Summer 2006

Sylabus
Biophysics II
(Cell Biophysics)

Lecturer: Josef A. Käs / Co-lecturer: Friedrich Kremer

English: Wed 15.15-16.45 SR224
German: Thu 9.15-10.45 SR224
Lecture notes with the according literature references will be published in the web.
Total of 16 lectures (each 2x45 minutes)

Studies of soft matter physics on the scale of nanometers to tens of microns, i.e., on the scale of proteins and cells, in complex multifunctional biological matter – often far from equilibrium and frequently behaving in a highly nonlinear manner – are the next big challenge for physics. This lecture is based on the idea that a complete understanding of cell biological systems calls forth a new type of fundamental physics, biological physics, which can describe biological soft matter with active elements and which is adaptive to multipurpose. Over the last decade there has been tremendous progress in molecular biology. Nevertheless, this progress will only impact the design and development of new materials if a novel combination of nanosciences and soft matter physics is developed – bridging biology and engineering. This synergetic research in physics, chemistry, engineering and biology simultaneously advances our fundamental knowledge-base and provides novel applications in biomedicine and materials science.

Topics:

1. **Basic Cell Biology** (cell types, components of a cell, signal transduction and gene expression, cell division) *1 lecture* (Käs 5.4/6.4)
2. **Membrane Biophysics**
   a. **Basic Physics of Liquid Crystals** (nematic ordering, Onsager criteria, different liquid crystal phases, self assembly of lipid membranes) *1 lecture* (Kremer 12.4/13.4)
   b. **Membrane Elasticity and Membrane Morphology** (bending modulus, vesicle shapes, endo- and exocytosis, viral entry, membrane tethers) *1 lecture*(Käs 19.4/20.4)
   c. **Diffusive Transport in Membranes** (single particle tracking, anomalous diffusion, lipid rafts, signal transduction) *1/2 lecture* (Guck/Selle 26.4/27.4)
   d. **Ion Channels and Proton Pumps** (different types, stress-induced signaling, actively driven membrane fluctuations) *1/2 lecture* (Guck/Selle 26.4/27.4)
3. **Biophysics of the Cytoskeleton**
   a. **Basic Polymer Physics** (Gaussian chain, polymer size, polymer concentration regimes, Flory-Huggins, rubber elasticity, persistence length) *1 lecture* (Kremer 3.5/4.5)
   b. **Stiffness of Cytoskeletal Filaments** (Brownian motion, micromanipulation, end-to-end distance) *1/2 lecture* (Käs 10.5/11.5)
   c. **Rheological Properties of Cytoskeletal Filaments** (entangled and crosslinked filaments, repation, filament bundles, microgelation, strain hardening) *1 lecture* (Käs 10.5/11.5 + Käs 17.5 + Guck/Selle 18.5)
   d. **Cell Elasticity** (measurement techniques, cell marker, mechanotransduction) *1 lecture* (Käs 17.5 + Guck/Selle 18.5 + Käs 24.5 lecture on 25.5 will take place on 24.5)
   e. **Active Polymer Gels** (self organization, viscoelastic properties) *1/2 lecture* (Käs 24.5 lecture on 25.5 will take place on 24.5)
   f. **Cell motility** (thermal ratchets, bead motility, stress fibers, lamellipodial motion, traction forces, Flagella motion) *1 lecture* (Käs 31.5/1.6)
4. **Biophysics of the Cell Nucleus**
   a. **Polyelectrolytes** (stiffening, Manning condensation) *1/2 lecture* (Kremer 14.6/15.6)
   b. **Lipofection** (DNA-lipid phase, plasmids and cell entry) *1/2 lecture* (Kremer 14.6/15.6)
   c. **From DNA to a Chromosome** (self organization, mechanical properties) *1/2 lecture* (Kremer 21.6/22.6)
   d. **Cell mitosis** (the mechanics of cell division) *1/2 lecture* (Guck/Selle 21.6/22.6)
5. **Neurophysics**
   a. **Electrical Signaling** *1/2 lecture* (Guck/Selle 28.6/29.6)
   b. **The Synapse** *1/2 lecture* (Guck/Selle 28.6/29.6)
   c. **Neuronal Networks** *1 lecture* (Käs 5.7/6.7)
   d. **Stochastic Resonance in Hearing and Neuronal Growth** *1 lecture* (Guck/Selle 12.7/13.7)
6. **Cell Organization and Nonlinear Pattern Formation** (slime molds, Ca-waves, bacterial colonies) *1 lecture*

Cell Biophysics

1. Basic Cell Biology

Lit. • "Molecular Cell Biology", Lodish, Baltimore, Berk
Zipursky, Matsudaira, Darnell
• "Molecular Biology of the Cell", Alberts, Johnson,
Lewis, Raff, Roberts, Walter

prokaryotic cells: all bacteria

eukaryotic cells:	all cells of the protist, fungus, animal and plant kingdoms

necessary condition for life:
lipid membranes

show Figure 1-5

⇒ liquid crystals

Typical animal cells

- blood < Erythrocytes / Macrophages, Neutrophils, Lymphocytes etc
- epithelial cells: covers all internal and external body surfaces
- endothelia cells: skin, fibroblasts, keratinocytes vascular wall,
- neurons, glia cells
- muscle cells
- secretory cells

Primary cells ⟺ cell lines

primary: ≈ 120 division mortal
cell line: immortal, hybridized with cancer cells

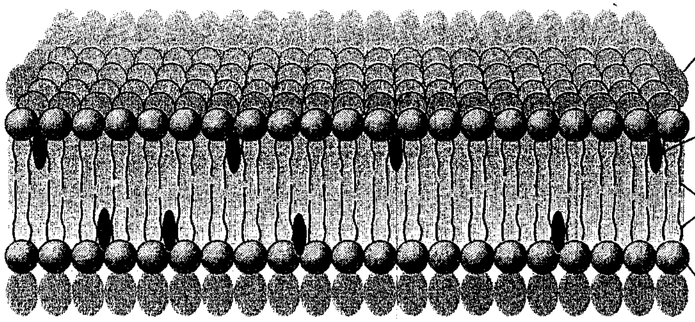
↗ Plant cells great potential

Organization of a Typical Animal Cell

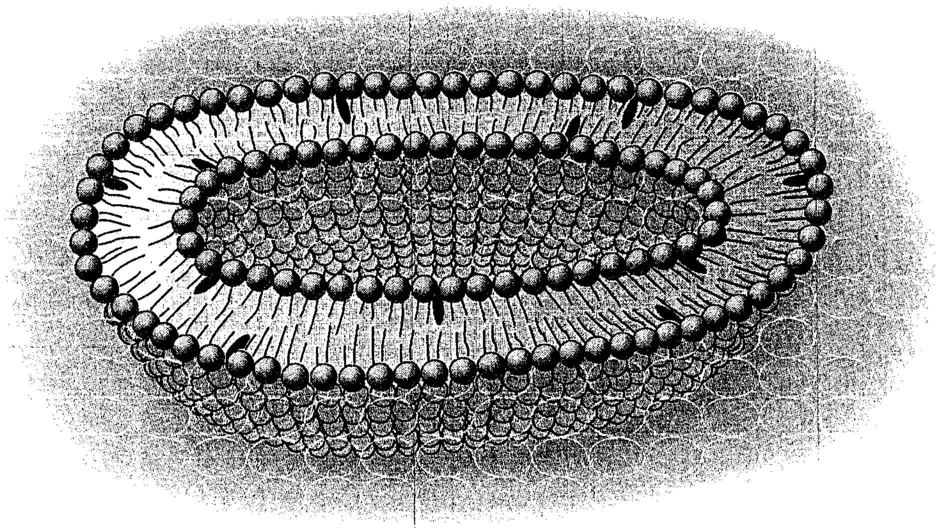
show figure

80% of a cell are water!

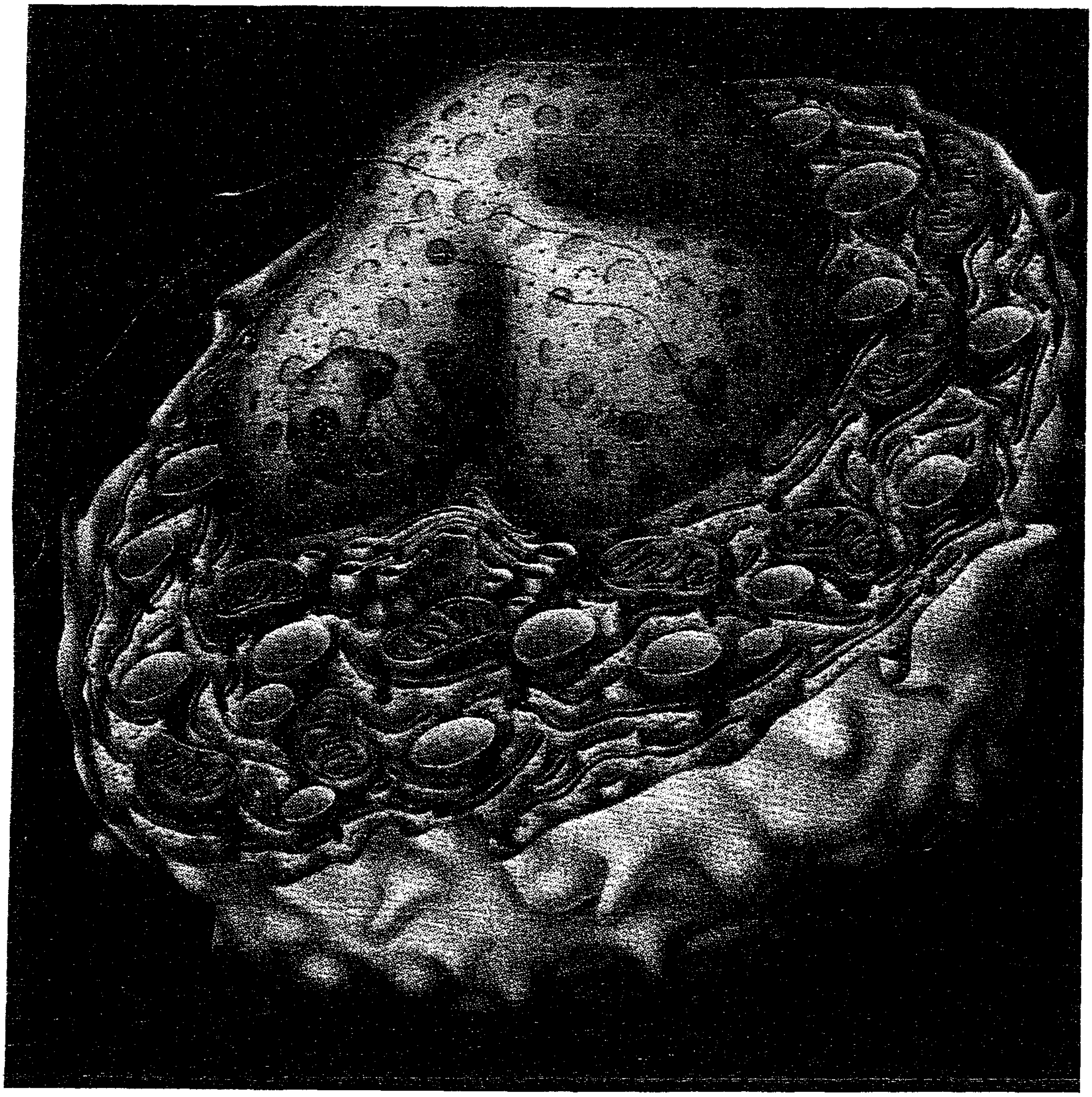
(a)



(b)



➤ FIGURE 1-5 Cells are formed with an outer fatty shell and an interior watery space. (a) The fatty molecules (lipids) align and orient themselves in a 2-layered sheet with the fat as an interior space. Cholesterol molecules provide some rigidity to the fatty layer. Each of the lipid molecules has a head group (*circular structure*) that combines easily with water. Thus both sides of the sheet are lined by water-seeking head groups, mainly charged phosphates. (b) A bilayer can fold to form an enclosed cell, with a watery space inside as well as surrounding the cell. In actuality, the interior space is much larger relative to the volume of the lipid.



An artist's rendering of a eukaryotic cell.

Nucleus: Chromosomes → DNA-Protein Complex
Fibrous Matrix → Lamin
→ are surrounded by nuclear membrane (nucleus)
except during cell division
Nucleolus → transcription of ribosomal RNA + attachment of accessory protein
nuclear membrane: double membrane with pores

soft matter physics (polymer, polyelectrolytes, liquid crystal), motors to overcome entropy

Peroxisome: degradation of fatty acids and amino acids
→ hydrogen peroxide → water + oxygen (catalase)

non equilibrium state!

Golgi complex: direct membrane constituents to appropriate places ⇒ transport vesicles, clathrin
⇒ exocytosis = fusion with plasma membrane

membrane physics

Lysosomes: degradative Enzymes
degrade ~~Prot~~ membranes and organelles
degrade proteins and particles taken up by the cell.
non equilibrium

mitochondrion : ATP - production
glucose → ATP
power plant , multiple , ~~[illegible]~~

show figure

rotary motors , nonequilibrium
membrane physics

centrioles : assembly of microtubles, 9 sets of triplet microtubles
organization of the mitotic spindle

self organization, polymer physics

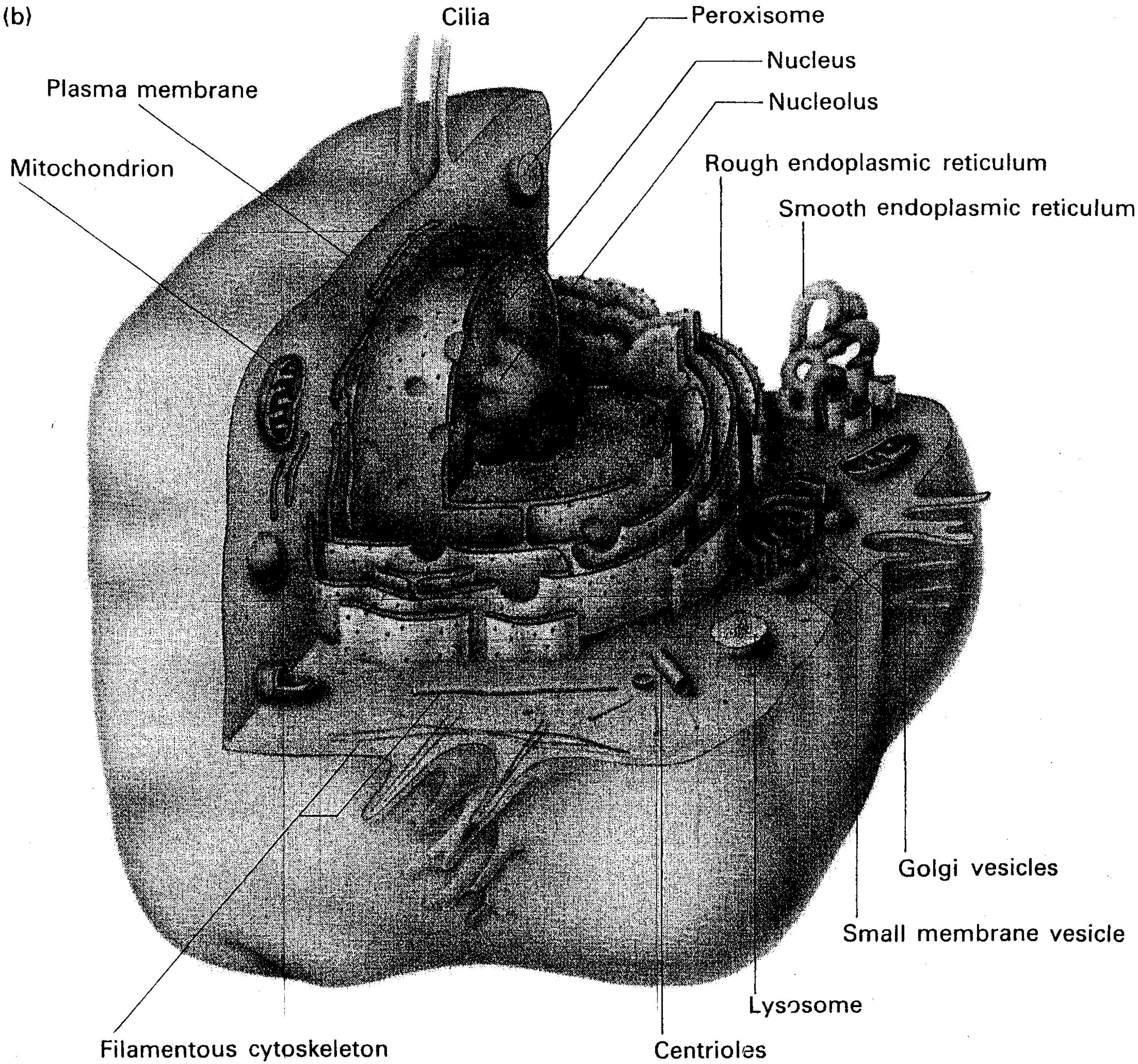
Rough ER : Ribosomes bound to the ER
sythesize membrane and ~~secretory~~
secretory proteins
large structure since it provides
building stones for the plasma
membrane

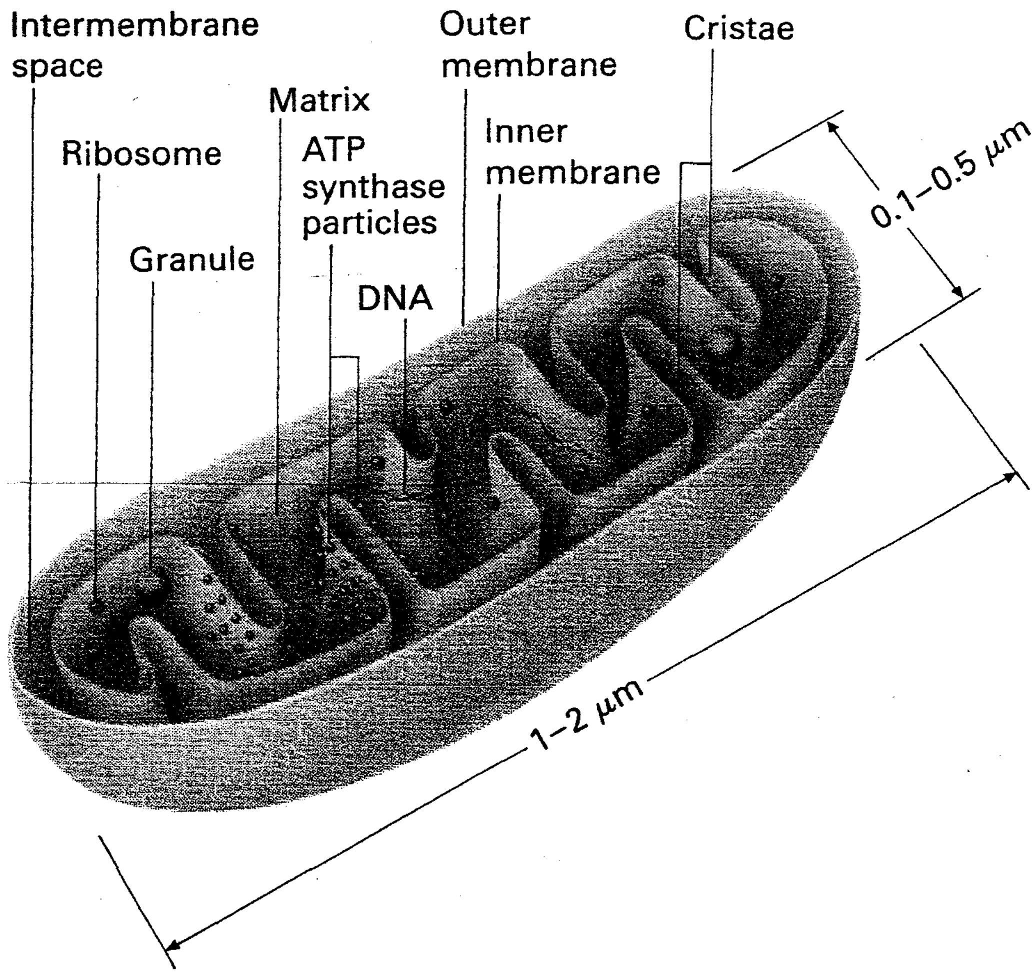
Smooth ER : synthesis ~~of~~ and metabolism of fatty acids
and phospholipids

nonequilibrium , lipid thethers

ribosomes : complex comprising several differnt
rRNA molecules and more than 50
proteins that is the site of
protein sythesis
bionetworks , ribosomal transport

(b)


Cilia
Peroxisome
Nucleus
Nucleolus
Plasma membrane
Mitochondrion
Rough endoplasmic reticulum
Smooth endoplasmic reticulum
Golgi vesicles
Small membrane vesicle
Lysosome
Filamentous cytoskeleton
Centrioles



▲ FIGURE 5-43 Three-dimensional diagram of a mitochondrion cut longitudinally.

plasma membrane:

permeability barrier that consists of a phospholipid bilayer and associated membrane proteins and is some cases cholesterol and glycolipids, cell receptors and second messengers → signal transduction, channels,
membrane physics (see syllabus)

Cytoskeleton:

network of protein filaments (actin, microtubles, intermediate filaments) that organize stell and give the cell mechanical stability
cytoskeletal physics (see sylabus)

Gene Expression

~~then~~ DNA → RNA : transcription
RNA → protein : translation

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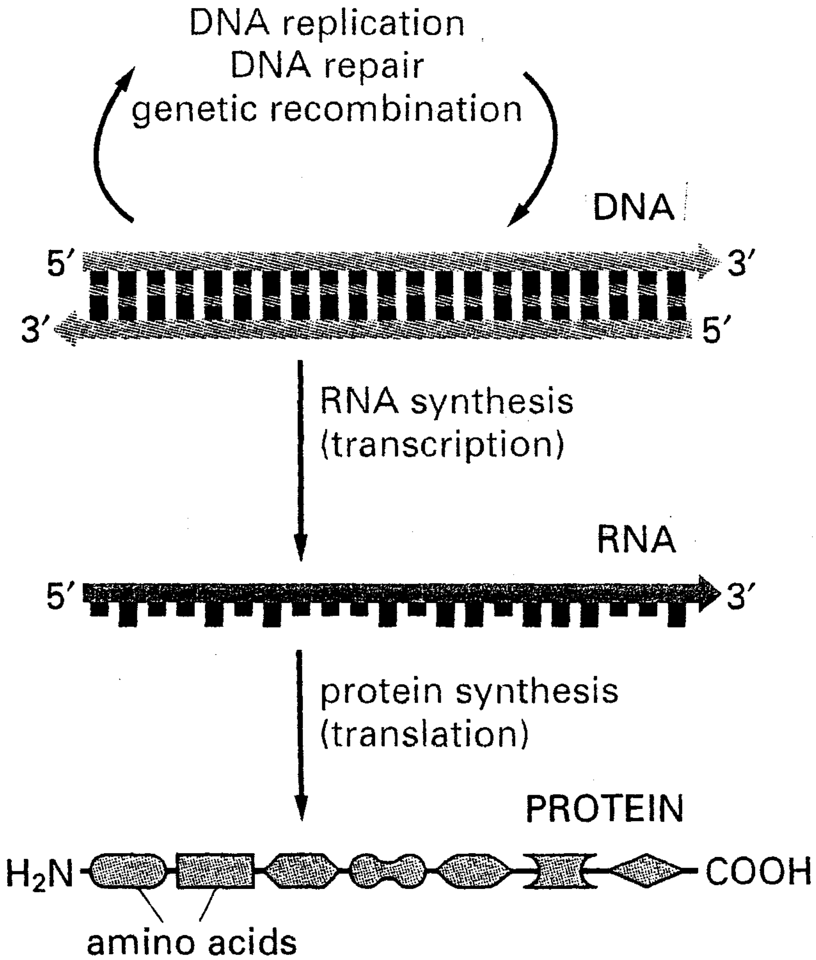


Figure 6–2 The pathway from DNA to protein. The flow of genetic information from DNA to RNA (transcription) and from RNA to protein (translation) occurs in all living cells.

Signal transduction

Mechanotransduction

Biomechanics

Chemotransduction

Receptors, second messengers, Ca^{2+}, PIP-lipids, IP_3, G-proteins, phosphorylation

receptor tyrosine kinases

receptor tyrosine-linked kinases

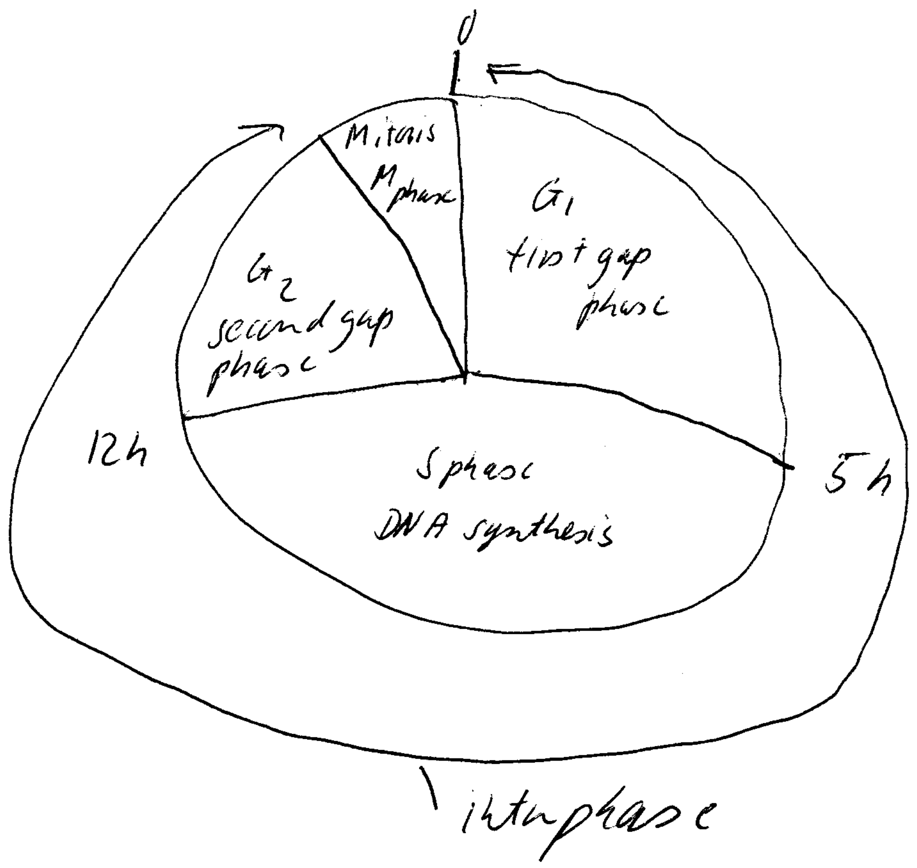
G-protein linked receptors

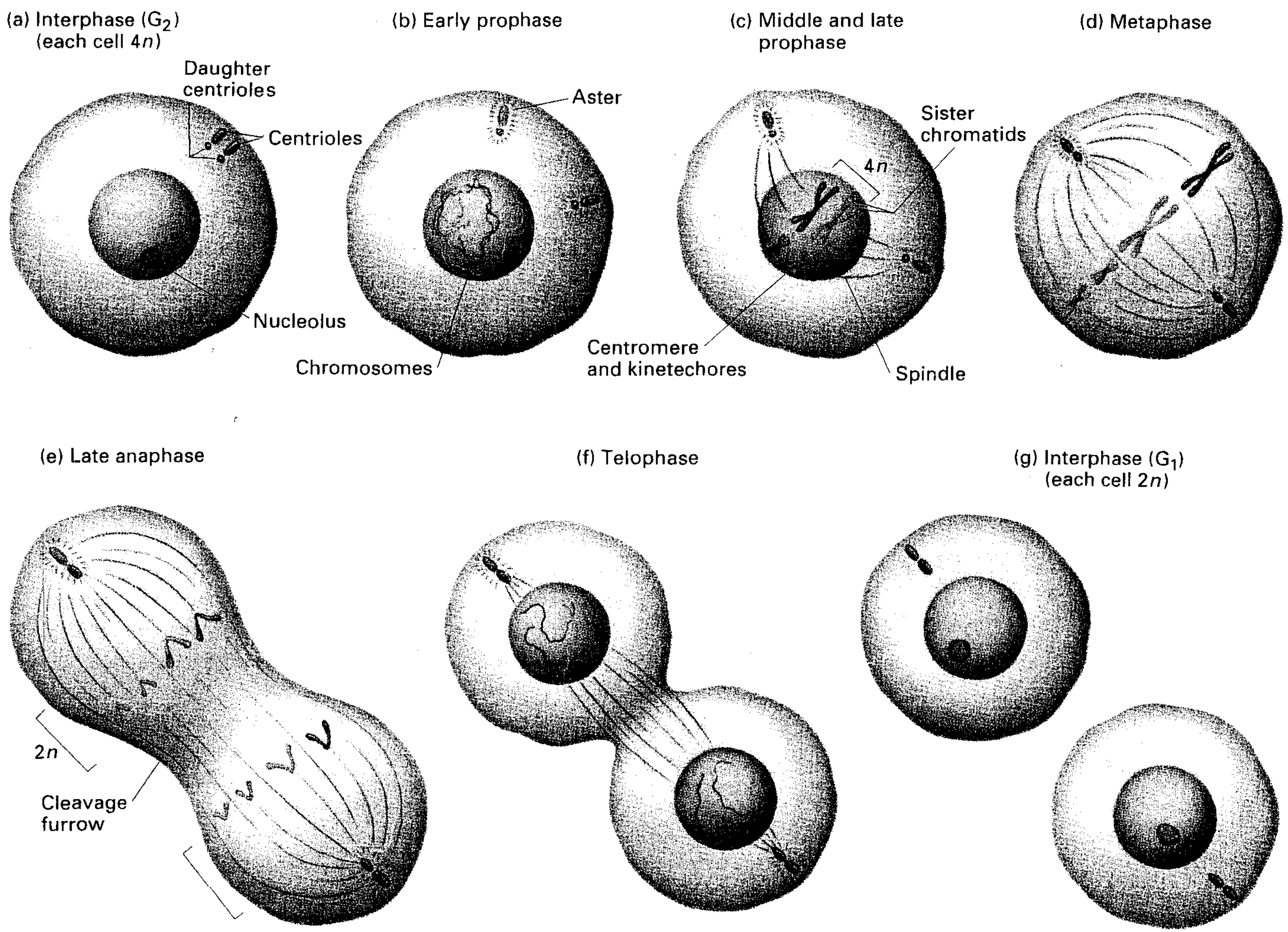
overcoming noise

Cell Division

- special phase of cell of the cell cycle
- rates very different, Yeast 120 min
  most animal cells 10-20h
  cells in adult do not divide at all
  ⇒ quiescent cells

- cell cycle of a animal cells




(a) Interphase (G_2)
(each cell $4n$)
Daughter centrioles
Centrioles
Nucleolus
(b) Early prophase
Aster
Chromosomes
(c) Middle and late prophase
$4n$
Sister chromatids
Centromere and kinetechores
Spindle
(d) Metaphase
(e) Late anaphase
$2n$
Cleavage furrow
(f) Telophase
(g) Interphase (G_1)
(each cell $2n$)