Chromosomal Basis of Inheritance

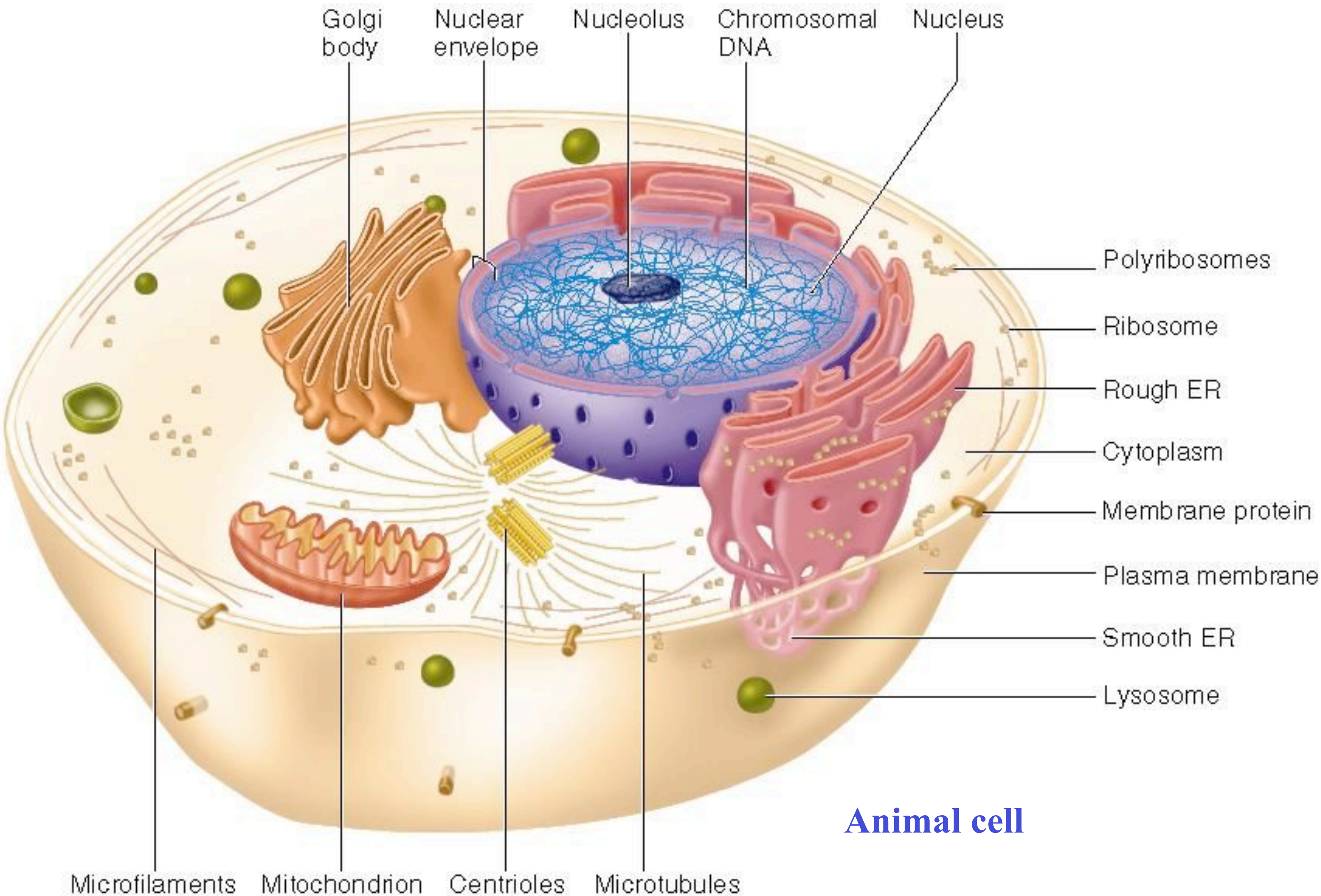
Ch. 3

INTRODUCTION

- In this chapter we will survey reproduction at the cellular level
- We will examine chromosomes at the microscopic level
  – This examination provides us with insights to understand the inheritance patterns of traits

GENERAL FEATURES OF CHROMOSOMES

- Chromosomes are structures within living cells that contain the genetic material
  - They contain the genes
- Biochemically, chromosomes are composed of
  - DNA, which is the genetic material
  - Proteins, which provide an organized structure


Golgi body
Nuclear envelope
Nucleolus
Chromosomal DNA
Nucleus
Polyribosomes
Ribosome
Rough ER
Cytoplasm
Membrane protein
Plasma membrane
Smooth ER
Lysosome
Microfilaments
Mitochondrion
Centrioles
Microtubules

Animal cell

Cytogenetics

- The field of genetics that involves the microscopic examination of chromosomes

- A cytogeneticist typically examines the chromosomal composition of a particular cell or organism
  - This allows the detection of individuals with abnormal chromosome number or structure
  - This also provides a way to distinguish between two closely-related species

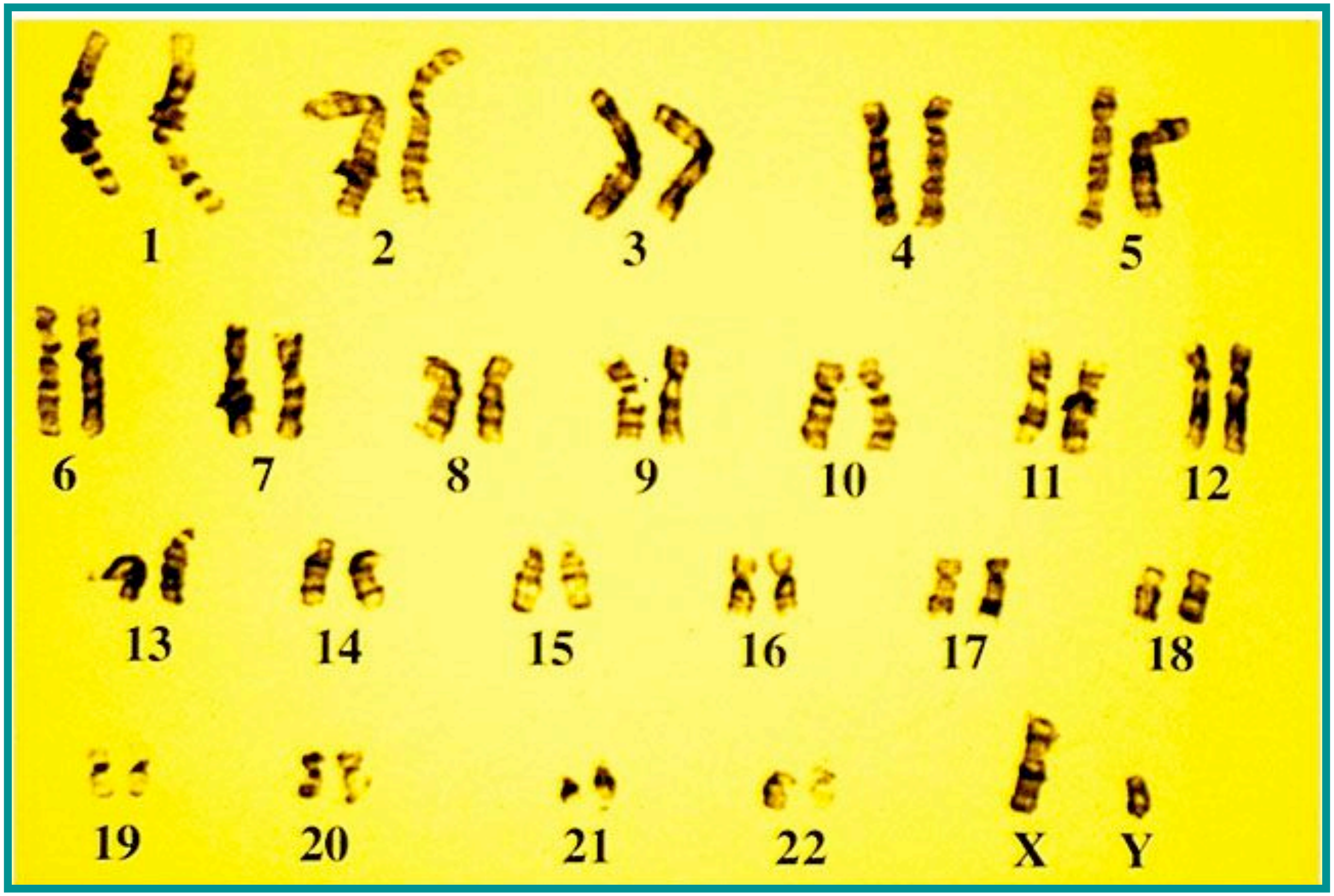
Cytogenetics

- Animal cells are of two types
  - Somatic cells
    - Body cells, other than gametes
      - Blood cells, for example
  - Germ cells
    - Gametes
      - Sperm and egg cells

Cytogenetics

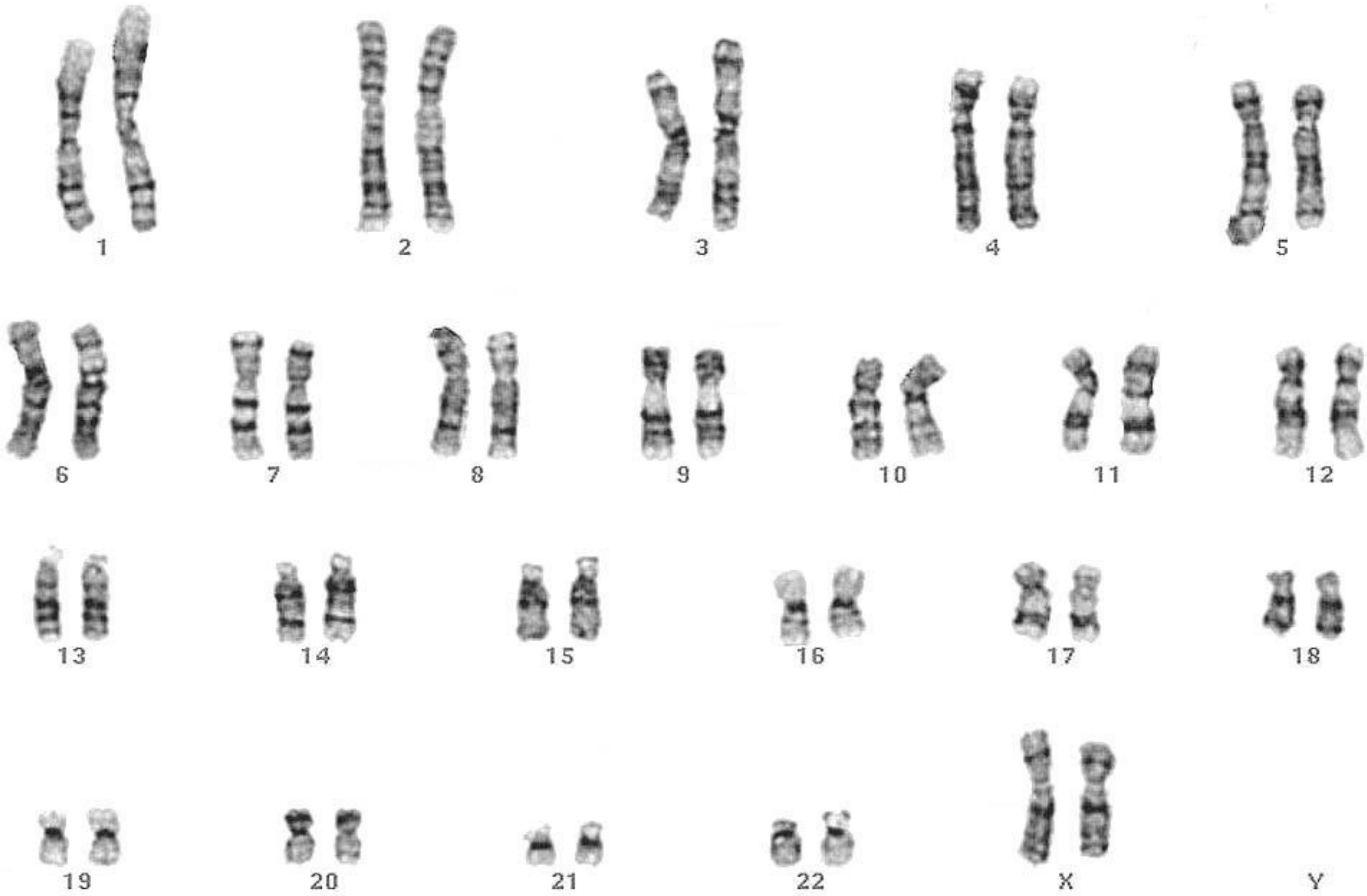
- In a cytogenetics laboratory, the microscopes are equipped with a camera
- Microscopic images can now be scanned into a computer
- There, they can be organized in a standard way, usually from largest to smallest
- A karyotype is the photographic representation of the chromosomes within a cell

Karyotypes can be produced by cutting micrograph images of stained chromosomes and arranging them in matched pairs



Human male karyotype

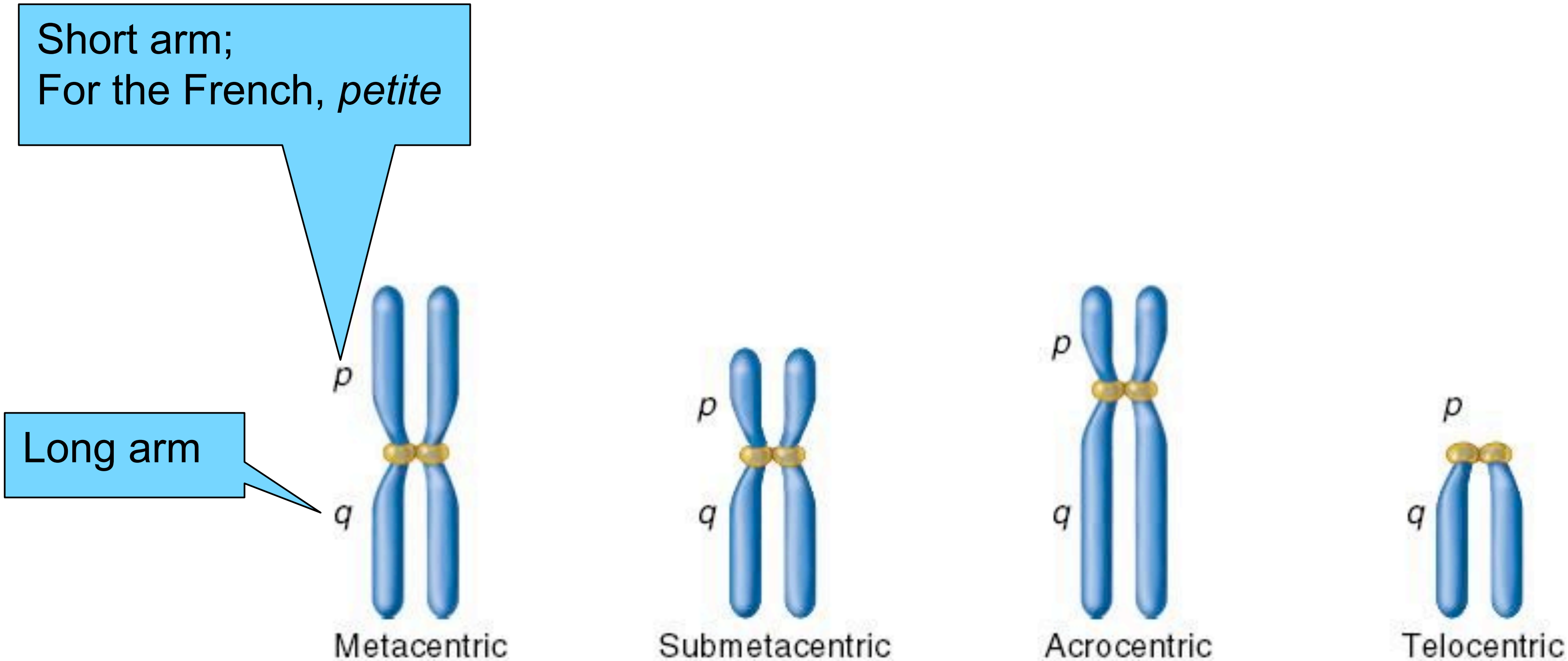
Female Karyotype



Cytogenetics

- Cytogeneticists use three main features to identify and classify chromosomes
  - 1. Size of arms
  - 2. Location of the centromere
  - 3. Banding patterns
    - Based on different staining dyes

Chromosomes



(b) A comparison of centromeric locations

Eukaryotic Chromosomes Are Inherited in Sets

- Most eukaryotic species are diploid (2n)
  - Have two sets of chromosomes

- For example
  - Humans
    - 46 total chromosomes (23 per set (n))
  - Dogs
    - 78 total chromosomes (39 per set (n))
  - Fruit fly
    - 8 total chromosomes (4 per set (n))

Eukaryotic Chromosomes Are Inherited in Sets

- Members of a pair of chromosomes are called homologues
  - The two homologues form a homologous pair

- The two chromosomes in a homologous pair
  - Are nearly identical in size
  - Have the same banding pattern and centromere location
  - Have the same genes
    - But not necessarily the same alleles

Eukaryotic Chromosomes Are Inherited in Sets

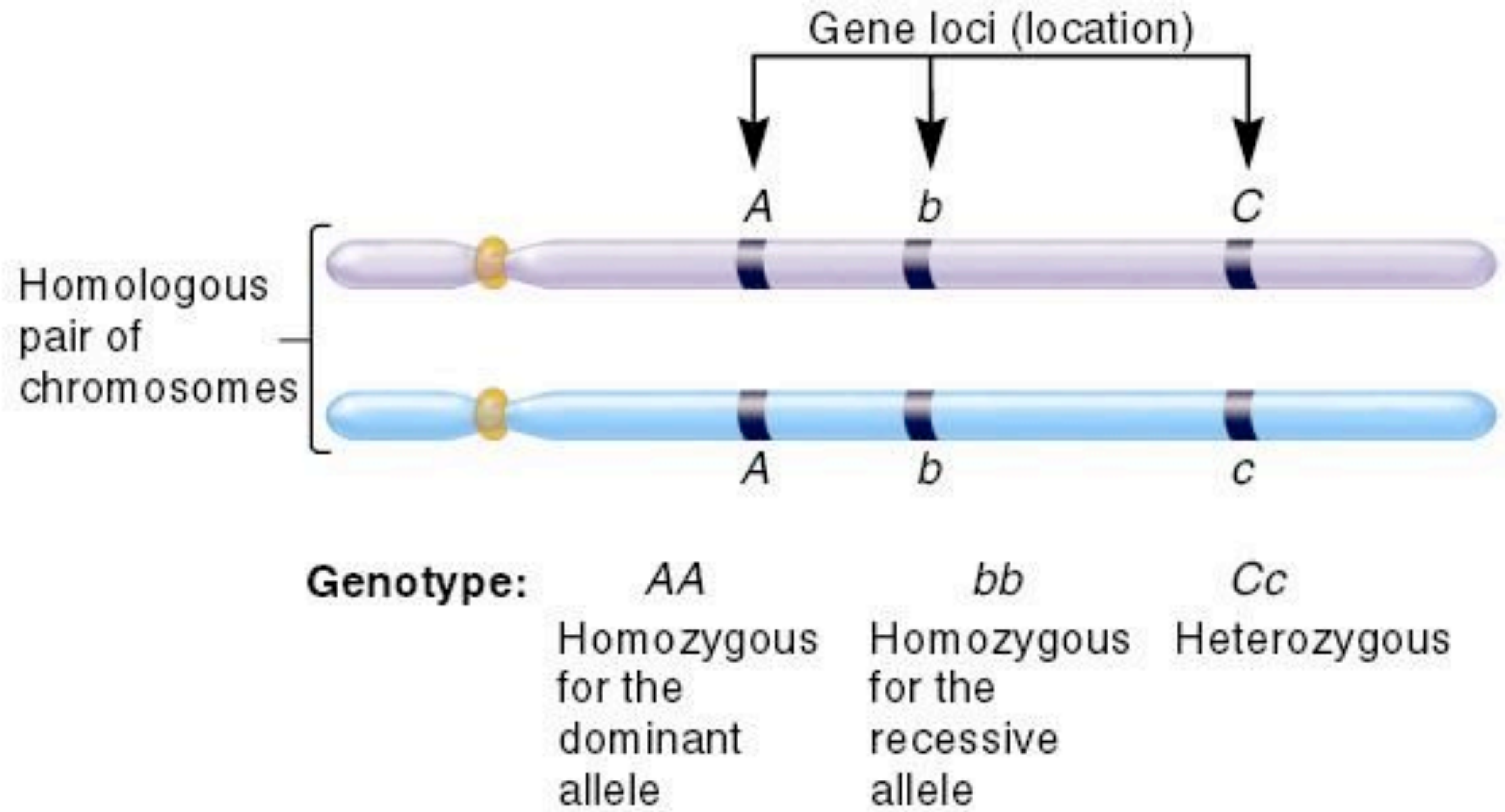
- The DNA sequences on homologous chromosomes are also very similar
  - There is usually less than 1% difference between homologues
- Nevertheless, these slight differences in DNA sequence provide the allelic differences in genes
  - Eye color gene
    - Blue allele *vs* brown allele

Eukaryotic Chromosomes Are Inherited in Sets

- The sex chromosomes (X and Y) are not homologous
  - They differ in size and genetic composition
- They do have short regions of homology that allow for homologous pairing in meiosis….

Two homologous chromosomes labeled with 3 different genes

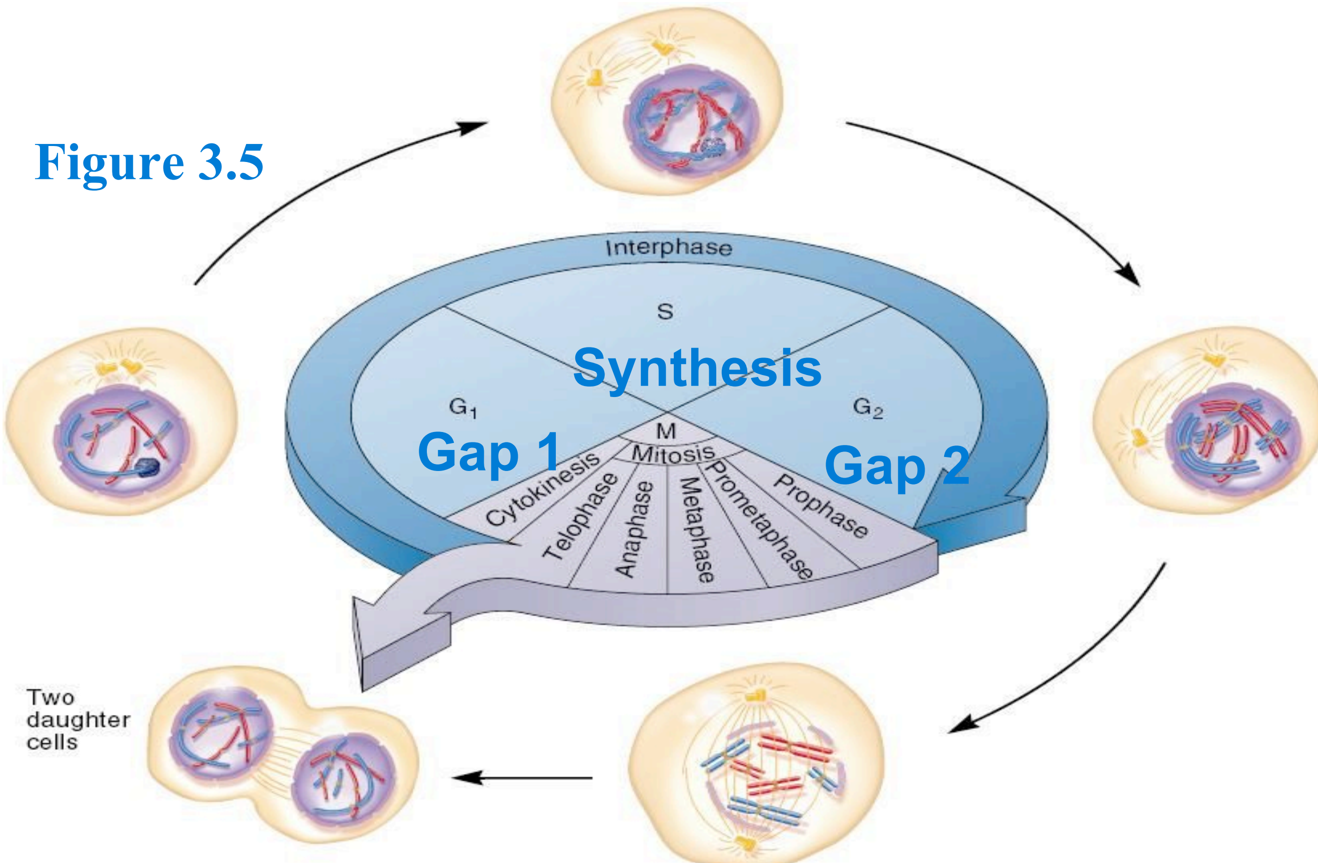
The physical location of a gene on a chromosome is called its locus.



Mitosis

- Eukaryotic cells that are destined to divide progress through a series of stages known as the cell cycle

Figure 3.5



Mitosis

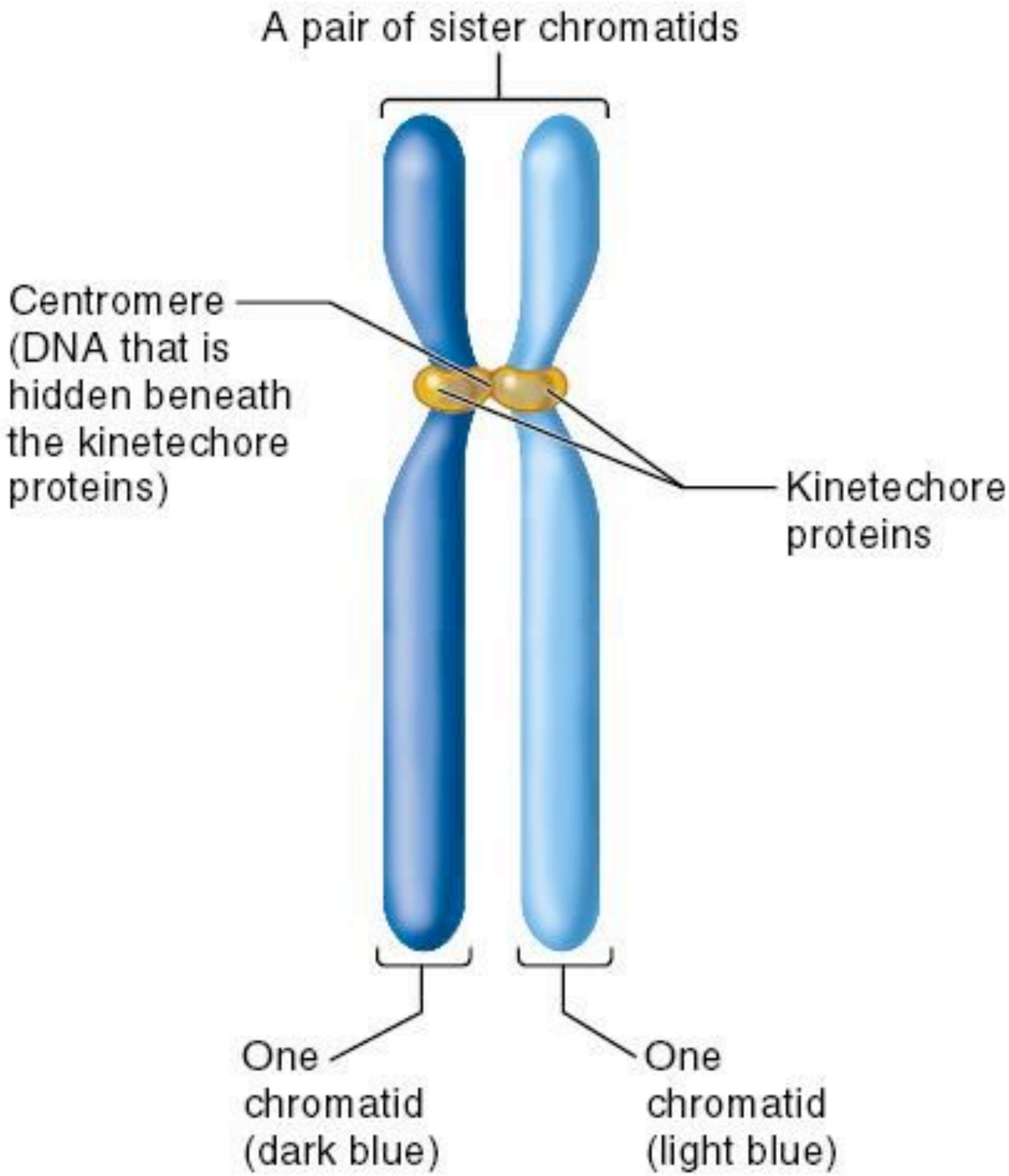
- In actively dividing cells, G_1, S and G_2 are collectively know as interphase
- A cell may remain for long periods of time in the G_0 phase
  - A cell in this phase has
    - Either postponed making a decision to divide
    - Or made the decision to never divide again
      - Terminally differentiated cells (e.g. nerve cells)

Mitosis

- During the G_1 phase, a cell prepares to divide

- The cell reaches a restriction point and is committed on a pathway to cell division

- Then the cell advances to the S phase, where chromosomes are replicated
  - The two copies of a replicated chromosome are termed chromatids
  - They are joined at the centromere to form a pair of sister chromatids


A pair of sister chromatids
Centromere (DNA that is hidden beneath the kinetechore proteins)
Kinetechore proteins
One chromatid (dark blue)
One chromatid (light blue)

Mitosis

- At the end of S phase, a cell has twice as many chromatids as there are chromosomes in the G_1 phase
  - A human cell for example has
    - 46 distinct chromosomes in G_1 phase
    - 46 pairs of sister chromatids in S phase

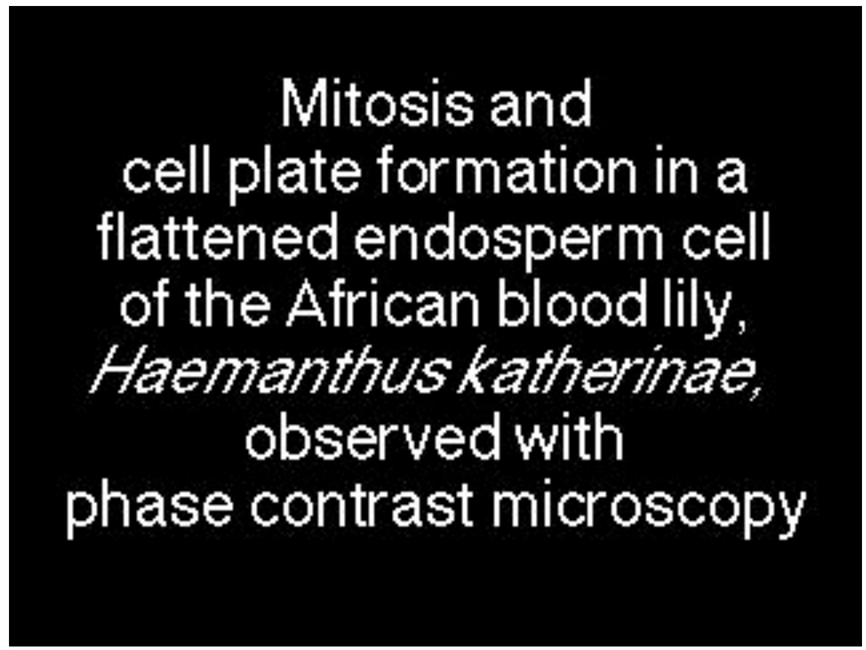
- Therefore the term *chromosome* is relatively confusing:
  - In G_1 and late in the M phase
    - it refers to the equivalent of one chromatid
  - In G_2 and early in the M phase
    - it refers to a pair of sister chromatids

Mitosis

- During the G_2 phase
  - the cell accumulates the materials necessary for
    - nuclear and cell division
- It then progresses into the M phase of the cycle
  - where mitosis occurs
- Purpose of mitosis is to distribute the replicated chromosomes to the two daughter cells
  - In humans for example,
    - The 46 pairs of sister chromatids are separated
    - Each daughter cell thus receives 46 chromosomes

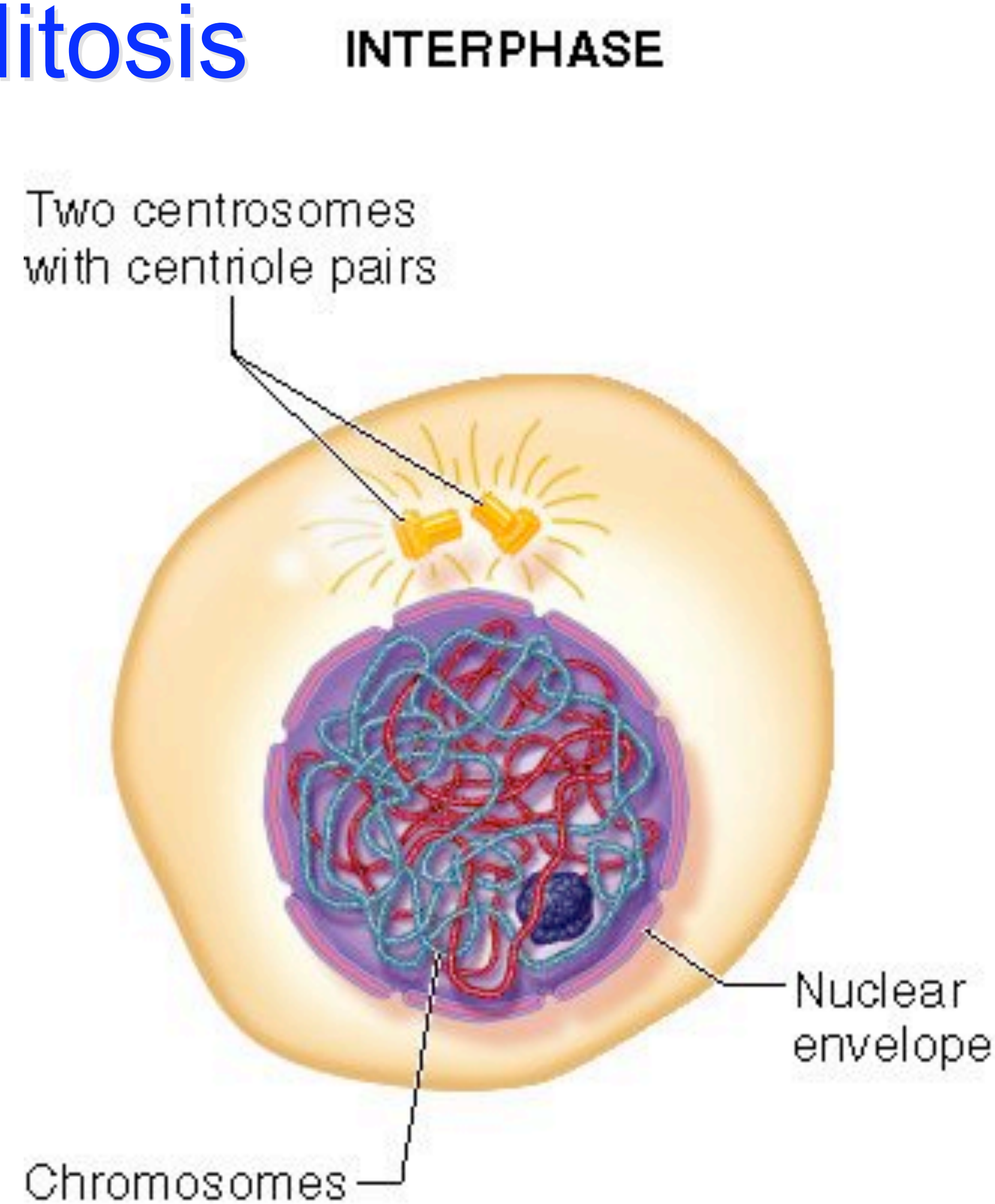
Phases of Mitosis

- Mitosis is subdivided into five phases
  - Prophase
  - Prometaphase
  - Metaphase
  - Anaphase
  - Telophase



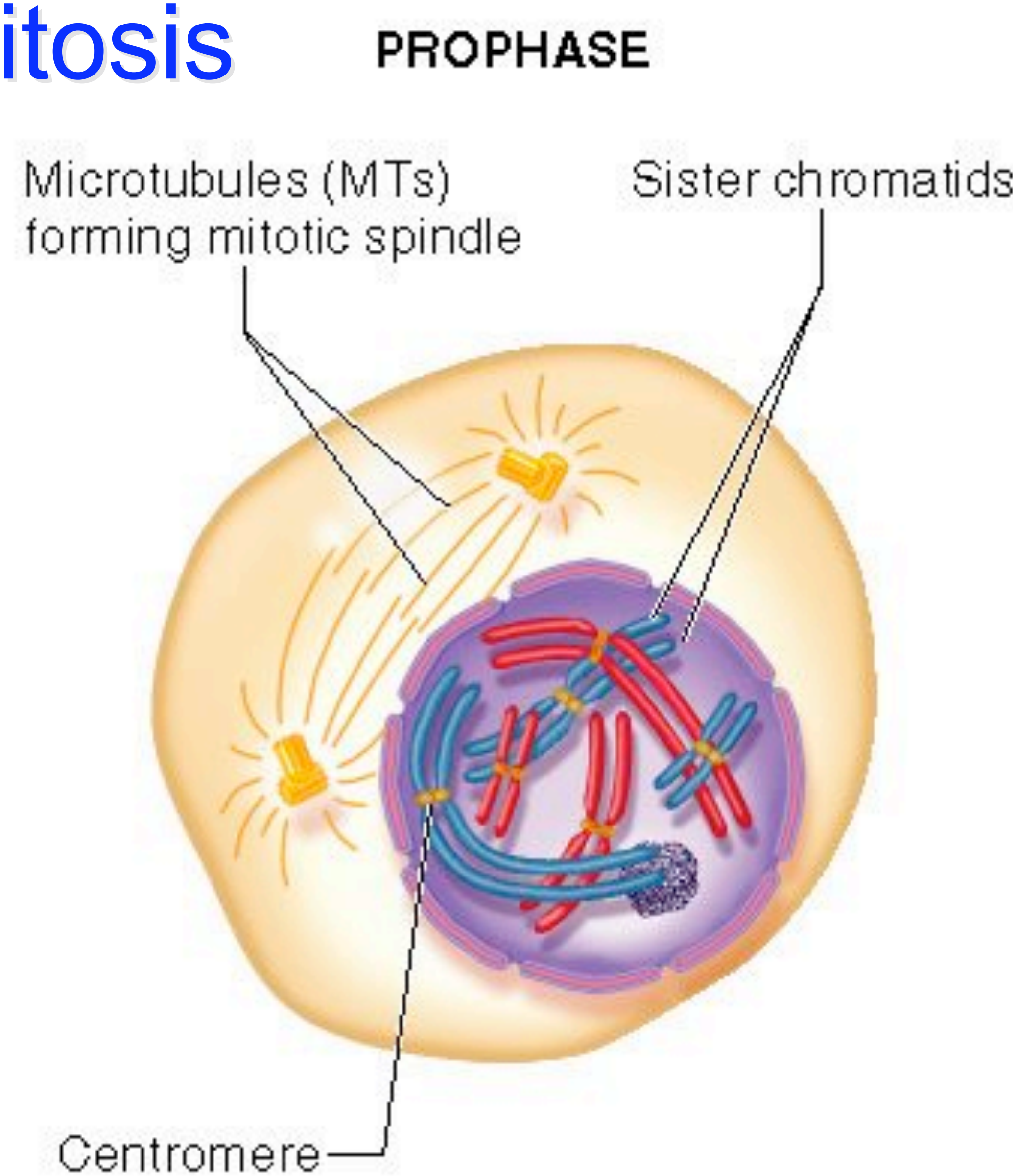
Mitosis

- Chromosomes are decondensed
- By the end of this phase, the chromosomes have already replicated
  - But the six pairs of sister chromatids are not seen until prophase
- The centrosome divides



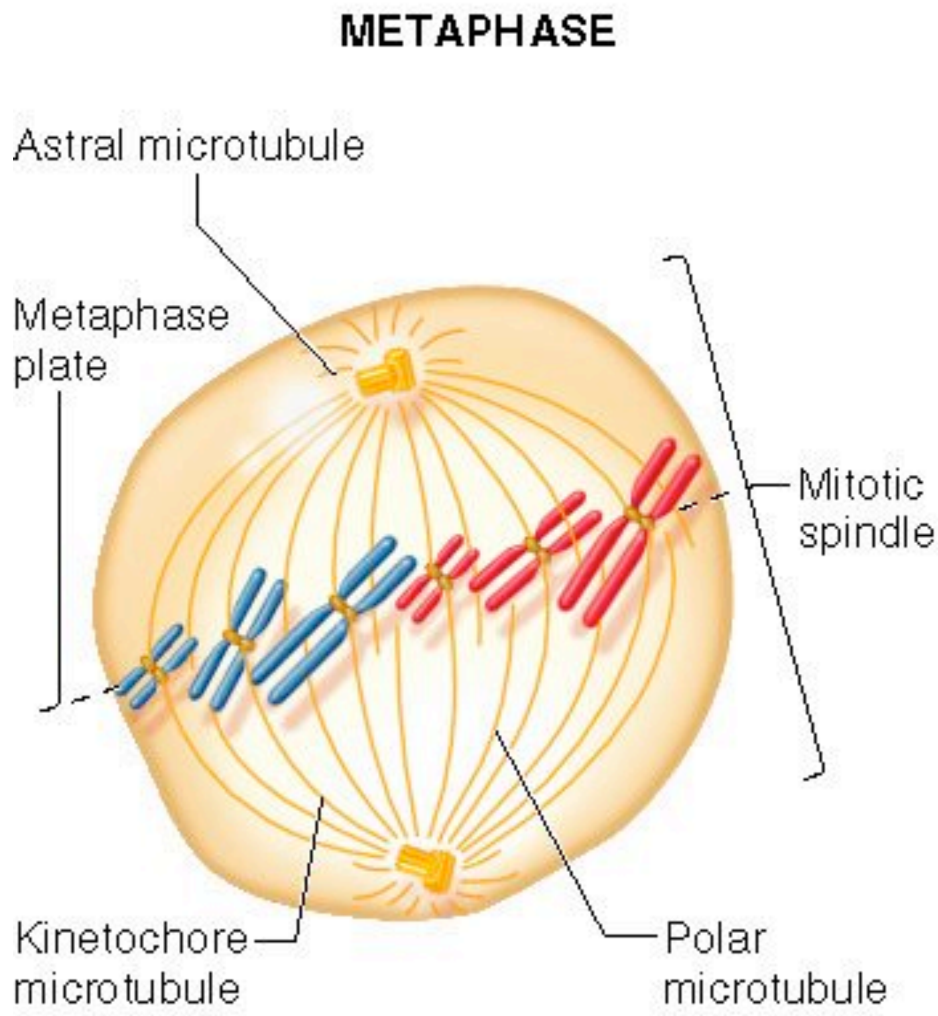
Mitosis

- Nuclear envelope dissociates into smaller vesicles
- Centrosomes separate to opposite poles
- The mitotic spindle apparatus is formed
  - Composed of mircotubules (MTs)



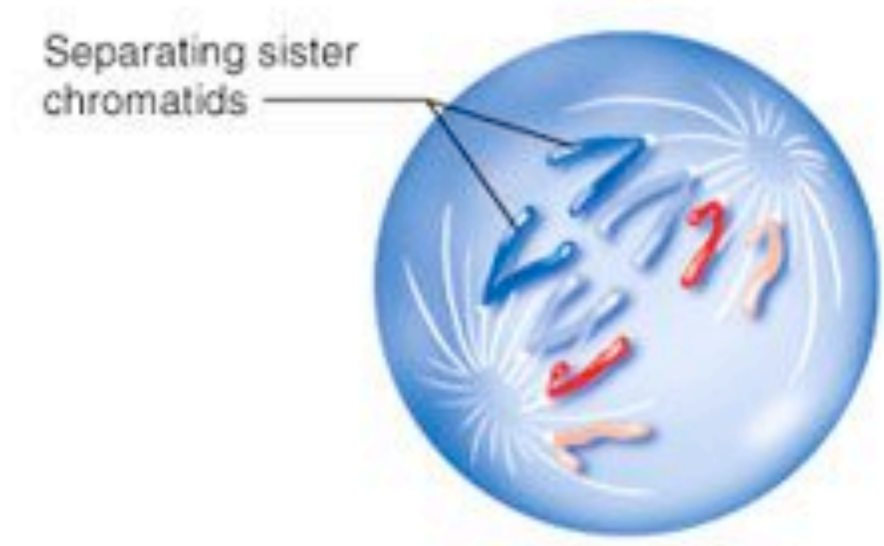
Mitosis

- Pairs of sister chromatids align themselves along a plane called the metaphase plate
- Each pair of chromatids is attached to both poles by kinetochore microtubules



Mitosis

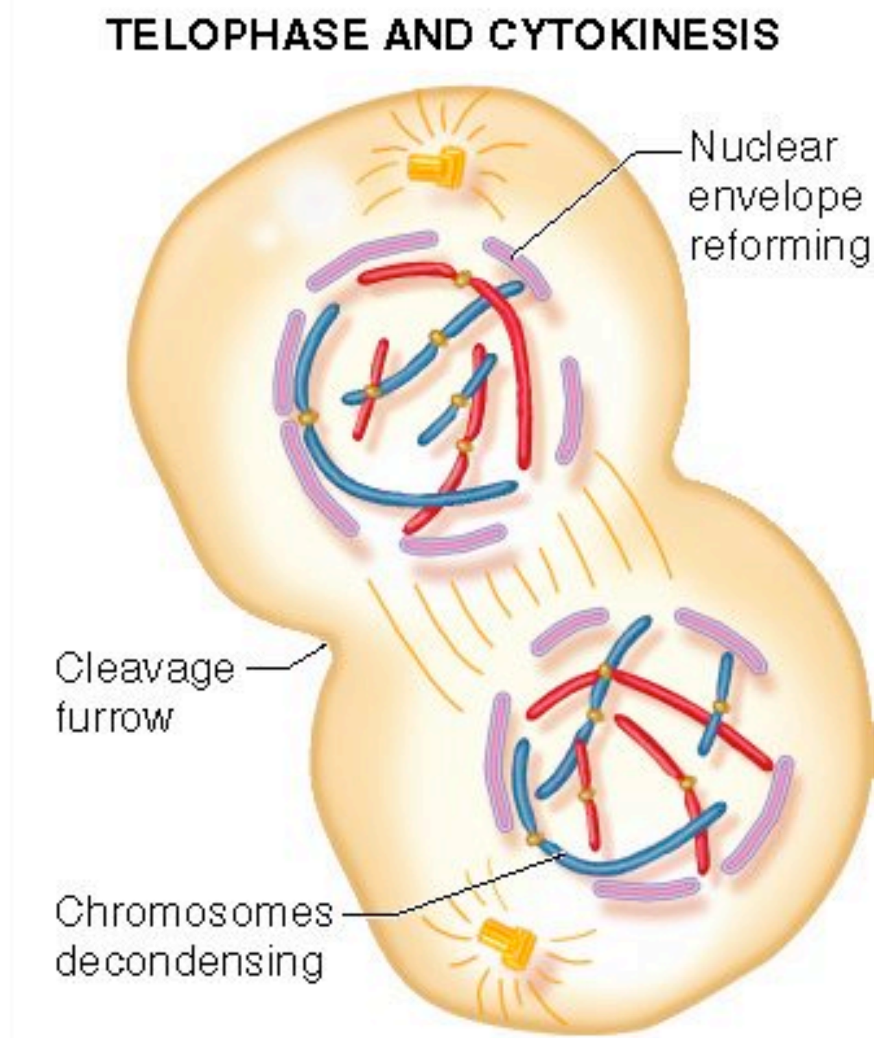
Separation of sister chromatids allows each chromatid to be pulled towards spindle pole connected to by kinetochore microtubule



Anaphase

Mitosis

- Chromosomes reach their respective poles and decondense
- Nuclear membrane reforms to form two separate nuclei
- In most cases, mitosis is quickly followed by cytokinesis
  - In animals
    - Formation of a cleavage furrow
  - In plants
    - Formation of a cell plate
    - Refer to Figure 3.9



Mitosis

- Mitosis and cytokinesis ultimately produce two daughter cells
  - having the same number of chromosomes as the mother cell
- The two daughter cells are genetically identical to each other
  - Barring rare mutations
- Thus, mitosis ensures genetic consistency from one cell to the next
- The development of multicellularity relies on the repeated process of mitosis and cytokinesis

Meiosis

From Diploid (2n) to Haploid (n)

Meiosis produces haploid germ cells

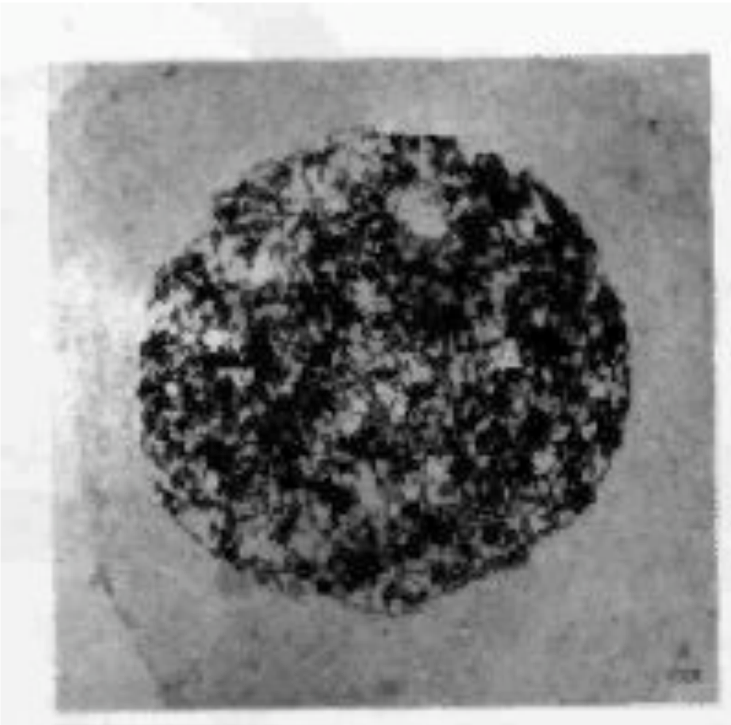
- Somatic cells –
  - divide mitotically and make up vast majority of organism's tissues
- Germ cells –
  - specialized role in the production of gametes
    - Arise during embryonic development in animals and floral development in plants
    - Undergo meiosis to produce haploid gametes
    - Gamete unites with gamete from opposite sex to produce diploid offspring

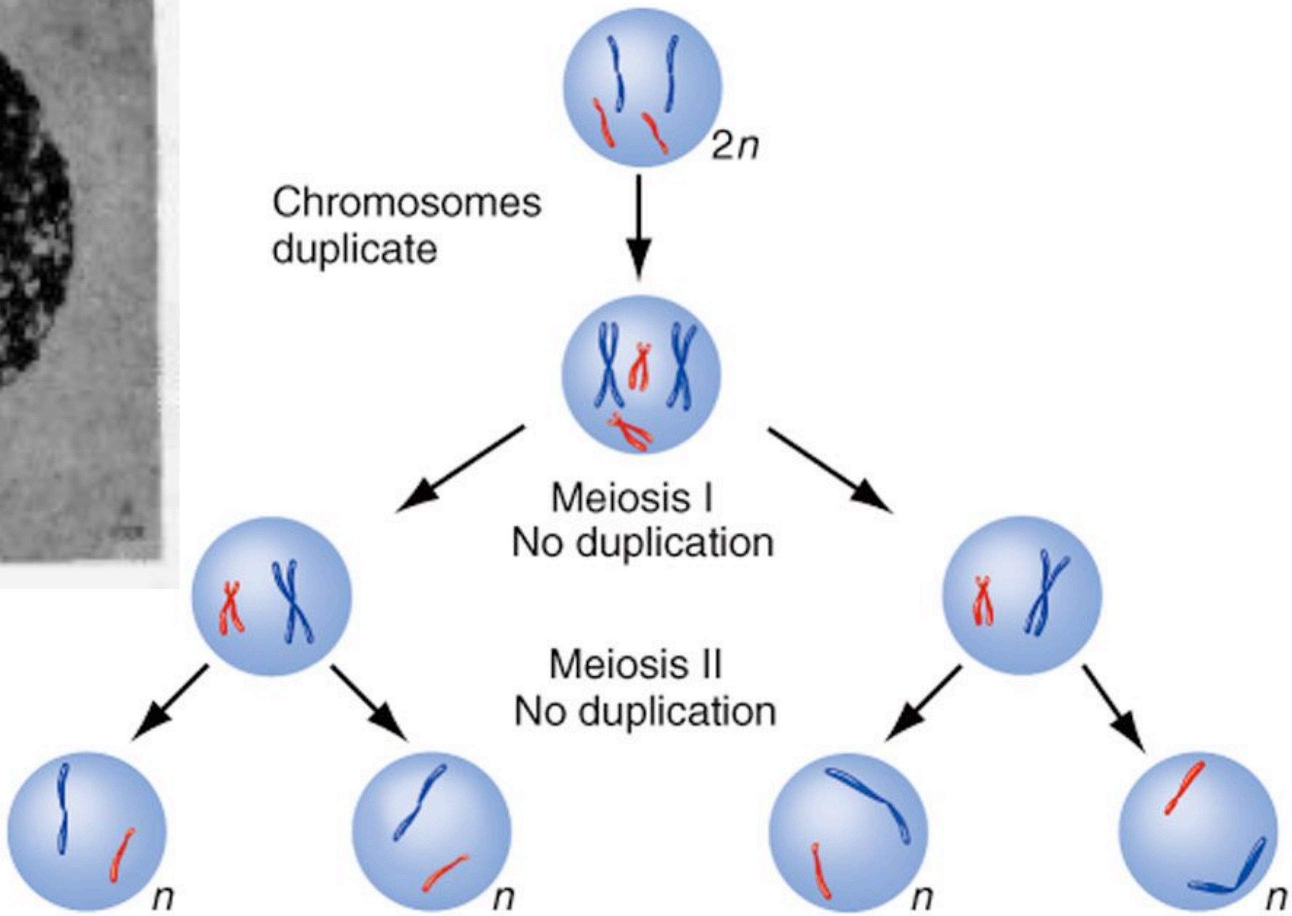
Meiosis

- Gametes are typically haploid
  - They contain a single set of chromosomes
- Gametes are 1*n*, while diploid cells are 2*n*
  - A diploid human cell contains 46 chromosomes
  - A human gamete only contains 23 chromosomes
- During meiosis, haploid cells are produced from diploid cells
  - Thus, the chromosomes must be correctly sorted and distributed to reduce the chromosome number to half its original value
    - In humans, for example, a gamete must receive one chromosome from each of the 23 pairs

Meiosis

Chromosomes replicate one time, nuclei divide twice





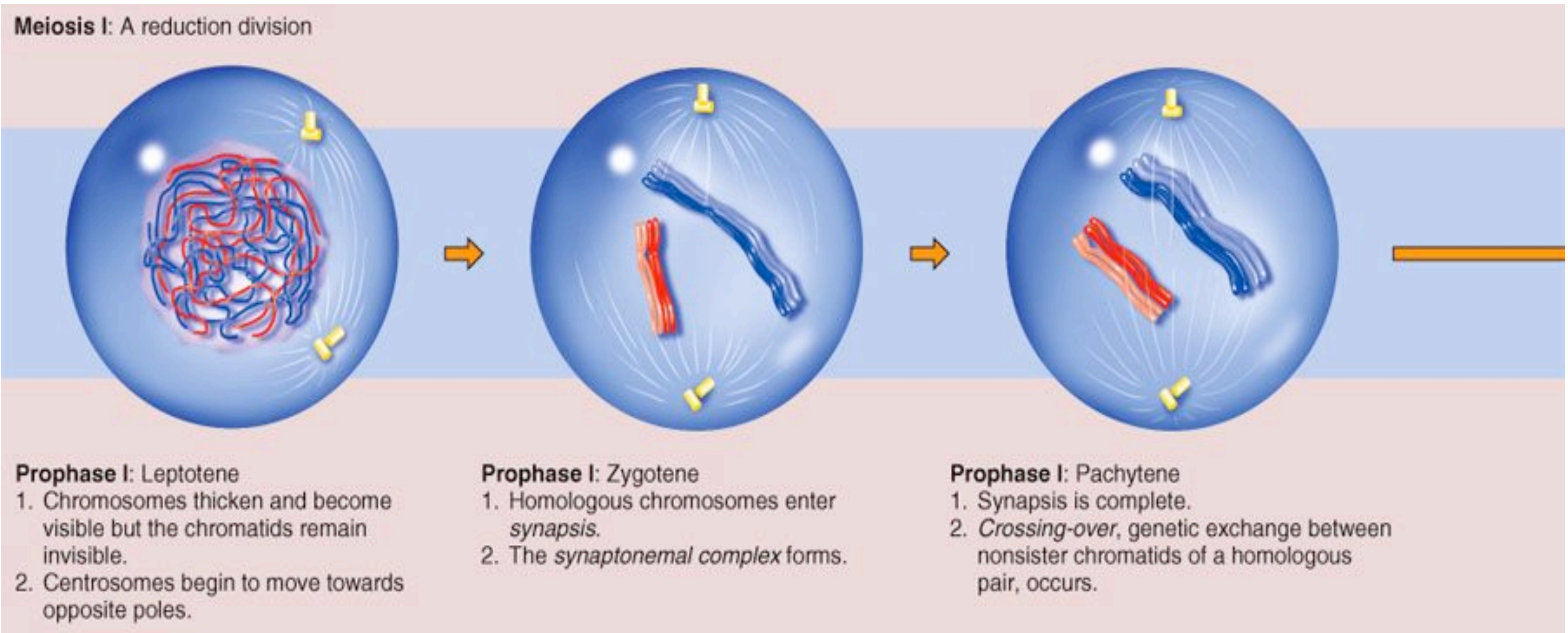
Stages of Meiosis

- Prophase I: Pairing of homologous chromosomes.
- Metaphase I: Alignment of paired chromosome at equator.
- Anaphase I: Homologous chromosomes move to opposite poles.
- Telophase I: Nuclear envelope reforms, 1 chromosome set.
- Interkinesis: Cell divides. No duplication of chromosomes.
- Prophase II: Chromosomes re-condense.
- Metaphase II: Chromosomes align at metaphase plate.
- Anaphase II: Centromeres divide, chromatids go to opposite poles.
- Telophase II: Chromosomes decondense, nuclear envelope reforms.
- Cytokinesis: Cytoplasm divides.

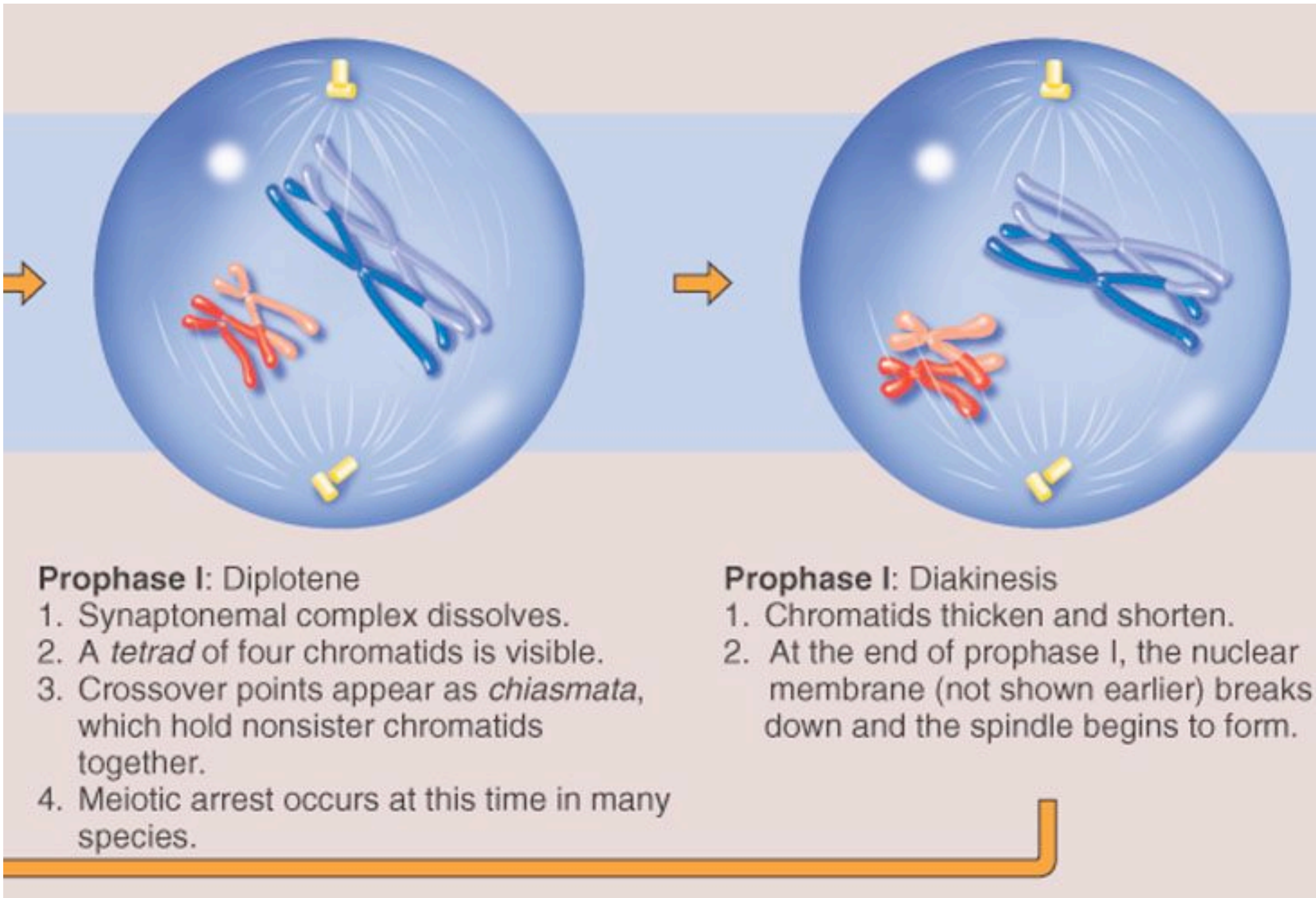
Meiosis I: Stages of Prophase I

- Prophase I: consists of multiple sub-stages:
  - Leptotene: Thickening of thin chromosomes.
  - Zygotene: Homologous chromosomes begin attaching to each other by a synaptosomal complex which exactly aligns the chromosomes.
  - Pachytene: Completion of the synaptosomal complex to form a bivalent chromosome structure. Crossing over occurs here.
  - Diplotene: disintegration of the synaptosomal complex, and slight seperation of homologous chromosomes.
  - Diakinesis: Further condensation (thickening) of chromatids.

Meiosis I– Prophase I



Meiosis I– Prophase I continued



Meiosis I: Crossing Over

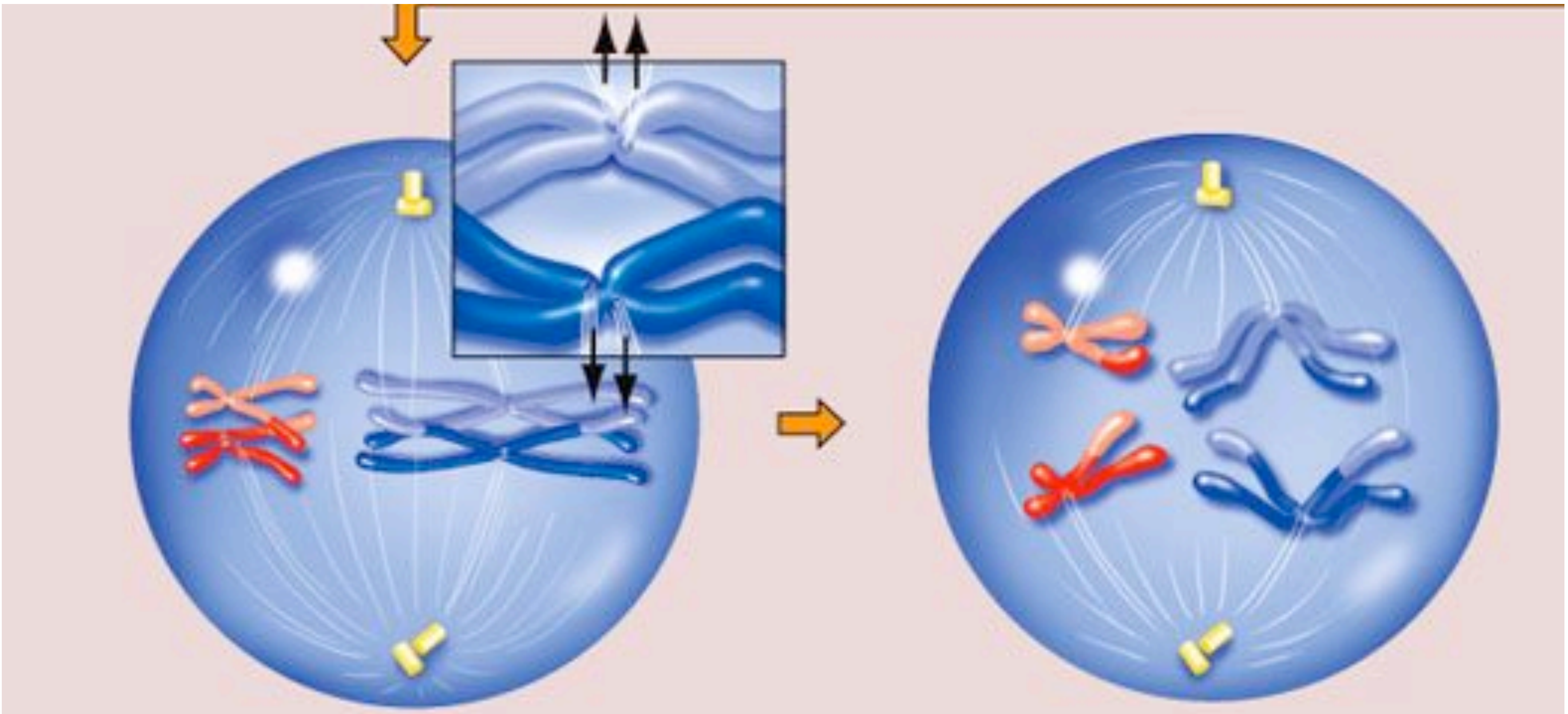
- An event where homologous chromosomes exchange parts, creating a new combination of gene alleles.
- The exchange of genetic material between the two homologous chromosomes is termed Recombination.
- Example
  - Before Crossover:
    - Maternal Chromosome Genes: ABCD
    - Paternal Chromosome Genes: abcd
  - After crossing over:
    - Maternal Chromosome Genes: ABcd
    - Paternal Chromosome Genes: abCD

Meiosis I: Crossing Over

(d) Diplotene: Bivalent appears to pull apart slightly but remains connected at crossover sites, called chiasmata.

(e) Diakinesis: Further condensation of chromatids. Nonsister chromatids that have exchanged parts by crossing-over remain closely associated at chiasmata.

Meiosis I – Metaphase and Anaphase



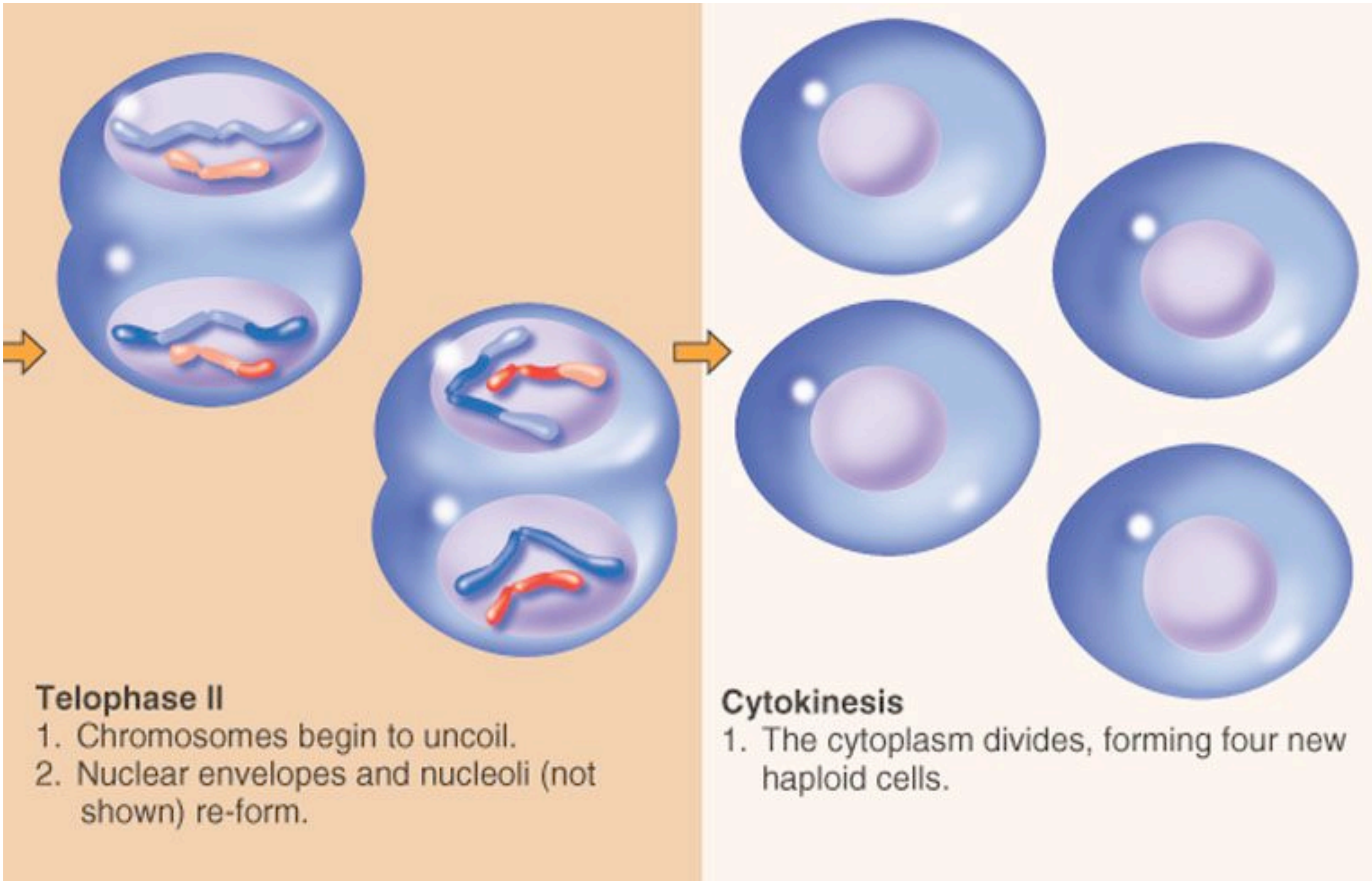
Metaphase I

1. Tetrads line up along the *metaphase plate*.
2. Each chromosome of a homologous pair attaches to fibers from opposite poles.
3. Sister chromatids attach to fibers from the same pole.

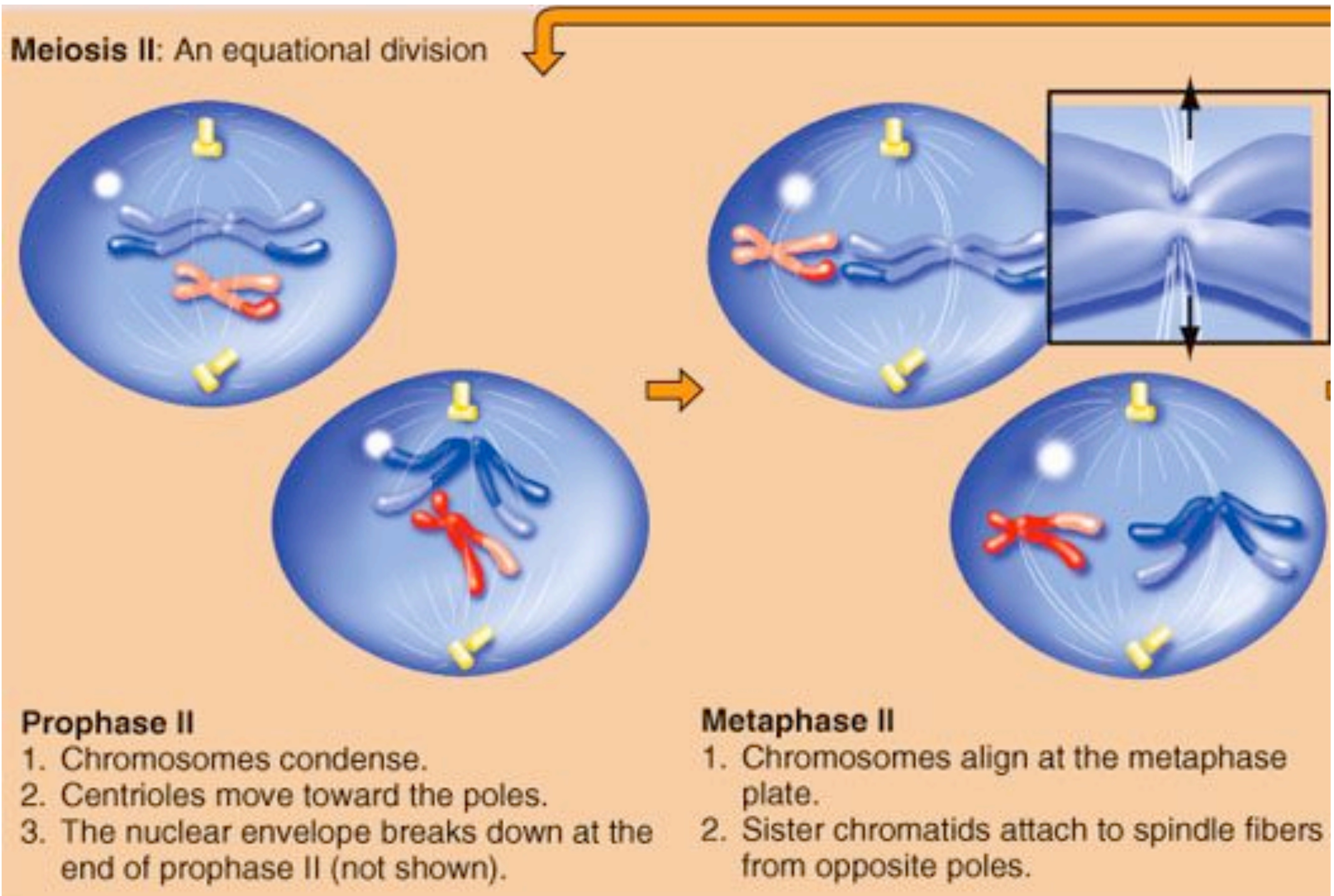
Anaphase I

1. The centromere does not divide.
2. The chiasmata migrate off chromatid ends.
3. Homologous chromosomes move to opposite poles.

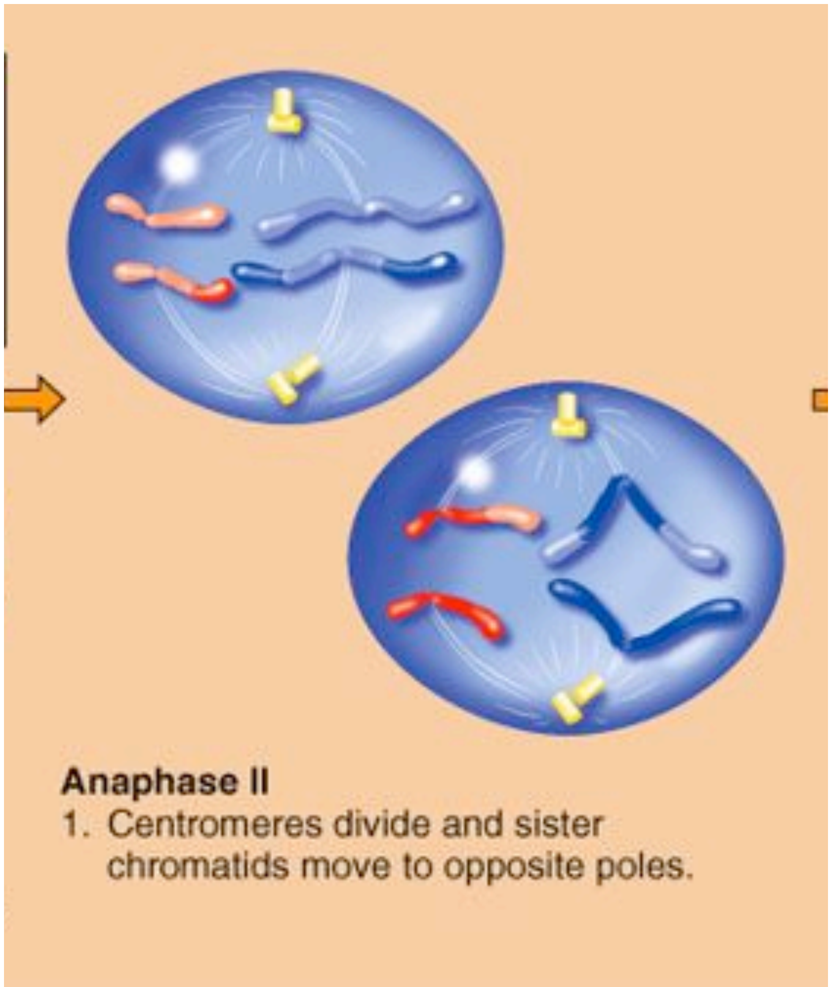
Meiosis I– Telophase I and Interkinesis

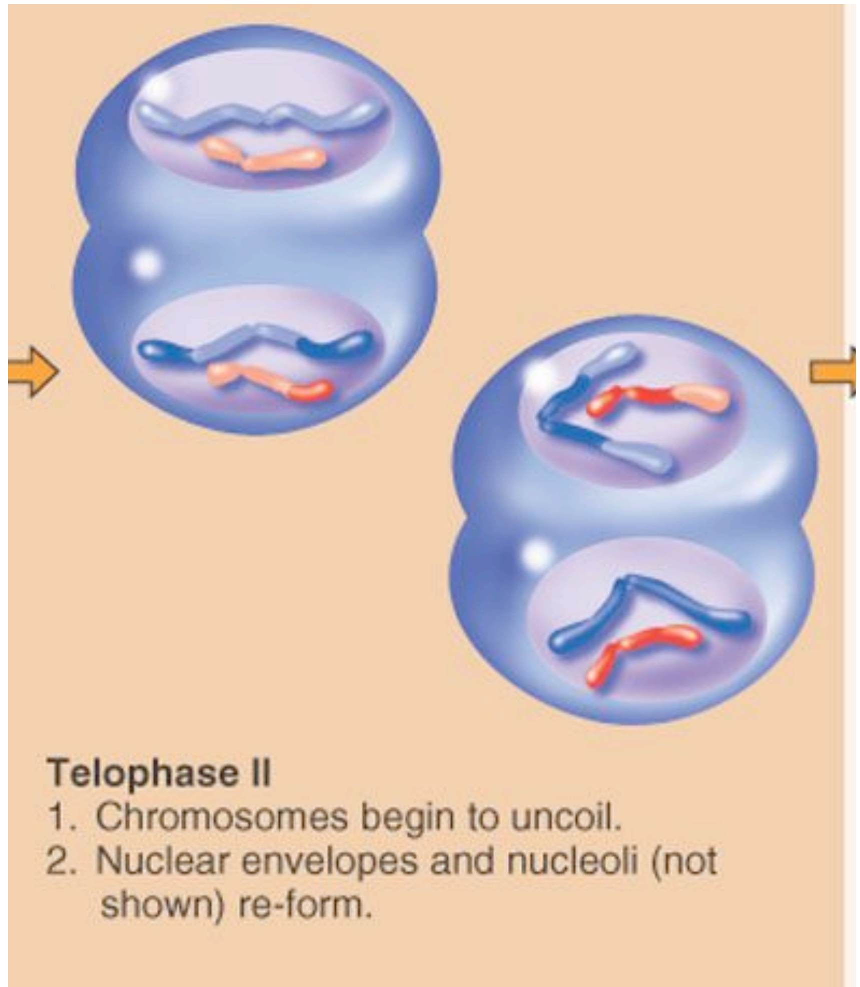


Meiosis II– Prophase II and Metaphase II

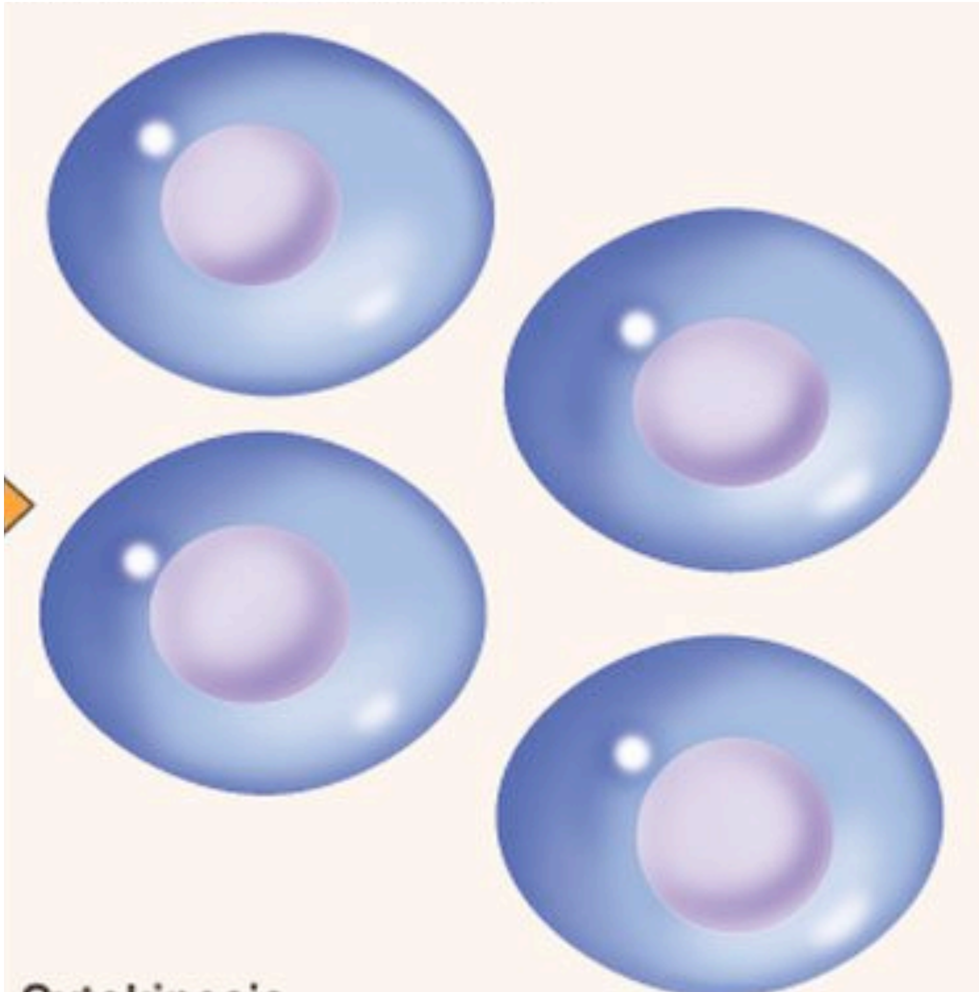


Meiosis II– Anaphase II and Telophase II





Meiosis II- Cytokinesis



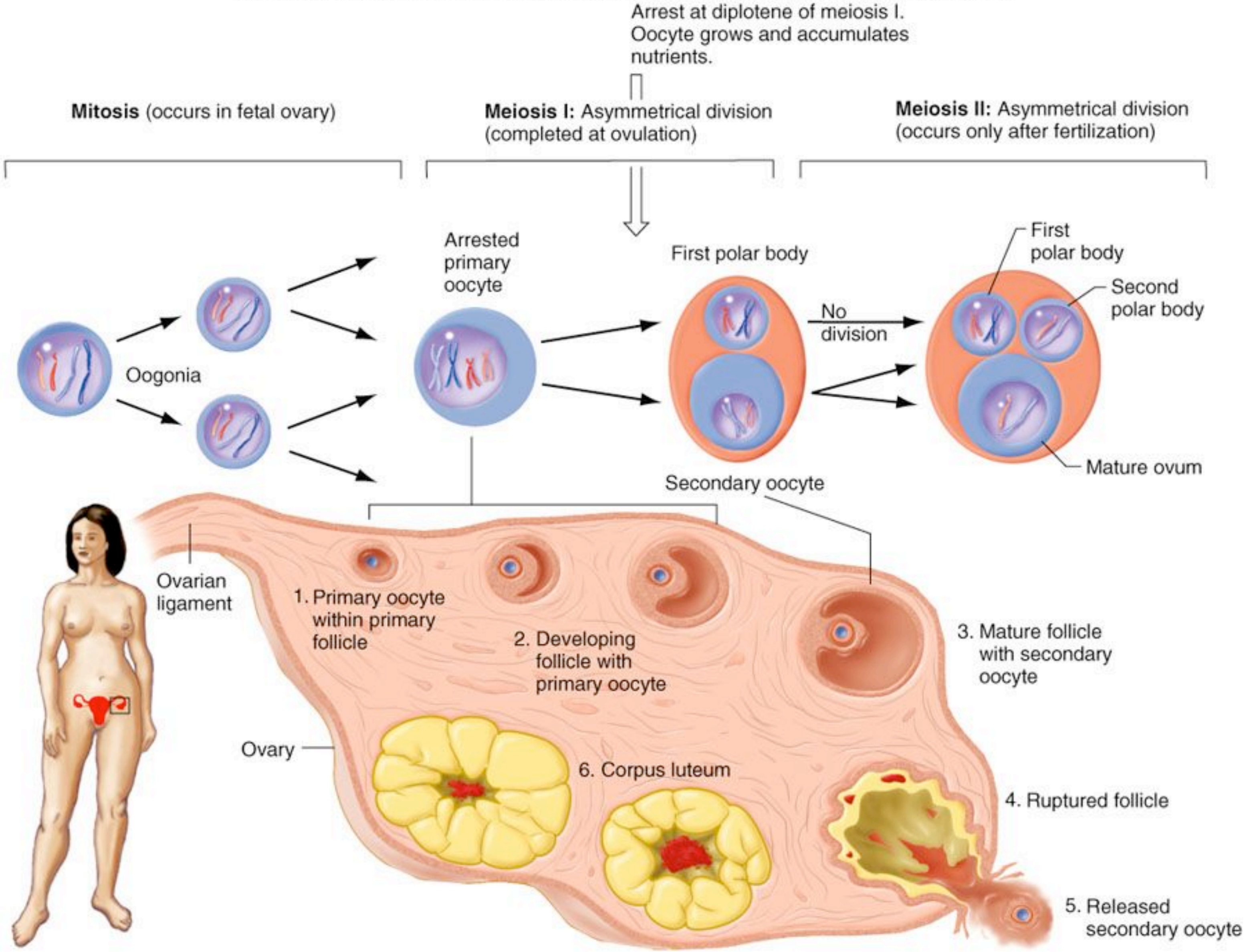
Cytokinesis

1. The cytoplasm divides, forming four new haploid cells.

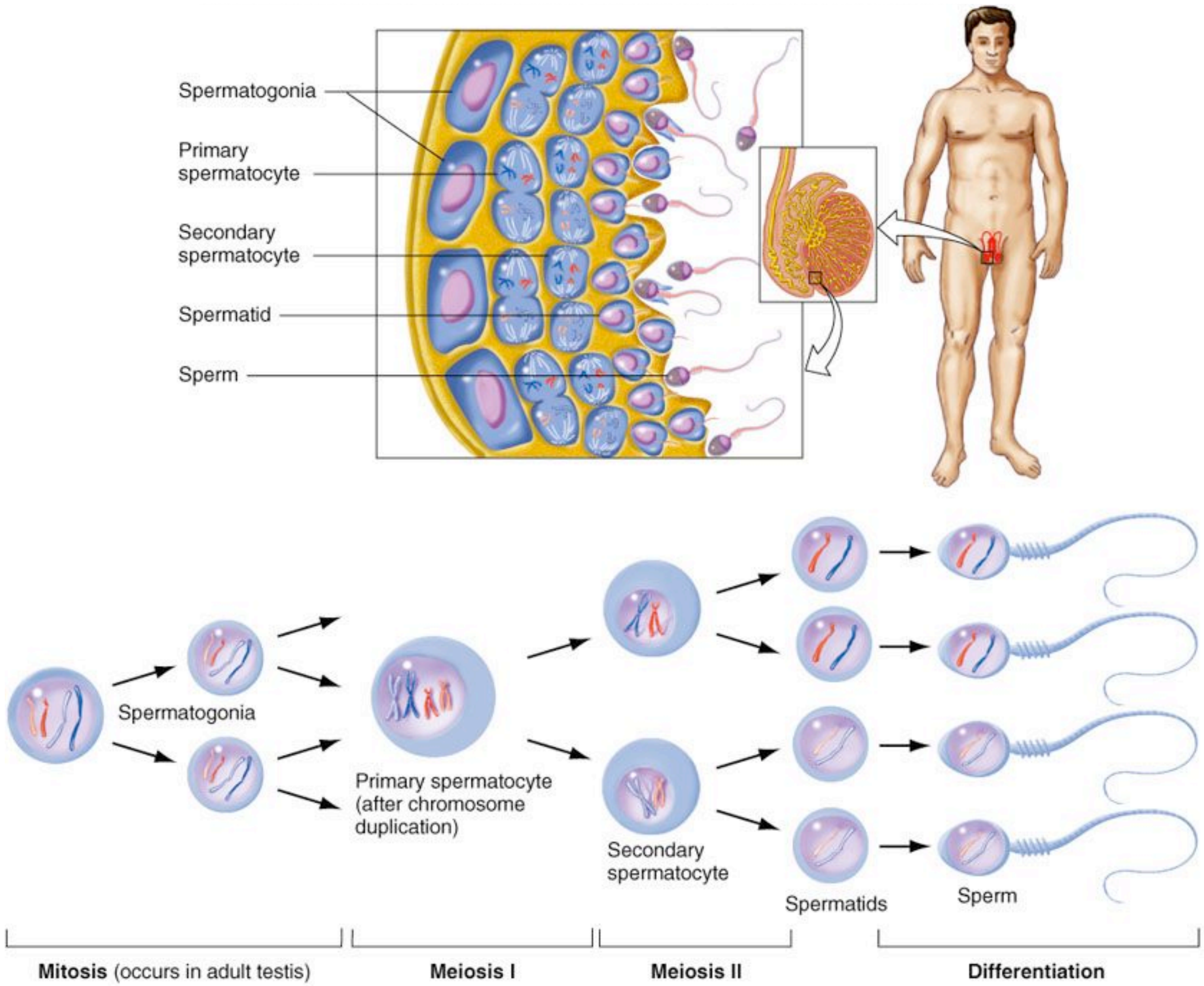
Meiosis contributes to genetic diversity

- Segregation of Alleles in Anaphase I
- Independent Assortment of nonhomologous chromosomes creates different combinations of alleles among chromosomes in Anaphase I
- Crossing-over between homologous chromosomes creates different combinations of alleles within each chromosome in Prophase I

Oogenesis in humans



Spermatogenesis in humans



Summary: Mitosis Vs Meiosis

Mitosis	**Meiosis**
-one round of DNA synthesis	-one round of DNA synthesis
-<u>one</u> cell division	-<u>two</u> successive cell divisions
-produces <u>two</u> somatic cells	-produces <u>four</u> germ cells
-no independent assortment	-independent assortment (anaphase I)
-produces <u>diploid</u> cells	-produces <u>haploid</u> <u>gametes</u>
-daughter cells are genetically *identical* to mother cell	-cells are genetically *different* from mother cell and each other
-no crossing over	-crossing over (in prophase I)
-for growth, cell replacement and asexual reproduction	-for sexual reproduction

Homework Problems

- Chapter 3
- # 5, 12, 37, 38, 39, 40,