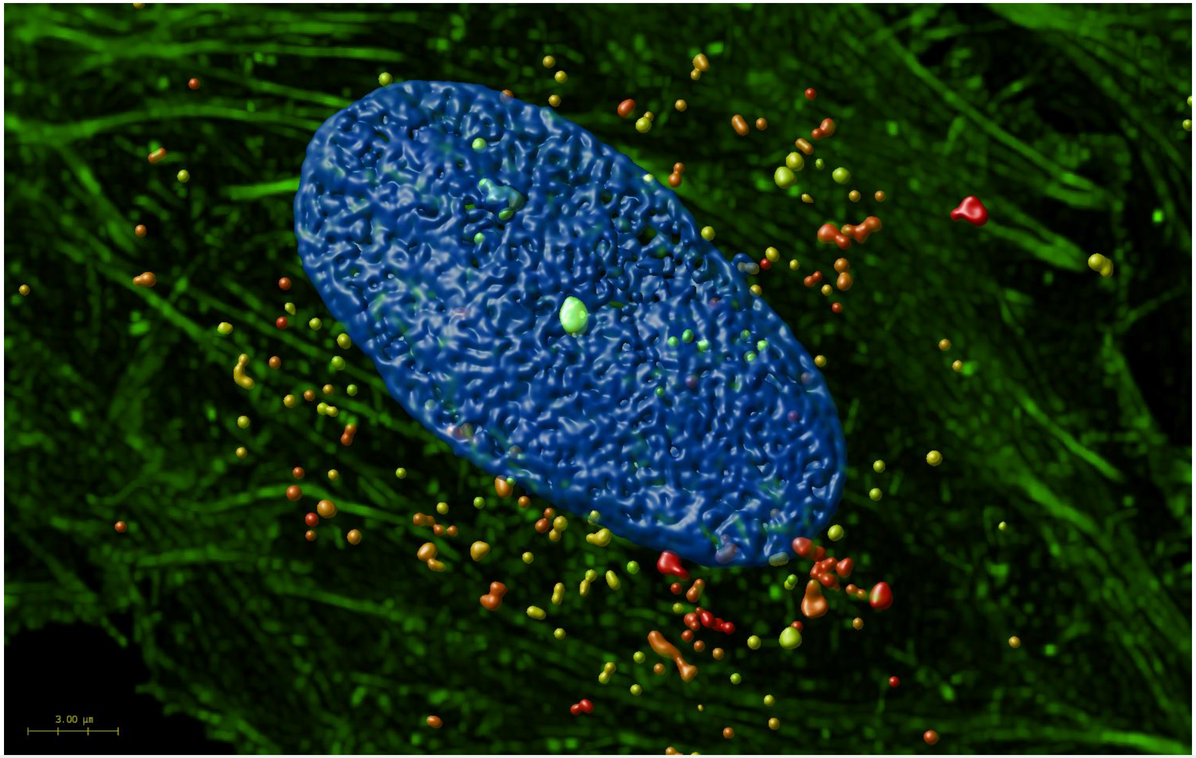
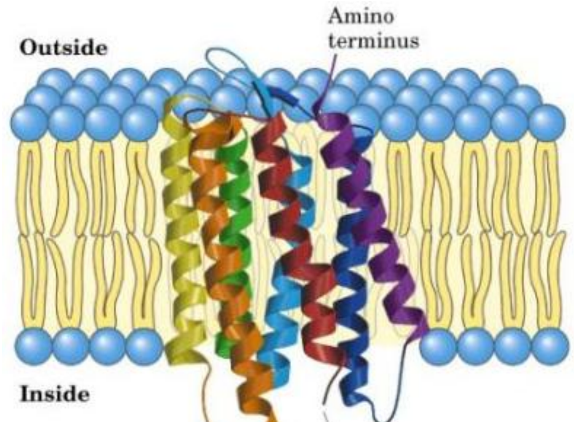


NanoBioMaterials 2

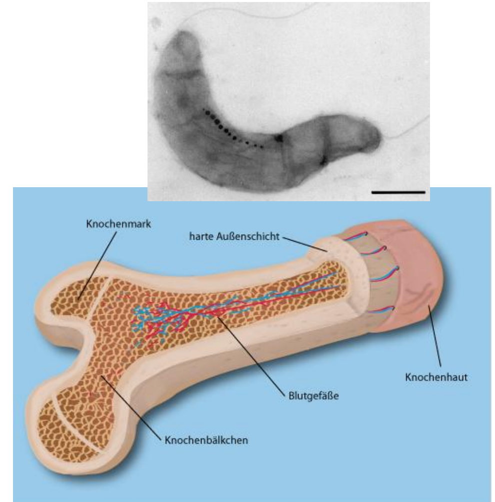
Dr. Annette Kraegeloh,
Prof. Dr. Eduard Arzt
INM - Leibniz Institute for New Materials

Nano/Materials and Bio: Interfaces

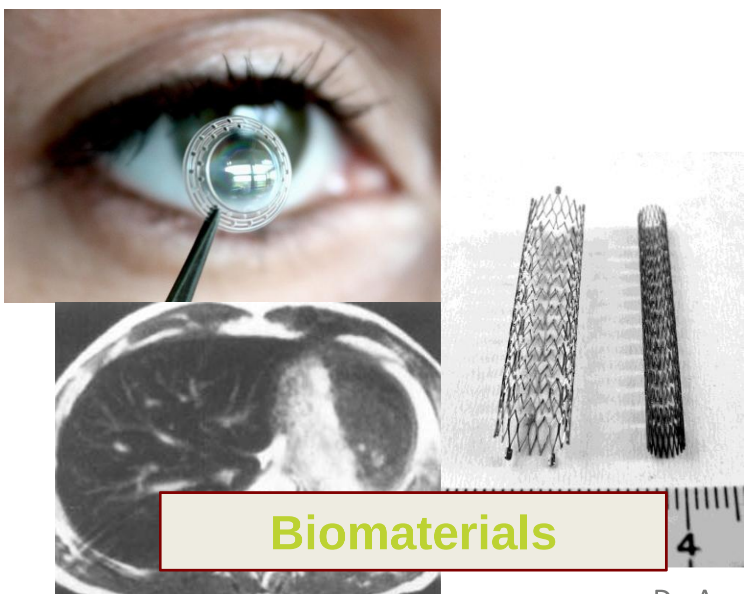
Biological Materials



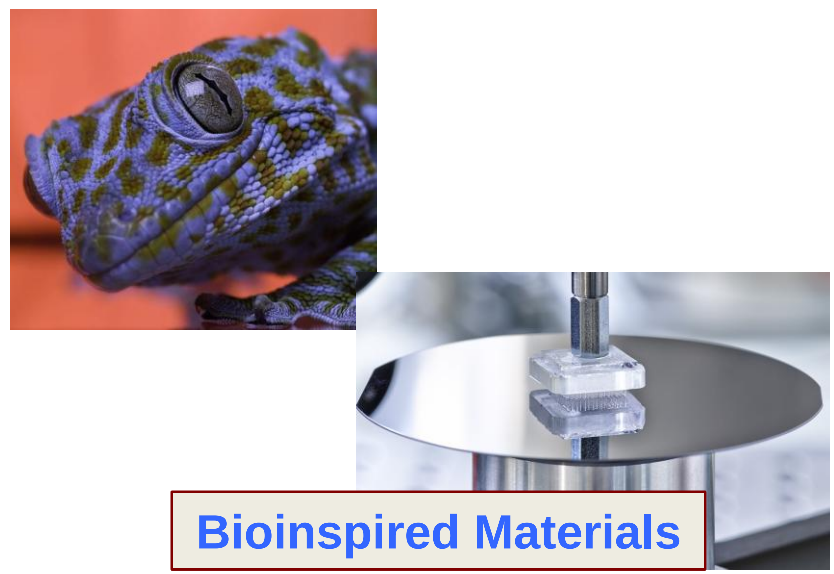
Molecular Machines



Biominerals



Biomaterials



Bioinspired Materials

[daviddarling.info; biomaterial2009.de; Hamm et al., 1994; Frank C. Müller; INM]

Nano/Materials and Bio - Interfaces

!

Biological materials are made up by natural structures and produced by living organisms.

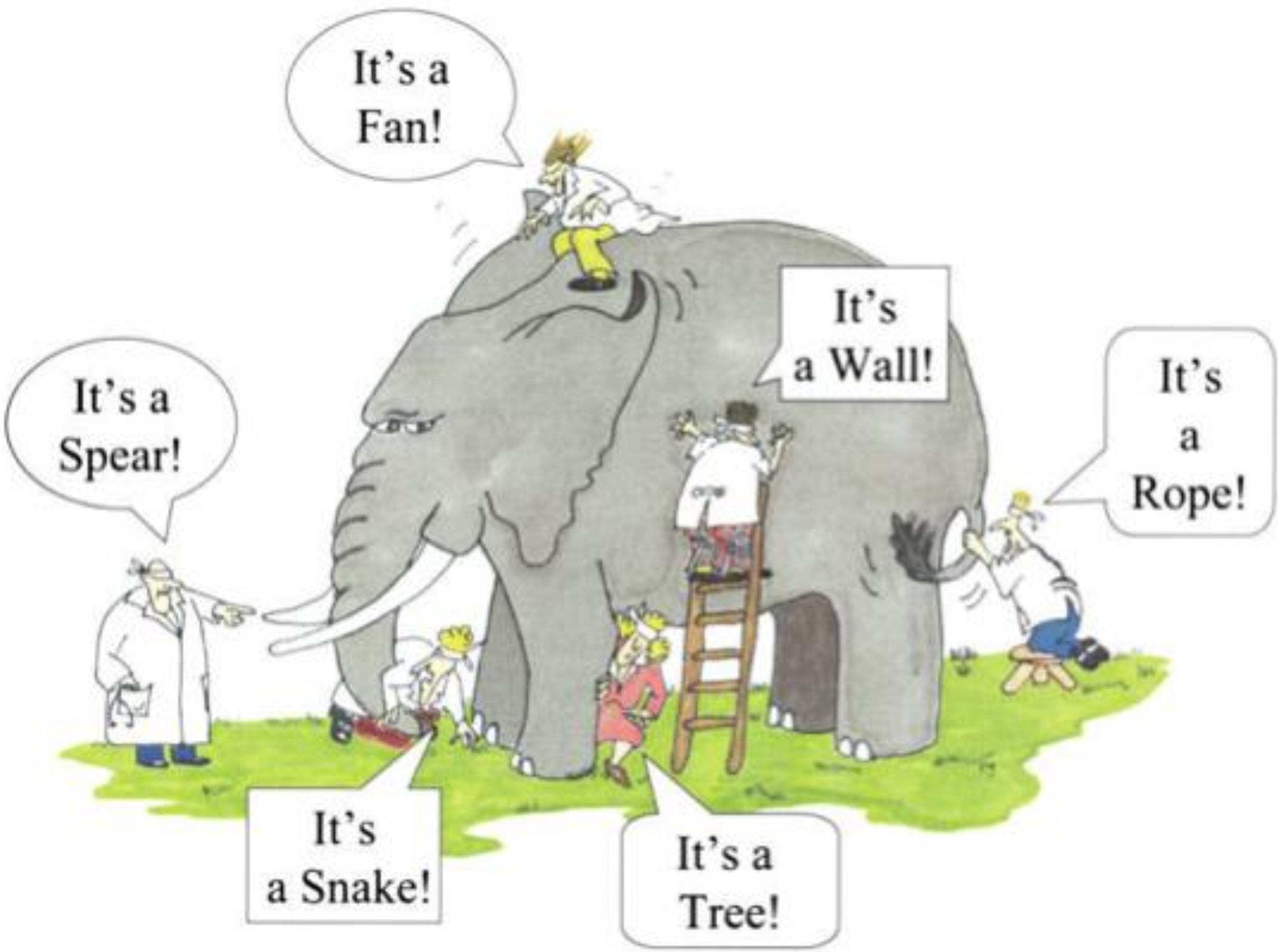
Biological molecular machines can actively control biological processes.

Biominerals are natural materials containing inorganic constituents.

Biomaterials are synthetic or natural non-living materials that are used for therapeutic or diagnostic purposes and come into contact with biological tissues within the body.

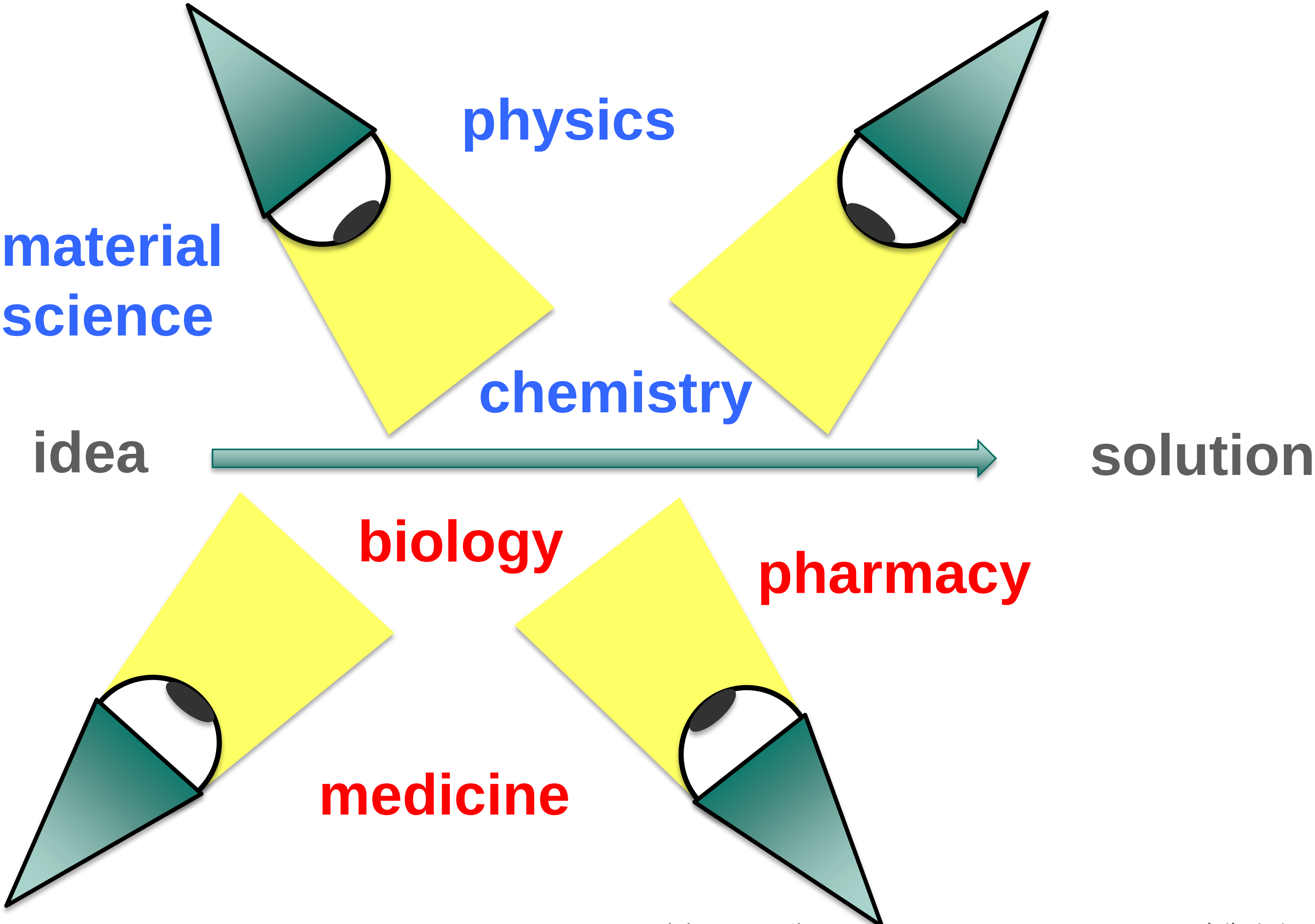
Bioinspired materials are synthetic materials whose structure, properties or function mimic those of natural materials or living matter.

Interdisciplinary Research

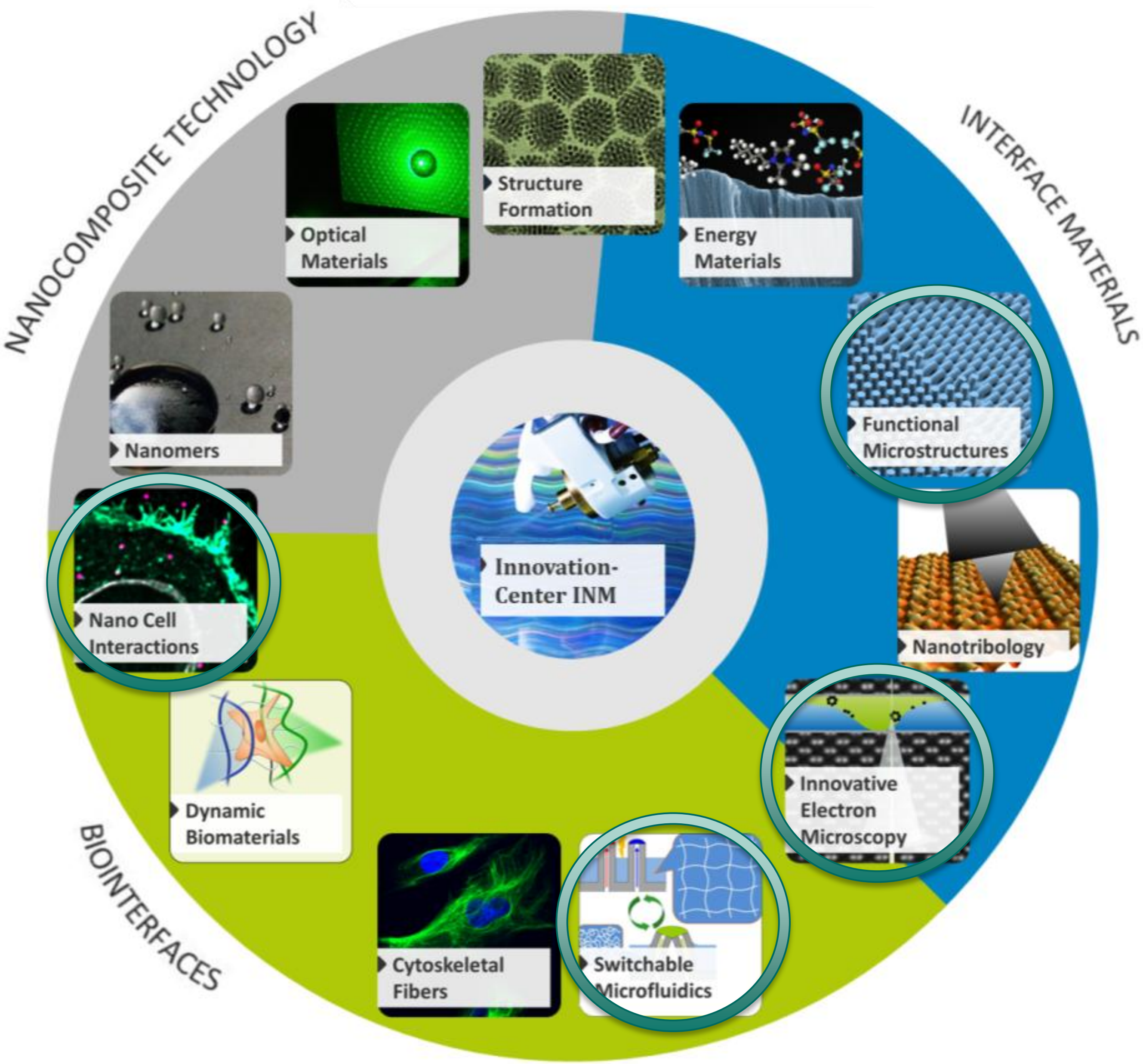


[pinterest.com]

Interdisciplinary Materials Research



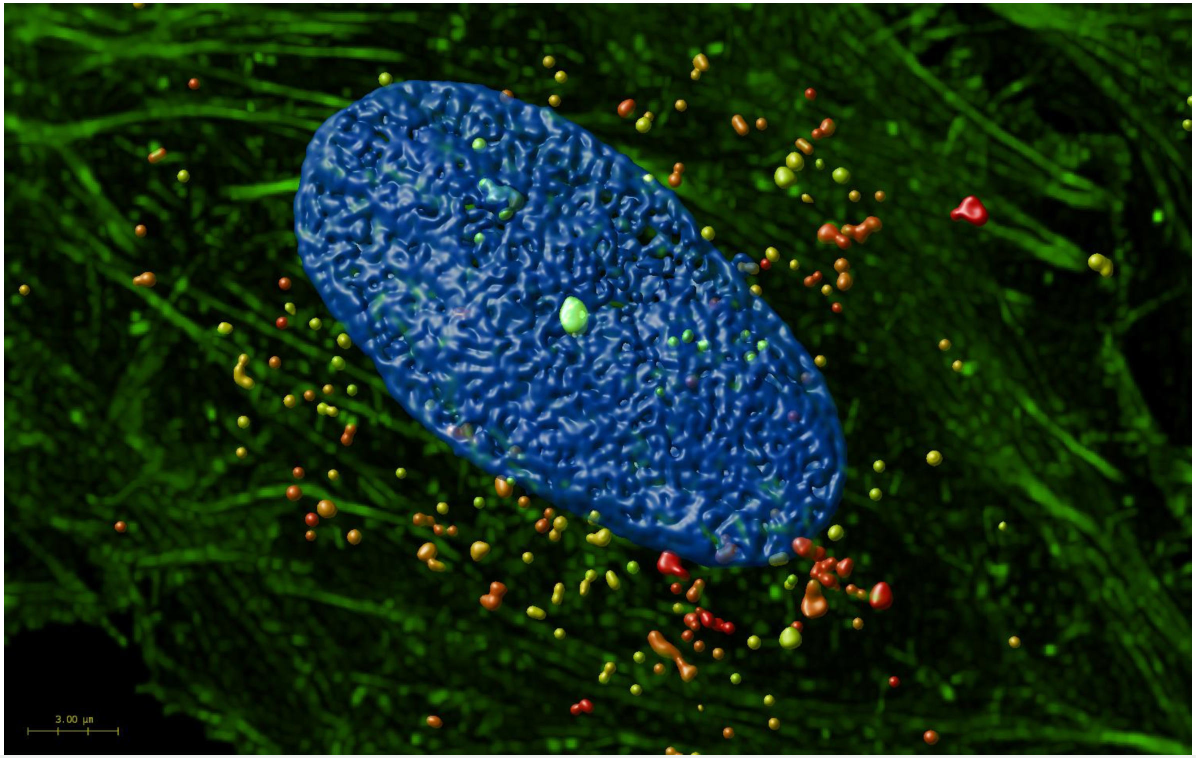
Research at INM



Topics and Schedule

Introduction*/Biological Building Blocks	krae	12.4
Karfreitag	-	19.04.
Molecular Machines and Subcellular Organisation	krae	26.4.
Cell and Tissue Functions	krae	03.5.
Polymer Networks	cui	10.5.
Biomaterials	krae	17.5.
Liquid-Repellent Surfaces	hen	24.5.
Brückentag (Christi Himmelfahrt)	-	31.5.
Basics of Electron Microscopy	da	7.6.
Demonstration Electron Microscopy	koc	14.06.
Brückentag (Fronleicham)	-	21.6.
Nano Bio Analytics at INM	fi	28.6.
Biomedical Applications of Nanoobjects	krae	5.7.
Nanosafety	krae	12.7.
Written examination (Klausur)		19.7.

*biological basics, materials and material bio aspects, analytics, no lecture



Biological Building Blocks
April 12, 2019

Dr. Annette Kraegeloh,
INM - Leibniz Institute for New Materials

Contents

- Cellular Building Blocks
- Proteins - Functions and Structure
- Spider Silk and Keratins

Chemical Components of a Cell

Table 2–2 The Approximate Chemical Composition of a Bacterial Cell

	PERCENT OF TOTAL CELL WEIGHT	NUMBER OF TYPES OF EACH MOLECULE
Water	70	1
Inorganic ions	1	20
Sugars and precursors	1	250
Amino acids and precursors	0.4	100
Nucleotides and precursors	0.4	100
Fatty acids and precursors	1	50
Other small molecules	0.2	~300
Macromolecules (proteins, nucleic acids, and polysaccharides)	26	~3000

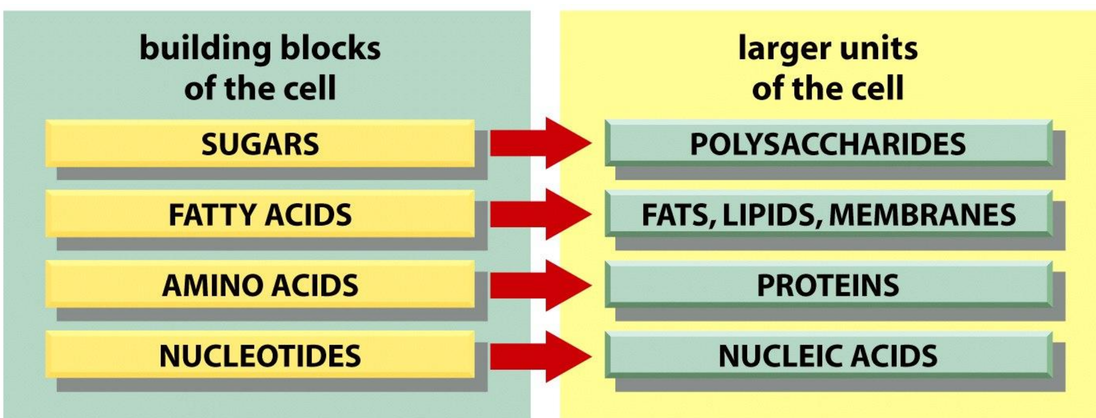


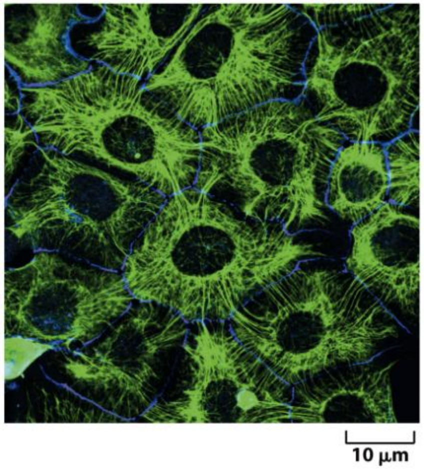
Table 2-2, Figure 2-17 *Molecular Biology of the Cell* (© Garland Science 2008)

Proteins and their Functions

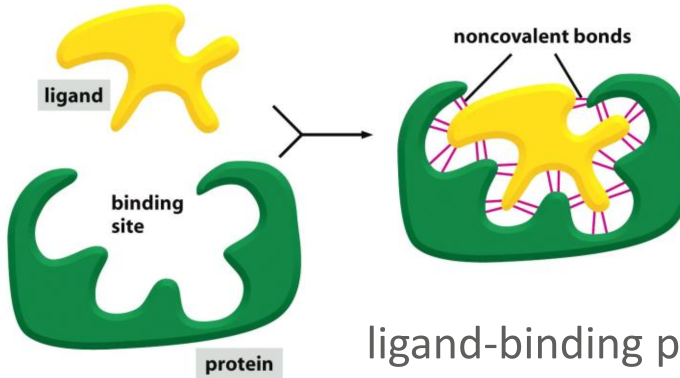
!

protein functions	specific functions	examples
structure	mechanical stability, interconnection, cellular movement	keratin, collagen, tubulin, actin
transport and storage	membrane transport, intracellular movement, molecule transport, storage	K^+ channels, dynein, hemoglobin, ferritin
pattern recognition	antigen binding	antibodies
catalysis	enzymes	pepsin
regulation and signal transduction	extra- and intracellular signalling	hormones, growth factor receptors

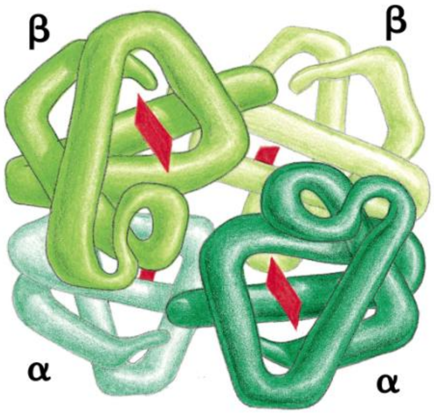
Protein Properties are Determined by their Structure



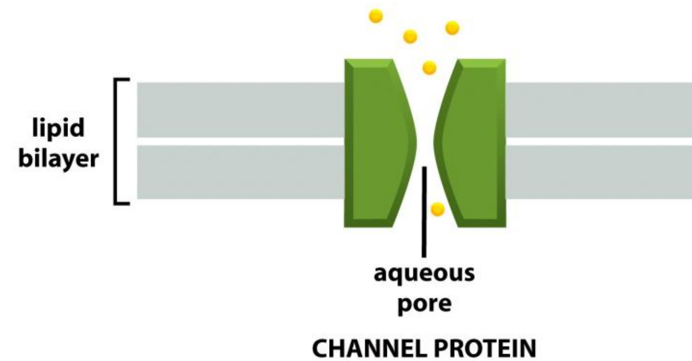
keratin, a fibrous structure protein



ligand-binding protein



hemoglobin, a tetrameric O_2 binding protein



channel protein, embedded in a membrane

Figure 3-22, 16-20, 11-3b, 3-36 *Molecular Biology of the Cell* (© Garland Science 2008)

Amino Acids are the Building Blocks of Proteins

!

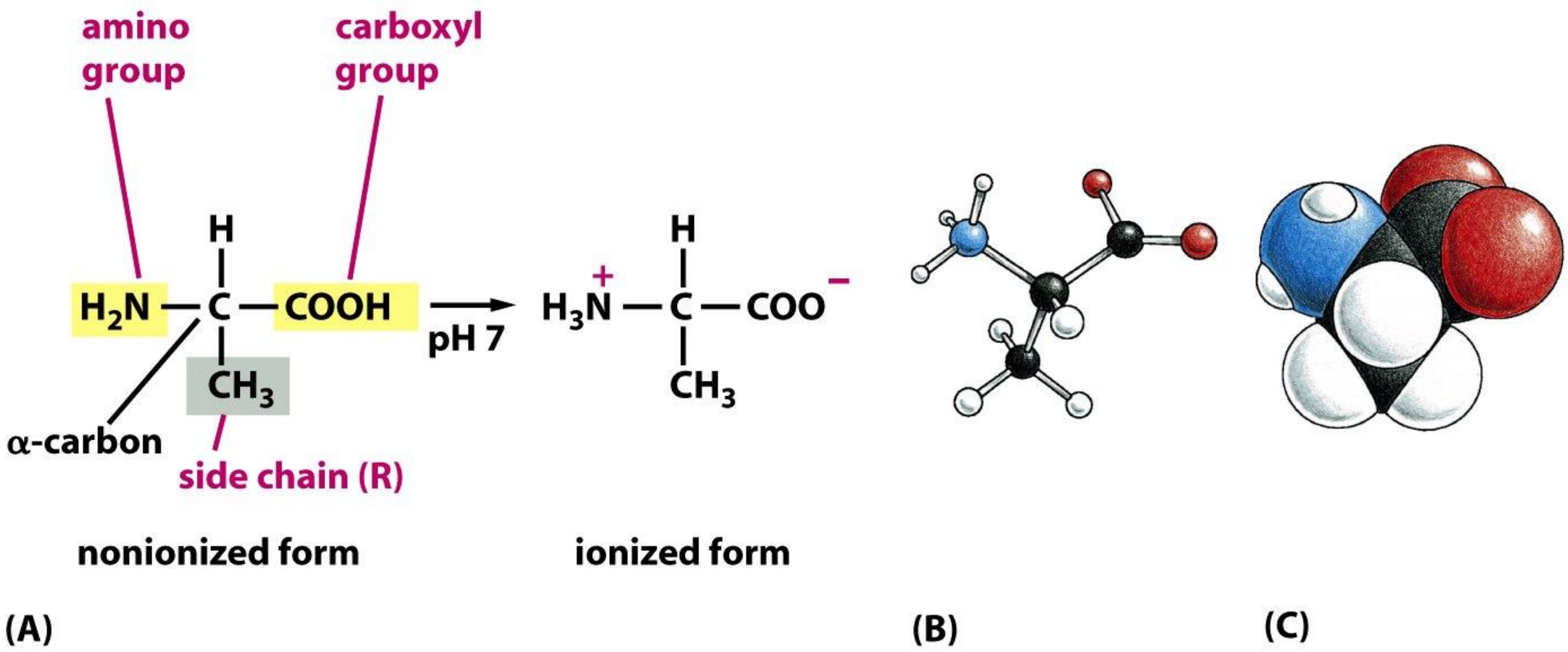


Figure 2-23 *Molecular Biology of the Cell* (© Garland Science 2008)

Amino Acids are the Building Blocks of Proteins

AMINO ACID			SIDE CHAIN
Aspartic acid	Asp	D	negative
Glutamic acid	Glu	E	negative
Arginine	Arg	R	positive
Lysine	Lys	K	positive
Histidine	His	H	positive
Asparagine	Asn	N	uncharged polar
Glutamine	Gln	Q	uncharged polar
Serine	Ser	S	uncharged polar
Threonine	Thr	T	uncharged polar
Tyrosine	Tyr	Y	uncharged polar

POLAR AMINO ACIDS

AMINO ACID			SIDE CHAIN
Alanine	Ala	A	nonpolar
Glycine	Gly	G	nonpolar
Valine	Val	V	nonpolar
Leucine	Leu	L	nonpolar
Isoleucine	Ile	I	nonpolar
Proline	Pro	P	nonpolar
Phenylalanine	Phe	F	nonpolar
Methionine	Met	M	nonpolar
Tryptophan	Trp	W	nonpolar
Cysteine	Cys	C	nonpolar

NONPOLAR AMINO ACIDS

Figure 3-2 *Molecular Biology of the Cell* (© Garland Science 2008)

The Amino Acid Sequence Determines a Protein

!

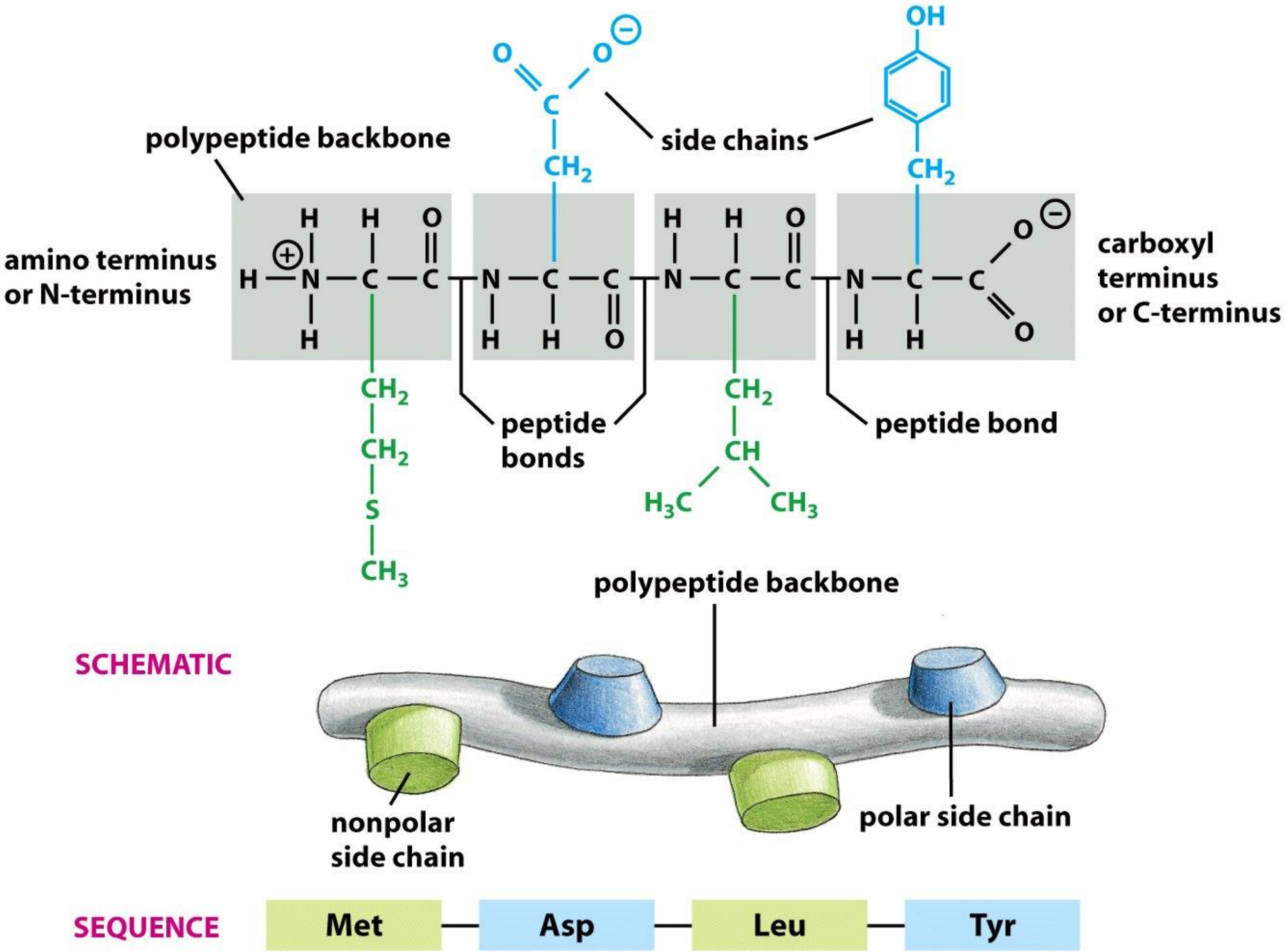


Figure 3-1 (part 2 of 2) *Molecular Biology of the Cell* (© Garland Science 2008)

Protein Conformation is Influenced by the Distribution of Polar and Unpolar Amino Acids

!

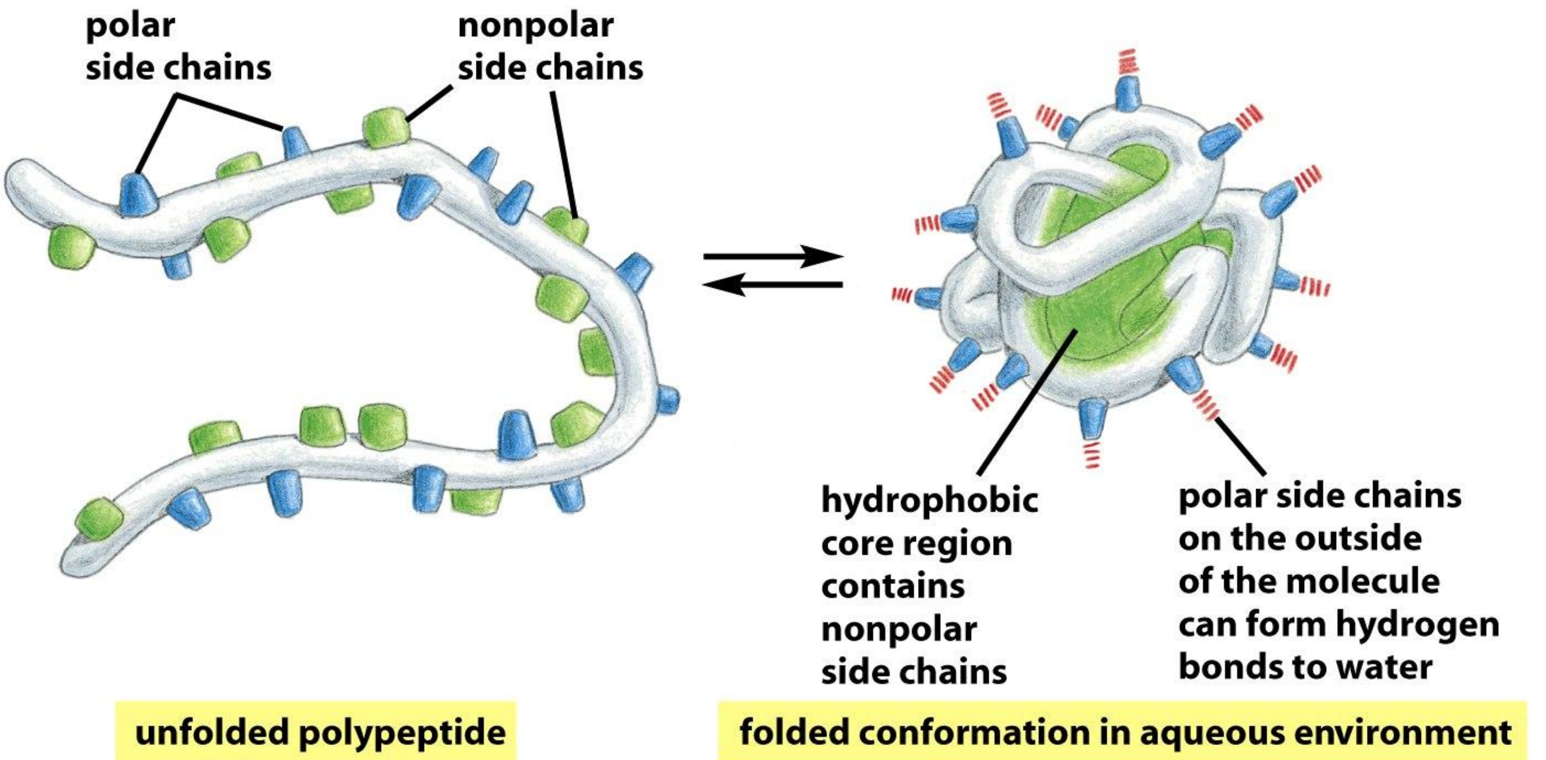
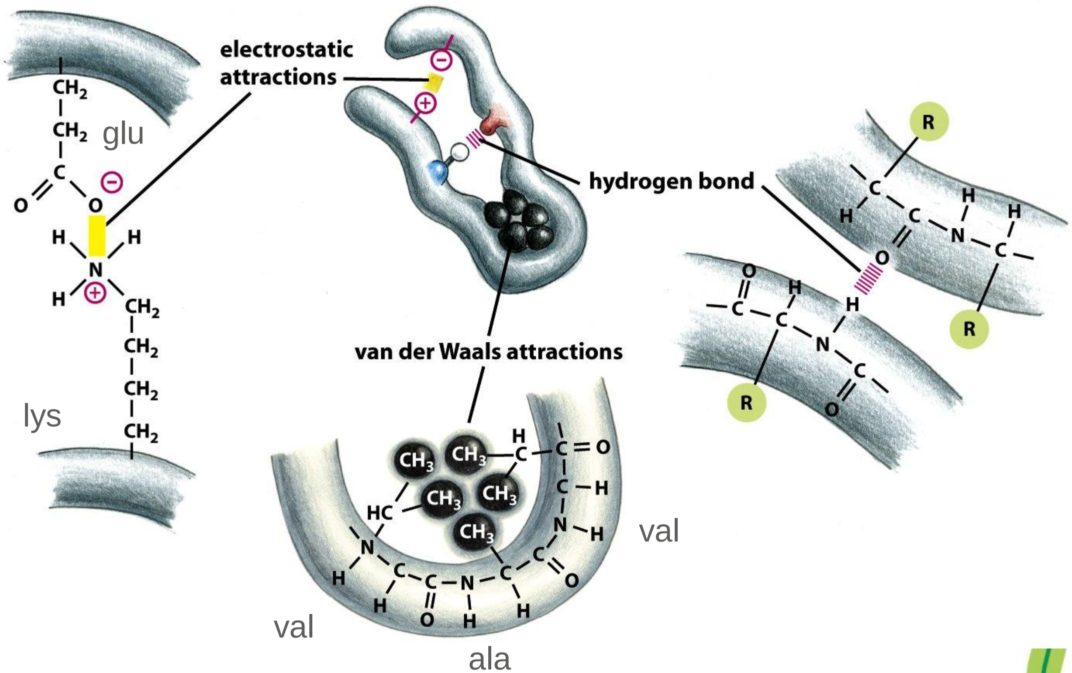
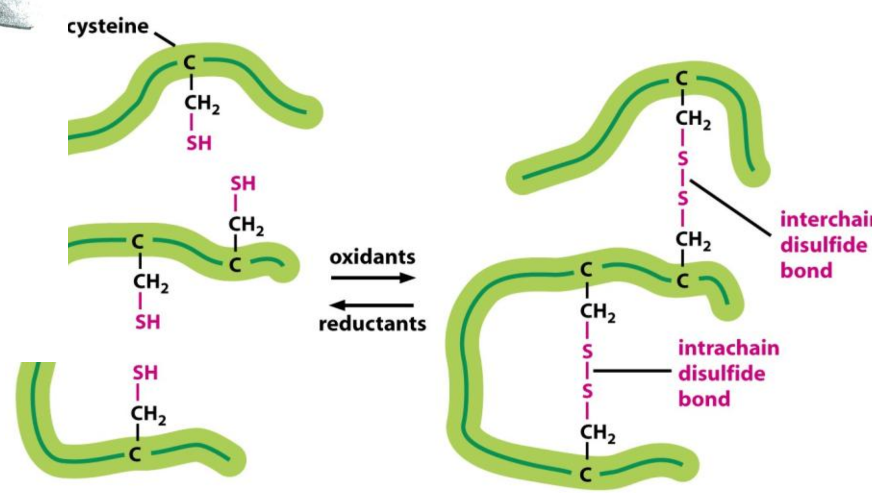


Figure 3-5 *Molecular Biology of the Cell* (© Garland Science 2008)

Bonds in Protein Folding



noncovalent



disulfide

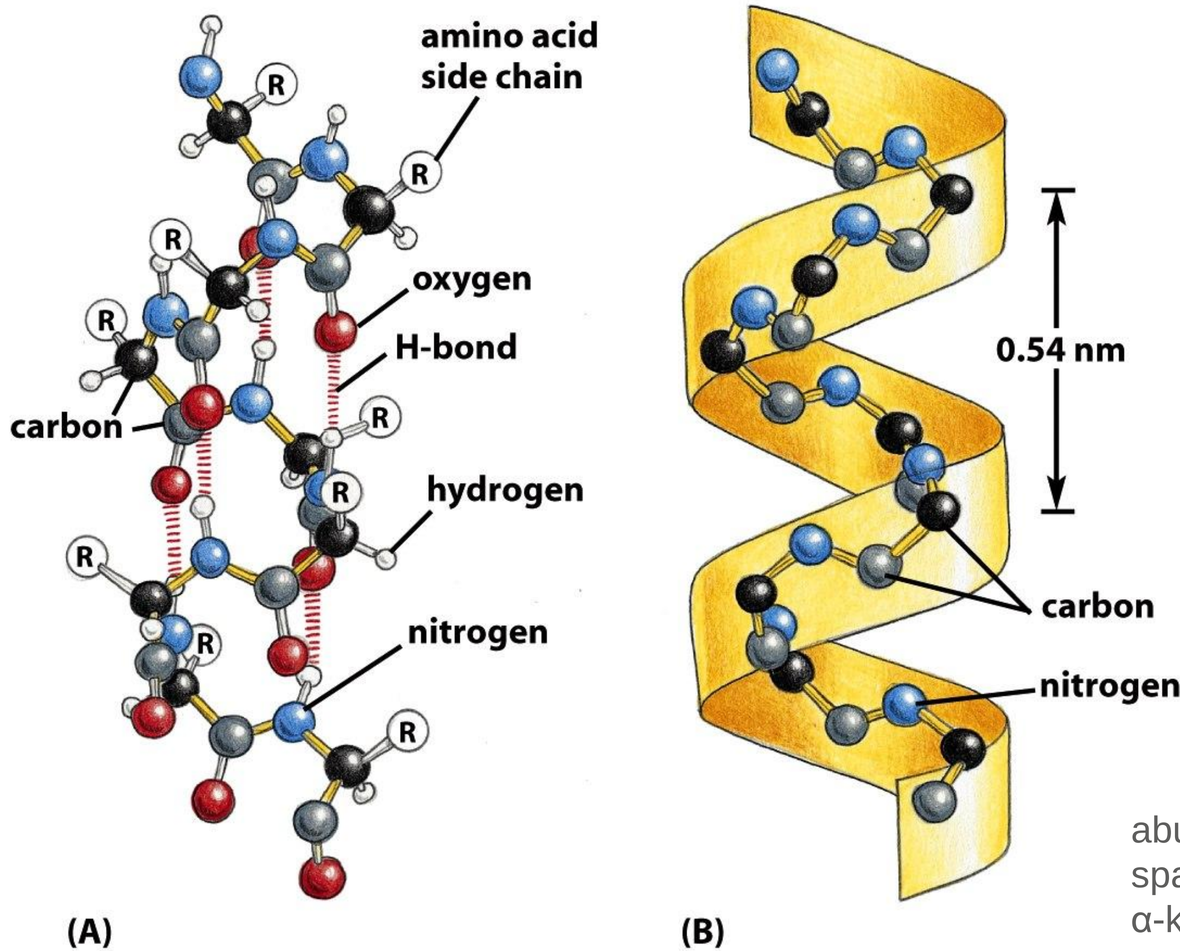
Table 2–1 Covalent and Noncovalent Chemical Bonds

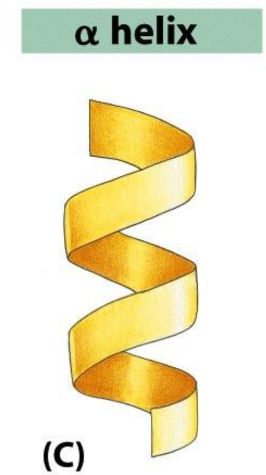
BOND TYPE	LENGTH (nm)	STRENGTH (kcal/mole) IN VACUUM	IN WATER
Covalent	0.15	90	90
Noncovalent: ionic*	0.25	80	3
hydrogen	0.30	4	1
van der Waals attraction (per atom)	0.35	0.1	0.1

*An ionic bond is an electrostatic attraction between two fully charged atoms.

Figure 3-4, 3-28 *Molecular Biology of the Cell* (© Garland Science 2008)

Common Folding Patterns of Proteins: The α Helix



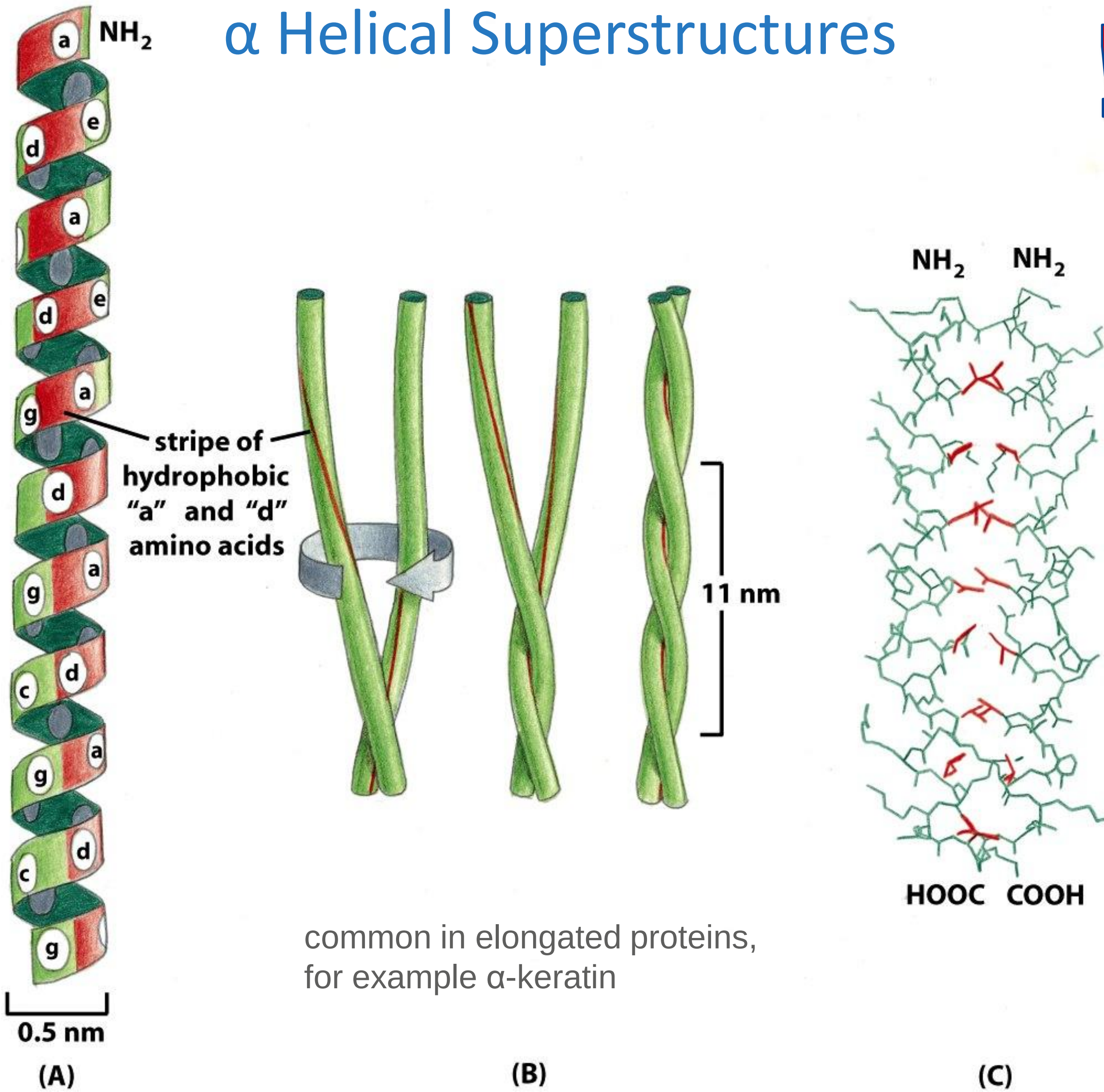


abundant in membrane spanning regions of proteins, α-keratin

Figure 3-7a,b,c *Molecular Biology of the Cell* (© Garland Science 2008)

Coiled-coils α Helical Superstructures

!

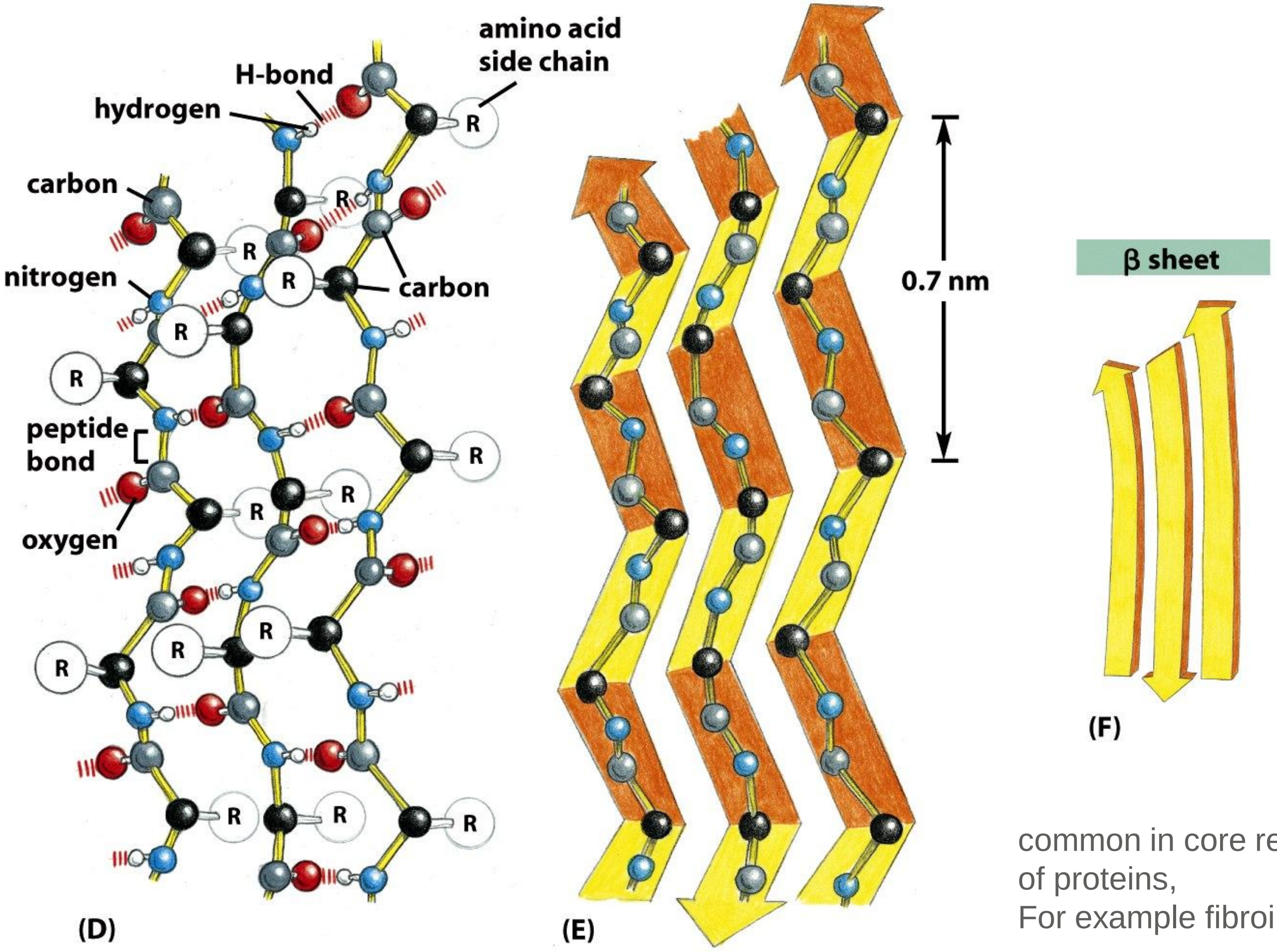


common in elongated proteins, for example α-keratin

Figure 3-9 *Molecular Biology of the Cell* (© Garland Science 2008)

Common Folding Patterns of Proteins: The β Sheet

!

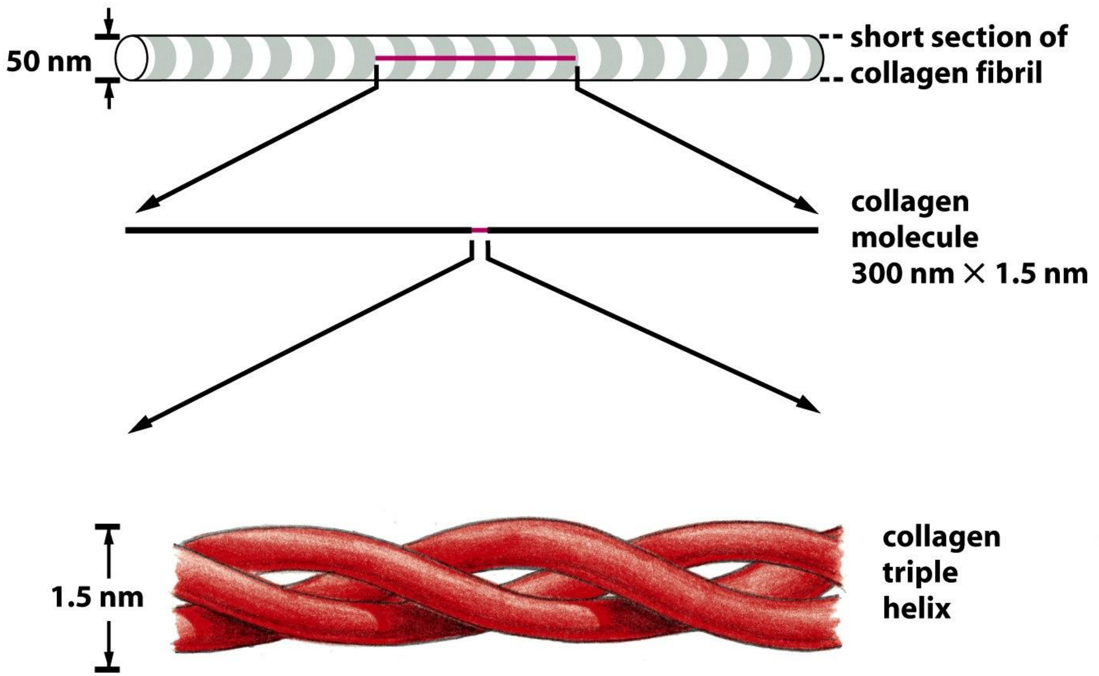


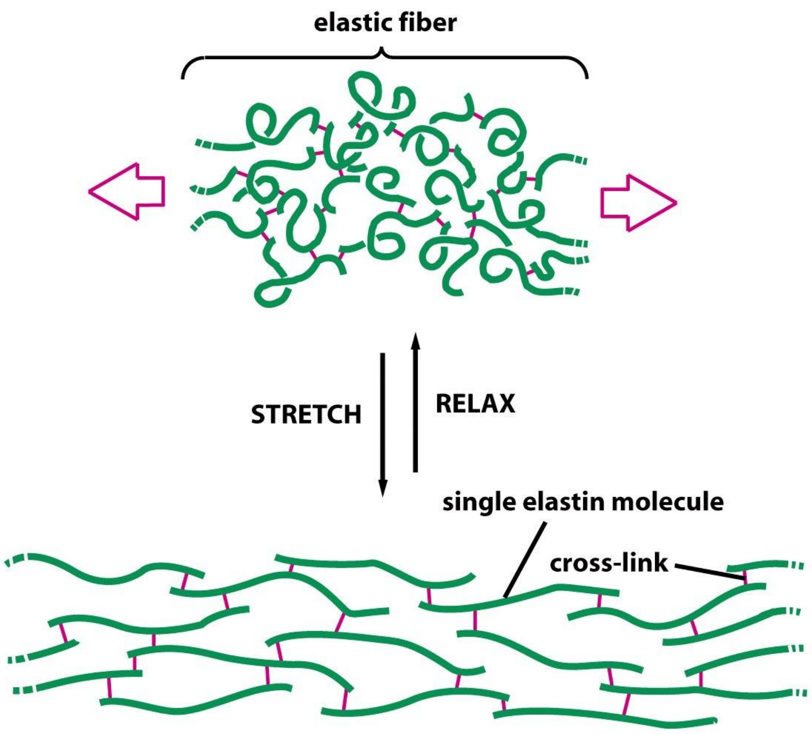
common in core regions of proteins,
For example fibroin (silk)

 Dr. Annette Kraegeloh – 12 April 2019 www.leibniz-inm.de

Figure 3-7d,e,f *Molecular Biology of the Cell* (© Garland Science 2008)

Secondary Structure Influences the Mechanical Properties of Proteins



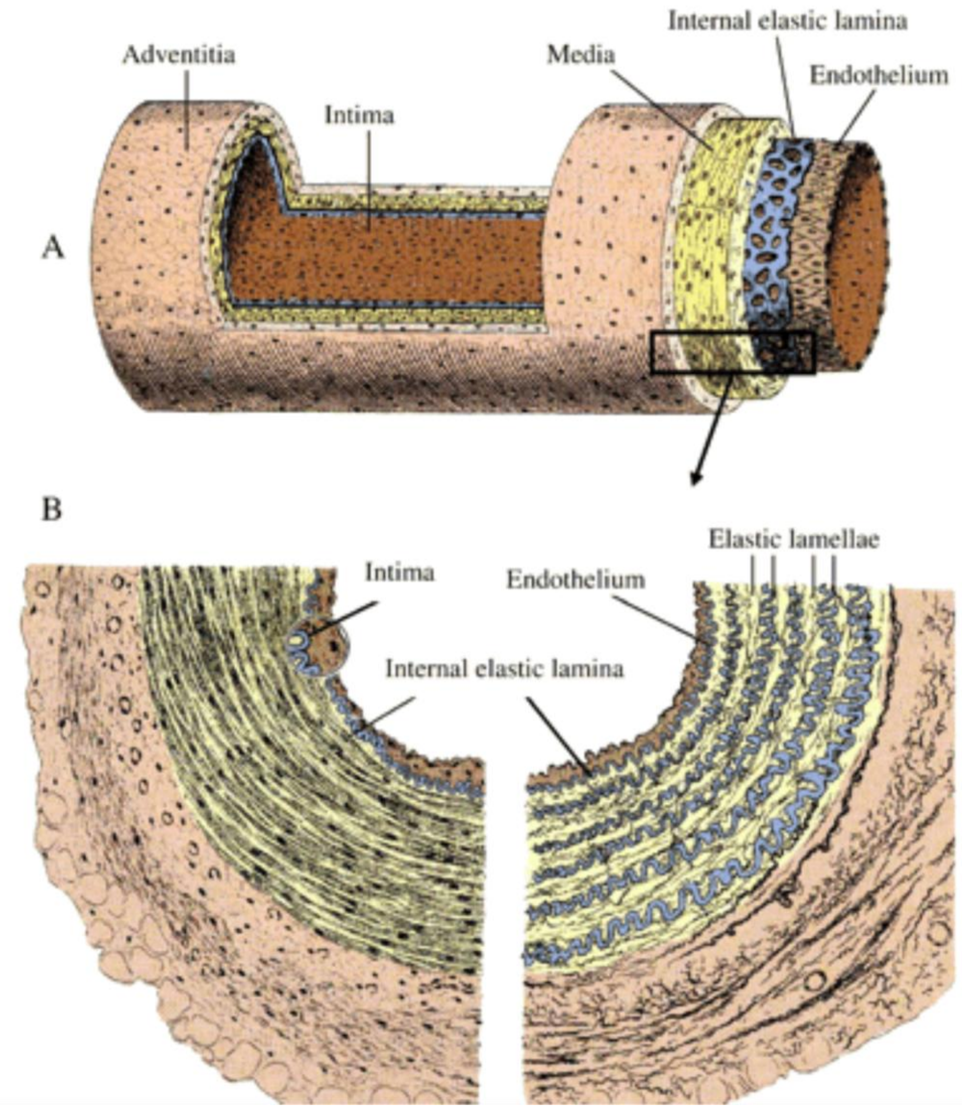


collagen

elastin

Figure 3-27 *Molecular Biology of the Cell* (© Garland Science 2008)

Elastin



OXFORD UNIVERSITY PRESS

A) The structure of blood vessels showing the three tunics.

B) The distribution of elastin within the vessel wall is shown for a muscular artery (left) and elastic artery (right)

(From: Elastin biosynthesis: The missing link in tissue-engineered blood vessels, Cardiovasc Res. 2006;71(1):40-49)

Spider Silk - a Biological Material

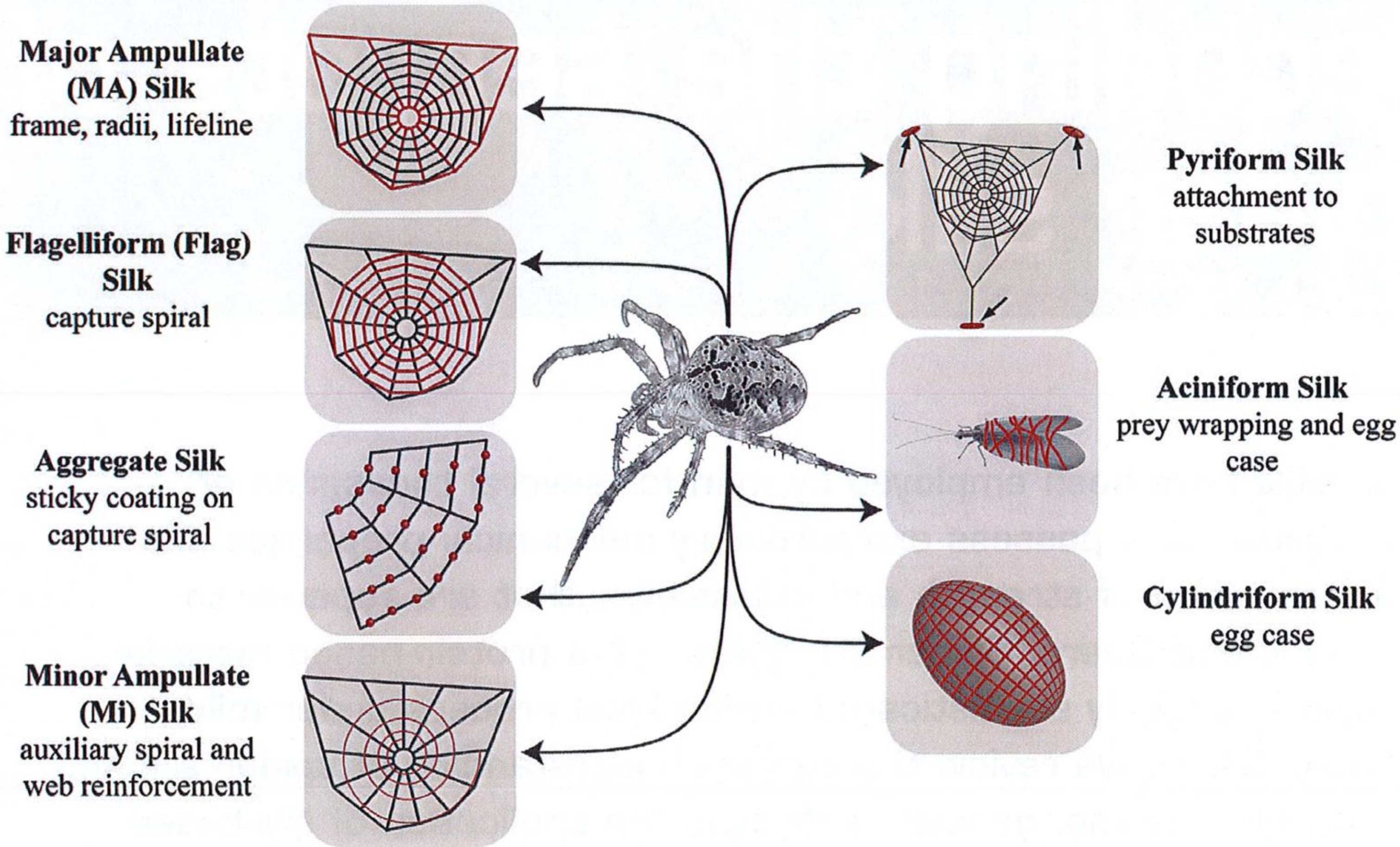


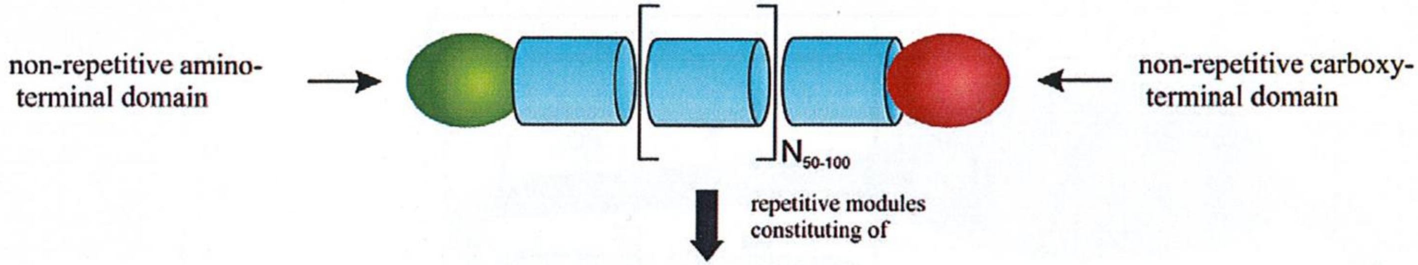
Fig. 1 Schematic overview of different silk types produced by female orb weaving spiders (Araneae). Each silk type (highlighted in red) is tailored for a specific purpose.

tensile strength: 0.02-1.7 GPa; steel 1.5 GPa, C fibres 3.5 GPa, Kevlar 3.6 GPa,
extensibility: 10-500%; steel 0.2%, C fibres 1.5%
high toughness, viscoelasticity, shape memory (twisting), supercontraction

(Eisoldt et al., 2011, Materials Today 14:80)

Spider Silk is Composed of Proteins

(a)



(b)

protein \ sequence motif	$(A)_{4\text{-}13}$	$(GA)_{\sim 4\text{-}6}$	GGX	GPGXX	Spacer	Termini
Major ampullate Spidroin 1 (MaSp1)	✓		✓			✓
Major ampullate Spidroin 2 (MaSp2)	✓			✓		✓
Minor ampullate Spidroins (MiSp)		✓	✓		✓	✓
Flagelliform spidroin (Flag)			✓	✓	✓	✓
Araneus Diadematus Fibroin 3 (ADF3)	✓		✓	✓		✓
Araneus Diadematus Fibroin 4 (ADF4)	✓			✓		✓

(c)

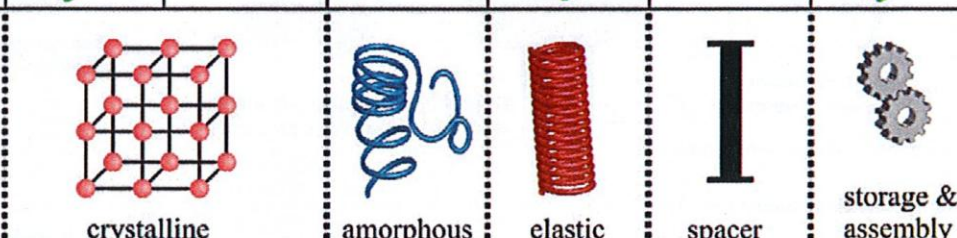


Fig. 2 The hierarchical setup of spider silk proteins. (a) Illustration of a spidroin comprised of up to 100 repetitive modules (blue) and two terminal domains (red and green). The components are not drawn to scale. (b) The repetitive modules of the most prominent silk types comprise a distinct subset of amino acid motifs. (c) Each motif is thought to fulfill a distinct structural role and contributes to the mechanical properties of the final fiber.

(Eisoldt et al., 2011, Materials Today 14:80)

The Spinning Process Influences the Fibre Properties

!

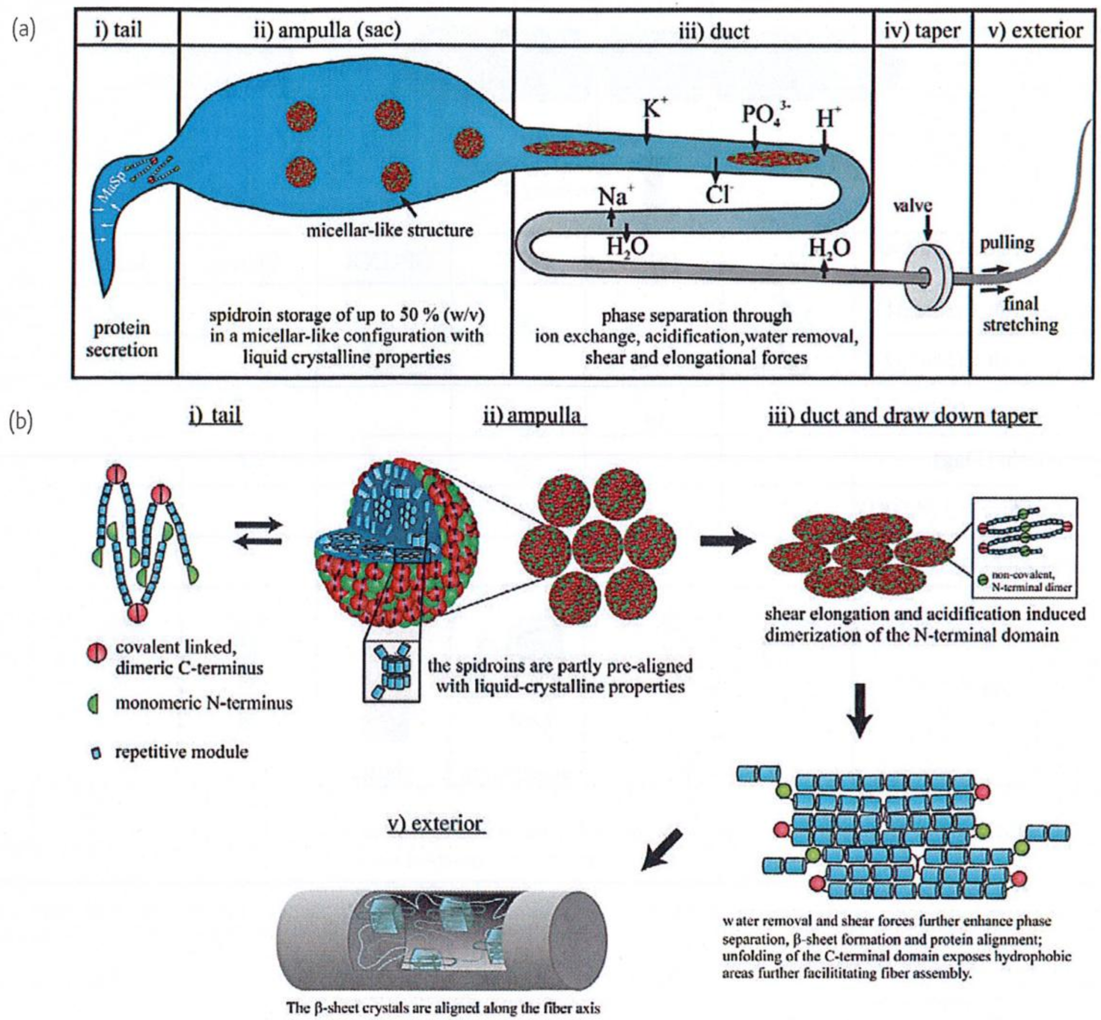
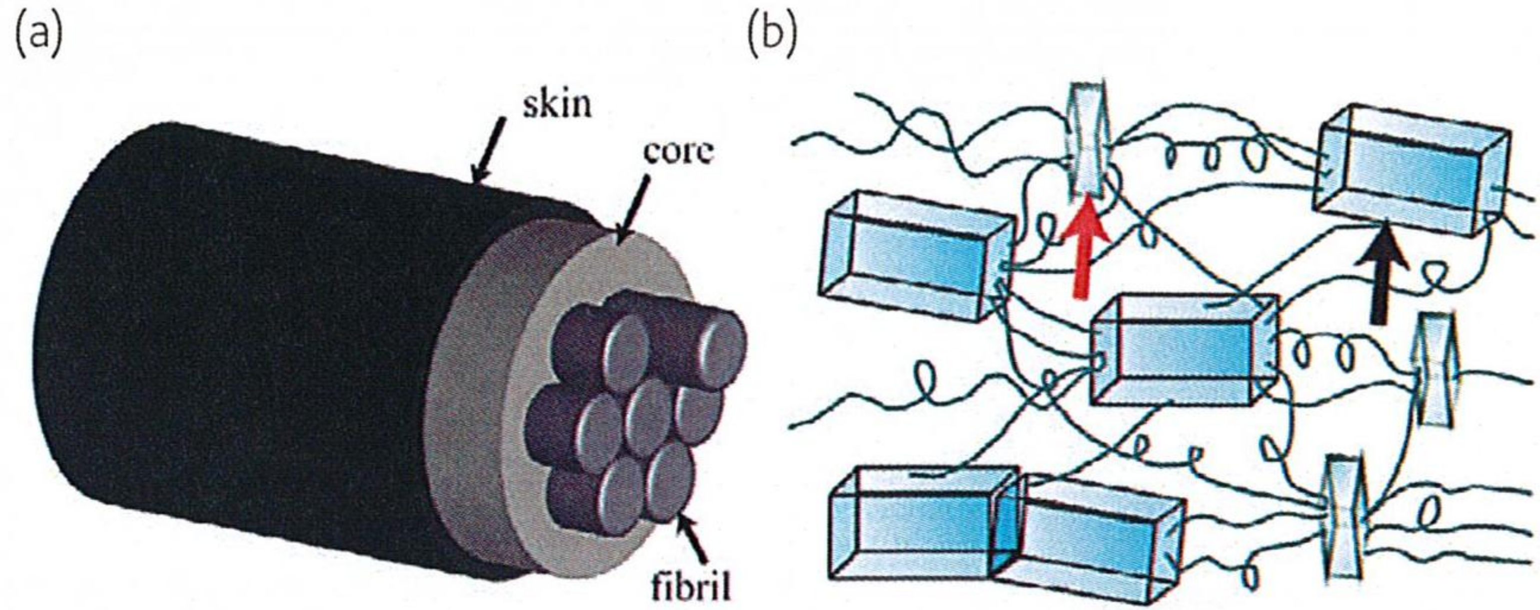


Fig. 3 The natural spinning process. (a) Illustration of a spider's spinning gland divided into four parts. (b) Schematic model of the silk fiber assembly mechanism occurring along the spinning apparatus.

(Eisoldt et al., 2011, Materials Today 14:80)

The Hierarchical Structure of Spider Silk



(Eisoldt et al., 2011, Materials Today 14:80)

Applications of Recombinant Spider Silk

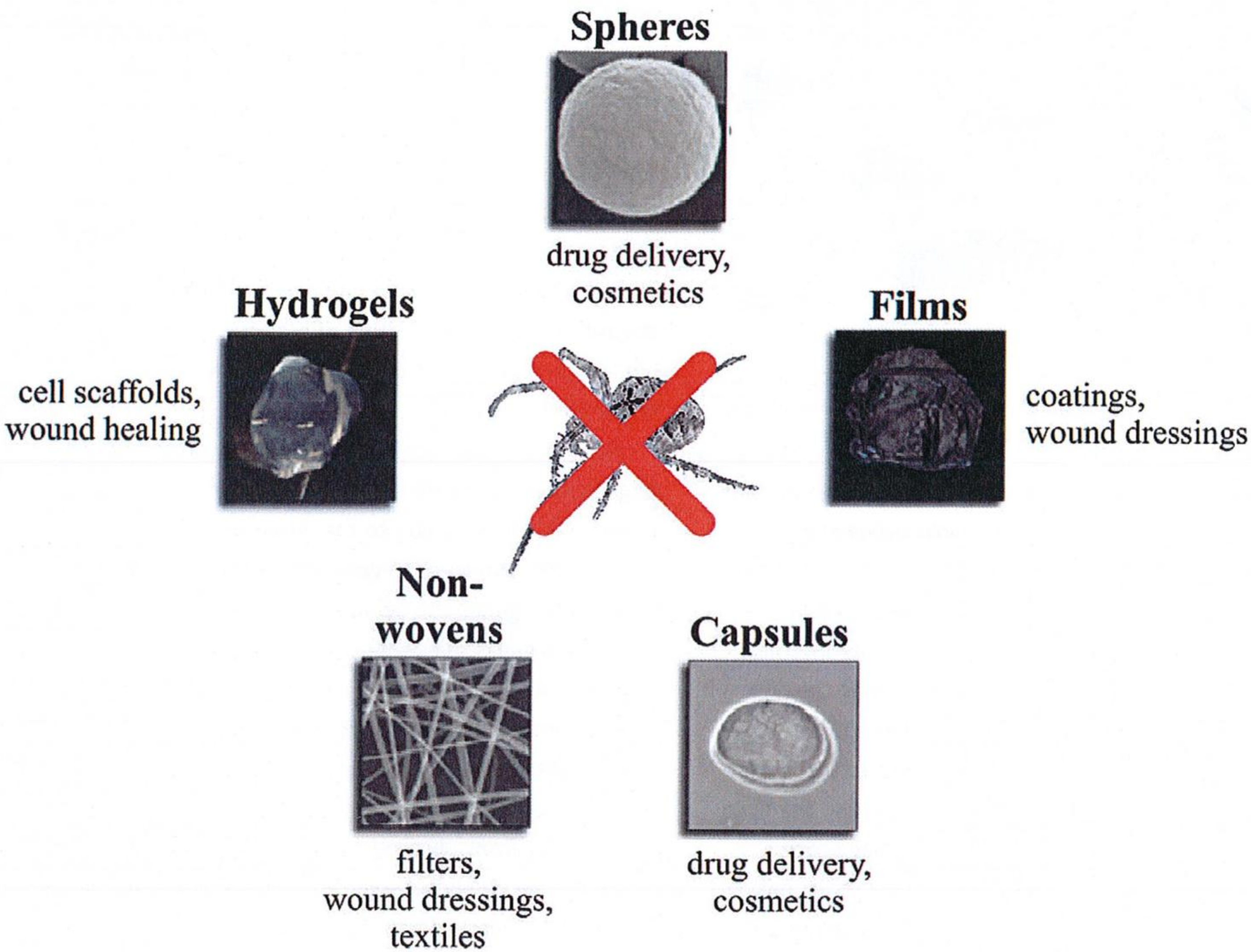


Fig. 5 Different non-natural assembly forms (bold text) of recombinant spider silk proteins and potential applications thereof.

(Eisoldt et al., 2011, Materials Today 14:80)

Keratinous Materials

[Wang et al., 2016]

α Keratins

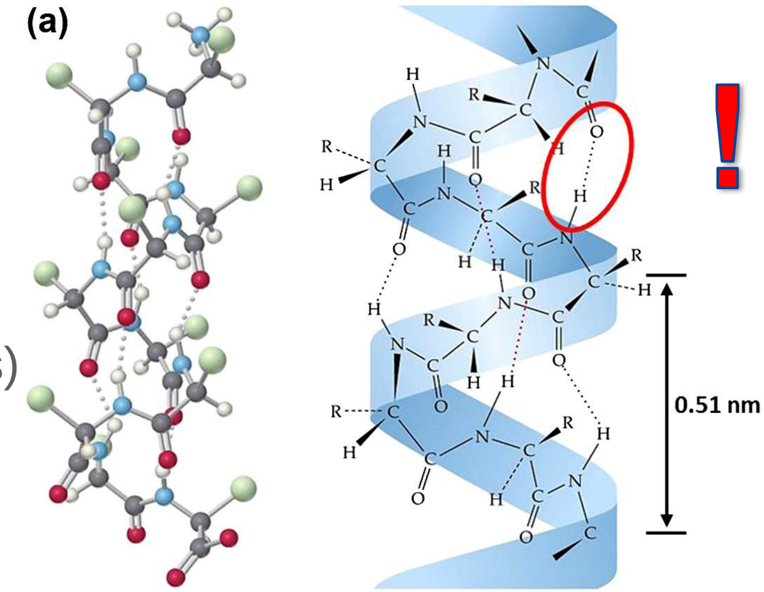
filament forming proteins, insoluble,
high cysteine content

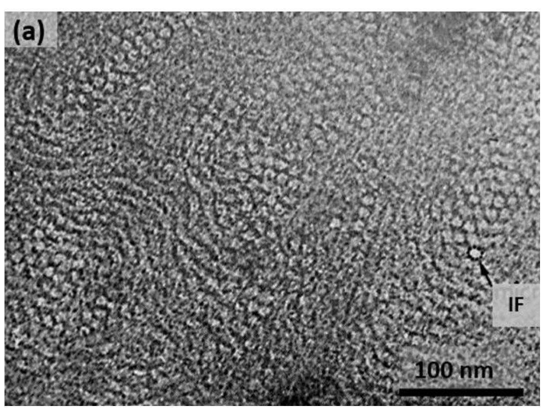
- α keratin: mammals (intermediate filaments)

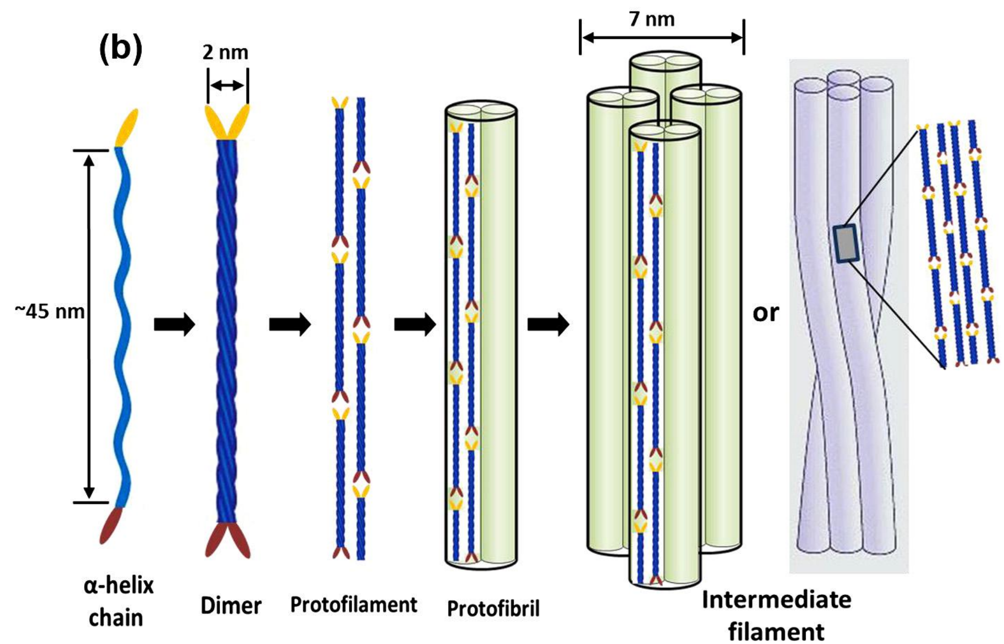
  right-handed α helix, left-handed coiled-coil

- β keratin: reptiles, birds, 3 nm

  β pleated sheet

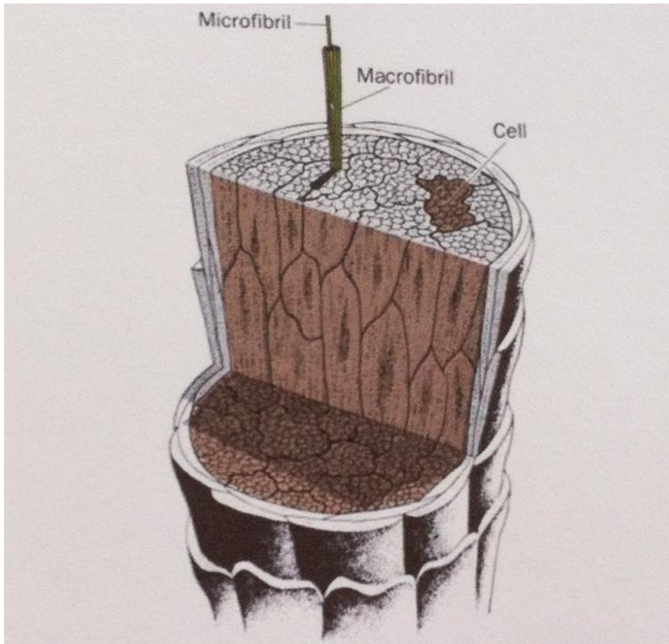


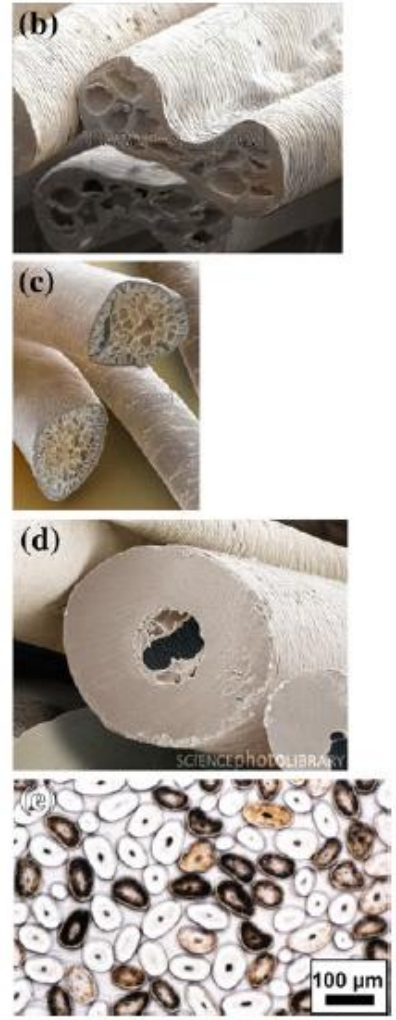




[Wang et al., 2016]

Hair





rabbit

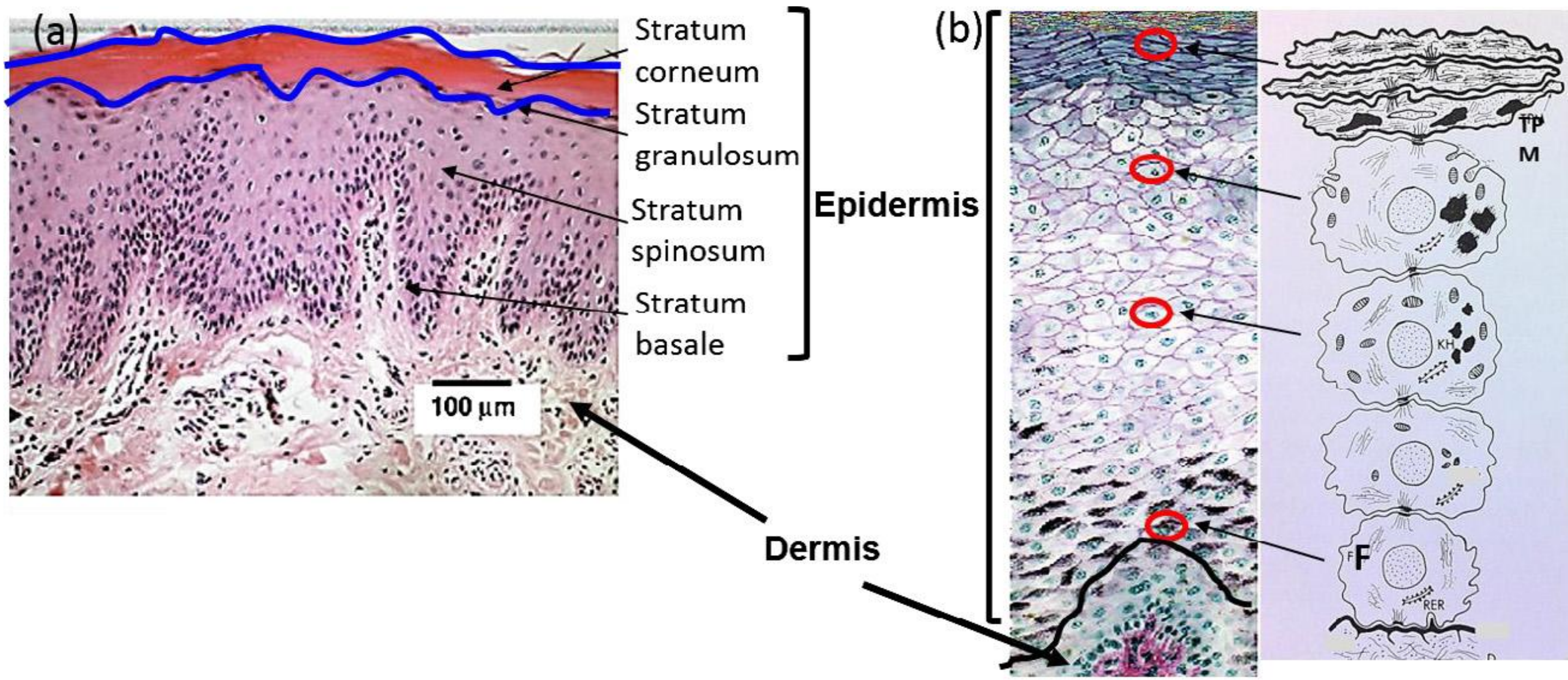
elk

polar bear

human hair

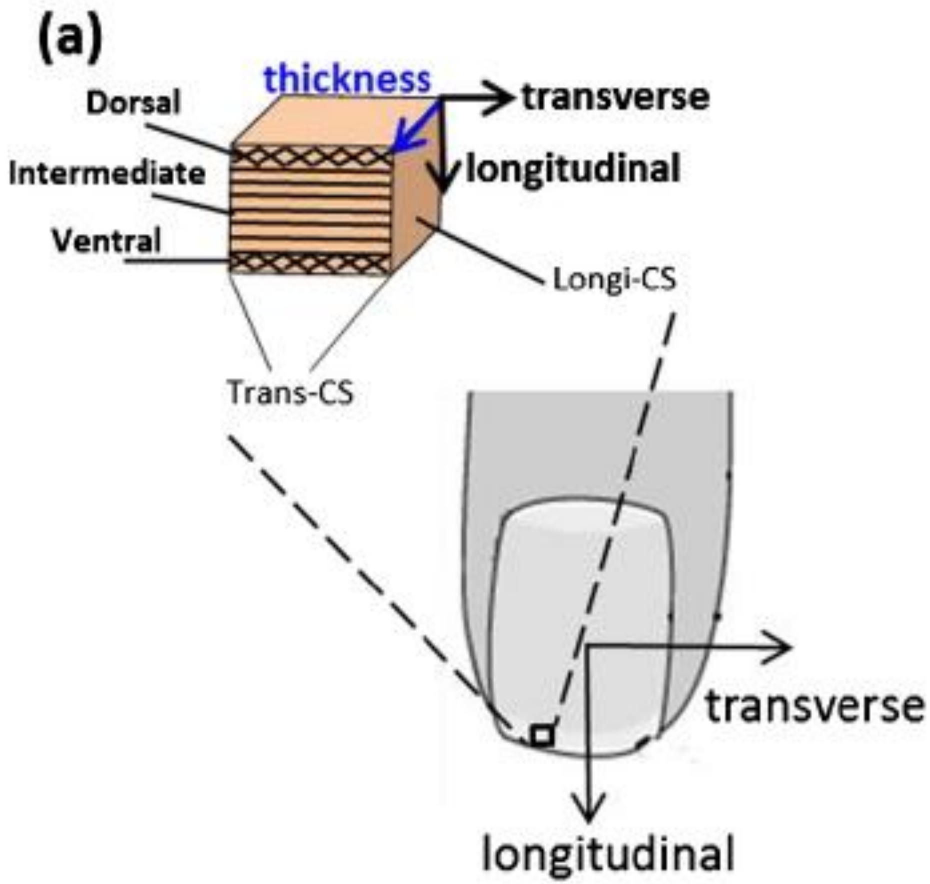
[McKittrick et al., 2012; Voet and Voet, 4. Auflage, 2011]

Skin



[Wang et al., 2016]

Nails



[Wang et al., 2016]

Questions

- What are biological materials, molecular machines, bioinspired materials, biominerals, biomaterials?
- What is the chemical composition of cells?
- What are proteins? What functions do they fulfil? What are their building blocks? What is the structure of amino acids? How can amino acids be grouped? Which types of bonds play a role in protein folding? What is the primary and secondary structure of proteins? What are common folding patterns of proteins, where do they occur?
- What is spider silk? What are its main properties? What are its building blocks? What are important structural motifs? How does the natural spinning process contribute to the silk properties?
- What is the structure of α keratins? Where do they occur? What are their functions?

Literature

Books:

- ❑ Molecular Biology of the Cell, ed. Alberts et al. (2008), Garland Science
- ❑ Biochemie, Stryer, (2012) Springer

Articles:

- ❑ Eisoldt et al., 2011, Materials Today 14: 80 Decoding the secrets of spider silk
- ❑ Wang et al., 2016, Progress in Materials Science, 76: 229 Keratin: Structure, mechanical properties, occurrence in biological organisms, and efforts at bioinspiration

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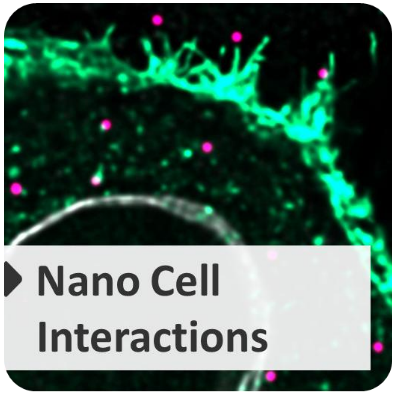
Next Lecture: April 17, 2019

Biological Building Blocks, Molecular Machines, and Subcellular Organization



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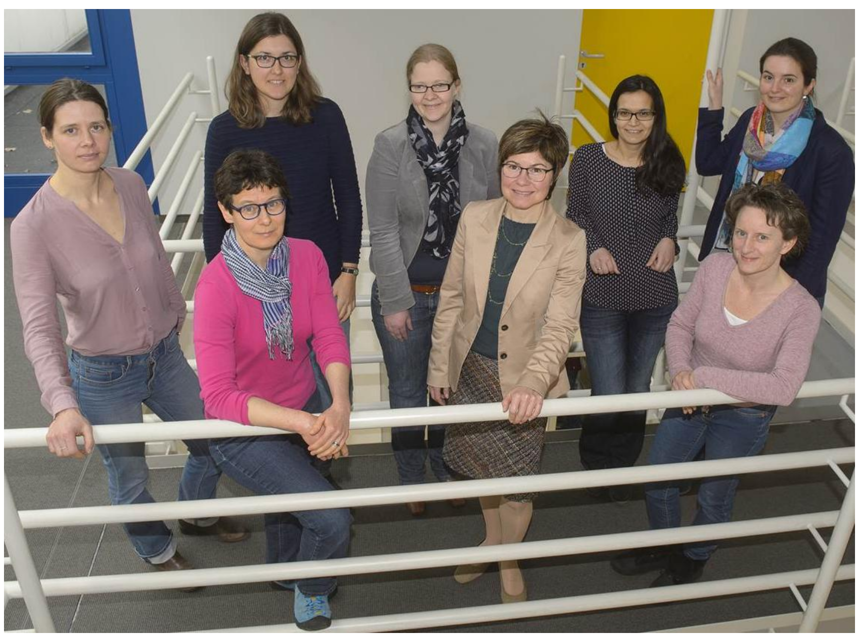
THANK YOU FOR YOUR ATTENTION



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