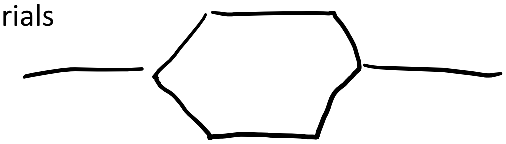
Climbing ropes 1

Monday, January 6, 2025 9:10 PM

Climbing Ropes Learning objectives
- Become familiar with polymer scientific terms
- Explain why different polymer materials are used in climbing ropes
- Differentiate materials used for dynamic vs static climbing ropes
- Identify pros and cons as well as typical properties in common rope materials



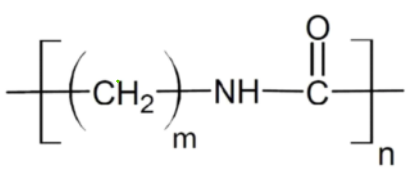
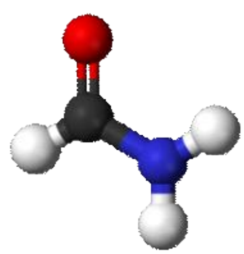
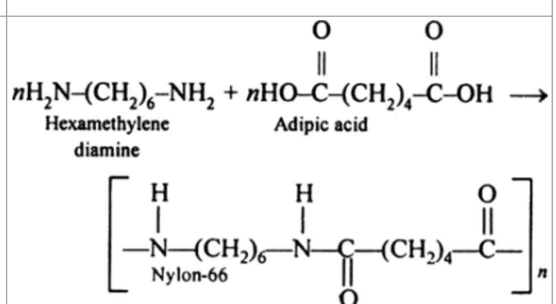
Scientific Terms
- **Viscoelasticity**: A property of materials that behave both like solids (elastic) and liquids (viscous), meaning they can stretch and slowly change shape over time under stress.
- **Molecular weight**: The total mass of a single molecule, calculated by adding the weights of all the atoms in the molecule. For polymers, it reflects the length of the chains.
- **Dihedral angle**: The angle between two planes formed by atoms in a molecule. In polymers, it determines how chains twist and fold.
- **Polymer conformations**: The different shapes or arrangements a polymer chain can take due to the flexibility of its bonds.
- **Amorphous**: A state of a material where molecules are arranged randomly rather than in a repeating, orderly structure. Example: glass.
- **Reptation**: The snake-like motion of polymer chains as they move through a tangled network, like spaghetti moving in a pot.
- **Phase transition**: A change in the physical state or structure of a material, such as from solid to liquid or glassy to rubbery.
- **Viscosity**: A measure of a material's resistance to flow. Honey has high viscosity, while water has low viscosity.
- **Elastomer and polymer networks**: Materials made of polymer chains that are crosslinked, allowing them to stretch and return to their original shape, like rubber bands.
- **Abrasion resistance**: The ability of a material to resist wearing down when rubbed against rough surfaces.
- **Hydrogen bonding**: A weak chemical attraction ***between*** molecules that helps make materials like nylon strong and durable. Typical bond strength is 4-50 kJ/mol while a covalent bond might be 150-400 kJ/mol
- **Glass transition temperature (T_g)**: The temperature at which a polymer changes from being hard and glassy to soft and rubbery.
- **Creep**: When a material slowly deforms over time under a constant load.
- **Stress relaxation**: When a material gradually reduces the force it exerts while being held at a fixed length.
- **Impact force (F)**: The force experienced by an object during a collision or sudden stop. In climbing, it's the force exerted on the rope, climber, and anchor system during a fall.
  - $F = \frac{\Delta p}{\Delta t} = \frac{\Delta mv}{\Delta t}$
  - Where p is momentum, m is mass, v is velocity, t is time, and Δ, delta, is the change in something

Climbing Rope Anatomy

https://m.media-amazon.com/images/I/51VYmLgDQAL.jpg

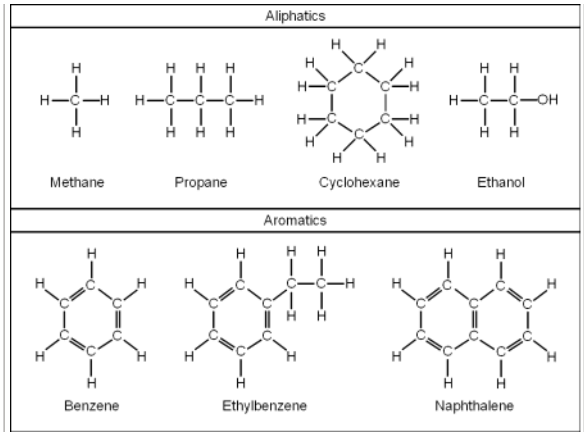
Core (Kern)

- The core is the primary load-bearing component, accounting for about 70–90% of a rope’s strength.
- Core material is typically nylon (polyamide) for dynamic ropes, known for its elasticity and toughness.
  - Polyamide just means that it has a structure consisting of repeating units linked by amide bonds where amide groups are carbon with a double bond to oxygen (carbonyl group) and single bonded to nitrogen with hydrogen (amide group)

	
Recall Nylon 6,6 from bike tires	

  - We can also have **aliphatic** vs **aromatics** versions of polyamide

        - Aromatic contain benzene rings



        - Aliphatic do not
        - Group Activity: Is polyurethane (remember from bike tires) an aromatic polyamide or aliphatic?

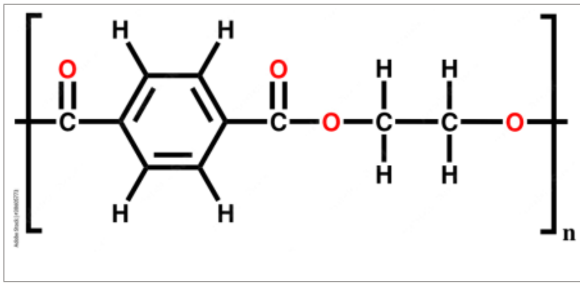
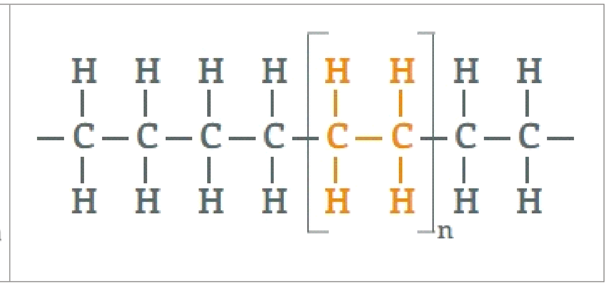
- Types of Core Construction:
    - **Twisted Cores**: Fibers twisted into bundles, providing flexibility but less resistance to compression.
    - **Parallel Cores**: Straight, untwisted fibers aligned along the rope's length, used for static ropes for strength and low stretch.
    - **Braided Cores**: Multiple strands braided together, offering balanced strength and flexibility.

Sheath (Mantle)

- The sheath provides abrasion resistance and protects the core from dirt, UV radiation, and physical damage.
- **Construction**:
    - Woven from nylon or polyester fibers in tight patterns.
    - Patterns can vary (e.g., smooth for reduced friction, textured for better grip, alternating to identify center of rope for double strand rappel etc).
- **Sheath-to-Core Ratio**: Determines the durability and handling of the rope. A higher sheath ratio increases durability but may reduce flexibility.

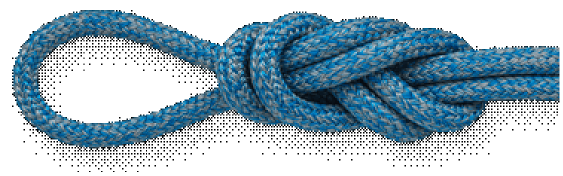
Types of climbing ropes

- Dynamic ropes
    - Designed to stretch under load reducing the impact force on the climber and anchor system during a fall
        - Stretching extends the time over which the same change in momentum occurs and thus the force is reduced
    - Applications: lead climbing (where you climb past your previous anchor until you reach the next anchor point), ice climbing, trad climbing (short for traditional where you place your own anchors instead of relying on drilled bolts)
    - Properties:
        - Elongation 5-10% under body weight, 30-40% under a fall
        - Impact force of 7-9 kN to minimize force transmitted to the climber (depends on height of fall, weight of climber, rope details etc)
        - UIAA fall rating dictates the number of falls a rope can sustain before failure
            - Tested under specific conditions
    - Material:
        - Nylon due to high elasticity, toughness, and ability to dissipate energy efficiently
        - Hydrogen bonding in nylon enhances bonds between polymer chains preventing stretching over time

- Static ropes
  - Designed for minimal elongation
  - Applications: hauling gear, rappelling, rescue operations, spelunking (caving)
  - Properties:
    - Elongation <5% under normal loads
    - Strength is maximized for tensile loads, but the actual load rating will depend on rope diameter (σ=F/A)
    - Abrasion resistance is enhanced by thicker sheath materials and construction
  - Material:
    - Polyester (aka PET, polyethylene teraphthalate) or high modulus polyethylene (HMPE)
    -  
    - HDPE stands for high density polyethylene with molecular weight of 50000-200,000 g/mol, but HMPE is much higher with molecular weight reaching 2-6 million g/mol or higher!
    - Polyester has low stretch, excellent abrasion resistance, and good UV stability.
    - HMPE offers extreme strength-to-weight ratios, low creep, and high resistance to abrasion and chemicals.

Climbing rope history

Early ropes -Natural fibers like hemp or manila -No elasticity leading to high impact falls -Prone to rotting and wear, especially in wet environments	 https://upload.wikimedia.org/wikipedia/commons/thumb/4/47/Cordage_en_chanvre.jpg/435px-Cordage_en_chanvre.jpg
1940s -Nylon -Core-sheath design to protect the load bearing fibers	 https://blog.triangular-pod.com/content/images/2021/04/nylon-rope-factory.jpg

1970s-1980s -Specialized ropes for climbing (dynamic vs static) -Dynamic rope development	 https://blog.weighmyrack.com/wp-content/uploads/2022/10/static-rope-color-examples.jpg
Modern era -Incorporation of HMPE for ultralightweight, high strength ropes. -Advanced coatings to protect from UV or water damage -Safety standards like UIAA with specific testing standards	 https://www.rope.com/cdn/shop/products/Image_5de7824b-15aa-4ec9-a046-6230c08bbe4d_384x231.png?v=1621362242

Climbing rope materials pros and cons

- Nylon
  - PROS: elasticity for absorbing energy during falls, durable and wear resistant, performs well at a range of temperatures
  - CONS: susceptible to UV degradation and moisture absorption (can be prevented with treatments)
- Polyester
  - PROS: low stretch, excellent abrasion resistance, resistant to UV degradation, low water absorption
  - CONS: poor shock absorption
- UHMPE
  - PROS: ultralight weight with tensile strength 15x steel at the same weight! High resistance to cutting and abrasion, low stretch
  - CONS: high cost, susceptible to UV degradation, poor heat resistance (melts at 140C which could be triggered by friction device!), slippery surface leads to unsafe knots, susceptible to creep

	UHMWPE Ultra High Molecular Weight Polyethylene	**Aramid** Aromatic Nylon	**PES** Polyester	**NY** Nylon	**PP** Polypropylene
Typical Marketing Term	Dyneema®	Technora®/ Twaron®/ Kevlar®	PES	NY	PP
Strength (daN/mm^2)	345	300	110	81	52
Specific weight (g/cm^3)	0.97	1.4	1.4	1.14	0.91
Water intake (%)	0	2	<0.5	4 – 6	0
UV-resistance	good	limited	very well	average	good
Elongation (%)	3.5	3.5	10 – 16	20 – 25	18 – 22
Abrasion resistance (dry)	very good	good	good	very good	sufficient
Abrasion	very good	good	very good	good	good

Typical Rope properties

- diameter: 8.5-11mm for dynamics rope, 9-13mm for static rope
- Weight: 50-70 grams/meter (depends on material and diameter)
- Strength: dynamic ropes are built to withstand 2000kg load, static ropes can be even higher!

Group Activity

What material would you pick for webbing used to connect ropes to anchors?

Future directions

- "smart" ropes with sensors to monitor wear, tension, and environmental conditions
- Sustainable rope materials
- Improved coatings to resist dirt, water, UV damage