# Chapter 16

Cellular Reproduction

# Objectives for this Chapter:

1. Examine the process of cell division and its significance
2. Describe the stages of the cell cycle
3. Describe how genetic material is organized within eukaryotic cells
4. Define and explain the significance of chromosome number in somatic cells
5. Prepare and interpret a model of a human karyotype

# Objectives for this Chapter:

6. Identify the phases of mitosis and describe their significance
7. Assess the similarities and differences between mitosis in plant cells and animal cells
8. Calculate the duration of individual phases of the cell cycle

# Objectives for this Chapter

9. Define and explain the significance of chromosome number in gametes
10. Examine how meiosis results in the production of gametes
11. Describe the ways in which meiosis contributes to genetic variation
12. Compare the processes of oogenesis and spermatogenesis
13. Compare the formation of fraternal and identical twins

# Objectives for this Chapter:

14. Describe the variety of reproductive strategies among living organisms
15. Evaluate the advantages and disadvantages of sexual and asexual reproduction
16. Assess how research on plant and animal reproduction has affected the development of new reproductive technologies

# Types of Cellular Division

- Cellular division can either be classed as sexual division or asexual division
- Asexual cellular division maintains the normal number of chromosomes after division and is known as mitosis
- Sexual cellular division produces gametes with half the number of chromosomes and is known as meiosis

# 16.1 – The Cell Cycle

- The life cycle of the cell is known as the cell cycle
- Somatic cells divide and produce cells that are identical to the parent cell

# The Organization of Genetic Material in Eukaryotes

- Genetic information is found in a cell's DNA
- DNA makes up the chromosomes found in the nucleus
- This DNA is tightly wound around a series of proteins (histones) that are found in the nucleus
- Most of the time, the genetic material is found in a mass of intertwined strands known as chromatin

- However, during cellular division the chromatin condenses and forms a chromosome
- Each chromosome has a centromere, a central, pinched-in region

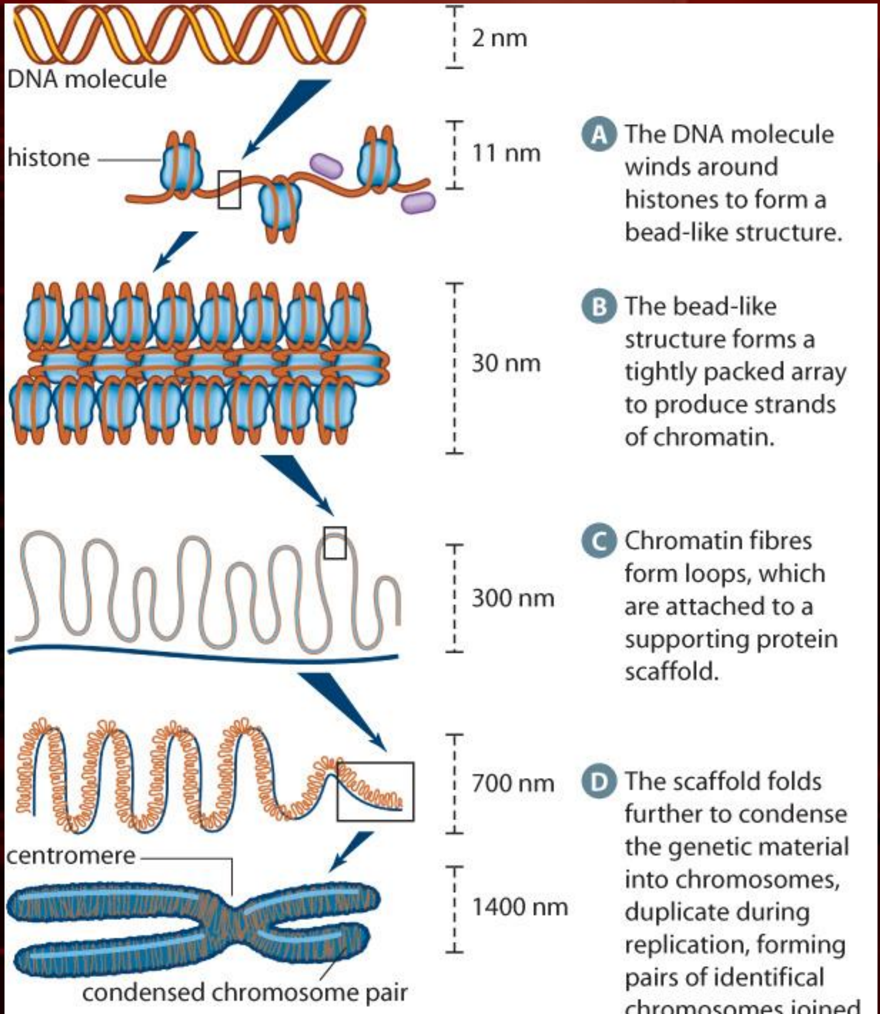



**Figure 16.2** The levels of organization of genetic material in a eukaryotic cell

# Chromosome Number

- The number of chromosomes found in each cell of a particular species will always be the same
- Chromosomes are typically found in pairs
- Humans have 22 autosome pairs and a single pair of sex chromosomes
- Paired chromosomes are homologous – sex chromosomes are not technically homologous, but they can have homologous regions

# Homologous Chromosomes

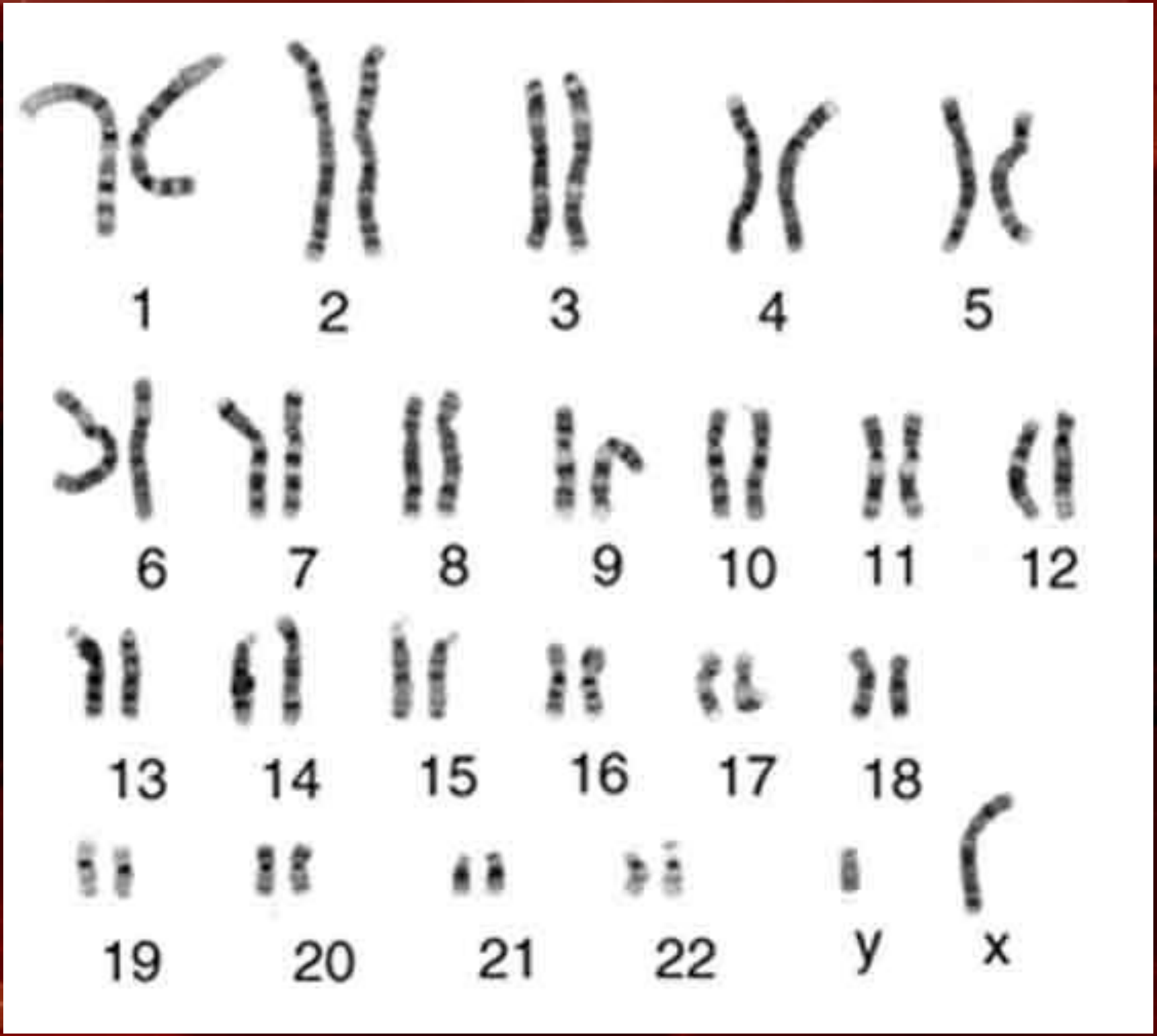
- Homologous chromosomes carry the same genes
- Each gene is found at a particular location or locus
- These genes may be different forms, however (these are known as alleles)

# Chromosome Number and Ploidy

- Diploid – The number of chromosomes in a somatic cell (2n = 46)
- Haploid – THE # OF CHROMOSOMES IN A GAMETE (n = 23)
- Polyploid – IN A CELL THAT HAS MORE THAN 2 OF EACH CHROMOSOME (8n: OCTAPLOID) (NOT HUMAN)

# Karyotyping

- Karyotyping is the process of looking at the chromosomes in a cell.
- In a karyotype, a picture of the chromosomes is taken during metaphase
- The chromosomes are then aligned in pairs and counted




http://www.biotechnologyonline.gov.au

# The Phases of the Cell Cycle

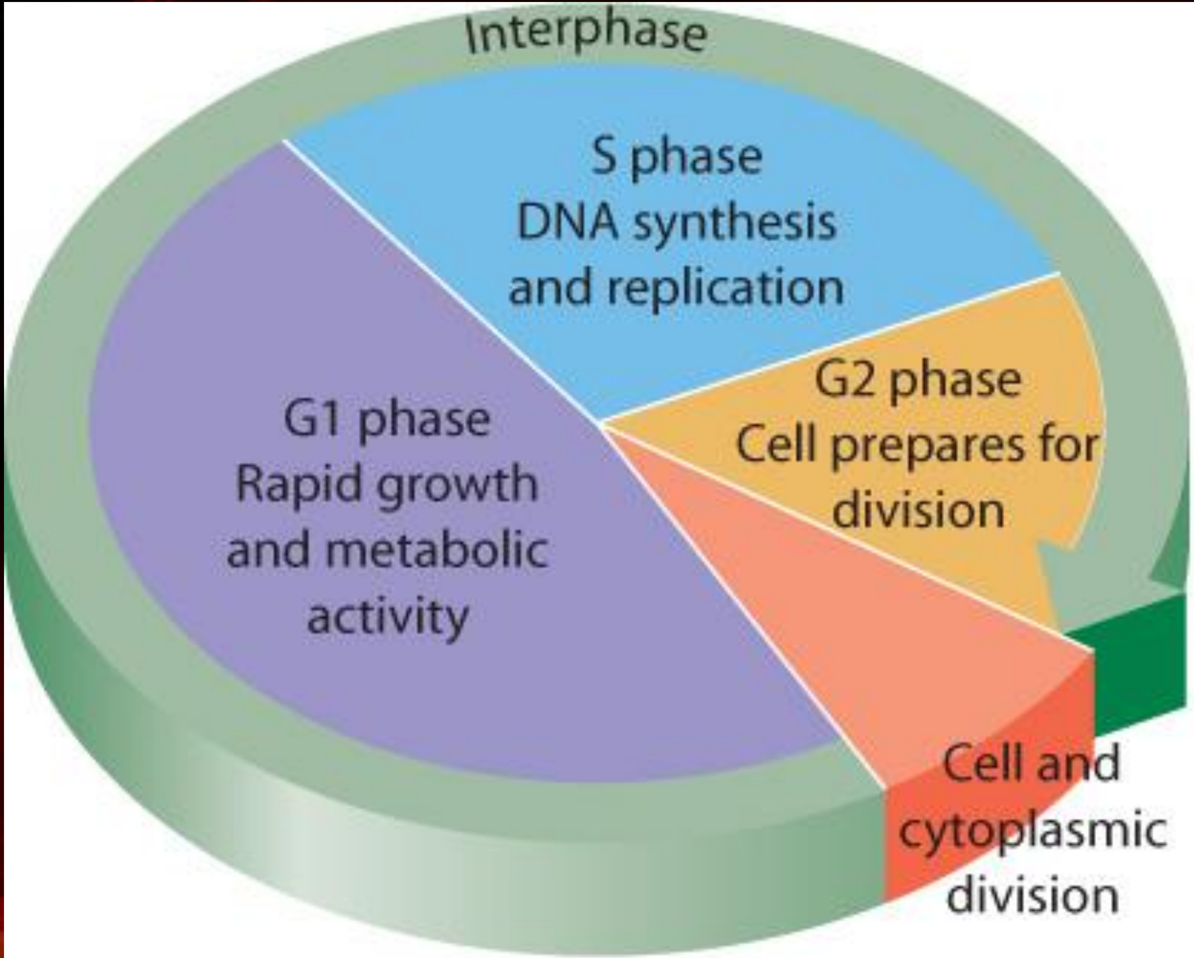



**Figure 16.5** The cell cycle. Interphase, the stage of growth and metabolic activity, occupies most of the cell cycle. The division stage involves the reproduction of the nucleus and the division of the cell contents.

# Growth stage and Mitotic Stage

- 2 main stages
  - Growth stage
    - Called Interphase
    - Cells grow in G1 phase
    - Midway through Interphase cells replicate to create their sister chromatid and this is called the S phase
    - During the G2 phase cells reserve their energy and make structures required for division
  - Mitotic Stage
    - Mitosis which is the actual division of genetic material
    - Cytokinesis which is the division of cytoplasm and actual splitting of the cell

# 16.2 – The Reproduction of Somatic Cells

- Somatic cells reproduce for a number of reasons:

- Growth

- Maintenance

- Repair

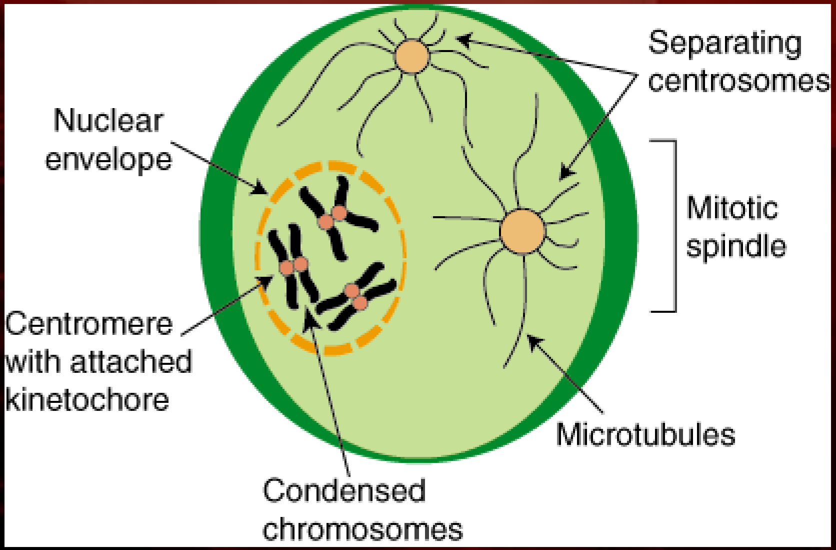
# Cellular Events During Division:

- The genetic material must be replicated
- The chromatin must be condensed and organized as the chromosomes in the nucleus
- Once complete set of chromosomes must be divided into each of two new nuclei
- The cell cytoplasm must divide to produce two complete and functional daughter cells

# Phases of Mitosis

- After the G2 phase, the process of mitosis begins in somatic cells
- At the end of interphase, there are two identical sets of DNA present in the nucleus
- The phases of mitosis are divided into phases based on the arrangement of chromosomes and the appearance or disappearance of cell structures

# Prophase

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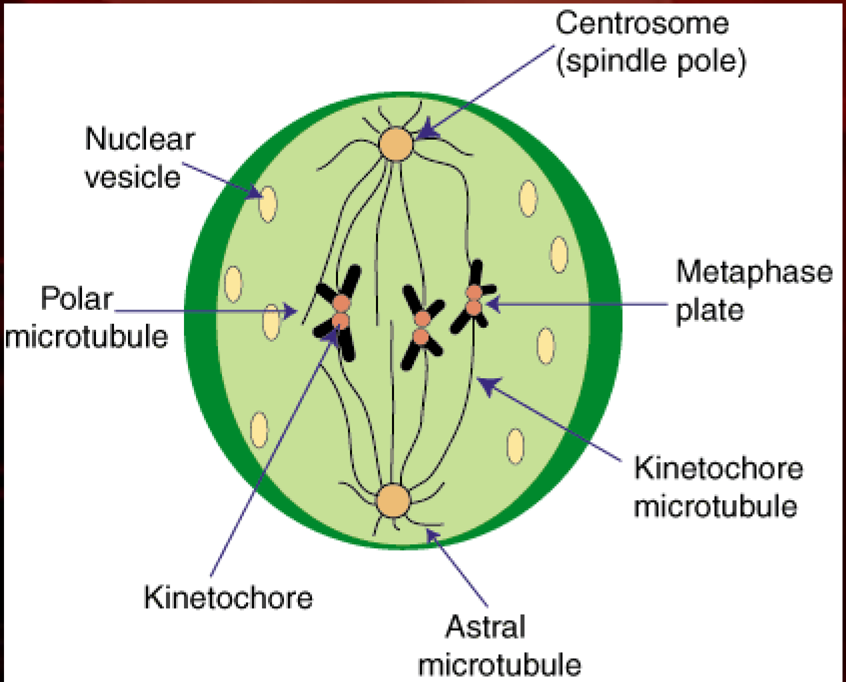
# Metaphase

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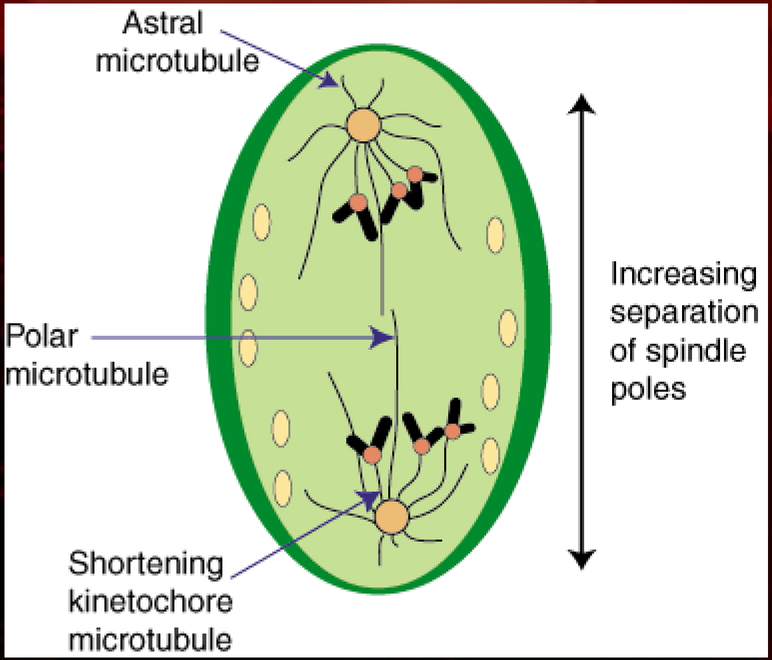
# Anaphase

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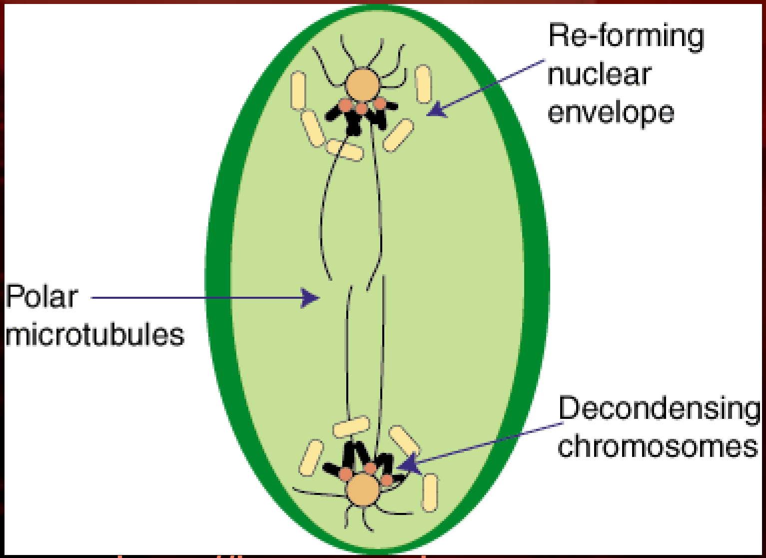
# Telophase

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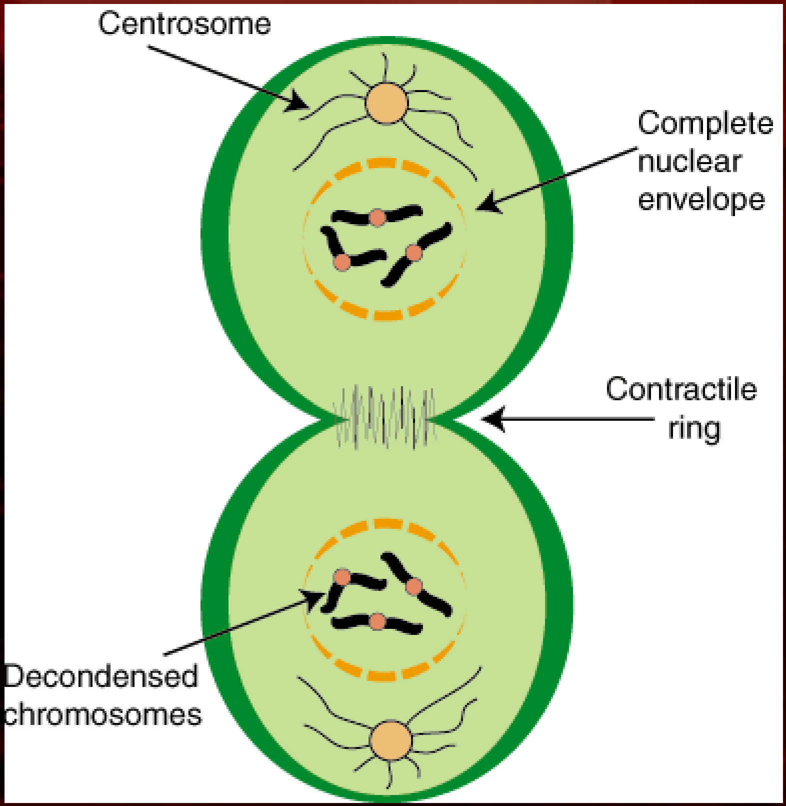
# Cytokinesis

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# Mitosis and Cytokinesis in Plant Cells

- Plant cells lack centrioles, but they still form spindle fibres
- The cell wall does not furrow and pinch during cytokinesis
- Instead, a membrane called a cell plate forms between the two daughter nuclei and extends to form a new cell wall

# Cloning

- Cloning occurs when identical offspring are produced from a single cell or tissue
- Cells that are used in cloning must be totipotent

http://www.mocpages.com

# Totipotent Cells

- A totipotent cell is a cell that is able to become any cell in the body of an organism (they are undifferentiated)
- In mammals, cells are undifferentiated until the 8-cell stage of development

# Creation of Clones

- Clones are created from single cells through the following process:

1. A developing embryo at an early stage is broken down into its single cells.
2. The nuclei from these cells are removed using a micropipette.
3. The nuclei are injected into unfertilized egg cells (with the nucleus removed)
4. These egg cells are cultured in a laboratory.
5. The blastulae are implanted into a recipient mother, which produces a number of cloned offspring.

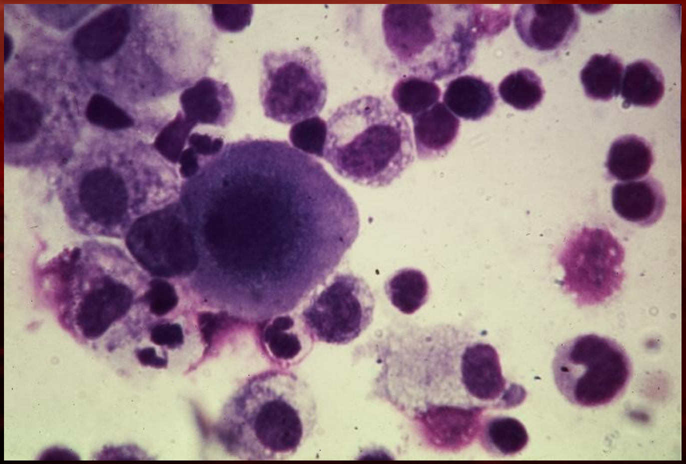
# The Possibilities of Cloning:

- Cloning could be used to produce new tissues that could be used for transplants
- Stem cells offer an opportunity for this, but they are only found in newly formed zygotes
- There is some controversy whether or not it is ethical to use fertilized embryos for research that could destroy the embryo

# Regulation of the Cell Cycle

- Within the average human, about 150 million cellular divisions take place per day
- Generally, cells will only divide at the correct time
- Within a cell, protein interactions serve as “start” and “stop” signals for division
- As well, external factors such as particular hormones, nutrient levels, and contact with other cells can regulate division

# Cancers



- A cancer is uncontrolled cell growth
- When this occurs, cells divide too quickly to perform their necessary functions
- Normally, cells divide only to replace damaged cells
- However, cancer cells divide even if there are healthy cells around it

# Tumor Growth

- Some cancer cells can divide in as little as 24 hours in isolation
- However, it seems that the body's tissues slow this growth
- Unlike normal cells, cancer cells do not stick together and therefore can move throughout the body
- The spreading of a cancer is known as metastasis

"Cancer Warrior" on PBS

# Cancer Treatments

- Cancer treatment can involve one of three main options:

1. Chemotherapy
2. Surgery
3. Radiation Therapy

# 16.3 – The Formation of Gametes (Meiosis)

The Meiosis Square Dance

- Gametes have half the number of chromosomes as the rest of the body cells (they are known as haploid cells)
- The haploid number is usually denoted by *n*, which in humans is 23 chromosomes
- The diploid number is usually denoted by *2n*, which in humans is 46 chromosomes

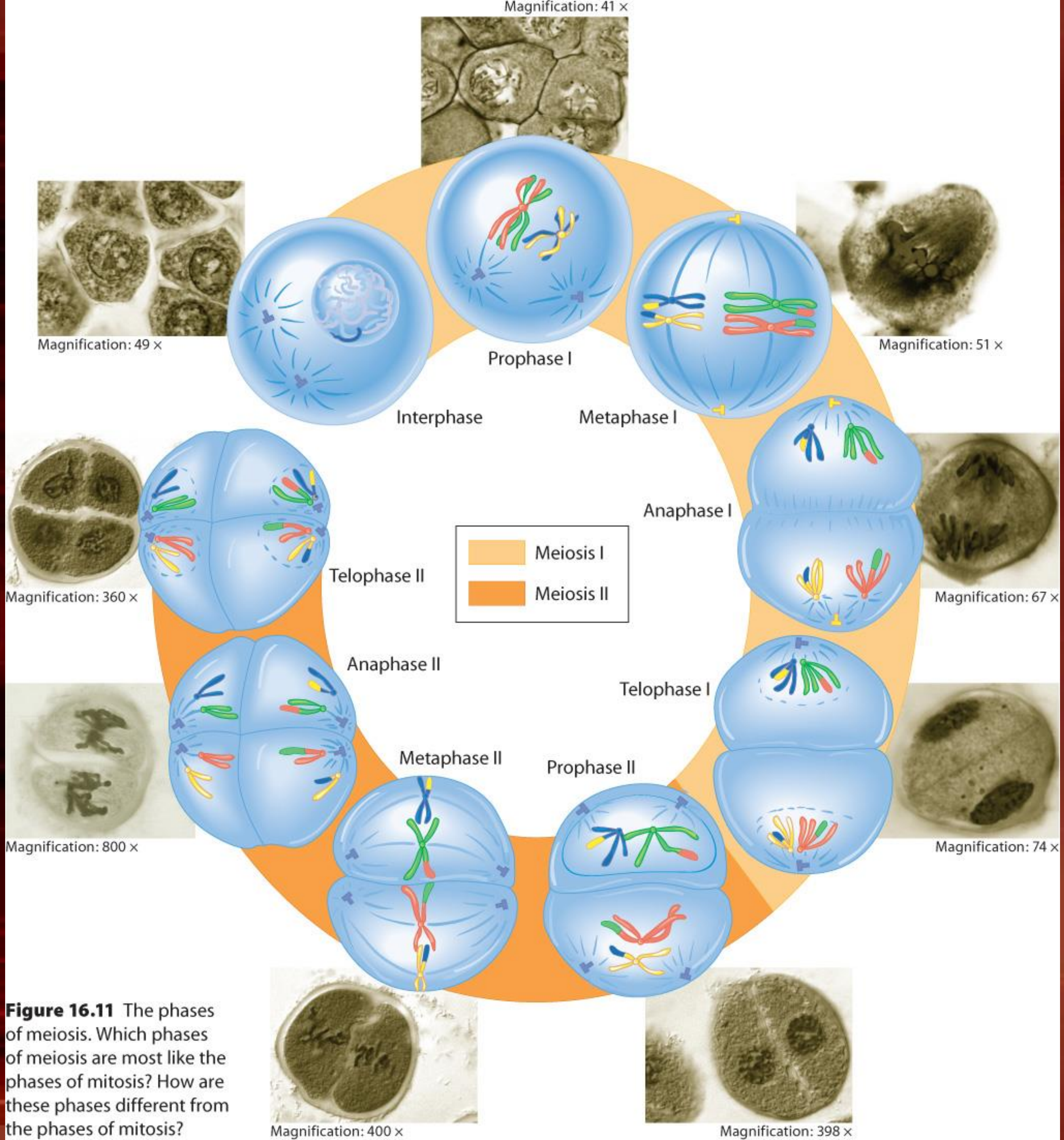



**Figure 16.11** The phases of meiosis. Which phases of meiosis are most like the phases of mitosis? How are these phases different from the phases of mitosis?

# Meiosis I

- This involves the four stages seen in mitosis, but with distinct differences:

1. In prophase I, chromatids assemble in homologous pairs known as tetrads
2. The chromosomes (paired chromatids) intertwine and exchange segments of DNA (known as crossing-over)
3. During metaphase I, the chromosomes line up in homologous pairs, with each pair eventually moving to one end of the cell
4. By the end of telophase I, the two daughter cells are not identical to their parent (due to the crossing-over)

# Meiosis II

- Meiosis II begins without a gap phase, which means that none of the DNA is replicated
- The process of meiosis II is identical to mitosis
- During anaphase II, the sister chromatids separate and are segregated into their individual gametes

# Sources of Genetic Recombination

- Genes are recombined during meiosis in a couple of ways
- First, independent assortment of chromosomes occurs (the likelihood of two gametes having the same combination of chromosomes from the parent is very slim)
- As well, non-sister chromatids exchange portions of their chromosome during crossing-over

# Independent Assortment

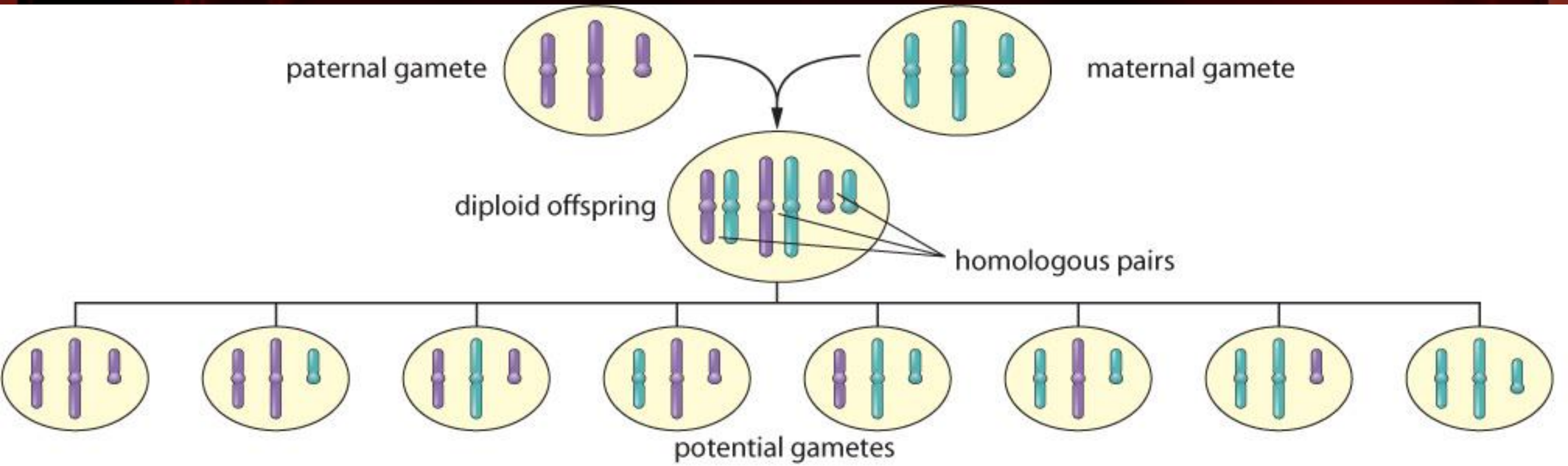



**Figure 16.13** The diploid offspring has three chromosome pairs. The potential combinations of chromosomes produce eight genetically different gametes. A cell that has seven chromosome pairs can give rise to $2^7$ or 128 different gametes.

# Crossing-Over

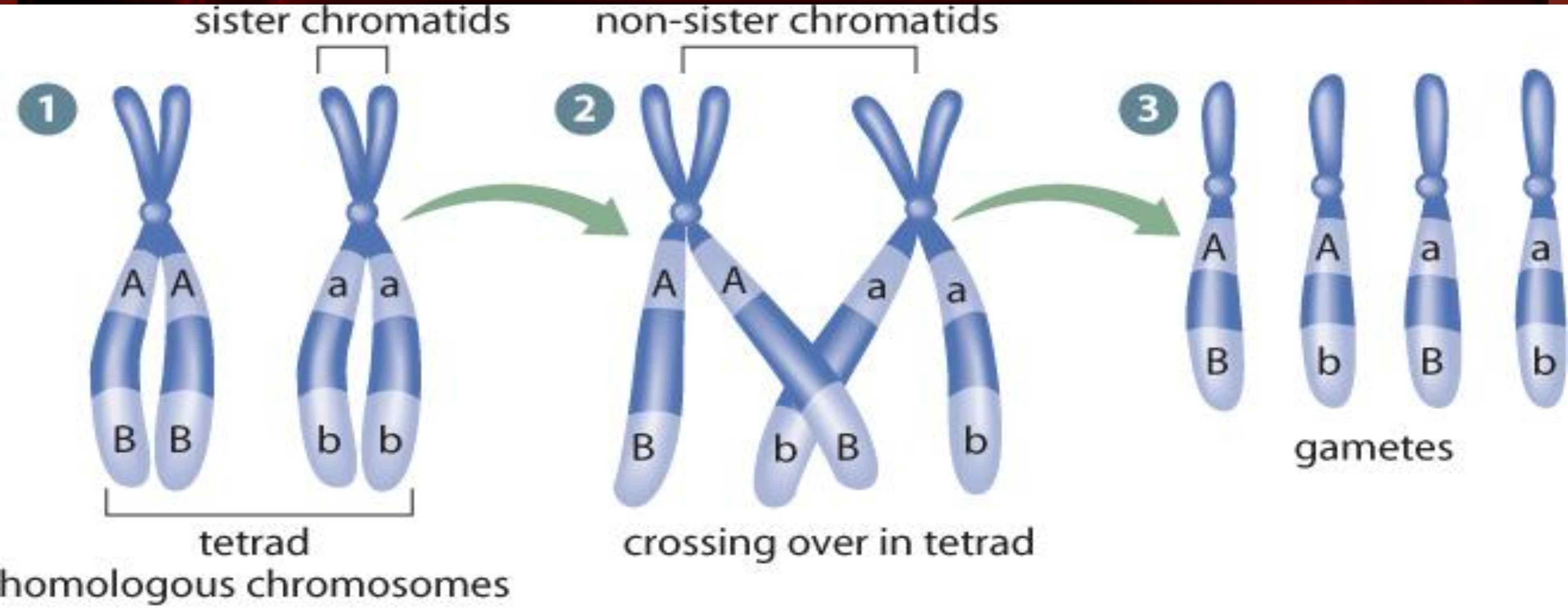


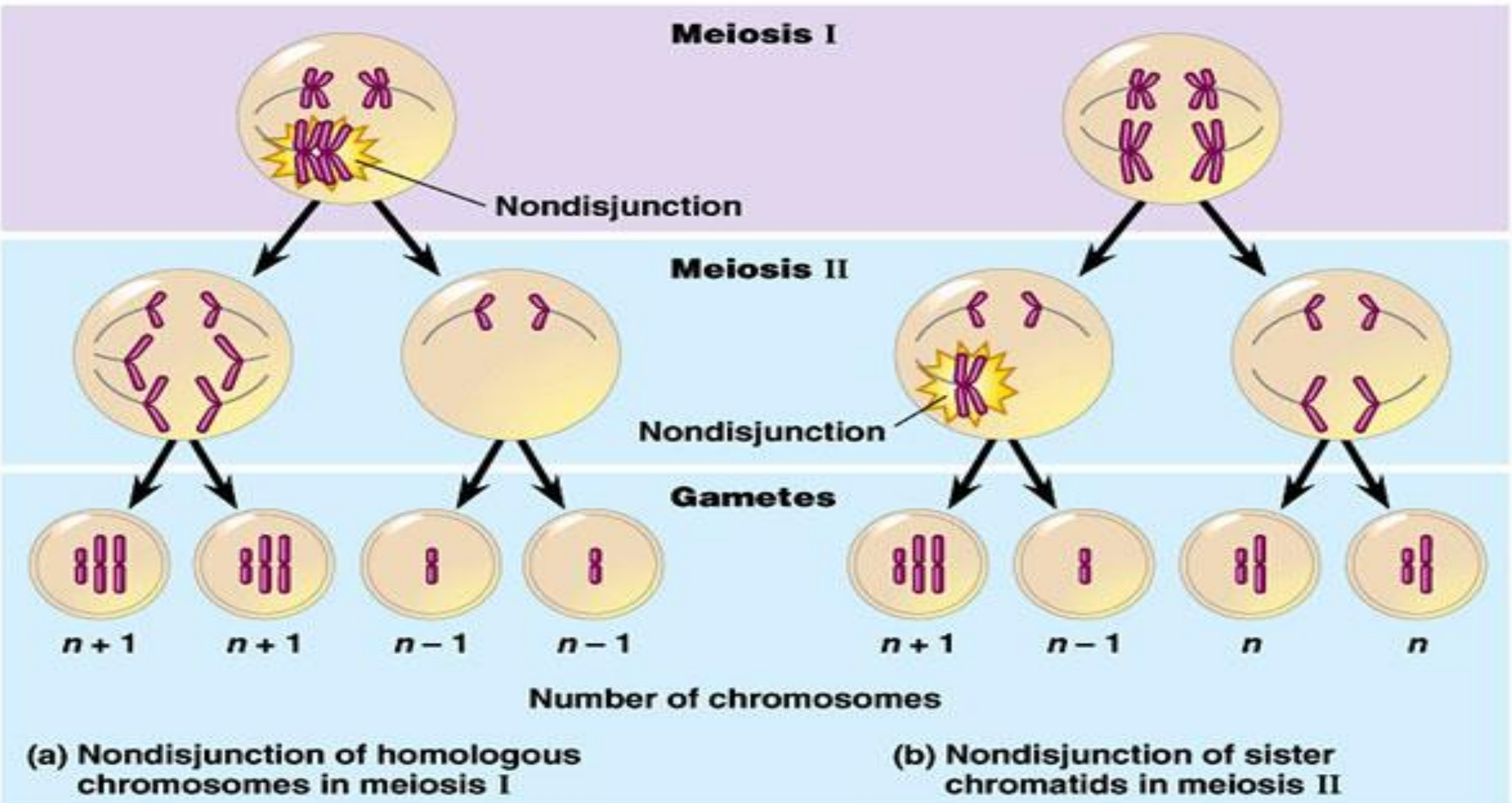

**Figure 16.14** **(A)** Crossing over occurs at random between pairs of homologous chromosomes. In these chromosomes, upper-case and lower-case letters denote different alleles, or different versions of the same gene. **(1)** During prophase, homologous chromosomes form pairs. **(2)** Non-sister chromatids cross over each other and exchange segments of chromosomes. As a result, chromosomes in the gametes **(3)** contain new combinations of genetic material.

# Nondisjunction

- The improper separation of chromatids in meiosis can lead to nondisjunction (two homologous chromosomes move to the same pole)
- The result is that one daughter cell will have 22 chromosomes while its sister will have 24
- As a result, when the zygote forms, it will have either 45 or 47 chromosomes
- These cells with too much or too little genetic information cannot operate effectively

# When does Nondisjunction Occur?

Anaphase I Anaphase II



# Trisomy & Monosomy

- Nondisjunction disorders can be classified as:
  - Trisomy:
    - Gamete with 24 chromosomes joins with normal 23 chromosome gamete producing a zygote with 47 chromosomes
- Monosomy:
  - Occurs when a sex cell containing 22 chromosomes joins with a normal gamete producing a 45 chromosome zygote

# Nondisjunction Disorders

Down Syndrome

- Child is born with extra chromosome in pair 21
- Trisomic disorder – too much genetic info

- Associated with intellectual disabilities
- Characteristics include
  - Round face
  - Enlarged creased tongue
  - Short height
  - Large forehead

# Down Syndrom Stats

- One in 600 babies born
- Risk of giving birth to Down Syndrome baby increases with age

Woman in 40s has a 1 in 40 chance

Joey Moss, who was born with Down Syndrome, has worked as an assistant to the training staff of both the Edmonton Oilers and Edmonton Eskimos since the 1984 – 1985 season

# Turner’s Syndrome

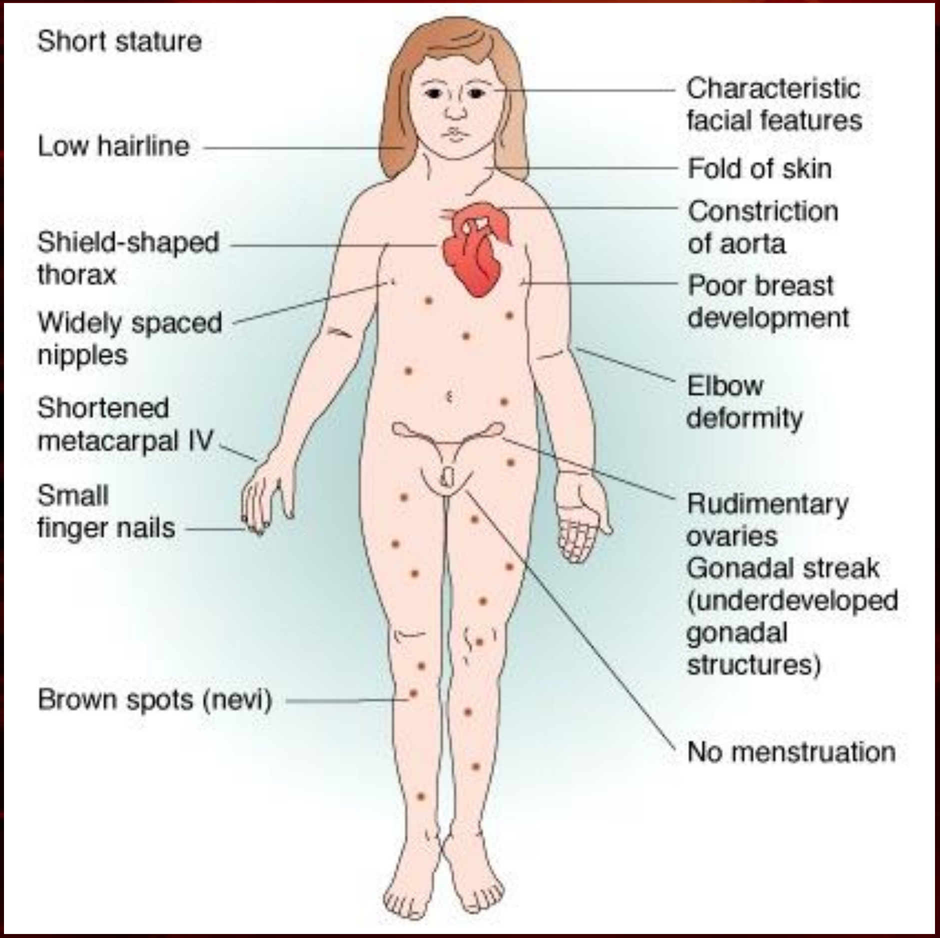
- Turner’s Syndrome
  - Monosomic disorder (XO)
  - Produces female with single X chromosome
  - In egg cell, both homologous X chromosomes move to same pole
  - One egg has no X and once fertilized produces zygote with 45 chromosomes
  - These females don’t develop sexually, are short with thick, widened necks

# Turner Syndrome

Stats

- One in every 10 000 births, however most are miscarried

- NOTE some go on to lead highly productive lives!




http://fig.cox.miami.edu

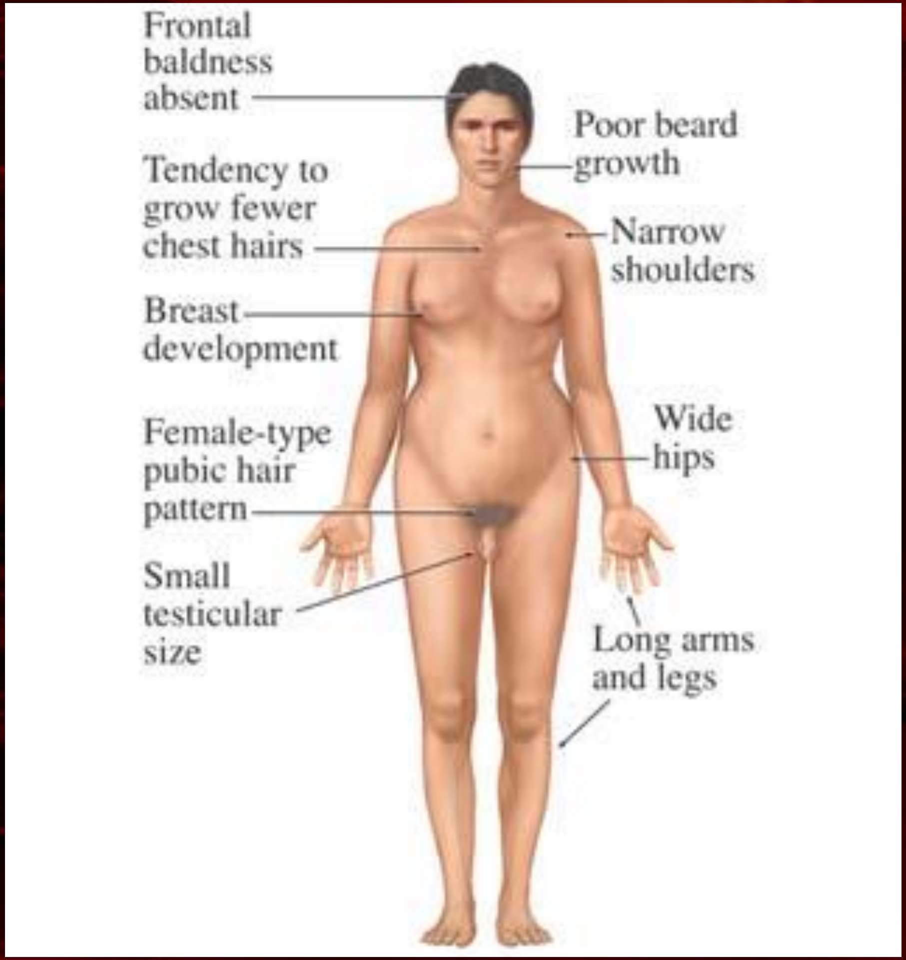
# Klinefelter's Syndrome

- – Occurs in sperm or egg
- – Child inherits two XX chromosomes and a Y
- – Child appears male at birth but starts producing female sex hormones at puberty
- – Males are sterile

# Klinefelter's Syndrome

Stats:

1 in every 1 000 births




http://www.thirdage.com

# Genetic Testing

- It is possible to detect genetic disorders in a developing fetus
- This can be done through two methods: amniocentesis and chorionic villus sampling (CVS)
- During amniocentesis, a needle is used to extract a sample of the amniotic fluid that surrounds the fetus

- This fluid contains cells from the developing fetus
- In chorionic villus sampling (CVS), cells are extracted from the chorion of the developing embryo
- This can be done much earlier (as early as 8 weeks into the pregnancy) than amniocentesis

# Issues Regarding Genetic Testing:

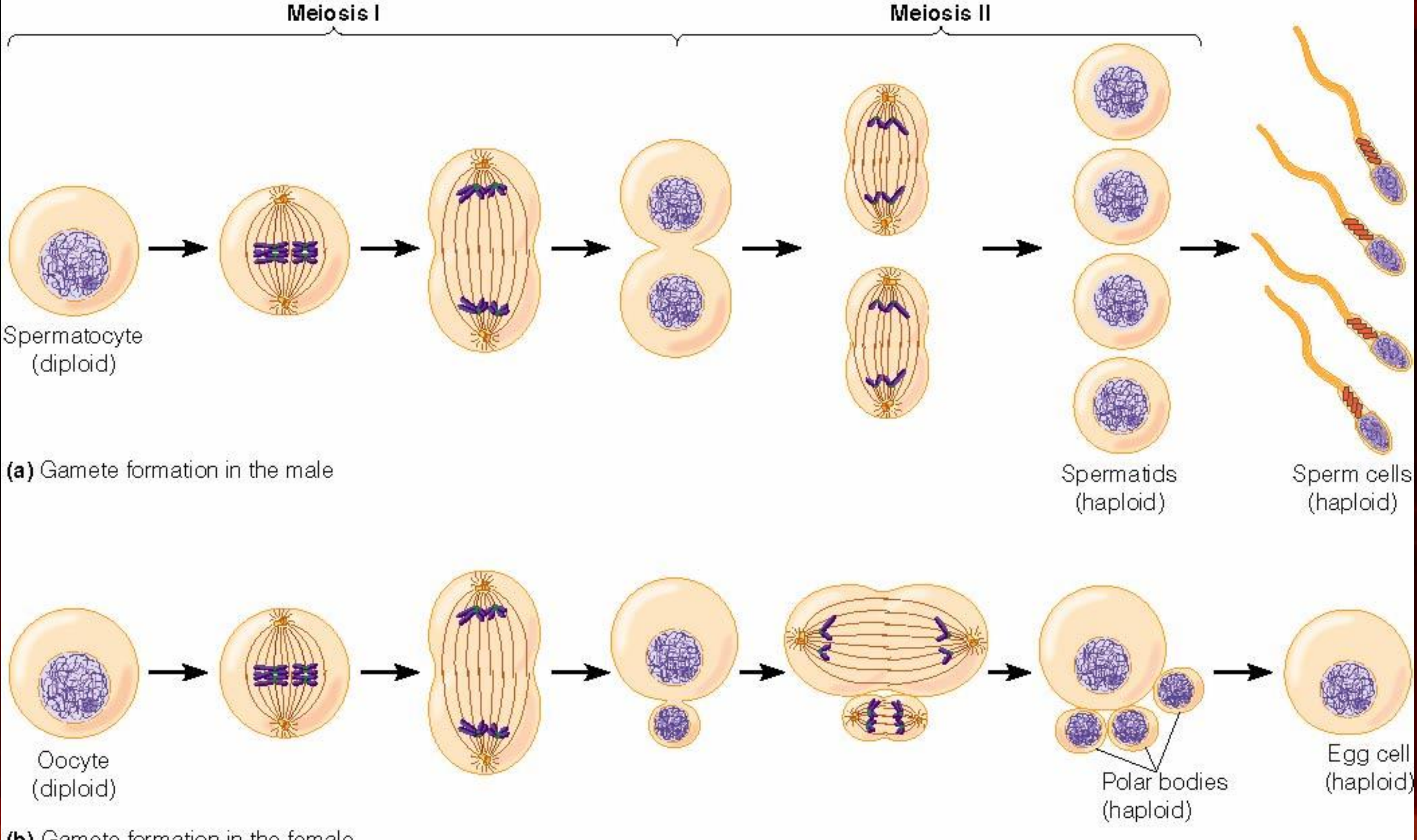
- What will the parents do with this knowledge?

- Decreased standard of life?  Who decides this?

# Male & Female Gametes

- Both sperm and eggs are produced through meiosis
- However, spermatogenesis produces four identical sperm cells (the division of the cells is equal), while only one egg cell and three polar bodies are formed in the ovary

# Sperm & Egg Production

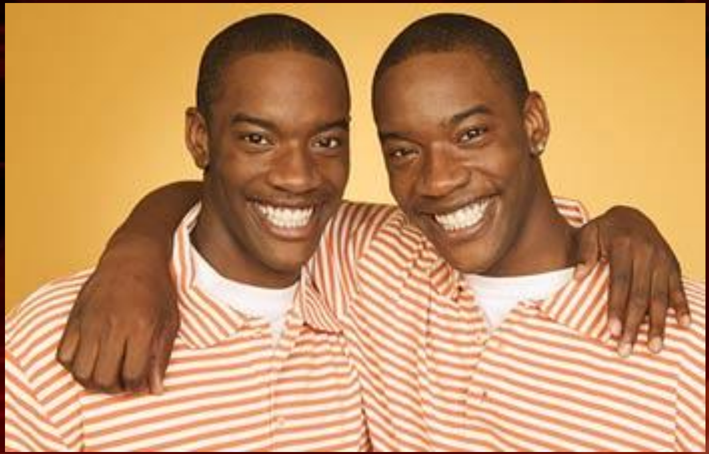


# Sex Determination

- The sex of a zygote is determined by the sex chromosomes (the X & Y chromosomes)
- The Y-chromosome contains a gene known as TDF (Testes Determining Factor)
- Any zygote with a Y chromosome is therefore male (XY)
- A zygote with two X chromosomes is female

# Twins – Natural Clones

- Identical twins form when a cell breaks free from the undifferentiated embryo and develops on its own
- Identical twins are clones of each other – they share the same DNA



http://publications.nigms.nih.gov

# Fraternal Twins

- Fraternal twins form when two eggs are fertilized and implant at the same time
- These twins may appear different because they do not have identical DNA

http://www.inkycircus.com

# The Myth of Criminal Chromosomes

- Early work on karyotypes seemed to support the idea that males with XYY nondisjunctive disorder (“supermales”) were prone to criminal action
- This is due to studies carried out in the 1960s that showed that 3.5% of violent male criminals in prisons had the XYY condition (this is 20 times the average found in the general population)

- This led to widespread panic regarding “criminal genes” in the 1960s and 1970s
- In Canada, there was mass testing for XYY in male infants
- However, it is now accepted that XYY males do not show a greater tendency towards violence, but rather the XYY disorder leads to learning difficulties which can lead to antisocial behavior
- The only true link to XYY that has been identified is greater than average height

# Reproductive Technologies

- There are a number of reproductive technologies that are used today
- Some methods are specifically used on livestock, while others are meant for humans

# Artificial Involution (Cattle)

- In this process, a low-grade cow can give birth to a high-grade calf
- A high-grade cow is given fertility drugs to produce multiple eggs which are then harvested under anesthetic
- These eggs are fertilized in a Petri dish with sperm from a high-grade bull *(in vitro* fertilization)

- The fertilized egg is allowed to grow for a short period in a nutrient-rich medium before it is implanted into the low-grade surrogate cow
- The newborn calf will have none of the surrogate cow’s genes

# Artificial Insemination

- In this process, selected high-grade sperm is injected into the female's reproductive system at the time of ovulation
- The high-grade sperm then (hopefully) fertilizes the egg to produce an offspring with the traits from the high-grade sperm

# Human IVF

- A mother is given numerous hormones to produce multiple eggs each month
- The multiple eggs are removed just before they leave the follicles in the ovaries (otherwise they will not develop normally)
- Removal of the eggs takes 30-60 minutes and may be done under anesthetic
- The eggs are immediately fertilized with the partner's sperm (which is collected at the same time) in a Petri dish

- The zygotes are allowed to mature for a short time (until the blastocyst forms)
- One (or more commonly 3 or 4) of the embryos are then implanted using a catheter
- A pregnancy test is run about 2 weeks later to confirm pregnancy
- In cases where the male has a low sperm count, sperm may be directly injected into the egg

# IVF Success Rates and Cost

- Successful pregnancy was achieved in 30.7% of all cycles.
- About 69% of the cycles carried out did not produce a pregnancy.
- Less than 1% of all cycles resulted in an ectopic pregnancy.
- About 11% of these pregnancies involved multiple fetuses.
- About 83% of pregnancies resulted in a live birth.
- About 17% of pregnancies resulted in miscarriage, induced abortion, or a stillbirth.
- The average cost of IVF is between $10 000 and $15 000 dollars, depending on medications, procedures and the number of IVF cycles required for a successful pregnancy

# What Can IVF Treat?

- IVF can treat the following causes of infertility:
- Endometriosis
- Low sperm counts
- Problems with the uterus or fallopian tubes
- Problems with ovulation
- Antibody problems that harm sperm or eggs
- The inability of sperm to penetrate or survive in the cervical mucus
- An unexplained fertility problem

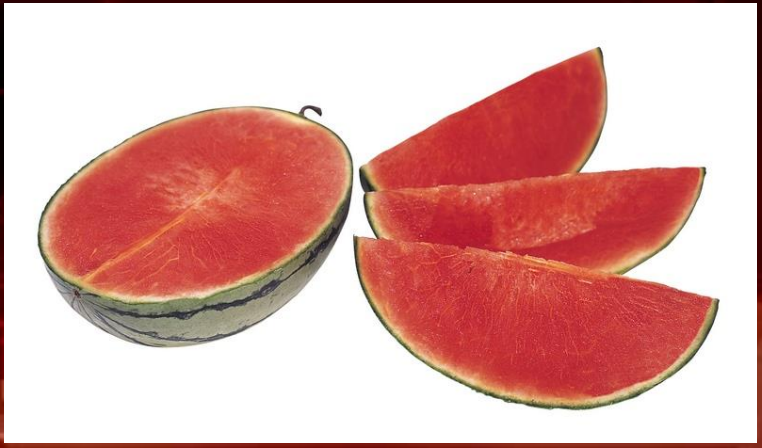
# Surrogate Mothers

- Sometimes a mother cannot carry a pregnancy to term
- In these cases, an egg is removed from the mother, fertilized via in vitro fertilization, and placed in a surrogate mother
- The surrogate mother then carries the pregnancy to term (the baby contains none of this mother's genes)

# Using Polyploids

- Some plants are able to survive with extra sets of chromosomes in their nuclei
- Some polyploid plants produce larger flowers and fruits than normal
- For instance, ordinary watermelon are diploid and have haploid gametes
- Using chemicals, biologists can produce tertraploid (*4n*) watermelons

- These *4n* watermelons are then crossed with *2n* watermelons to make a *3n* zygote
- The *3n* plants produce fruit, but these fruit do not produce seeds
- This is because the extra pair of homologous chromosomes means that synapsis of homologous chromosomes will not occur at metaphase I



# 16.4 – Reproductive Strategies

- Reproduction can generally be classified as sexual or asexual reproduction
- Sexual reproduction involves the production of gametes by meiosis, followed by fertilization

# Prokaryote Reproduction

- Bacteria replicate their single circular chromosome (plasmid) and then divide (this is not considered to be meiosis – it is known as binary fission)
- Bacteria can reproduce in as little as 20 minutes in this fashion

# Bacterial Conjugation

- Bacteria can exchange genetic material with nearby bacteria when they come into contact
- The bacteria produce a bridging structure known as a pilus that allows them to exchange genetic material (typically in the form of a plasmid – a circular ring of DNA)
- Through this method, bacteria can exchange genes from other species of bacteria

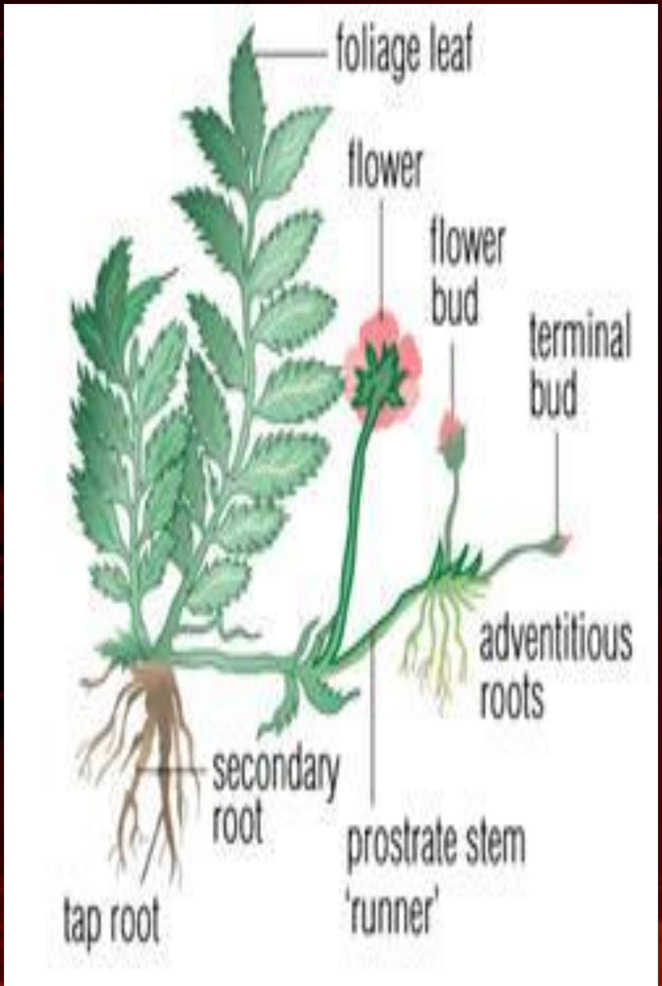
# Budding

- A form of asexual reproduction where a complete, but miniature version grows out from the parent

http://www.dkimages.com/discover/previews/887/45065712.JPG

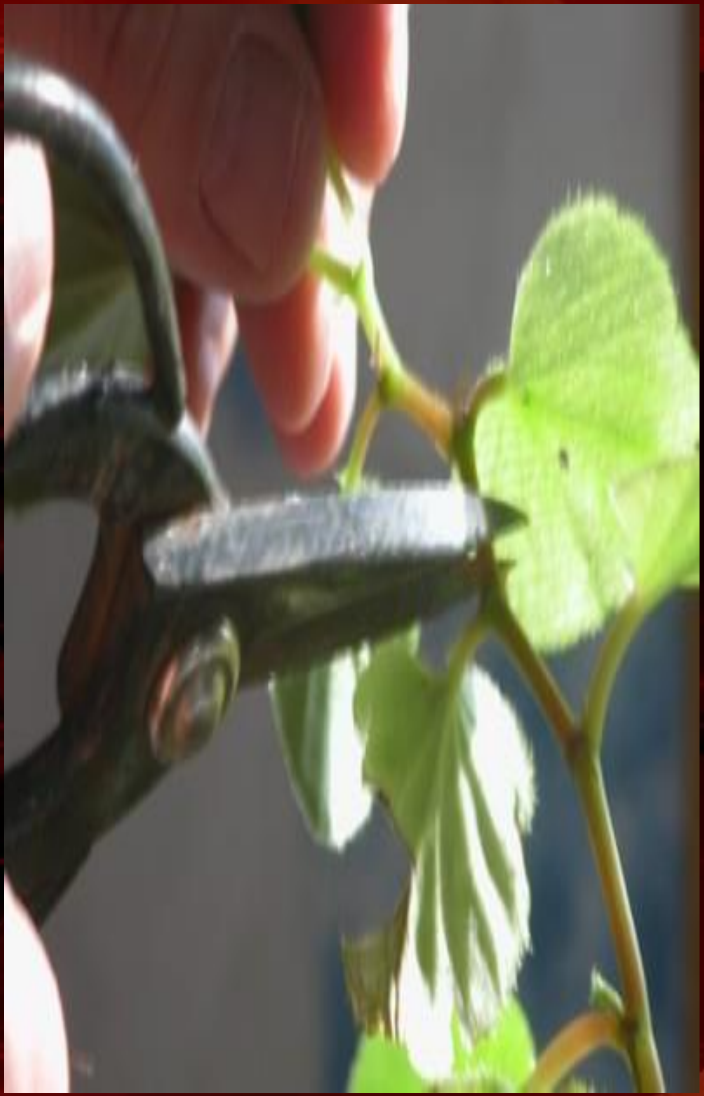
# Vegetative Reproduction

- A form of asexual reproduction where a new plant grows from a modified stem.



# Fragmentation

- A form of asexual reproduction where a new organism is created from a fragment (portion) of a Parent.



http://z.about.com/d/gardening/1/5/Q/Cutting.jpg

# Parthenogenesis

- A form of asexual reproduction where an unfertilized egg grows Into an adult organism.

http://content.answers.com/

# Spores

- A form of asexual reproduction where a spore (reproductive cell) grows into an adult organism without fusion with another cell
- Spores can be dormant for months, or even years before activating.

http://upload.wikimedia.org

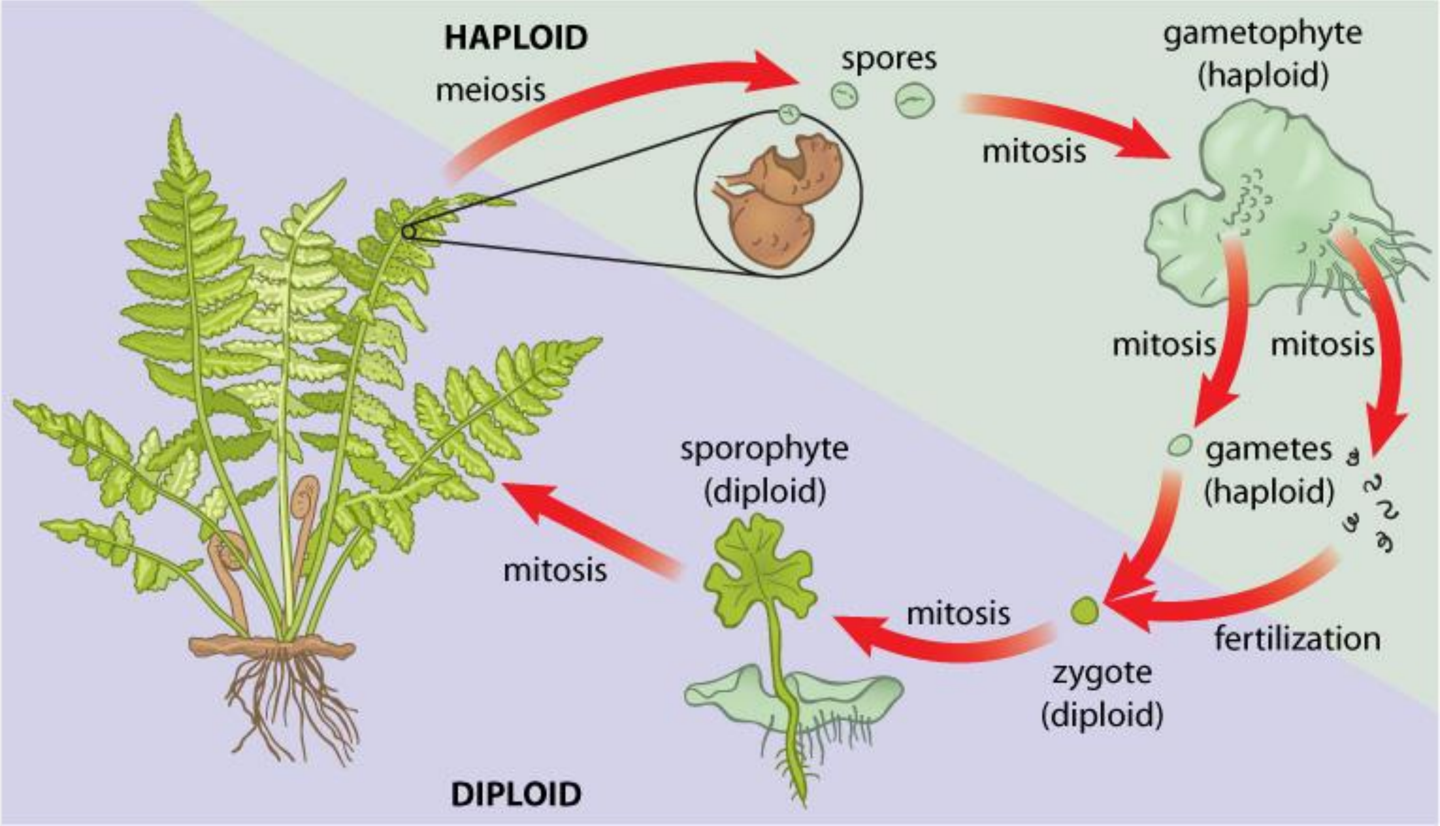
# Alternation of Generations

- The life cycle of plants involves two distinct generations – a haploid generation and a diploid generation that alternate
- This would be like giving birth to sperm and eggs which then grew up and mated to form a diploid baby

- The diploid generation of a plant is called the sporophyte  (spore-making body)
- These sporophytes use meiosis to make haploid spores
- The spores then grow into a plant body called a gametophyte
- These gametophytes produce male and female gametes which fuse and form another sporophyte
- This cycle is repeated over and over

# Alternation of Generations

**Figure 16.25** The life cycle of a fern, like all plants, consists of the alternation of generations of diploid sporophytes and haploid gametophytes.



# Mosses

- The leafy green mat that is characteristic of mosses is the gametophyte
- At certain times of year, a stalk (the sporophyte) grows out of the mat and produces new spores that fall to the ground
- These spores develop into the gametophyte

# Mosses

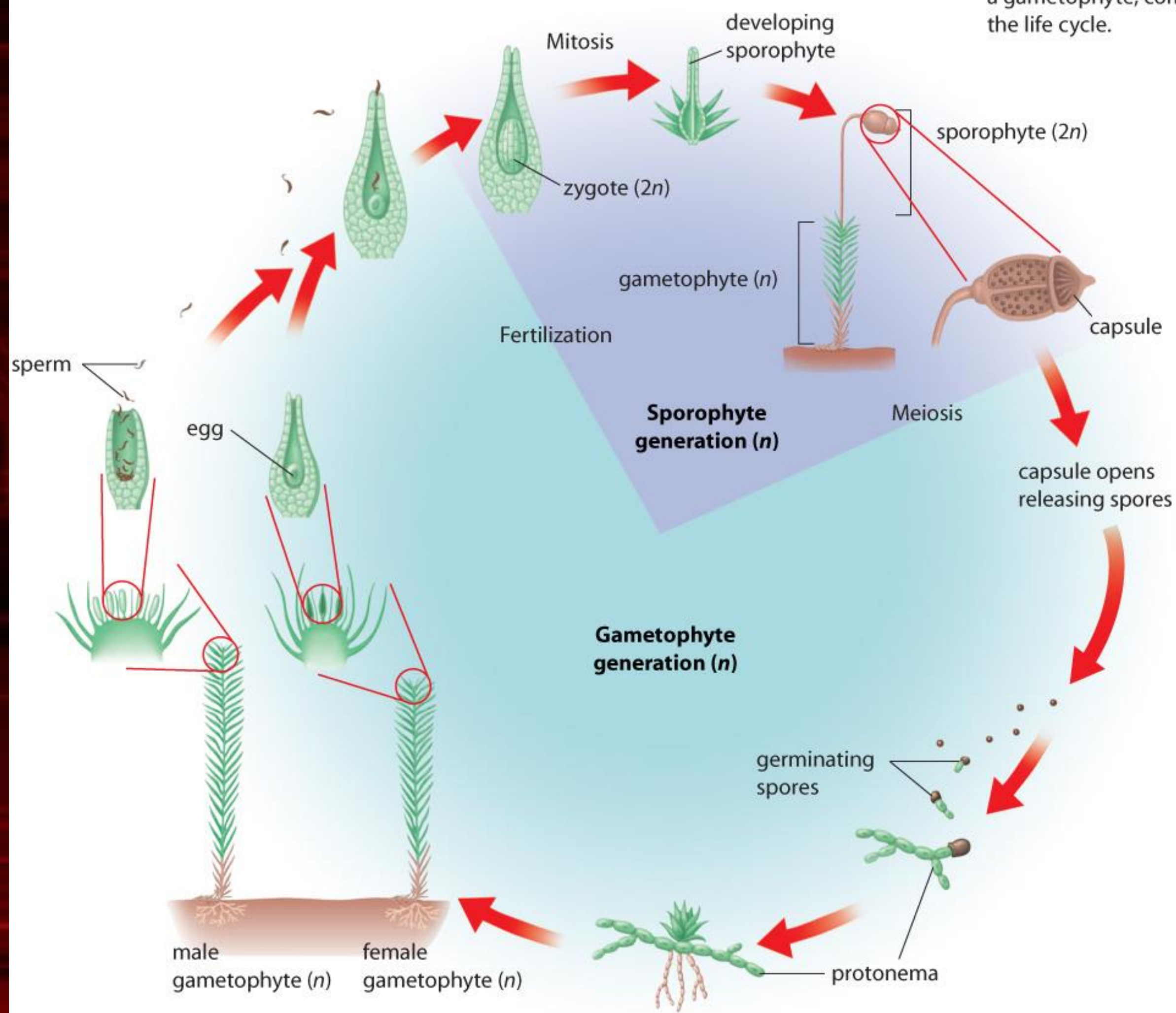



**Figure 16.26** The life cycle of moss. The moss gametophyte produces gametes that join to form a zygote. The zygote develops into the sporophyte that produces spores. Spores can germinate and grow into a gametophyte, completing the life cycle.

# Conifers

- Conifer trees are diploid sporophytes
- The haploid gametophytes are microscopic structures within the male and female cones of the tree
- The male gametophyte produces pollen which is carried by the wind to the female gametophyte, and a seed forms

# Conifers

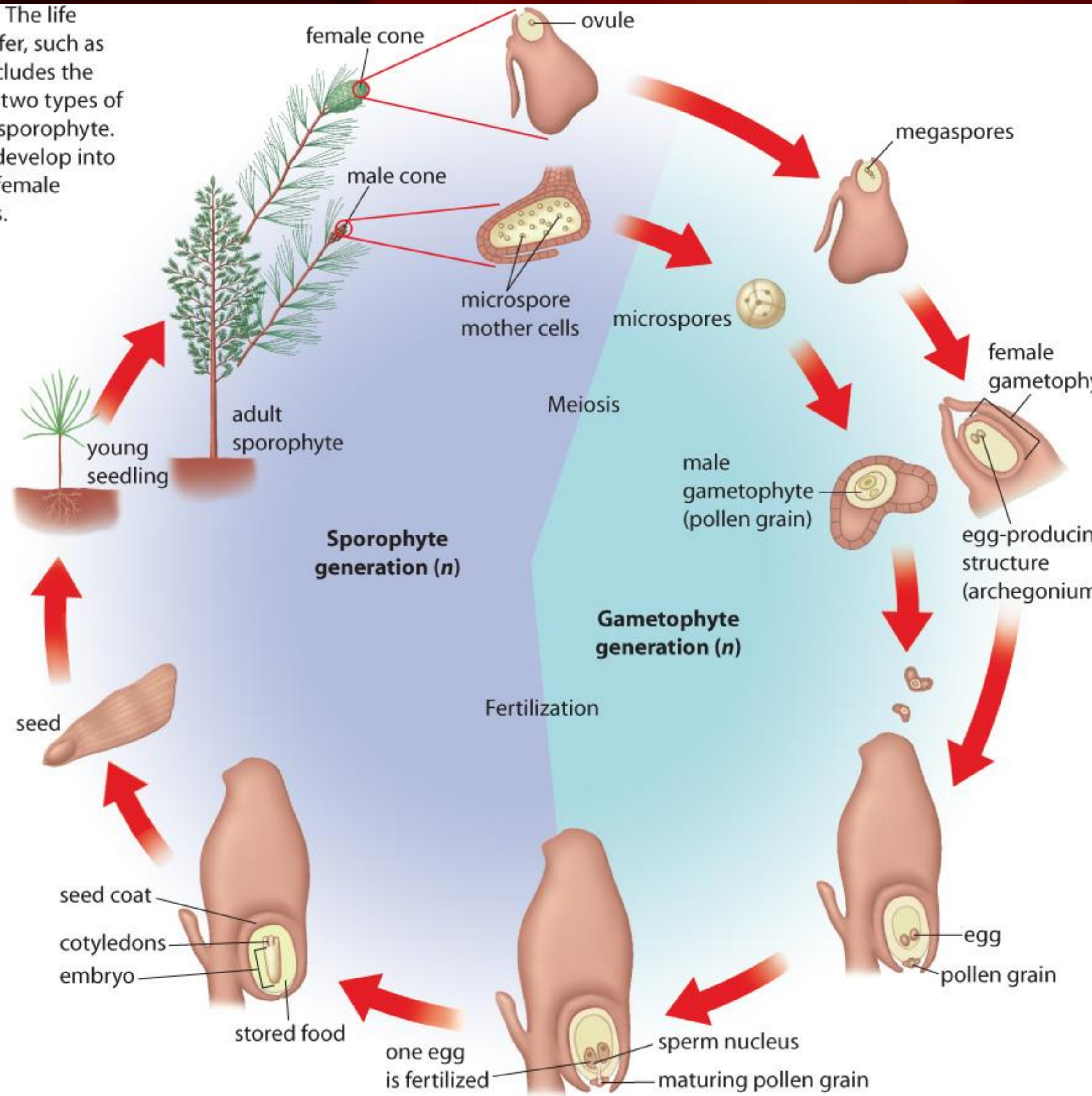



**Figure 16.27** The life cycle of a conifer, such as a pine tree, includes the production of two types of spores by the sporophyte. These spores develop into the male and female gametophytes.

# Alternation in Sexual Cycles

- Some animal life cycles alternate between asexually-reproducing and sexually-reproducing phases
- For instance, *Cnidaria* (jellyfish, anemones, and corals) spend part of their lives reproducing asexually, while at other times they will reproduce sexually

# Advantages of Sexual Reproduction

1. Adaptation

2. Reduced Competition

3. Repair of Damaged Chromosomes

# Disadvantages of Sexual Reproduction

1. May Interfere with Adaptation

2. Requires Mates

3. Requires Resources

# Advantages of Asexual Reproduction

1. Rapid

2. Reduced Energy Requirement

3. Increased Offspring Survival Rate

# Disadvantages of Asexual Reproduction

1. Limits Variation