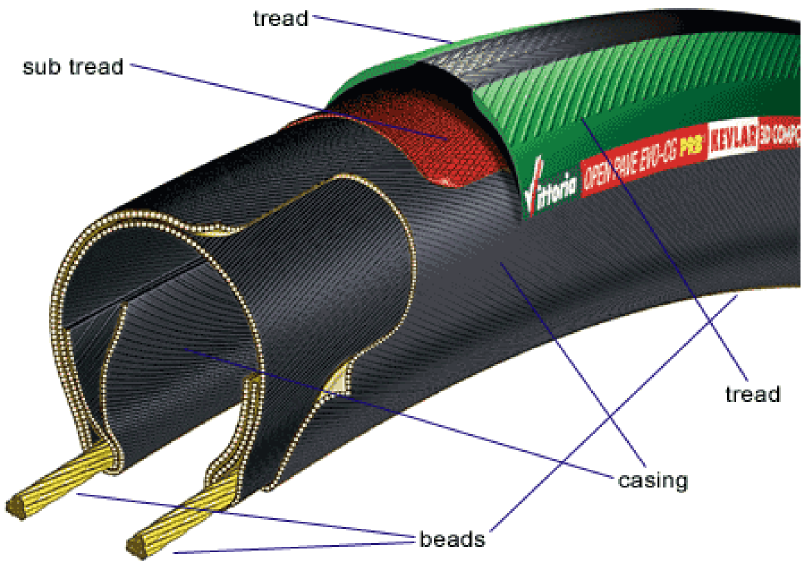
Bike Tires 1

Monday, January 6, 2025 9:10 PM

Bike Tires Learning objectives

- List the materials requirements of a bike tire
- Identify the roles that a bike tire plays in cycling
- Select proper materials for the different components of a bike tire
- Explain role of internal air pressure in bikes
- Describe the chemical structure of rubbers and other common polymers in bike tires

Tire Anatomy



https://www.sefiles.net/images/library/site/tires_cutaway_bg_405_m.gif

Tire Roles

- Suspension
- Generate lateral force necessary for balancing and turning
- Generate longitudinal force necessary for propulsion and braking
- Reduce rolling resistance while providing traction
- Casing stiffness to support rider weight (stiffness a function of material and internal pressure)
- Hold in air to a specific pressure

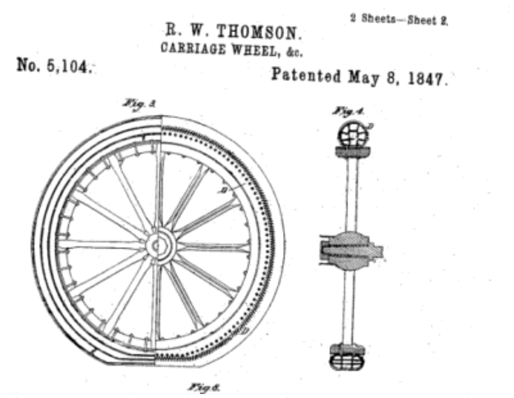
Scientific Terms

- **Resilience**: The ability of a material to absorb energy when it's deformed and then return to its original shape when the force is removed. Think of how a rubber ball bounces back after being squished.
- **Pressure**: The amount of force exerted on a surface per unit area. For example, the air inside a bike tire exerts pressure on the tire walls, keeping it inflated. (stress but with force applied across entire inner chamber of a material)
- **Vulcanization**: A process where rubber is heated with sulfur to make it stronger, more elastic, and more durable. It turns sticky natural rubber into tough material for bike tires and other uses.
- **Permeability**: How easily a material allows gases or liquids to pass through it. For example, a tire's inner tube

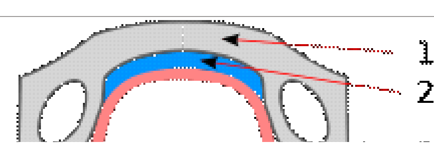
should have low permeability so air doesn't leak out quickly.
- **Polymerization**: The chemical process of joining small molecules (monomers) into long chains called polymers. For example, this is how rubber is made into the strong, stretchy material used in bike tires.
- **Ideal gas law**: A formula that describes how pressure, volume, and temperature of a gas are related:
  PV = nRT
  P = Pressure
  V = Volume
  n = Amount of gas
  R = Gas constant
  T = Temperature
  It explains why a bike tire gets firmer when you pump more air into it or when the temperature increases.

History of bike tires

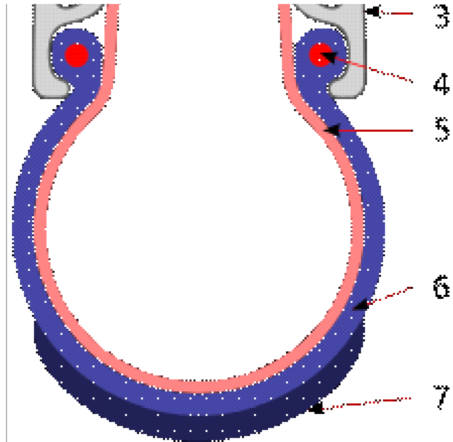
No tires! Just wooden wheels	
Iron bands on wooden wheels	
1868 "rubberized wheels" patent -Clement Ader (same guy who invented tubes of metal for frame to reduce weight) -Penny farthings had solid rubber tires	
Hollow core rubber tires -Softer ride	
1869 "Airless" tires	

	https://static.designboom.com/wp-content/uploads/2021/10/airless-bike-tires-the-q-designboom-003.jpg  https://static.boredpanda.com/blog/wp-content/uploads/2016/11/airless-flat-free-tire-bike-nexo-fb.png
1887 First practical pneumatic tire - Dad invented for son to reduce headaches from bumpy path - John Boyd Dunlop inventor (patent declared invalid because of prior patent by Robert William Thomson - Dunlop selected rubber to "withstand wear and tear while retaining resilience" - Dunlop Pneumatic Tyre Co. Ltd 1889	 https://www.shutterstock.com/editorial/image-editorial/O5Tdk0x7NfTaUa5fMDAxNg==/photograph-fist-pneumatic-tryes-ever-made-displayed-440nw-9841473a.jpg  https://www.dpma.de/images/bilder_intern/schutzrechtsdokumente/aj_0813_us5104a_thomson_carriagewheel_lupe.jpg
1890 tough canvas outer layer to prevent punctures in rubber pneumatic tube	
1891 detachable tires - Invented by Edouard Michelin - Held to rim with clamps, instead of glue, so it was easy to replace or patch	

Different ways to attach tires to rims

Clincher is the most common method ○ Relies on bead interlocking with rim flange to hold tire in place ○ Internal pressure keeps bead and flange interlocked	

- ○ Possible to avoid the pneumatic tube altogether and pressurize the tire against the rim to hold a seal "Tubeless" tires
    - Airless tires reduce air loss with semi solid sponge type elastomers OR a liquid polymer sealant to improve seal and to stop leaks caused by punctures
    - Tubeless set ups avoid "pinch flats" because tire wall is thick and tough compared to thin pneumatic tube material
    - Special rims required to avoid air escaping the rim where spokes connect
        - ○ "Gorilla Tape" solution



Clincher cross section schematic with 1: rim, 2: rim strip, 3: rim braking surface, 4: bead core, 5: inner tube, 6: casing, 7: tread
https://en.wikipedia.org/wiki/Bicycle_tire

Tire materials rely extensively on polymers

Polymers, sometimes called "plastics", are large molecules made up of many repeating small molecules called monomers to form long chains.

- Greek "polymer" = "many parts"
- Properties change dramatically depending on…
    1. Which monomers are selected to repeat in the chain
    2. The arrangement of the chains
    3. How the chains interact with one another

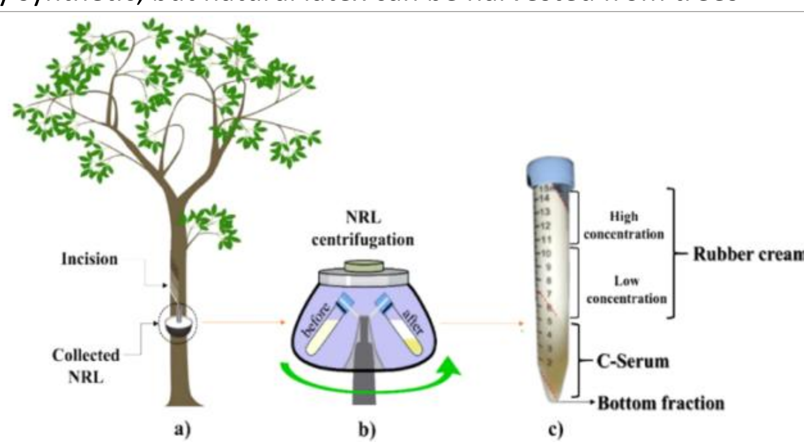
Key features of polymers includes:

- Structure: linear, branched, or cross-linked
- Properties: Can be flexible, rigid, lightweight, durable, soft, or elastic depending on their chemistry and structure
- Versatility: Used in everything from soft, stretchy materials (like rubber) to hard, durable materials (like plastics)

Modern rubber is very different from natural rubber (latex)

Rubber as we know it is totally synthetic, but natural latex can be harvested from trees


https://ecoworldonline.com/wp-content/uploads/2020/02/harvesting-latex.jpg



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Natural **latex** has serious limitations

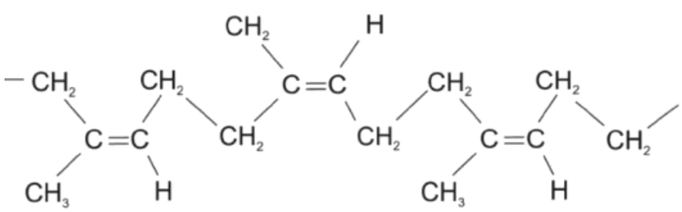
- Not durable. Prone to wear and tear. Degrades when exposed to air, UV light, and ozone leading to cracking
- Poor heat resistance. Breaks down at high temps that tires generate during use

Fordlandia, Brazil!

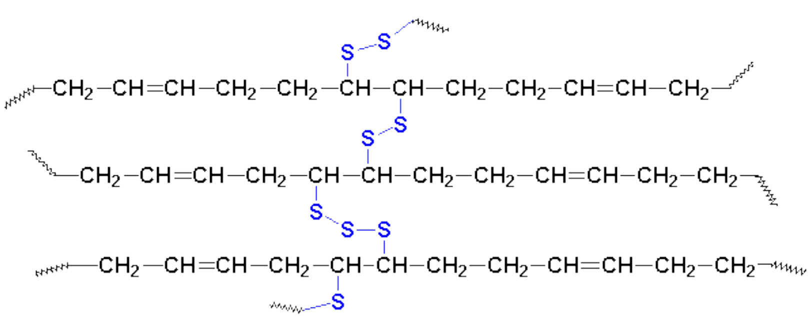
due to friction -Poor abrasion resistance. It would wear away if rubbed against road surface -Swelling. Latex will swell and degrade in the presence of oils or other chemicals. -Highly non-uniform properties depending on source, harvest condition, and processing -It's challenging to scale growth of natural materials -Sticky, brittle in cold, melts in heat	 https://i.ytimg.com/vi/e-3XX0ap6_M/maxresdefault.jpg

Charles Goodyear in 1839 accidentally discovers that you can drastically modify the properties of natural rubber.

- **Vulcanization** is a chemical process that improves the properties of natural rubber by adding sulfur (or other curatives) and applying heat. This creates cross-links between the long polymer chains in rubber, turning it from a sticky, soft material into one that is stronger, more elastic, and more durable.



Natural rubber



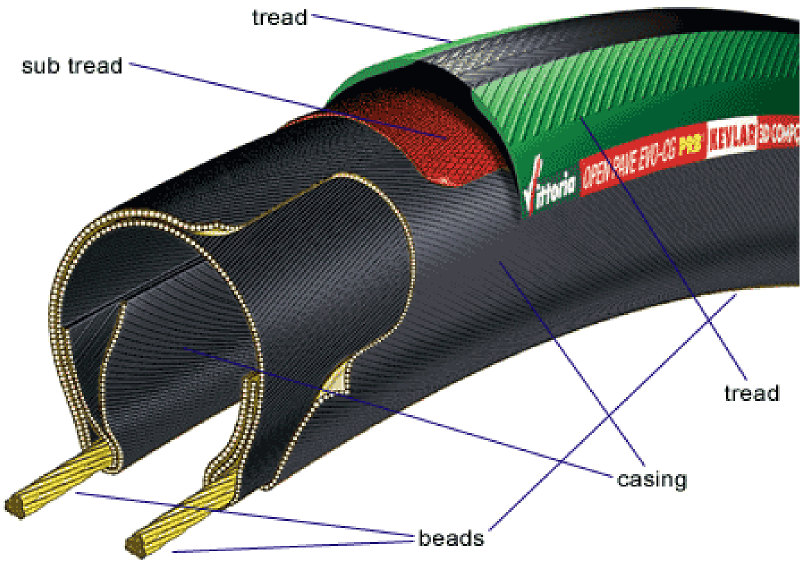
The Effects of Vulcanization:

Improved Elasticity: The cross-linked structure allows the rubber to stretch and return to its original shape without permanent deformation.

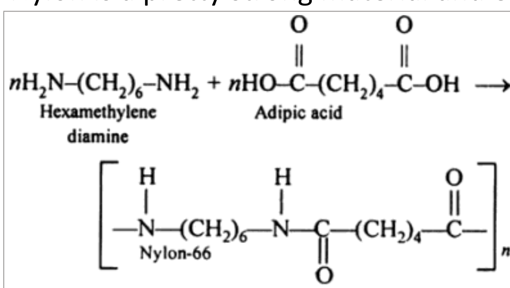
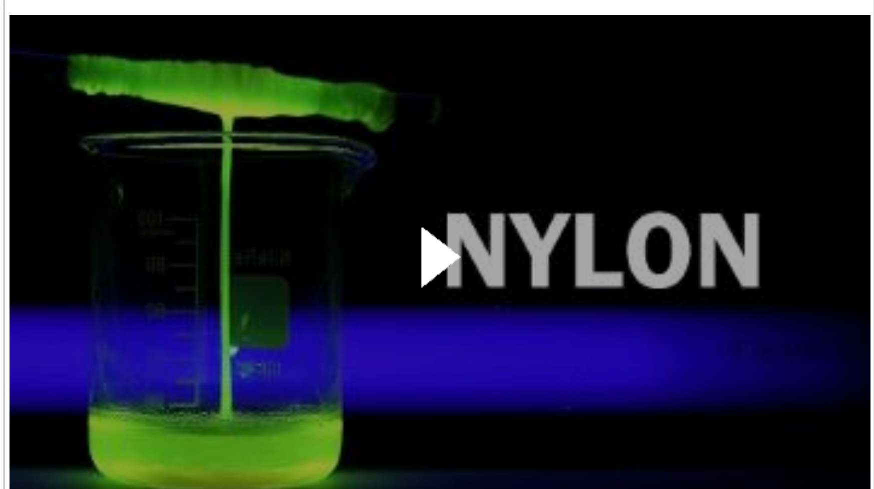
Increased Strength: Vulcanized rubber resists wear, tear, and abrasion better than untreated rubber.

Heat Resistance: The process makes rubber more stable at high temperatures, preventing it from melting or becoming overly soft.

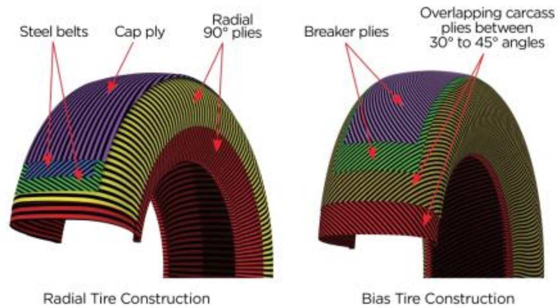
Chemical Resistance: Vulcanized rubber is less affected by oils, fuels, and other chemicals.



- **Casing**: rubber-impregnated cloth material also called the carcass
  - Cloth is usually nylon but cotton and silk have been used
    - Must resist stretching to retain internal pressure
    - Must be flexible enough conform to road surface
    - Nylon is a pretty strong material and easily forms fibers
    -

	Making nylon (NileRed) 

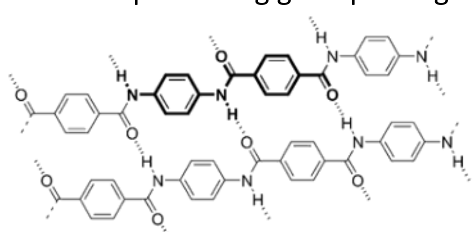
  - Thread count is variable. Higher thread count improves ride quality and reduces rolling resistance, but reduces durability and puncture resistance



- Radial vs bias ply of fibers. Fibers not usually woven but kept separate to improve wear and rolling resistance
- Radial bias had poor handling, so bias is more common

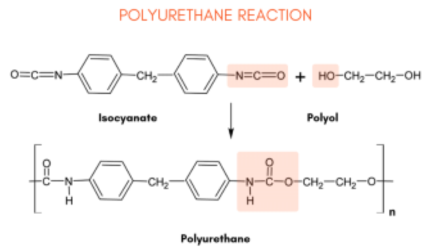
- **Tread**: rubber (70-80%) with additives (20-30%)
  - Blend of natural and synthetic rubber for elasticity, wear resistance, and grip
  - Additives: carbon black (improved durability, UV resistance, tensile strength), silica (enhances grip especially in wet conditions, wear resistance), and polymer modifiers (winter performance or high speed etc)
  - Oils and lubricants can make rubber softer for better grip at expense of wear resistance.
  - Tread can be **functionally graded** to be tougher in the middle, grippier in the edges.
  - Omnidirectional or directional
  - Dimples to reduce air drag

- **Bead**: kevlar or steel wire
  - Steel offers strength and rigidity at low cost
  - Kevlar fibers offer similar strength at far lower density (1.44g/cc vs 7.85g/cc!) Additional benefit of being foldable for easier storage/packaging.
    - Kevlar has great strength because of (1) the carbon rings (benzene) along the chain backbone keeping the chain rigid and flat, (2) **Hydrogen bonds** form between adjacent chains, and (3) flat chains are linear chains promoting good packing and alignment for stronger forces



- **Sidewall**: rubber but with nylon or polyester fiber reinforcement
  - Needs to connect tread to the bead. Provides flexibility and shock absorption while protecting the casing.
  - "Skinwall" tires have very little rubber if any. Reduced rolling resistance by reducing sidewall stiffness at cost of damage protection.
  - Reflective strips as optional ways to improve nighttime visibility

- **Puncture protection layer (optional)**: kevlar, polyurethane, or silicone-based gel.
  - Extra layer of protection to protect vulnerable inner rubber tube that needs to remain air-tight
  - Kevlar is high strength to blunt thorns
  - Polyurethane is lightweight inexpensive and decent strength

- 

  - Silicone based gel is self-healing and **dynamic bonds** can break and reform to heal after puncture (more on this later)

- **Tube or Inner liner if tubeless**: butyl rubber, latex, or other **elastomer.**
  - Hold in air to maintain desired internal pressure
  - Butyl rubber is a synthetic rubber with known low gas **permeability**
  - Latex used in higher performance tubes, but less air-tight

Tires of the future and special cases
- SMART tires
- Open research area (Curiosity on Mars)
- Studded tires for winter (steel studs or even pricier carbide studs)
- Balloon tires and fat tires with low pressure (as low as ~5psi compared to normal 30-100psi)

How NASA Reinvented The Wheel
Veritasium