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CHAPTER 15 LECTURE SLIDES

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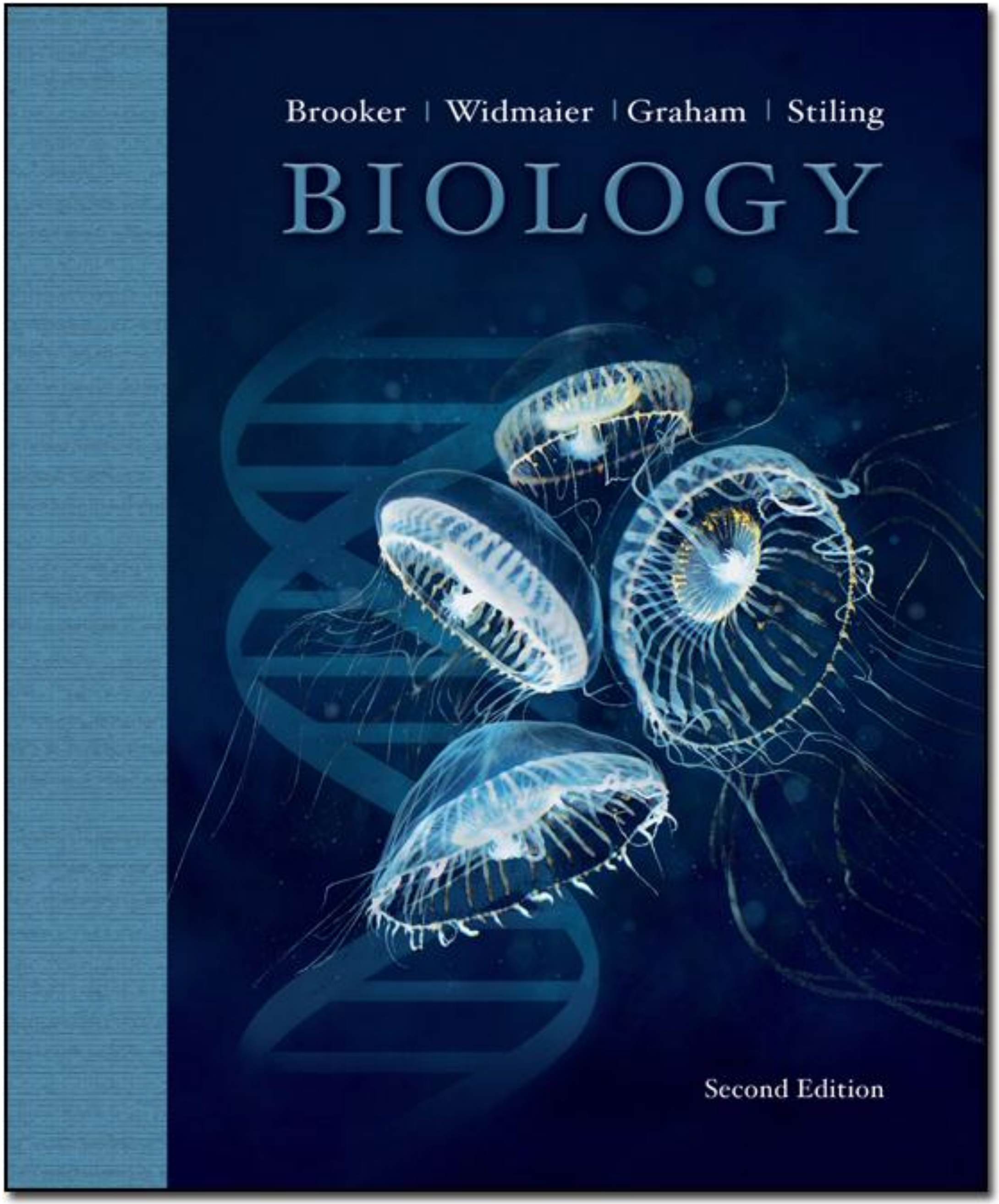


15.1 The Eukaryotic Cell Cycle

1. Describe the structure of eukaryotic chromosomes.
2. Distinguish between homologous chromosomes and sister chromatids.
3. Name the four phases in a eukaryotic cell's life cycle, and briefly describe the events occurring in each phase.
4. Describe the events that take place during interphase.
5. Explain the importance of checkpoints in the cell cycle.
6. Describe the functional relationship between cyclins and CDKs and the importance of these proteins in the regulation of the cell cycle.

15.2 Mitotic cell Division

1. Outline the steps involved in the mitotic phase, culminating in the production of two daughter cells.
2. Compare cytokinesis in plants and animals.
3. Explain why mitotic cell division results in two genetically identical daughter cells.

- **Note:** This is NOT covered in the PowerPoint. However, you are still responsible for these learning objectives.

15.3 Meiosis and Sexual reproduction

1. Describe the events in prophase I that lead to the physical recombination of maternal and paternal genes.
2. Compare and contrast the events of metaphase I and anaphase I of meiosis with metaphase and anaphase of mitosis.
3. Explain what is meant by “reduction division.”
4. Compare and contrast the means by which gametes are formed by plants, animals, and fungi.

- **Note:** Much of this is NOT covered in the PowerPoint (LO2, 3). However, you are still responsible for these learning objectives.

15.4 Variation in Chromosome Structure and Number

- List several different types of alterations in normal chromosome number, and describe some medical conditions that occur as a result.

Cell division

- Reproduction of cells
- Highly regulated series of events
- 2 types in eukaryotes
  - Mitosis
  - Meiosis

Eukaryotic chromosomes

- Cytogenetics – field of genetics involving microscopic examination of chromosomes and cell division
- When cells get ready to divide, the chromosomes compact enough to be seen with a light microscope
- Karyotype reveals number, size, and form of chromosomes in an actively dividing cell

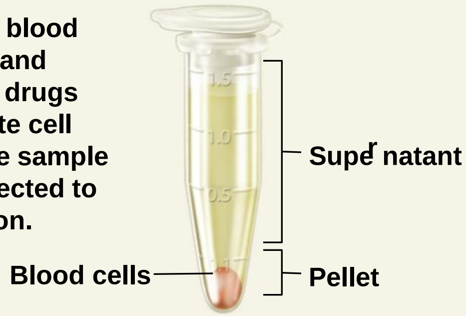
Sets of chromosomes

- Humans have 23 pairs of chromosomes or 46 total chromosomes
  - Autosomes – 22 pairs in humans
  - Sex chromosomes – 1 pair in humans
    - XX or XY
- Ploidy
  - Diploid or 2n – humans have 23 pairs of chromosomes
  - Haploid or n – gametes have 1 member of each pair of chromosomes or 23 total chromosomes

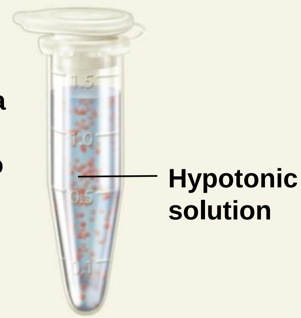
Homologous

- In diploid species, members of a pair of chromosomes are called homologues
  - They are homologous chromosomes
- Each homologue nearly identical in size and genetic composition
  - Both carry gene for eye color but one may have brown and the other blue
- Sex chromosomes are very different from each other - X and Y differ in size and composition

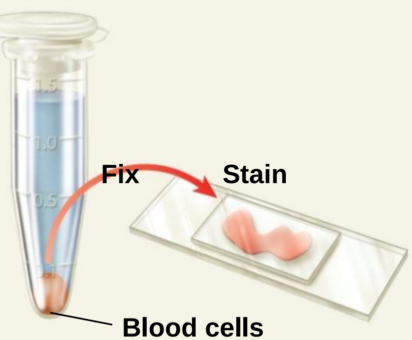
1 A sample of blood is collected and treated with drugs that stimulate cell division. The sample is then subjected to centrifugation.



2 The supernatant is discarded, and the cell pellet is suspended in a hypotonic solution. This causes the cells to swell and the chromosomes to spread out from each other.

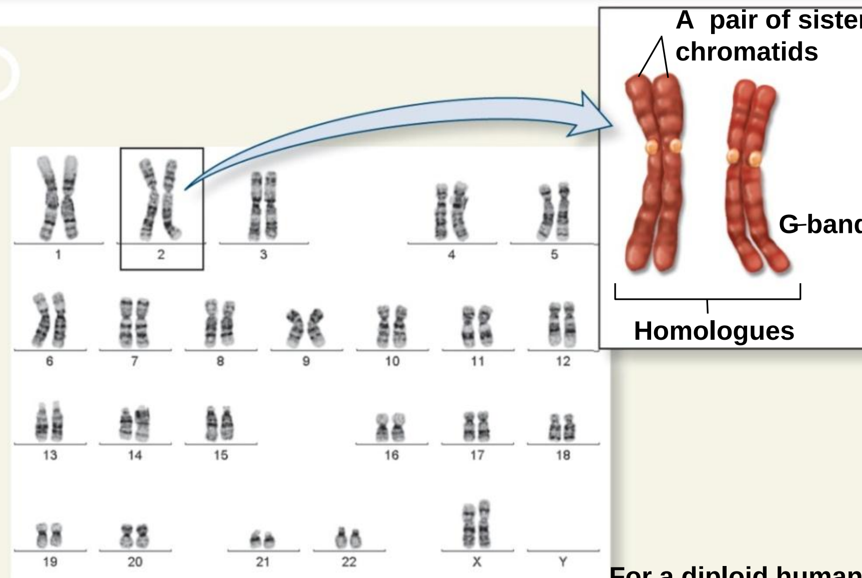


3 The sample is subjected to centrifugation a second time to concentrate the cells. The cells are suspended in a fixative, stained, and placed on a slide.



4 The slide is viewed by a light microscope equipped with a camera; the sample is seen on a computer screen. The chromosomes can be photographed and arranged electronically on the screen.

5



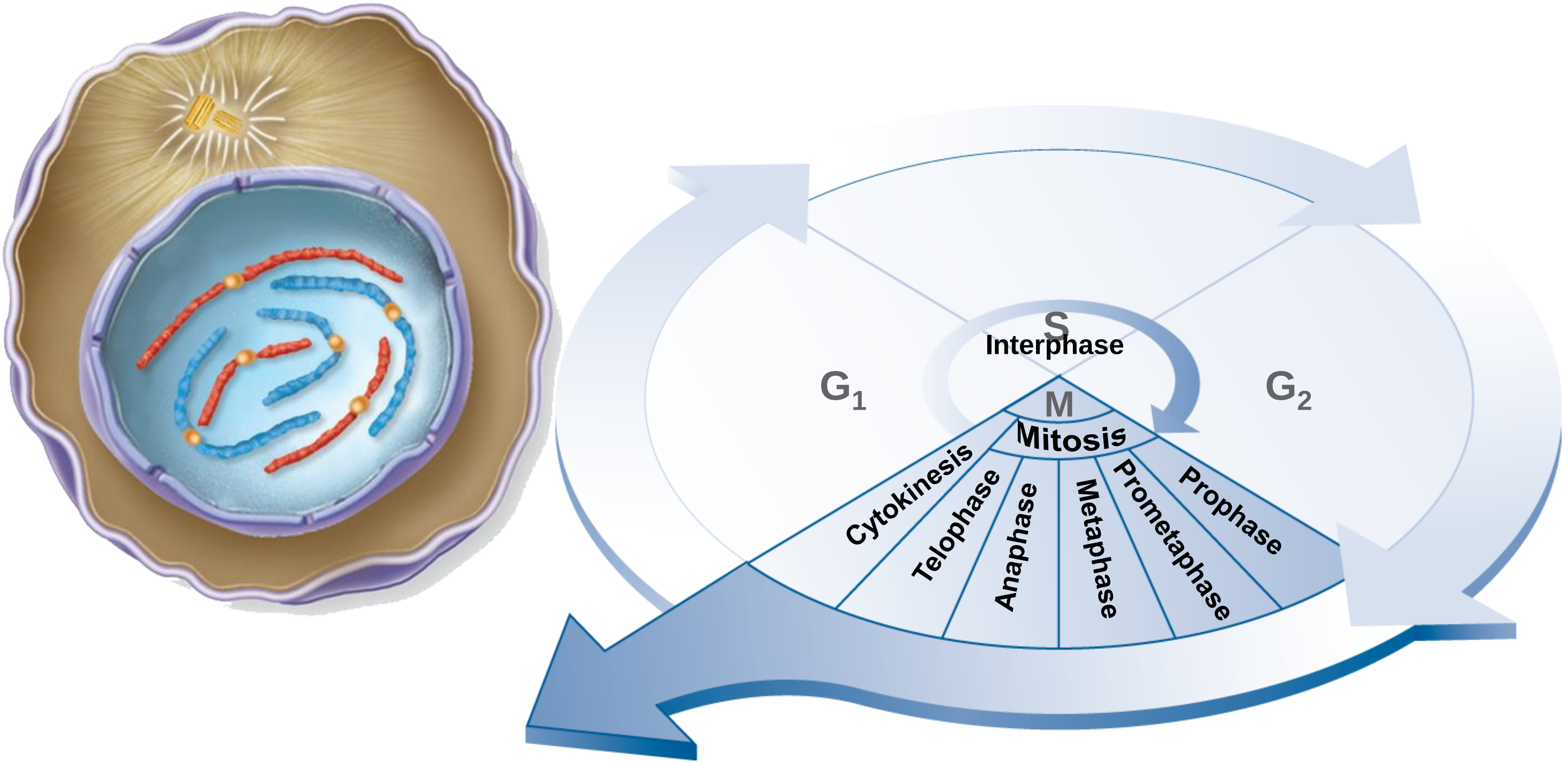
For a diploid human cell, 2 complete sets of chromosomes from a single cell constitute a karyotype of that cell.

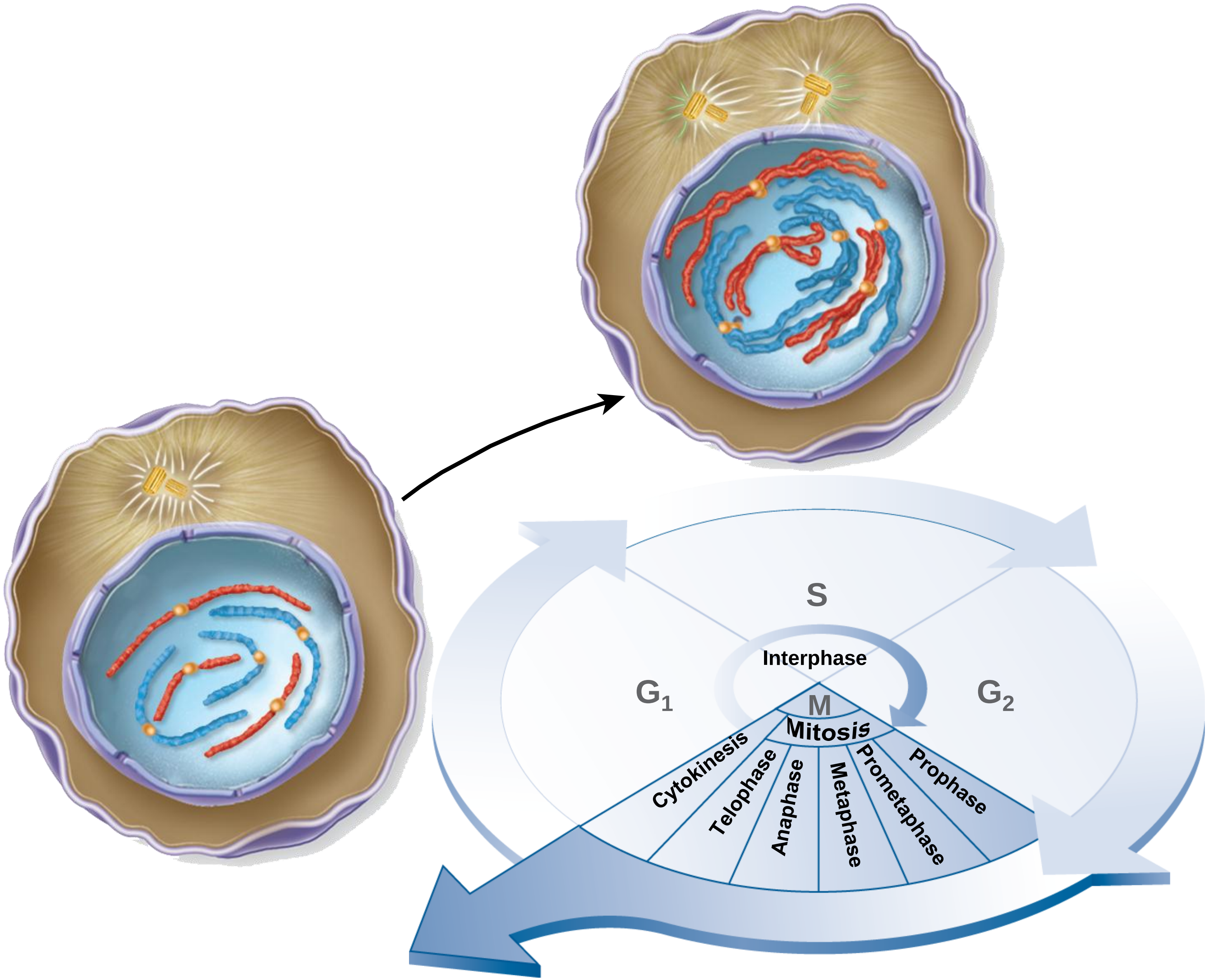
Cell cycle

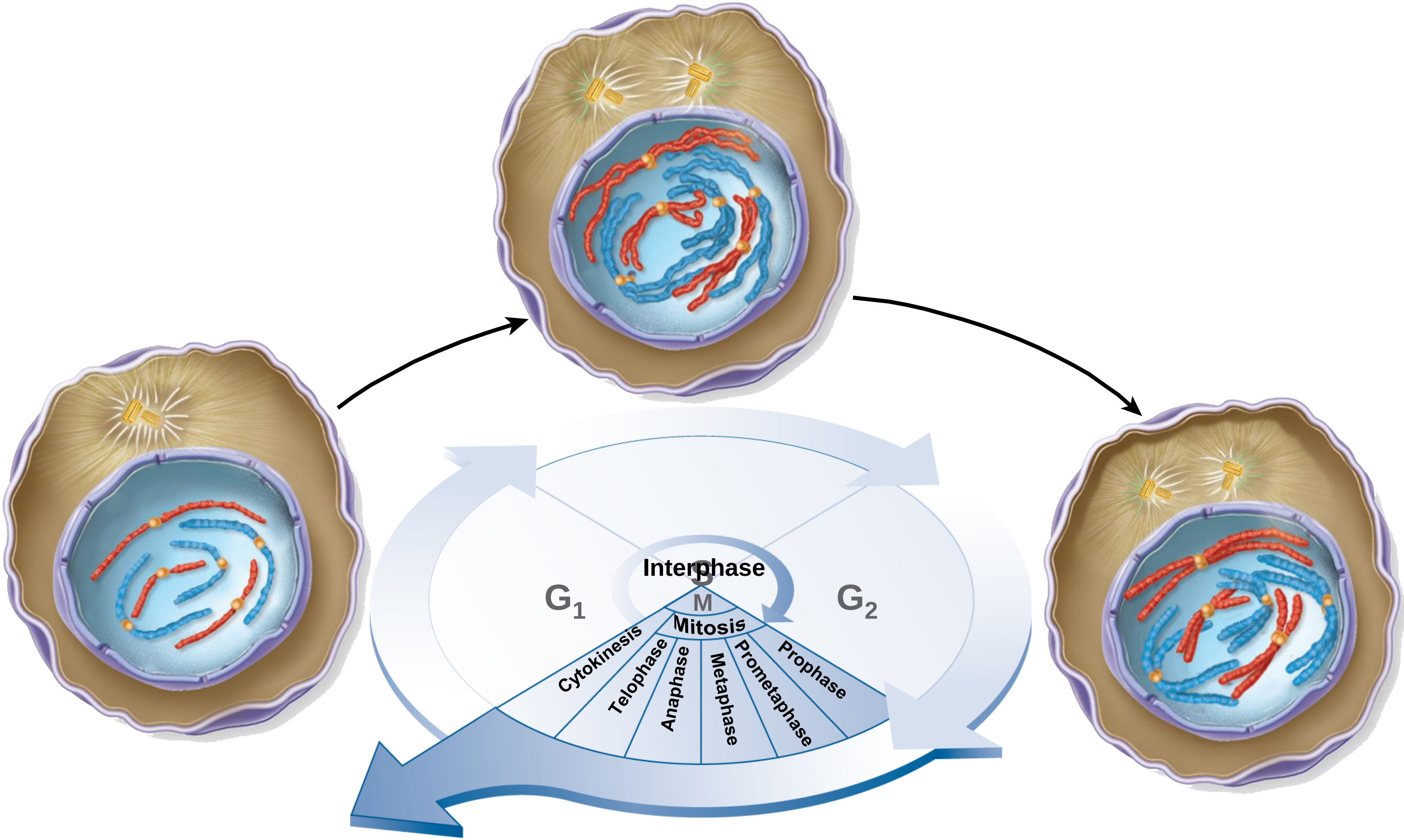
- G_1 – first gap
- S – synthesis of DNA
- G_2 – second gap
- M – mitosis and cytokinesis

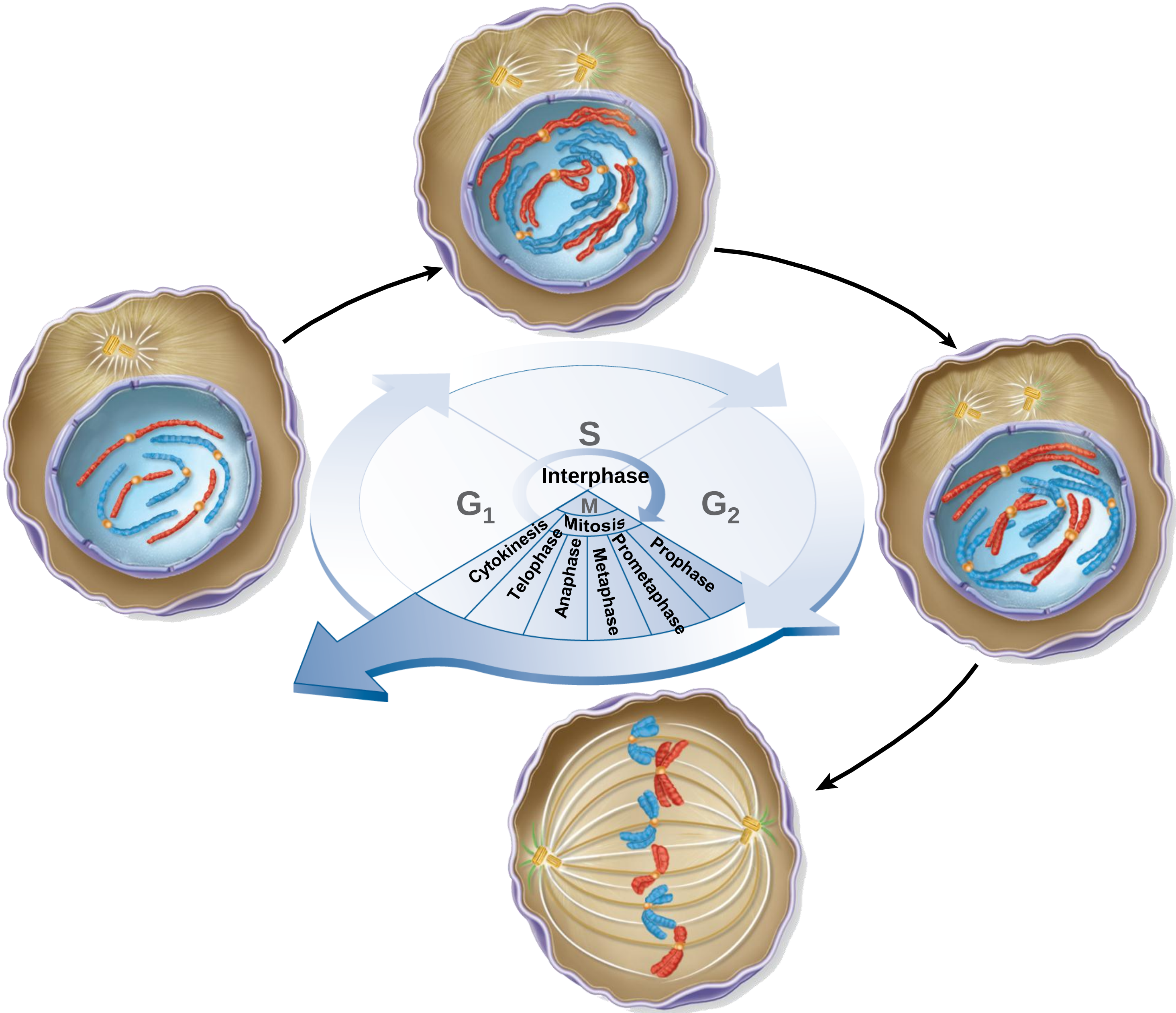
(G_1, S and G_2: Interphase)

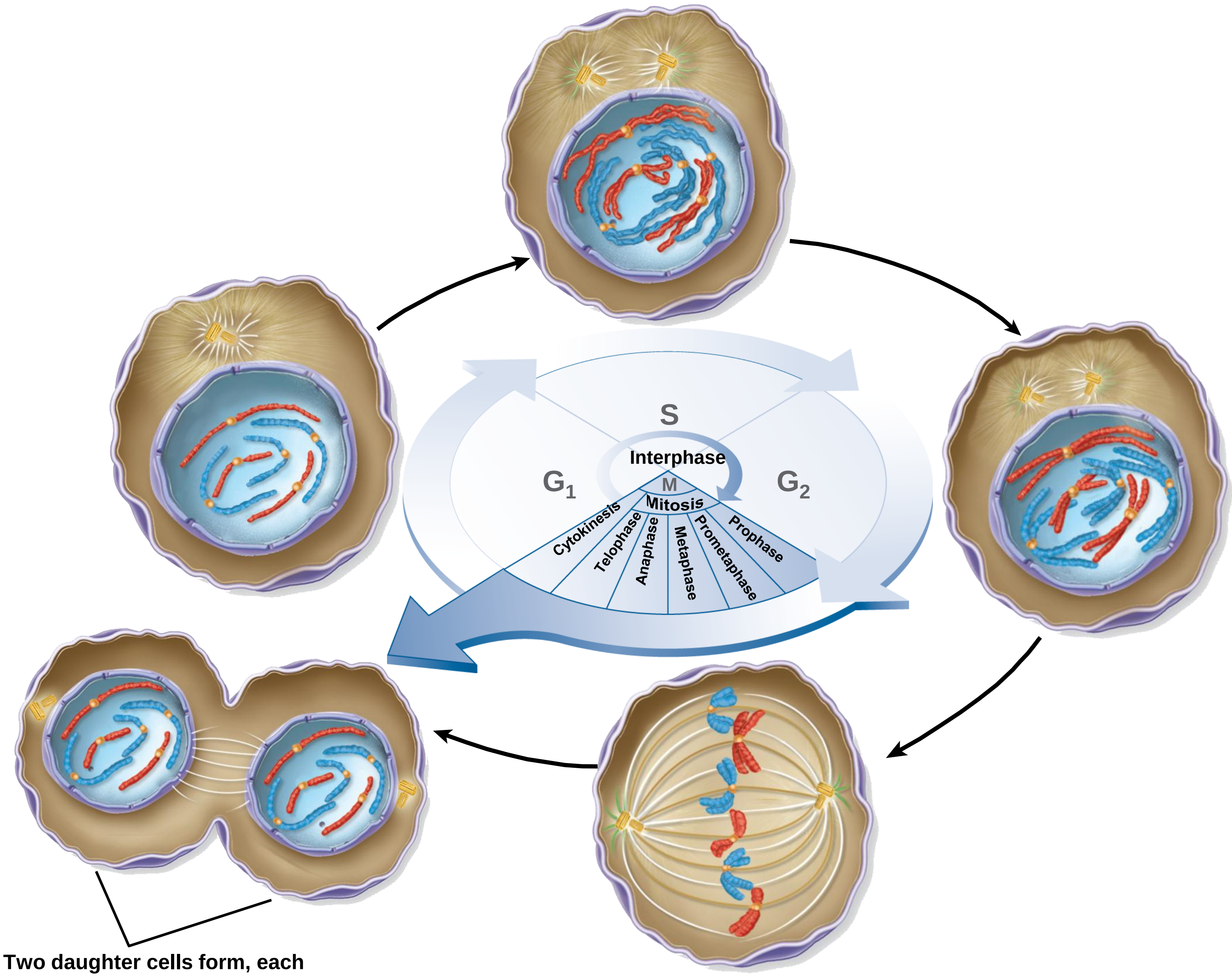
- G_0 – substitute for G_1 for cells postponing division or never dividing again


S
Interphase
G1
G2
M
Mitosis
Cytokinesis
Telophase
Anaphase
Metaphase
Prometaphase
Prophase


S
Interphase
G1
G2
M
Mitosis
Cytokinesis
Telophase
Anaphase
Metaphase
Prometaphase
Prophase


Interphase
S
M
Mitosis
G_1
G_2
Cytokinesis
Telophase
Anaphase
Metaphase
Prometaphase
Prophase


S
Interphase
G_1
G_2
M
Mitosis
Cytokinesis
Telophase
Anaphase
Metaphase
Prometaphase
Prophase



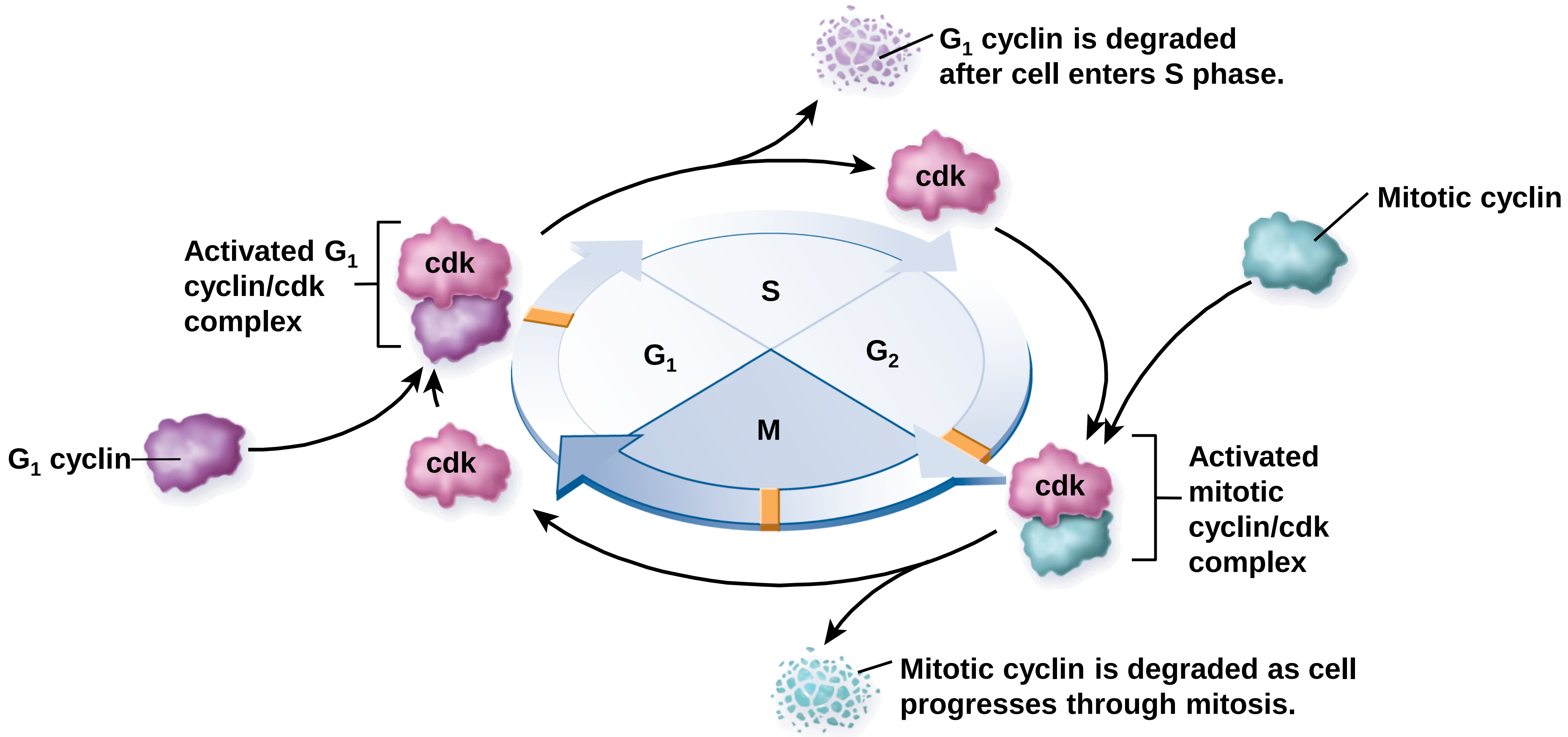
Two daughter cells form, each containing 6 chromosomes.

Decision to divide

- External factors
  - Environmental conditions
  - Signaling molecules
- Internal factors
  - Cell cycle control molecules
  - Checkpoints

Checkpoint proteins

- Cyclins or cyclin-dependent kinases (cdks) responsible for advancing a cell through the phases of the cell cycle
- Amount of cyclins varies through cycle
- Kinases controlling cell cycle must bind to a cyclin to be active



G1 cyclin is degraded after cell enters S phase.
cdk
Mitotic cyclin
Activated G1 cyclin/cdk complex
cdk
S
G1
G2
M
G1 cyclin
cdk
cdk
Activated mitotic cyclin/cdk complex
Mitotic cyclin is degraded as cell progresses through mitosis.

- 3 critical regulatory points or checkpoints in eukaryotes
  - G_1 checkpoint (restriction point)
  - G_2 checkpoint
  - Metaphase checkpoint
- Checkpoint proteins act as sensors to determine if the cell is in proper condition to divide
- Cell cycle will be delayed or until problems fixed or prevents division entirely
- Loss of checkpoint function can lead to mutation and cancer

Masui and Markert's study of oocyte maturation led to the identification of cyclin and cyclin-dependent kinase

- Frog oocytes are dormant in G_2
- Progesterone makes oocytes progress to M
- Progesterone must be affecting triggers to progress to M
- 3 groups of donor oocytes
  - Progesterone for 2 hours
  - Progesterone for 12 hours
  - No progesterone
- Inject donor oocyte cytosol into recipient oocytes
- Only 12 hour donor caused progression
- Maturation Promoting Factor (MPF) is mitotic cyclin and cyclin-dependent kinase

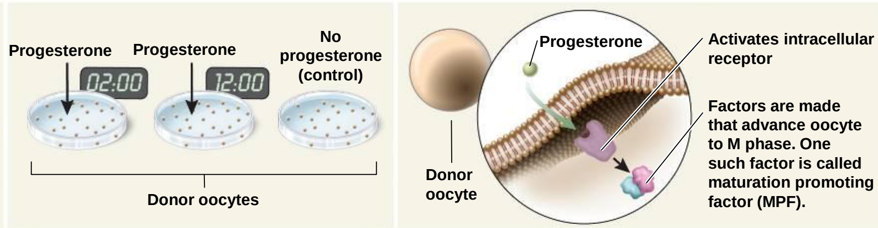
Feature Investigation

HYPOTHESIS Progesterone induces the synthesis of a factor(s) that advances frog oocytes through the cell cycle from G_2 to M phase.

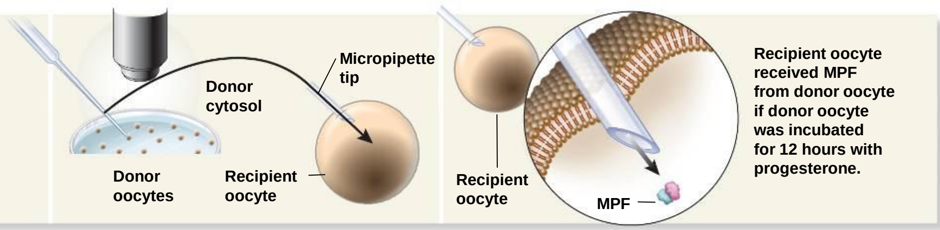
KEY MATERIALS Oocytes from Rana pipiens.

	Experimental level	Conceptual level

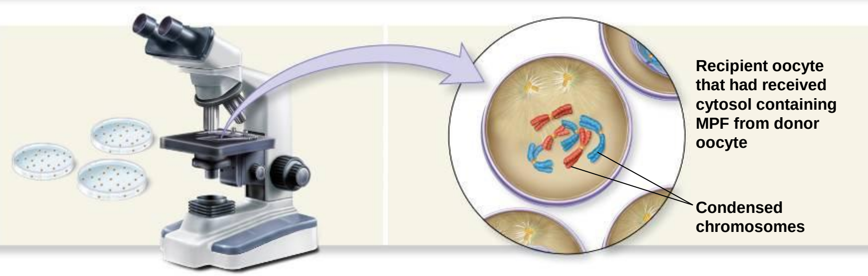
1 Expose oocytes to progesterone, then incubate for 2 or 12 hours. As a control, also use oocytes that have not been exposed to progesterone. All 3 types are donor oocytes.



2 Using a micropipette, transfer some cytosol from the 3 types of donor oocytes to recipient oocytes that have not been exposed to progesterone.



3 Incubate for several hours, and observe the recipient oocytes under the microscope to determine if the recipient oocytes advance to M phase. Advancement to M phase can be determined by the condensation of the chromosomes.



4 **THE DATA**

Donor oocytes	Recipient oocytes proceeded to M phase?
Control, no progesterone exposure	No
Progesterone exposure, incubation for 2 hours	No
Progesterone exposure, incubation for 12 hours	Yes

5 **CONCLUSION** Exposure of oocytes to progesterone for 12 hours results in the synthesis of a factor(s) that advances frog oocytes through the cell cycle from G_2 to M phase.

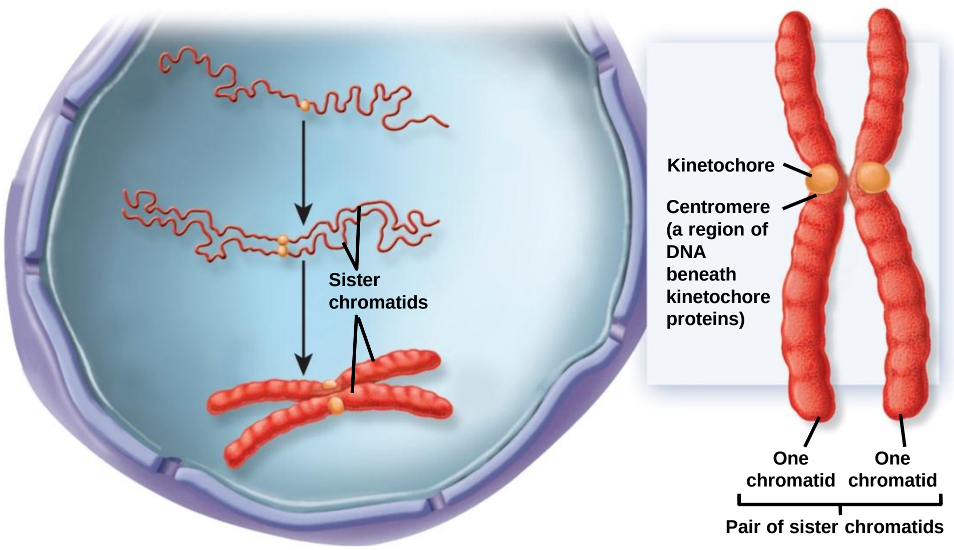
6 **SOURCE** Masui, Y., and Markert, C.L. 1971. Cytoplasmic control of nuclear behavior during meiotic maturation of frog oocytes. Journal of Experimental Zoology 177:129-145.

Mitotic cell division

- A cell divides to produce 2 new cells genetically identical to the original
- Original called mother, new cells called daughters
- Involves mitosis and cytokinesis
- Can be for asexual reproduction or for production and maintenance of multicellularity

Preparation for cell division

- DNA replicated
- Sister chromatids - 2 identical copies with associated proteins
- Tightly associates at centromere
- Serves as attachment site for kinetochore used in sorting chromosomes



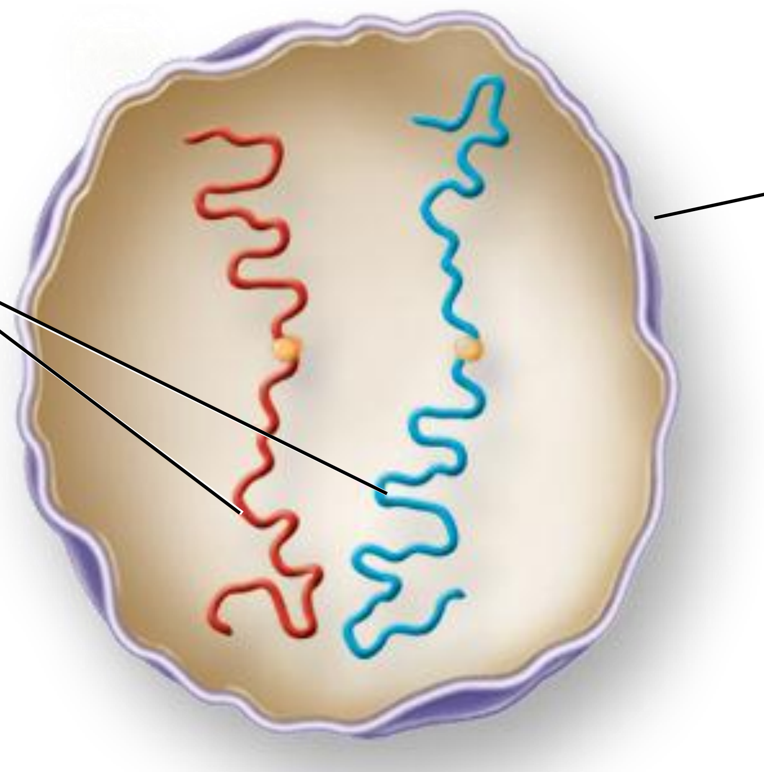
(a) Chromosome replication and compaction

(b) Schematic drawing of a metaphase chromosome

Meiosis

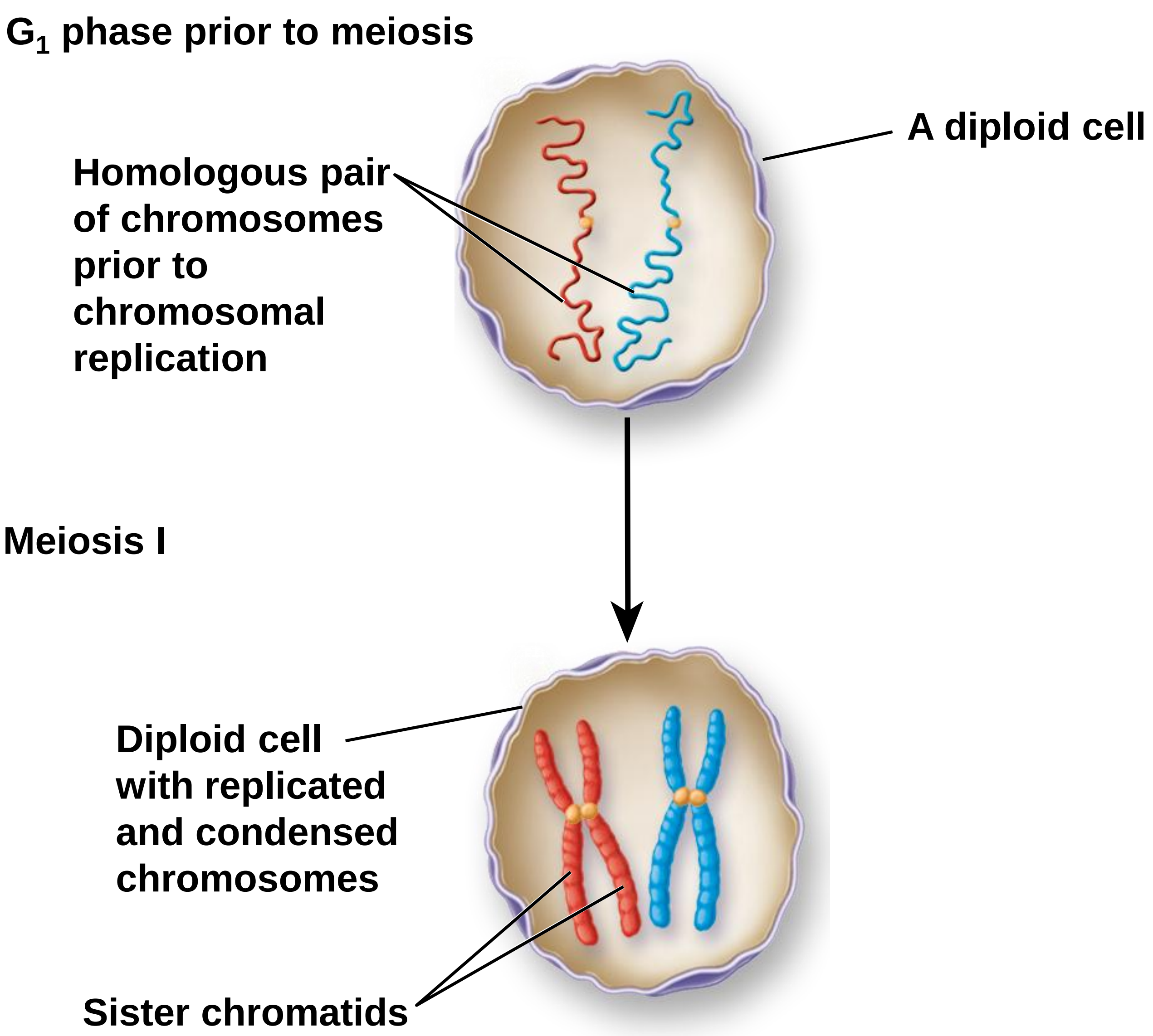
- Sexual reproduction requires a fertilization event in which two haploid gametes unite to create a diploid cell called a zygote
- Meiosis is the process by which haploid cells are produced from a cell that was originally diploid

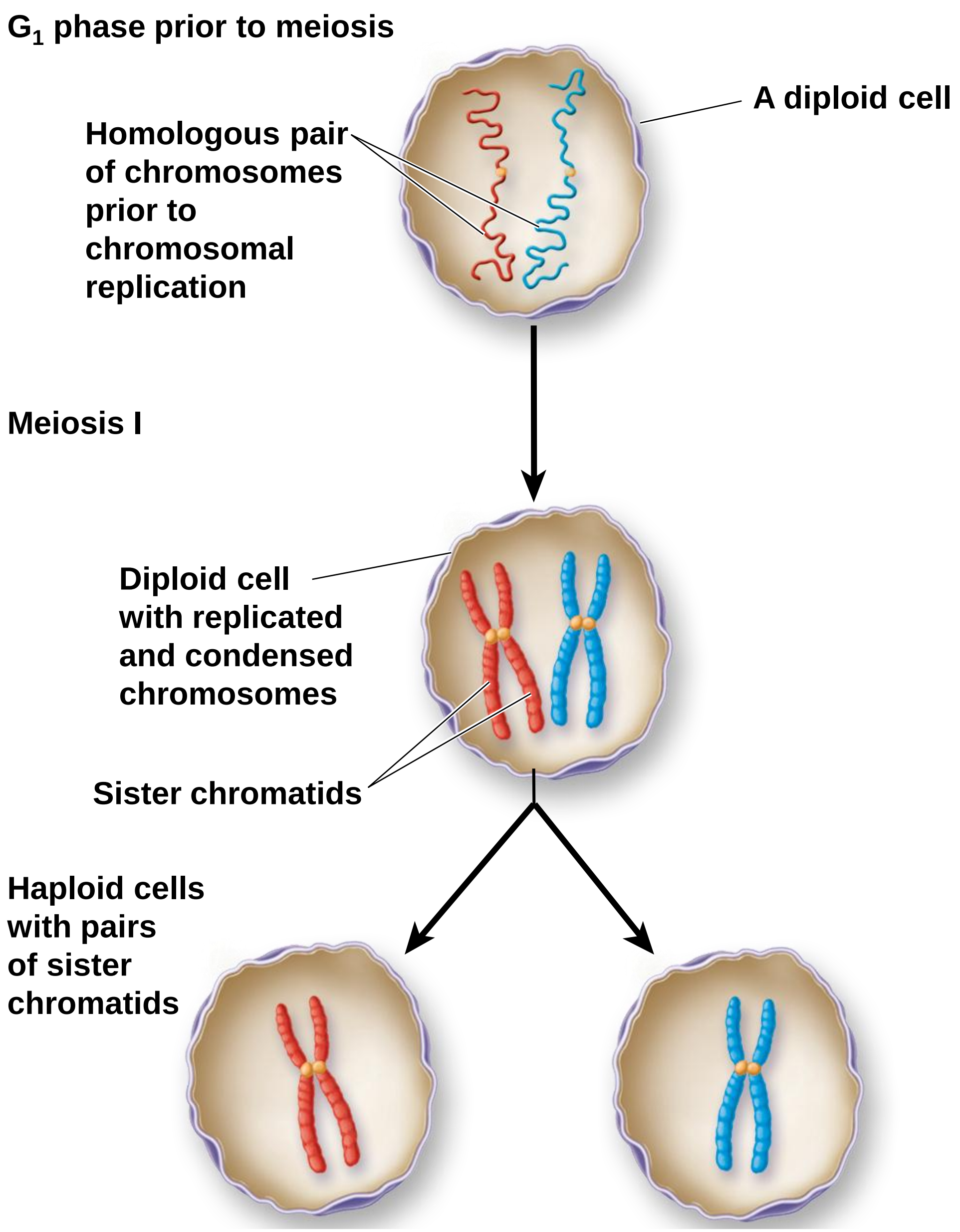
G_1 phase prior to meiosis

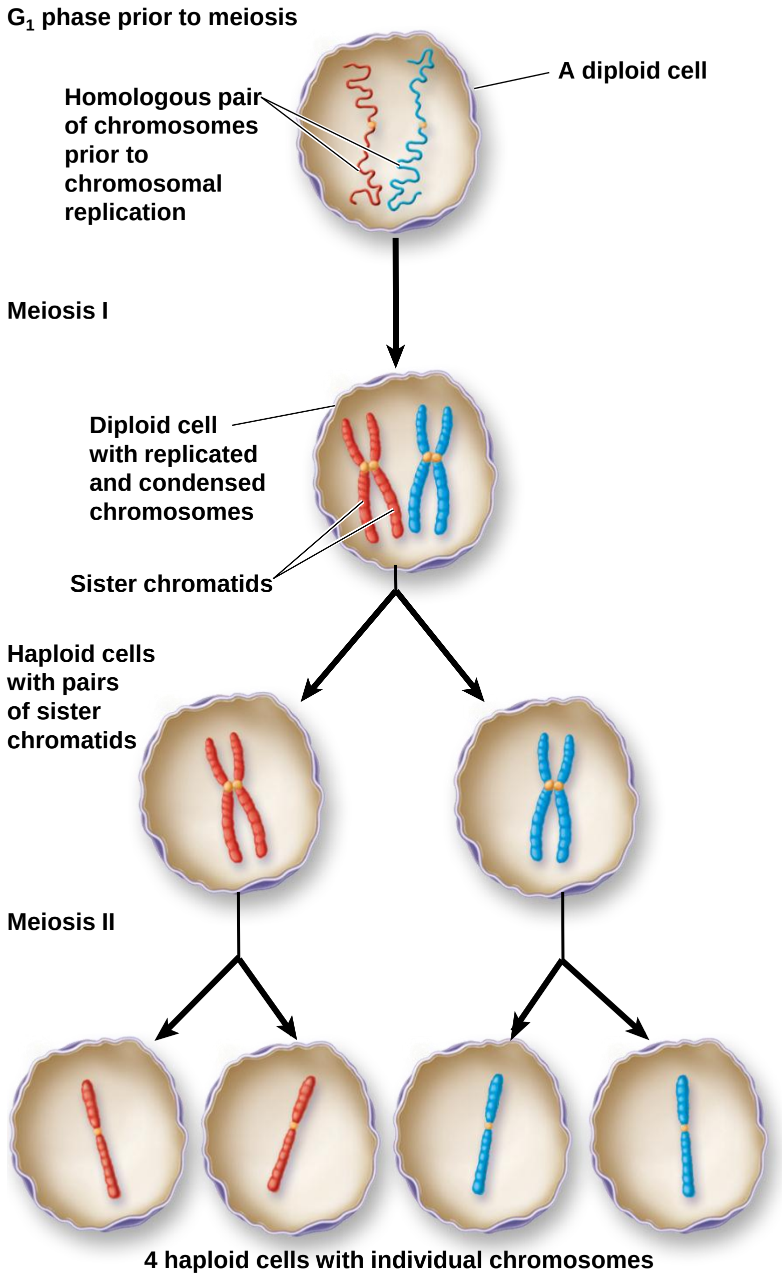


A diploid cell

Homologous pair of chromosomes prior to chromosomal replication


G$_1$ phase prior to meiosis
A diploid cell
Homologous pair of chromosomes prior to chromosomal replication
Meiosis I
Diploid cell with replicated and condensed chromosomes
Sister chromatids


G$_1$ phase prior to meiosis
A diploid cell
Homologous pair of chromosomes prior to chromosomal replication
Meiosis I
Diploid cell with replicated and condensed chromosomes
Sister chromatids
Haploid cells with pairs of sister chromatids

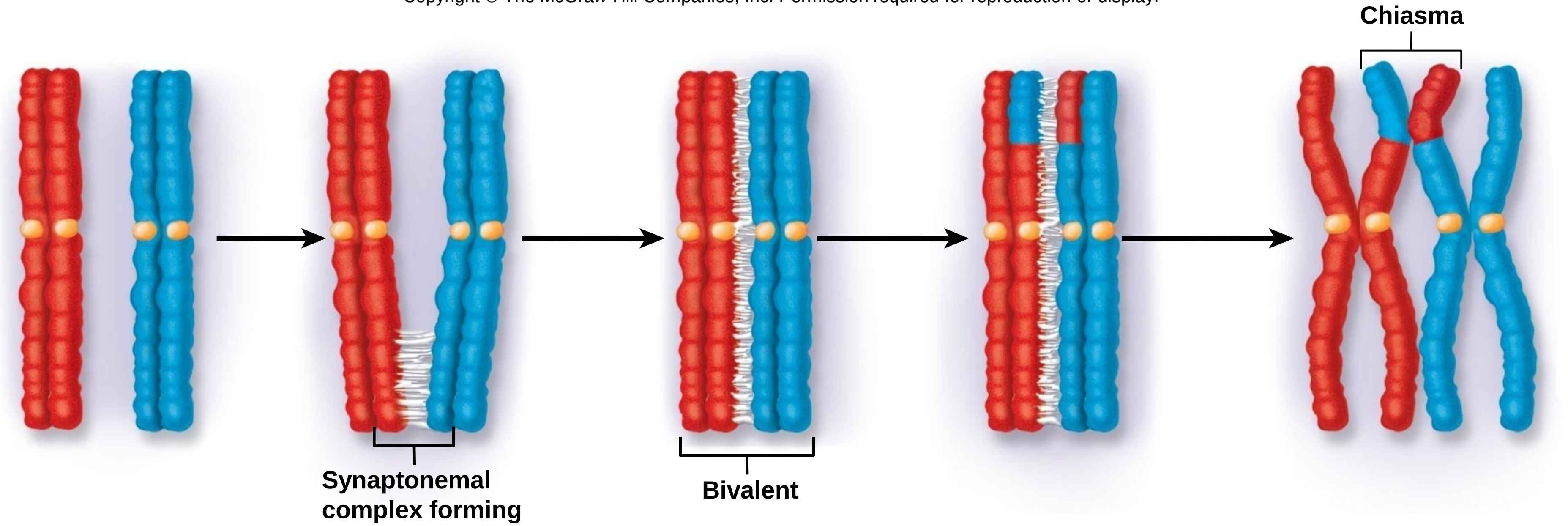

G_1 phase prior to meiosis
A diploid cell
Homologous pair of chromosomes prior to chromosomal replication
Meiosis I
Diploid cell with replicated and condensed chromosomes
Sister chromatids
Haploid cells with pairs of sister chromatids
Meiosis II
4 haploid cells with individual chromosomes

- Like mitosis, meiosis begins after a cell has progressed through the G1, S, and G2 phases of the cell cycle
- 2 key differences

1. Homologous pairs form a bivalent or tetrad
2. Crossing over

Crossing over

- Physical exchange between chromosome pieces of the crossing bivalent
- May increase the genetic variation of a species
- Chiasma - arms of the chromosomes tend to separate but remain adhered at a crossover site
- Number of crossovers carefully controlled by cells


Chiasma
Synaptonemal complex forming
Bivalent

Meiosis vs. Mitosis

- Mitosis produces two diploid daughter cells that are genetically identical
  - 6 chromosomes in 3 homologous pairs
- Meiosis produces four haploid daughter cells
  - Each daughter has a random mix of 3 chromosomes

Table 15.1 A Comparison of Mitosis, Meiosis I, and Meiosis II

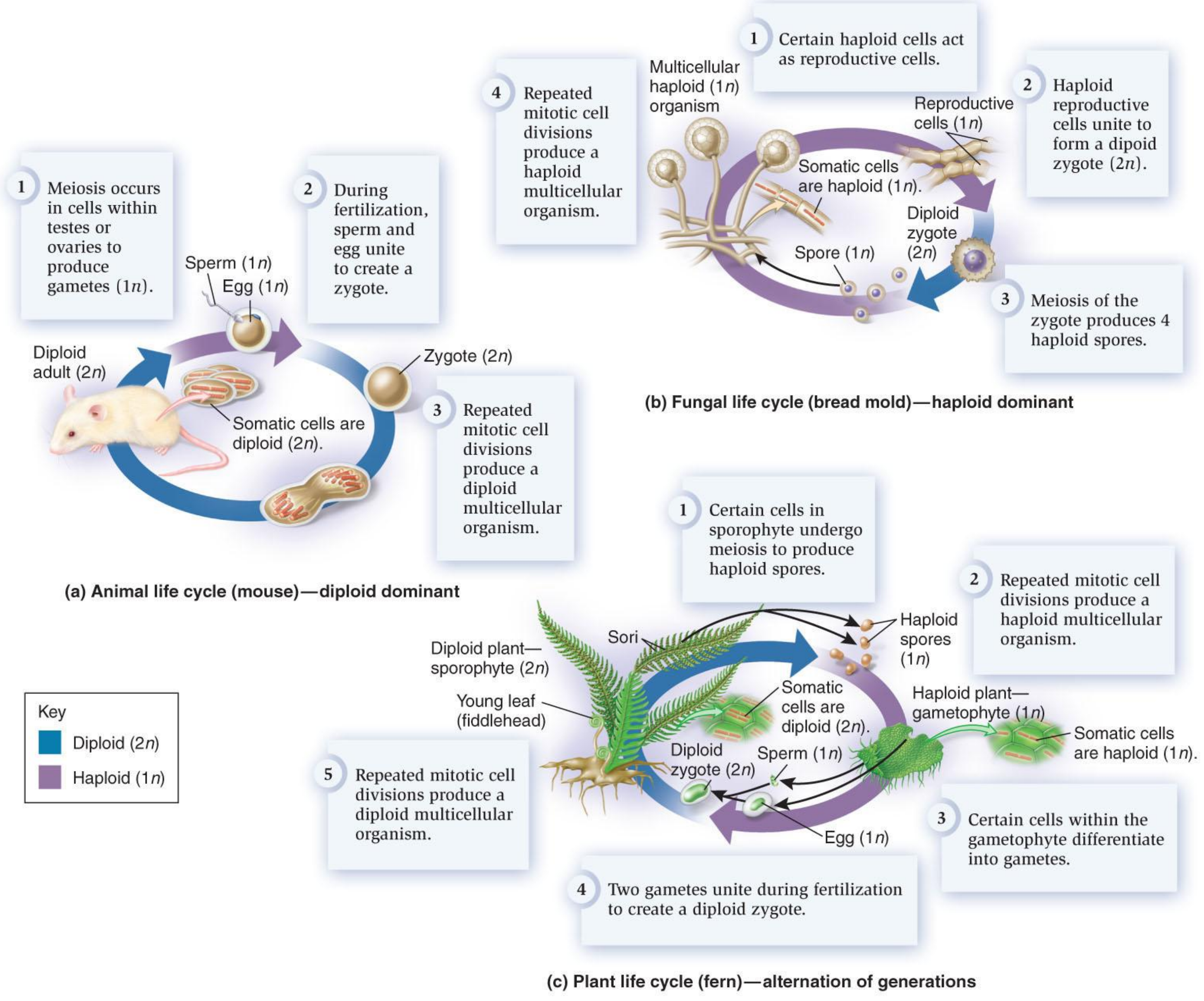
Event	Mitosis	Meiosis I	Meiosis II
Synapsis during prophase:	No	Yes, bivalents are formed.	No
Crossing over during prophase:	Rarely	Commonly	Rarely
Attachment to poles at prometaphase:	A pair of sister chromatids is attached to kinetochore microtubules from both poles.	A pair of sister chromatids is attached to kinetochore microtubules from just one pole.	A pair of sister chromatids is attached to kinetochore microtubules from both poles.
Alignment along the metaphase plate:	Sister chromatids align.	Bivalents align.	Sister chromatids align.
Type of separation at anaphase:	Sister chromatids separate. A single chromatid, now called a chromosome, moves to each pole.	Homologous chromosomes separate. A pair of sister chromatids moves to each pole.	Sister chromatids separate. A single chromatid, now called a chromosome, moves to each pole.
End result when the mother cell is diploid:	Two daughter cells that are diploid	—	Four daughter cells that are haploid

Life Cycle

- Sequence of events that produces another generation of organisms
- For sexually reproducing organisms, involves an alternation between haploid cells or organisms and diploid cells or organisms

- Diploid-dominant species
  - Most animal species are diploid
  - Haploid gametes are a specialized type of cell
- Haploid-dominant species
  - Many fungi and some protists
  - Multicellular organism is haploid
  - Haploid cells unite to form diploid zygote, then proceeds immediately through meiosis to make 4 haploid spores

- Alternation of generations
  - Plants and some algae
  - Intermediate dominance
  - Multicellular diploid organism – sporophyte
  - Multicellular haploid organism – gametophyte
  - Among species, relative size of sporophyte and gametophyte varies


1 Meiosis occurs in cells within testes or ovaries to produce gametes (1n).
Sperm (1n)
Egg (1n)
2 During fertilization, sperm and egg unite to create a zygote.
Diploid adult (2n)
Zygote (2n)
Somatic cells are diploid (2n).
3 Repeated mitotic cell divisions produce a diploid multicellular organism.
(a) Animal life cycle (mouse)—diploid dominant
4 Repeated mitotic cell divisions produce a haploid multicellular organism.
Multicellular haploid (1n) organism
1 Certain haploid cells act as reproductive cells.
Reproductive cells (1n)
2 Haploid reproductive cells unite to form a dipoid zygote (2n).
Somatic cells are haploid (1n).
Diploid zygote (2n)
Spore (1n)
3 Meiosis of the zygote produces 4 haploid spores.
(b) Fungal life cycle (bread mold)—haploid dominant
Key
Diploid (2n)
Haploid (1n)
1 Certain cells in sporophyte undergo meiosis to produce haploid spores.
2 Repeated mitotic cell divisions produce a haploid multicellular organism.
Sori
Diploid plant—sporophyte (2n)
Haploid spores (1n)
Young leaf (fiddlehead)
Somatic cells are diploid (2n).
Haploid plant—gametophyte (1n)
Somatic cells are haploid (1n).
Diploid zygote (2n)
Sperm (1n)
Egg (1n)
5 Repeated mitotic cell divisions produce a diploid multicellular organism.
3 Certain cells within the gametophyte differentiate into gametes.
4 Two gametes unite during fertilization to create a diploid zygote.
(c) Plant life cycle (fern)—alternation of generations

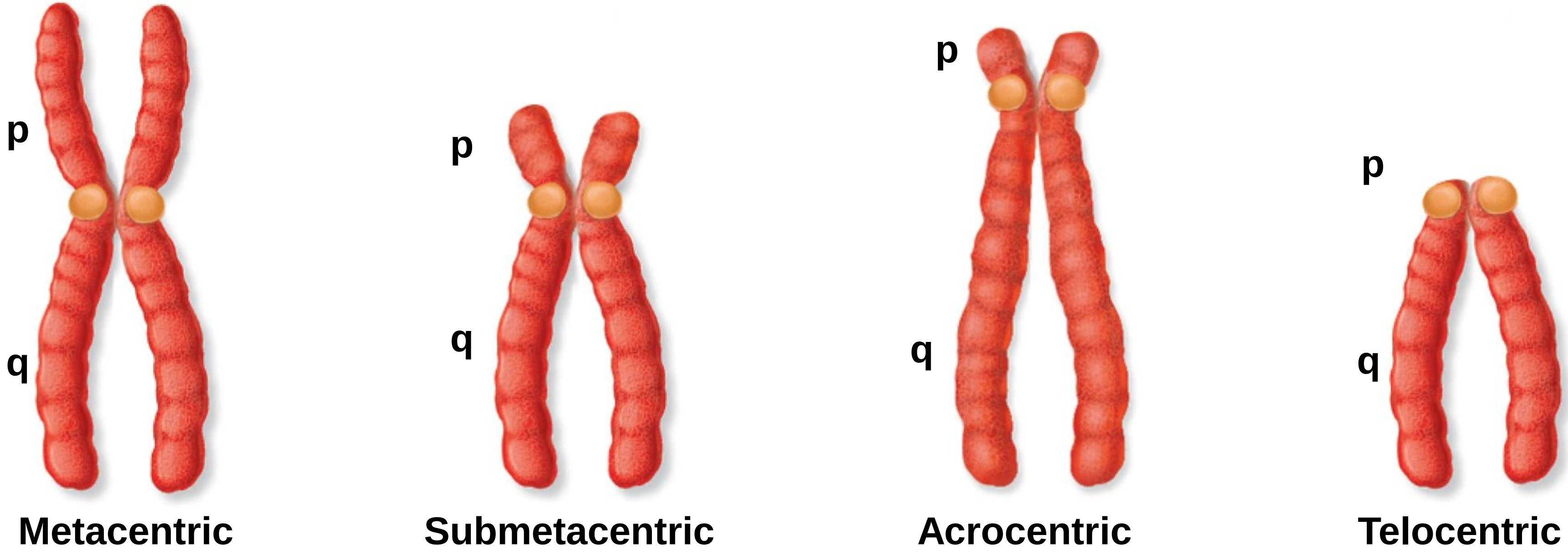
Chromosomes

- Geneticists have discovered that variations on chromosomes structure and number can have major effects on organisms
  - Several human diseases
  - Important in evolution of new species
- Chromosome variation
  - On rare occasions, structure or number of chromosomes changes so that individual is different from other members of same species – abnormal
  - Normal for structure and number of chromosomes to vary between species

Variation in Chromosomes

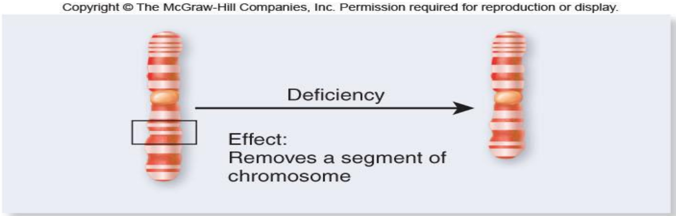
- Chromosome composition within a given species tends to remain relatively constant
  - Humans - 2 sets of 23 chromosomes (total of 46)
  - Dog - 78 chromosomes (39 per set)
  - Fruit fly - 8 chromosomes (4 per set)
  - Tomato - 24 chromosomes (12 per set)

- Chromosomes identified by
  - Size
  - Location of centromere
    - Short arm is *p*, long arm is *q*, short arms on top
    - Metacentric – middle
    - Submetacentric – off center
    - Acrocentric – near end
    - Telocentric – at the end
  - Banding pattern
    - Giemsa stain gives G banding

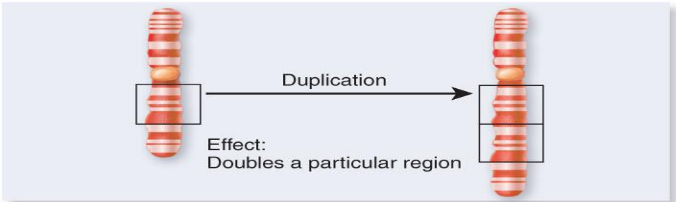

p
q
Metacentric
p
q
Submetacentric
p
q
Acrocentric
p
q
Telocentric

Chromosomal mutations

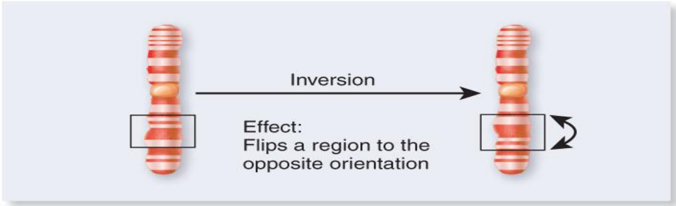
- Deletions
  - Segment missing
- Duplications
  - Section occurs 2 or more times in a row
- Inversions
  - Change in direction along a single chromosome
- Translocations
  - One segment becomes attached to another chromosome
  - Simple or reciprocal



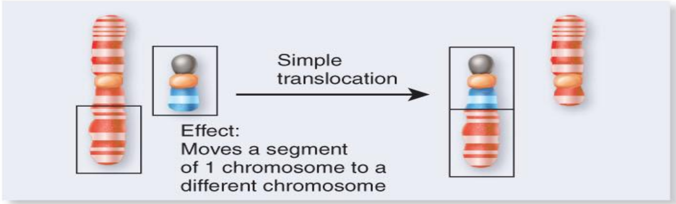
(a) Deficiency (deletion)



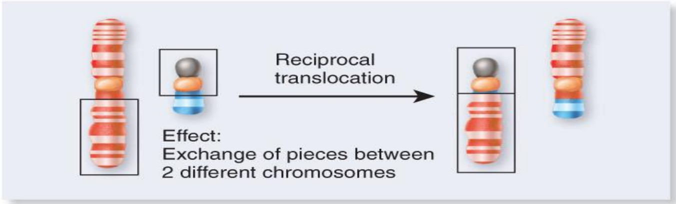
(b) Duplication



(c) Inversion



(d) Simple translocation

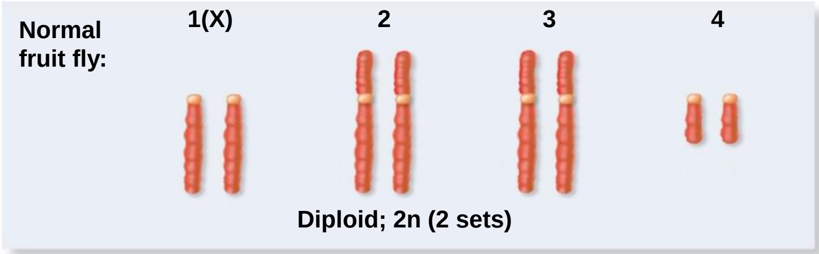


(e) Reciprocal translocation

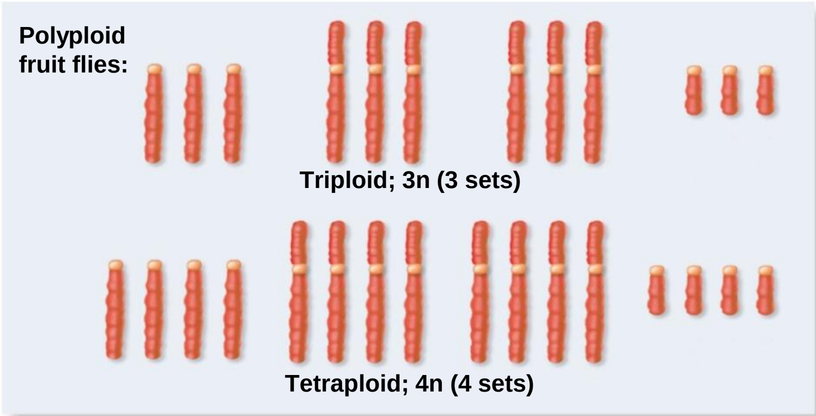
Changes in chromosome number

- Euploid - chromosome number that is viewed as the normal number
  - In a diploid organism, 2 sets is normal
- Polyploid - 3 or more sets of chromosomes
  - Diploid 2n
  - Triploid 3n
  - Tetraploid 4n

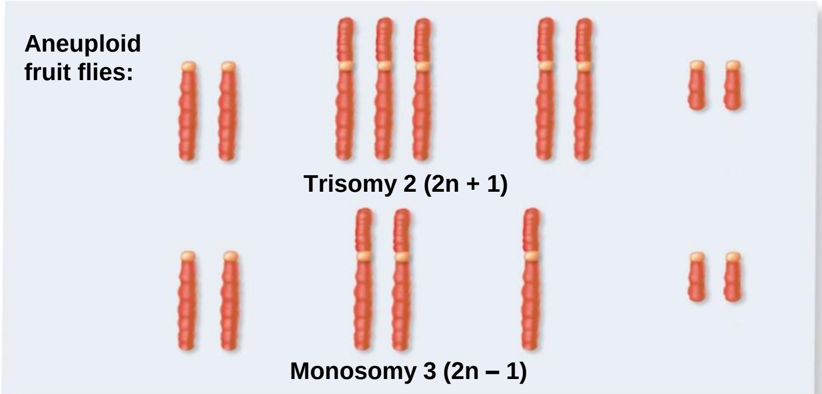
- Aneuploidy
  - Alteration number of particular chromosomes
  - Total number not an exact multiple of a set
- Trisomic
  - Normal 2 copies of a chromosome plus a 3rd
  - 2n+1
- Monosomic
  - Missing one of normal copies of a chromosome
  - 2n-1



(a) Normal fruit fly chromosome composition



(b) Polyploidy



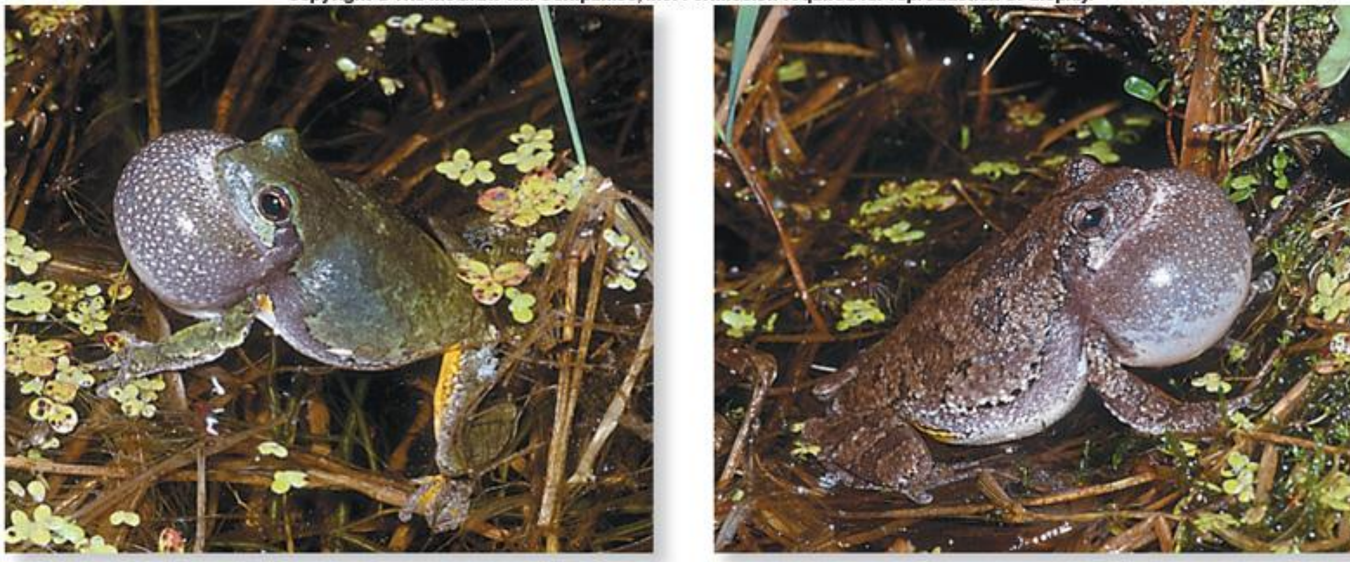
(c) Aneuploidy

Nondisjunction

- Chromosomes do not sort properly during cell division
- During meiosis can produce gametes with too many or too few chromosomes

Consequences

- Animals do not tolerate deviations from diploidy well – usually lethal
  - However, male bees (drones) contain a single set of chromosomes while female bees are diploid
  - Diploid and polyploid species of amphibians and reptiles
- Plants commonly exhibit polyploidy
  - 30-35% of fern and flowering plant species are polyploid
  - Important in agriculture - Wheat example



(a) *Hyla chrysorelis* (b) *Hyla versicolor*

(a) Wheat, *Triticum aestivum* (hexaploid)

- Aneuploidy in all eukaryotic species usually has detrimental consequences
- Trisomic and monosomic individuals have an imbalance in the level of gene expression interfering with proper cell function

Aneuploidy in humans

- About 5-10% of all fertilized human eggs result in an embryo with an abnormality in chromosome number
- Approximately 50% of all spontaneous abortions are due to alterations in chromosome number
- Can survive some abnormalities
  - Trisomies or abnormalities in sex chromosome number

Table 15.2 Aneuploid Conditions in Humans

Condition	Frequency (# of live births)	Syndrome	Characteristics
Autosomal			
Trisomy 21	1/800	Down	Mental impairment, abnormal pattern of palm creases, slanted eyes, flattened face, short stature
Trisomy 18	1/6,000	Edward	Mental and physical impairment, facial abnormalities, extreme muscle tone, early death
Trisomy 13	1/15,000	Patau	Mental and physical impairment, wide variety of defects in organs, large triangular nose, early death
Sex chromosomal			
XXY	1/1,000 (males)	Klinefelter	Sexual immaturity (no sperm), breast swelling (males)
XYY	1/1,000 (males)	Jacobs	Tall
XXX	1/1,500 (females)	Triple X	Tall and thin, menstrual irregularity
XO	1/5,000 (females)	Turner	Short stature, webbed neck, sexually undeveloped