, 6, 634 (1952).
[3] Chargaff, E., for references see Zamenhof, S., Brawerman, G., and Chargaff, E., *Biochim. et Biophys. Acta*, 9, 402 (1952).
[4] Wyatt, G. R., *J. Gen. Physiol.*, 36, 201 (1952).
[5] Astbury, W. T., Symp. Soc. Exp. Biol. 1, Nucleic Acid, 66 (Camb. Univ. Press, 1947).
[6] Wilkins, M. H. F., and Randall, J. T., *Biochim. et Biophys. Acta*, 10, 192 (1953).

This figure is purely diagrammatic. The two ribbons symbolize the two phosphate—sugar chains, and the horizontal rods the pairs of bases holding the chains together. The vertical line marks the fibre axis

The above article by J. D. Watson and F. H. C. Crick is a historical landmark in modern biochemistry. (Reprinted in its entirety by special permission from Nature, April 25, 1953, p. 737.) It was followed some weeks later by a second article in which the replication process was more explicitly described.

WATSON, LEFT, AND CRICK, IN 1953, EXPLAINING THE DOUBLE-HELIX STRUCTURE OF DNA. THEY USED MODELS LIKE THE ONE SHOWN HERE TO TEST THEIR IDEAS





THE DOUBLE HELIX

Shining a Light on the 'Dark Lady of DNA'

By Josh Fischman

Four people in England, back in 1953, gazed at the mysterious image called Photo 51. It wasn't much—a grainy picture showing a black X. But three of these people won the Nobel Prize for figuring out what the photo really showed—the shape of DNA, the basic unit of life on Earth. The discovery brought fame and fortune to scientists James Watson, Francis Crick, and Maurice Wilkins. The fourth, the one who actually made the picture, was left out.

Her name was Rosalind Franklin. "She should have been up there," says Mary Ellen Bowden, a historian at the Chemical Heritage Foundation in Philadelphia. "If her images hadn't been there, the others couldn't have come up with the structure." One reason Franklin was missing was that she had died of cancer four years before the Nobel decision, and it can't be awarded after death. But there is a growing suspicion among scholars that Franklin was not only robbed of her life by disease but robbed of credit by her competitors. She, as much as the men around her, was first in the race to understand DNA.

Scientists knew, in the 1940s, that DNA was the thing carrying hereditary information from an organism to its descendants. But because it was too small to see directly, they had no idea how the molecule performed this feat.

Cutouts. So at Cambridge University in the 1950s, Watson and Crick went at it indirectly, by making models; they cut up shapes of DNA's constituents and tried to piece them together. Meanwhile, at King's College in London, Franklin and Wilkins shined X-rays at the molecule. The rays produced patterns reflecting the shape.

But Wilkins and Franklin's relationship was a lot rockier than the celebrated teamwork of Watson and Crick. Wilkins thought Franklin was hired to be his assistant. But the college actually brought her on to take over the DNA imaging project.

Which is what she did, producing X-ray pictures that, among other things, told Watson and Crick that one of their early models was inside out. And she was not shy about saying so. That antagonized Watson, who lambasted her in his 1968 book, *The Double Helix:* "Mere inspection suggested that she would not easily bend. By choice she did not emphasize her feminine qualities. . . . Clearly Rosy had to go or be put in her place." (Other colleagues remember her as a supportive and highly skillful scientist.)

FRANKLIN, AS MUCH AS THE MEN CREDITED, DISCOVERED THE CODE

As Franklin's rivals, Watson and Wilkins had much to gain by cutting her out of the clubby little group of researchers, says science historian Pnina Abir-Am of Brandeis University. Exclusion was made easy by her gender—King's banned women from important dining rooms. And Wilkins grew closer to Watson. Close enough to show to Watson, casually, Franklin's Photo 51. "My mouth fell open," Watson wrote. That X shape was in fact a double helix, two strands wrapped around one another but running in opposite directions. This made it a biological copying machine, able to transmit mirror images of information from one cell to a daughter cell, from a parent to a child.

Watson and Crick, Wilkins, and Franklin published separate papers describing this code of life in the same 1953 issue of *Nature*. Franklin went on to study viruses, and then took sick, and in 1962 the others took to the Nobel podium. Wilkins gave a speech in which he thanked 13 colleagues by name before he mentioned Franklin. Watson wrote his book deriding her. Crick wrote in 1974 that "Franklin was only two steps away from the solution."

No, says Abir-Am: Franklin *was* the solution. "She contributed more than any other player to solving the structure of DNA. She must be considered a codiscoverer." Lynne Osman Elkin, a biographer of Franklin, agrees, saying that Franklin's notebooks show she was on to the double helix—a claim backed up by Aaron Klug, who worked with Franklin on viruses and later won a Nobel Prize himself. Once described as the "Dark Lady of DNA," Franklin is finally coming into the light. ●

REVOLUTIONARY. From top left: Franklin's image of bands indicating the double helix; Franklin; graphs showing the results of DNA sequencing

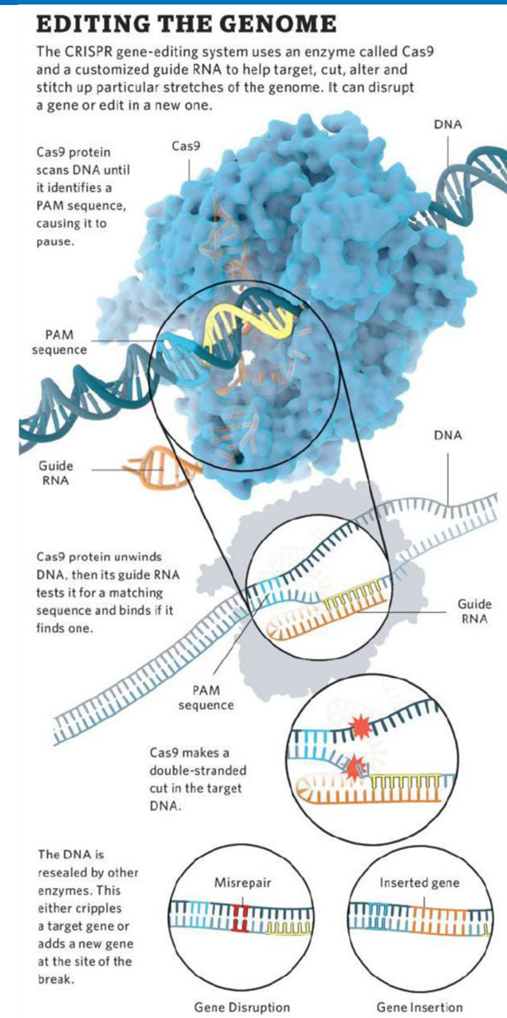
Entering the Crispr Era: DNA Hacking Tool Enables Shortcut to Evolution

Watch: Learn—and visualize—how CRISPR technology works in this animated graphic video.

The 2010s marked huge advances in our ability to precisely edit DNA, in large part thanks to the identification of the CrisprCas9 system. Some bacteria naturally use CrisprCas9 as an immune system, since it lets them store snippets of viral DNA, recognize any future matching virus, and then cut the virus's DNA to ribbons. In 2012, researchers proposed that CrisprCas9 could be used as a powerful genetic editing tool, since it precisely cuts DNA in ways that scientists can easily customize. Within months, other teams confirmed that the technique worked on human DNA. Ever since, labs all over the world have raced to identify similar systems, to modify CrisprCas9 to make it even more precise, and to experiment with its applications in agriculture and medicine.

While CrisprCas9's possible benefits are huge, the ethical quandaries it poses are also staggering. To the horror of the global medical community, Chinese researcher He Jiankui announced in 2018 the birth of two girls whose genomes he had edited with Crispr, the first humans born with heritable edits to their DNA. The announcement sparked calls for a global moratorium on heritable "germline" edits in humans.

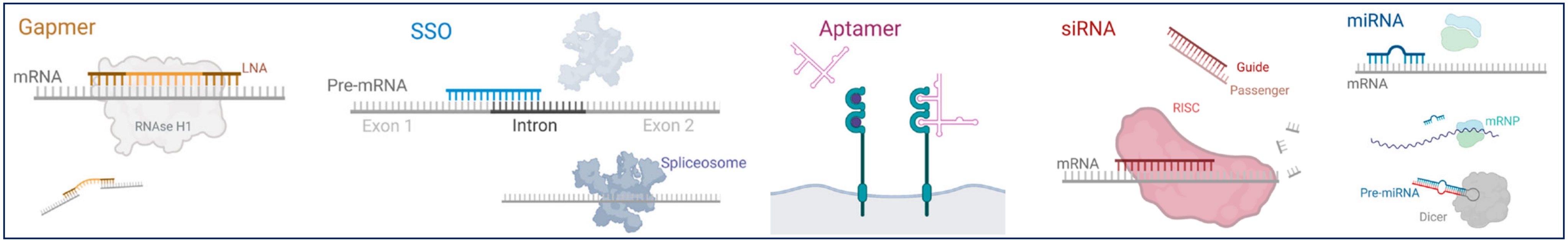
https://www.nationalgeographic.com/science/2019/12/top20scientificdiscoveriesofdecade2010s/?cmpid=org=ngp::mc=crmemail::src=ngp::cmp=editorial::add=SpecialEdition_20191229&rid=FF526C1F1B0738788B420FE1D0034350



Scientific American January 2020. p. 23
Jennifer Doudna

Oligonucleotide

Bost 2021, Delivery of oligonucleotide therapeutics



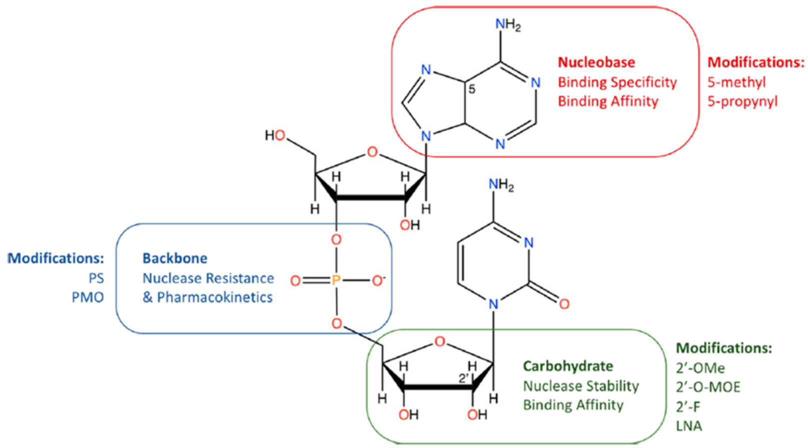


Figure 2. Common chemical modifications for RNA oligonucleotides (Ons). The three sites for common modifications of RNA ONs include the nucleobase, the phosphate backbone, and the carbohydrate sugar. Advantageous characteristics of modifications are listed for each site, and chemical modifications which are utilized FDA-approved ONs are listed for each. The 5-carbon of the nucleobase and the 2′-carbon of the carbohydrate are annotated with their relevant location number. Abbreviations: PS, phosphorothioate; PMO, phosphorodiamidate morpholino oligomer; 2′-OMe, 2′-O-methyl; 2′-O-MOE, 2′-O-methoxyethyl; 2′-F, 2′-fluoro;LNA, locked nucleic acid.

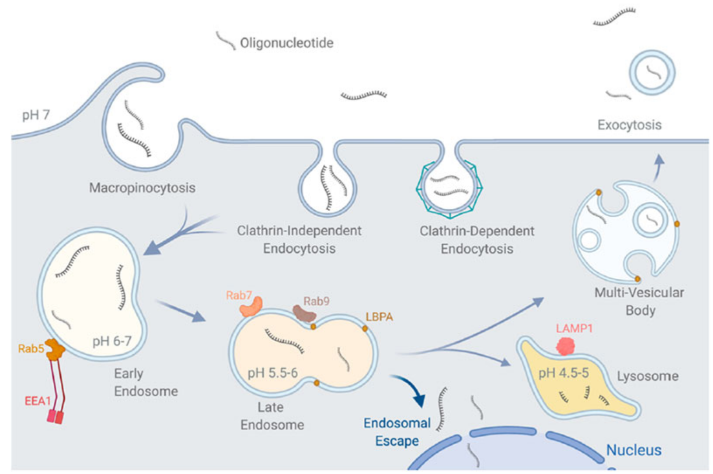


Figure 3. Endocytic uptake and endosomal escape of ONs. The major identified internalization routes of ONs are clathrin-dependent endocytosis, clathrin-independent endocytosis, and macropinocytosis. ON is then trafficked sequentially to the early endosome and sequentially to the late endosome, where it is trafficked to the lysosome or to the multivesicular bodies and exocytosed. Late endosome membrane remodeling and transition to MVB or lysosome have been indicated as likely points of endosomal escape. Commonly used endosomal markers are shown. Abbreviations: Rab, Ras-associated protein; EEA1, early endosome antigen 1; LBPA, lysobisphosphatidic acid; LAMP1, lysosomal-associated membrane protein 1.

Aptamer

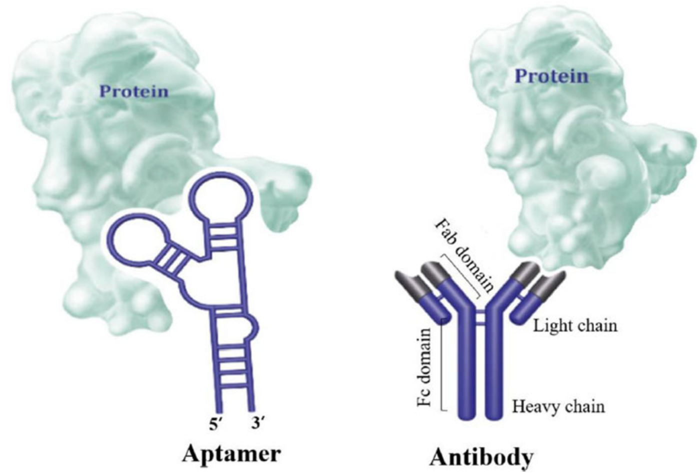


Fig. 1 Illustration of how (A) aptamer and (B) antibody attaches to proteins and structure of (A) aptamer and (B) antibody

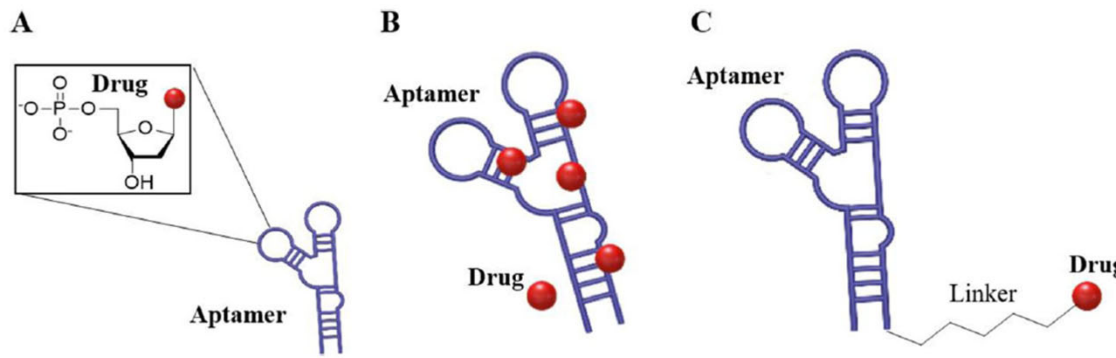


Fig. 2 (A) ApDC constructed by Nucleotide Analogs. (B) ApDC by drug and aptamer intercalation (C) ApDC by using linker between drug and an aptamer

Table 1. The difference between aptamers and antibodies

	Aptamers	Antibodies
Size	Small (~12-30 KDa)	Relatively Big (~ 50-170 KDa)
Target	Wide range	Immune related protein
Synthesis	Simple (chemical synthesis)	Complicate (in vivo production)
Stability	Stable	Susceptible to temperature and pH
Modification	Various modification	Limited modification
Storage Term	Long	Relatively short
Cost	Low	High
Immunogenicity	Low	High

Kim 2021, Design and clinical developments of aptamer-drug conjugates for targeted cancer therapy

Sustainable Bioplastic Made from Biomass DNA and Ionomers

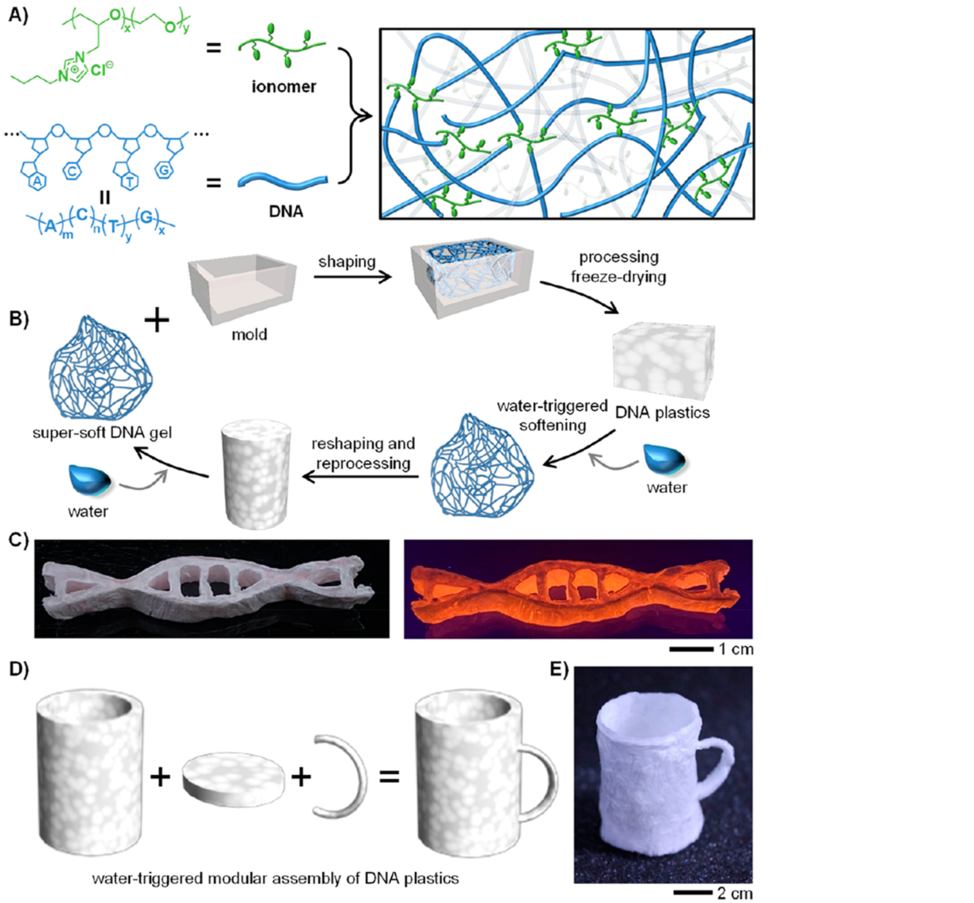


Figure 1. Design and preparation of sustainable DNA plastics. (A) Scheme of the formation of DNA/ionomer hydrogel networks. (B) Scheme of the recyclable use of DNA plastics. (C) Digital photos of DNA plastics with the shape of double helix structure of DNA. The wavelength of UV light was 312 nm. (D) Scheme of the modular assembly process to form a plastic cup. (E) Digital photo of a plastic cup. Without special explanation, DNA plastics were stained green and red by SYBR Green I and GelRed, respectively.

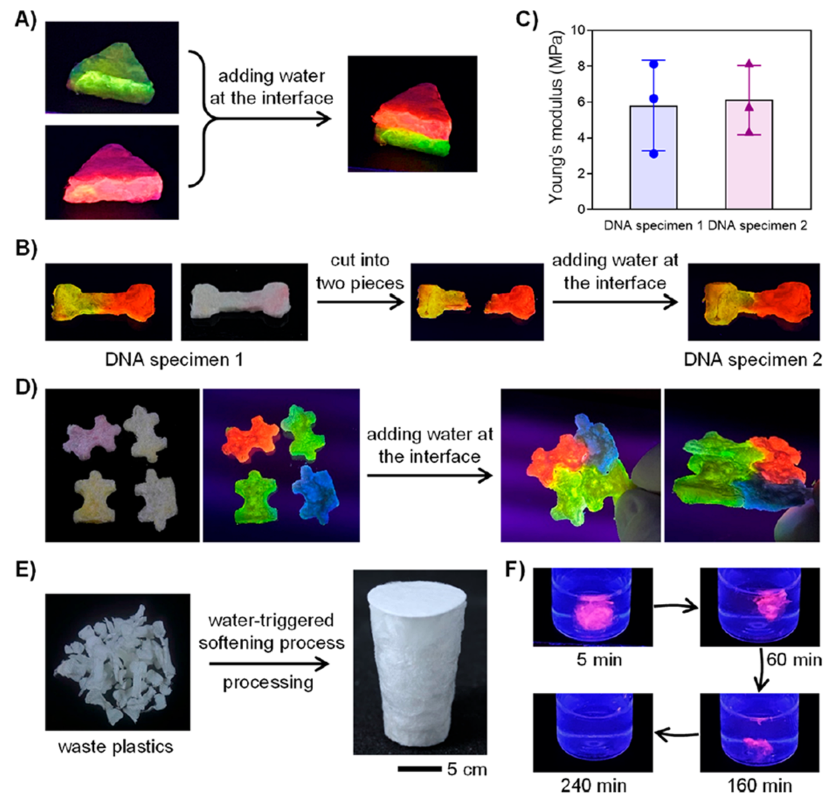
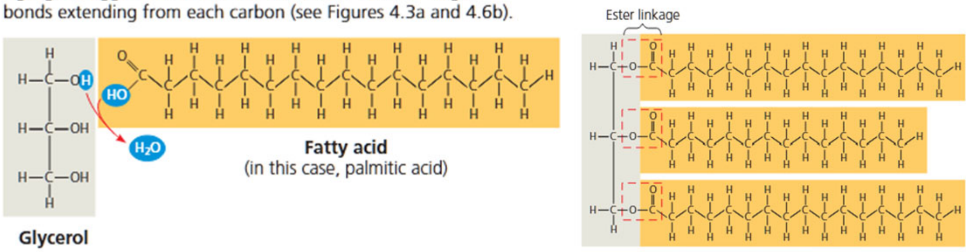


Figure 4. Healing and welding of sustainable DNA plastics to form 3D architectures using water. The wavelength of UV light was 312 nm. (A) Digital photos of the healing process of two pieces of triangular prism-shaped plastics that were stained green and red, respectively. (B) Digital photos of the healing process of a fractured dumbbell-shaped specimen. (C) Young's modulus of original and healed plastic specimens. Results are presented as means ± standard deviation (SD) ($n = 3$). (D) Digital photos of the healing process of four pieces of plastic puzzles. The puzzles were stained red, green, blue, and green by GelRed, SYBR Green I, carbon dots, and fluorescein, respectively. (E) Preparation of a plastic cup with a cover using waste DNA plastics. (F) Digital photos of the degradation of plastics in DNase I solution (5 U/μL).

Han 2021, Sustainable bioplastic made from biomass DNA and ionomers

Lipids

Figure 5.9 The synthesis and structure of a fat, or triacylglycerol. The molecular building blocks of a fat are one molecule of glycerol and three molecules of fatty acids. **(a)** One water molecule is removed for each fatty acid joined to the glycerol. **(b)** A fat molecule with three fatty acid units, two of them identical. The carbons of the fatty acids are arranged zigzag to suggest the actual orientations of the four single bonds extending from each carbon (see Figures 4.3a and 4.6b).



(a) One of three dehydration reactions in the synthesis of a fat
(b) Fat molecule (triacylglycerol)

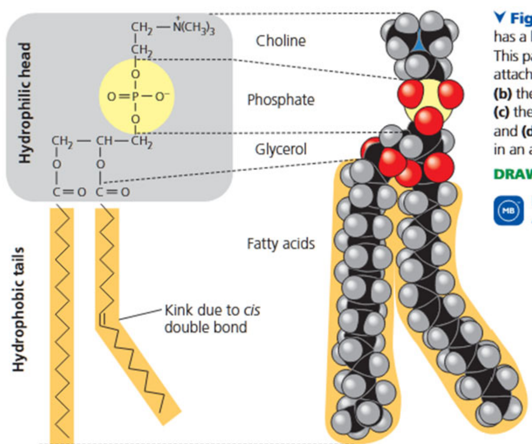
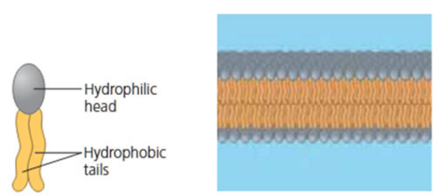


Figure 5.11 The structure of a phospholipid. A phospholipid has a hydrophilic (polar) head and two hydrophobic (nonpolar) tails. This particular phospholipid, called a phosphatidylcholine, has a choline attached to a phosphate group. Shown here are **(a)** the structural formula, **(b)** the space-filling model (yellow = phosphorus, blue = nitrogen), **(c)** the symbol for a phospholipid that will appear throughout this book, and **(d)** the bilayer structure formed by self-assembly of phospholipids in an aqueous environment.

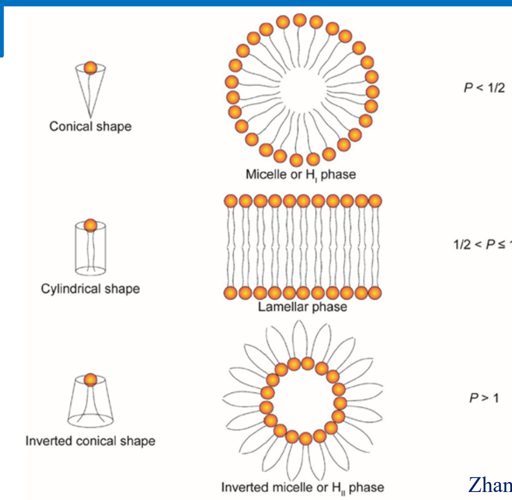
DRAW IT > *Draw an oval around the hydrophilic head of the space-filling model.*

Figure Walkthrough
Animation: Space-Filling Model of a Phospholipid



(a) Structural formula (b) Space-filling model (c) Phospholipid symbol (d) Phospholipid bilayer

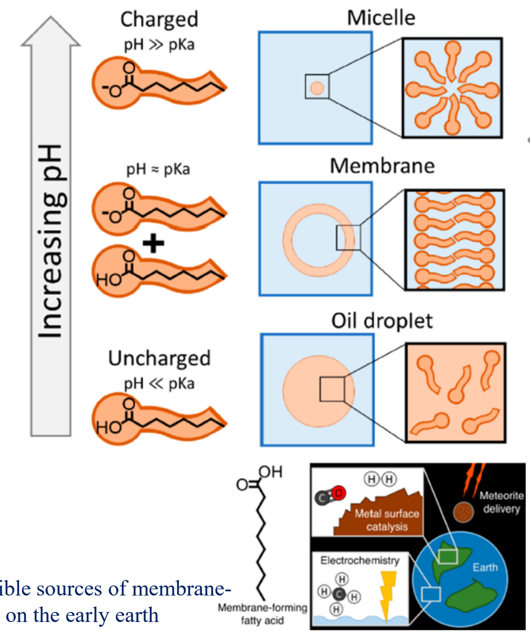
Urry 2021, The structure and function of large biological molecules

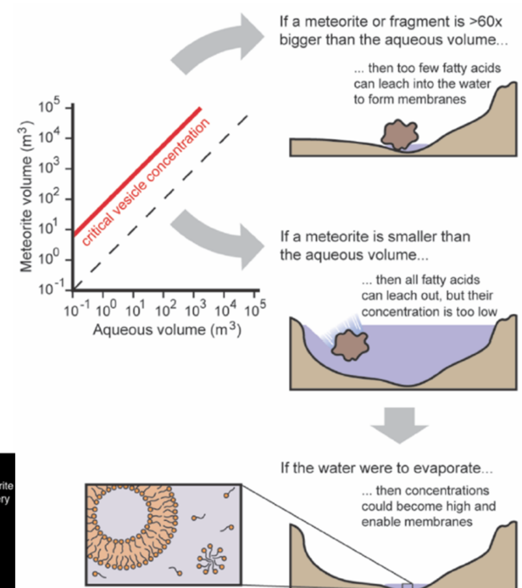


The packing parameter P of the lipid, which is defined as the ratio of the amphiphile lipid volume (V) to its head group area (a), and the critical tail length (l_c) ($P = V/a{\cdot}l_c$). When P is less than 1/2, the conical-shaped amphiphile lipids assemble into micelles or a hexagonal (H_I) phase. When $1/2 < P \leq 1$, cylindrical-shaped amphiphile lipids with a curvature close to 0 adopt the stable lamellar phase.

Figure 3. Schematic illustration of the shape structure concept of lipids.

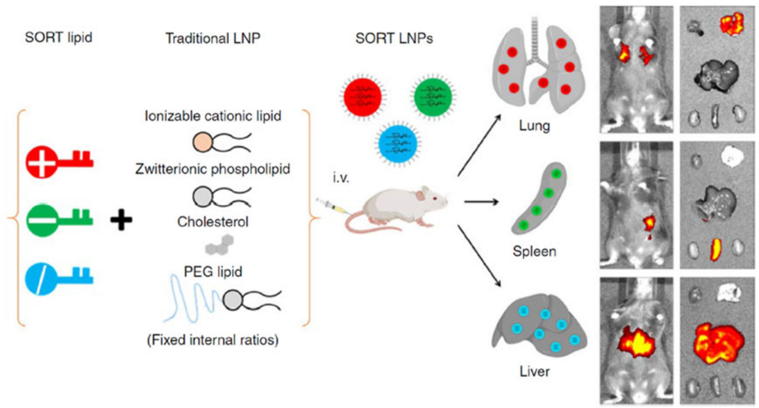
Zhang 2021, Lipids and Lipid Derivatives for RNA Delivery

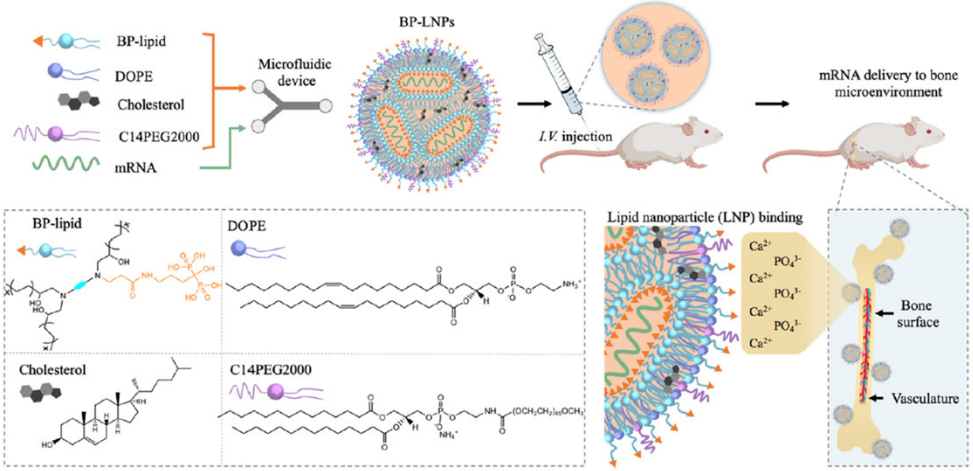




Cohen 2023, Plausible sources of membrane-forming fatty acids on the early earth

RNA Delivery





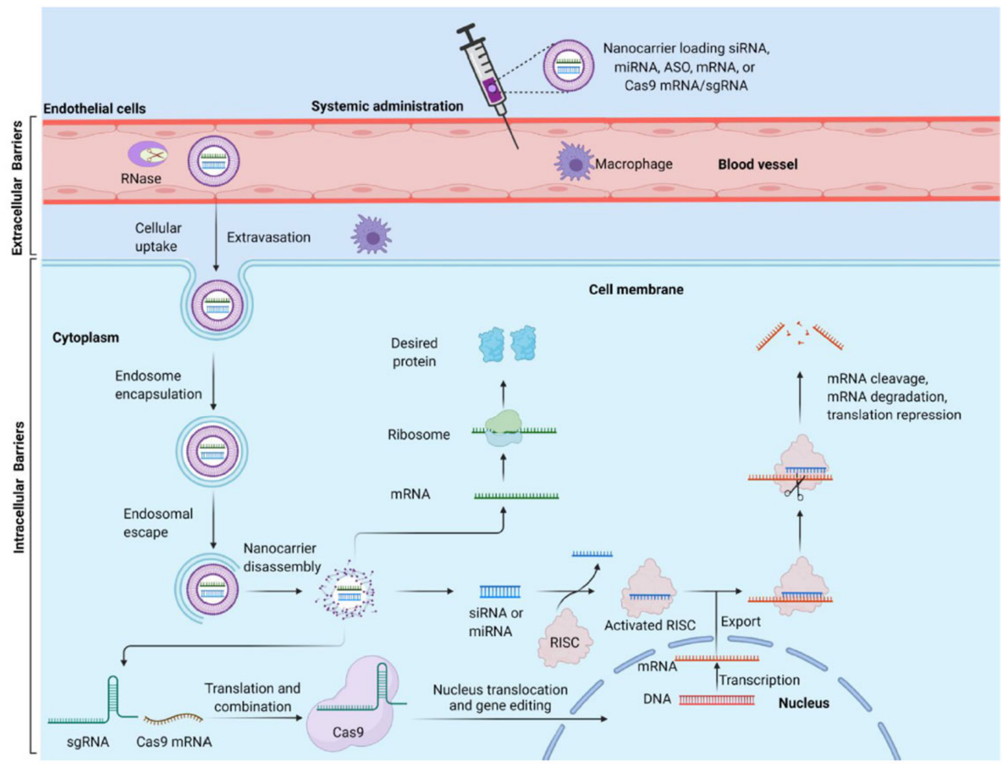
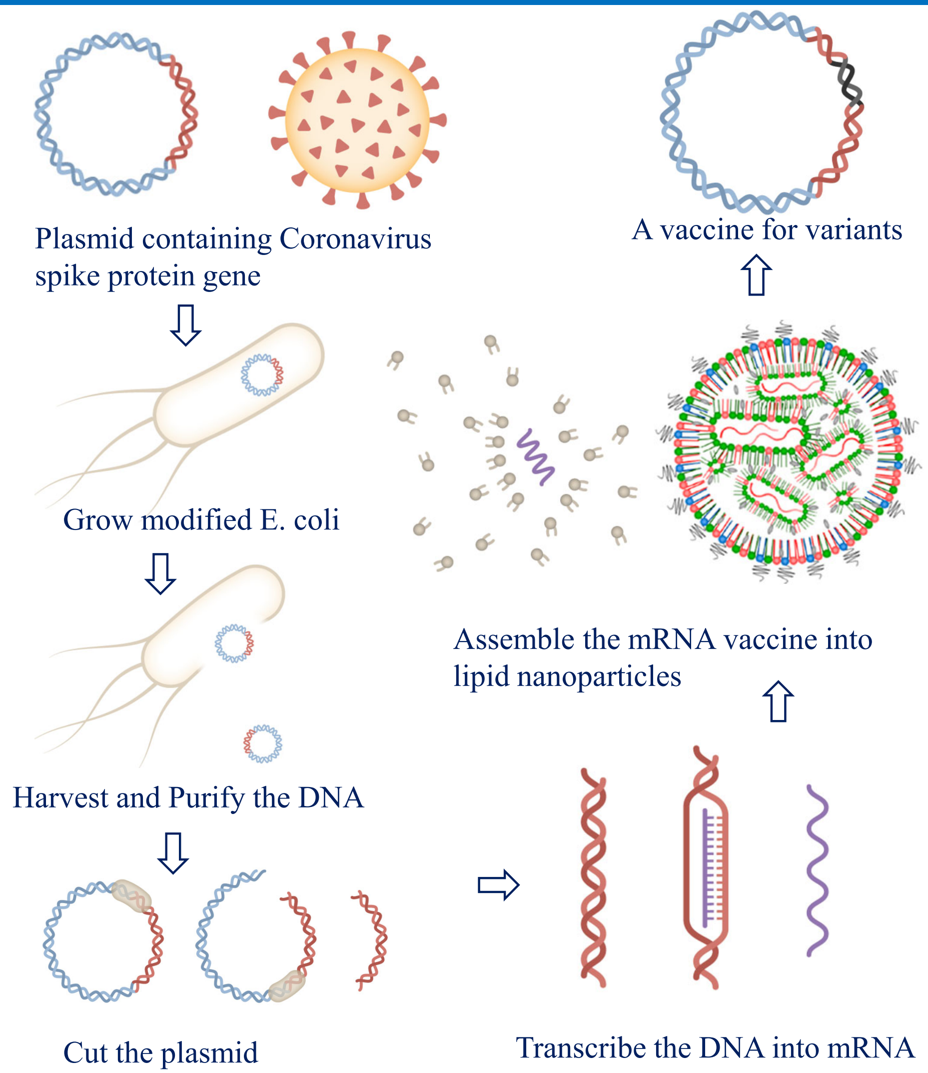


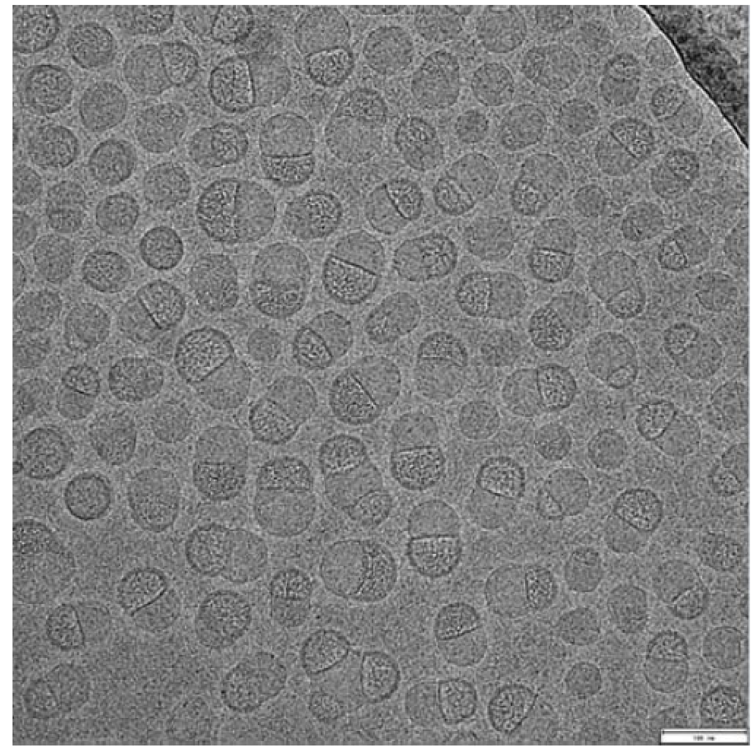
Figure 1. Schematic illustration of the extracellular and intracellular barriers to effective systemic delivery of RNAs and the mechanism of RNA-based therapeutics. Figure was created with BioRender.com.

Xu 2023, Recent advances in site-specific lipid nanoparticles for mRNA delivery

Zhang 2021, Lipids and Lipid Derivatives for RNA Delivery

mRNA COVID-19 Vaccine



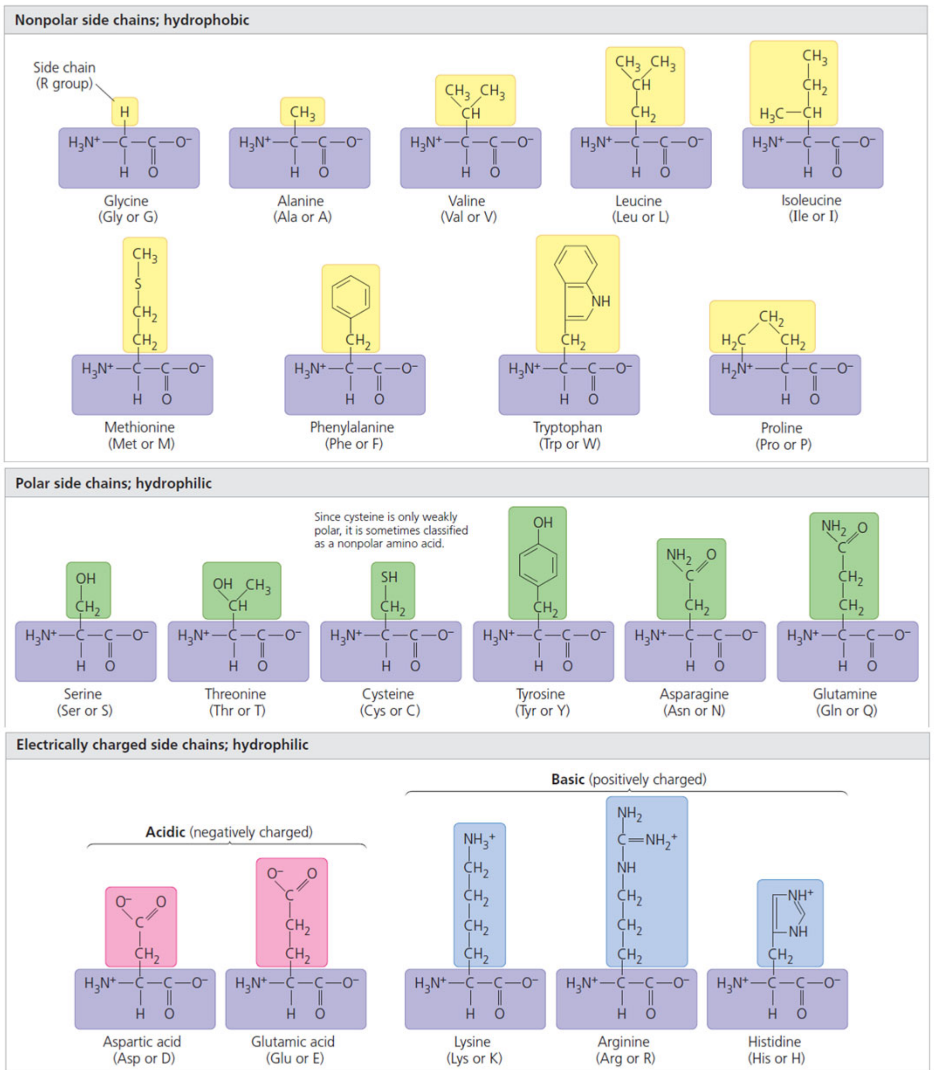


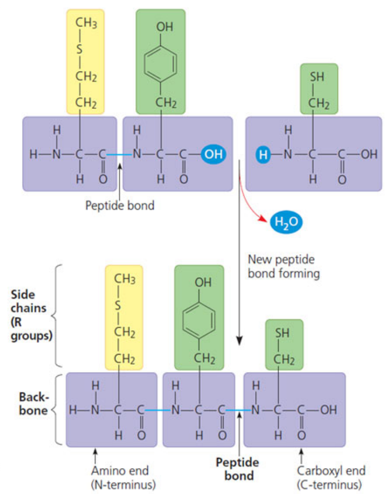
Brader 2021, Encapsulation state of messenger RNA inside lipid nanoparticles. Biophys. J. 120: 1-5.

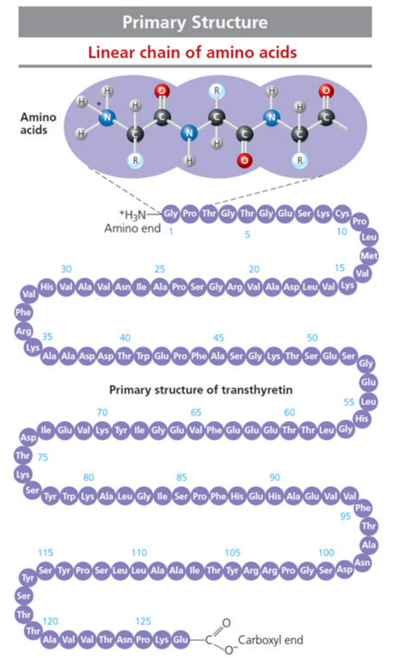
Elia 2021, Design of SARS-CoV-2 hFc-conjugated receptor-binding domain mRNA vaccine delivered via lipid nanoparticles, ACS Nano

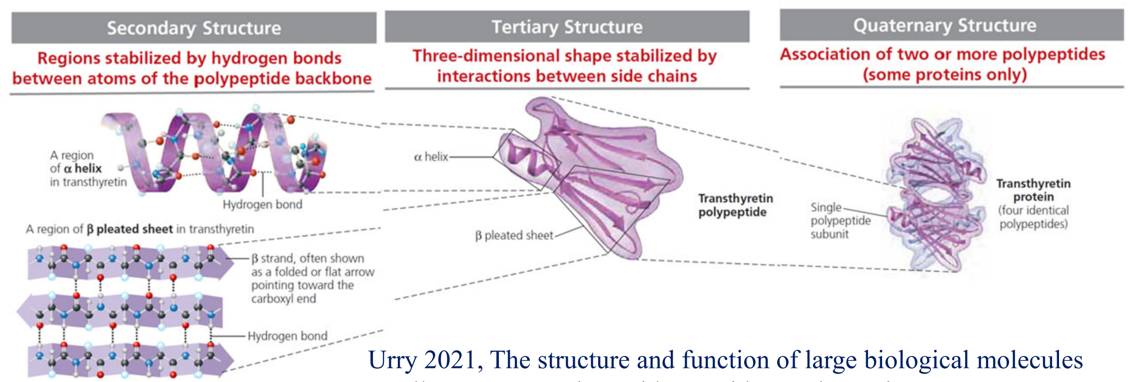
https://www.nytimes.com/interactive/2021/health/pfizer-coronavirus-vaccine.html?referringSource=articleShare

Proteins: Amino Acids





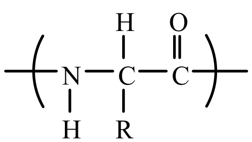


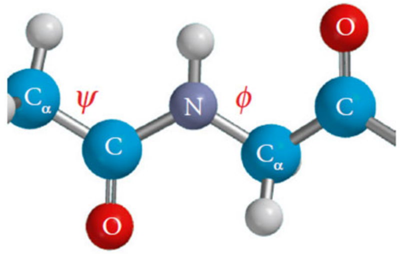


Urry 2021, The structure and function of large biological molecules
Ouellette 2014, Amino acids, peptides, and proteins

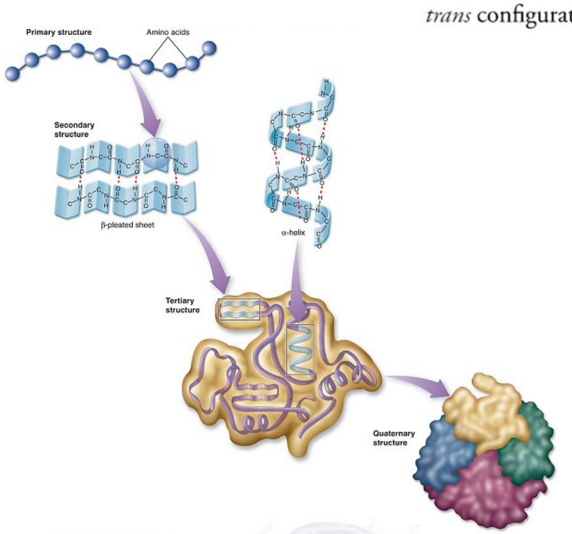
Natural Polymers: Proteins

Peptide bond





trans configuration of peptide bond

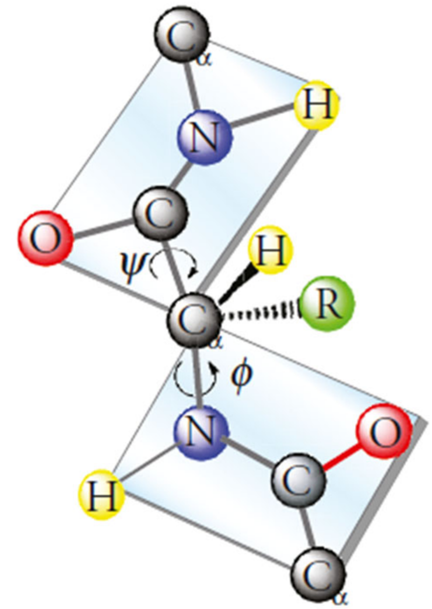


Discovery of Fire

http://apbrwww5.apsu.edu/thompsonj/Anatomy%20&%20Physiology/2010/2010%20Exam%20Reviews/Exam%201%20Review/Ch02%20Protiens%20and%20Enzymes.htm

Figure 27.9 Structure of the Peptide Bond
(a) Rotation around the C—N bond, which has 50% double bond character, does not occur at room temperature. However, rotation around the N—C$_\alpha$ bond (ϕ) and the C—Ca bond (ψ) is possible, and many conformations are possible in peptides and proteins.
(b) we can think of the a-carbon as a "hinge" between two planar peptide bonds. If one takes two note cards and links them with a swivel, it is easy to see that many arrangements are possible.

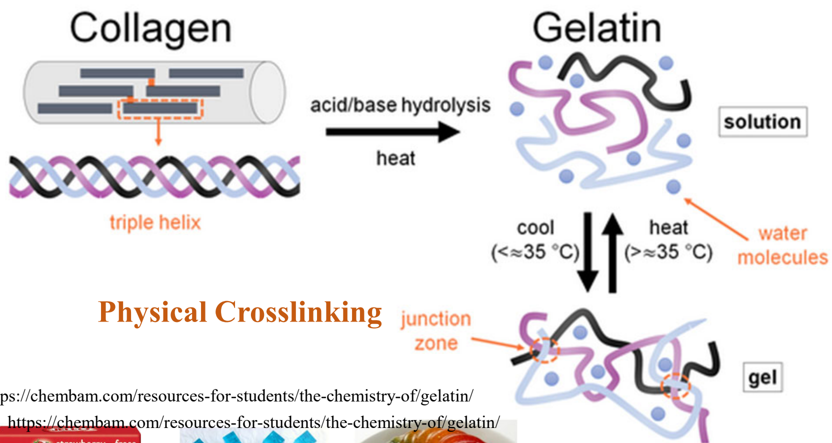
Ouellette 2014, Amino acids, peptides, and proteins



Protein Aggregation by Acid

Cheese is made from milk that has been curdled by the addition of acids and an enzyme from the stomach of calves called rennet. The curds are salted, and moisture pressed out, so the product will not be as easily attacked by bacteria as raw milk would. Thus cheese making is a way of preserving milk. (http://kitchenscience.scitoys.com/protein)

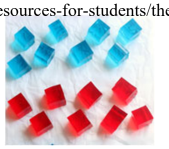
Proteins: Gelatin



Physical Crosslinking

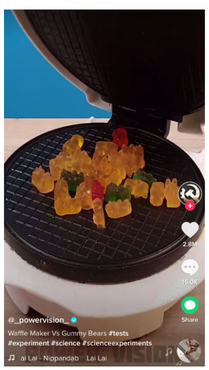
https://chembam.com/resources-for-students/the-chemistry-of/gelatin/

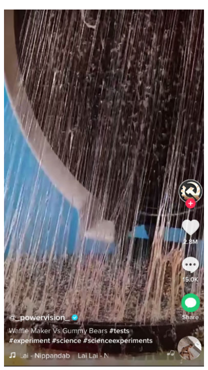
https://chembam.com/resources-for-students/the-chemistry-of/gelatin/

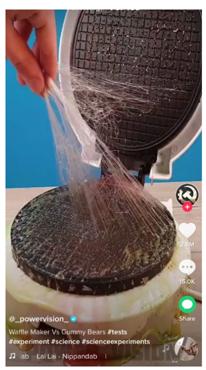


Hydrogels

The major component is water: Jello behaves like a solid. Removing water from Jello without melting?

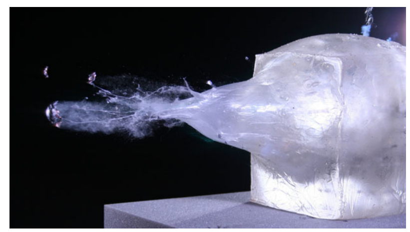




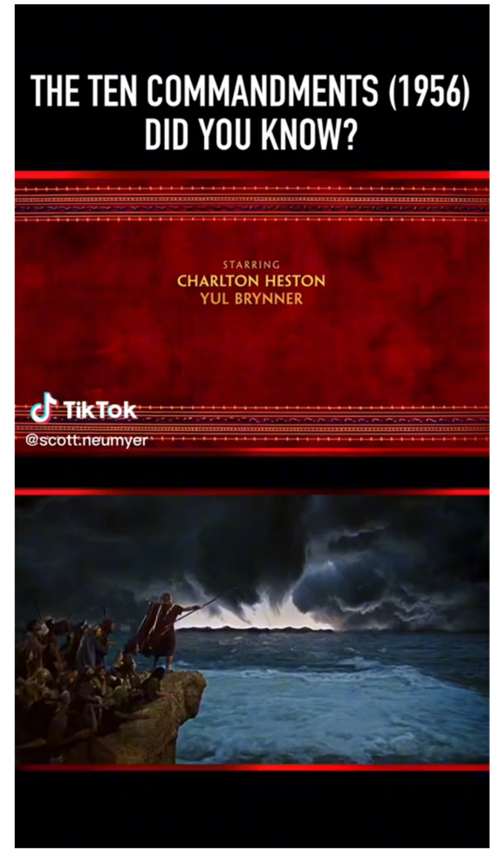


Ballistics Gel for Bullet Tests

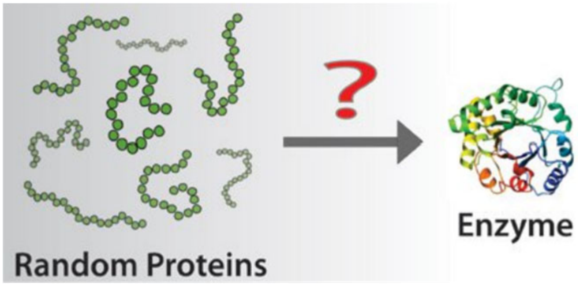
10% Gelatin gel (250 Bloom): The density and viscosity of human and animal muscle tissue.



https://en.wikipedia.org/wiki/Ballistic_gelatin
https://www.luckygunner.com/labs/10mm-auto-self-defense-ammo-ballistic-gel-tests/



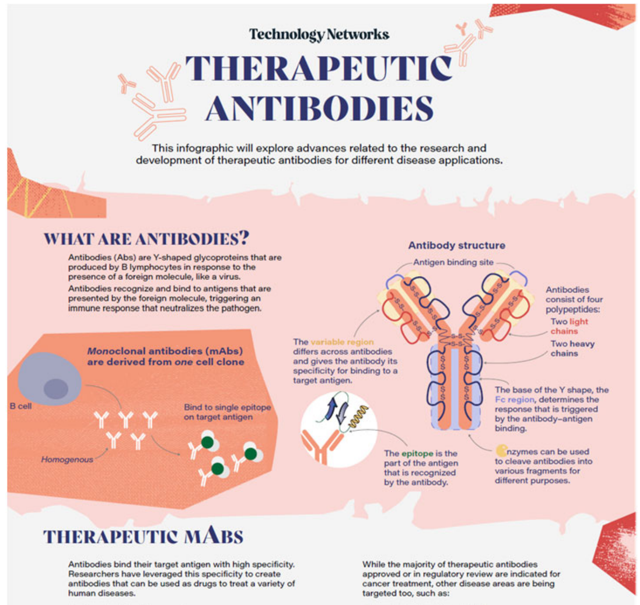
Proteins: The Engine of Life



Experiments by Seelig and Szostak show that small, simple enzymes can evolve rather easily. They describe the generation of an artificial enzyme by simulating evolution in a test tube. The researchers at first produced a random library of 4 trillion small protein molecules that were all slightly different from each other and then isolated a new enzyme by subjecting those protein molecules to an in vitro process of selection and evolution. In a matter of a few weeks this procedure yielded the novel enzyme. This enzyme, an RNA ligase, catalyzes the joining of two RNA molecules – a reaction for which no natural enzymes are known.

This study presents a potential scenario for the origin of the earliest biopolymers that facilitated the chemical reactions supporting life. The successful creation of novel enzymes that are not derived from biological proteins sheds new light on the potential of life beyond earth.

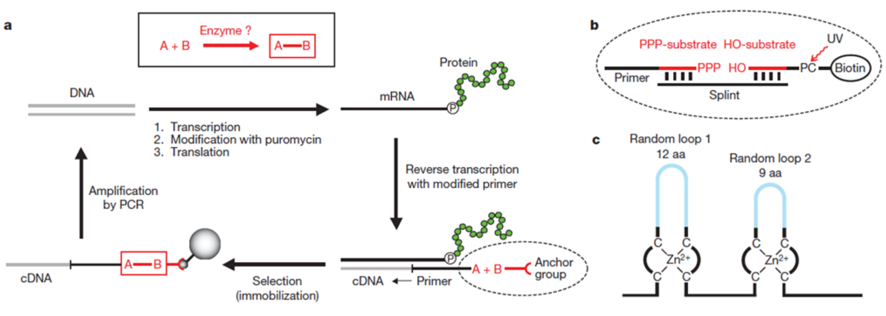
Andrzej Pohorille: Potential Origin of Primordial Protein Enzymes (2007)
https://astrobiology.nasa.gov/news/check-type-potential-origin-of-primordial-protein-enzymes/



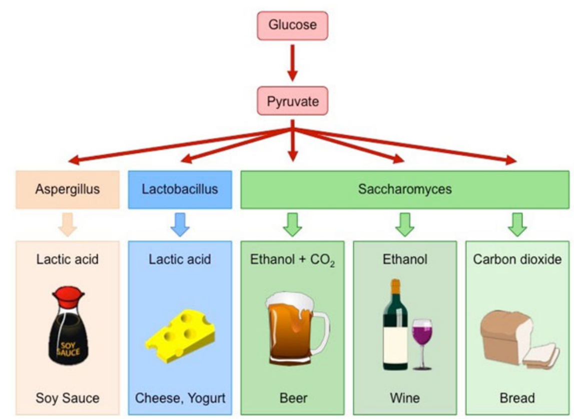
ThermoFisher 2022, Therapeutic antibodies

Fermentation is a biochemical process of getting energy from carbohydrates without oxygen.

Fermenting means "boiling" at low temperatures, thus, known as "cold fire."



Seelig 2007, Selection and evolution of enzymes from a partially randomized non-catalytic scaffold



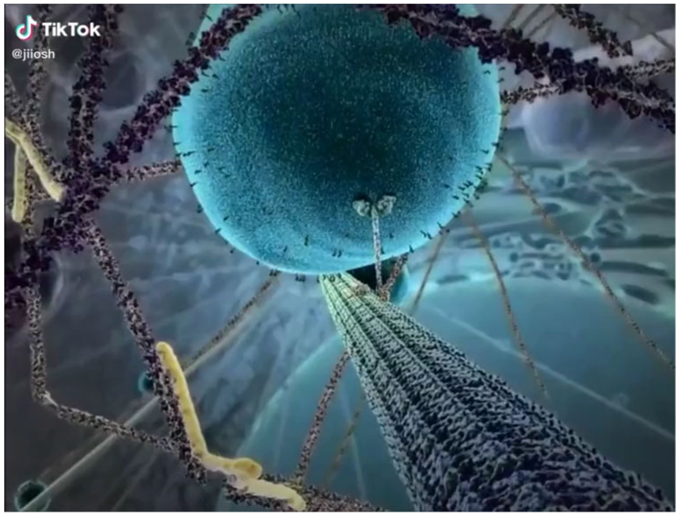
glucose → ethanol + carbon dioxide + energy

$$C_6H_{12}O_6 \rightarrow 2\,C_2H_5OH + 2\,CO_2$$

https://sciencenotes.org/what-is-fermentation-definition-and-examples/
https://ib.bioninja.com.au/standard-level/topic-2-molecular-biology/28-cell-respiration/yeast-fermentation.html

Proteins: Microtubules

Microtubule Motor Protein



Actomyosin-Assisted Pulling of Lipid Nanotubes from Lipid Vesicles and Cells

Kevin Jahnke, Stefan J. Maurer, Cornelia Weber, Jochen Estebano Hernandez Bücher, Andreas Schoenit, Elisa D'Este, Elisabetta Ada Cavalcanti-Adam, and Kerstin Göpfrich*

Cite This: *Nano Lett.* 2022, 22, 1145−1150 Read Online

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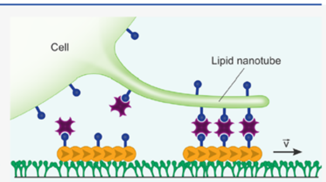
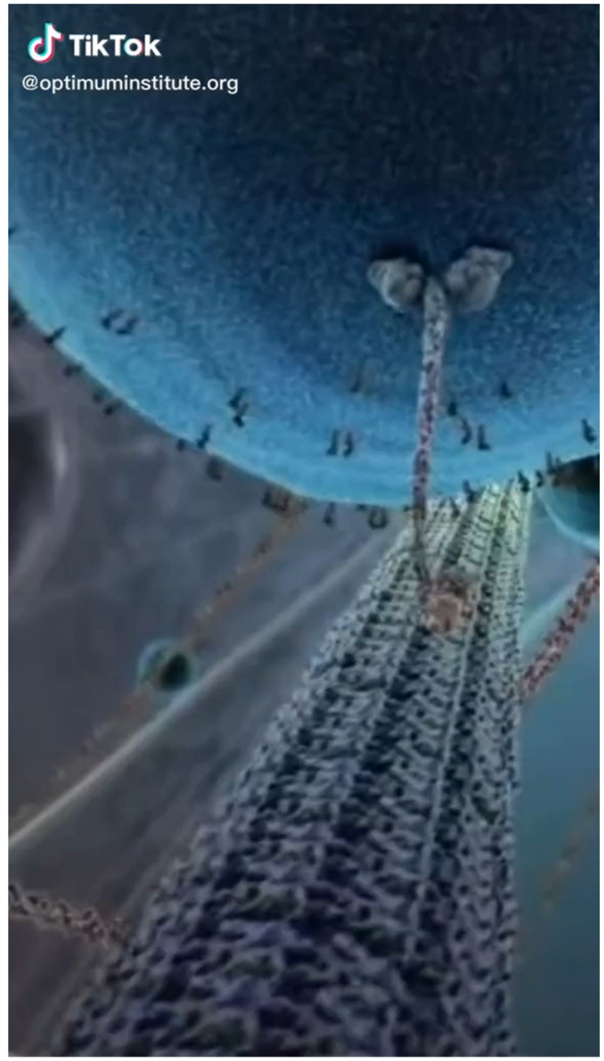
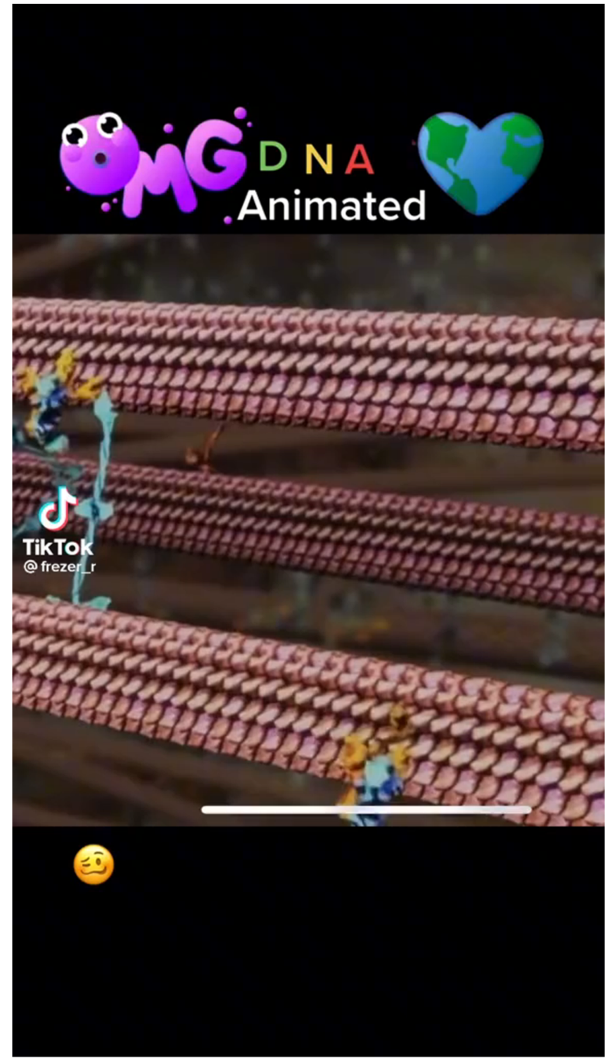
ABSTRACT: Molecular motors are pivotal for intracellular transport as well as cell motility and have great potential to be put to use outside cells. Here, we exploit engineered motor proteins in combination with self-assembly of actin filaments to actively pull lipid nanotubes from giant unilamellar vesicles (GUVs). In particular, actin filaments are bound to the outer GUV membrane and the GUVs are seeded on a heavy meromyosin-coated substrate. Upon addition of ATP, hollow lipid nanotubes with a length of tens of micrometer are pulled from single GUVs due to the motor activity. We employ the same mechanism to pull lipid nanotubes from different types of cells. We find that the length and number of nanotubes critically depends on the cell type, whereby suspension cells form bigger networks than adherent cells. This suggests that molecular machines can be used to exert forces on living cells to probe membrane-to-cortex attachment.



KEYWORDS: *Lipid nanotubes, lipid tether pulling, motility assay, giant unilamellar vesicle, membrane-to-cortex attachment, actin, heavy mero-myosin*

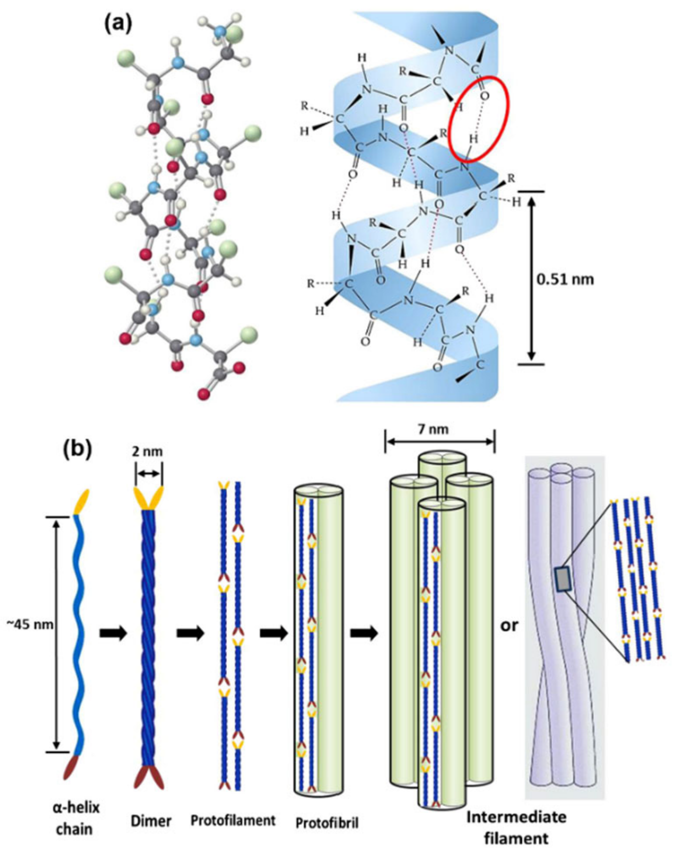
Jahnke 2022, Actomyosin-assisted pulling of lipid nanotubes from lipid vesicles and cells





Proteins: Keratin

Intermediate filament structure of α-keratin



Wang 2016, Keratin: Structure, mechanical properties, occurrence in biological organisms, and efforts at bioinspiration

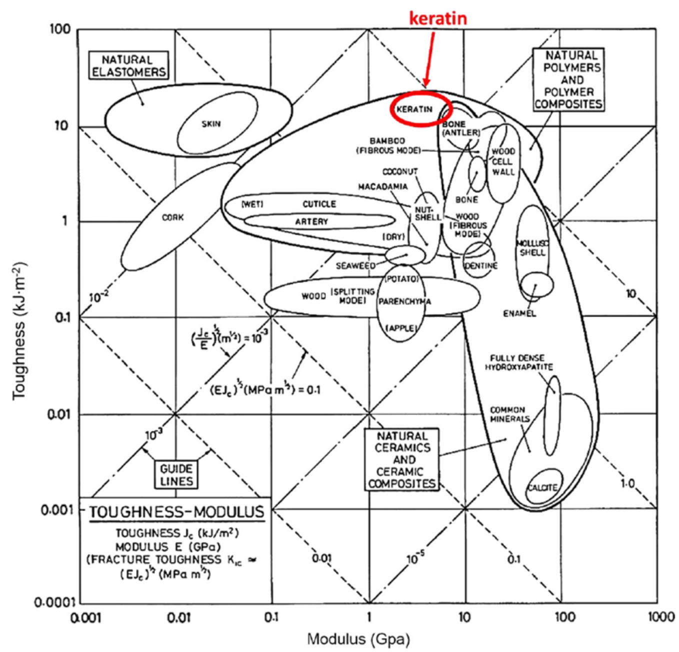
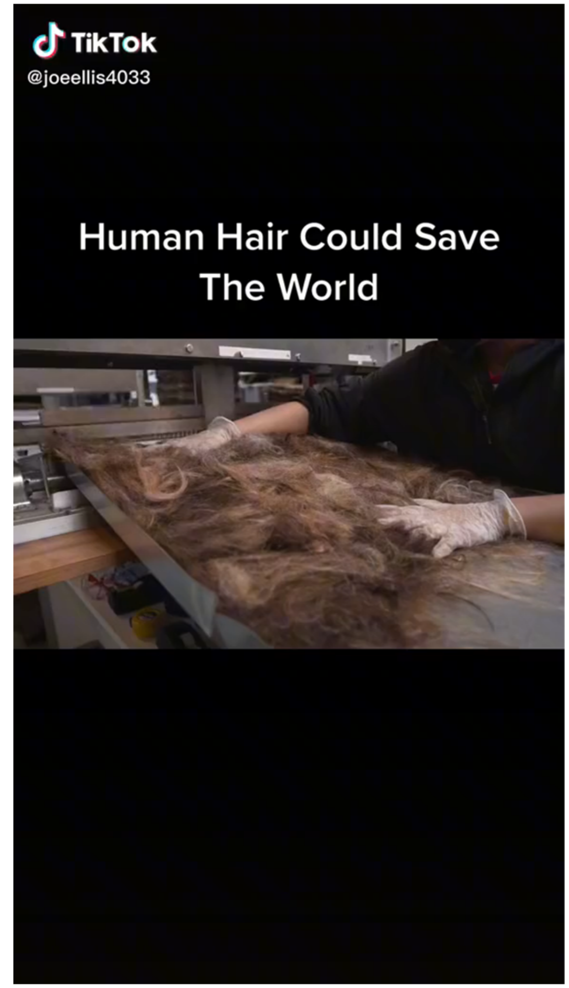
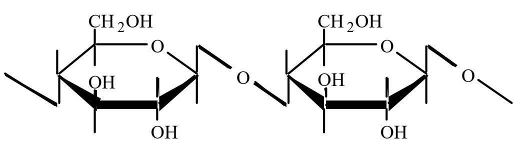


Fig. 1. Materials property chart for biological materials: toughness versus Young's modulus [13].

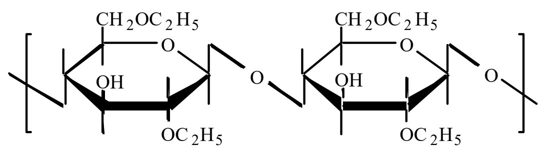


Natural Polymers: Polysaccharides

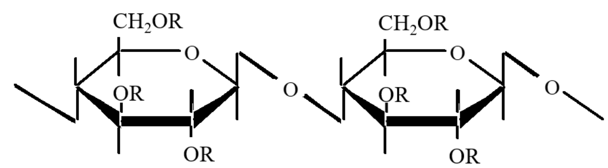
Cellulose = Cellulle (a living cell) + glucose



Cellulose: β(1→4) linked Dglucose



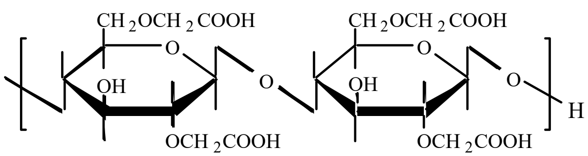
Ethylcellulose



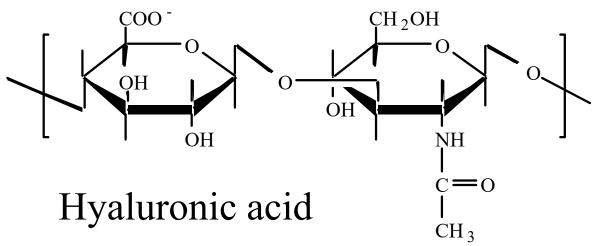
R = H, CH_3, or $CH_2CH(OH)CH_3$

Hydroxypropyl methylcellulose

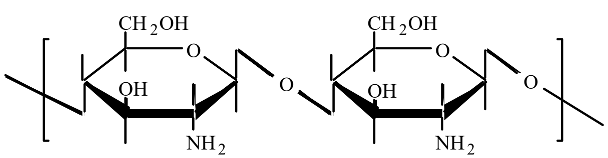
(HPMC, Methocel™)



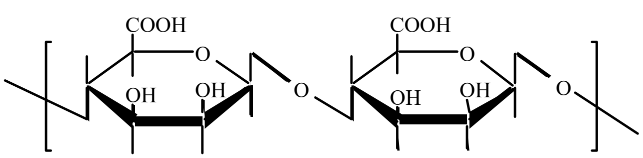
Carboxymethylcellulose



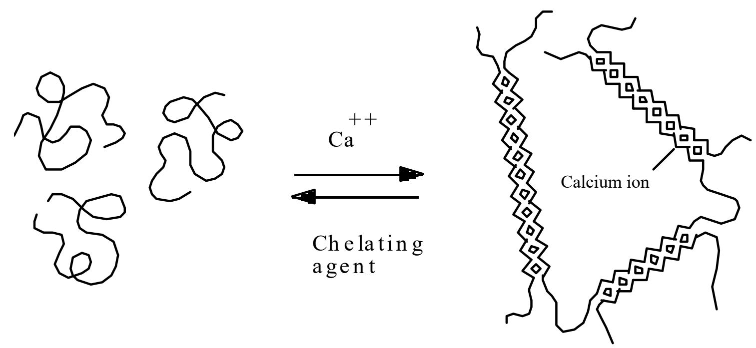
Hyaluronic acid



Chitosan



Alginic acid

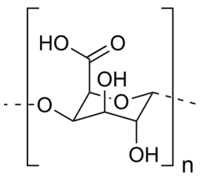


Aravamudhan 2014, Natural polymers-Polysaccharides

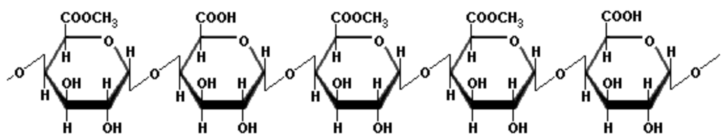
Polysaccharides: Carbohydrate Polymers

Natural Polysaccharides

Pectic Acid

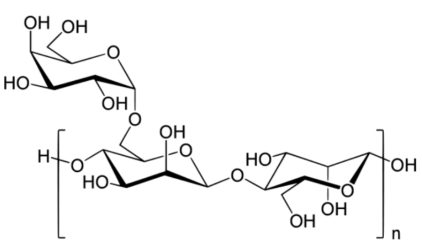


Pectin

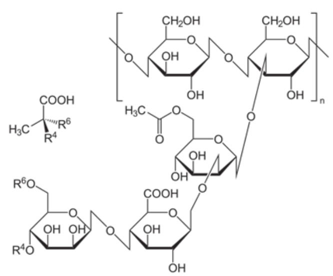


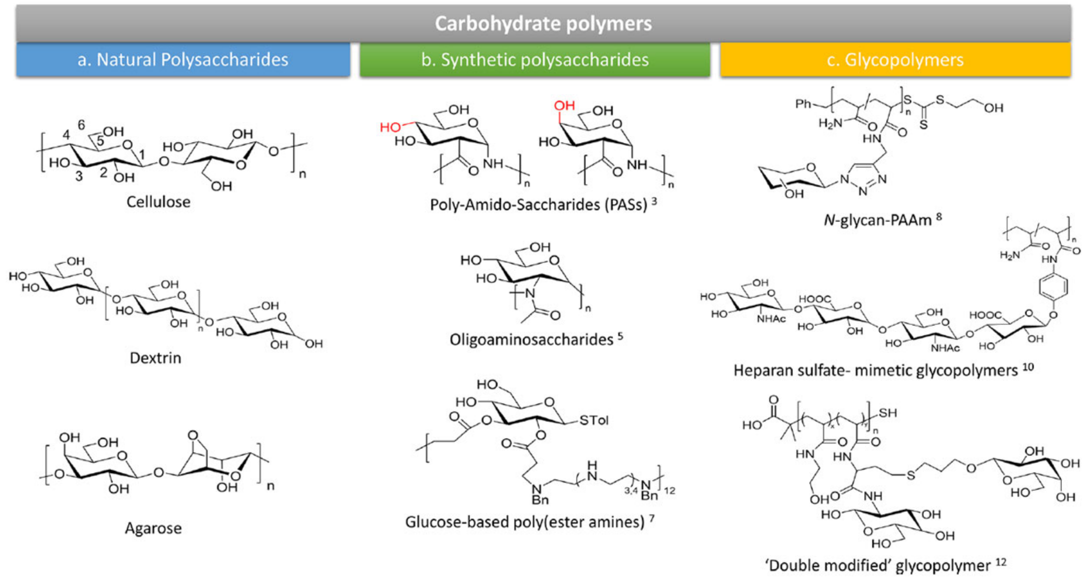
Pectin is a polymer of α-Galacturonic acid with a variable number of methyl ester groups.

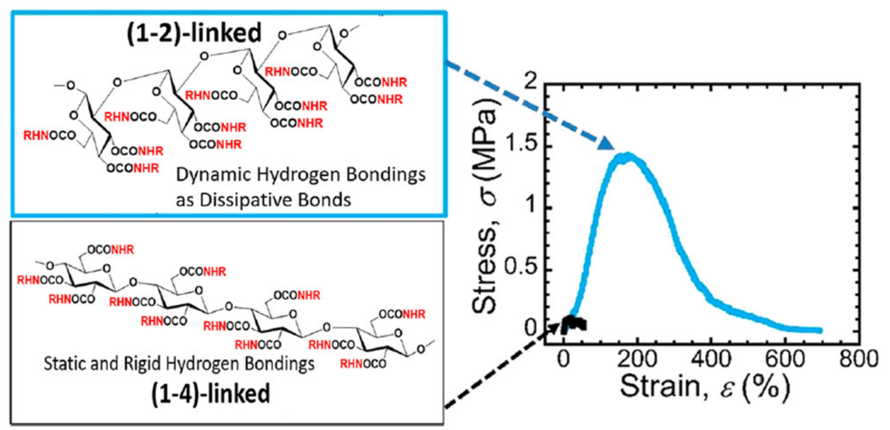
Guar Gum



Xanthan Gum







Chen 2021, The past ten years of carbohydrate polymers in ACS Macro Letters

Polysaccharides: Mucins

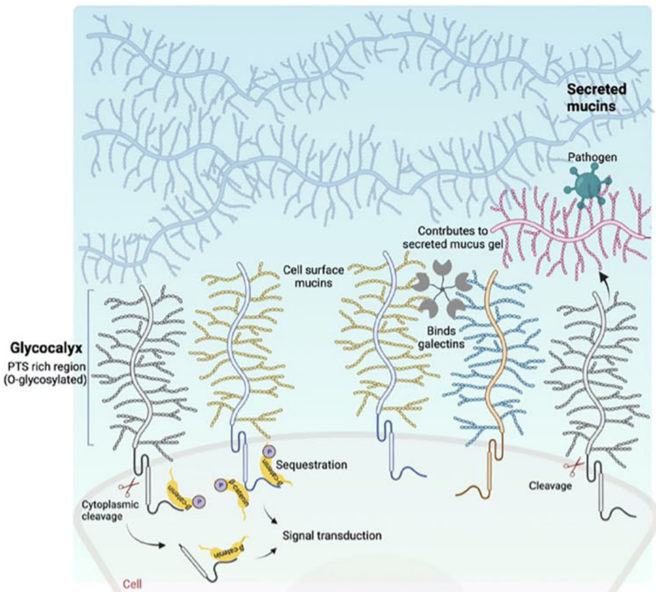
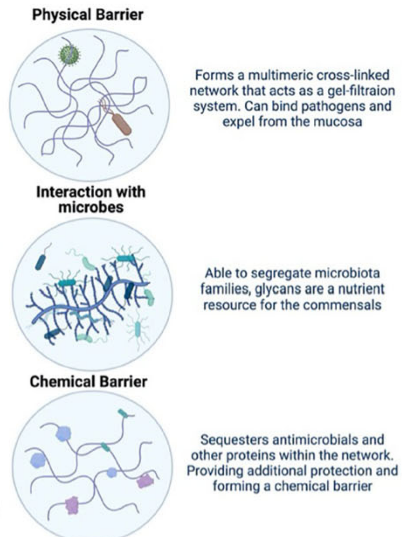


FIGURE 1 | Schematic depicting the role of cell surface and gel-forming mucins at the mucosal barrier.

Sheng 2020, Mucus and mucins: The underappreciated host defence system.



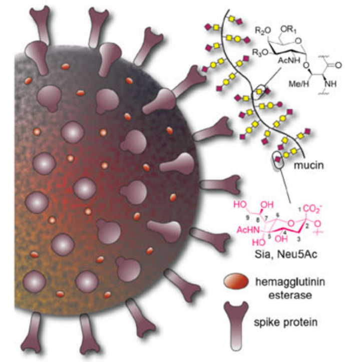
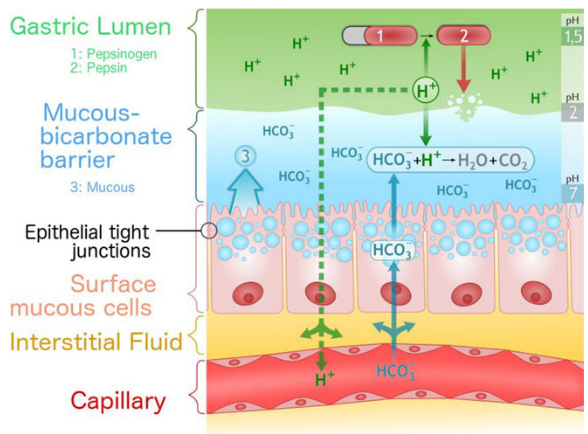


Figure 1. Coronavirus and mucin structure where viral spike proteins bind to mucin Sia glycans.

Mucins are a diverse and heterogeneous family of glycoproteins that comprise the bulk of mucus and the epithelial glycocalyx.

Mucins are at the forefront of epithelial defense.

Wardzala 2022, Mucins Inhibit Coronavirus Infection in a Glycan-Dependent Manner



The gastric mucosal barrier is the property of the stomach that allows it to safely contain the gastric acid required for digestion.

https://en.wikipedia.org/wiki/Gastric_mucosal_barrier

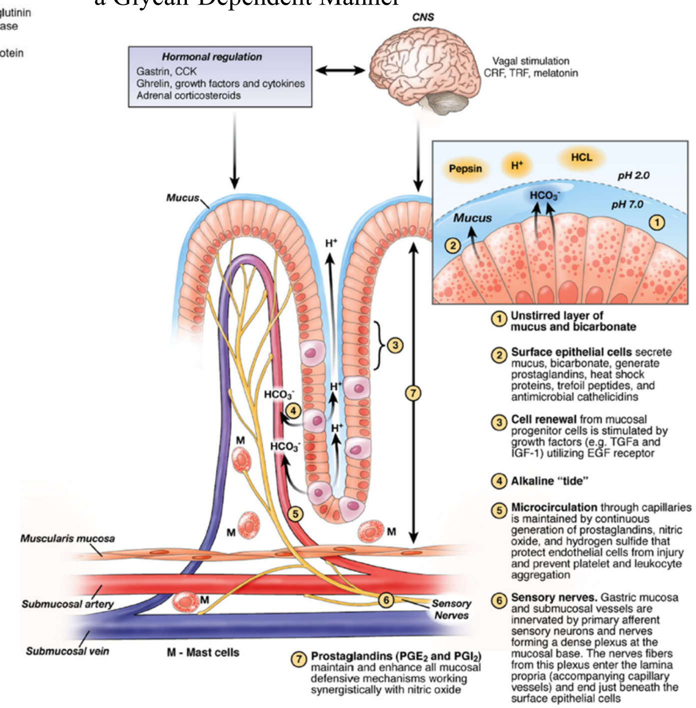
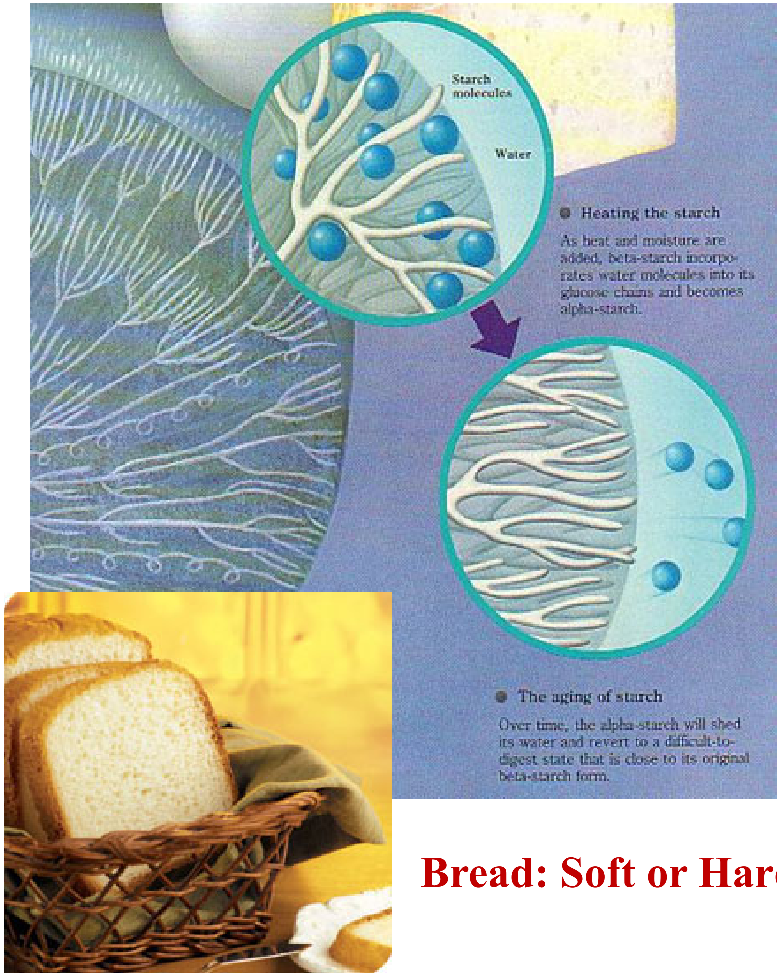


Fig. 1 This illustration depicts the major protective factors of gastric and duodenal mucosa. (Yandrapu 2015, Protective factors of the gastric and duodenal mucosa: An overview)

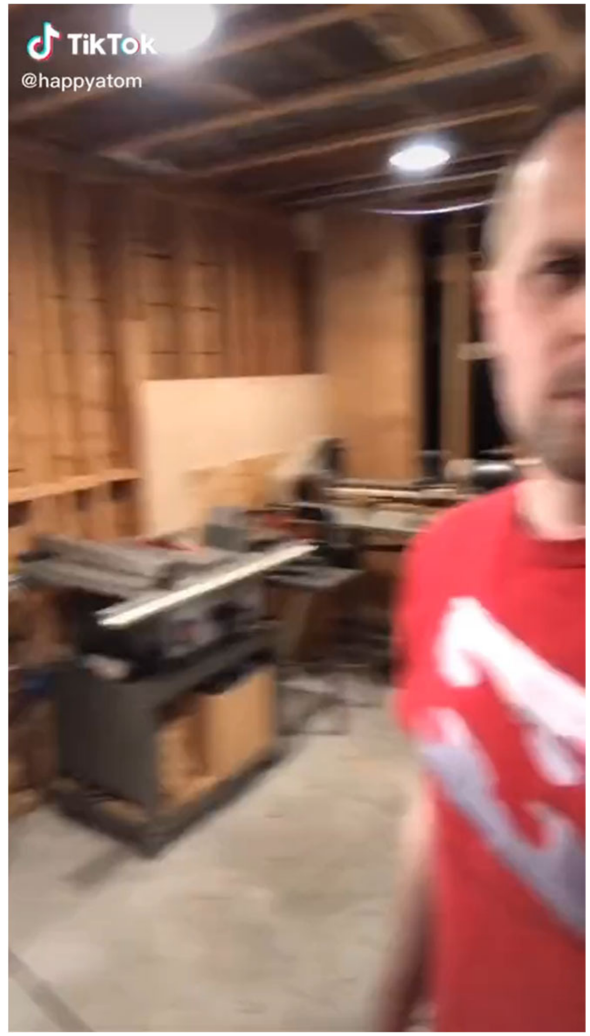
Polysaccharides

Starch: α(1→4) linked D-glucose polymer



Bread: Soft or Hard

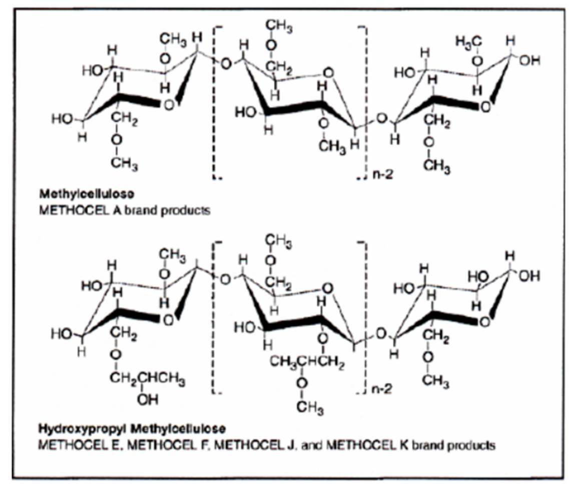
Natural Wood



Ghost Busters (1984): Ghost Slime is Good for Health

https://www.bing.com/videos/search?q=ghost+burster+slime+physical+contact&docid=608052564831962443&mid=EF73645CCE5E3427F107EF73645CCE5E3427F107&view=detail&FORM=VIRE

Figure 1. Typical Chemical Structure of METHOCEL™ Products



METHOCEL™ cellulose ether products are available in two basic types: methylcellulose and hypromellose.

METHOCEL™ A: **Methylcellulose** is made using only methyl chloride.

METHOCEL™ E, F & K: **Hypromellose** products are made using propylene oxide in addition to methyl chloride to obtain hydroxypropyl substitution on the anhydroglucose units. This substituent group, $-OCH_2CH(OH)CH_3-$, contains a secondary hydroxyl on the number two carbon and may also be considered to form a proplyene glycol ether of cellulose.

These products possess varying ratios of hydroxypropyl and methyl substitution, a factor which influences organic solubility and the thermal gelation temperature of aqueous solutions.

file:///C:/Users/kp/AppData/Local/Temp/pi_methocel_gen_prop.pdf

Natural Polymers: Polyesters

(Vinning) Maurice A. Lemoigne, a biologist at the Pasteur Institute of Paris, reported in 1925 that a bacteria produced a polyester with properties similar to those of synthetic plastics. These natural polyesters, or polyhydroxyalkanoates (PHAs), can be melted, molded, and shaped to form articles, like other thermoplastics. In June of 1991, Britain's Imperial Chemical Industries opened a factory containing large fermenters for polymer producing bacteria to grow. Adjusting the mixtures of raw materials fed to the bacteria produces different polyesters with different properties.

Subsequently, Douglas Dennis, a molecular biologist at James Madison University, found that recombinant bacteria could also produce PHAs by identifying and transferring the genes controlling PHA production into a common bacterium, E. Coli. Inspired by this research, scientists are Michigan State University inserted the gene responsible for PHB production into a plant known as the arabidopsis, or "mouse ear cress". This plant was able too successfully produce polyester. These plastics are completely biodegradable because they are naturally occurring food reservoir for bacteria.

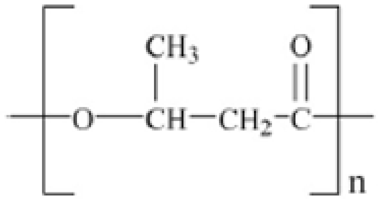
These polymers generally do not trigger an immune response, and they are widely used in medical industry. Unfortunately, they are more expensive than those from conventional petroleumproduced plastics.

William J. Vinning and Richard S. Stein
Exploring the World of Plastics. Version 1.0
by National Plastics Center and Museum. 1999.
Leominster, MA

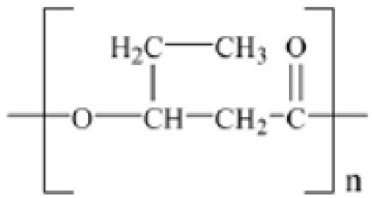
Natural Polymers: Polyesters

Polyhydroxyalkanoates (PHAs) are naturally produced.

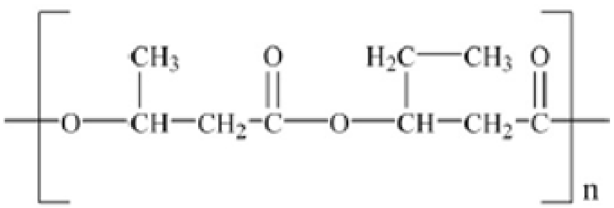
Poly3hydroxybutyrate
(PHB or PH3B)

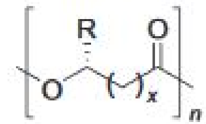


Poly3hydroxyvalerate
(PHV)



Poly(3-hydroxy butyrate-co-3-hydroxyvalerate)
(PHBV)





Polyhydroxyalkanoates (PHAs)

	R Groups	Polymers	Abbreviations
X = 1	Hydrogen	Poly(3-hydroxypropionate)	PHP
	Methyl [-CH_3]	Poly(3-hydroxybutanoates)	PHB
	Ethyl [-CH_2CH_3]	Poly(3-hydroxyvalerate)	PHV
	Propyl [-$(CH_2)_2CH_3$]	Poly(3-hydroxyhexanoate)	PHHex
	Pentyl [-$(CH_2)_4CH_3$]	Poly(3-hydroxyoctanoate)	PHO
	Heptyl [-$(CH_2)_6CH_3$]	Poly(3-hydroxydecanoate)	PHD
X = 2	Hydrogen	Poly(4-hydroxybutyrate)	P(4HB)
X = 3	Hydrogen	Poly(5-hydroxyvalerate)	P(5HV)

FIGURE 23.9 Polyhydroxyalkanoate family.

McKeen 2012, Renewable Resource and biodegradable polymers, in Film Properties of Plastics and Elastomers (3rd Edn). 14.8. Poly-3-hydroxybutyrate (PHB or PH3B)

Ross 2017, Bioplastics- New routes, new products, in Brydson's Plastics Materials (Eighth Edition), Marianne Gilbert, Ed., 2017
Ch. 23.

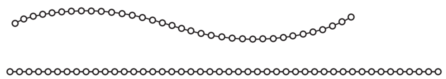
Synthetic Polymers

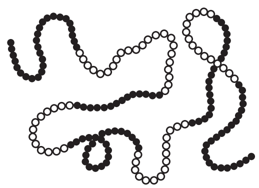
Linear Polymers (1930s)

Homopolymer

Copolymer

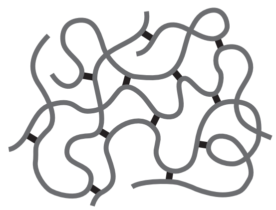
Random copolymer



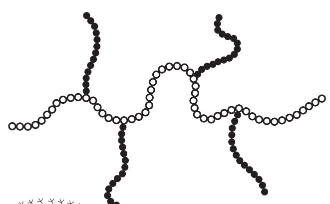


Block copolymer

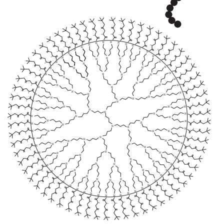
Crosslinked Gel (1940s)



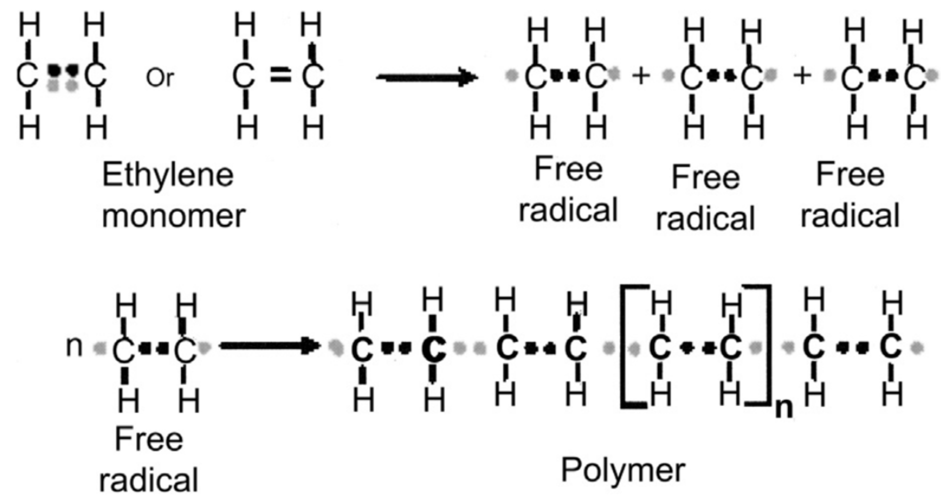
Branched Polymers (1960s)



Dendrimers (1980s)



Free Radical Polymerization



Wagner 2014, Polymer Overview and Definitions

Linear polymers can pack together very closely, resulting in a high density material.

Branched polymers cannot pack as tightly, resulting in less dense and more flexible material.

Crosslinked polymers can swell in solutions, but cannot dissolve in the solvents unless the crosslinkers are broken.

Synthetic Polymers: Additives

Additives

When plastics emerge from reactors, they may have the desired properties for a commercial product or not. The inclusion of additives may impart to plastics specific properties. Some polymers incorporate additive during manufacture. Other polymers include additives during processing into their finished parts. Additives are incorporated into polymers to alter and improve basic mechanical, physical or chemical properties. Additives are also used to protect the polymer from the degrading effects of light, heat, or bacteria; to change such polymer processing properties such as melt flow; to provide product color; and to provide special characteristics such as improved surface appearance, reduced friction, and flame retardancy.

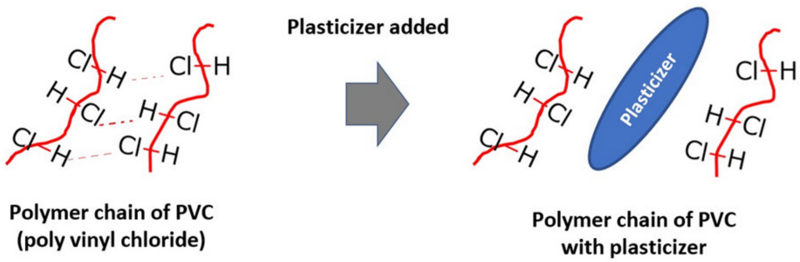
Types of Additives

Antimicrobials:	used for shower curtains and wall coverings
Antioxidants:	for plastic processing and outside application where weathering resistance is needed
Antistats:	to reduce dust collection by static electricity attraction
Colorants:	for colored plastic parts
Flame retardants:	to improve the safety of wire and cable coverings and cultured marble
Foaming agents:	for expanded polystyrene cups and building board and for polyurethane carpet underlayment
Lubricants:	used for making fibers
Plasticizers:	used in wire insulation, flooring, gutters, and some films

https://plastics.americanchemistry.com/EducationResources/HandsonPlastics/IntroductiontoPlasticsScienceTeachingResources/HistoryofPolymerandPlasticsforStudents.html

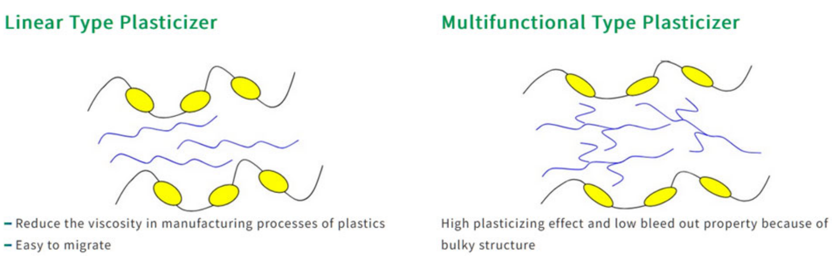
Plasticizers

Plasticizers are added to synthetic resins to improve their plasticity and to give them flexibility. It is mainly used for thermoplastic resins, which are linear polymers, but is also used for thermosetting resins.

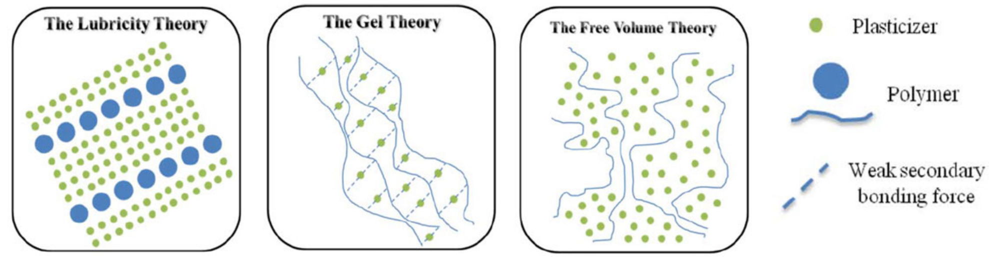


Advantages of Polymer Plasticizers

When PVC electrical cords and water hoses are used for long periods of time, they may harden and become difficult to use. This is due to the fact that the low-molecular plasticizer seeps into the surface over time, volatilizes, and is washed away, causing the original plasticizing effect to be lost. Since this phenomenon is caused by the low molecular weight of the plasticizer, using a high-molecular plasticizer with a molecular weight of several thousand or more makes it difficult for the plasticizer to move within the resin and enables the plasticizing effect to be maintained for a long time.



https://sanyo-chemical-solutions.com/products/sanflex/



The low molecular weight of a plasticizer allows reducing secondary forces (hydrogen bonding, van der Waals forces. . .) between the polymer chains by occupying intermolecular spaces. Thus, the 3-D molecular organization of polymers decreases the energy required for molecular motion.

The lubricity theory provides that the plasticizer diffuses into the polymer, inserting into the polymer chains and reducing the intermolecular frictions. The macromolecules slip over each other when a plastic part is flexed. Then, the plasticizer lubricates the movement of the molecules reducing their internal resistance to slide and to prevent the re-formation of the rigid matrix. The lubricity theory assumes that the rigidity of polymers comes from internal frictions and that plasticizers act by lubricating the layers of polymer.

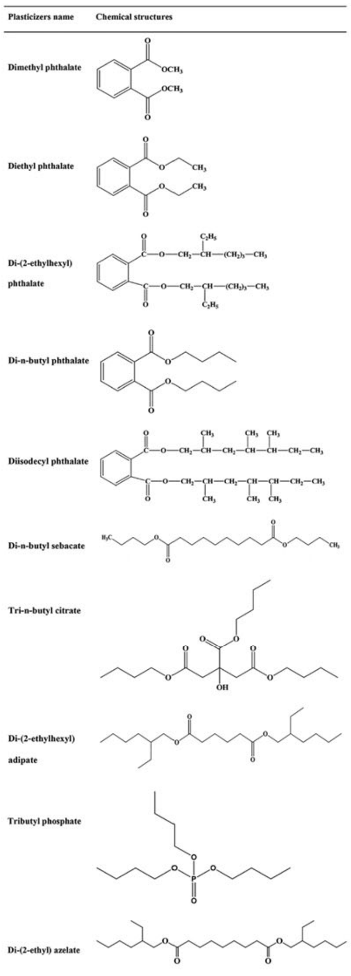
The gel theory is based on the assumption that the plasticized polymer is considered to be a three-dimensional network with plasticizer molecules bonded to resin chains by weak secondary forces. The plasticizer acts by breaking the polymer–polymer bonds and interactions, masking these centers of attachment from each other and preventing their reformation. The gel theory supposes that it comes from points of attachments of polymer to polymer and that plasticizers reduce the number of these sites.

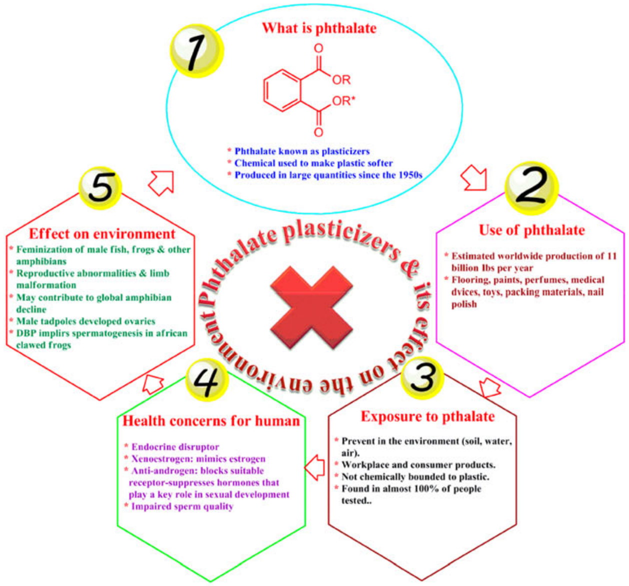
The free volume is the internal space available within a polymer. A rigid polymer possesses very little free volume. When a plasticizer is added, it increases the free volume making the polymer soft and rubbery, increasing motion of polymer molecules. This free volume is maintained when the resin plasticizer mixture is cooled down after melting. Free volume comes from three principal sources: motion of chain ends, motion of side chains and motion of the main chain. This theory is the one giving more precise explanation on plasticization since it is based on relationships between properties (specific volume, viscosity. . .) and variables (molecular weight, terminal groups content. . .) of polymers that were not yet explained at the time the other two theories appeared.

Bocque 2015, Petro-based and bio-based plasticizers: Chemical structures to plasticizing properties

Plasticizers

Table 1. Name and Chemical Structure of the Generally Employed Plasticizers for PVC[63]





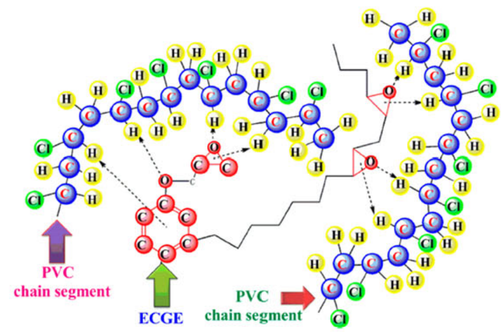
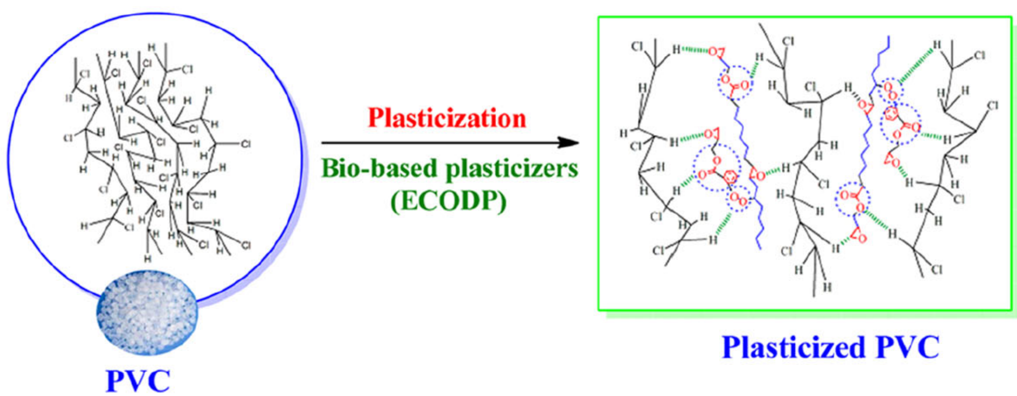


Figure 12. Schematic representation of the chemical interaction of plasticizers (ECGE) and PVC system.



Kumar 2019, Recent developments of biobased plasticizers and their effect on mechanical and thermal properties of PVC

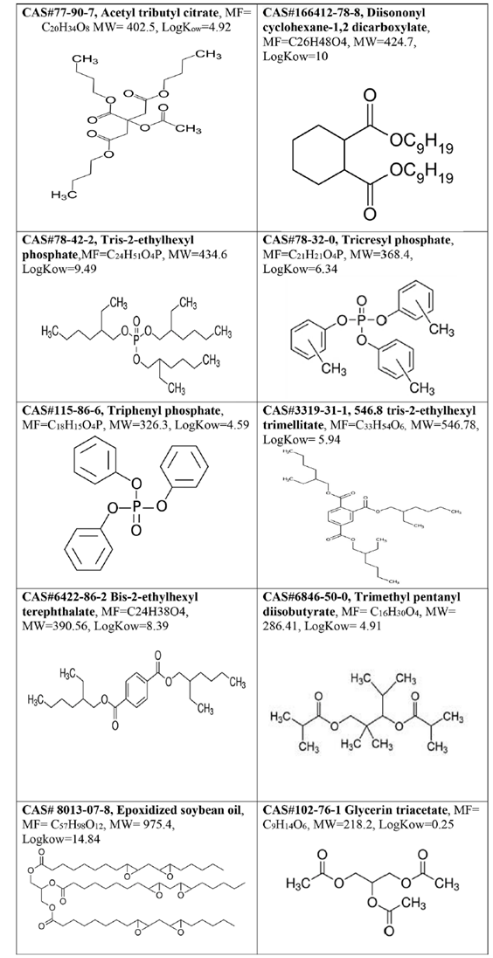
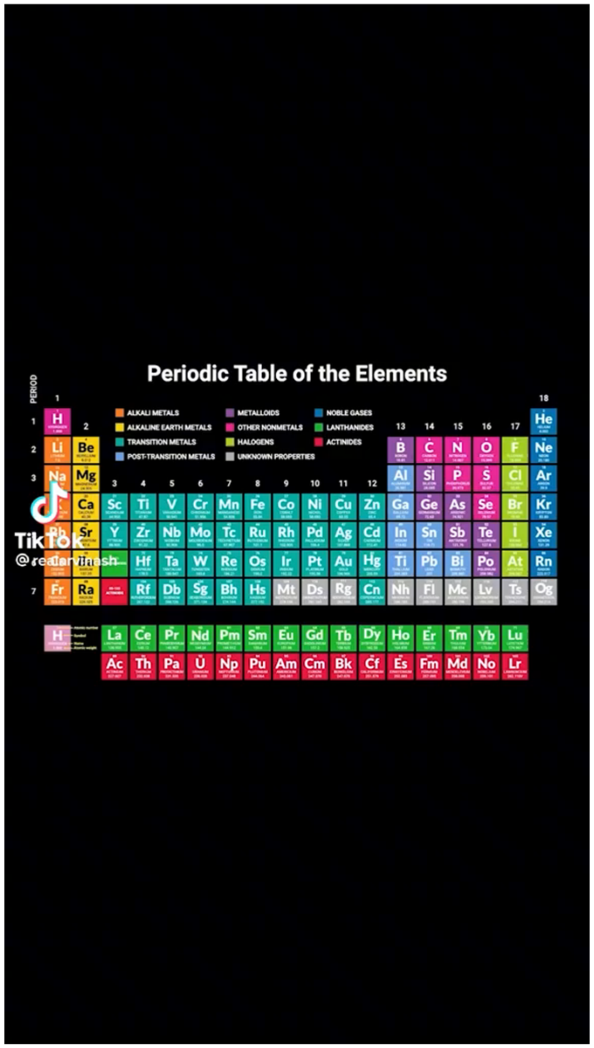


Figure 1. Names, chemical structures, CAS numbers, and basic properties of typical alternative plasticizers.

Qadeer 2022, Alternative plasticizers as emerging global environmental and health threat-another regrettable substitution

Carbon as the Backbone of Polymers



Silicon-Based Life May Be More Than Just Science Fiction
Scientists are showing that nature can evolve to incorporate silicon into carbon-based molecules — the building blocks of life on Earth.

"In the universe of possibilities that exist for life, we've shown that it is a very easy possibility for life as we know it to include silicon in organic molecules. And once you can do it somewhere in the universe, it's probably being done."

https://www.nbcnews.com/mach/science/silicon-based-life-may-be-more-just-science-fiction-n748266

Silicon-Based Life May Be More Than Just Science Fiction

Scientists are showing that nature can evolve to incorporate silicon into carbon-based molecules – the building blocks of life on Earth.

Artist rendering of organosilicon-based life. Recent research shows, for the first time, that bacteria can create organosilicon compounds. Lei Chen and Yan Liang (BeautyOfScience.com) / Caltech

Polymer Characterization

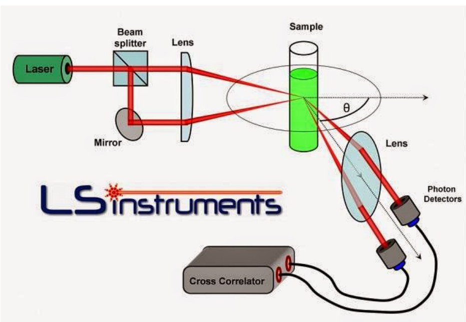
Foundation of Polymer Science

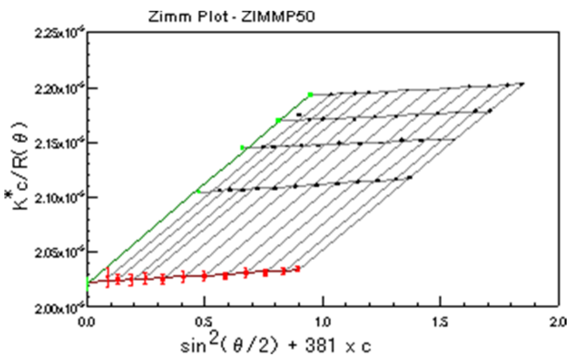
- Understanding the relationships between chemical structure and (molecular and bulk) properties of polymers.
- Characterization of molecular and bulk properties
- Use the relationships to design new materials with predictable properties, and to mimic natural substances without need to duplicate their structures in detail.

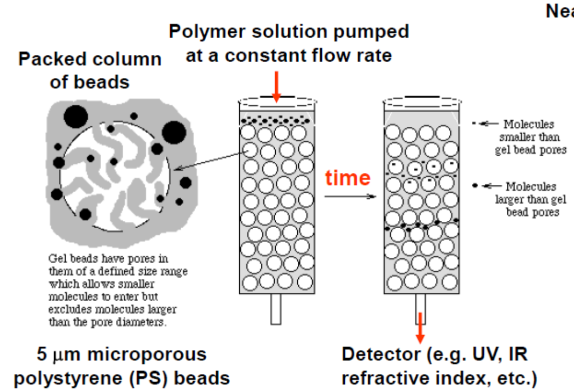
Past & Present	Present & Future
Existing Polymers	Applications: Specific Polymer Properties
Find Applications	Design New Polymers

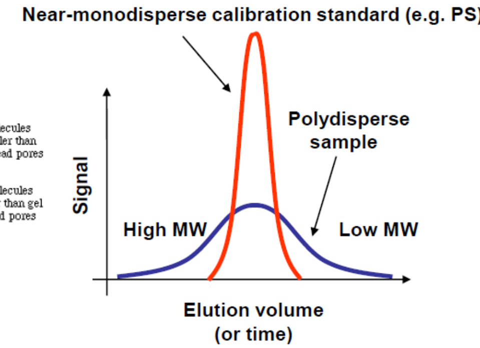
Characterization: Polymer Molecules

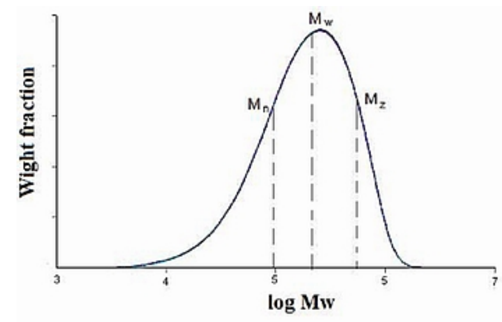
- **Molecular Weights**
  Weightaverage
  Numberaverage









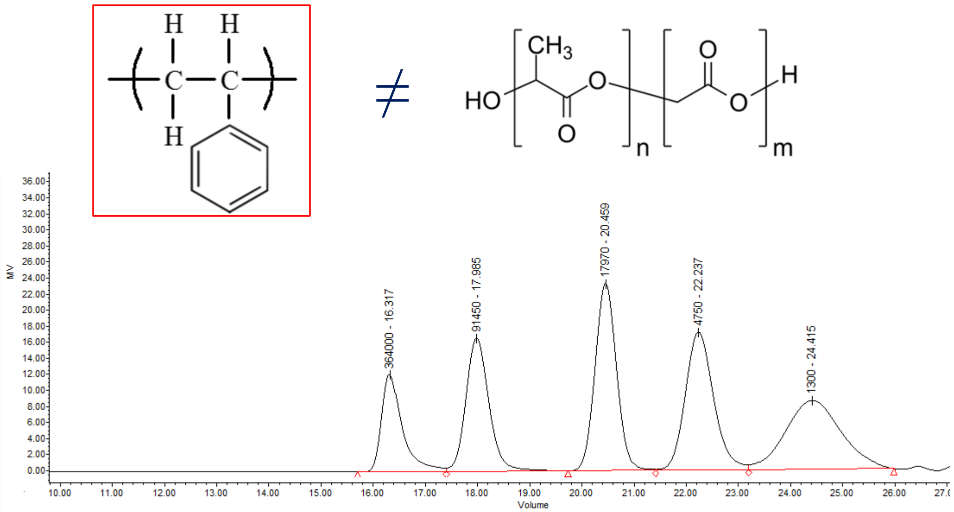


https://chemisyou.blogspot.com/2015/03/polymerchemistrymolecularweightof.html

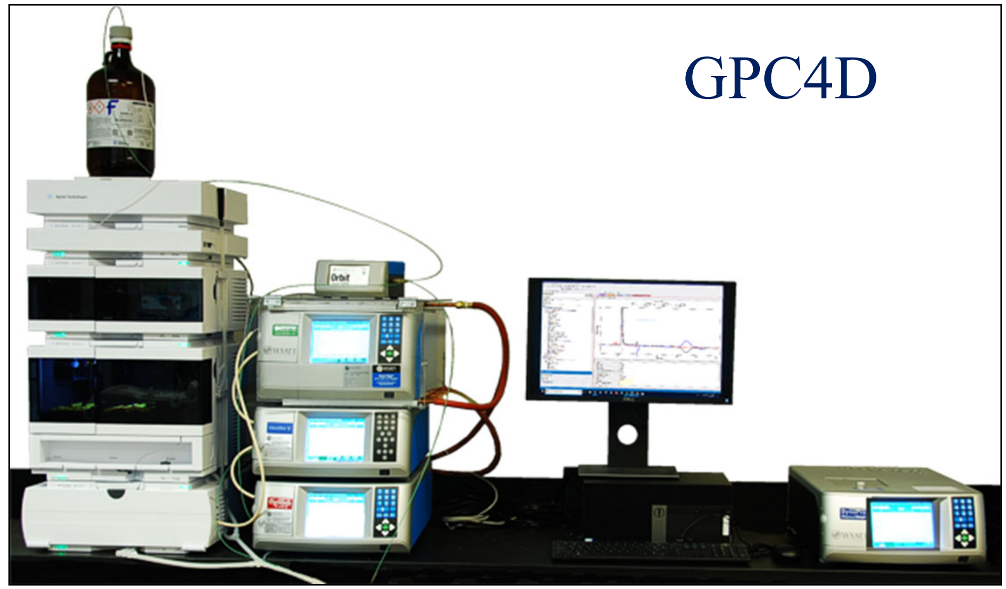
- **Molecular Structure**
  Monomers: Single monomer, Comonomers
  Architecture: Linear, Branched, Dendritic, Crosslinked

- **Solubility**
  Polymers dissolved in a solvent are used in paints, varnishes, and glues. As a general rule, as the size of a polymer increases, the difficulty with which it dissolves also increases.

PLGA Molecular Weight by GPC with Polystyrene External Standard



Polystyrene Standards (1ml/min THF)

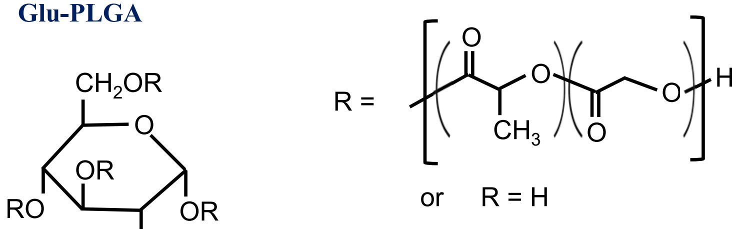


- Size exclusion chromatography/gel permeation chromatography separate based on the hydrodynamic volume
- Solvation between polymer/solvent, interaction with column also controls the retention time.
- Non-representative standard (typically polystyrene) and the lack of standardized methods mean labtolab differences in GPC measured molecular weights.

- GPC separation followed by MALLS (R_g, MW), Viscometry (intrinsic viscosity), inline dynamic light scattering (R_h), and refractive index (concentration).
- Universal calibration, no external standards, no solvation artifacts.
- Light scattering is better for lowRI solvents (acetone) than high RI solvents (THF).
- In depth information about PLGA for determination of molecular shape & branching.

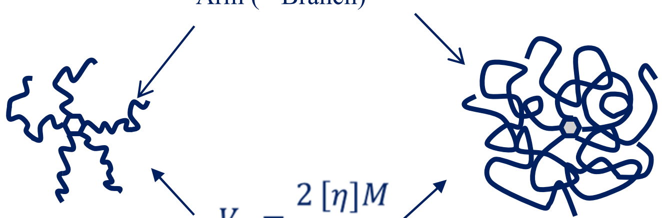
Star-Shaped PLGA (Glucose-PLGA)

Glu-PLGA



R represents either PLGA or hydrogen

Arm (= Branch)

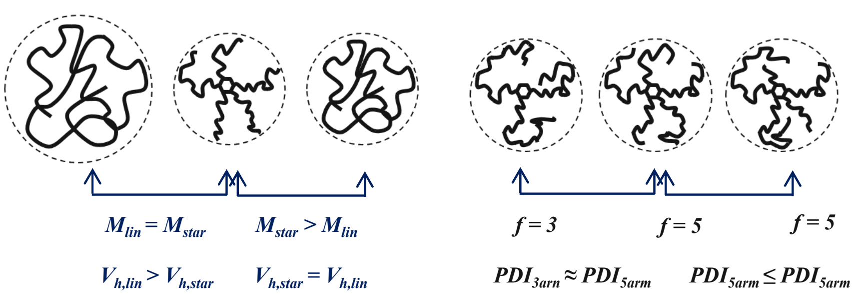


$$V_h = \frac{2}{5}\frac{[\eta]M}{N_A}$$

(V_h: Hydrodynamic Volume)

Low Molecular Weight

High Molecular Weight



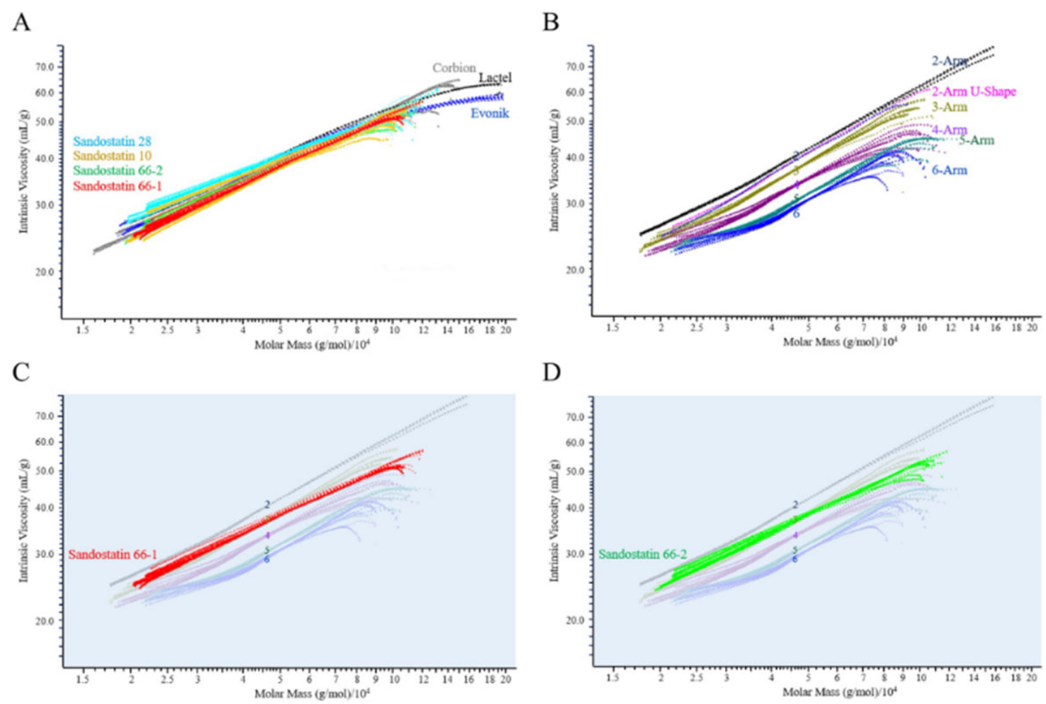


Fig.7.Mark-Houwink plots of Glu-PLGAs of Sandostatin LAR, Corbion,E vonik, and Lactel(A), branch standards with triplicate measurements of each sample (B), Glu-PLGAs of Sandostatin LAR (lots356166 (CandD) in comparison with the branch standards of 2–6 arms.

The branch units of Glu-PLGAs can be determined without any theoretical model from the Mark-Houwink plots, [η]=KMα or log[η]=logK+α(logM), where [η] and M are intrinsic viscosity and molecular weight, respectively.

Hadar 2019 , Characterization of branched PLGA polymers used in injectable, long-acting formulations

Polymer Properties

Properties

Mechanical properties: Solid, Elastomer, Liquid

Glass transition temperature (T_g) & Melting temperature (T_m)

Elastic modulus, Flexibility, Tensile strength

The polymer crystallinity increases its strength, stiffness, and chemical resistance.

Resilience: The ability of the plastic to resist abrasion and wear

Permeability: Polyethylene is used to wrap foods because it is 4000 times less permeable to oxygen then polystyrene.

Crystallinity: Amorphous arrangement of polymer chains are usually transparent

(Contact lenses, windows, headlight lenses, food wrap)

The higher degree of crystallinity, the less light through the polymer.

Heat conductivity: Effective insulators against the flow of heat

Refractive index: The extent to which the plastic affects light as it passes through the polymer

Thermal expansion: Polymers are usually anisotropic. They contain strong covalent bonds along the polymer chain and much weaker dispersive forces between the polymer chains. As a result, polymers can expand by differing amounts in different directions.

Resistance to electric current: Most polymers do not conduct an electric current, except some conducting polymers.

Emerging Applications and Opportunities of New Polymers

Polymer Mechanochemistry

The force-induced activation of a latent mechanophore can cause a change in its optical properties, rendering the mechanophore an optical force probes (OFP).

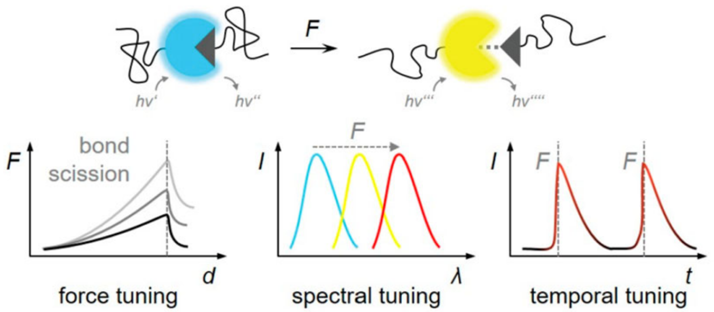


Figure 1. Optical force probe concept and exemplary tunable characteristics, such as scission force threshold, spectral properties, and temporal response for reversibility.

The mechanochemical release of bioactive molecules, being an imperative feature for drug delivery systems, has paved the way toward the emerging field of sonopharmacology

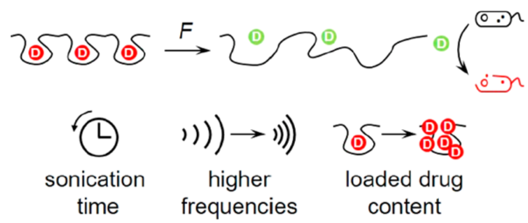
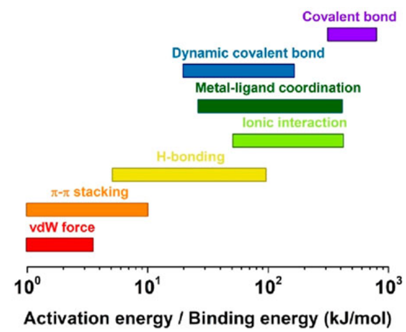
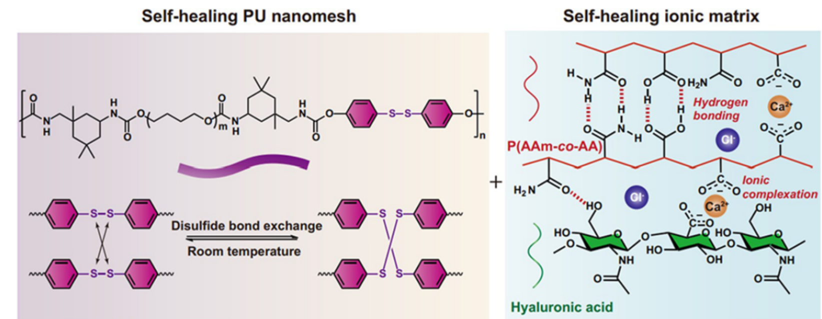


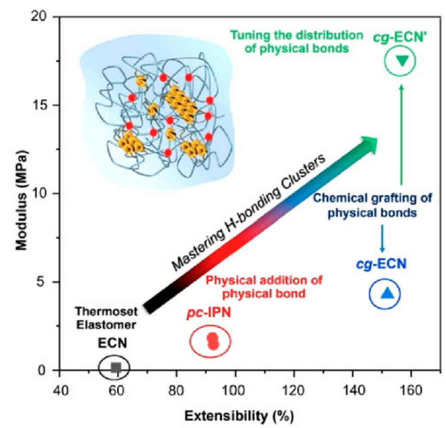
Figure 3. Principle of sonopharmacology for drug (D) activation and associated standing challenges for its successful future biomedical application.

Klok 2022, Force ahead- Emerging applications and opportunities of polymer mechanochemistry

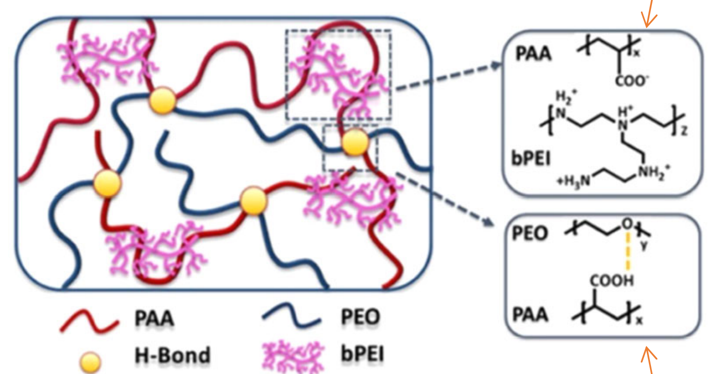
Self-Healing Polymers







Ionic interaction at pH > pK_a



Hydrogen bonding at pH < pK_a

(Poly(acrylic acid) pK_a = ~4.5)

Li 2022, Intrinsically self-healing polymers- From mechanistic insight to current challenges
Swift 2016, The pH-responsive behaviour of poly(acrylic acid) in aqueous solution is dependent on molar mass
Wisniewska 2014, Comparison of adsorption affinity of polyacrylic acid for surfaces of mixed silica–alumina

Properties: Phase Separation

Phase separation

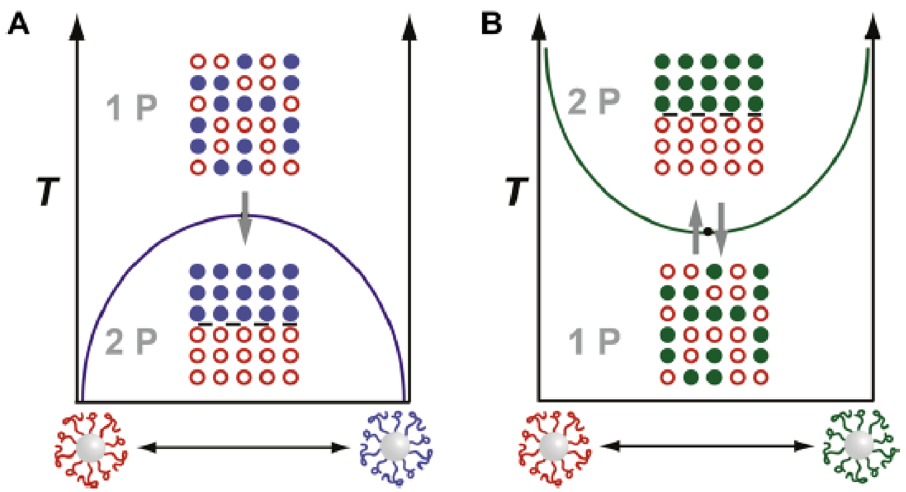
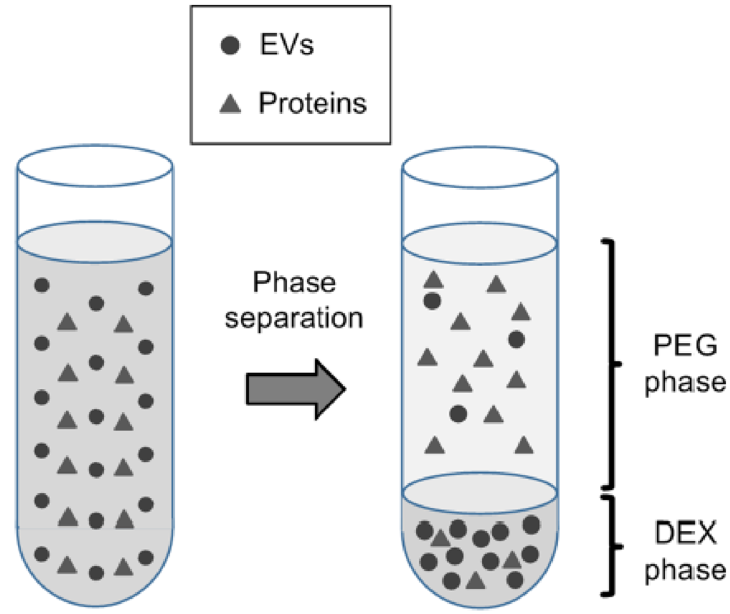


Fig. 1. Illustration of ligand-induced phase separation in particle brush blends. (**A**) UCST phase behavior. (**B**) LCST phase behavior. LCST blends allow for reversible cycling of blend through homogeneous one-phase (1 P) and phase-separated two-phase (2 P) states.



Schmitt 2016, Polymer ligand–induced autonomous sorting and reversible phase separation in binary particle blends

Kim 2015, Isolation of high-purity extracellular matrix

Phase Behavior: Phase Separation in Polymer Blends

Phase Separation depends on Temperature and Composition

Utracki et al. [1] classified the polymer blends with respect to their phase structures as follows:

- Miscible blends: Those polymer blends which behave as a single-phase material and show homogeneity at a macroscopic (molecular) scale.

- Partially miscible blends: This class of polymer blends refers to those blends that are miscible within a range of temperatures and compositions.
- Immiscible blends: This refers to those polymer blends having phase-separated structures at all compositions and temperatures with phases having the same characteristics as those of the components before blending.

It has been reported that phase separation could be a result of low miscibility or crystallization of one of the phases [3]. This, in turn, would give rise to different phase diagram behaviors (Fig. 4.1). However, it has been shown that most high molecular-weight polymer pairs are partially miscible, showing lower critical solution temperature (LCST) behavior as a result of entropy effects [1,3].

Utracki, L.A.,Weiss ,R.A., Eds., Multiphase Polymers: Blends and Ionomers, ACS symposium series 395: 532, 1989.

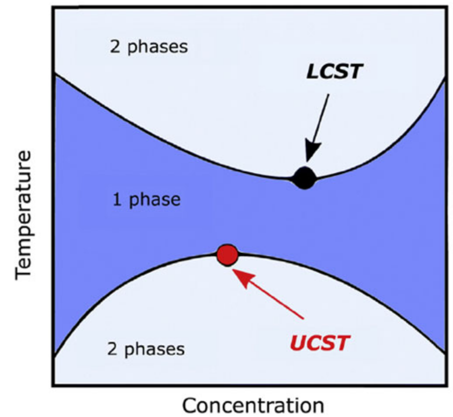


FIGURE 4.1. Upper and lower critical solution temperatures (UCST) and (LCST) behaviors of polymers shown in a phase diagram [4].

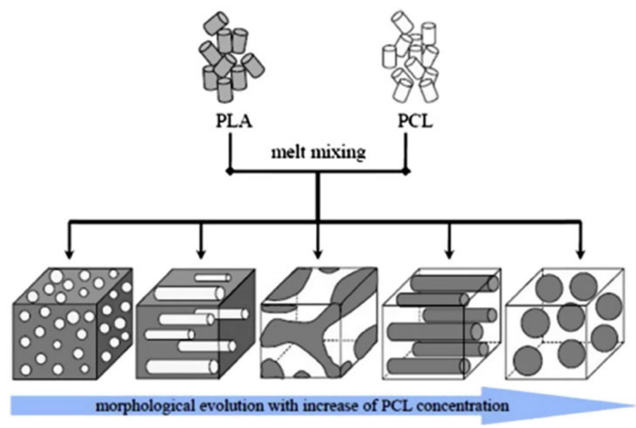


FIGURE 4.2. Cartoon illustrating the morphological changes in PLA/PCL blends when the PCL concentration is increased [5].

Ray 2020, Fundamentals of immiscible polymer blends

Phase Separation

Phase separation is a ubiquitous process and finds applications in a variety of biological, organic, and inorganic systems. Nature has evolved the ability to control phase separation to both regulate cellular processes and make composite materials with outstanding mechanical and optical properties. Striking examples of the latter are the vibrant blue and green feathers of many bird species, which are thought to result from an exquisite control of the size and spatial correlations of their phase-separated microstructures. By contrast, it is much harder for material scientists to arrest and control phase separation in synthetic materials with such a high level of precision at these length scales.

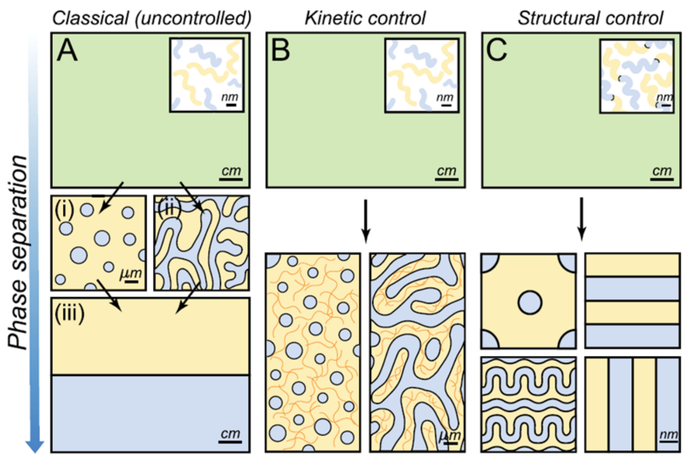


Figure 1. Liquid−liquid phase separation and some established methods to control it. (A) Classical (uncontrolled) phase separation of an homogeneous mixture where the two immiscible components (blue and yellow) demix by either (i) nucleation and growth or (ii) spinodal decomposition until they form (iii) two distinct macroscopic phases. (B) Kinetic control of phase separation by vitrification or cross-linking of one of the phases. (C) Structural control of phase separation by using block-co-polymers: the two immiscible components are chemically bound (inset), which introduces an internal length scale: a range of periodic structures are obtained.

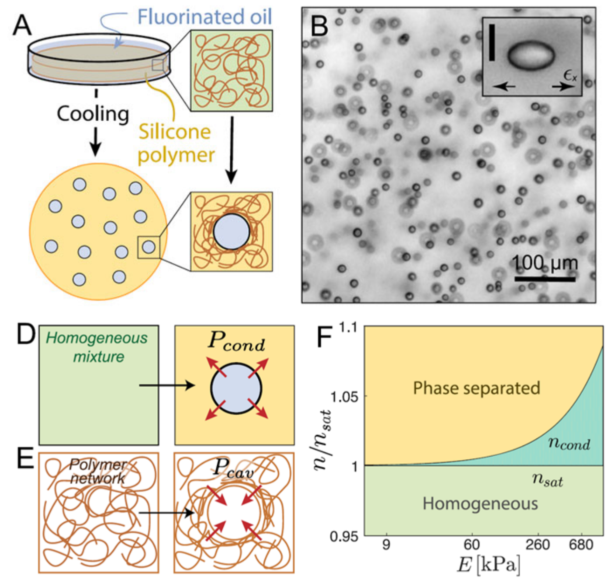


Figure 3. Elastic control of phase separation. (A) Schematic diagram of temperature-induced nucleation and growth of fluorinated oil droplets in silicone polymer networks. (B) Bright-field microscopy image of the typical oil droplets formed in the silicone gels. Inset shows how network stresses cause the droplets to grow with elliptical shapes. The scale bar is 10 µm. (D) Schematic of the condensation of a single droplet, exerting a condensation pressure, P_{cond} into the continuous phase. (E) Schematic of the creation of a spherical cavity on a polymer matrix. The opposing pressure exerted by the network is the cavitation pressure P_{cav}. (F) Phase diagram of the stability of an homogeneous mixture depending on the supersaturation of the mixture and the stiffness of the network.

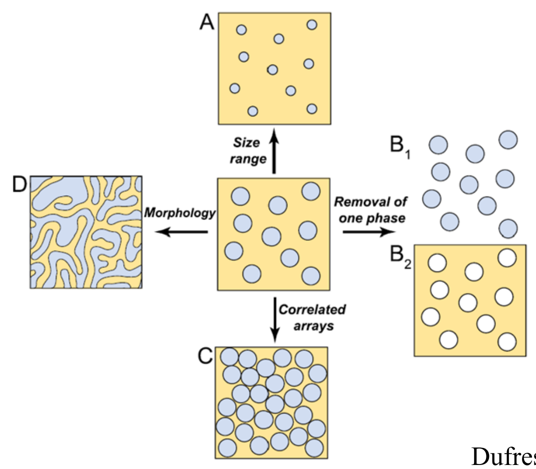


Figure 4. Potential developments in the fabrication of microstructured materials through phase separation in elastic media. (A) Access to a wider range of droplet sizes. (B) Fabrication of (B_1) standing-free liquid or polymer particles and (B_2) porous materials. (C) Assembly of structures with higher packing factions showing structural correlations. (D) Fabrication of interconnected channel structures via spinodal decomposition.

Dufresne 2022, Putting the squeeze on phase separation

Polymer Applications

Applications: Thermoplastics and Thermoset Plastics

Thermoplastics (Secondary bonds between polymer chains)

Polyethylene:	Packaging, Electrical insulation, Milk and water bottles, Packaging film, House wrap, Agricultural film
Polypropylene:	Carpet fibers, Automotive bumpers, Microwave containers, External prostheses
Polyvinyl Chloride:	Sheathing for electrical cables, Floor and wall coverings, Siding, Automobile instrument panels, Credit card

Thermoset Plastics (Primary bonds between polymer chains; crosslinked)

Polyurethanes:	Mattresses, Cushions, Insulation
Unsaturated Polyesters:	Boat hulls, Bath tubs and shower stalls, Furniture
Epoxies:	Adhesive glues, Coating for electrical devices, Helicopter and jet engine blades
Phenol Formaldehyde:	Oriented strand board, Plywood, Electrical appliances, Electrical circuit boards and switches

https://plastics.americanchemistry.com/EducationResources/HandsonPlastics/IntroductiontoPlasticsScienceTeachingResources/HistoryofPolymerandPlasticsforStudents.html

Applications: Polymers for Packaging

Polymer	Properties	Applications
High density polyethylene	Excellent resistance to most solvents Relatively stiff material with useful temperature capabilities.	Bottles for milk, water, juice, cosmetics, shampoo, dish and laundry detergents, and household cleaners. Bags for groceries and retail purchases. Cereal box liners.
Low density polyethylene	Good combination of properties for packaging applications requiring heat-sealing. Can be made into thin films.	Bags for dry cleaning, newspapers, bread, frozen foods. Shrink wrap and stretch film. Coatings for paper milk cartons and hot and cold beverage cups. Container lids. Squeezable bottles (e.g., mustard)
Poly(ethylene terephthalate)	Clear, tough, and has good gas and moisture barrier properties. Cleaned, recycled PET pellets are used for spinning fiber for carpet yarns and producing fiberfill and geotextiles.	Plastic bottles for soft drinks, water, juice, sports drinks, beer, mouthwash, catsup, and salad dressing. Food jars for peanut butter, jelly, jam, and pickles. Ovenable film and microwavable food trays
Polypropylene	Good chemical resistance, strong, high melting point ideal for hot-fill liquids. Flexible and rigid packaging, fibers, and large molded parts for automotive and consumer products.	Containers for yogurt, margarine, takeout meals, and deli foods. Medicine bottles. Bottle caps. Bottles for catsup and syrup. Buckets, ropes, carpets.

https://www.plasticpackagingfacts.org/plasticpackaging/resinstypesofpackaging/
https://www.bbc.co.uk/bitesize/guides/ztr7b82/revision/2

Applications: Polymers for Packaging

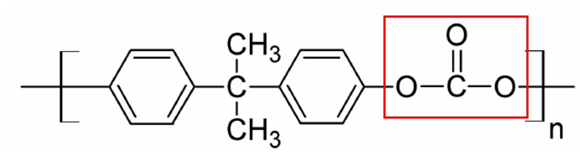
Polymer	Properties	Applications
Polystyrene	Rigid or foamed. Relatively low melting point. Excellent moisture barrier for short shelf life products. Significant stiffness in both foamed and rigid forms. Low thermal conductivity and excellent insulation properties in foamed form.	Typical applications include protective packaging, food service packaging, bottles, and food containers. PS is often combined with rubber to make high impact polystyrene (HIPS) which is used for packaging and durable applications requiring toughness, but not clarity
Poly(vinyl chloride)	Good chemical resistance, weatherability, flow characteristics, and stable electrical properties. High impact strength. Brilliant clarity. Resistance to grease, oil, and chemicals.	Blister packs and clamshells. Shrink wrap, deli and meat wrap and tamper resistance. Insulator for electrical wires. Windows, gutters, pipes.

https://www.plasticpackagingfacts.org/plasticpackaging/resinstypesofpackaging/
https://www.bbc.co.uk/bitesize/guides/ztr7b82/revision/2

Applications: Bullet-Proof Glass

- **Clarity and Strength**
  Polycarbonate: Strong, light weight, UV resistant, scratch resistant. heat resistant, transparent.
  Used in safety glasses, airline windows, riot police shields, bullet-proof glass

- **Lexan®**
  Made by GE. Tough, transparent, high tensile strength, temperature-resistant, light weight.
  Used in bicycle, motorcycle, and football helmets, automobile and aircraft equipment, safety glass, unbreakable glass, signs, race car exterior.



A plastic that is transparent, resilient, bulletproof, that doesn't burn, scorch or melt, and it's natural, eatable and sweet. It would be marvelous… if it was true.
Each one of the characteristics can be found in several plastics, but no plastic has them all. Maybe a technical plastic with all this characteristics exists nowadays, but most surely it wouldn't be a bioplastic —made of sugar cane—. Notice that the development of this kind of plastics started at the beginning of 1950s, so it means that was an actual topic when the movie was filmed.
One of the evidences that the plastic they were talking about was not actually the one used in the film is that this one did scorch —check the black spot in the plastic in Image 5—. It's just that in the scene, it's obvious that you are looking at Linus (Humphrey Bogart) and David (William Holden) faces, and not at the plastic.

Sabrina. 1954

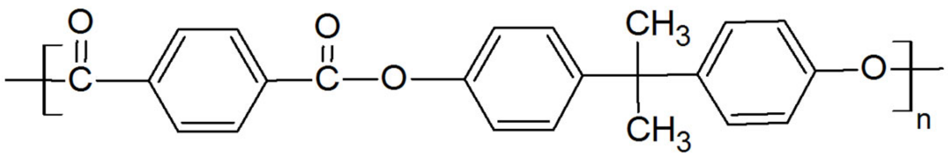
http://toldbydesign.com/?portfolio=billy-wilder-sabrina

Polyarylates (Aromatic Polyesters)

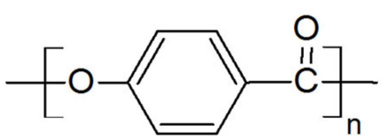
Polyarylates are a family of aromatic polyesters. The repeat units consists of ester groups (chemical formula -CO-O-) and aromatic rings. They are produced by polycondensation of a diacid chloride derivative of a dicarboxylic acid with a phenolic compound. The dicarboxylic acid is usually terephthalic or isophthalic acids and the phenol is Bisphenol A or a derivate of it. The bulky aromatic rings and the absence of methylene groups in the polymer backbone greatly stiffen the polymer chain by interfering with the rotation of the repeat units around the ester linkages. The two most common polyarylates are poly(-p-hydroxybenzoate) and polybisphenol-A terephthalate. The chemical structure of these arylates is given below.

Polybisphenol-A terephthalate is the most common polyarylate. It has one of the highest-levels of heat resistance among transparent resins. For example, its deflection temperature under 1.8 MPa load is about 175 °C (345 °F) (Ardel Polyarylate). It also has high transparency and excellent resistance to degradation from ultraviolet radiation. The material undergoes a molecular rearrangement resulting in the formation of a protective layer that essentially serves as a UV stabilizer. Because UV irradiation increases the UV-blocking property of the polymer, it exhibits excellent weather resistance without addition of any stabilizers. (Although some yellowing occurs, there is hardly any change in physical properties.) Arylates have a transparency as high as PC or PMMA, transmitting almost 90% light. The polymer exhibits excellent elastic recovery and has a high tolerable strain ratio. It also has excellent creep resistance and retains its properties for an extended period of time. For these reasons, the polymer can be used as springs.

Some other noteworthy arylate monomers are 4-acetoxybenzoic acid, 4-hydroxybenzoic acid, hydroxynaphthalene-2-carboxylic acid, and 4-pivaloyloxybenzoic acid. The polymer Ekonol produced by Saint-Gobain, is based on 4-hydroxybenzoic acid. It is a highly crystalline linear thermoplastic polymer with no melting point and virtually no creep below 350 °C. It retains good stiffness at temperatures up to 315°C and, at temperatures around 425°C, it undergoes a second-order transition and becomes malleable and can be forged like ductile metals. Some other properties are high heat resistance, dielectric strength, elastic modulus, thermal conductivity, and good resistance to wear and solvents. It is also good machinable. Poly(hydroxybenzoate) can be blended with polytetrafluoroethylene (PTFE). This composite material is self-lubricating and has excellent temperature and wear resistance. Another important polyarylate is the Vectran fiber, manufactured by Kuraray. It is produced by polycondensation of 4-hydroxybenzoic acid and 6-hydroxynaphthalene-2-carboxylic acid and has similar good properties.



Poly(bisphenol-A-terephthalate)

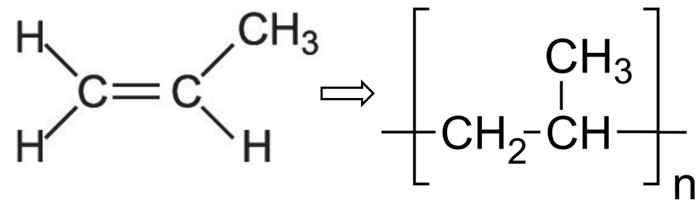


Poly(4-hydroxybenzoate)

https://polymerdatabase.com/polymer%20classes/Polyarylate%20type.html

Applications: Polypropylene

- **Greasy, Oily, and Fairly Stiff**
  Polypropylene: Hydrophobic, greasy, oily, fairly stiff, transparent. inexpensive
  Used in laminations, automobile interiors, automobile battery cases, textiles, toys, bottle caps, carpetting, street signs



Top 5 Common Uses of Polypropylene

1. Flexible and Rigid Packaging

2. Flexible and Rigid Packaging

3. Medical Applications

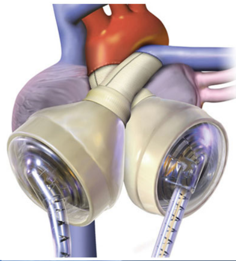
4. Consumer Products

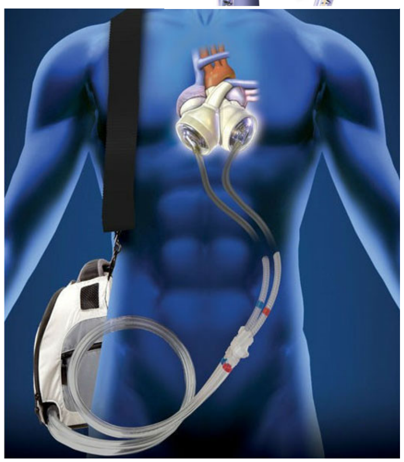
5. The Automotive Industry

https://totebagfactory.com/blogs/news/commonusesofpolypropylene

Applications: Biomedical Polymers

- **Biomedical Applications**
  Arificial Heart. Tissue engineering





Six Million Dollar Man

- **Cosmetic Applications**
  Hyaluronic acid filler, PLGA filler
  Botulinum toxin

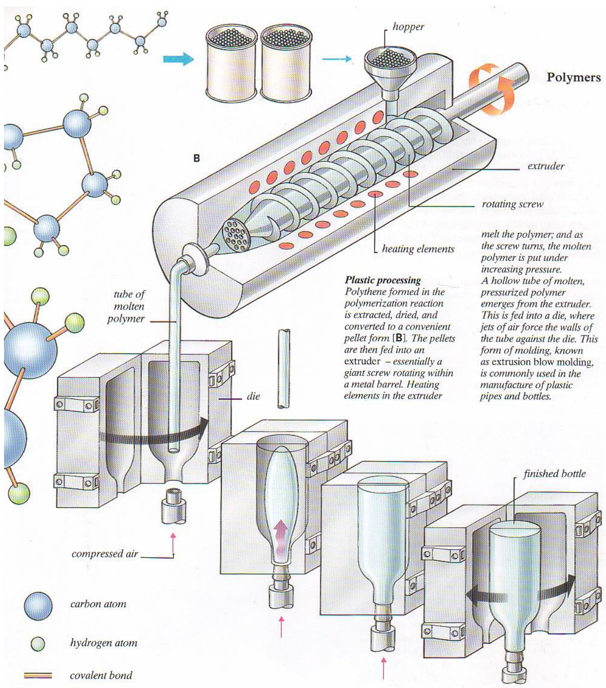
- **Adhesives**

https://www.youtube.com/watch?v=0CPJ-AbCsT8

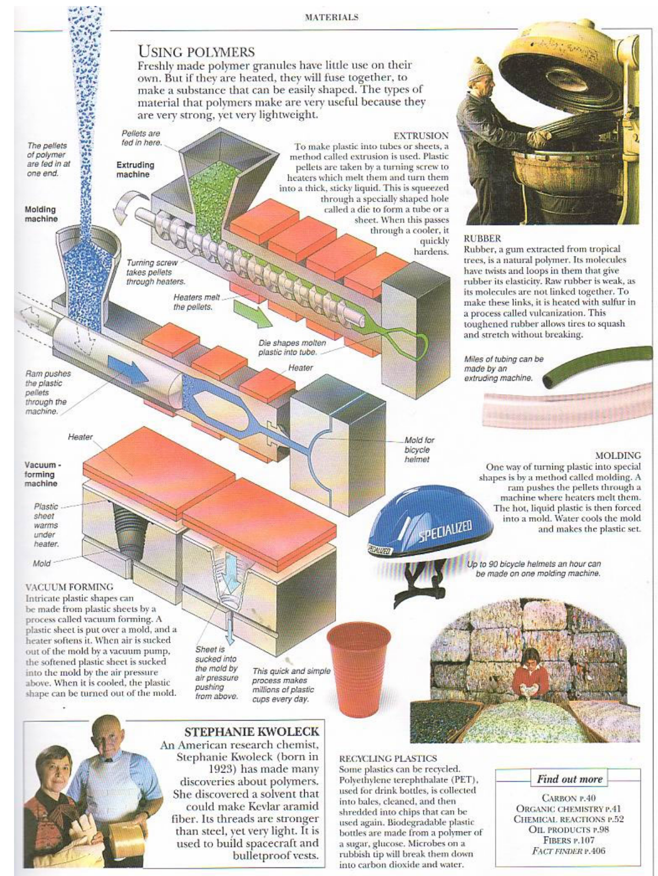
The Bionic Woman
https://www.youtube.com/watch?v=Pz_DT54sfAo

Applications: Products for Daily Use

Polymer Molding



Plastic processing
*Polythene formed in the polymerization reaction is extracted, dried, and converted to a convenient pellet form [***B***]. The pellets are then fed into an* extruder *– essentially a giant screw rotating within a metal barrel. Heating elements in the extruder melt the polymer; and as the screw turns, the molten polymer is put under increasing pressure.*
A hollow tube of molten, pressurized polymer emerges from the extruder. This is fed into a die, where jets of air force the walls of the tube against the die. This form of molding, known as extrusion blow molding, *is commonly used in the manufacture of plastic pipes and bottles.*



USING POLYMERS
Freshly made polymer granules have little use on their own. But if they are heated, they will fuse together, to make a substance that can be easily shaped. The types of material that polymers make are very useful because they are very strong, yet very lightweight.

EXTRUSION
To make plastic into tubes or sheets, a method called extrusion is used. Plastic pellets are taken by a turning screw to heaters which melt them and turn them into a thick, sticky liquid. This is squeezed through a specially shaped hole called a die to form a tube or a sheet. When this passes through a cooler, it quickly hardens.

RUBBER
Rubber, a gum extracted from tropical trees, is a natural polymer. Its molecules have twists and loops in them that give rubber its elasticity. Raw rubber is weak, as its molecules are not linked together. To make these links, it is heated with sulfur in a process called vulcanization. This toughened rubber allows tires to squash and stretch without breaking.

MOLDING
One way of turning plastic into special shapes is by a method called molding. A ram pushes the pellets through a machine where heaters melt them. The hot, liquid plastic is then forced into a mold. Water cools the mold and makes the plastic set.

VACUUM FORMING
Intricate plastic shapes can be made from plastic sheets by a process called vacuum forming. A plastic sheet is put over a mold, and a heater softens it. When air is sucked out of the mold by a vacuum pump, the softened plastic sheet is sucked into the mold by the air pressure above. When it is cooled, the plastic shape can be turned out of the mold.

STEPHANIE KWOLECK
An American research chemist, Stephanie Kwoleck (born in 1923) has made many discoveries about polymers. She discovered a solvent that could make Kevlar aramid fiber. Its threads are stronger than steel, yet very light. It is used to build spacecraft and bulletproof vests.

RECYCLING PLASTICS
Some plastics can be recycled. Polyethylene terephthalate (PET), used for drink bottles, is collected into bales, cleaned, and then shredded into chips that can be used again. Biodegradable plastic bottles are made from a polymer of a sugar, glucose. Microbes on a rubbish tip will break them down into carbon dioxide and water.

Find out more
CARBON P.40
ORGANIC CHEMISTRY P.41
CHEMICAL REACTIONS P.52
OIL PRODUCTS P.98
FIBERS P.107
FACT FINDER P.406

Applications: Foods

Bread: Starch (Yeast, Kneading)

Kneading is the process of working a dough mixture to form a smooth and cohesive mass. It can be done by hand or mechanically. Proper kneading is essential for the formation of dough with adequate viscoelastic properties including gas retention capacity.

Milk: Lactose-intolerant
Yogurt

Marshmallow

Artificial meat

Polymer Recycling

Recycling

Plastic Types

After the plastics are separated from other materials, they need to be stored by type.
The separated plastics can be reused easily, as those are far superior to mixed plastics.
The separated plastics are washed (and optionally sterilized), and ground or shredded into a pellet (small piece) or flake form that can be melted and molded for new use.

Importance of Separating Different Types of Plastics

Single type of polymers produce high quality products compared with blended polymers.

Separation of Different Plastics

Bar codes encoding each plastic, Spectroscopic analysis, Density (in solution), by Consumers

Removing Dirt from Plastics

The presence of dirt can be critical for spinning recycled plastics into fibers, as the dirt may block the pores of the spinners easily. Washing may not remove all dirt. Dissolving and filtering is difficult and expensive.

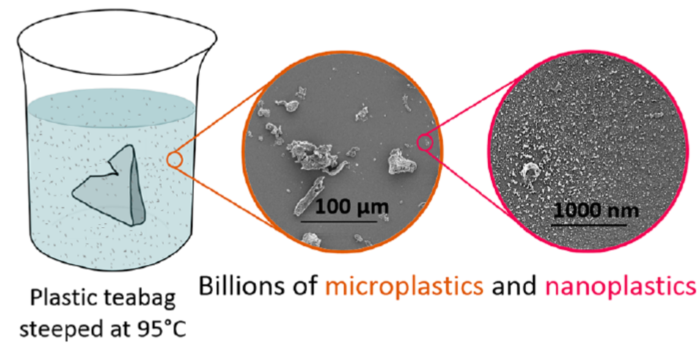
Recycled Plastics

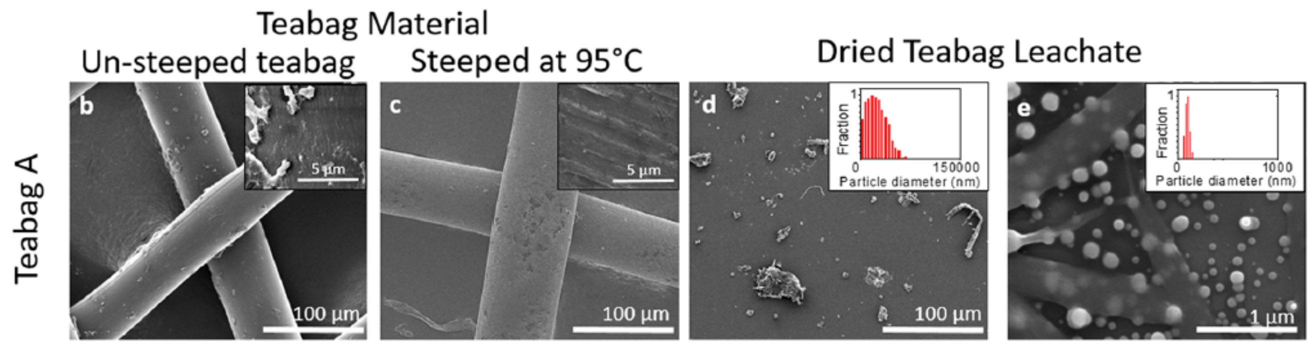
They can be used for many applications, especially where tensile strength is not critical.

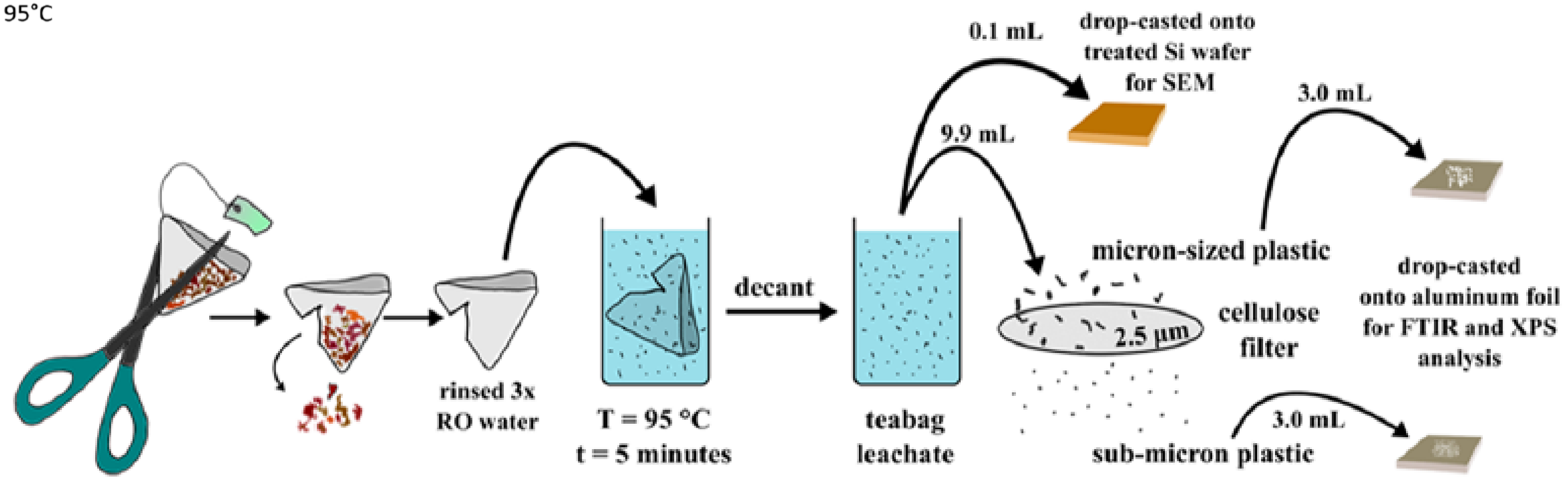
Plastic Pollution: Our Urgent Problems

Microplastics & Nanoplastics

(Hernandez 2019, Plastic teabags release billions of microparticles and nanoparticles into tea. Environ. Sci. Technol. 2019, 53, 12300–12310)
Steeping a single plastic teabag at brewing temperature (95 °C) releases approximately 11.6 billion microplastics and 3.1 billion nanoplastics into a single cup of the beverage. The composition of the released particles is matched to the original teabags (nylon and polyethylene terephthalate) using Fouriertransform infrared spectroscopy (FTIR) and Xray photoelectron spectroscopy (XPS).

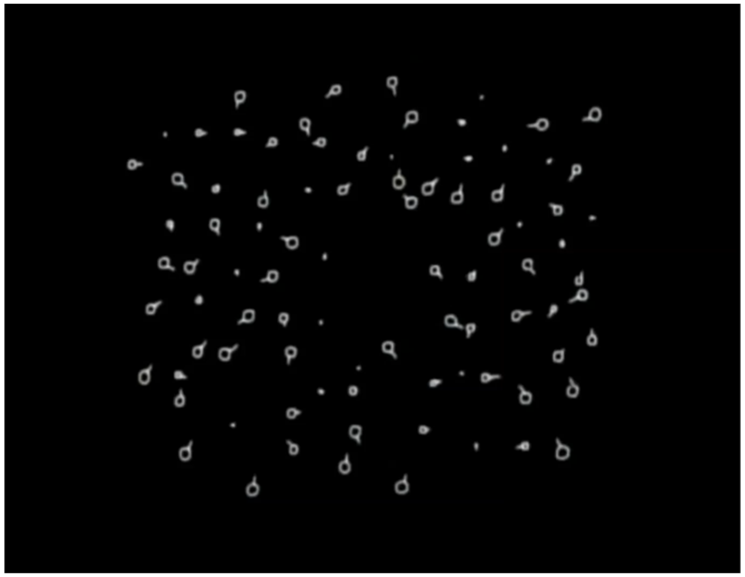






Polymers in History

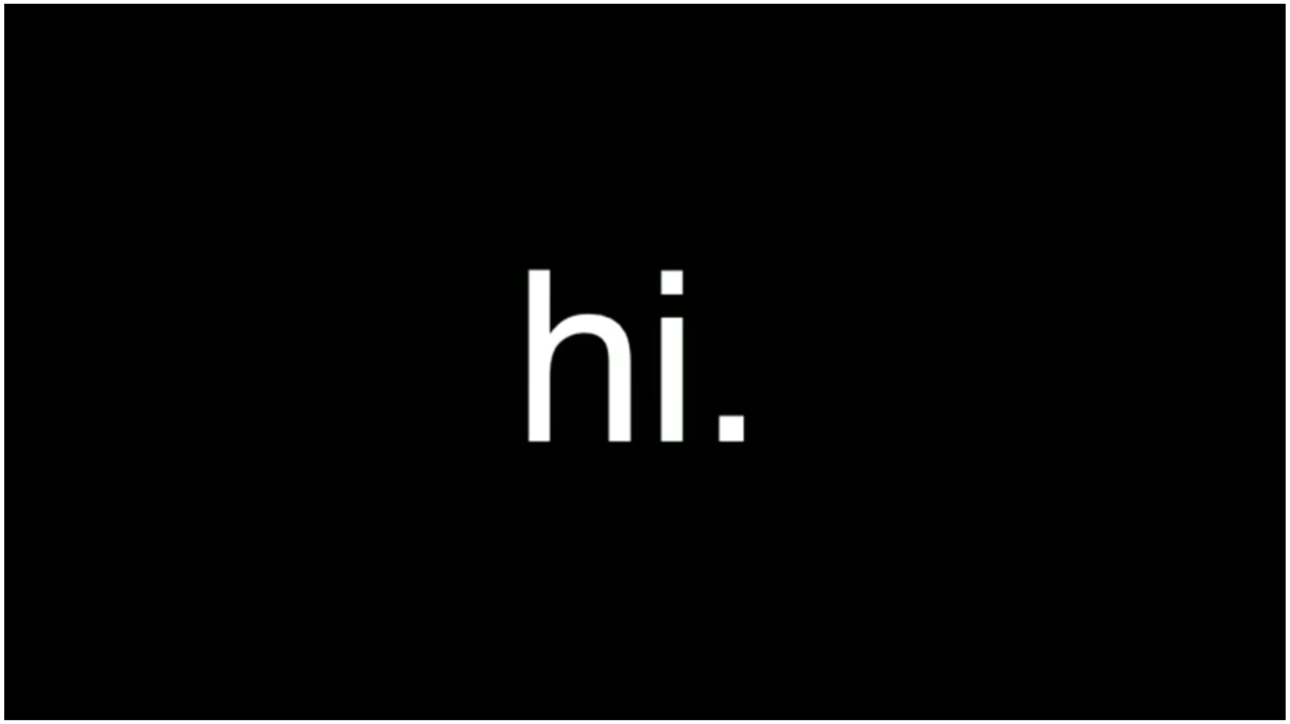
4 Billion Years of Evolution in 40 Seconds.



https://www.youtube.com/watch?v=UX-1ovsEBAs

carlsagan.com

History of the Entire World



https://www.vox.com/world/2017/5/15/15641594/worldhistoryvideobillwurtz

Van Gogh's "Starry Night": The Best Way to Enjoy

TikTok @...secretlytiktoking

v09044g40000c6mhkcbc77ucdo6bnn70

Information on the Presentation on February 27 and Report

Your presentation and report should focus on "polymers for the future."
A few examples of the topics are:

- What benefits have polymers brought to the world, what problems have they caused for the future, and what can (or should) we do about it?
- Is it sustainable to develop and dispose of new polymers that are not environmentally degradable even though they are indispensable in our lives?
- What are the real issues in using polymers, and what can be the authentic solutions

1. Assemble a team of 8 students.
2. Inform me of the list of your team members by January 16.

3. The presentation time is 30 min.
4. The number of slides and the report length is up to each team.
5. The presentation style is up to each team. The goal is to present your findings and their summary most efficiently to convince the audience of your conclusions.

6. Submit the final slides in PowerPoint format by February 22.
7. Submit the final report by March 1.

8. Each student, not as a team, needs to send me a letter indicating their expected grade and the rationale for the grade by March 1.