Biotechnology of drugs – Introduction

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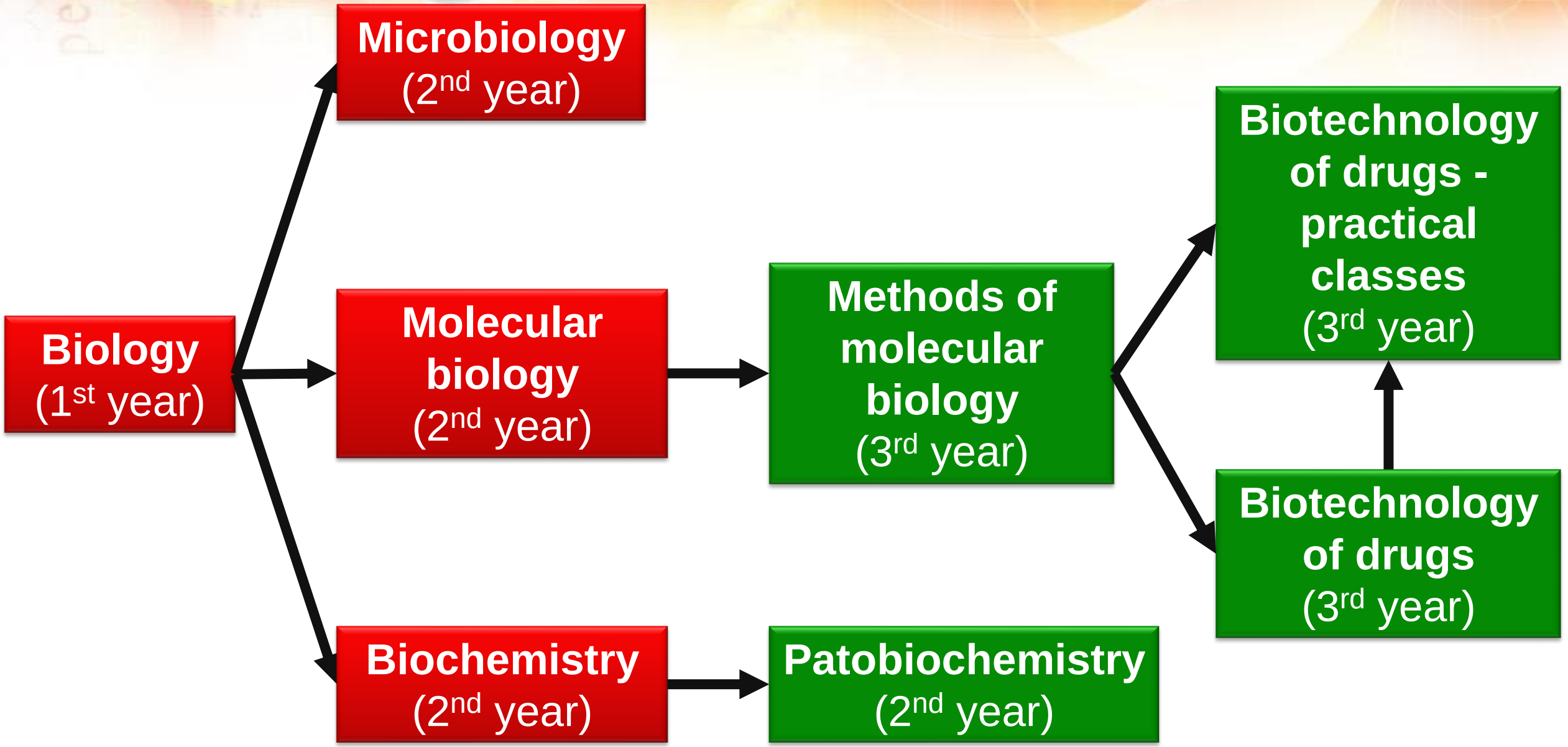
Syllabus of lectures 2024

1. week	19.02.2024	9:00 - 11:30	Introduction to pharmaceutical biotechnology, status, historical milestones; The cell as a biotechnologist's tool, the function of the endoplasmic reticulum, the Golgi apparatus, post-translational processes, chaperones	Hošek
2. week	26.02.2024	9:00 - 11:30	Basics of genetic engineering I - principles of how to obtain a recombinant gene, vectors	Hošek
3. week	04.03.2024	9:00 - 11:30	Fundamentals of Genetic Engineering II - preparation of genes for cloning, host cells, transformation, selection and identification of transformants	Hošek
4. week	11.03.2024	9:00 - 11:30	Expression of recombinant proteins in prokaryotic cells and yeast	Bartoš
5. week	18.03.2024	9:00 - 11:30	Expression of recombinant proteins in eukaryotic cells - insect cells and baculoviruses, mammalian cells and adenoviruses	Hošek
6. week	25.03.2024	9:00 - 11:30	Classic biotechnological procedures in pharmacy	Bartoš
7. week	01.04.2024			
8. week	08.04.2024	9:00 - 11:30	Biotechnological process - definition of the term, stages of the biotechnological process, raw materials for the biotechnological process, fermenters and bioreactors, methods of product purification	Bartoš
9. week	15.04.2024	9:00 - 11:30	Genetic engineering in higher plants - plant genome structure, vectors, expression cassettes	Bartoš
10. week	22.04.2024	9:00 - 11:30	Plant biotechnology - methods of transformation and identification of transgenic plants, molecular farming	Bartoš
11. week	29.04.2024	9:00 - 11:30	Examples of classical and recombinant biotechnology products in pharmaceuticals, cytokines as tools in the fight against infections and in tumor therapy, hormones, enzymes, antibodies and their derivatives	Hošek
12. week	06.05.2024	9:00 - 11:30	Gene and cell therapy, tissue engineering, genomics and proteomics in pharmacy	Hošek
13. week	13.05.2024	9:00 - 11:30	Application of genetic engineering and plant biotechnology in pharmacy, medicine and food industry, issues of dealing with genetically modified organisms	Bartoš
14. week	20.05.2024	9:00 - 11:30	Preparation of recombinant vaccines	

Knowledge-flow of biology subjects on DMP



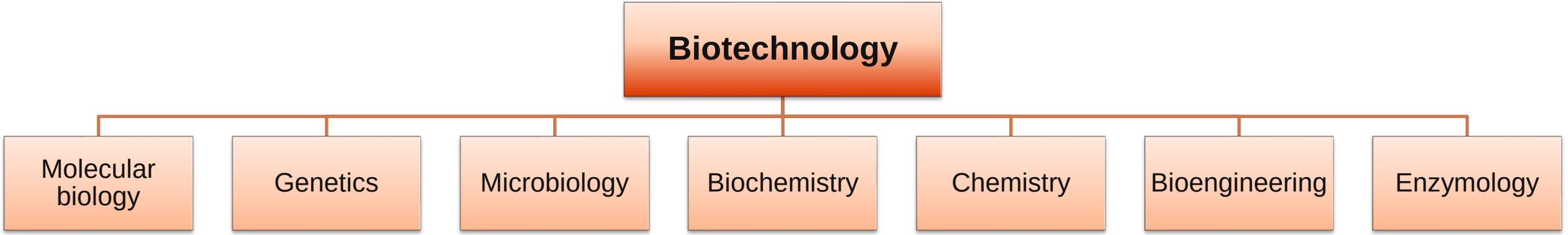
Recommended literature

- **Essential Cell Biology – Alberts et al., 1998**
- **Pharmaceutical biotechnology – Crommelin et al. 2013**
- **Biotechnology Foundations, 2nd Edition – Jack O´Grady, 2019**

  (https://legacy.cnx.org/content/col26095/1.5)

What is BIOTECHNOLOGY?

Processes using **living organisms or their components** to produce or modify products; breeding of animals, plants and microorganisms for specific uses (commercial application and **benefit to mankind**).



Prof. Drobník

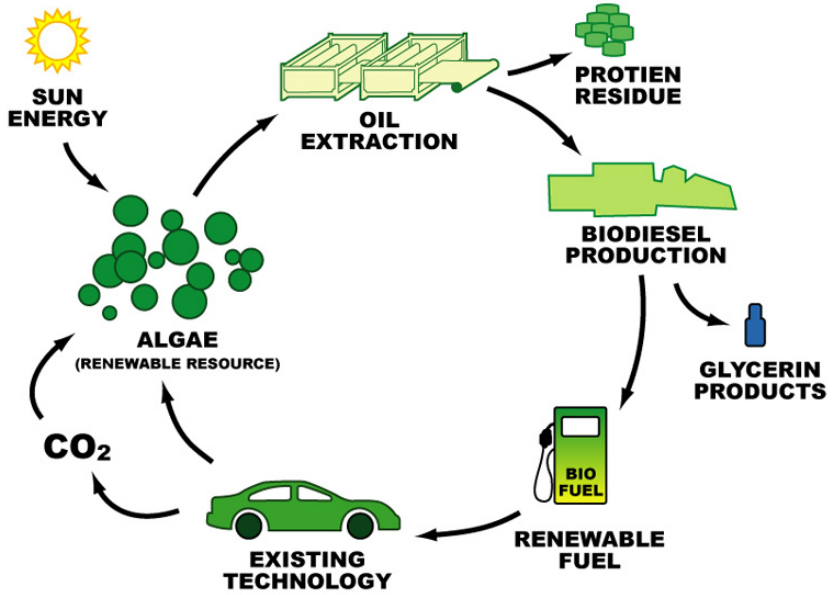
The nature of biotechnology is intrinsically linked to the application of biology, i.e with industry, and thus also with commerce..

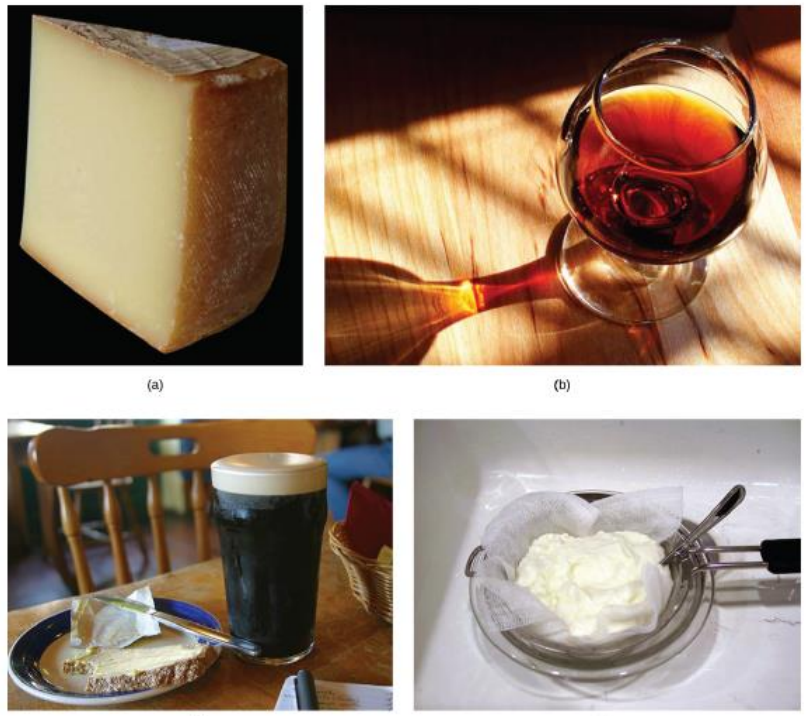
Therefore, it is necessary to operate it in such a way that people benefit from its results as much as possible, which is not possible without a commercial outcome.

For that reason, the quality of scientific work in biotechnology should be measured by patents rather than the impact factor of publications.

Biotechnological outputs

- Food and beverage production
- Production of materials and fuels
- Production of drugs and medical materials





ure 1.1 Some foods produced by microorganisms. Some of the products derived from the use of prokaryotes in ly biotechnology include (a) cheese, (b) wine, (c) beer and bread, and (d) yogurt. (credit bread: modification of rk by F. Rodrigo/Wikimedia Commons; credit wine: modification of work by Jon Sullivan; credit beer and bread: dification of work by Kris Miller; credit yogurt: modification of work by Jon Sullivan)

Biopharmaceuticals

Biopharmaceuticals *are drugs or potential drugs obtained by other than the classical route of synthetic chemistry (including combinatorial chemistry) or drugs originally obtained by isolation from plant (biological) material.*(Beneš, 2007, *Chem. Listy* 101, 18−24)

- Creation using genetic engineering and recombinant technologies
- Therapeutic proteins, DNA or RNA, antibodies, parts or whole cells, drug conjugates with proteins or natural polymers,...

Dan Race/Stock.Adobe.com

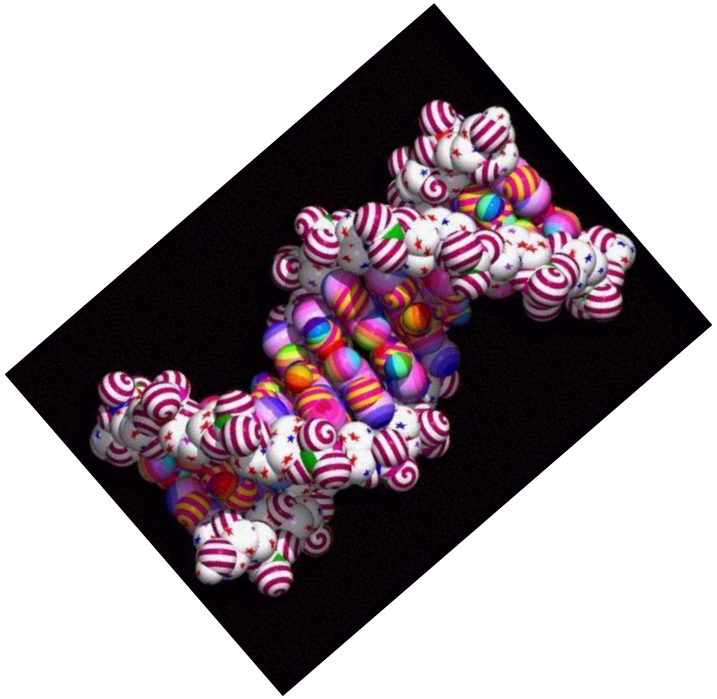
Classification of biotechnology

- Classic microbial technology
- Enzyme technologies
- Use of animal and plant cells
- Gene technology
- Pharmaceutical biotechnology

Pharmaceutical biotechnology

According to European Association of Pharma Biotechnology (EAPB)

…is the science that covers all the technologies necessary to create, manufacture and register biotechnological drugs.



Is it really science?

1) Existence of the subject of research
2) Central theory
3) Existence of methodological approaches
4) Institutionalization
5) Own journal

Subject of pharmaceutical biotechnology

- The subject of studying pharmaceutical biotechnology is **medicine created by a specific (biotechnological) procedure** - using organisms, living cells or their components.

- It requires a **specific approach in all stages of production** - own design, development and finally production.

- Medicines created through biotechnological procedures are subject to a **special registration regime**, as they are **products of genetically modified organisms**.

Central theory of pharmaceutical biotechnology

- common evolutionary origin of organisms
- the universality of the genetic code across living systems
- similarity of transcription and translation apparatuses

Substances biologically active in one organism can be produced in any other organism..

1) The recombinant product (although not produced in its original organism) is functionally identical or at least very similar to the "original".
2) A biopharmaceutical product can be appropriately modified by a biotechnologist to have special properties that allow it to perform a specific function in the target organism.

Methodical approach of pharmaceutical biotechnology

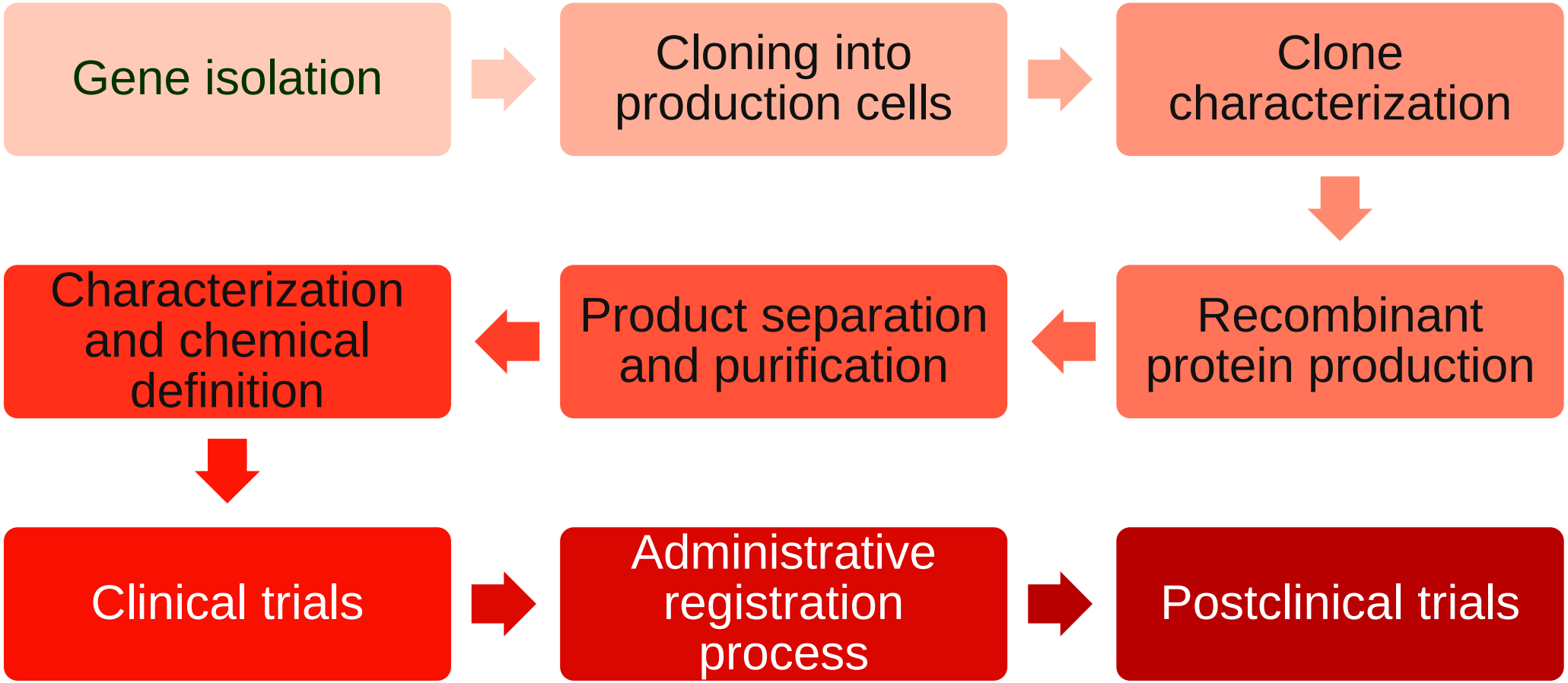
Diversity of sources = wide spectrum of methods

- Drug development = molecular biology, genetics and genetic engineering
- Drug production = classic microbiology, genetics
- Purification and characterization of products = biochemistry, analytical chemistry
- Drug Development = Biochemistry, Enzyme Engineering, Organic Chemistry, Pharmaceutical Chemistry, Drug Technology and Pharmacology
- Drug registration = applied pharmacy

The specifics of the methodical approach

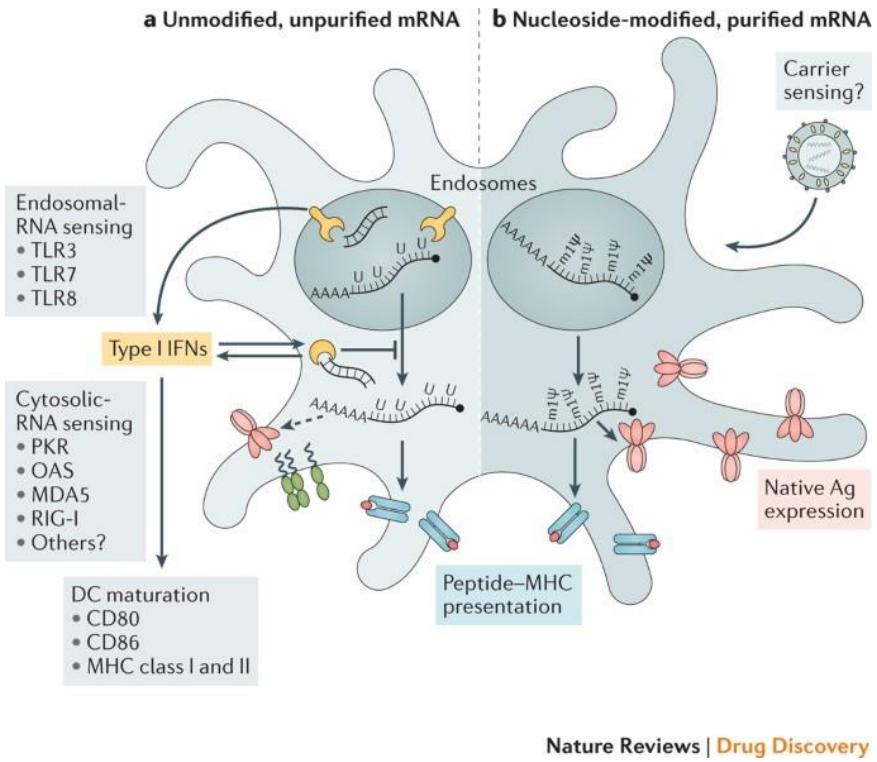
COMPLEXITY

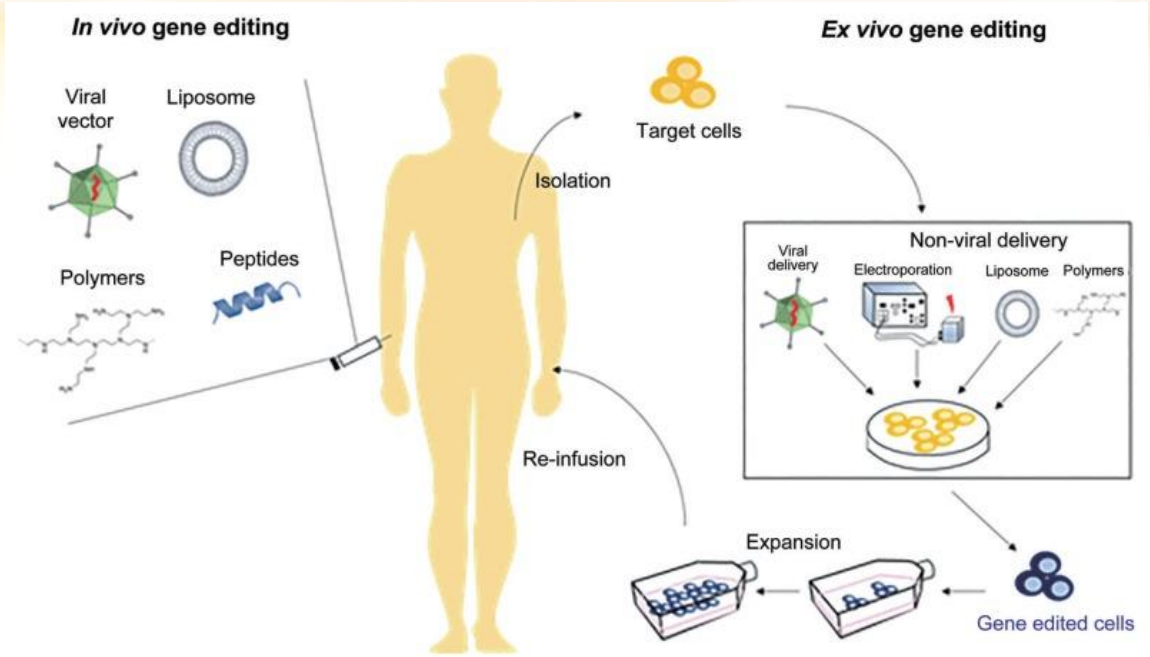
Example of recombinant protein production



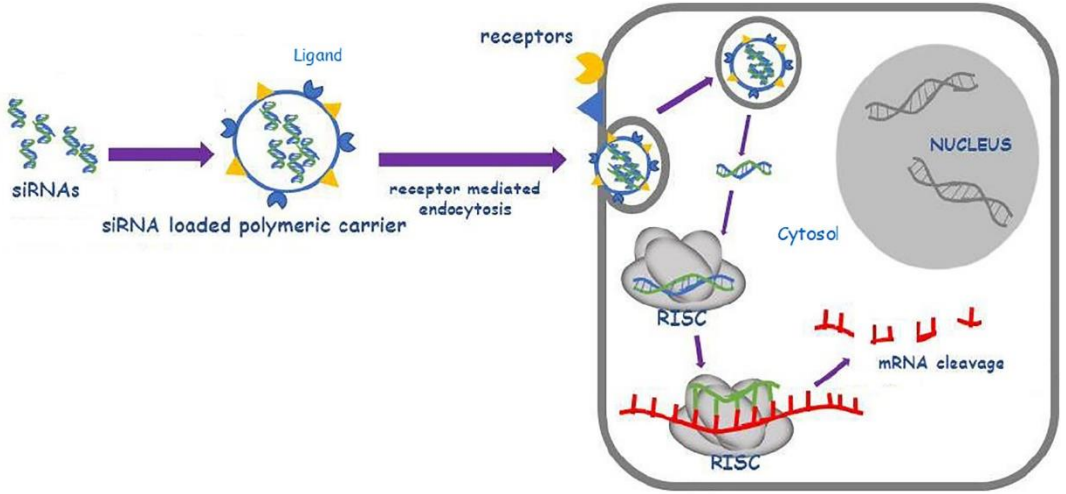
Specific methodological approaches

- Gene therapy
- DNA/RNA vaccines
- siRNA-based drugs





DOI: 10.1038/aps.2017.2



doi.org/10.1016/j.nano.2020.102239

Scientific societies

The European Association of Pharma Biotechnology, EAPB

http://www.eapb.org/

The American Association of Pharmaceutical Scientists (AAPS)

https://www.aaps.org/home

Research institutions

- **Foreign**:
  - **The North Carolina Central University, Biotechnology and Pharmaceutical Law Institute** (https://www.nccu.edu/research/institutes-and-special-facilities/bpli)
  - **Department of Pharmaceutical Technology and Biopharmaceutics, Martin-Luther-University Halle, Germany** (https://www.pharmazie.uni-halle.de/institutsbereiche/)
- **Czech:**
  - **PRO.MED.CS Praha a.s.** (https://www.promed.cz/)
  - **Biopharm – Výzkumný ústav biofarmacie a veterinárních léčiv, a.s., Jílové u Prahy, Česká republika** (https://www.bri.cz/)

Journals

- According to WoS, 170 journals in the **BIOTECHNOLOGY & APPLIED MICROBIOLOGY** category (February 2024)

- **Current Pharmaceutical Biotechnology** (https://benthamscience.com/journals/current-pharmaceutical-biotechnology/)

A brief history of biotechnology

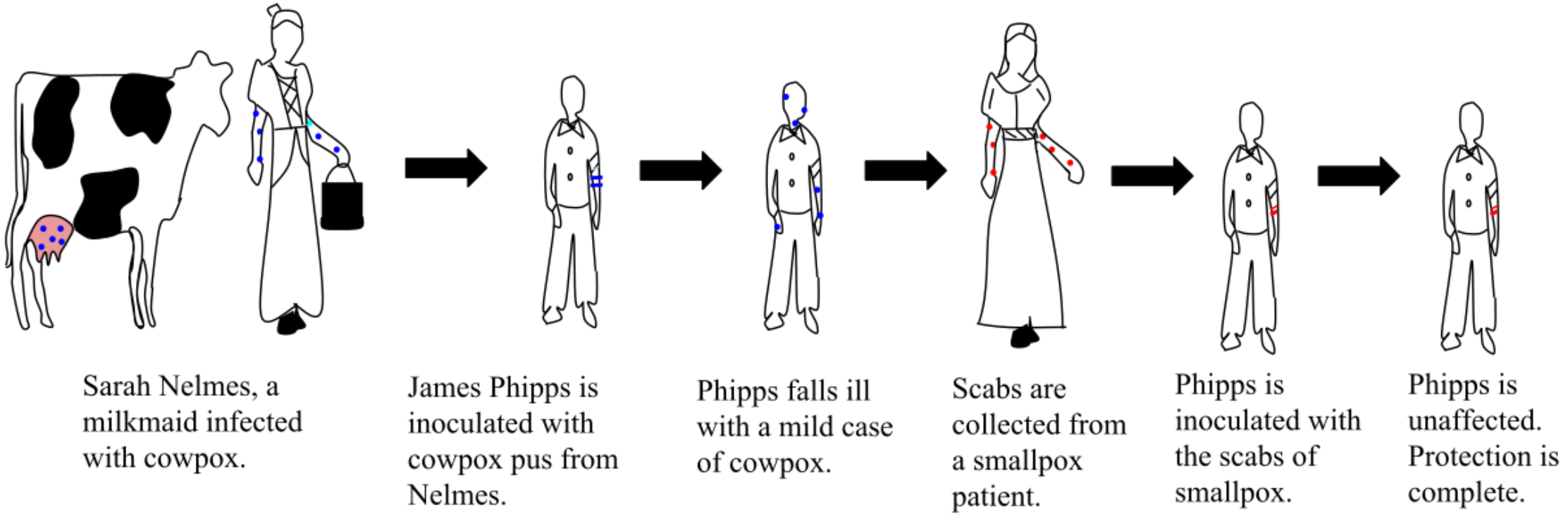
- *Initial period to 1850*
- *The Era of Pasteur*
- *The era of industrial biotechnology*
- *The era of new biotechnologies*
- *Transgenic organisms*

Biotechnology in prehistoric times…

- empirical use of wild microorganisms to prepare fermented products
- in Mesopotamia by the Sumerians in the 7th millennium BC – beer production
- about 4,000 years BC the use of yeast to ferment bread dough in ancient Egypt
- about 4,000 years BC preservation of milk by fermentation in ancient China – production of cheese, wine, vinegar

The beginnings of pharmaceutical biotechnology

- The discovery of vaccination
  - Edward Jenner 1796 – first vaccination against smallpox

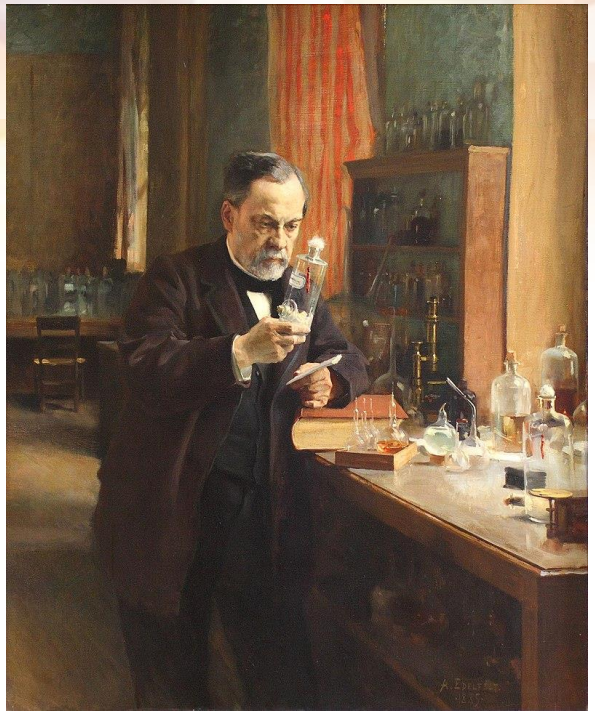


https://commons.wikimedia.org/wiki/File:Edward_Jenner-_Smallpox.svg

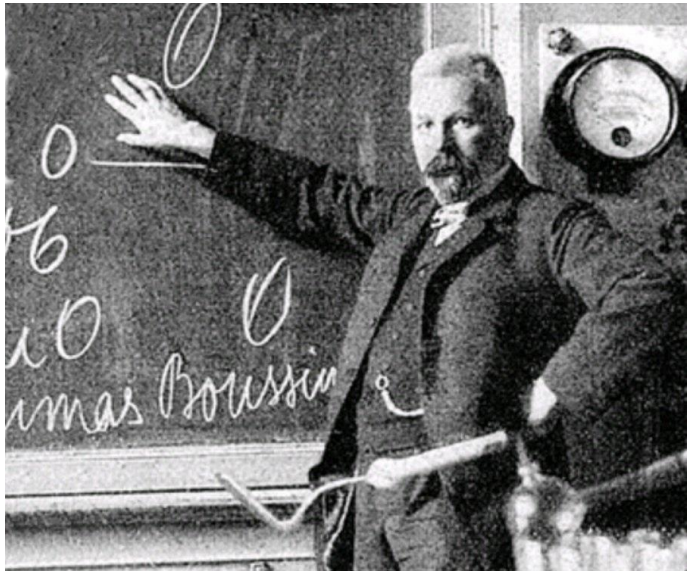
Difficult beginnings of vaccination…

Engraving by Jamese Gillraye (1802)

The Era of Pasteur



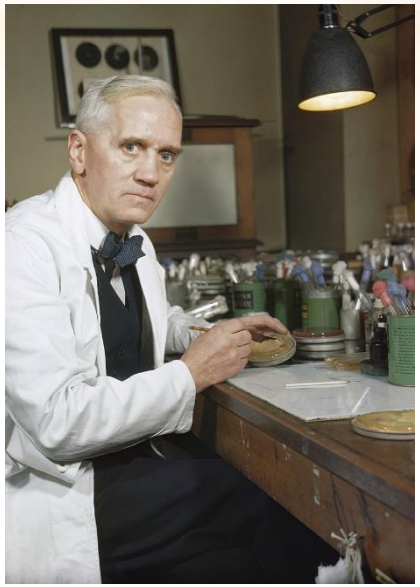
- **Louise Pasteur (1822 – 1895)** - assumes that fermentation is caused by living microorganisms; discovery of heat sterilization - **pasteurization**; **vaccine research** based on killed pathogens (**anthrax, rabies**)



- **Eduard Buchner (1860 – 1917) – demonstrated fermentation using yeast cell-free extract** - basics of enzymology

The era of industrial biotechnology

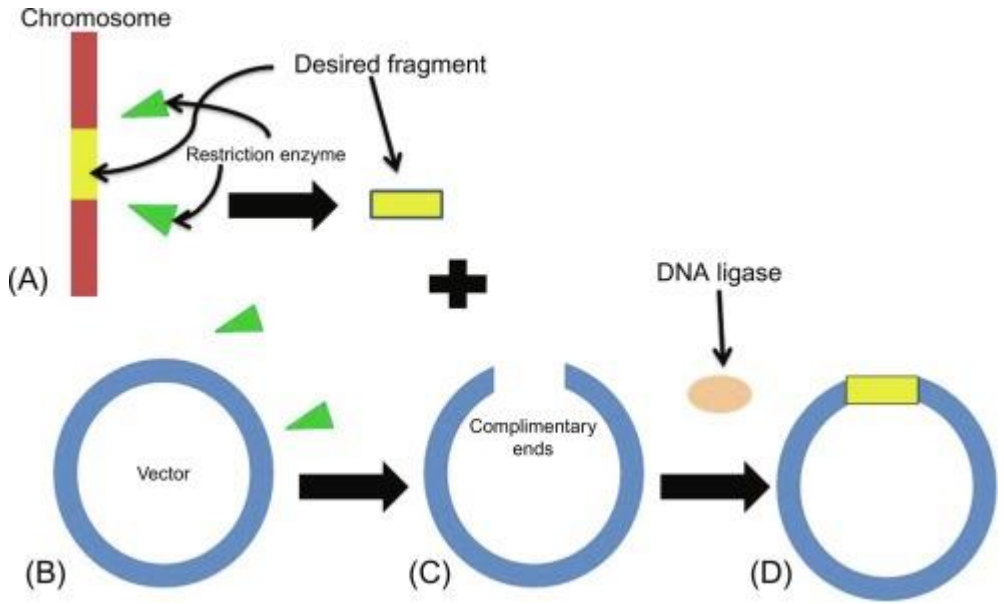
- **Chaim Weizmann (1874 – 1952)** – the first **industrial production of acetone** from corn starch using **a pure culture of *Clostridium acetobutylicum***
- **Alexander Fleming (1881 – 1955) –** discovery of the fungus *Penicillinum notatum* and its antibacterial activity (1928)
  - **Howard Florey, Ernst Boris Chain and Norman Heatley (1940)** – description of the isolation of pure penicillin and its industrial production – **the first biotechnological product**



J. Tramper, Y. Zhu, *Modern Biotechnology – Panacea or new Pandora's box?*

The era of new biotechnologies I.

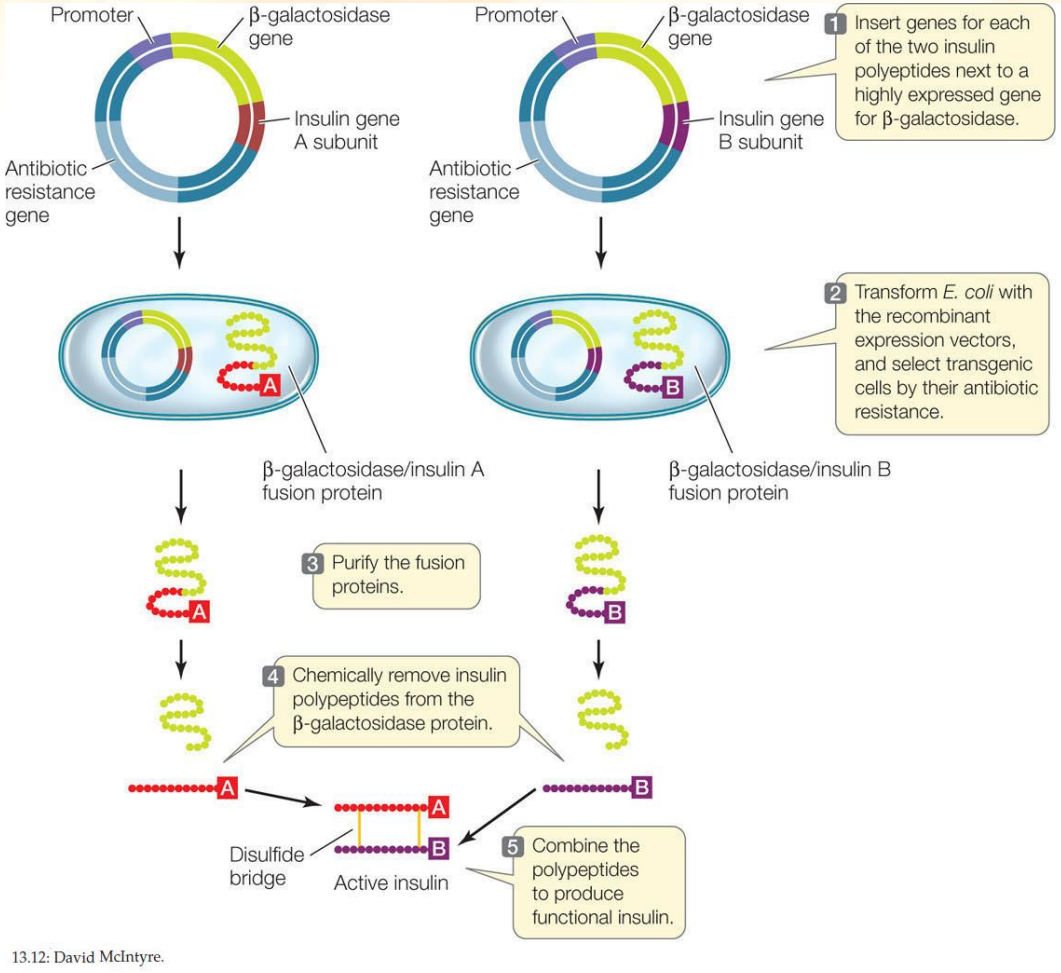
- **70s‘** – discovery of restriction endonucleases ⇨ **creation of recombinant DNA** ⇨ **basics of genetic engineering** (Paul Berg, Herbert W. Boyer, Stanley N. Cohen)
- **1972/3** – transfer of foreign DNA into a bacterium ⇨ **the first transgenic organism**
- ***recombinant technology***
  - **targeted genetic modification information**
  - **GMOs**
  - **production of proteins in modified form**



https://www.sciencedirect.com/topics/chemical-engineering/genetic-engineering

The era of new biotechnologies II.

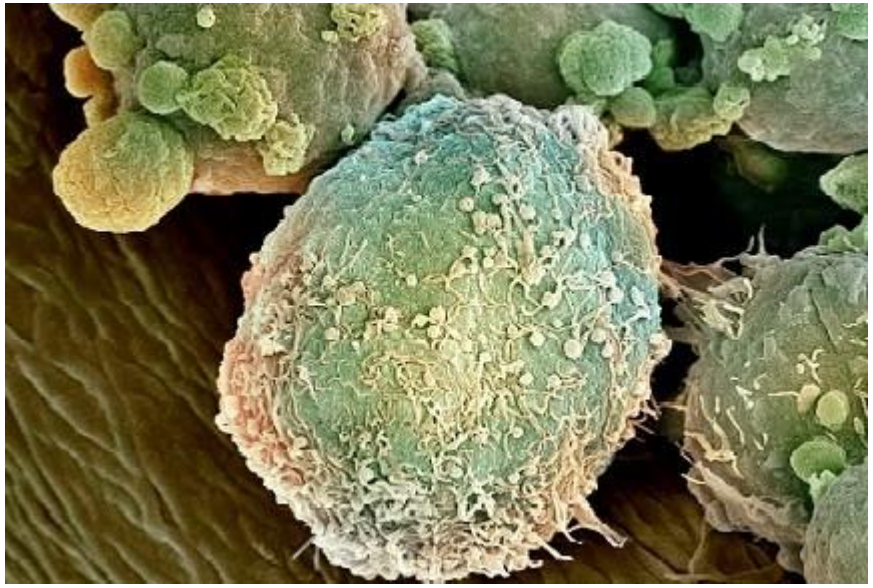
- **1980** - Cohen and Boyer obtain the first US patent for cloning and creation of genetically modified microorganisms
- **1982** - The FDA approved the first drug produced by biotechnology techniques, a human insulin, **Humulin®**, produced by genetically modified bacteria



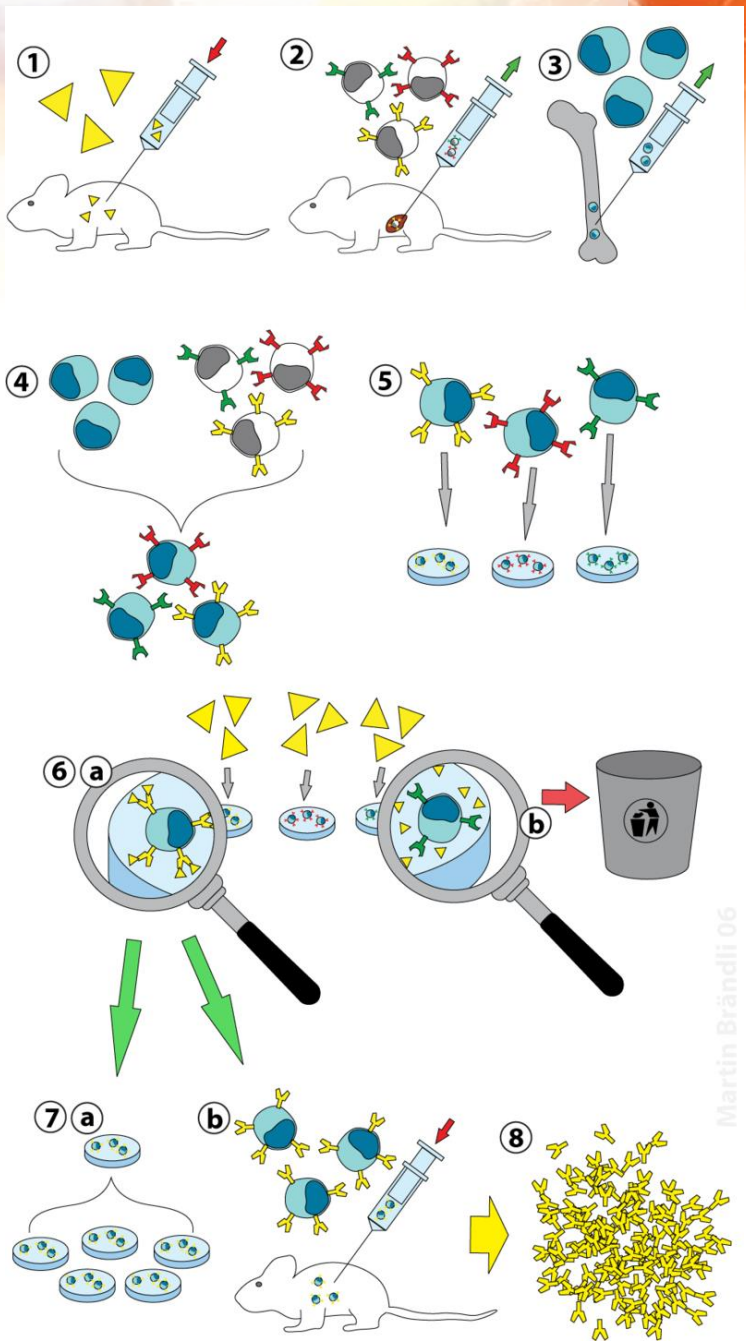
Human Insulin: From Gene to Drug Human insulin chains are made by recombinant DNA technology and then combined to produce the widely used drug.

The era of new biotechnologies III.

- **1975** – discovery of **hybridomas** (César Milstein and Georges J. F. Köhler) – cells created by the fusion of B-cells and myeloid cells ⇨ mass **production of monoclonal antibodies**



© Biological Industries



Transgenic organisms

- Development since the 1970s (1972 – viruses, 1973 – bacteria, 1974 – claw, 1974 – mouse, 1983 – tobacco, 1985 – cow, 2000 – rice)
- **Animals**
  - **production of human proteins (**e.g. anticoagulant protein in goat milk)
  - **disease models** (knock-out and knock-in organisms)
- **Plants**
  - more resistant to herbicides, immune to harmful insects; modified appearance (bigger fruits, flowers)…
  - higher production of biologically active substances (e.g. vitamin A in rice)

doi:10.1186/1471-2407-12-21

https://www.flickr.com/photos/ricephotos/5516789000/in/set-72157626241604366

Modern milestones

- **1978** **Human insulin is produced for the first time**
- **1980** **US Supreme Court - patent protection of a biotech product**
- **1982** **The FDA approved the first biotechnologically prepared drug – human *insulin***
- **1983** ***PCR* technique discovered**
- **1986** **Recombinant human *hepatitis B vaccine***
  The first field tests of a transgenic plant – *tobacco*
- **1997** **The first animal cloned from an adult cell - *Dolly the sheep***
- **2004** **FDA approves first anti-angiogenic cancer drug, *Avastin* (bevacizumab)**

Industrial application of biotechnology

Biotechnology in industry means

→ appropriate addition of chemical technology

→ expanding the range of manufacturable substances

- Substances that can only be produced by chemical synthesis
- Substances that can only be produced using biotechnology
- Substances that can be produced by chemical technology and biotechnology

Advantages and disadvantages of biotechnology

Advantages

- Cheap raw material base
- Lower energy consumption
- Higher speed of biochemical events

Disadvantages

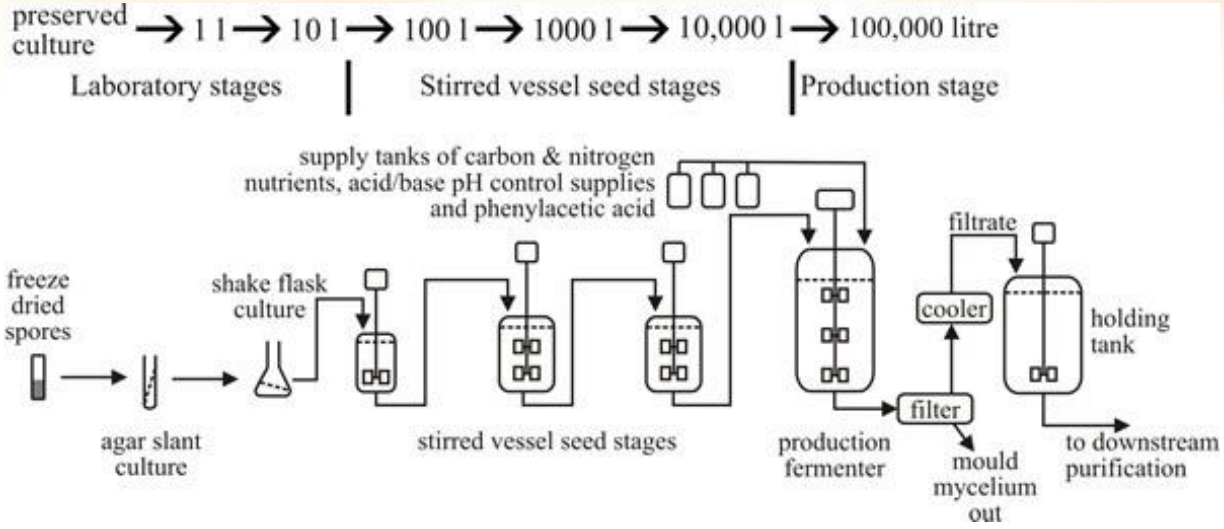
- High R&D and initial investment costs
- Little efficiency
- Low concentration of the substances involved
- Still unclear risks

Considerations in choosing between synthesis and biotechnological manufacturing

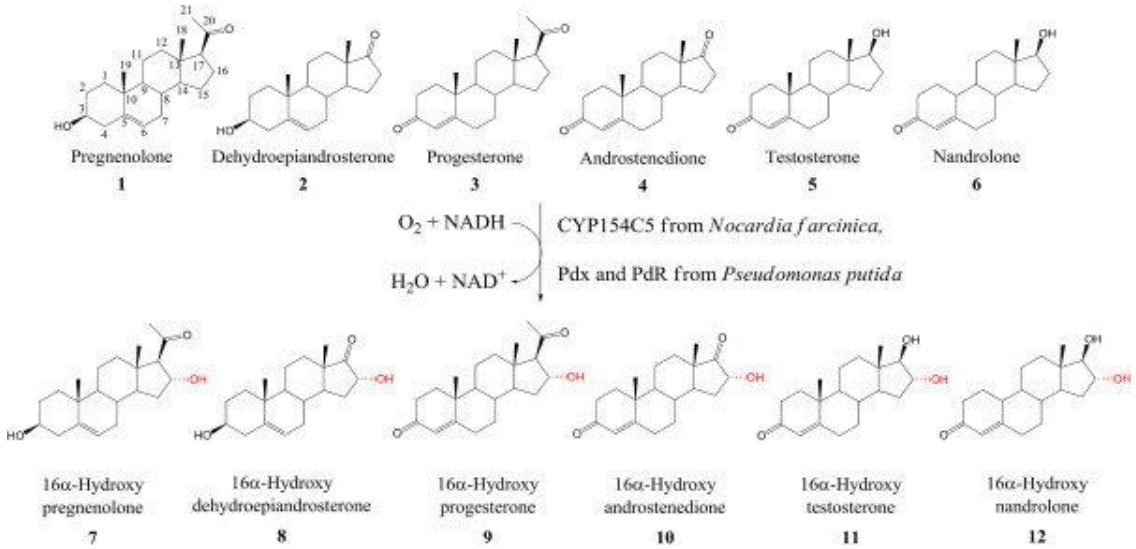
- **technical feasibility of the biotechnological process**
- **current price of raw materials**
- **ease of isolation of the final product and its purity**
- **the possibility of obtaining useful by-products**
- **success in terms of speed of commercialization,** etc.

Main areas of use of biotechnology in the pharmaceutical industry

- **Natural metabolites**
  - Biosynthesis; all the information needed for such production can be found in the genome of the cell
  - e.g. ATB, vitamines etc.
- **Substances prepared by biocatalysis**
  - Biotransformation
  - e.g. steroid compounds
- **Human proteins and polypeptides**
  - Gene manipulation



21st Century Guidebook to Fungi, SECOND EDITION



DOI: 10.1186/1475-2859-12-95

Examples of the use of biotechnology in medicine and pharmacy

- Amino acids, vitamins (riboflavin B_2, pyridoxine B_6, vitamin B_{12}, biotin H, β-carotene, astaxanthin, etc.), polysaccharides (dextran, xanthans, pullulan, etc.)
- Medicines (antibiotics, steroids, antifungals, ergot alkaloids...)
- Monoclonal antibodies, vaccines
- Interferons, interleukins
- Hormones - human growth hormone, FSH, insulin
- Production enzymes and pure enzymes for bioanalytical methods (immunoassay)
- Gene therapy

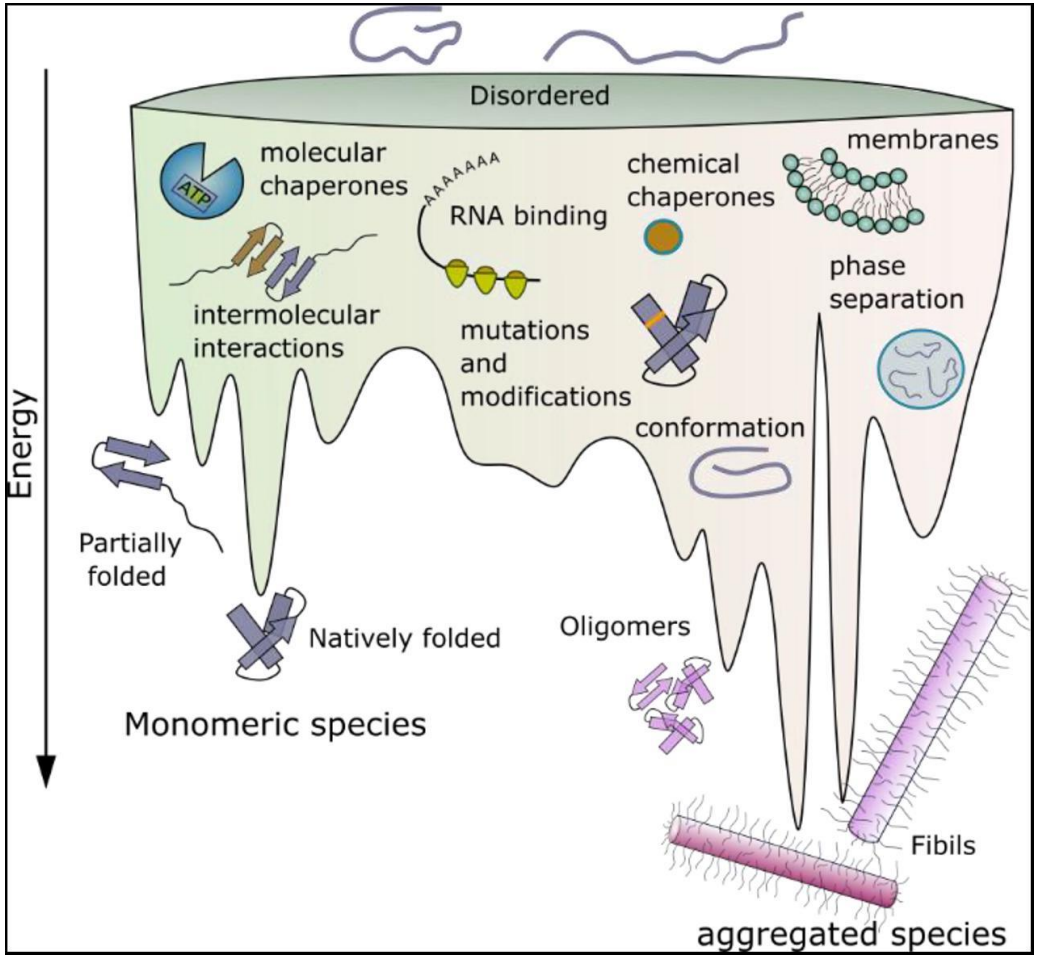
Biotechnology of drugs – Proteins, major biopharmaceutical

Tertiary structure of proteins

It is crucial for the creation of functional molecules – thermodynamically optimal conformation

It includes the following processes:

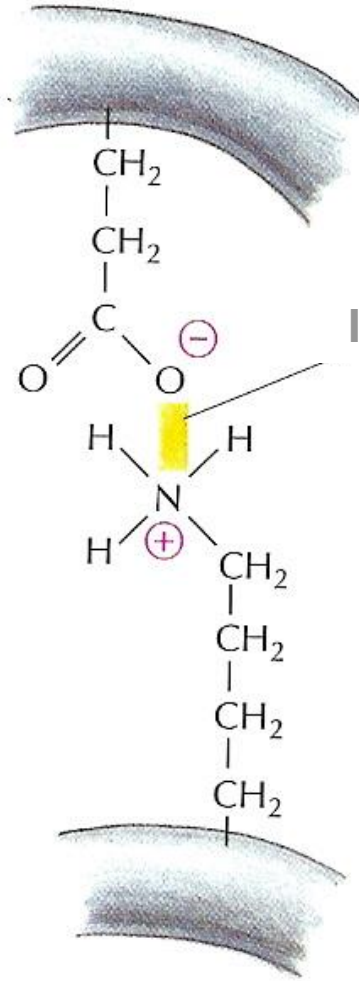
- **Creation of 3D conformation**
- **Addition of cofactors**
- **Modification by kinases or other protein-modifying enzymes**



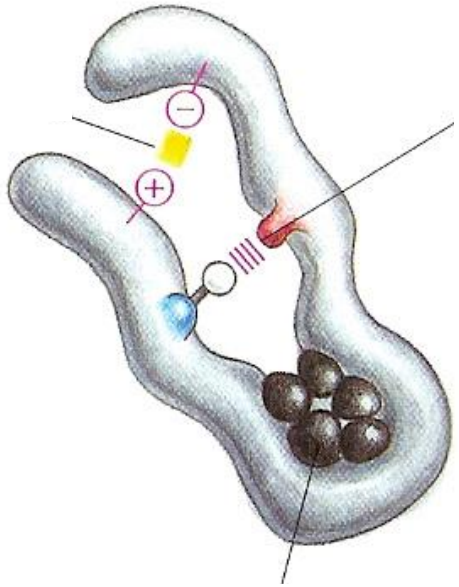
https://doi.org/10.3389/fnins.2020.611285

Forces responsible for the 3D structure of proteins

Primarily non-covalent interactions

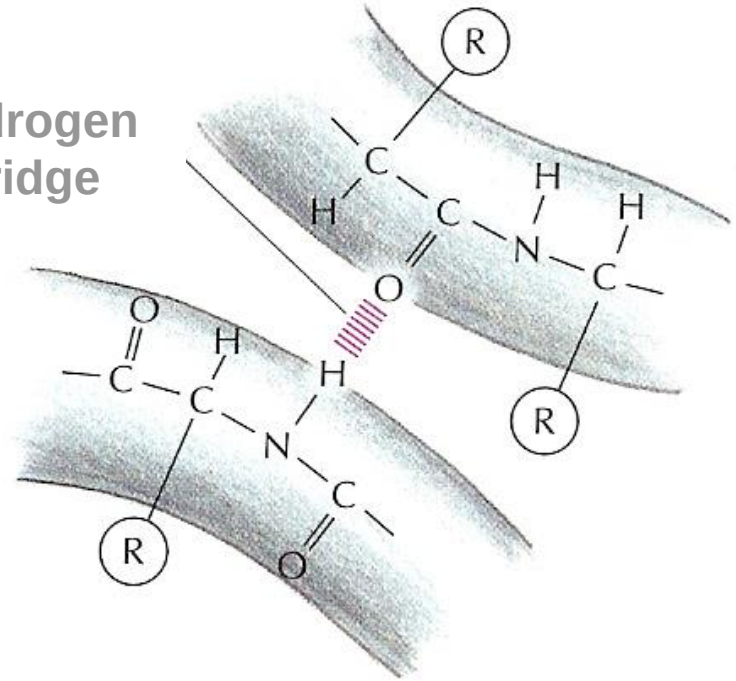


Ion binding



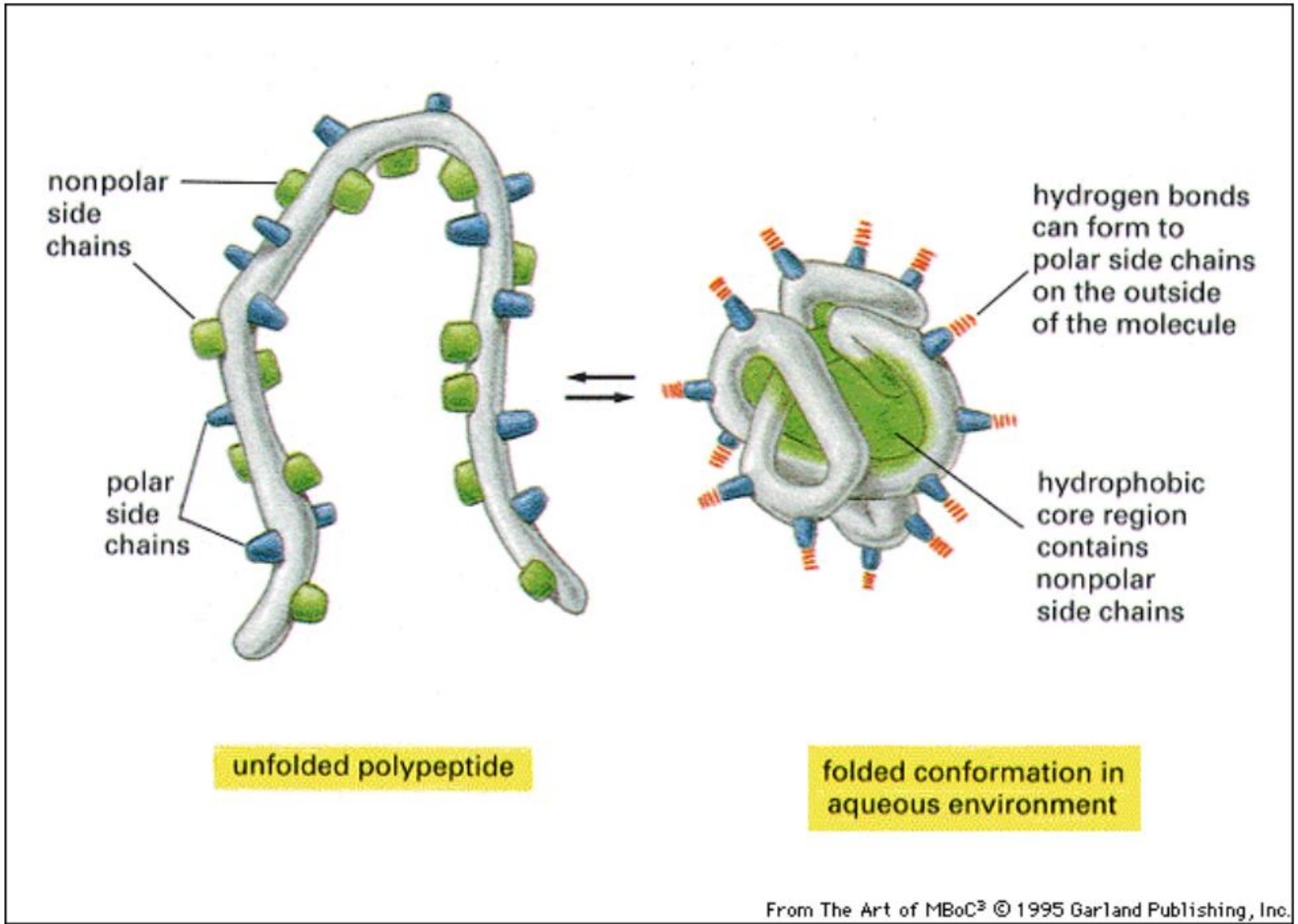
van der Waals force

Hydrogen bridge



Hydrophobic interactions

… is the most important for 3D creation

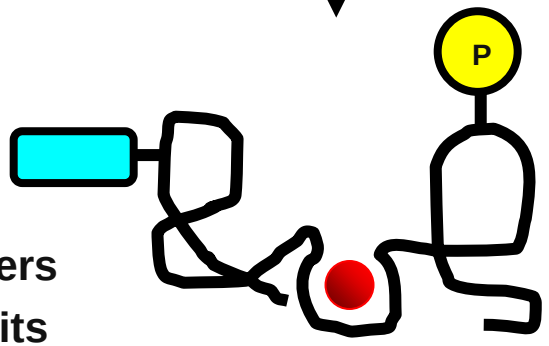


Overview of steps in 3D protein formation

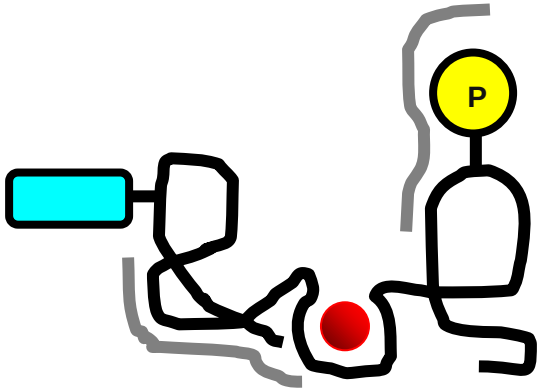
nascent polypeptide chain

Folding and cofactor binding (non-covalent interaction)

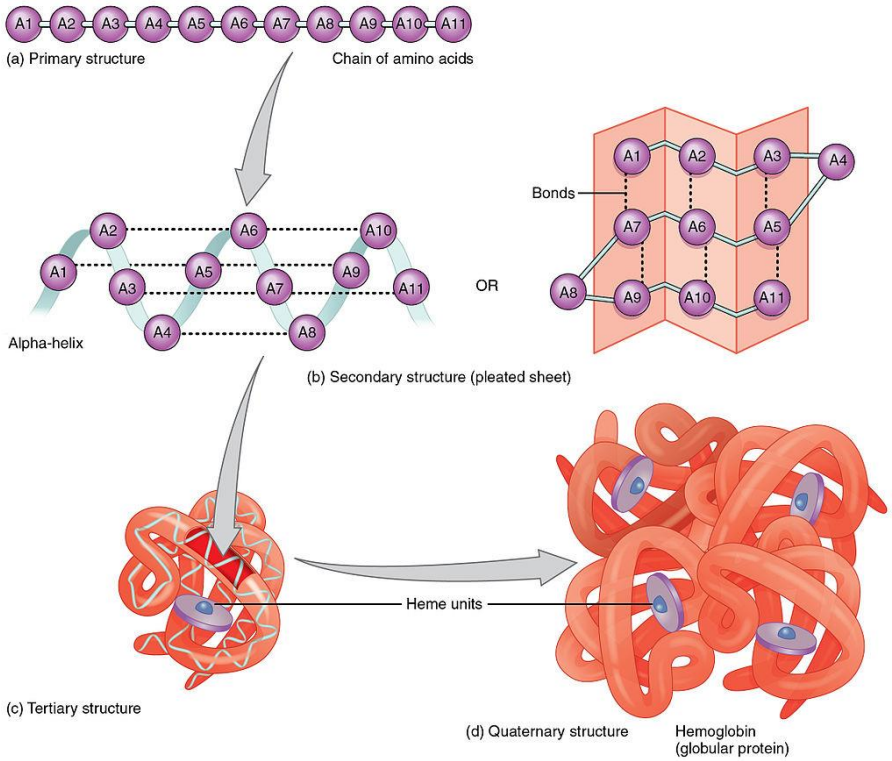
Glycosylation, phosphorylation, acetylation (covalent interaction)



Binding to others protein subunits



mature functional protein



OpenStax College - Anatomy & Physiology, Connexions Web site. http://cnx.org/content/col11496/1.6/

Why is knowledge of the formation of 3D protein structures important for a pharmacist?

Understanding the very structure of proteins and the processes of its formation is important for **drug design**, because drugs often act at the level of the **binding or allosteric site of enzymes**.

Where to study protein structures?

Protein Sequence Database

SWISS-PROT database established at the University of Geneva in 1986

Managed by the Swiss Institute for Bioinformatics(SIB)

www.expasy.org

Contains automatically completed translations of gene sequences from EMBL (www.ebi.ac.uk)

Database PDB (The Protein Databank)

It archives and analyzes protein structures and complexes of informative biomacromolecules

http://www.rcsb.org/pdb/home/home.do

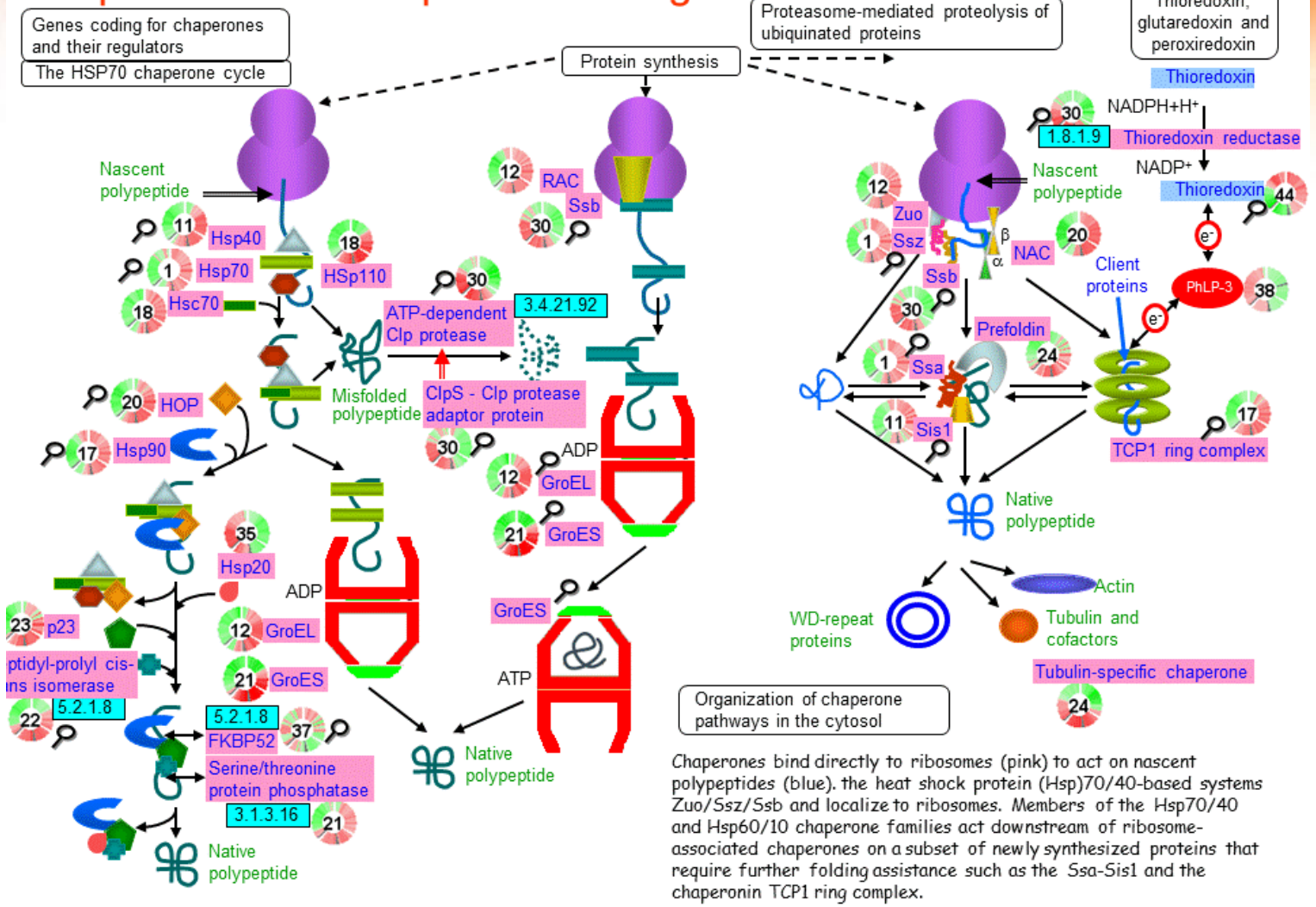
Protein folding

- an autonomous process requiring no additional factors or energy input
- Christian Anfinsen 1972 Nobel Prize
- tertiary structure after leaving the ribosome *in vivo*
- native conformation until the moment of degradation
- chaperones help protein folding

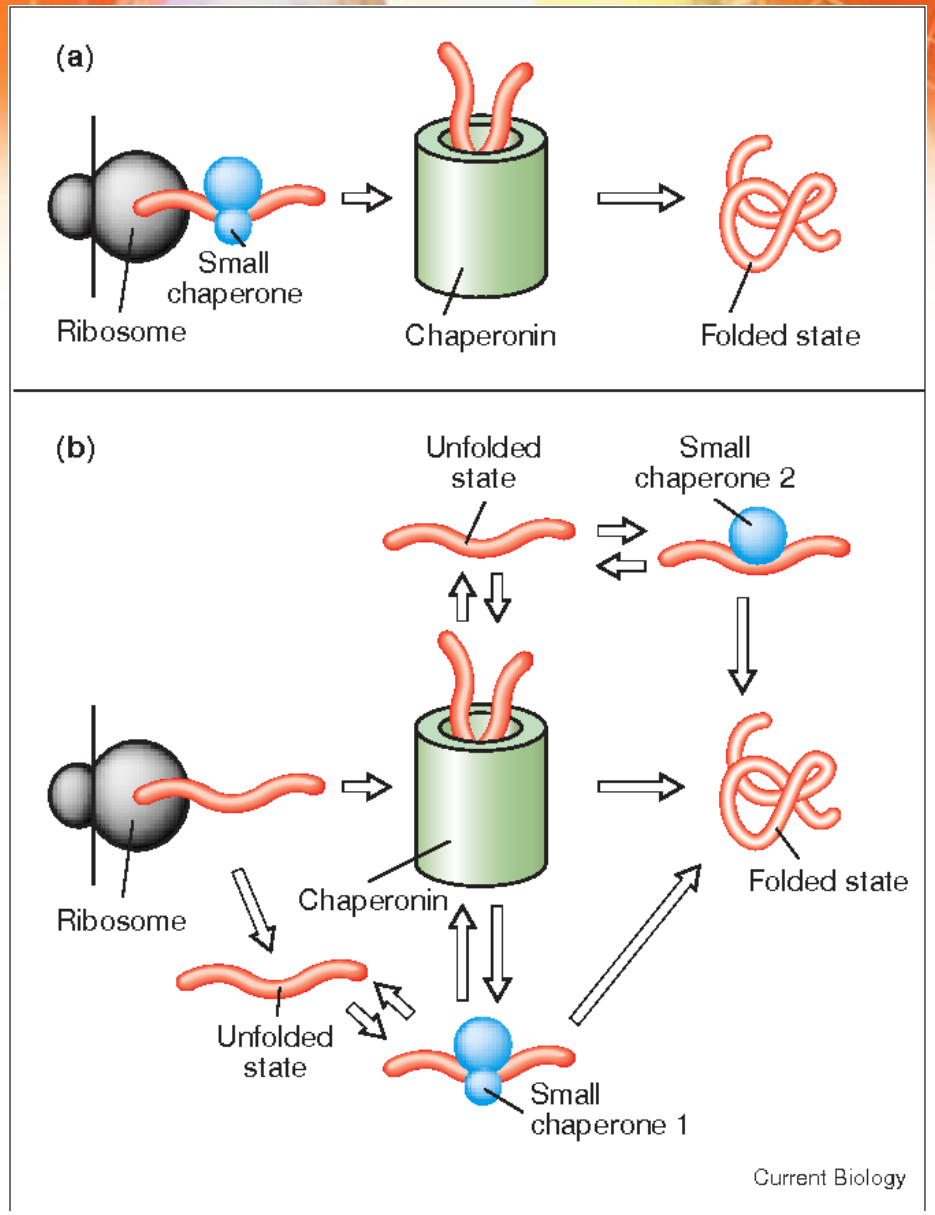
Chaperones a chaperonines

- **chaperones** (monomers 70 – 100 kDa) are proteins that help the covalent folding or unfolding and assembly or disassembly of other macromolecular structures (mainly Heat shock proteins – Hsp)
- **chaperonines** (oligomers 800 kDa) are a class of molecular chaperones that provide favorable conditions for the correct folding of denatured proteins, thus preventing aggregation (e.g. GroEL, TRiC)
- they do not provide steric information
- they inhibit unproductive interactions
- they are located in all compartments
- protein packaging
- conformational rearrangements

Chaperone-assisted protein folding



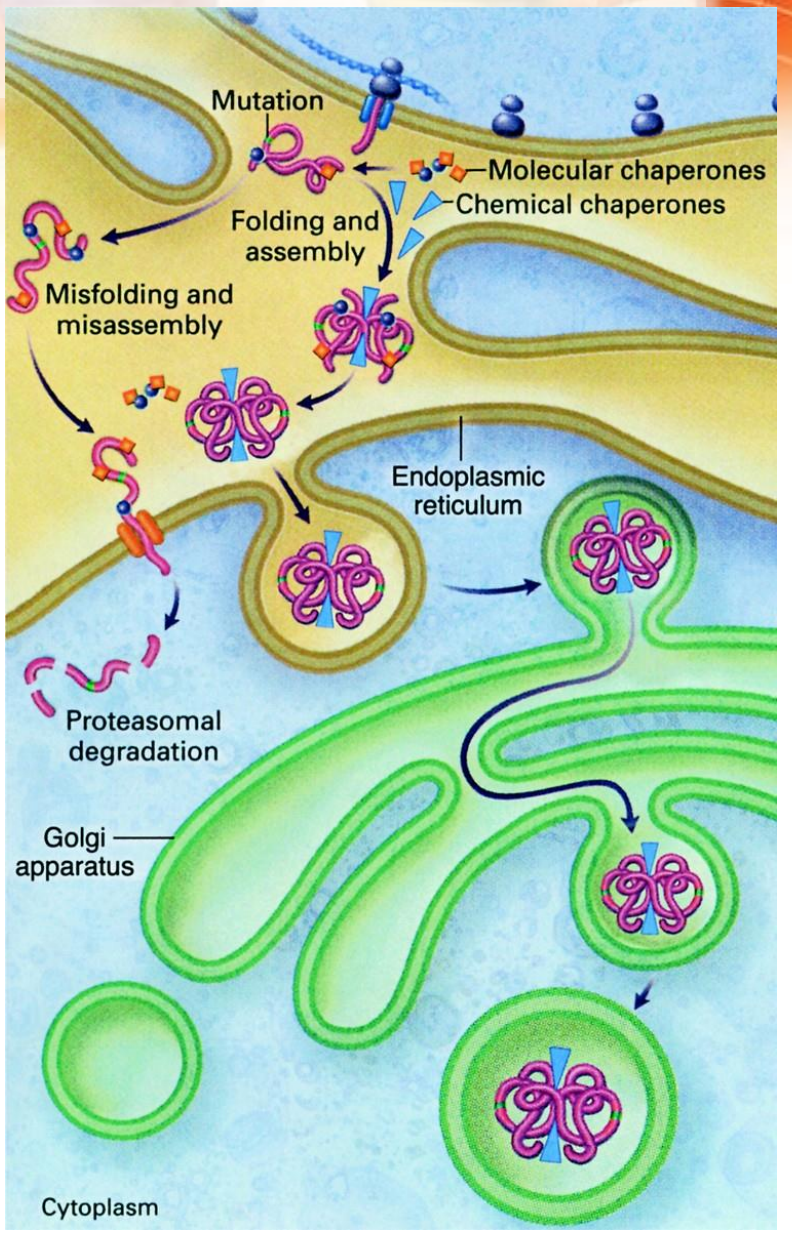
Chaperones bind directly to ribosomes (pink) to act on nascent polypeptides (blue). the heat shock protein (Hsp)70/40-based systems Zuo/Ssz/Ssb and localize to ribosomes. Members of the Hsp70/40 and Hsp60/10 chaperone families act downstream of ribosome-associated chaperones on a subset of newly synthesized proteins that require further folding assistance such as the Ssa-Sis1 and the chaperonin TCP1 ring complex.



https://doi.org/10.1016/S0960-9822(99)80082-7

Chemical chaperones

- Small molecules that bind to misfolded proteins and stabilize them or ensure their proper folding
- They stabilize poorly packed proteins, reduce aggregation, prevent unproductive interaction with other proteins
- E.g. glycerol, trimethylamine N-oxide
- **Re-aggregation of inclusion bodies upon expression of recombinant proteins**

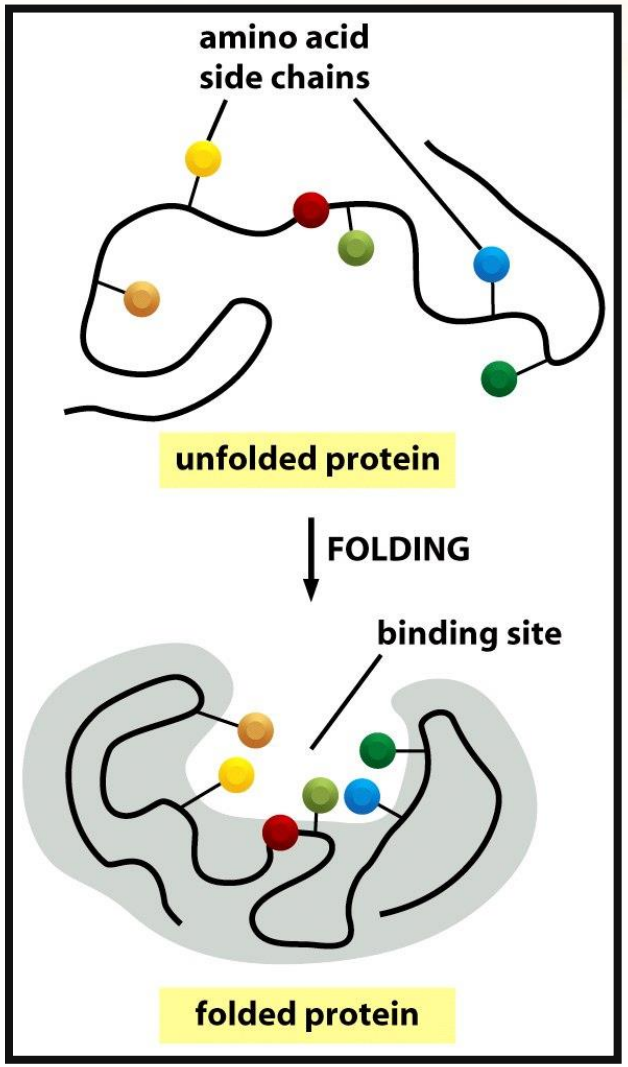


<u>It is used, for example, for treatment of</u>

- **Amyloidosis transthyretin (Tafamidis)**
- **Cystic fibrosis**
- **and other diseases associated with protein packaging**

https://doi.org/10.1203/00006450-200212000-00004

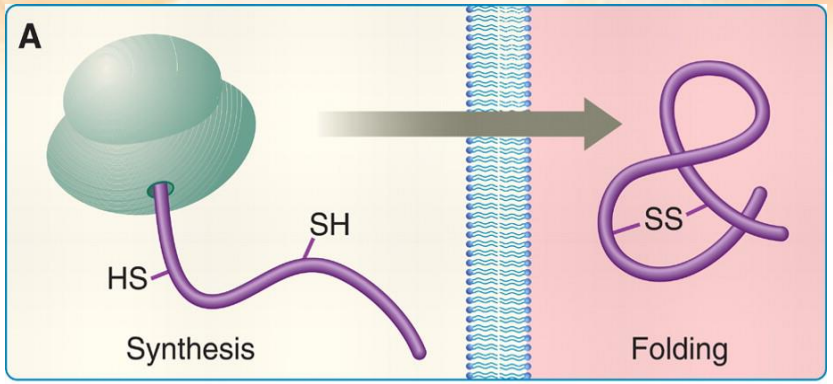
The result of folding = creation of an active conformation

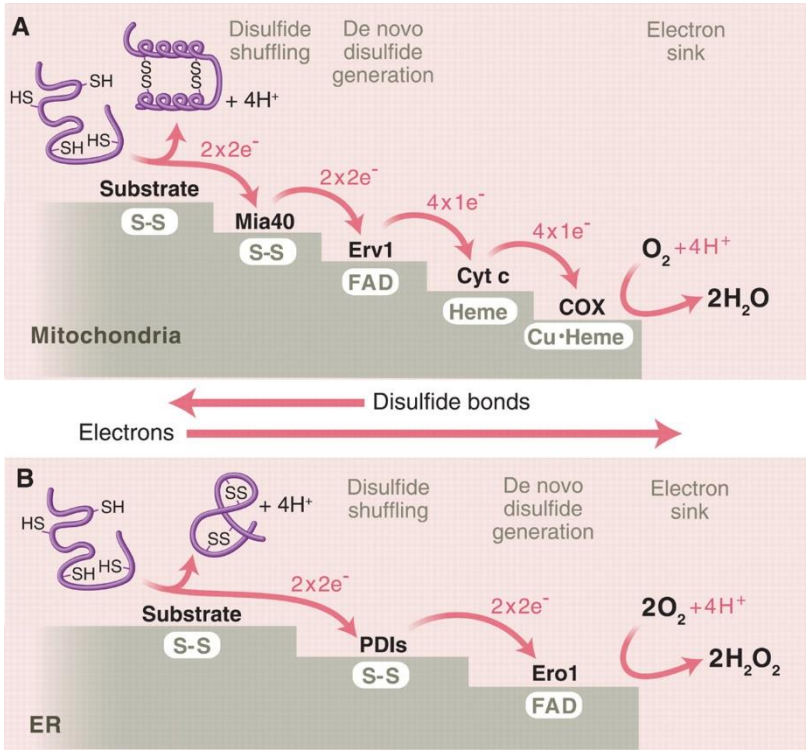


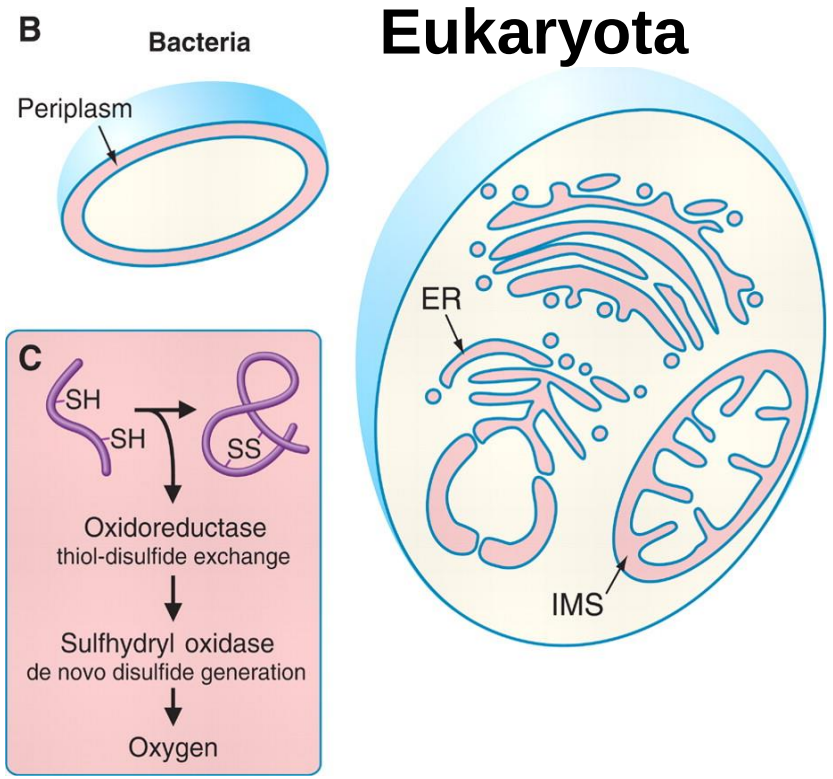
Alberts et al 2008: Figure 3-37a *Molecular Biology of the Cell* (© Garland Science 2008)

Formation of disulfide bridges in the cell

- Part of the protein folding process
- It takes place in the periplasmic space of prokaryotes and in the mitochondria and ER of eukaryotes







J. Riemer et al., Science 324, 1284 -1287 (2009)

Post-translational modification of proteins

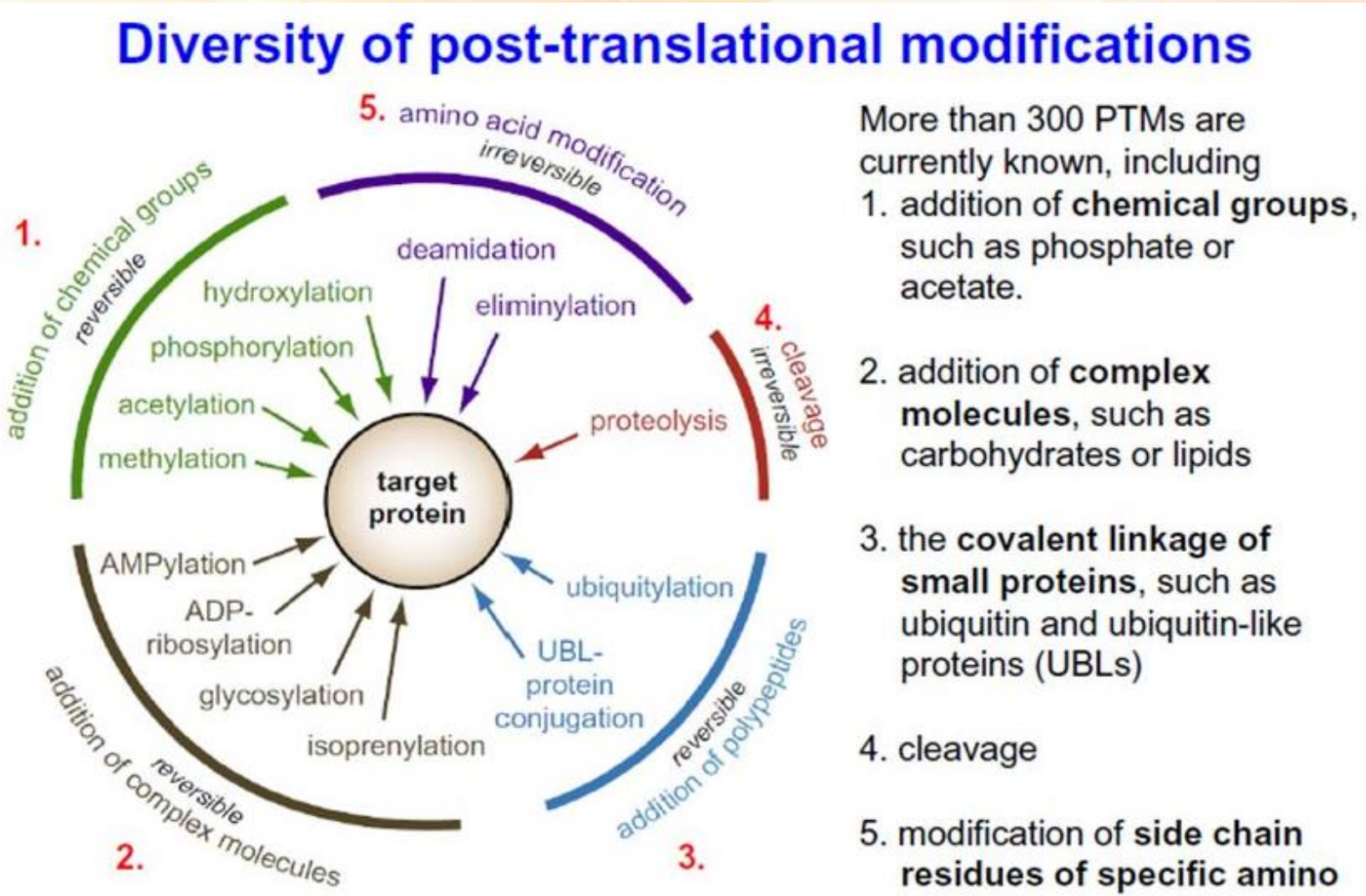
Modification changes the structure and biological activity of proteins

Some processes are co-translational, others truly post-translational

The most common is glycosylation

Other post-translational modifications of proteins

- Most often **glycosylation** or **phosphorylation**
- In total, more than 300 types of covalent modifications of polypeptide chains have been described



3

D. Ribet, P. Cossart / FEBS Letters 584 (2010) 2748–2758

Modification of therapeutic proteins

Modification type	Importance
Glycosylation	↗ solubility, affects biological half-life or biological activity
Carboxylation	Important for the binding of some blood proteins to Ca^{2+}
Hydroxylation	Important for structural arrangement
Sulphatation	It affects the biological activity of neuropeptides and the proteolytic processing of polypeptides
Amidation	It affects biological activity and stability

Glycosylation

- attachment of a sugar residue to a polypeptide chain
- it occurs mainly in extracellular proteins and proteins found on the surface of cells

Glycosylation produces glycoproteins

- For some proteins, deglycosylation has no effect on biological activity
- Deglycosylated forms can be prepared by the action of glycosylation inhibitors, e.g. the antibiotic tunicamycin in the growth medium or by enzymatic degradation of the glycidic part of the preformed glycoprotein with glycosidase.

- **Differential glycosylation causes problems in heterologous expression systems**

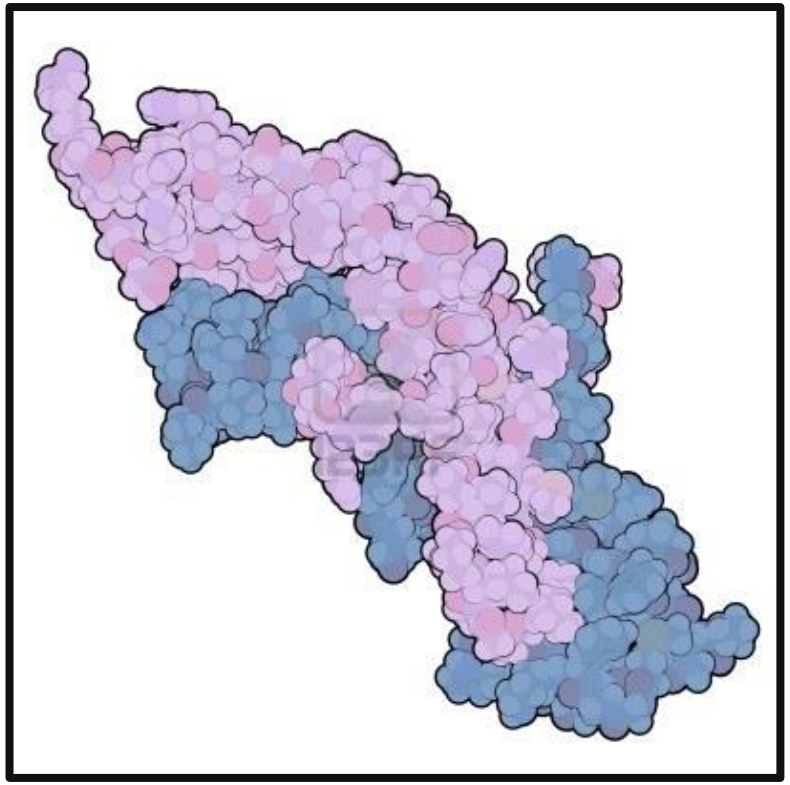
Effects of the glycidic part of glycoproteins

- Protein packaging
- Protein transport/targeting
- Ligand recognition/binding
- Biological activity
- Stability
- It regulates the biological half-life of the protein
- Immunogenicity

Human gonadotropic hormone

- Highly glycosidated

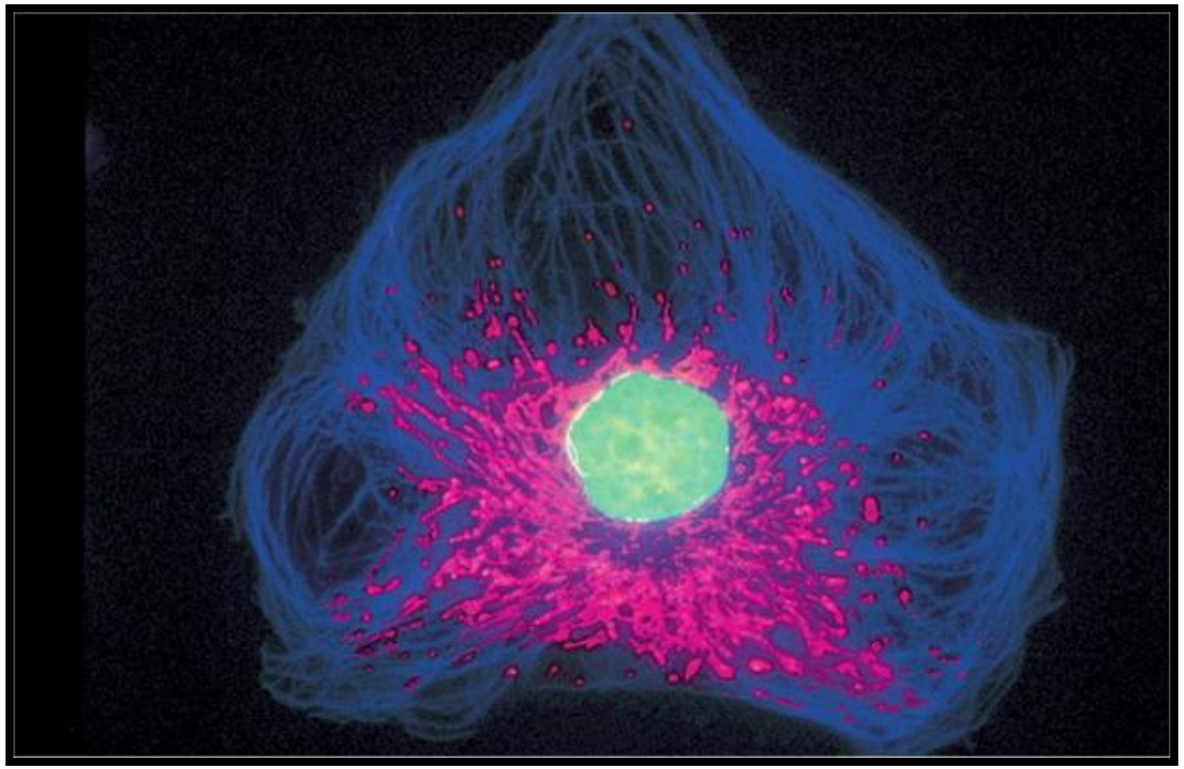
- **Removal of the glycidic moiety results in loss of biological activity, although the hormone still binds to its receptor, sometimes even with higher affinity**



Cell – a pharmaceutical biotechnologist's tool

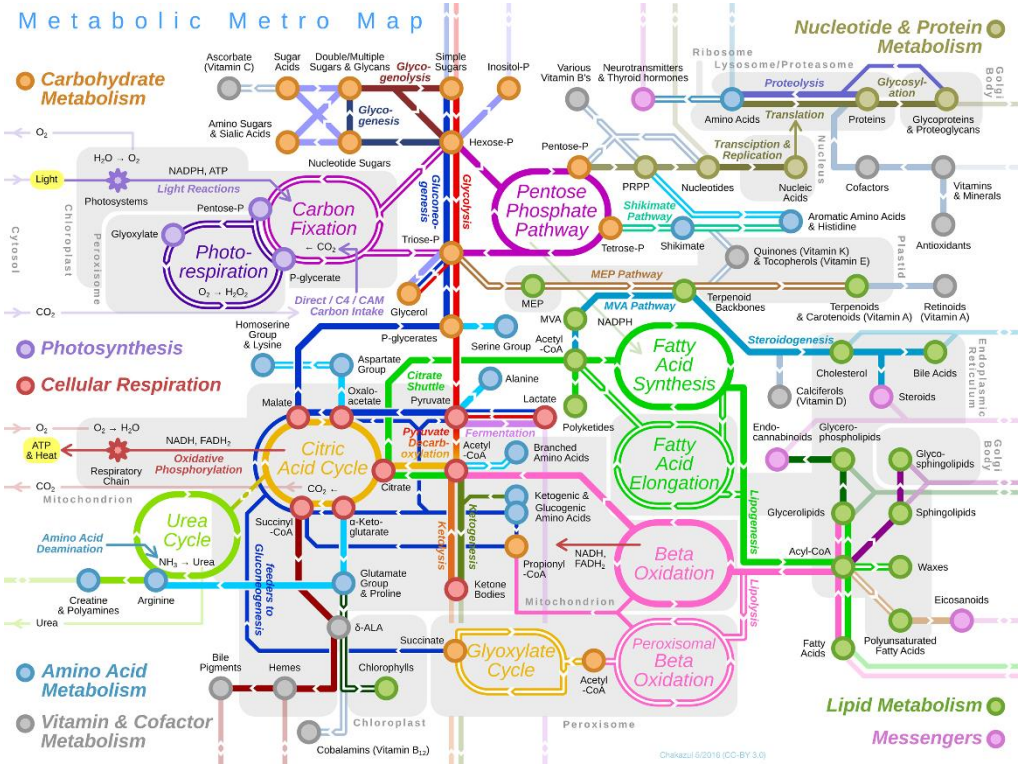
Cell

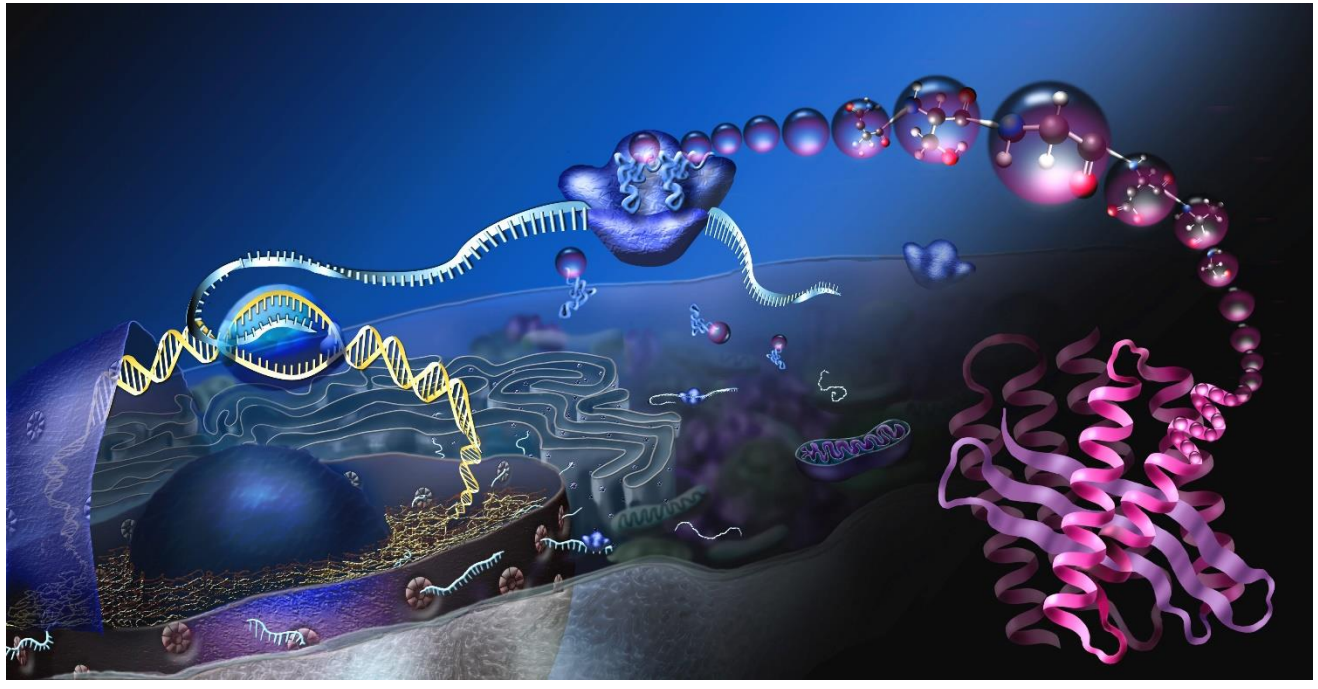
a small, membrane-bound unit filled with a concentrated aqueous solution of chemical compounds and endowed with the extraordinary ability to make copies of itself by growth and division



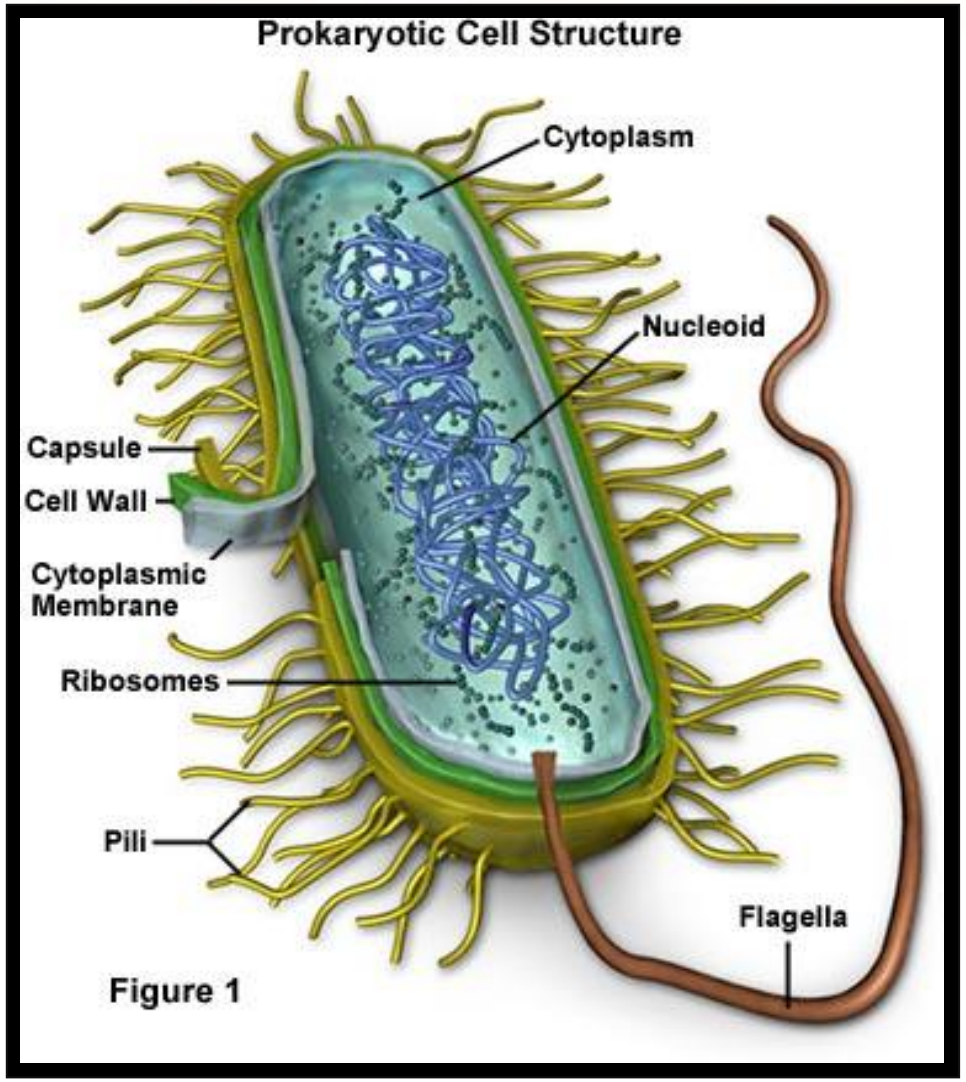
Cell meaning

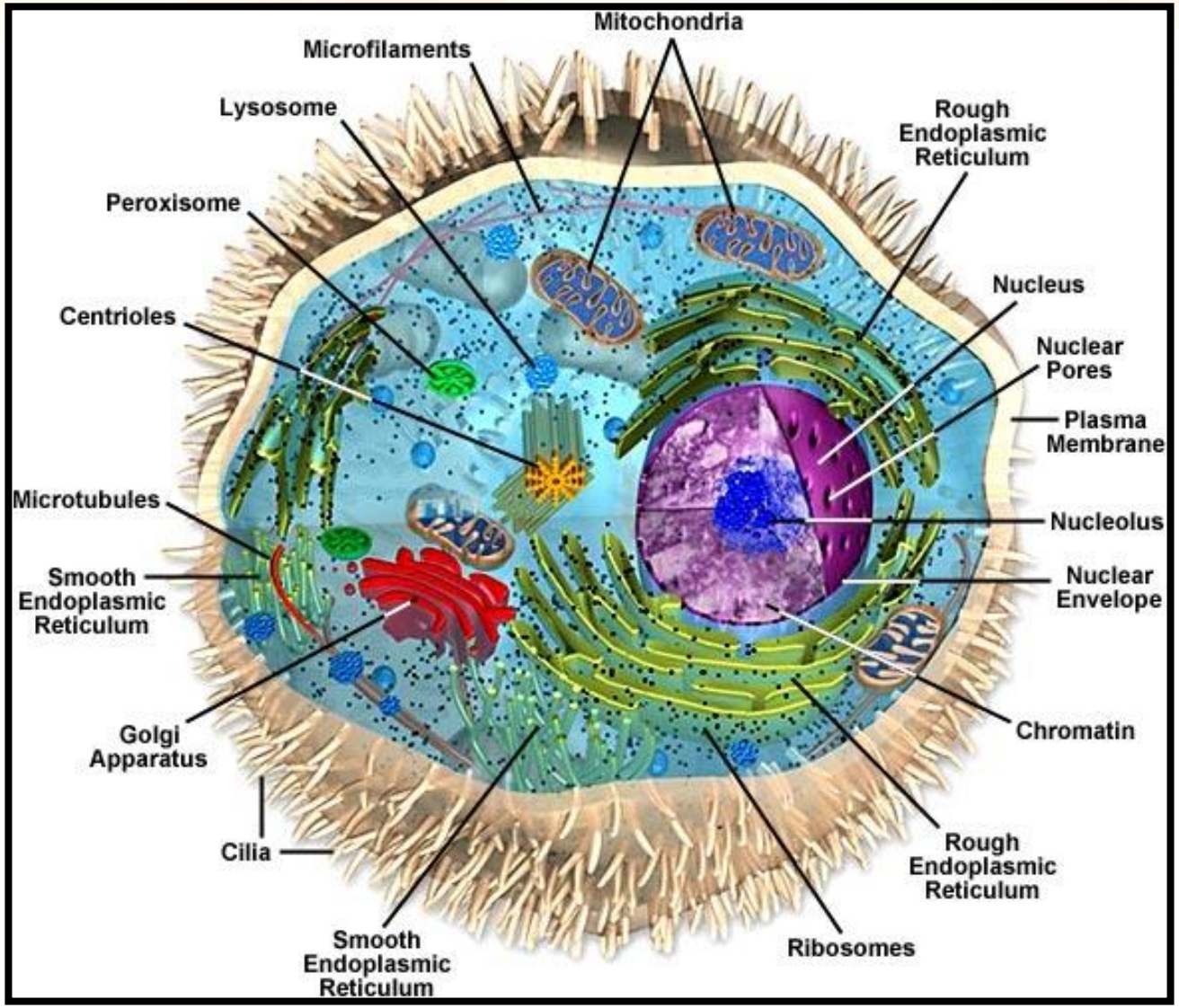
- **The cell serves as a source of starting materials,** because only the cell is capable of creating new compounds that are useful as medicine.
- Except in very exceptional situations, when we use only some of its parts for so-called *in vitro* translation, **the cell is the factory where all biotechnological processes take place**.





Prokaryotes vs. eukaryotes





What interests the biotechnologist about the cell

- **Everything related to protein formation and localization**

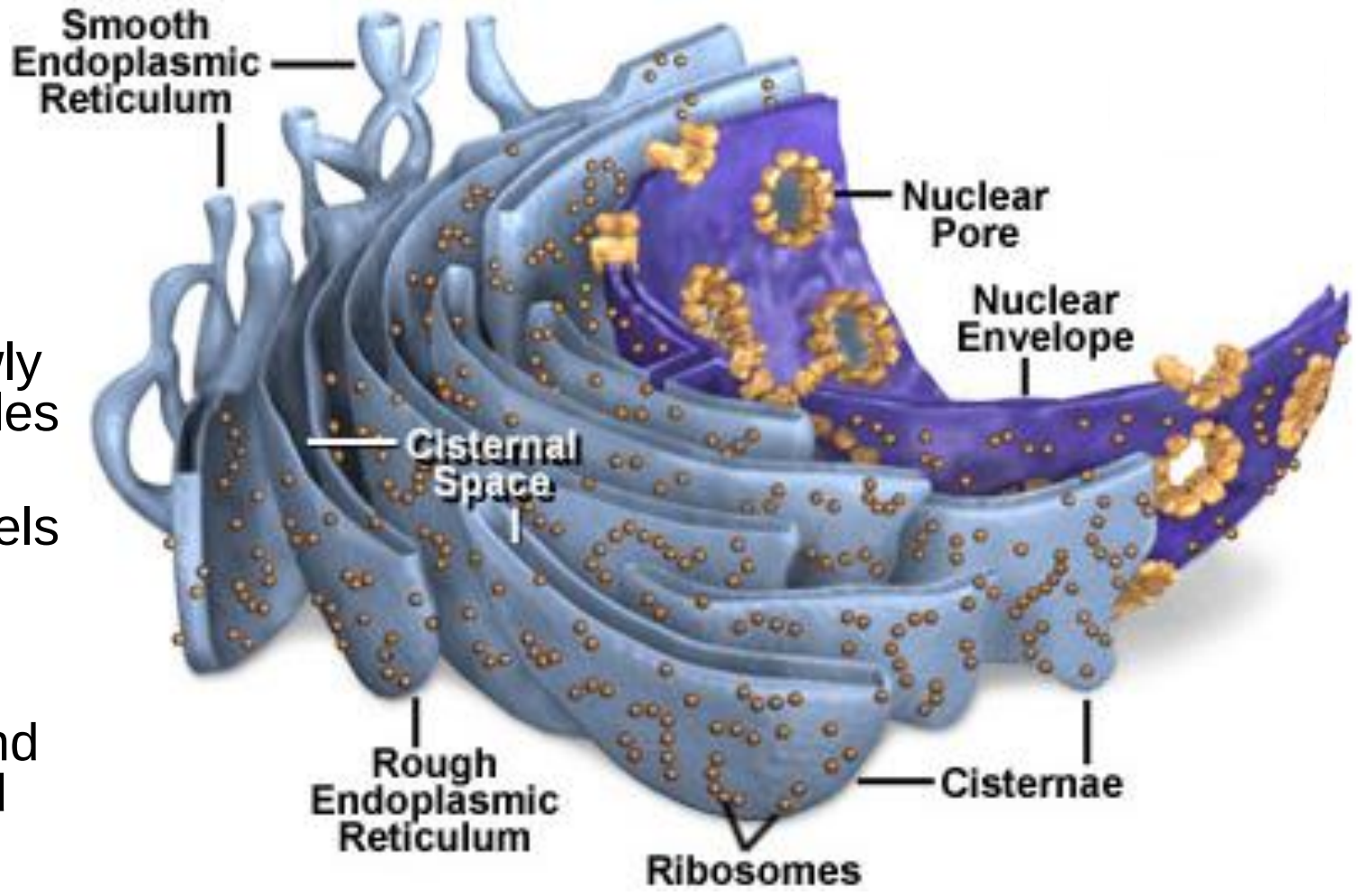
- Genophore
- Endoplasmic reticulum
- Golgi apparatus

Endoplasmic reticulum (ER)

Multiple curved membrane sheet, which forms closed sac - endoplasmic lumen (cisternal space)

https://micro.magnet.fsu.edu/cells/endoplasmicreticulum/endoplasmicreticulum.html

- Rough ER
  - is studded with ribosomes
  - is the site of protein formation
- Smooth ER
  - Opening vesicles that carry newly formed protein and lipid molecules for intracellular transport
  - It forms a network of thin channels connected directly to the rough plasmatic reticulum
  - Enzymes catalyzing the transformation of lipids are bound to its membranes; in specialized cells also steroid hormones, arising from cholesterol



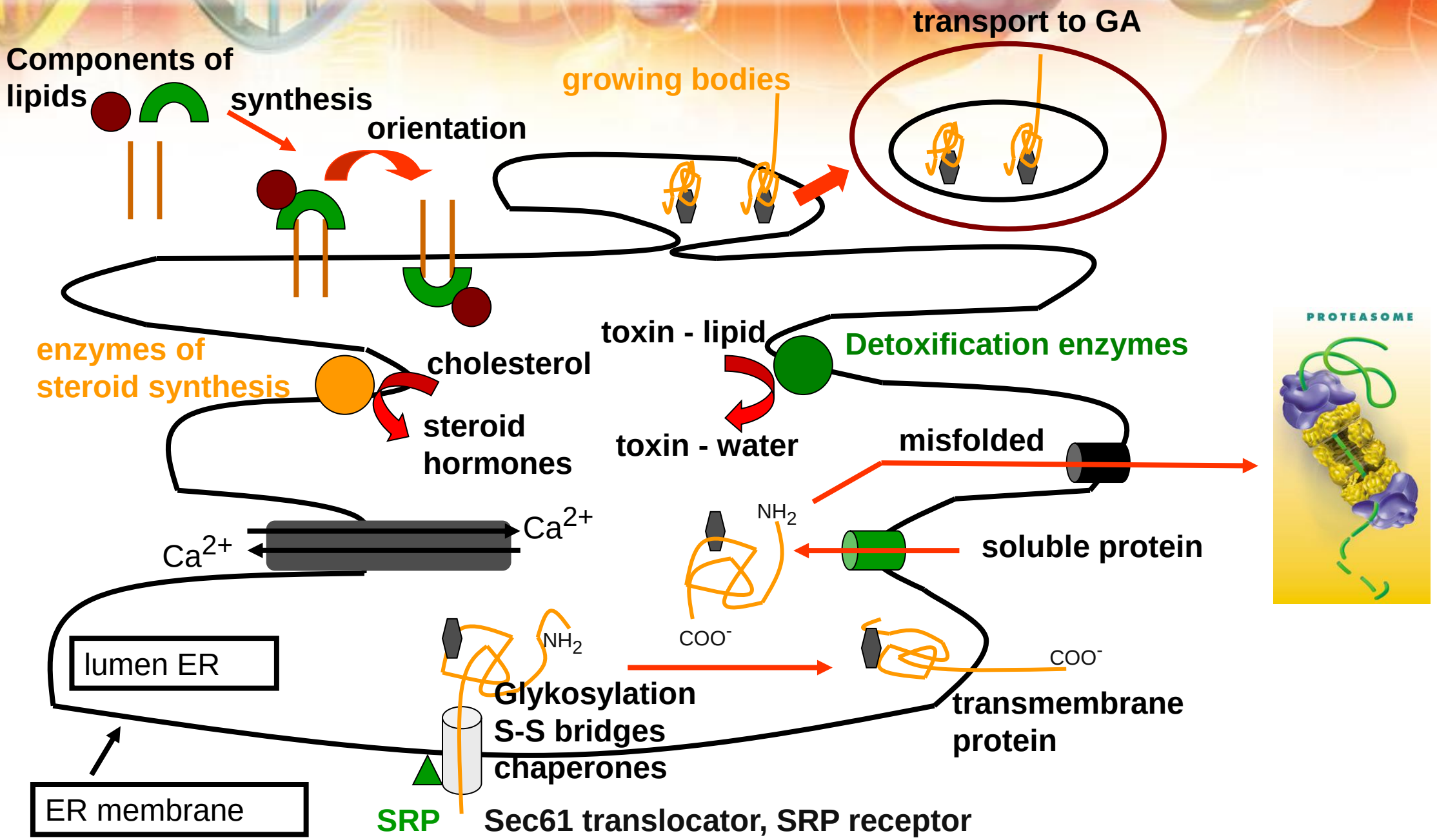
Functions of endoplasmic reticulum I

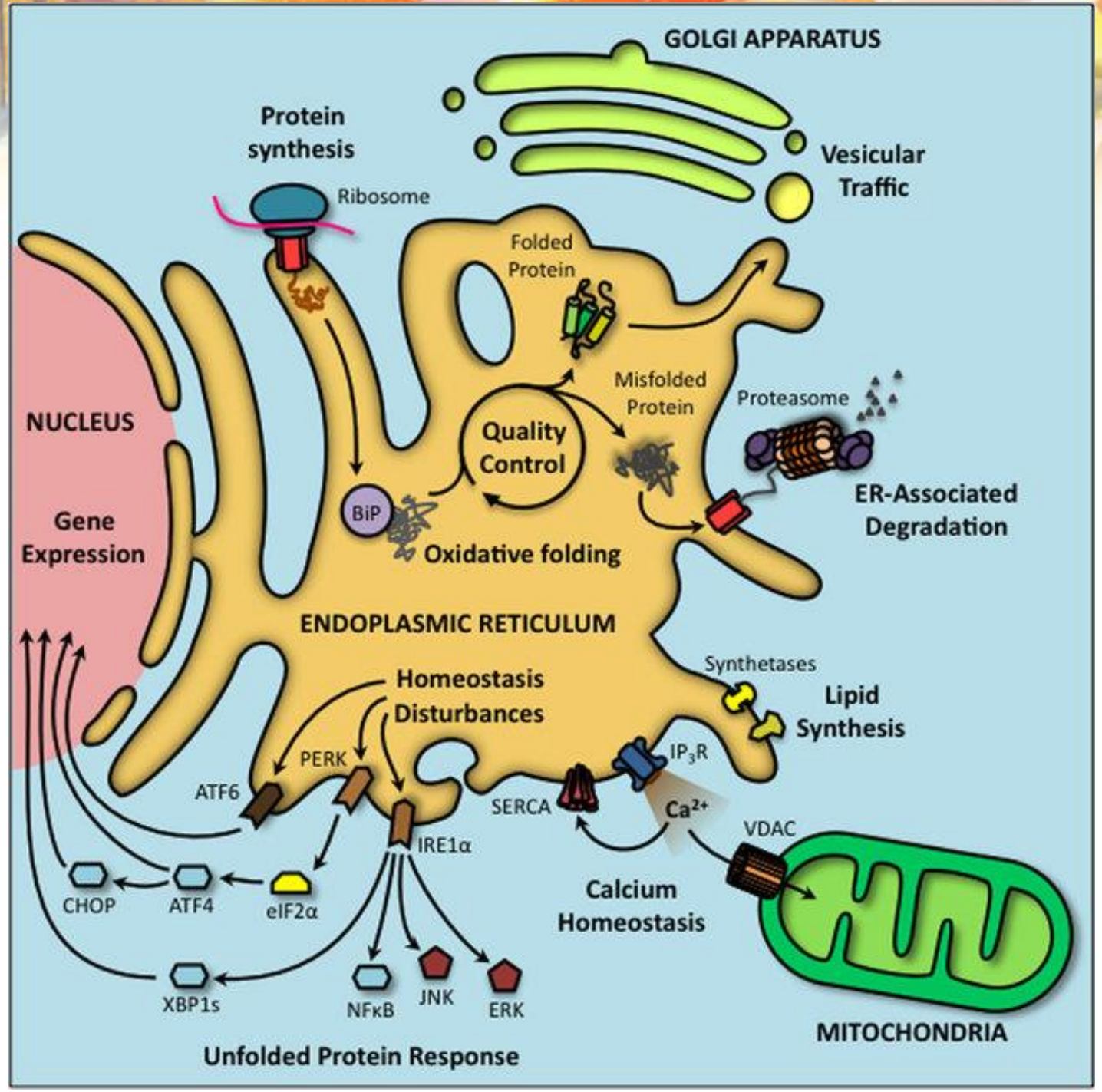
- central role in the synthesis of lipids, proteins, steroids
- it facilitates the formation of the correct tertiary or quaternary structure of proteins
- transport system – distribution of proteins to the cytoplasm or organelles
- maintaining osmotic pressure

Functions of endoplasmic reticulum II

- **chemical modification of proteins**
  - **disulfide bridges are formed by oxidation of cysteine pairs of side chains**
  - **formation of glycoproteins by covalent attachment of a short oligosaccharide side chain – is completed in GA**
  - **the oligosaccharide precursor is linked by an O- or N-bond to a protein molecule**
  - **protein output is controlled = misfolded protein is retained by chaperone or degraded**

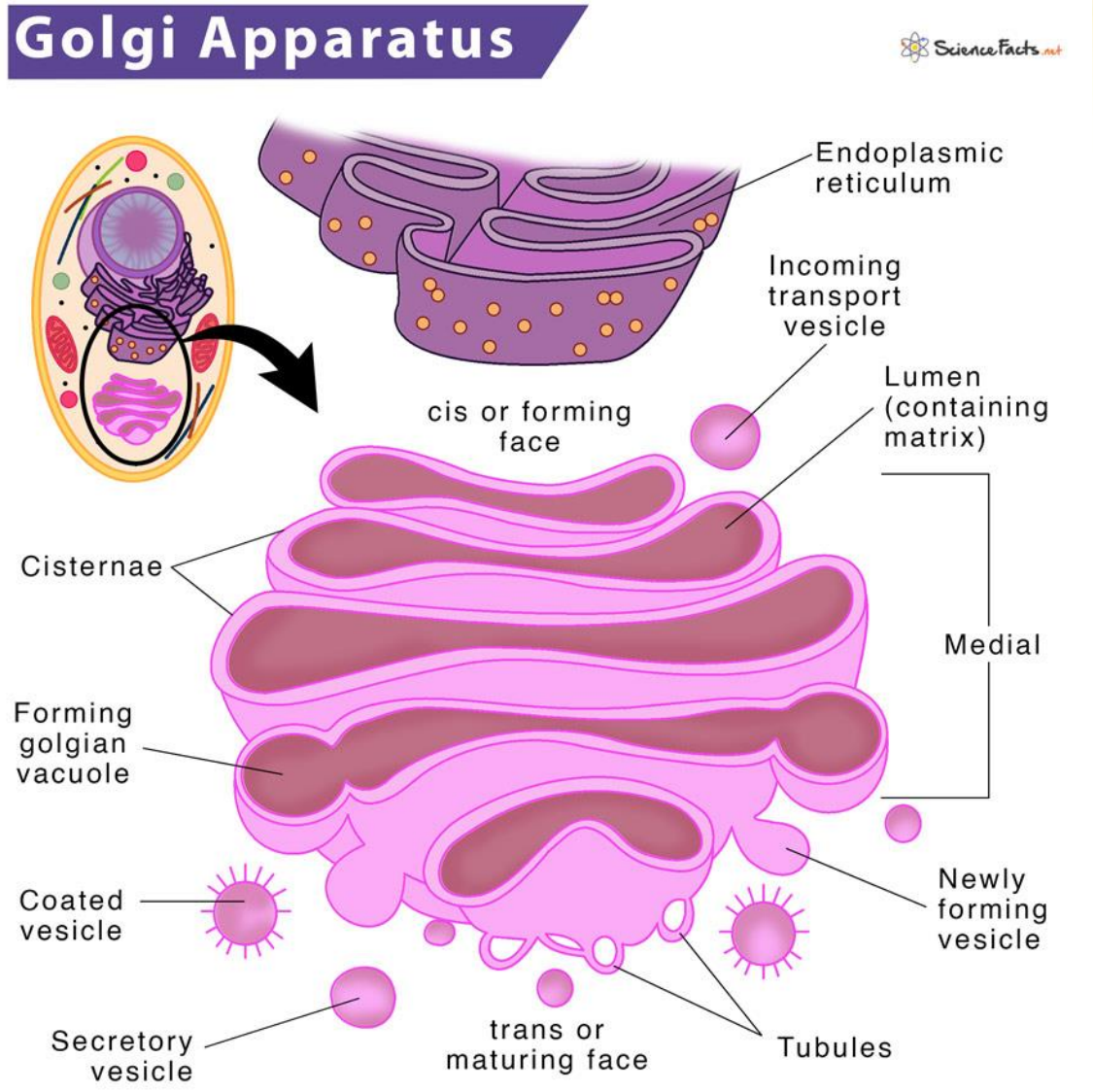
Schematic representation of ER functions





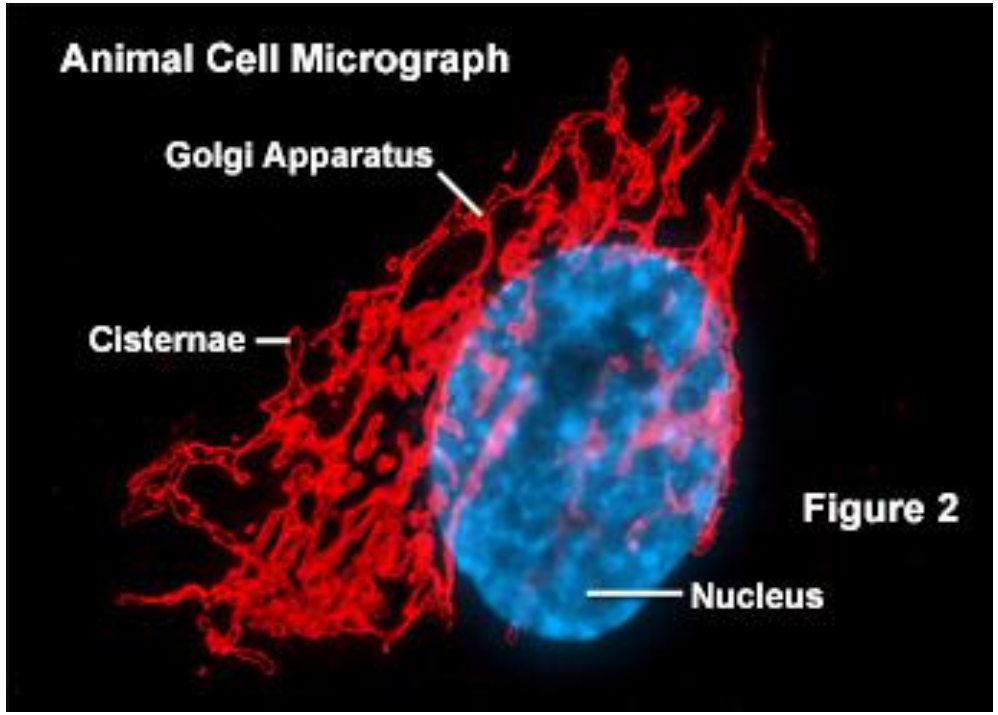
DOI: 10.1016/j.biocel.2011.10.012

Golgi apparatus (GA)



https://www.sciencefacts.net/golgi-apparatus.html

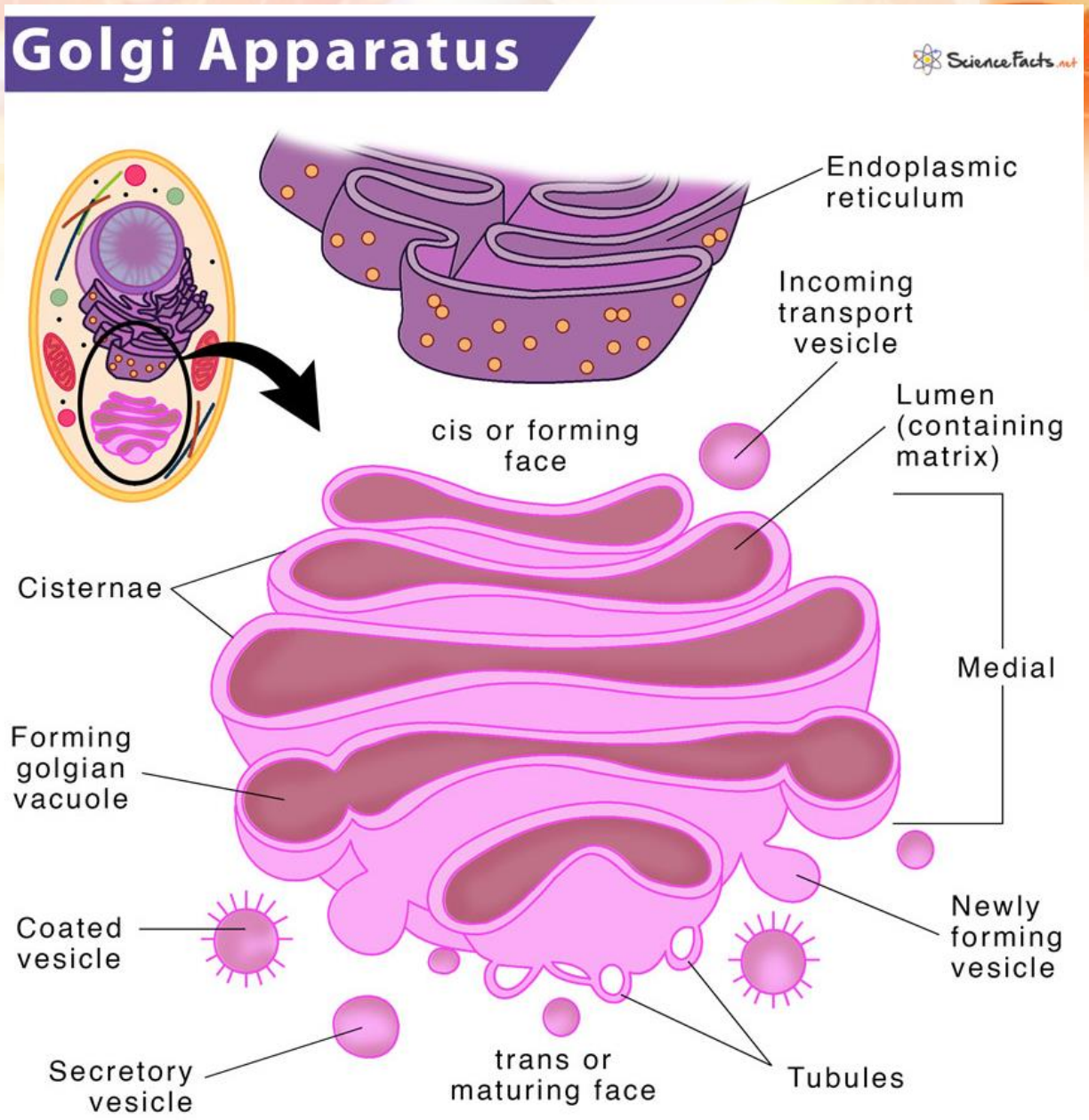
- **modification and sorting of proteins and lipids for secretion or for delivery to another organelle**



Described in 1898 by the Italian cytologist Camillo Golgi in nerve cells

Golgi apparatus (GA)

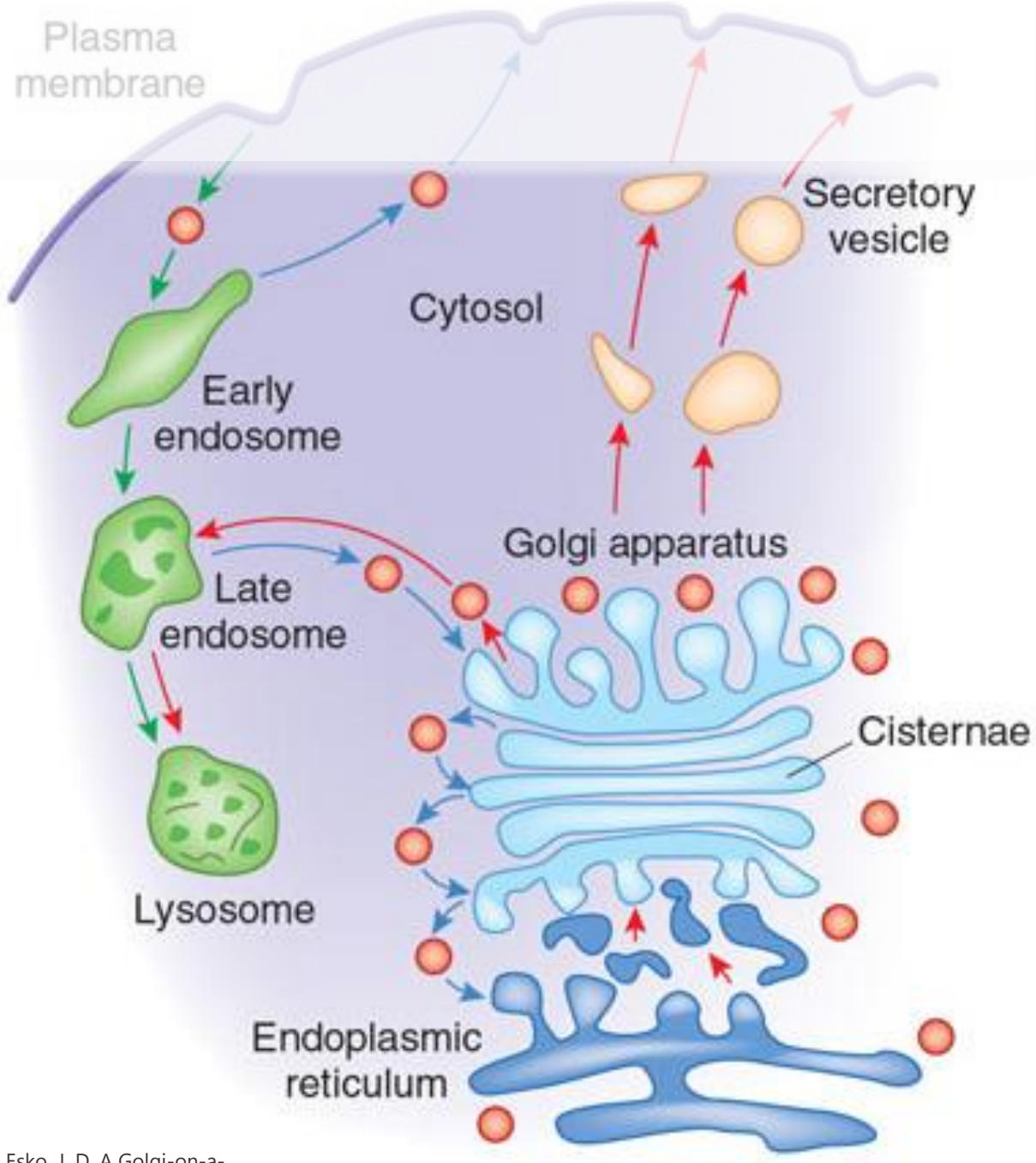
- Complex of **cisternae** and **vesicles**
- Located close to nukleus and ER
- **Vesicles** – sacs containing proteins produced in the rough ER deliver their contents to the **cis face** of the GA with which they fuse
- **Secretory vesicles** – vesicles containing processed proteins and suffocating from the **trans face** of the GA from where they move to the plasma membrane where they excrete their contents into the extracellular environment



https://www.sciencefacts.net/golgi-apparatus.html

GA functions

- Transport and storage of differnt compounds
- Posttranslation modification of proteins
  - **The most common are glycosylation, phosphorylation, sulphatation, specific proteolysis**
- Synthesis of polysaccharides and immunoglobulins
- Creation of secretory vesicles used during exocytosis
- Production of materiál for cell wall
- Creation and diferentiation of lysosomes
- Reparation of cell surface
- Creation of vacuols



Genophores

- Nuclear chromosomes
- Mitochondrial and chloroplast DNA
- Bacterial nucleoid
- Plasmids

For the pharmaceutical biotechnologist, they are sources of genetic information and tools for gene manipulation

Cell structure	Metabolic event
nucleus	DNA biosynthesis, RNA biosynthesis and modification
cytoplasm	glycolysis, pentose cycle, biosynthesis of carbohydrates and fatty acids
mitochondria	respiratory chain and oxidative phosphorylation, citrate cycle, fatty acid degradation, aminoacid metabolism
ribosomes	protein biosynthesis
Endoplasmic reticulum	synthesis, modification and transport of some proteins, synthesis of cholesterol, phospholipids and triacylglycerols, detoxification
Golgi apparatus	modification, sorting, transport and excretion of some proteins
lysosomes	breaking down worn-out biomacromolecules and foreign structures
peroxisomes	oxidation to form hydrogen peroxide, photorespiration
chloroplasts	photosynthesis, fatty acid synthesis
glyoxisomes	glyoxylate cycle