A review on

Spider Silk – Spider Web
Smart Material – Smart Structure

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Spiders and their webs

- 319Ma-present
- 109 families
- 40,000 species
Orb web - family Araneidae
Cobweb – family Theridiidae
Sheet web - Family Linyphiidae
Funnel web - Sydney funnel-web spider (*Atrax robustus*)
Effect of Caffeine on the weaving behavior
Spider’s silk plant
Silk fibers emerge from spinnerets
Spider feet – front spinneret
Natural spinning process

(a) i) tail | ii) ampulla (sac) | iii) duct | iv) taper | v) exterior

- Protein secretion
- Micellar-like structure
- Spidroin storage of up to 50% (w/v) in a micellar-like configuration with liquid crystalline properties
- Phase separation through ion exchange, acidification, water removal, shear and elongational forces
- Water removal and shear forces further enhance phase separation, β-sheet formation and protein alignment; unfolding of the C-terminal domain exposes hydrophobic areas further facilitating fiber assembly.

(b) i) tail → ii) ampulla → iii) duct and draw down taper → v) exterior

- Covalent linked, dimeric C-terminus
- Monomeric N-terminus
- Repetitive module

The β-sheet crystals are aligned along the fiber axis.
**Silk glands**

<table>
<thead>
<tr>
<th>Gland</th>
<th>Silk Use</th>
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</thead>
<tbody>
<tr>
<td>Ampullate (Major)</td>
<td>Dragline silk—used for the web’s outer rim and spokes and the lifeline.</td>
</tr>
<tr>
<td>Ampullate (Minor)</td>
<td>Used for temporary scaffolding during web construction.</td>
</tr>
<tr>
<td>Flagelliform</td>
<td>Capture-spiral silk—used for the capturing lines of the web.</td>
</tr>
<tr>
<td>Tubuliform</td>
<td>Egg cocoon silk—used for protective egg sacs.</td>
</tr>
<tr>
<td>Aciniform</td>
<td>Used to wrap and secure freshly captured prey; used in the male sperm webs; used in stabilimenta</td>
</tr>
<tr>
<td>Aggregate</td>
<td>A silk glue of sticky globules</td>
</tr>
<tr>
<td>Piriform</td>
<td>Used to form bonds between separate threads for attachment points</td>
</tr>
</tbody>
</table>
# Silk types

<table>
<thead>
<tr>
<th>Silk</th>
<th>Use</th>
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</thead>
<tbody>
<tr>
<td>major-ampullate (dragline) silk</td>
<td>Used for the web's outer rim and spokes and the lifeline. Can be as strong per unit weight as steel, but much tougher.</td>
</tr>
<tr>
<td>capture-spiral silk</td>
<td>Used for the capturing lines of the web. Sticky, extremely stretchy and tough.</td>
</tr>
<tr>
<td>tubiliform (aka cylindriform) silk</td>
<td>Used for protective egg sacs. Stiffest silk.</td>
</tr>
<tr>
<td>aciniform silk</td>
<td>Used to wrap and secure freshly captured prey. Two to three times as tough as the other silks, including dragline.</td>
</tr>
<tr>
<td>minor-ampullate silk</td>
<td>Used for temporary scaffolding during web construction</td>
</tr>
</tbody>
</table>
Different silk types produced by Araneae female spider

- Major Ampullate (MA) Silk
  - frame, radii, lifeline
- Flagelliform (Flag) Silk
  - capture spiral
- Aggregate Silk
  - sticky coating on capture spiral
- Minor Ampullate (Mi) Silk
  - auxiliary spiral and web reinforcement

Pyroform Silk
- attachment to substrates

Aciniform Silk
- prey wrapping and egg case

Cylindrical Silk
- egg case
Are insects specialized uni-taskers?

A spider’s task is simple. To weave its web, catch a prey and eat it. But how?

So many specialized tools.

What is ruling the universe? Unity in Diversity, or Diversity in Unity?
Common false myth about spider silk

![Graph showing tensile strength, toughness, and stiffness of spider dragline silk compared to Kevlar.](image-url)
Hierarchical setup of spider silk protein

(a) Non-repetitive amino-terminal domain → Repetitive modules constituting of N_{50-100} → Non-repetitive carboxy-terminal domain

(b) | Protein | Sequence motif | (A)_{4-13} | (GA)_{4-6} | GGX | GPGXX | Spacer | Termini |
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</thead>
<tbody>
<tr>
<td>Major ampullate Spidroin 1 (MaSp1)</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Major ampullate Spidroin 2 (MaSp2)</td>
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<tr>
<td>Minor ampullate Spidroins (MiSp)</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Flagelliform spidroin (Flag)</td>
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<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Araneus Diadematus Fibroin 3 (ADF3)</td>
<td></td>
<td></td>
<td>✓</td>
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<td>✓</td>
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<tr>
<td>Araneus Diadematus Fibroin 4 (ADF4)</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
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(c) Structural role:
- Crystalline
- Amorphous
- Elastic
- Spacer
- Storage & assembly
Multi-scale structural components of an orb web
Mechanical properties of spider silk
Different behavioral regimes

(a) Stress-strain curve showing different regimes: Yield point, Entropic unfolding, Stiffening, and Stick-slip.

(b) Diagram illustrating Spiral threads and Radial threads, with symbols for $dR$ and $d\theta$.

(c) Graph plotting Force (N) against $\delta$ (m) for different conditions: No defects, d1, d2, d3, d4.

(d) Force (N) plotted against $\delta$ (m) showing Loading radial and Loading spiral.

(e) Images and diagrams depicting loading patterns.

(f) Additional images and diagrams illustrating different loading scenarios.
Different silk types, different behavior
Change of mechanical properties due to moisture

Signals have a higher vibrational frequency after exposure. The signal transfer time is shortened by 22% under moist conditions, whereas the vibration amplitude in the center remains on a similar level.
Moisture effect on the silk stiffness

(a) Stress (GPa) vs. Strain
- Yield point
- Break
- $E_c$

(b) Stress (GPa) vs. Strain
- At 200 mm s$^{-1}$
- At 2 mm s$^{-1}$

(c) Stress (GPa) vs. Strain
- In water
- In air

(d) Stress (GPa) vs. Strain
- Without bar
- With bar
Damage pattern in the web as a function of silk behavior
Spider’s supersensitive strain sensor
Inspirations

• Spider web and silk, interact synergistically across many length scales to achieve certain properties.

• The various types of web found in nature provide many exciting opportunities to improve the design of structures, signaling strategies, armors and biomaterials.
References

• Cranford et al., *NATURE*, 2012.
• Nova et al., *NANO Letters*, 2010.
The artist is a **receptacle** for the **emotions** that come from all over the place: from the sky, from the earth, from a scrap of paper, from a passing shape, **from a spider's web**.

Pablo Picasso