The Living World

Fourth Edition

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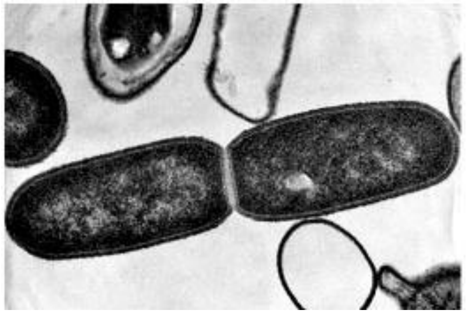
7 How Cells Divide

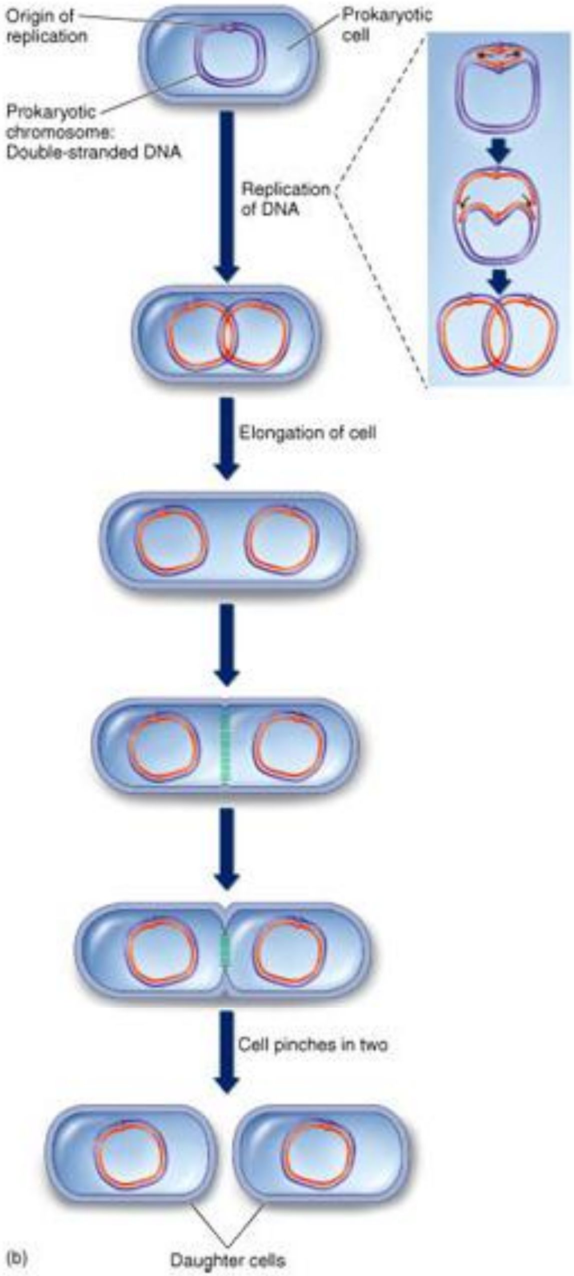
PowerPoint® Lectures prepared by Johnny El-Rady

7.1 Prokaryotes Have a Simple Cell Cycle

- Cell division in prokaryotes takes place in two stages
  - The DNA is replicated
  - The cell elongates, then splits into two daughter cells
    - The process is called binary fission

Fig. 7.1 Cell division in prokaryotes





7.2 Eukaryotes Have a Complex Cell Cycle

- Cell division in eukaryotes is more complex than in prokaryotes because
  - 1. Eukaryotic contain far more DNA
  - 2. Eukaryotic DNA is packaged differently
    - It is in linear chromosomes compacted with proteins

7.2 Eukaryotes Have a Complex Cell Cycle

- Eukaryotic cells divide in one of two ways
  - Mitosis
    - Occurs in somatic (non-reproductive) cells
  - Meiosis
    - Occurs in germ (reproductive) cells
    - Results in the production of gametes

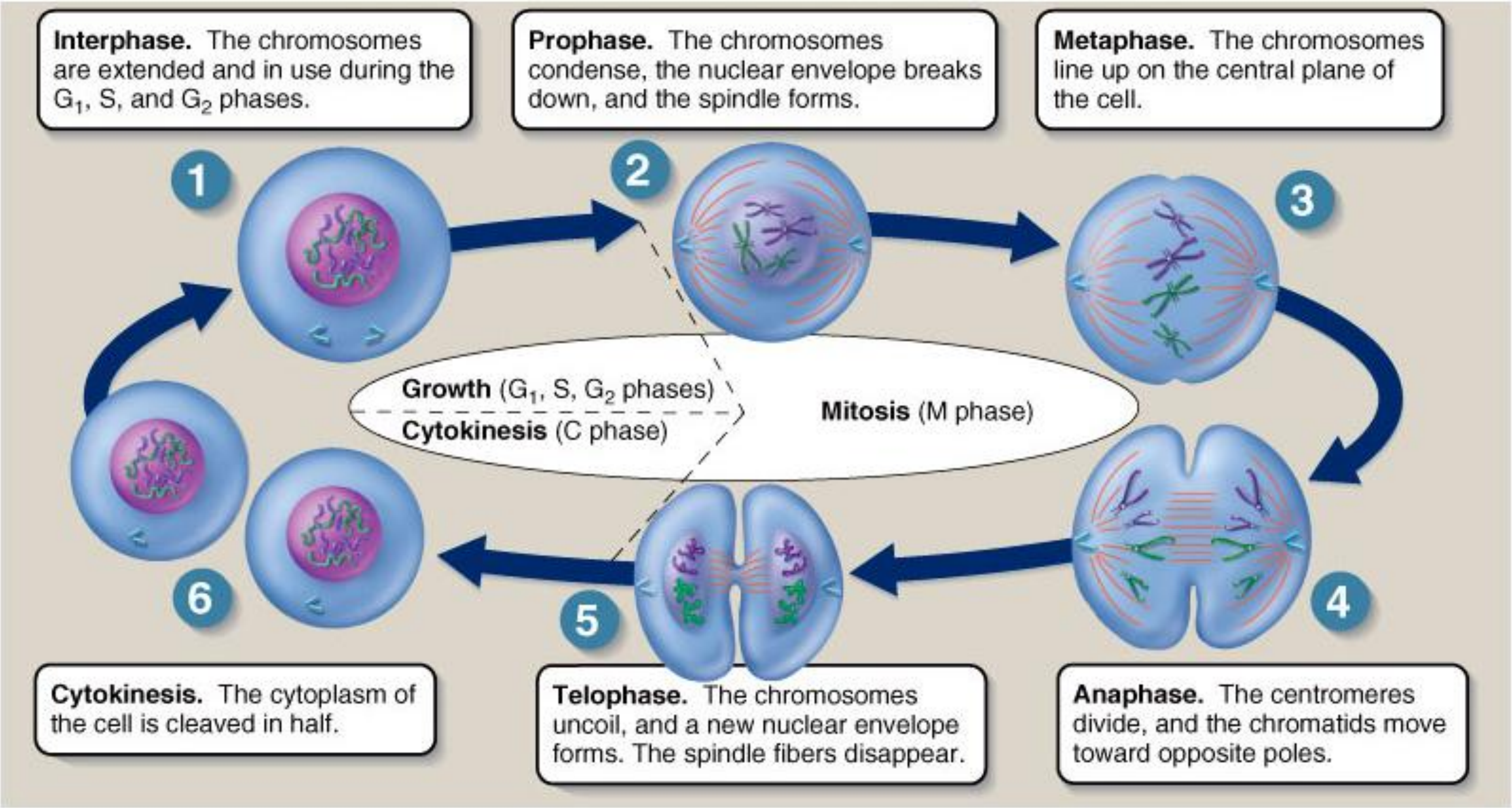
- The complex cell cycle of eukaryotic cell is composed of several stages

Interphase
- G_1 phase
  - Primary growth phase
- S phase
  - DNA replication
- G_2 phase
  - Microtubule synthesis

Mitosis
- M phase
  - Chromosomes pull apart

Cytokinesis
- C phase
  - Cytoplasm divides

Fig. 7.2 How the cell cycle works



7.3 Chromosomes

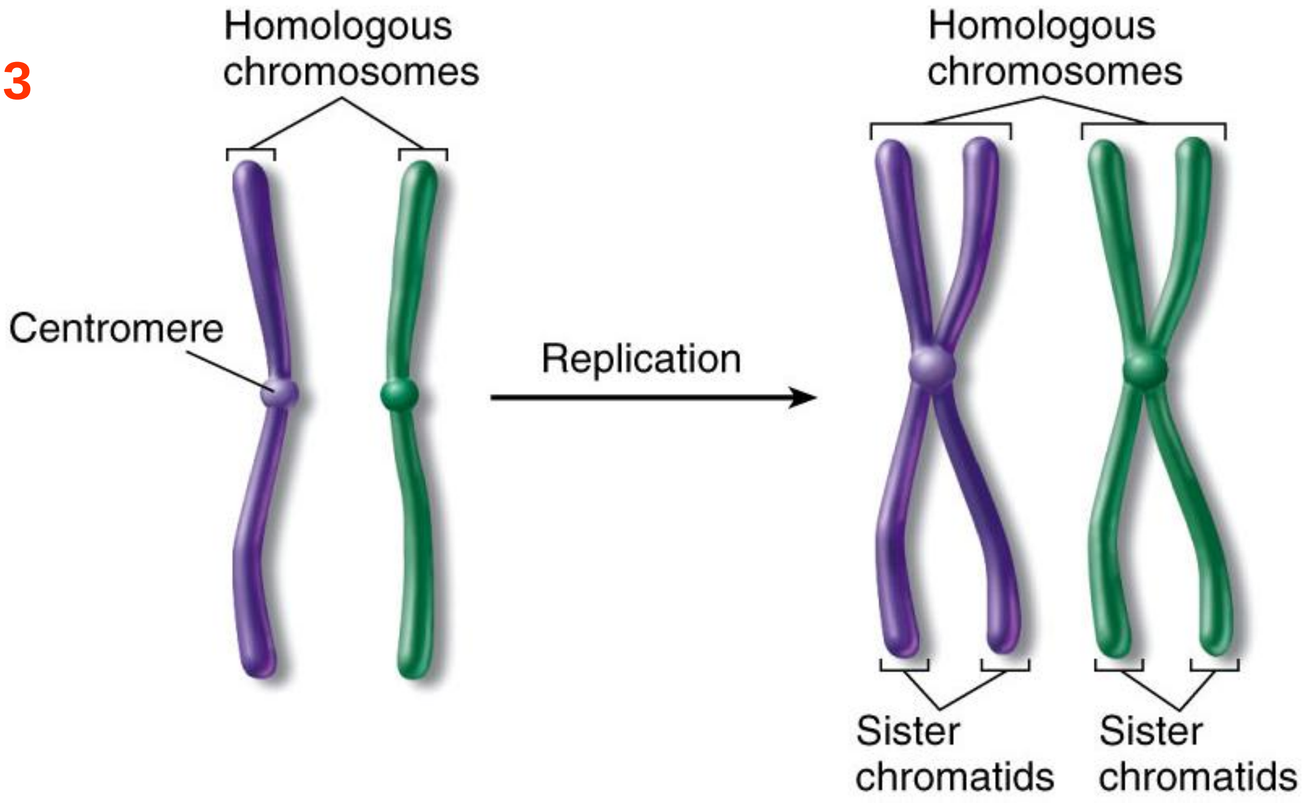
- Chromosomes were first observed by the German embryologist Walther Fleming in 1882

- The number of chromosomes varies enormously from species to species
  - The Australian ant *Myrmecia* spp. has only 1 pair
  - Some ferns have more than 500 pairs

- Chromosomes exist in somatic cells as pairs
  - Homologous chromosomes or homologues

- Diploid cells have two copies of each chromosomes
- Replicated chromosomes consist of two sister chromatids
  - These are held together at the centromere

Fig. 7.3



7.3 Chromosomes

- Humans have 46 chromosomes
- The 23 pairs of homologous chromosomes can be organized by size
- This display is termed a karyotype

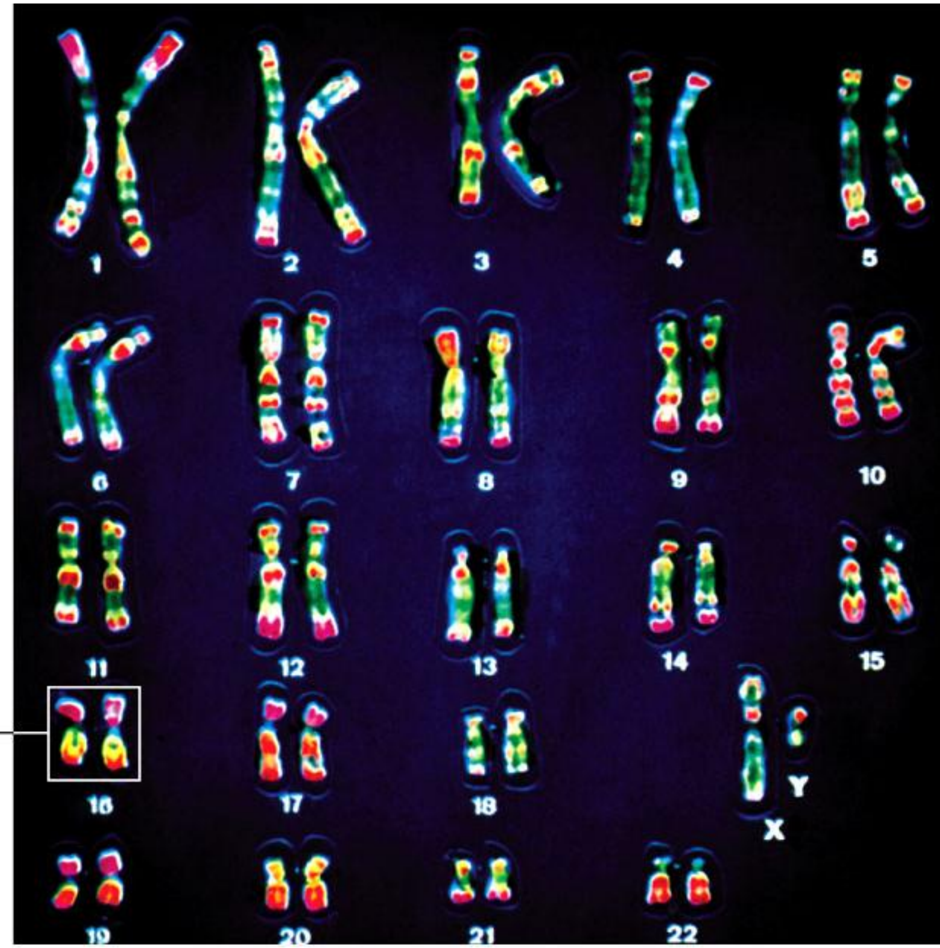


Fig. 7.4

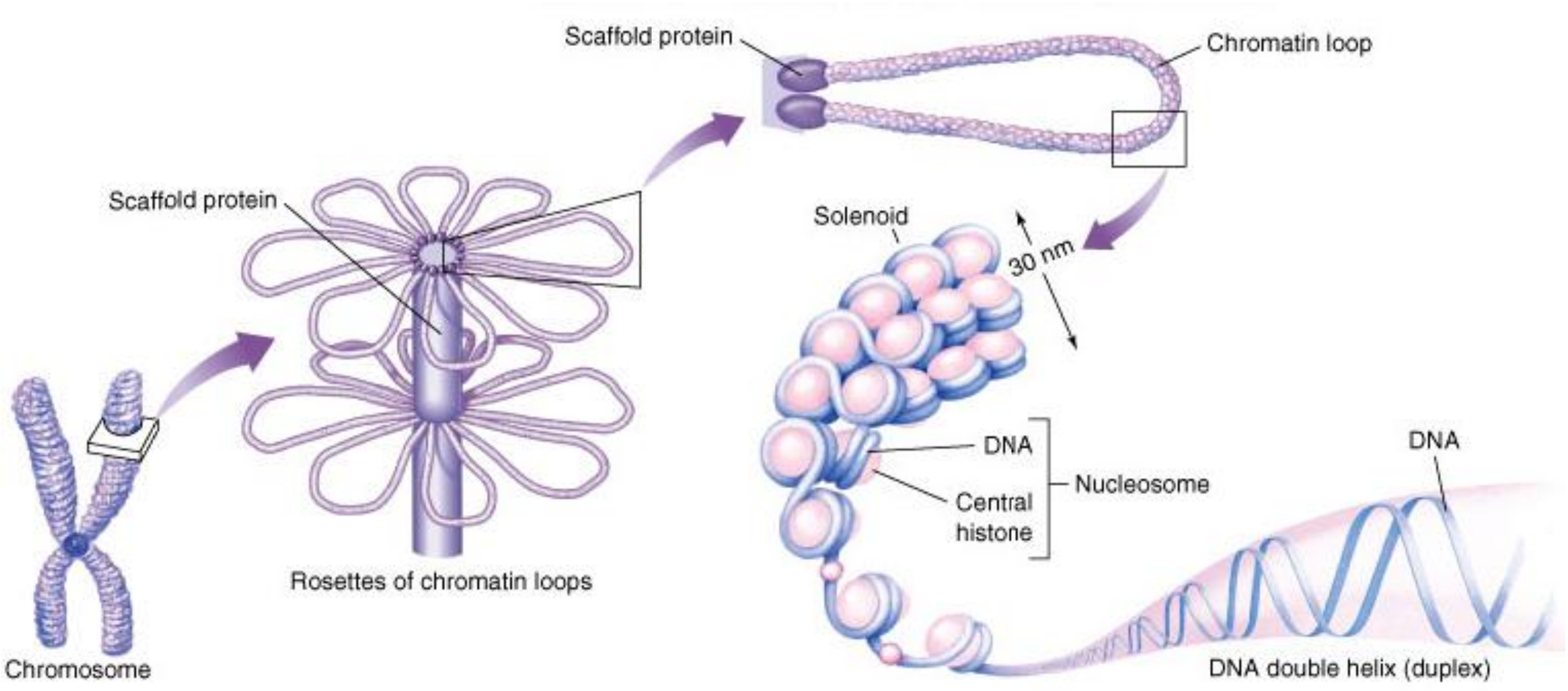
7.3 Chromosomes

- Chromosomes are composed of chromatin
  - Complex of DNA (~ 40%) and proteins (~ 60%)
- A typical human chromosome contains about 140 million nucleotides in its DNA
  - This is equivalent to
    - About 5 cm in stretched length
    - 2,000 printed books of 1,000 pages each!
- In the cell, however, the DNA is coiled

7.3 Chromosomes

- The DNA helix is wrapped around positively-charged proteins, called histones
- 200 nucleotides of DNA coil around a core of eight histones, forming a nucleosome
- The nucleosomes coil into solenoids
- Solenoids are then organized into looped domains
- The looped domains appear to form rosettes on scaffolds

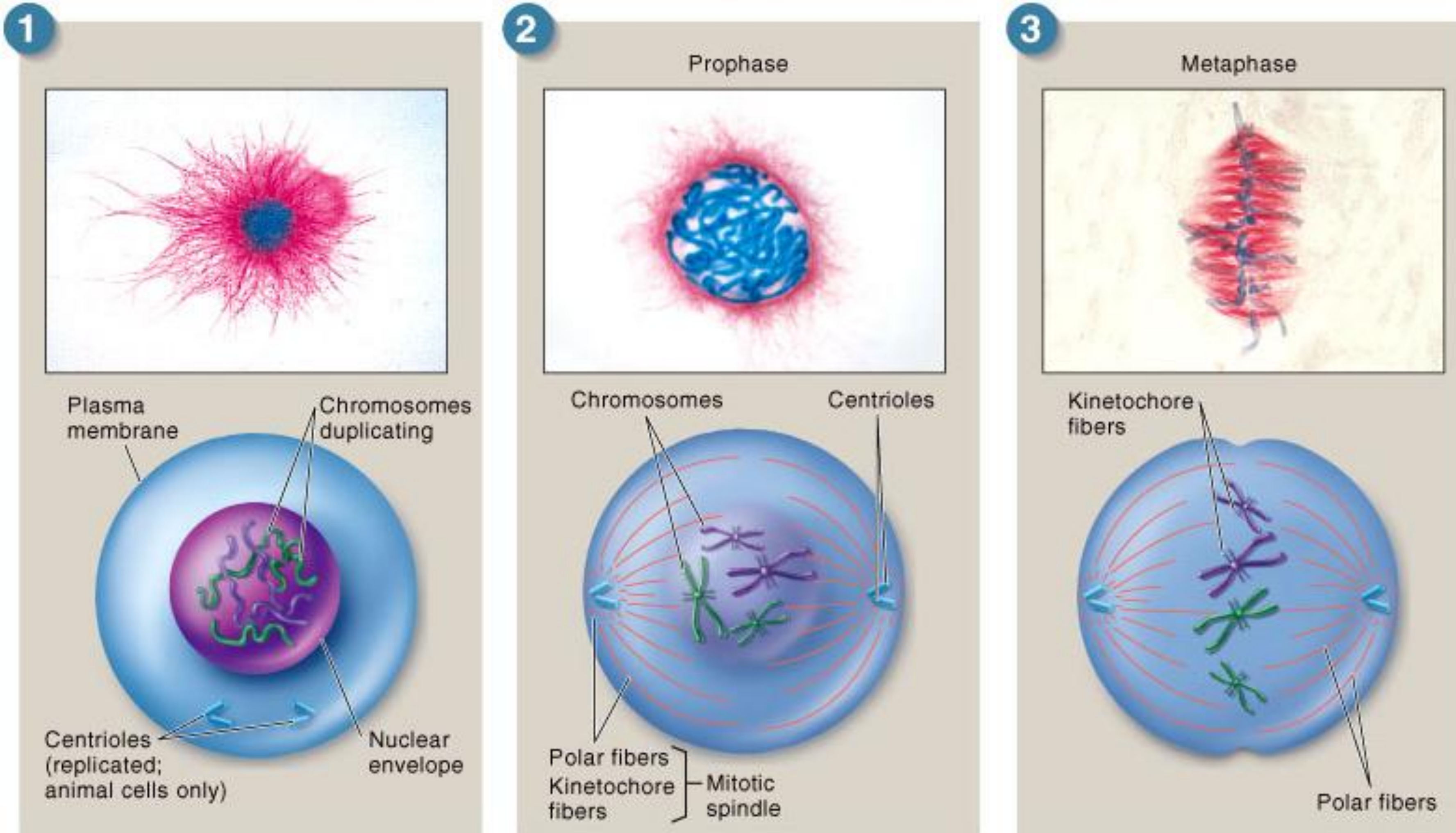
Fig. 7.5 Levels of eukaryotic chromosome organization



7.4 Cell Division

- The eukaryotic cell cycle consists of the following stages
  - Interphase
  - Mitosis
    - Division of the nucleus
      - Also termed karyokinesis
    - Subdivided into
      - Prophase, metaphase, anaphase, telophase
  - Cytokinesis
    - Division of the cytoplasm

- Interphase
  - Chromosomes replicate and begin to condense
- Mitosis
  - Prophase
    - Nuclear envelope breaks down
    - Chromosomes condense further
    - Spindle apparatus is formed
  - Metaphase
    - Chromosomes align along the equatorial plane
    - Spindle fibers attach at the kinetochores
      - On opposite sides of the centromeres



DNA replicates and begins to condense. Centrioles, if present, also replicate, and the cell prepares for division.

The nuclear envelope begins to break down. DNA further condenses into chromosomes. The mitotic spindle begins to form; it is complete at the end of prophase.

The chromosomes align on a plane in the center of the cell. The kinetochore fibers attach to the kinetochores on opposite sides of the centromeres.

Fig. 7.7

- Mitosis
  - Anaphase
    - Sister chromatids separate
    - They are drawn to opposite poles by shortening of the microtubules attached to them
  - Telophase
    - Nuclear envelope reappears
    - Chromosomes decondense
    - Spindle apparatus is disassembled
- Cytokinesis
  - Two diploid daughter cells form

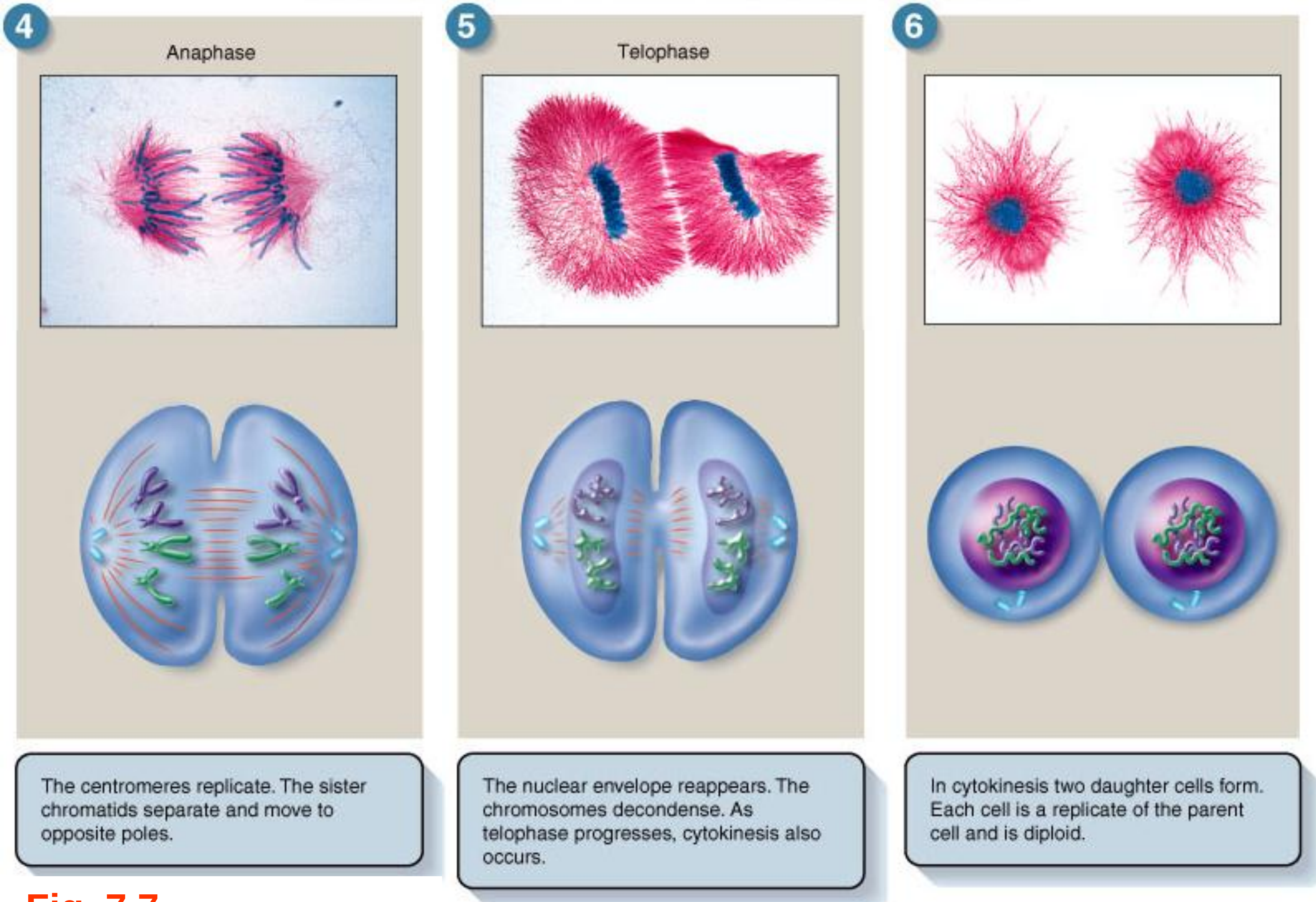
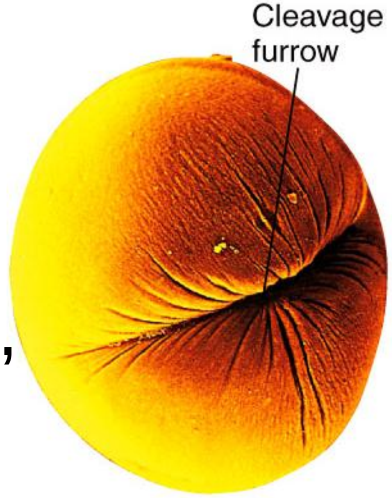

4
Anaphase
5
Telophase
6
The centromeres replicate. The sister chromatids separate and move to opposite poles.
The nuclear envelope reappears. The chromosomes decondense. As telophase progresses, cytokinesis also occurs.
In cytokinesis two daughter cells form. Each cell is a replicate of the parent cell and is diploid.

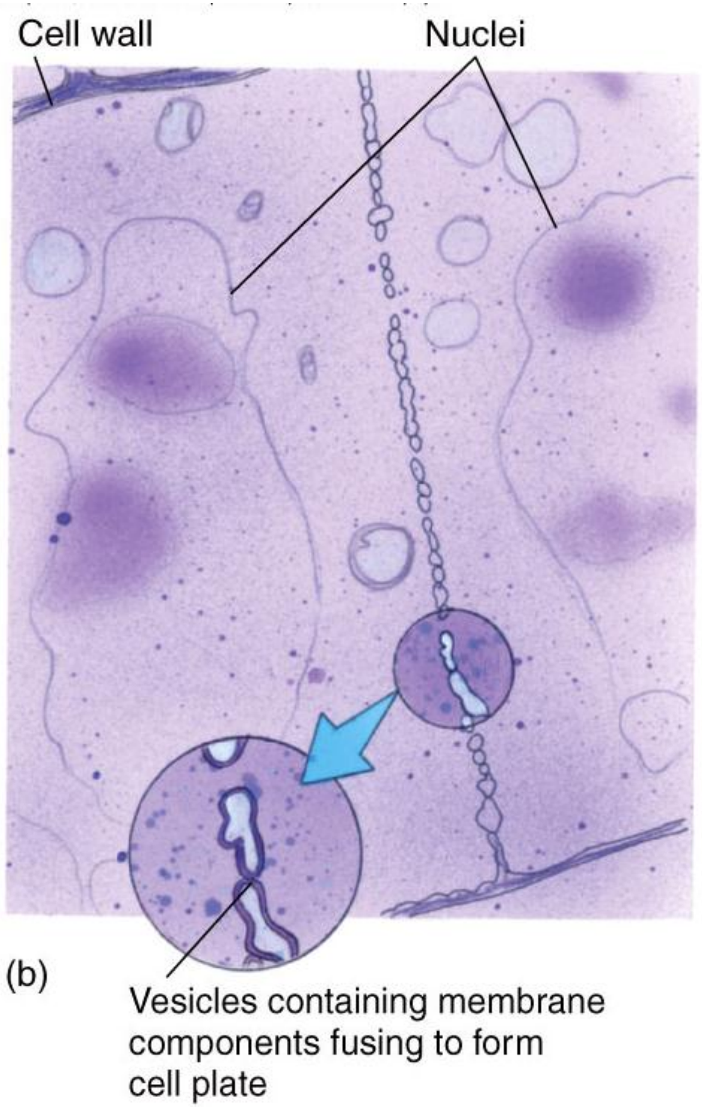
Fig. 7.7

- Cytokinesis
- Animal cells
  - Cleavage furrow forms, *pinching* the cell in two

Fig. 7.8



- Plant cells
  - Cell plate forms, *dividing* the cell in two



Cell Death

- During fetal development, many cells are programmed to die
- Human cells appear to be programmed to undergo only so many cell divisions
  - About 50 in cell cultures
- Only cancer cells can divide endlessly

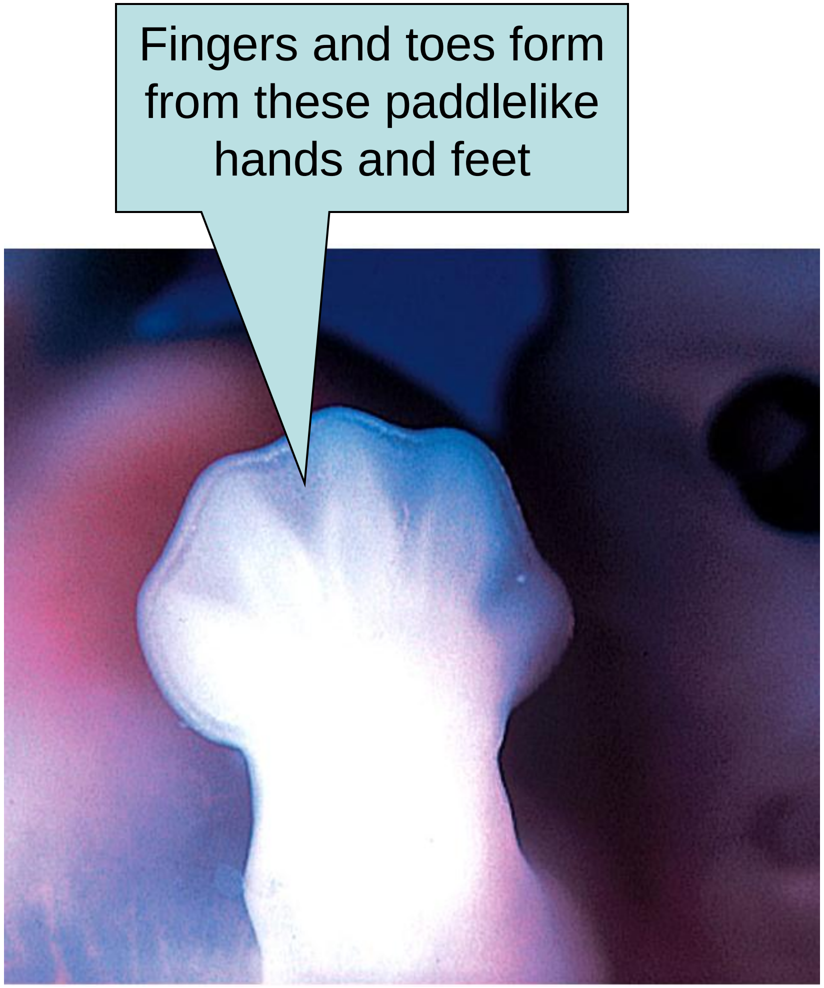


Fig. 7.9 Programmed cell death

7.5 Controlling the Cell Cycle

- The eukaryotic cell cycle is controlled by feedback at three checkpoints

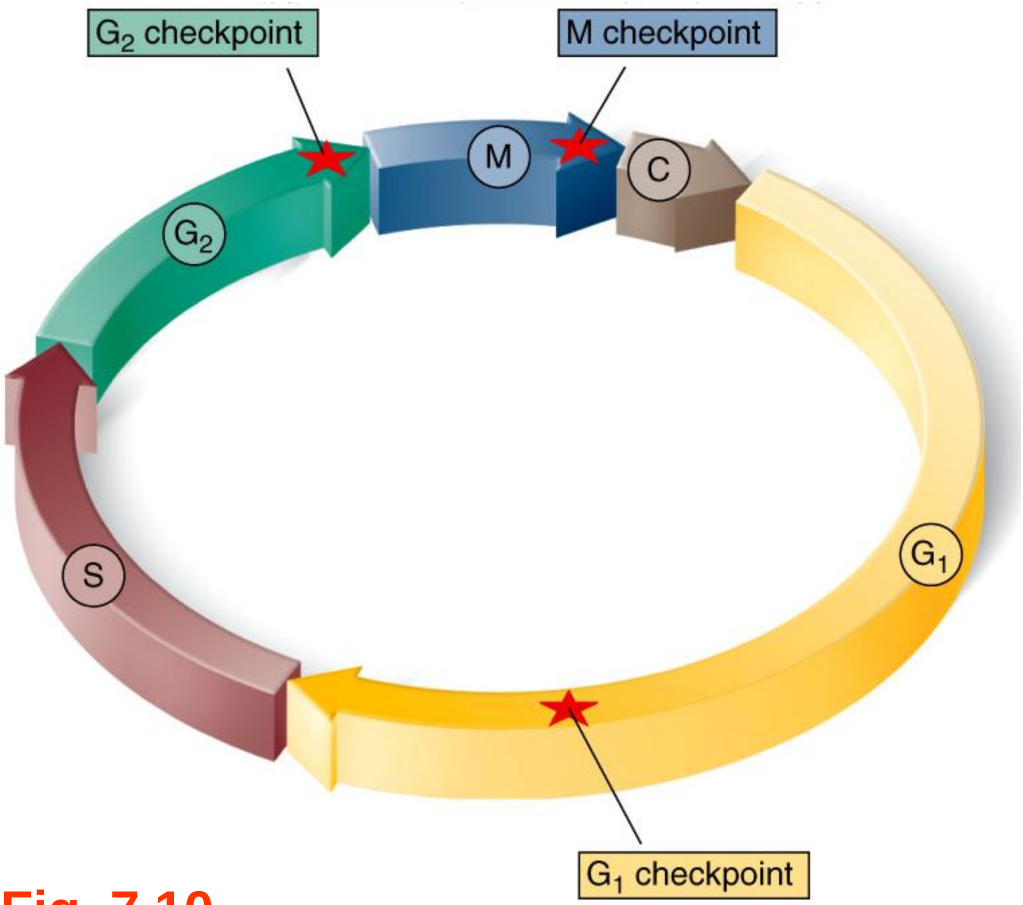


Fig. 7.10

7.5 Controlling the Cell Cycle

- 1. Cell growth is assessed at the G$_1$ checkpoint
- 2. DNA replication is assessed at the G$_2$ checkpoint
- 3. Mitosis is assessed at the M checkpoint

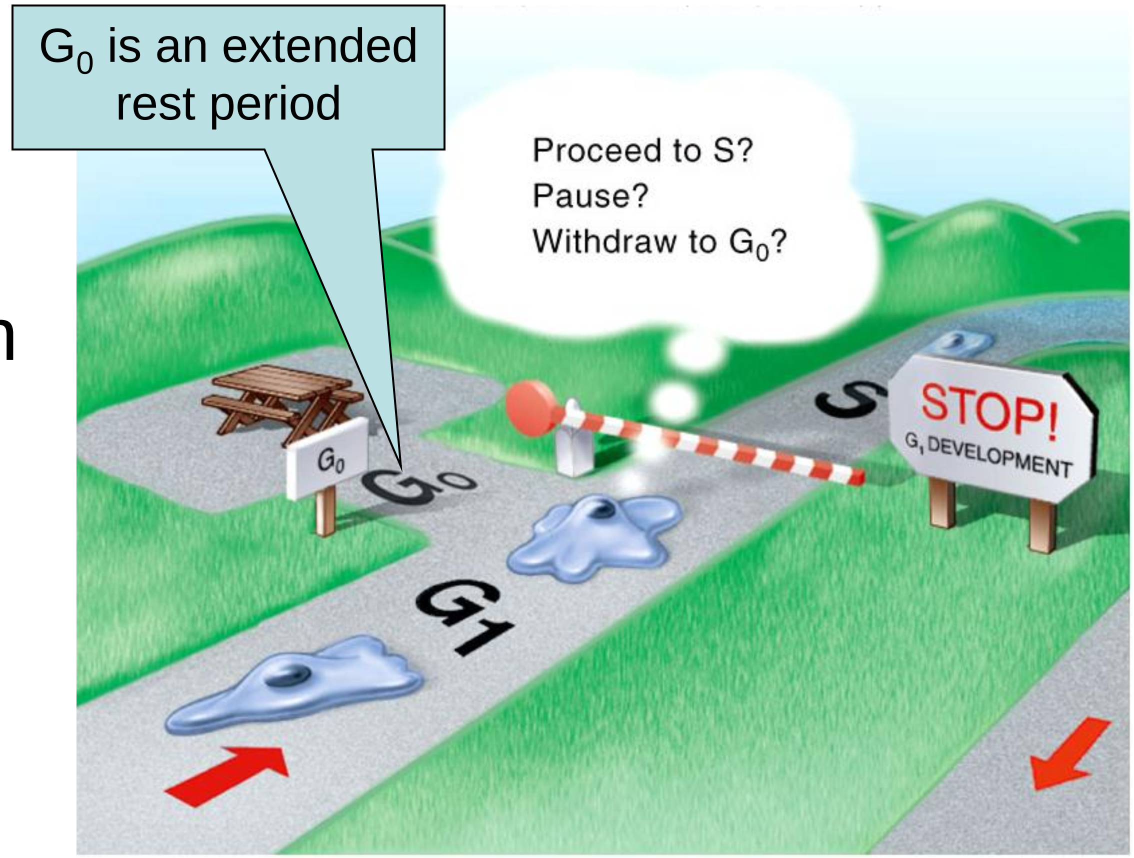


Fig. 7.11

7.6 What is Cancer?

- Cancer is unrestrained cell growth and division
- The result is a cluster of cells termed a tumor

- Benign tumors
  - Encapsulated and noninvasive
- Malignant tumors
  - Not encapsulated and invasive
  - Can undergo metastasis
    - Leave the tumor and spread throughout the body

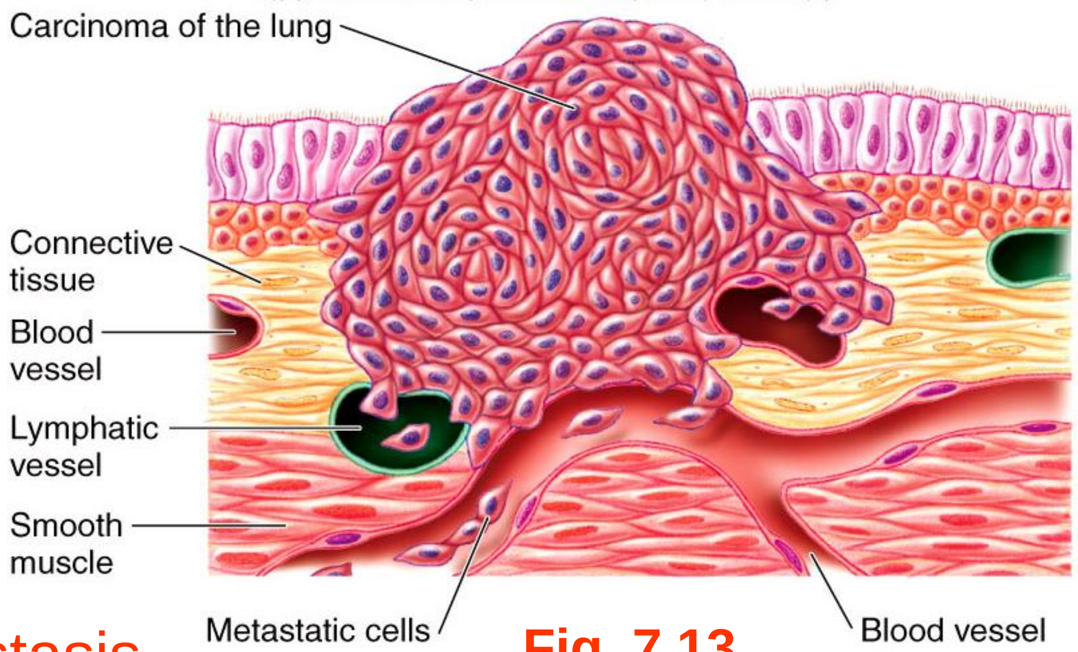


Fig. 7.13

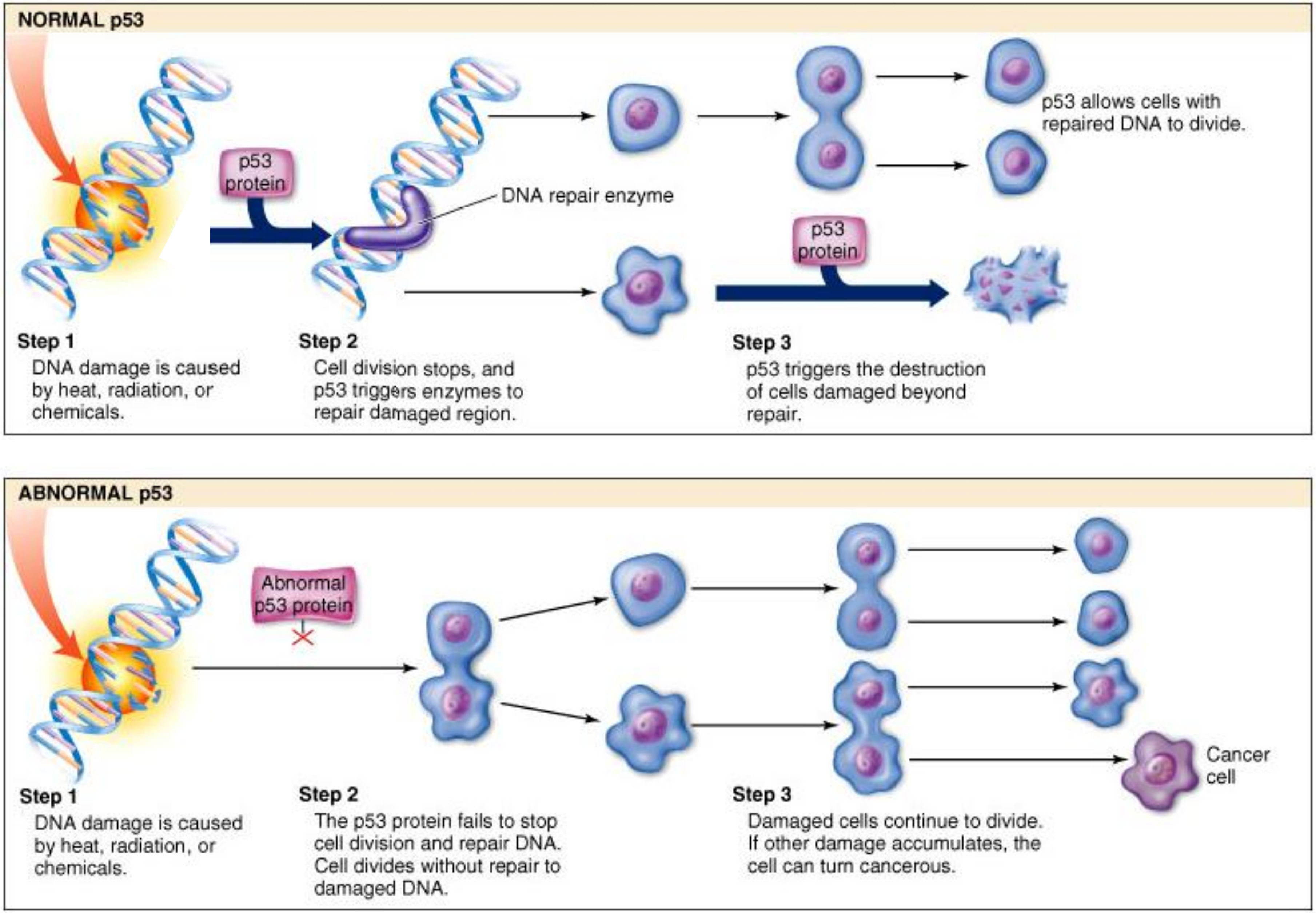
7.6 What is Cancer?

- Most cancers result from mutations in growth-regulating genes
- There are two general classes of these genes
  - 1. Proto-oncogenes
    - Encode proteins that simulate cell division
    - If mutated, they become oncogenes
  - 2. Tumor-suppressor genes
    - Encode proteins that inhibit cell division
- Cancer can be caused by chemicals, radiation or even some viruses

7.7 Cancer and Control of the Cell Cycle

- The *p53 gene* plays a key role in the G_1 checkpoint of cell division
- The p53 protein (the gene's product), monitors the integrity of DNA
  - If DNA is damaged, the protein halts cell division and stimulates repair enzymes
- If the *p53* gene is mutated
  - Cancerous cells repeatedly divide
  - No stopping at the G_1 checkpoint

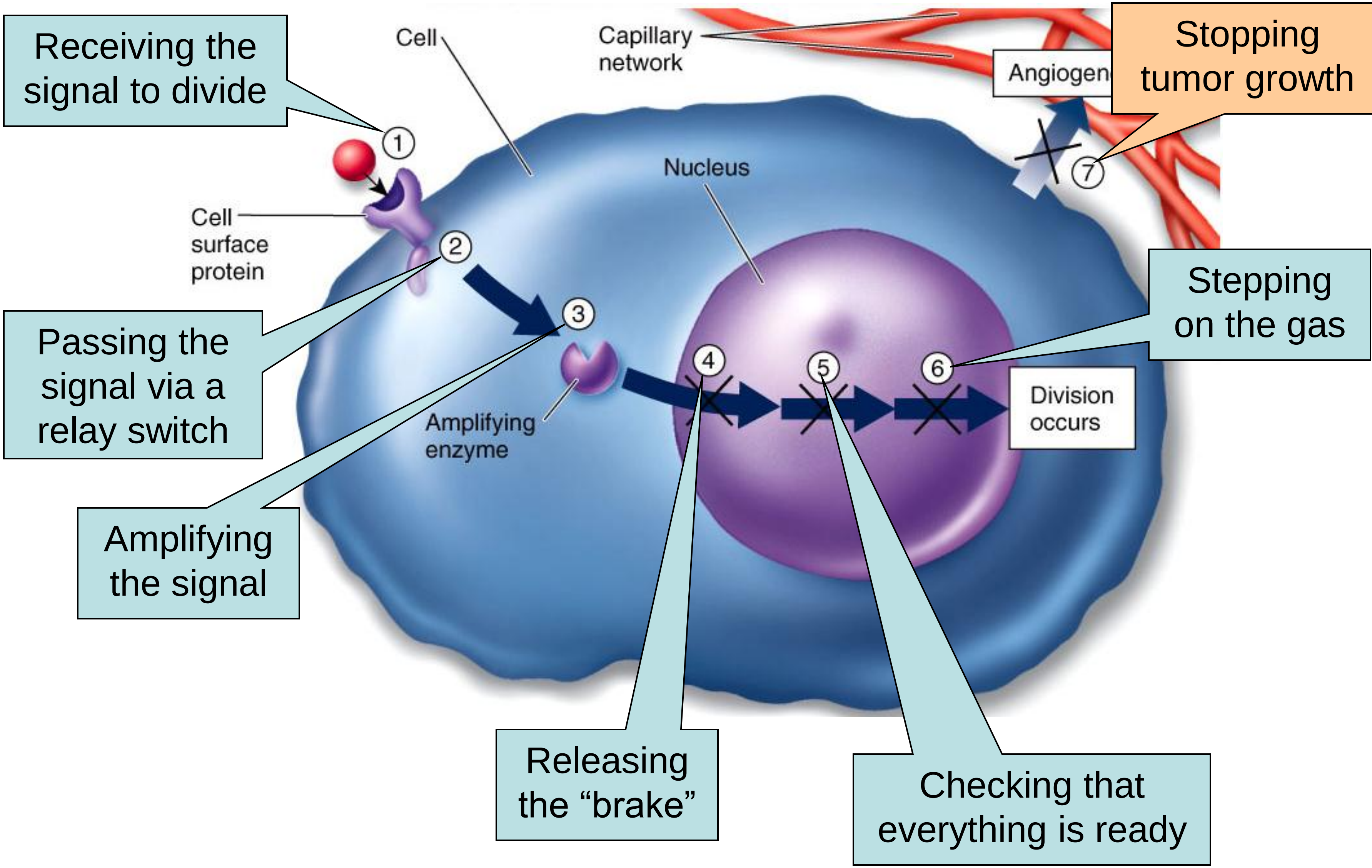
Fig. 7.14 Cell division and p53 protein



7.8 Curing Cancer

- Potential cancer therapies are being developed to target seven different stages in the cancer process
  - Stages 1-6
    - Prevent the start of cancer within cells
    - Focus on the decision-making process to divide
  - Stage 7
    - Act outside cancer cells
    - Prevents tumors from growing and spreading

Fig. 7.15 New molecular therapies for cancer

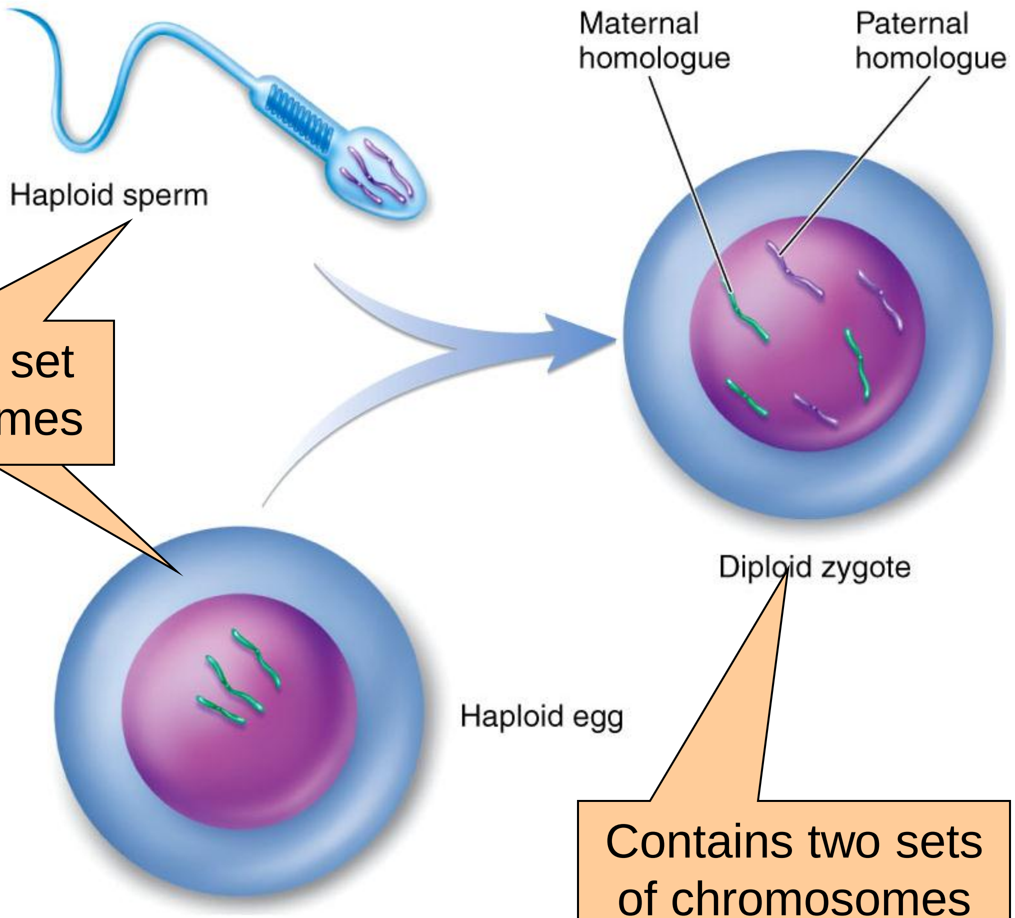


7.9 Discovery of Meiosis

- Meiosis was first observed by the Belgian cytologist Pierre-Joseph van Beneden in 1887
- Gametes (eggs and sperm) contain half the complement of chromosomes found in other cells
- The fusion of gametes is called fertilization or syngamy
  - It creates the zygote, which contains two copies of each chromosome

- Sexual reproduction
  - Involves the alternation of meiosis and fertilization
- Asexual reproduction
  - Does not involve fertilization

Fig. 7.16



Contain one set of chromosomes

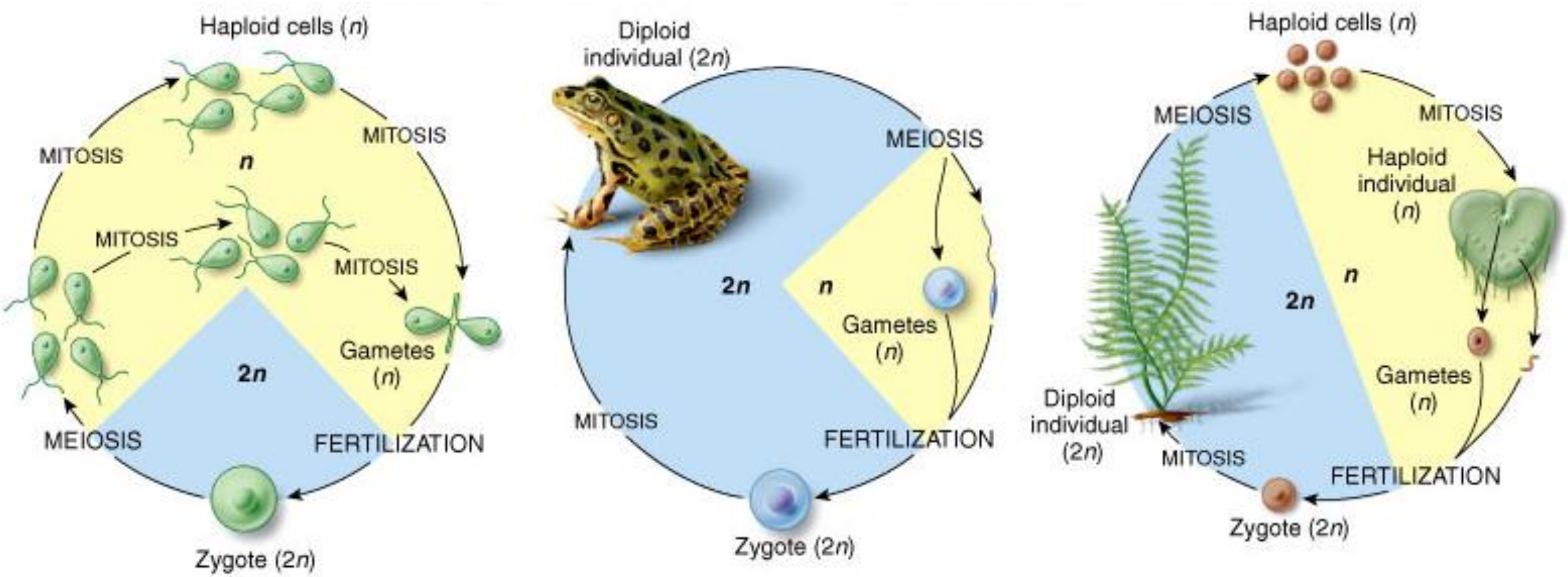
Contains two sets of chromosomes

7.10 The Sexual Life Cycle

- The life cycles of all sexually-reproducing organisms follows the same basic pattern
  - Haploid cells or organisms alternate with diploid cells or organisms

- There are three basic types of sexual life cycles

Fig. 7.18 Three types of sexual life cycles

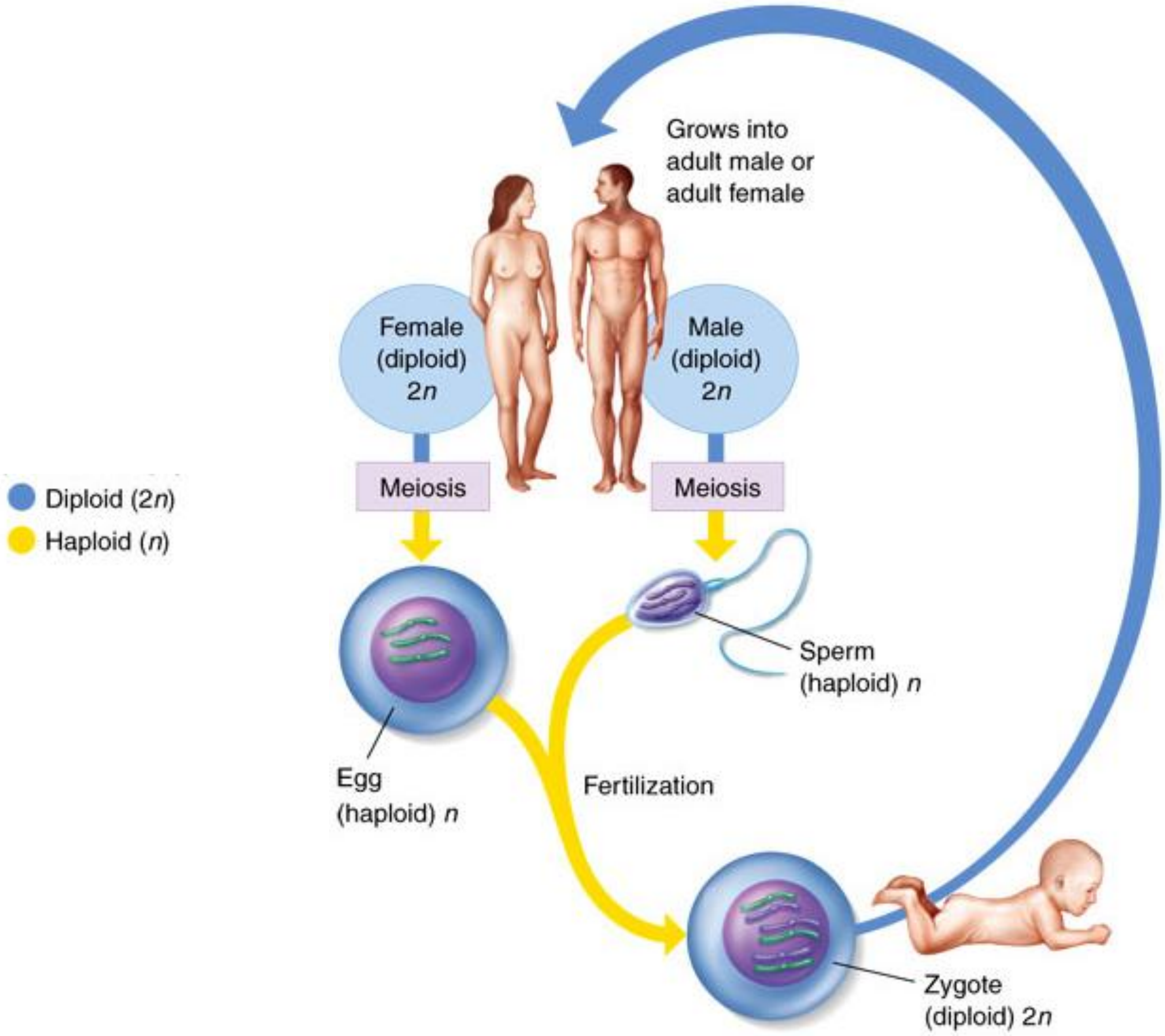


(a) Some types of algae

(b) Most animals

(c) Some plants and some algae

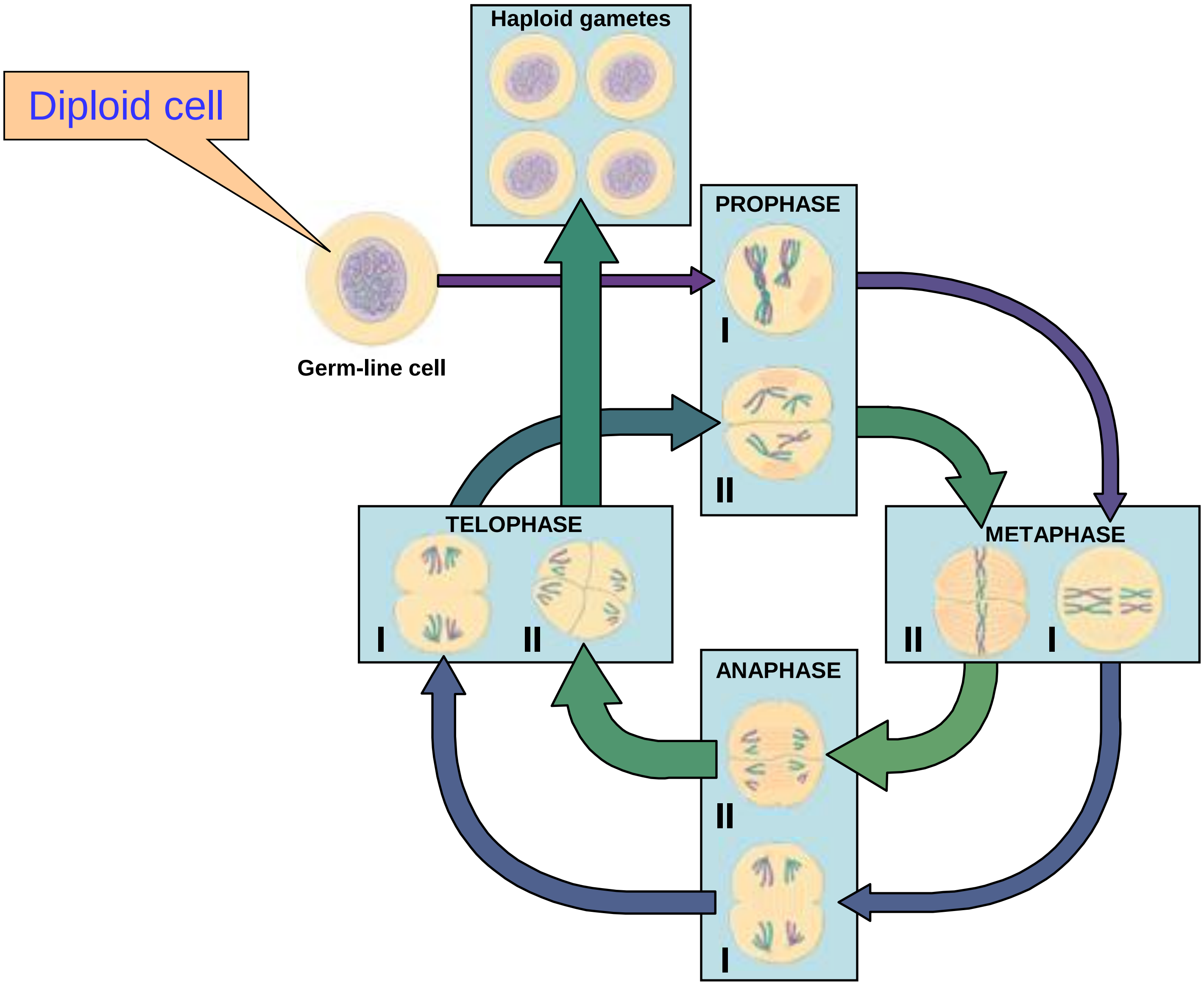
Fig. 7.19 The sexual life cycle in animals



7.11 The Stages of Meiosis

- Meiosis consists of two successive divisions, but only one DNA replication
  - Meiosis I
    - Separates the two versions of each chromosome
  - Meiosis II
    - Separates the two sister chromatids of each chromosome
- Meiosis halves the number of chromosomes

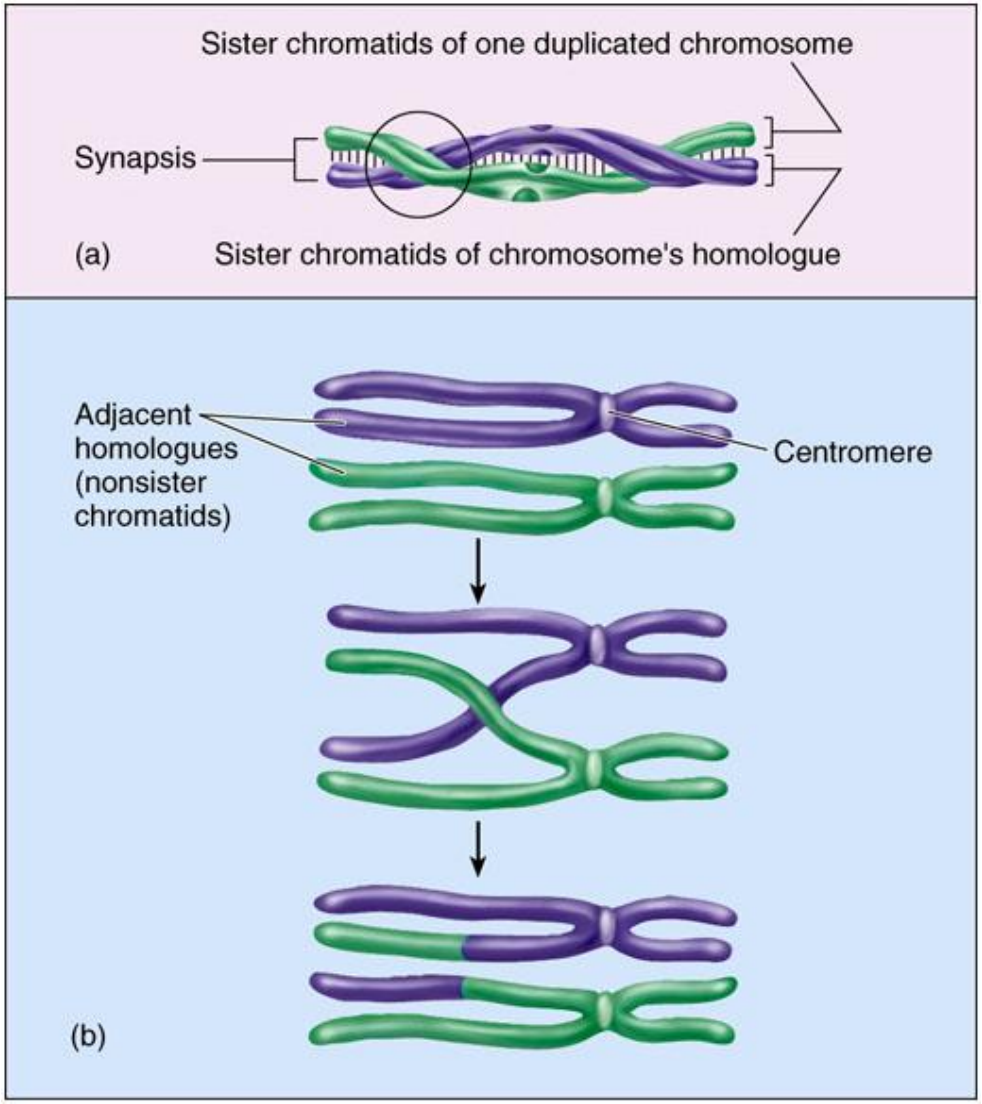
Fig. 7.22 How meiosis works

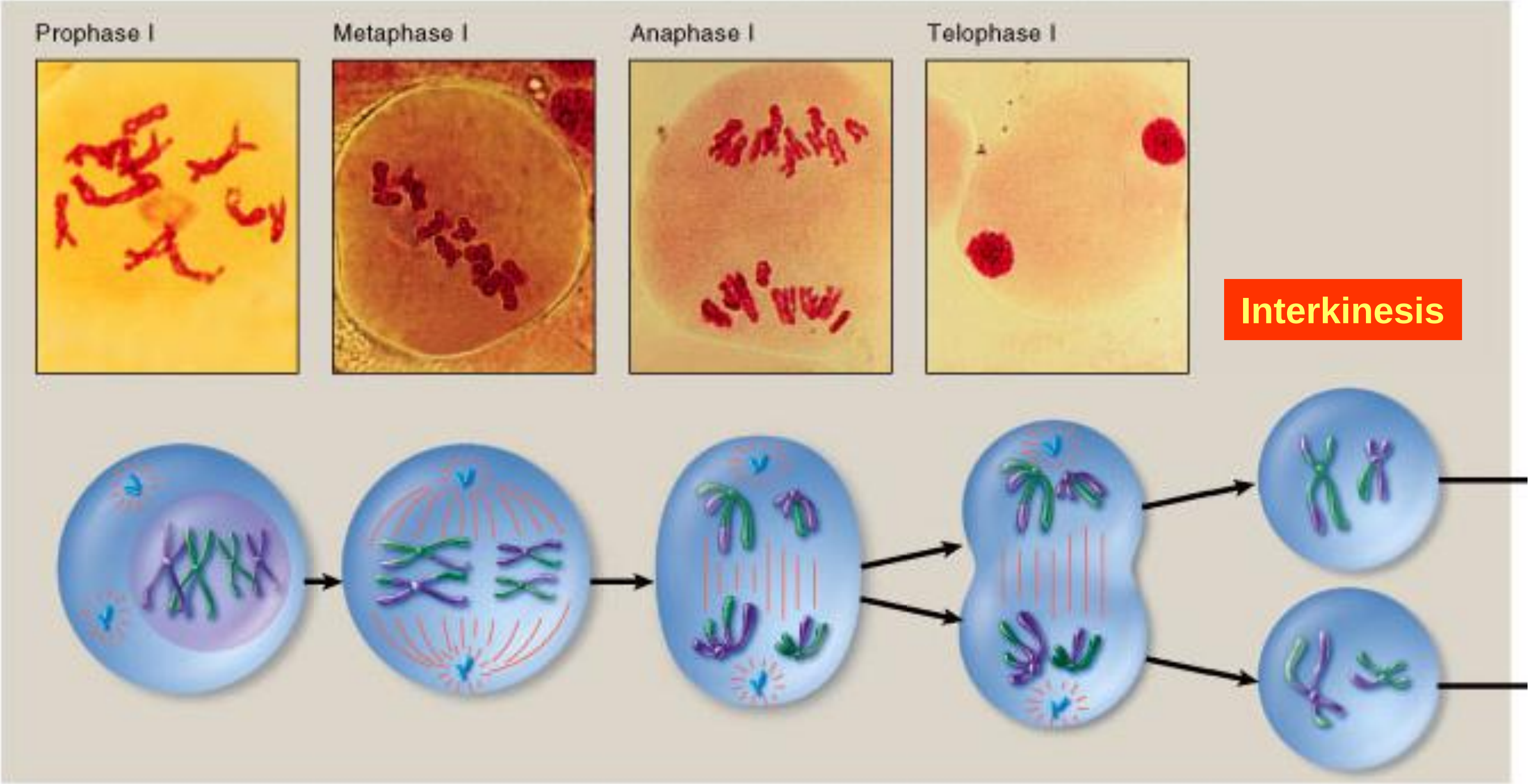


- Meiosis I
  - Prophase I
    - Homologous chromosomes pair up and exchange segments
  - Metaphase I
    - Homologous chromosome pairs align at random in the equatorial plane
  - Anaphase I
    - Homologous chromosomes separate and move to opposite poles
  - Telophase I
    - Individual chromosomes gather together at each of the two poles

- Meiosis I
  - Prophase I
    - The longest and most complex stage of meiosis
    - Homologous chromosomes undergo synapsis
      - Pair up along their lengths
    - Crossing over occurs

Fig. 7.20





Homologous chromosomes further condense and pair. Crossing over occurs. Spindle fibers form.

Microtubule spindle apparatus attaches to chromosomes. Homologous pairs align along spindle equator.

Homologous pairs of chromosomes separate and move to opposite poles

One set of paired chromosomes arrives at each pole, and nuclear division begins.

Fig. 7.23

Meiosis II

- After meiosis I there is a brief interphase
  - No DNA synthesis occurs
- Meiosis II is similar to mitosis, but with two main differences
  - 1. Haploid set of chromosomes
  - 2. Sister chromatids are not identical

- Meiosis II
  - Prophase II
    - Brief and simple, unlike prophase I
  - Metaphase II
    - Spindle fibers bind to both sides of the centromere
  - Anaphase II
    - Spindle fibers contract, splitting the centromeres
    - Sister chromatids move to opposite poles
  - Telophase I
    - Nuclear envelope reforms around four sets of daughter chromosomes

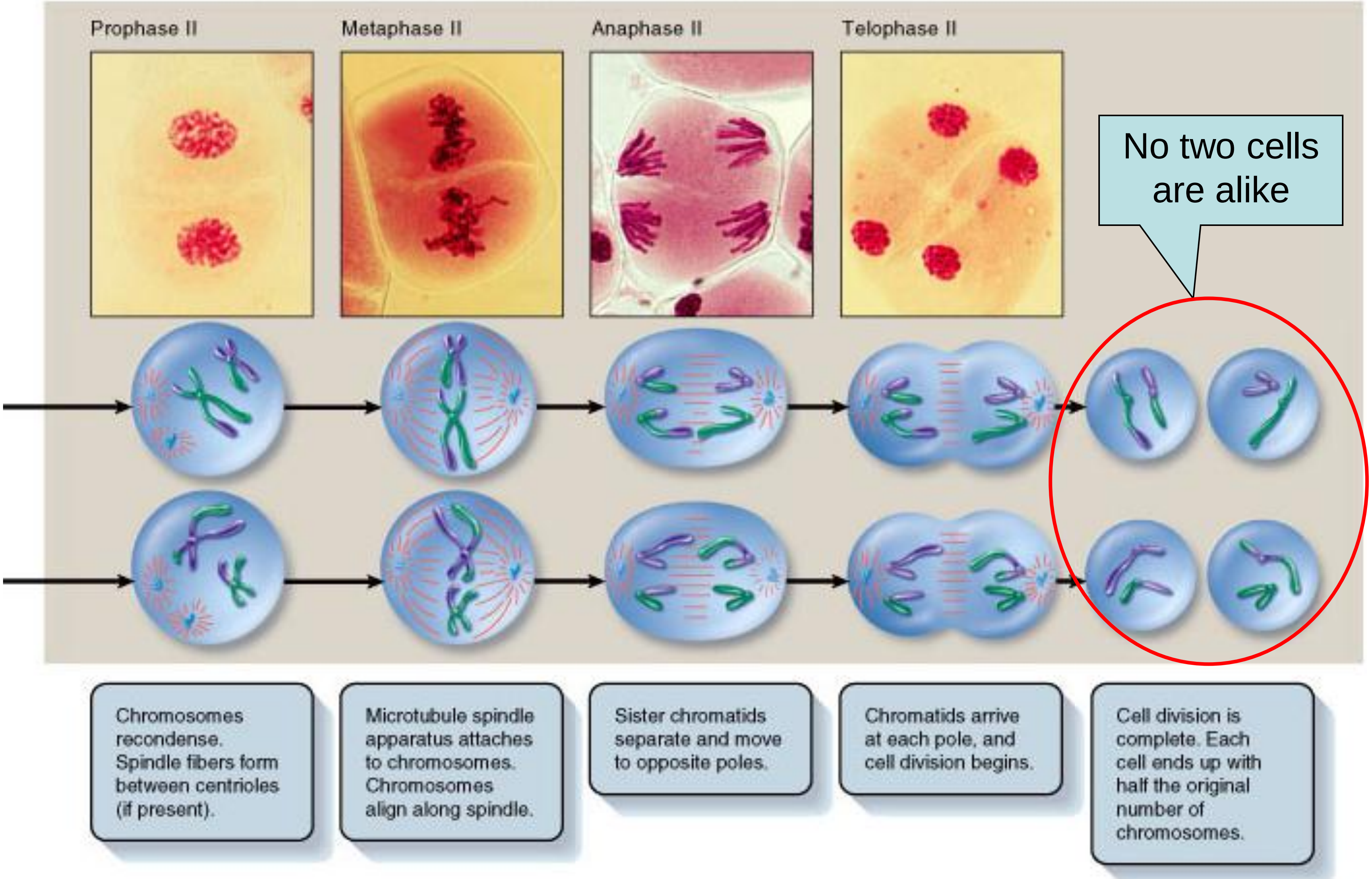
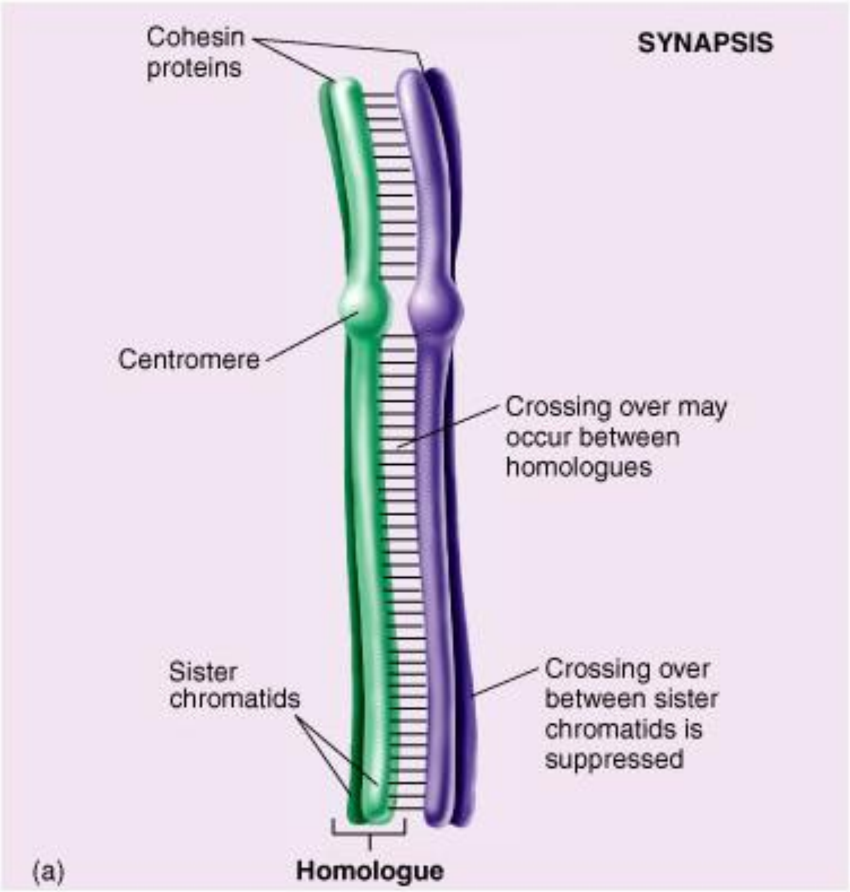

Prophase II
Metaphase II
Anaphase II
Telophase II
No two cells are alike
Chromosomes recondense. Spindle fibers form between centrioles (if present).
Microtubule spindle apparatus attaches to chromosomes. Chromosomes align along spindle.
Sister chromatids separate and move to opposite poles.
Chromatids arrive at each pole, and cell division begins.
Cell division is complete. Each cell ends up with half the original number of chromosomes.

Fig. 7.23

7.12 Comparing Meiosis and Mitosis

- Meiosis and mitosis have much in common
- However, meiosis has two unique features
  - 1. Synapsis
    - Homologous chromosomes pair all along their lengths in meiosis I
  - 2. Reduction division
    - There is no chromosome duplication between the two meiotic divisions
    - This produces haploid gametes

Fig. 7.24 Unique features of meiosis



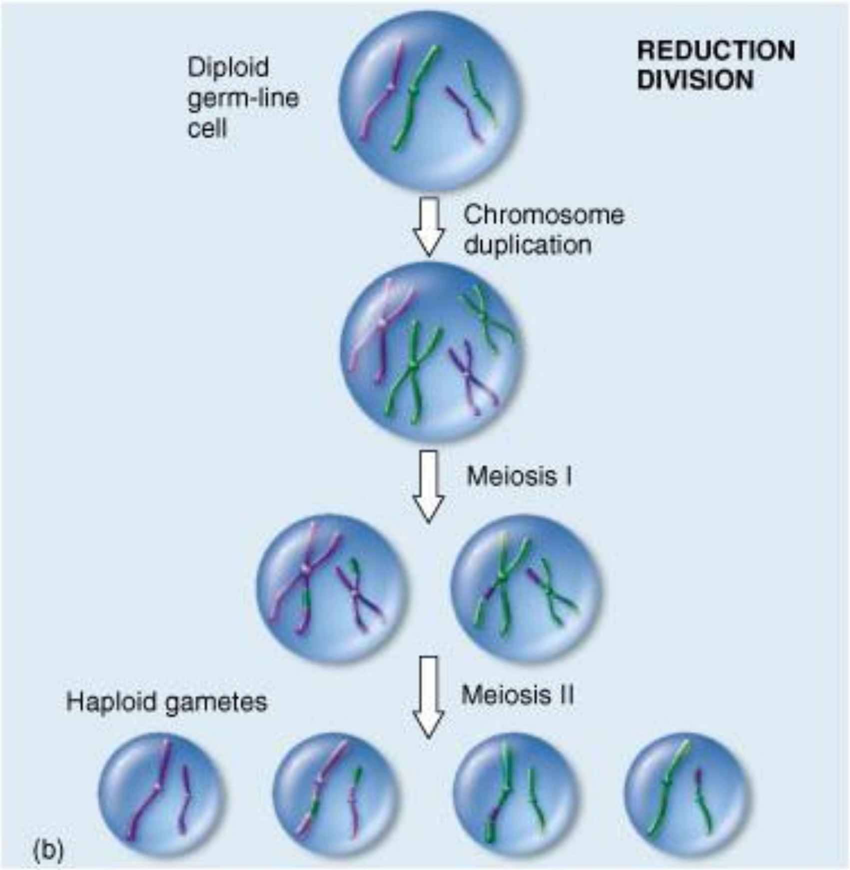
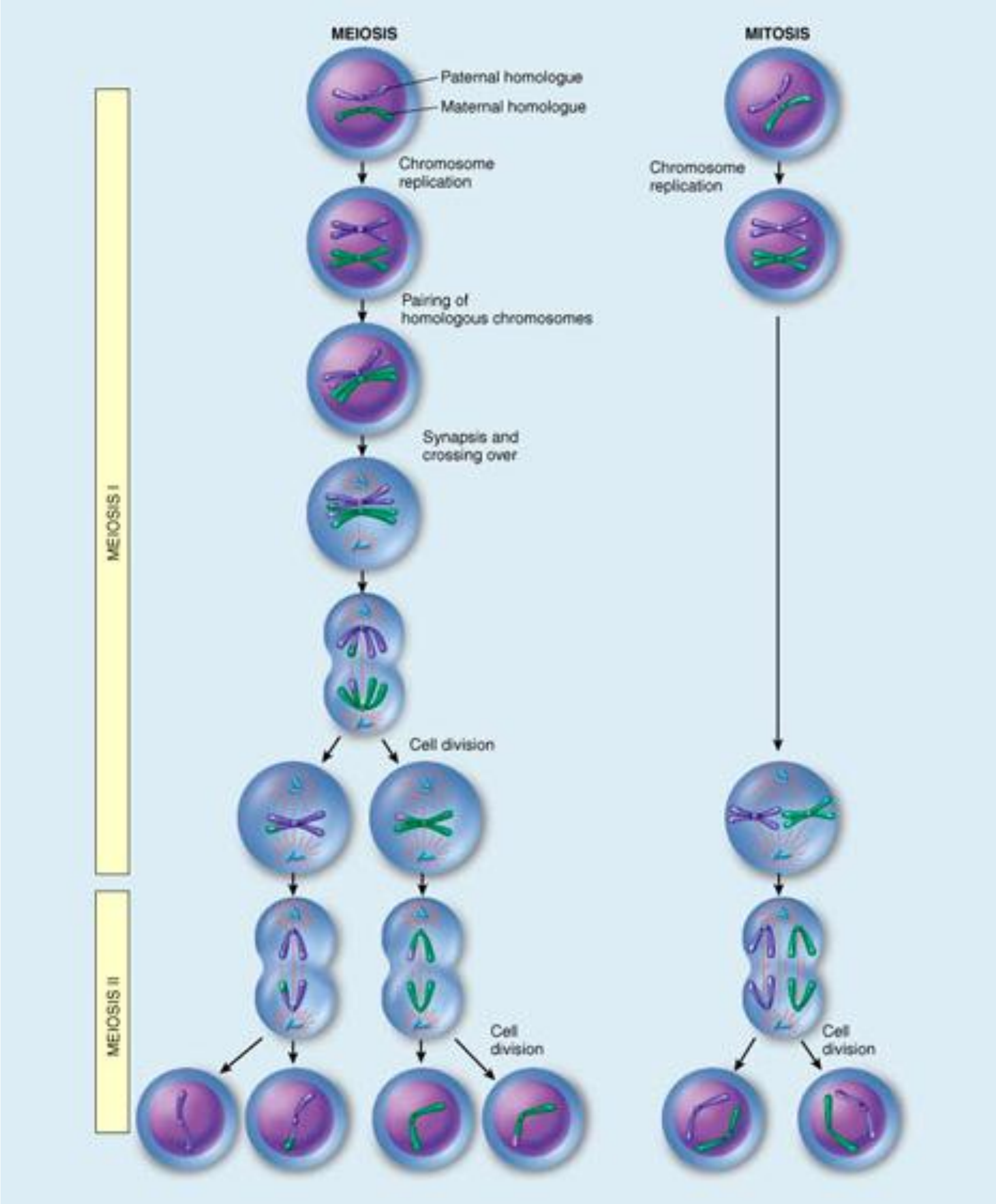


Fig. 7.25 A comparison of meiosis and mitosis



7.13 Evolutionary Consequences of Sex

- Sexual reproduction increases genetic diversity through three key mechanisms
  - 1. Independent assortment
  - 2. Crossing over
  - 3. Random fertilization

Independent assortment

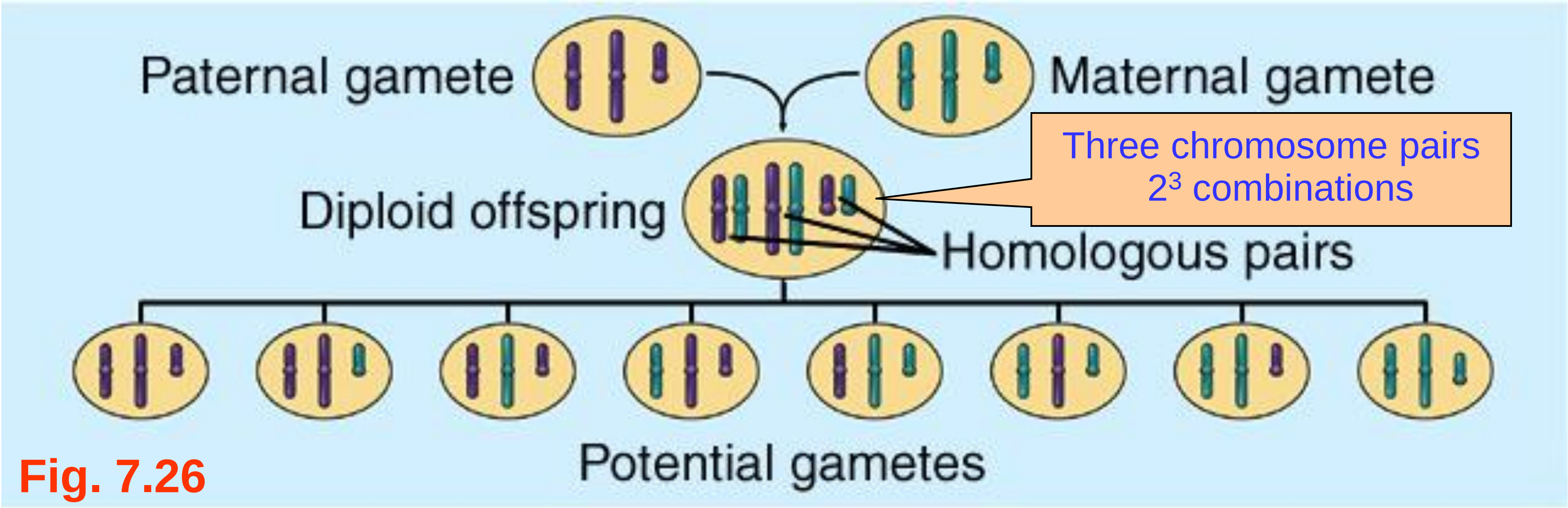


Fig. 7.26

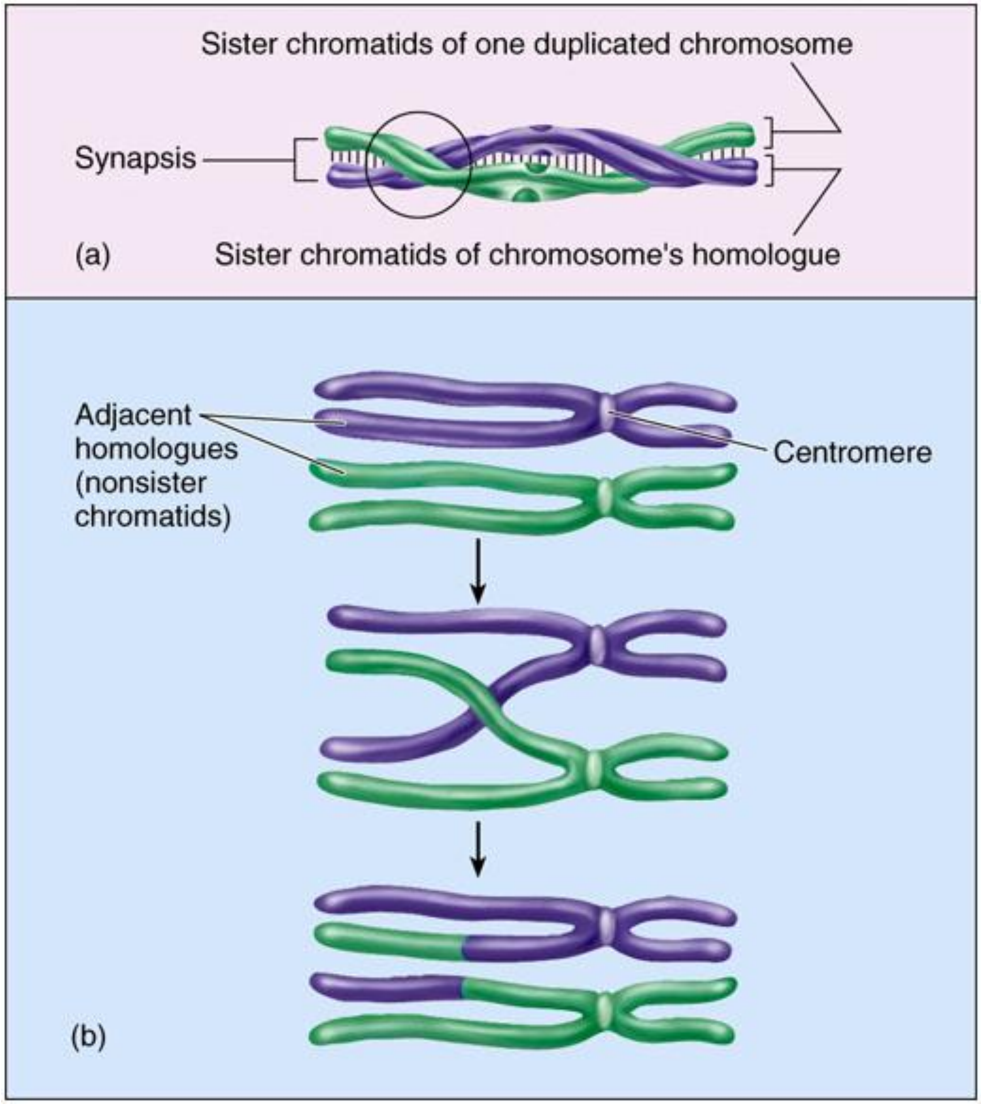
- In humans, a gamete receives one homologue of each of the 23 chromosomes
  - Humans have 23 pairs of chromosomes
    - 2^{23} combinations in an egg or sperm
    - 8,388,608 possible kinds of gametes

Crossing over

- DNA exchanges between maternal and paternal chromatid pairs

- This adds even more recombination to independent assortment that occurs later

Fig. 7.20



Random fertilization

- The zygote is formed by the union of two independently-produced gametes

- Therefore, the possible combinations in an offspring

  - 8,388,608 X 8,388,608 =

  - 70,368,744,177,664
  - More than 70 trillion!
    - And this number does not count crossing-over

Importance of Generating Diversity

- Genetic diversity is the raw material that fuels evolution
  - And no genetic process generates diversity more quickly than sexual reproduction