Grade 11 Biology

Genetic Processes

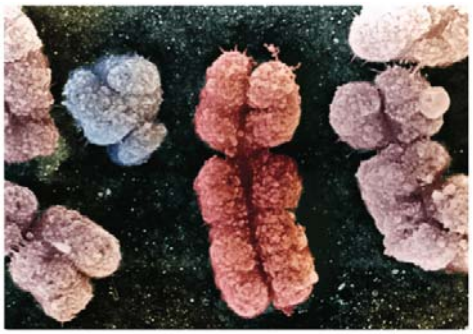
Class 3

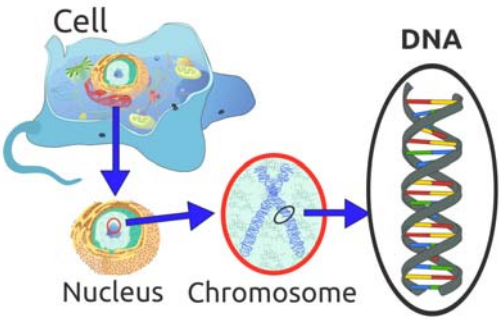
Overall Expectations

- Evaluate the importance of some recent contributions to our knowledge of genetic processes, and analyze social and ethical implications of genetic and genomic research
- Investigate genetic processes, including those that occur during meiosis, and analyze data to solve basic genetics problems involving monohybrid and dihybrid crosses
- Demonstrate an understanding of concepts, processes, and technologies related to the transmission of hereditary characteristics

Heredity

- **Heredity** – the passing of chromosomes from parents to offspring
  - Chromosomes carry information for traits
  - Genetic information is contained in DNA





Genetics

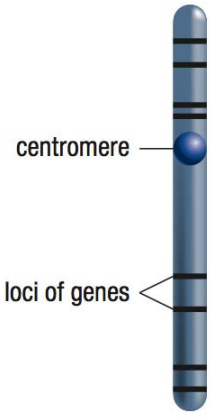


Figure 2 A typical human chromosome contains thousands of genes. Each gene is located at a different locus.

- The scientific study of heredity and variation
- **Gene** – portion of the DNA molecule that carries the information to produce a particular trait of an organism
- **Locus** – specific location on a chromosome

Chromosomes

- Found in the nucleus of all eukaryotic cells
- Vary in number, shape and size between different species

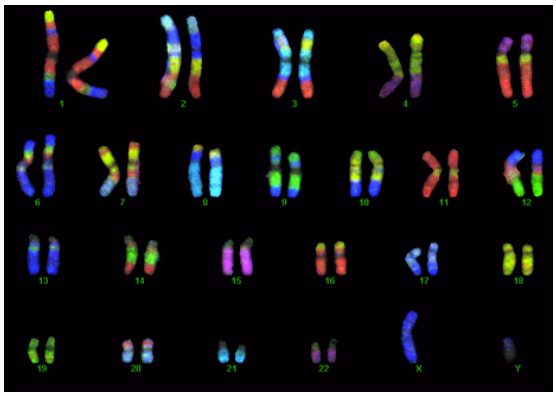
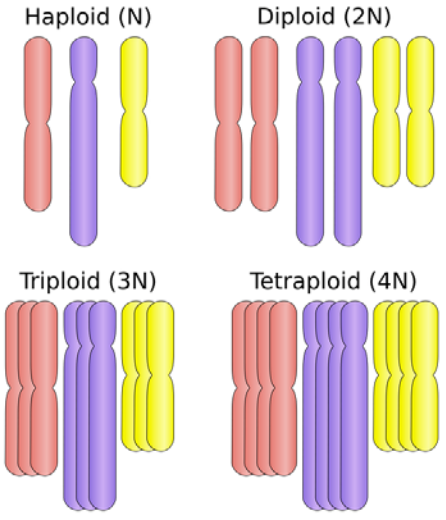


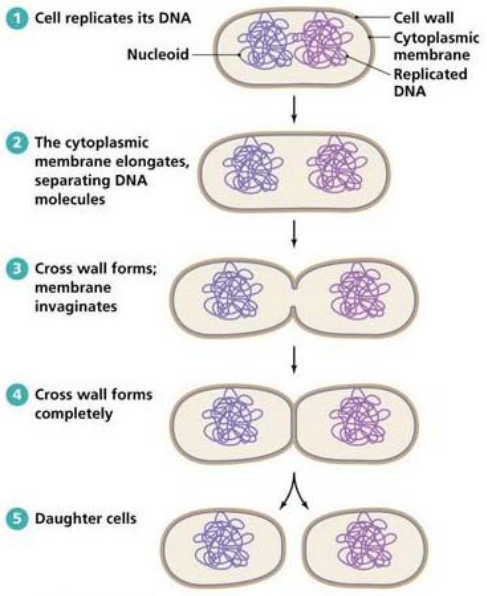
Table 1 Chromosome Numbers in Assorted Species

Species	Number of chromosomes per body cell
human	46
dog	78
mosquito	6
banana	22

- **Diploid** – two sets of chromosomes
- **Haploid** – half the normal number of chromosomes
- **Polyploid** – three or more sets of chromosomes



Asexual Reproduction



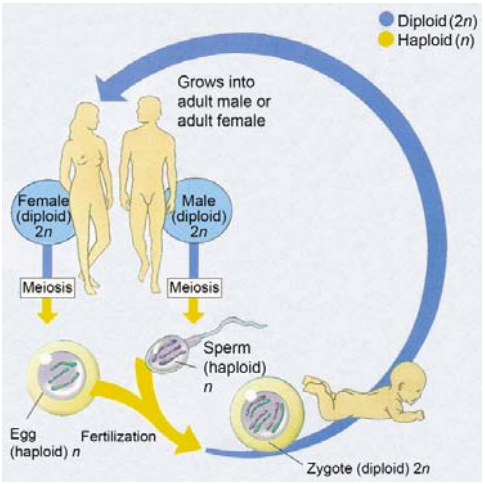
- A new individual is produced from a single parent by cell division (without the use of sex cells)
- Chromosomes of parent cell are duplicated and divided to form two new daughter cells
- Offspring are genetically identical to the parent cell

Advantages of Asexual Reproduction

- Parent organisms does not have to find a mate, perform specialized mating behaviors or posses specialized anatomy
- Asexual reproduction is direct and invariable

Figure 3 Known as the "mother of thousands" plant, *Kalanchoe daigremontiana* produces asexual "baby" plants along the edges of its leaves.

Sexual Reproduction



- Individuals are produced from the fusion of two sex cells (gametes)
- Offspring are not genetically identical to the parents or to each other
- Obtain half of their genetic information from each of their parents

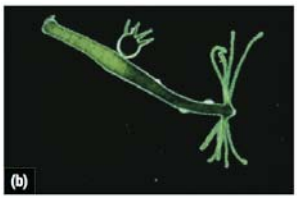
Disadvantages of Sexual Reproduction

- Must have specialized organs to produce sex cells
- Mating calls or brightly coloured features can attract mates and predators
- Offspring may inherit a combination of genetic information that makes them weak and unable to survive

Asexual vs. Sexual Reproduction

- If the environment changes, genetically identical offspring would not be able to survive; i.e. infectious diseases
- Sexual reproduction produce genetic variable offspring that may adapt well to a new environments

Modes of Asexual Reproduction

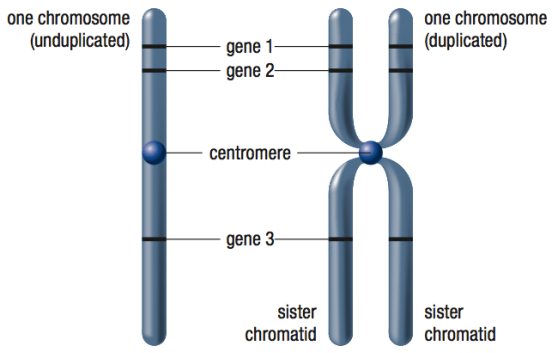


- **Budding** – a new individual develops from an outgrowth on the body of an organism
- **Cloning** – aphids can reproduce asexually and produce genetically identical female offspring
- **Fragmentation** – a piece or body fragment of the parent organisms develops into a mature individual

Cell Division

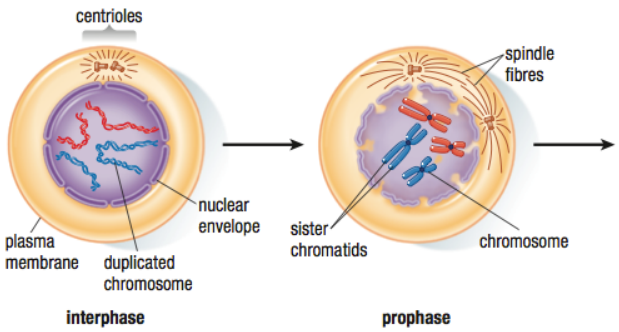
- **Mitosis** – the process by which a eukaryotic cell divides the genetic material in its nucleus into two new identical nuclei
- **Cytokinesis** – the process in which the cell physically divides
- **Interphase** – the portion of the cell cycle in which the cell grows and carries out its normal functions; genetic material (chromatin) is duplicated

- Chromatin – long, thin strands of DNA and protein within a eukaryotic nucleus
- During interphase, chromosomes are replicated forming sister chromatids, each containing the same genes at the same loci
- Sister chromatids are attached at the centromere

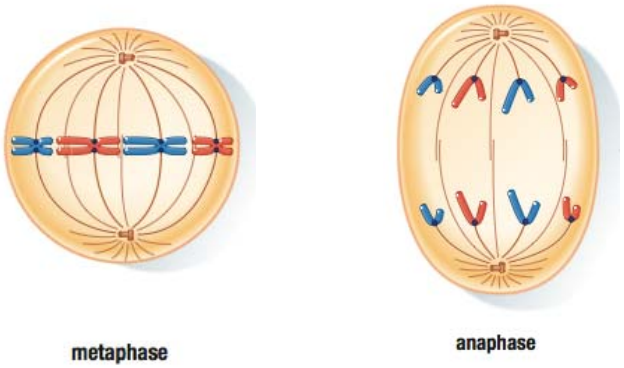


Mitosis

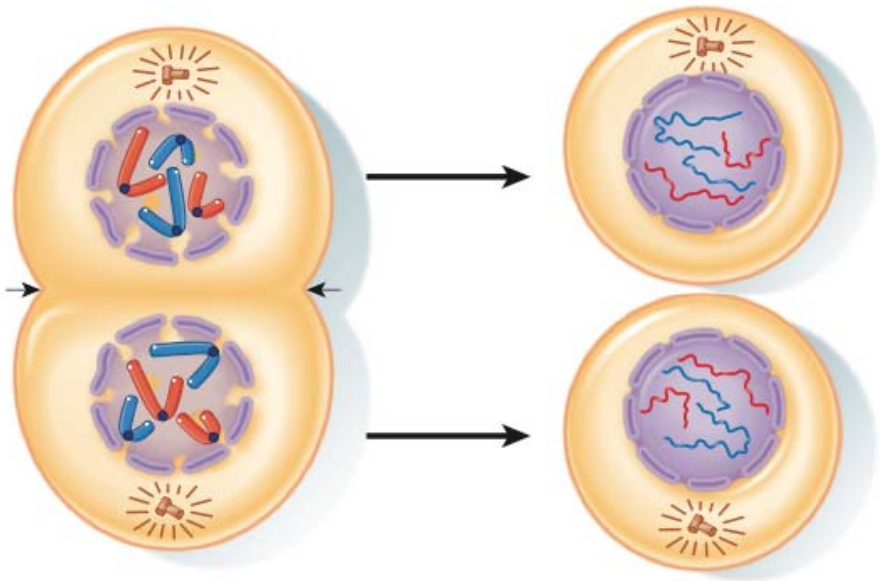
- Prophase – the chromosomes begin to shorten and thicken and become visible under a microscope
  - Nuclear membrane starts to dissolve
  - Centrioles move to the opposite poles in animal cells



- Metaphase – spindle fibres from the centrioles move and align the chromosomes and its centromere across the middle of the cell
- Anaphase – centromeres divide and the sister chromatids move to the opposite poles of the cell

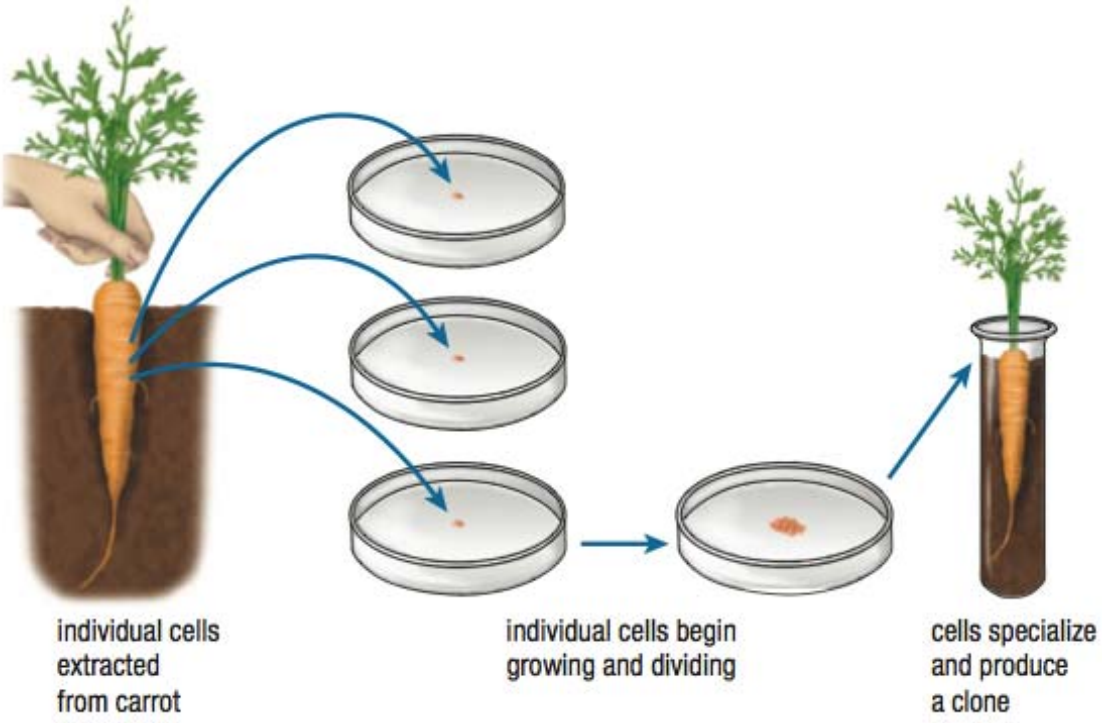


- Telophase – chromosomes at each side of the cell begin to unwind; spindle fibres dissolve and nuclear membrane start to form around each set of chromosomes
- Cytokinesis – cytoplasm of a eukaryotic cell is divided to form two new cells
  - A furrow develops which pinches off the cell into two parts
  - In plants, vesicles from the Golgi Apparatus gather at the middle; vesicles fuse and their contents form a cell plate



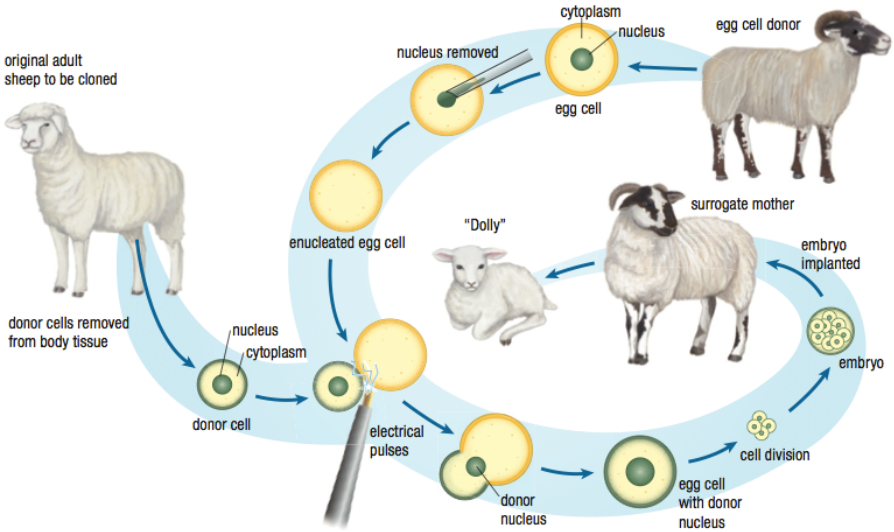
Cloning

- The process of producing one individual that is genetically identical to another using a single cell or tissue
- Biotechnology – the use of living things in engineering, industry and medicine
  - Plant cloning by plant biologist Frederick Steward in 1958 using a mature, specialized cell from another carrot



Animal Cloning

- July 5, 1996, Dolly the first mammal cloned from an adult body cell was born



- Other species of mammals have been cloned in the last decade
- Cloned individuals typically do not live as long as normal individuals and often suffer health complications
- Dolly died prematurely of a lung disease more common in older sheep

Applications and Implications of Cloning

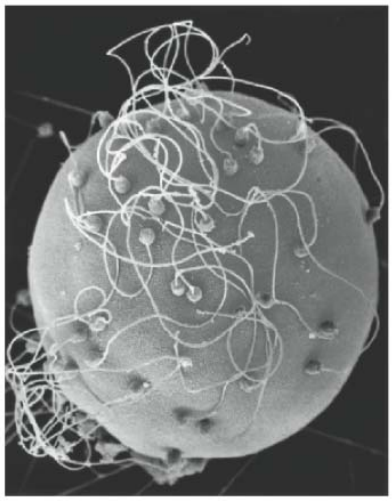
- Mass production of livestock and crop plants
  - Choose parent organisms that are of the highest quality, farmers and increase yields
  - Cons: Expensive, ethics, vulnerability to diseases due to genetic uniformity
- Genetically modified organisms (GMOs)
  - Organisms that carry genes from another species
  - Useful for insulin production to help diabetic patients

Table 1 The Use of Genetically Modified (GM) Organisms in Medicine and Industry

Organism	New gene action	Benefit
GM goats	gene from the golden orb spider can be used to produce silk protein	Goats produce spider silk protein in their milk, which is then purified and used to make high-strength "spider web" fibre.
GM bananas	genes for the production of a hepatitis vaccine	Bananas would contain a vaccine—making vaccines readily available in developing countries.
GM pigs	gene involved in the production of omega-3 fatty acids	Pigs produce bacon and other pork products containing "healthy" fats.
GM potatoes	genes involved in starch production have been altered	Potatoes produce starch that is more suitable for industrial applications such as the production of biodegradable "eco-plastics."

- Cloning endangered species
  - In 2003, a banteng, which was an endangered species from Java was cloned
  - May be possible to clone extinct species if DNA can be obtained

Modes of Sexual Reproduction

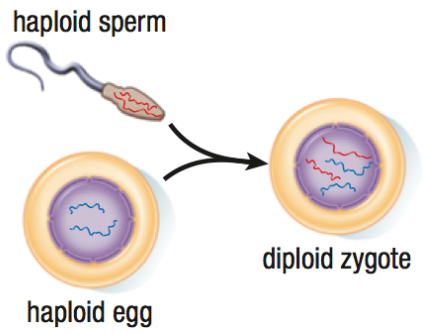


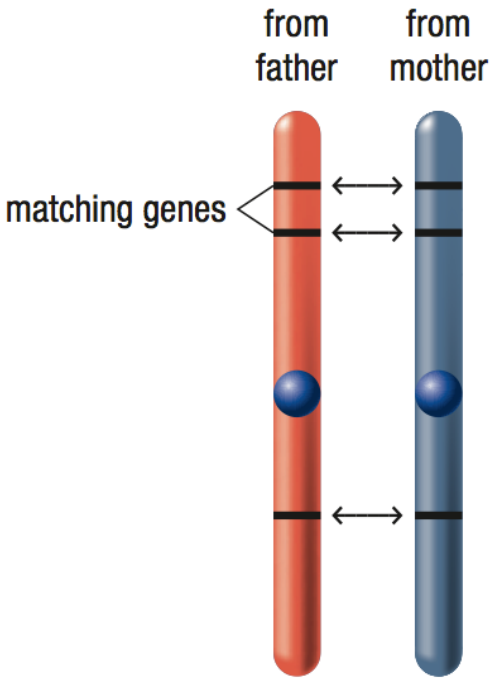
- Gametes (sex cells) are haploid and include sperm cells in males and egg cells in females; vary in size, shape and mobility
- Animals – testes produce sperm and ovaries produce eggs
- Plants – pollen grains contain male gametes and cones/flowers contain female gametes

Organism	Types of individuals and gametes	Fertilization method
bread mould fungus	• "+" and "−" individuals produce similar-looking gametes where they come in contact	Gametes fuse, forming a zygote.
willow tree	• Separate male and female trees • Male pollen grains and female eggs	Insects pollinate "pussy willow" flowers.
giant clam	• Young clams are males and change to females as they mature. • Sperm and egg cells	External fertilization. All individuals in an area simultaneously release their sex cells into the open water.
earthworm	• Hermaphrodites with both sperm and eggs	Internal fertilization. Two worms exchange sperm, fertilizing each other's eggs.
parrot fish	• Separate males and females. • Fish can change sexes. • Sperm and egg cells	External fertilization. Sperm are released over eggs in water.
Canada goose	• Separate sexes • Sperm and egg cells	Internal fertilization

Meiosis

- A two-stage cell division in which the resulting daughter cells have half the number of chromosomes as the parent cell
- Gametes are haploid (*n*), Parent cells are diploid (2*n*)





- Homologous Chromosomes – matching pairs of chromosomes, similar in size and carrying information for the same genes
- Ex: Both parents give you a gene containing information for eye colour

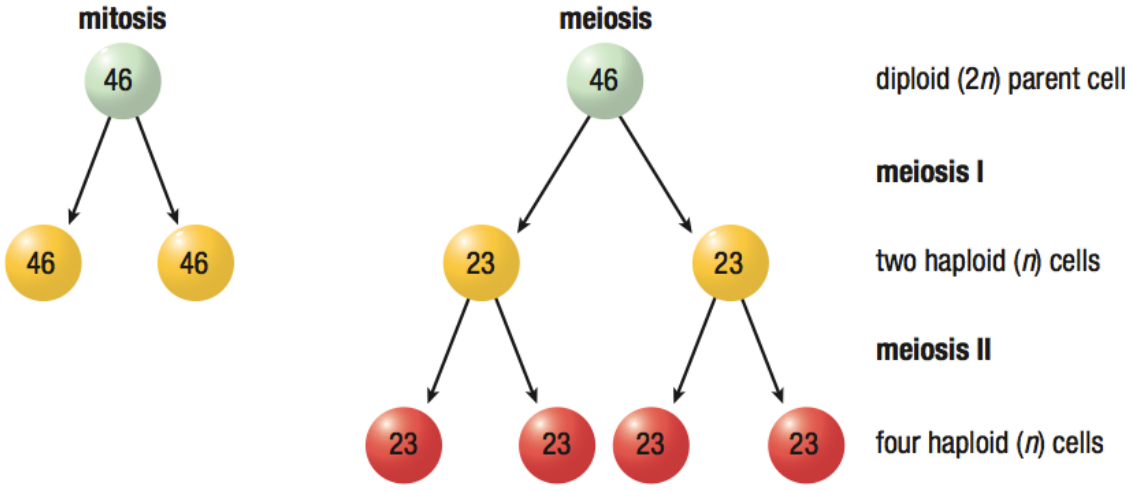
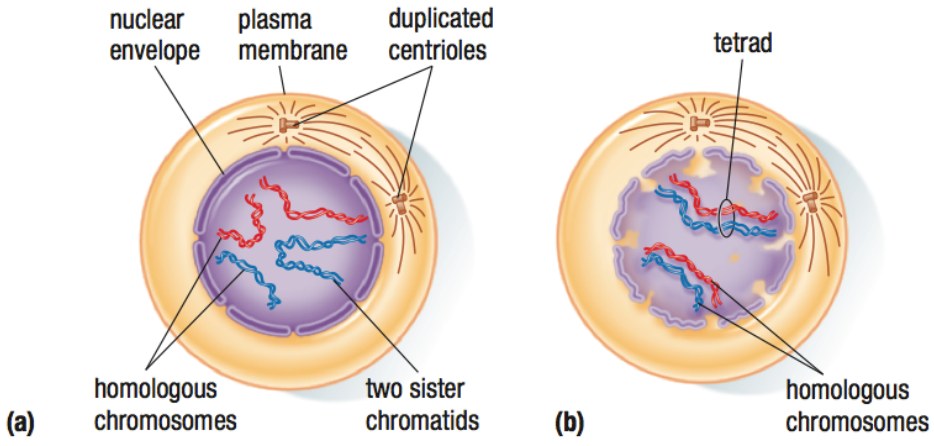
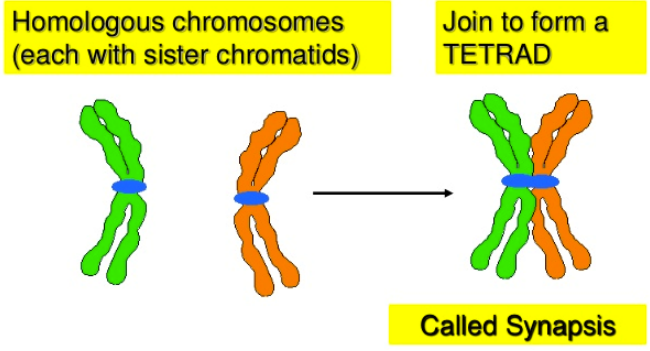


Figure 4 In mitosis, a single division results in two daughter cells with the same number of chromosomes as the original parent cell. Meiosis involves two division stages resulting in four daughter cells—each with half the number of chromosomes of the original parent cell.

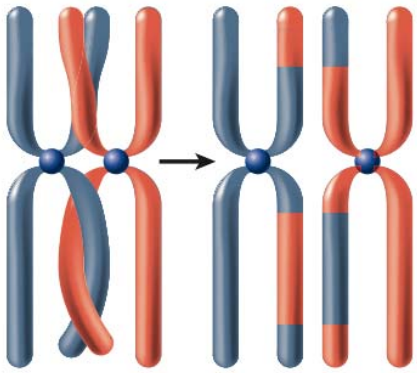
Meiosis I

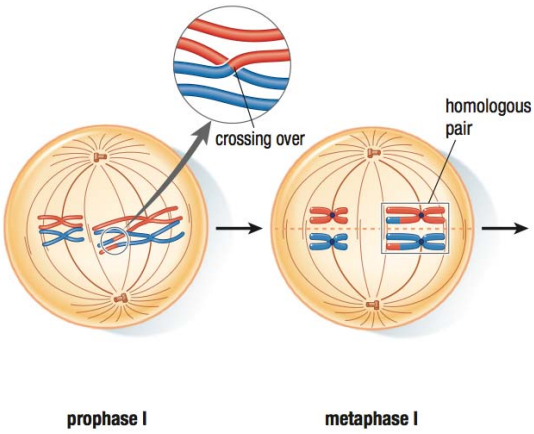
- Interphase – DNA replication occurs
- Prophase I – chromosome begin to shorten and thicken; nuclear membrane starts to dissolve; centrioles separate and move to opposite poles
- Chromosomes form homologous pairs called a tetrad with four sister chromatids
- Synapsis – the physical pairing up of homologous chromosomes during prophase I



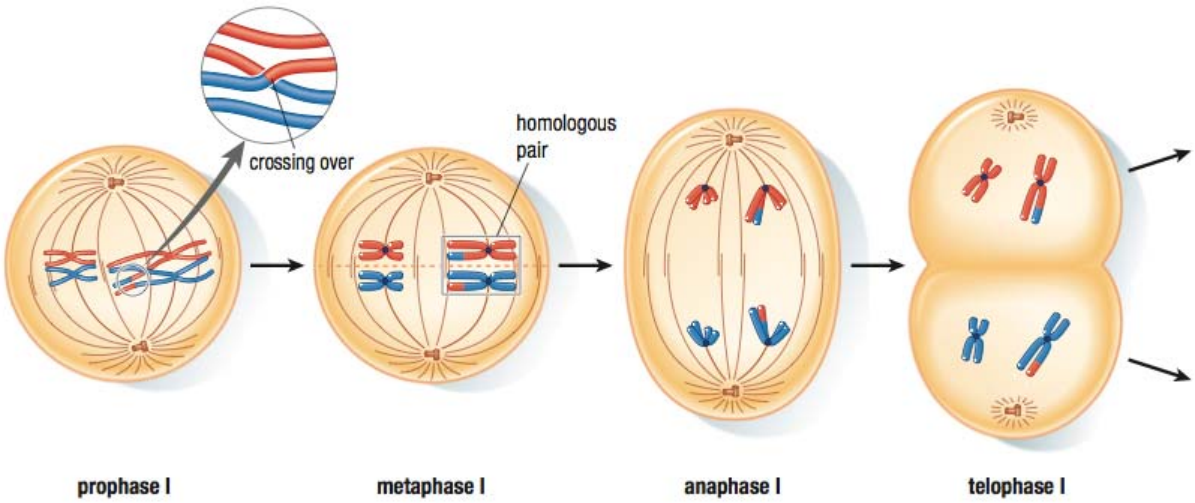


- Intertwined chromosomes can undergo crossing over – the exchange of chromosome segments between homologous pairs during synapsis
- Results in recombination of genetic information



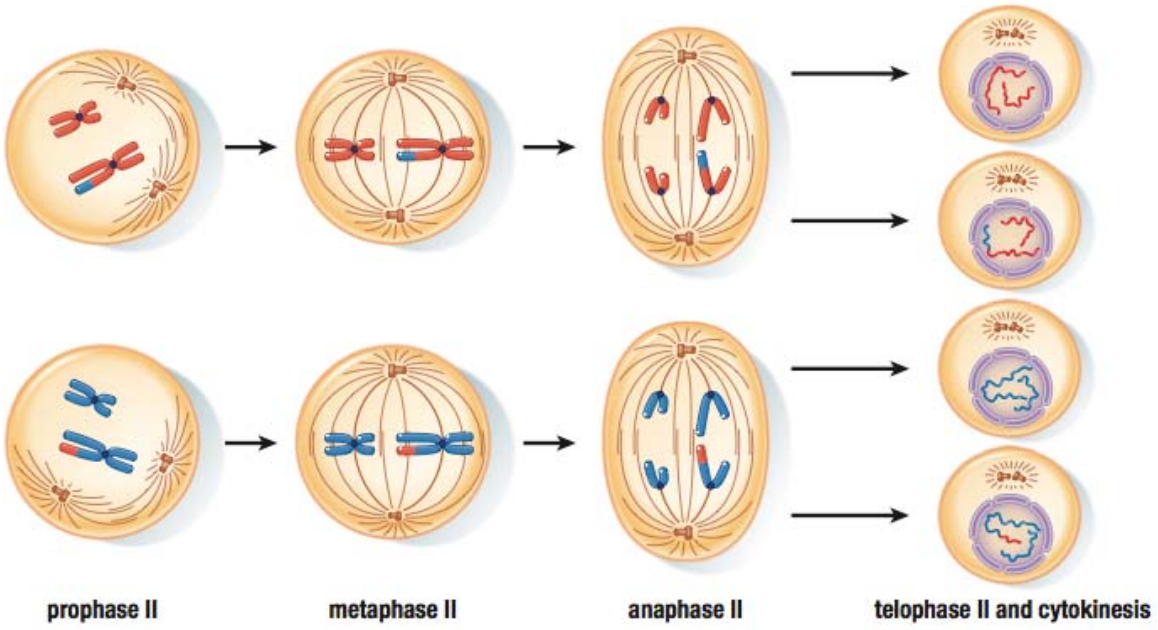


- Metaphase I – tetrads migrate toward the centre of the cell and align their centromeres along the middle of the cell
- Anaphase I – homologous chromosomes move to opposite poles and reduction division occurs; only one chromosome from each homologous pair will be found in each new daughter cell
- Telophase I – nuclear membrane begin to form but the two nuclei are not identical in gene content (haploid)

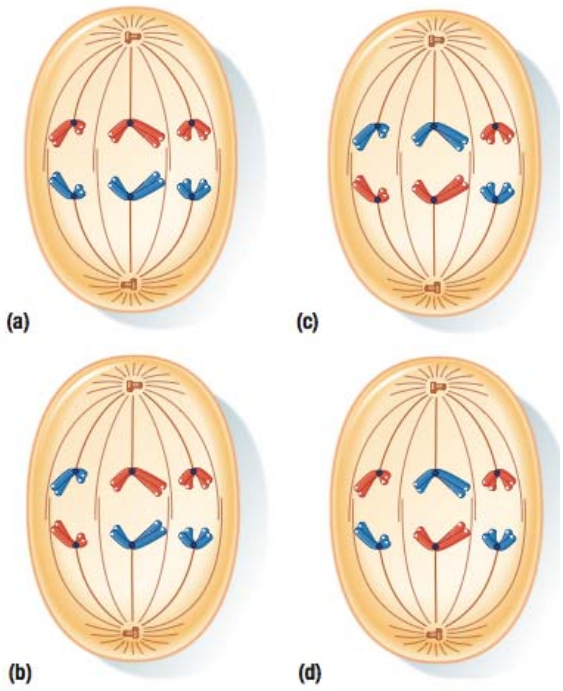


Meiosis II

- No duplication of DNA occurs between Meiosis I and II
- Prophase II – nuclear membrane dissolves and spindle fibres begin to form
- Metaphase II – chromosomes arrange across the middle of the cell
- Anaphase II – sister chromatids separate and are pulled to opposite ends of the cell
- Telophase II – nuclear membrane begins to form



Random Assortment

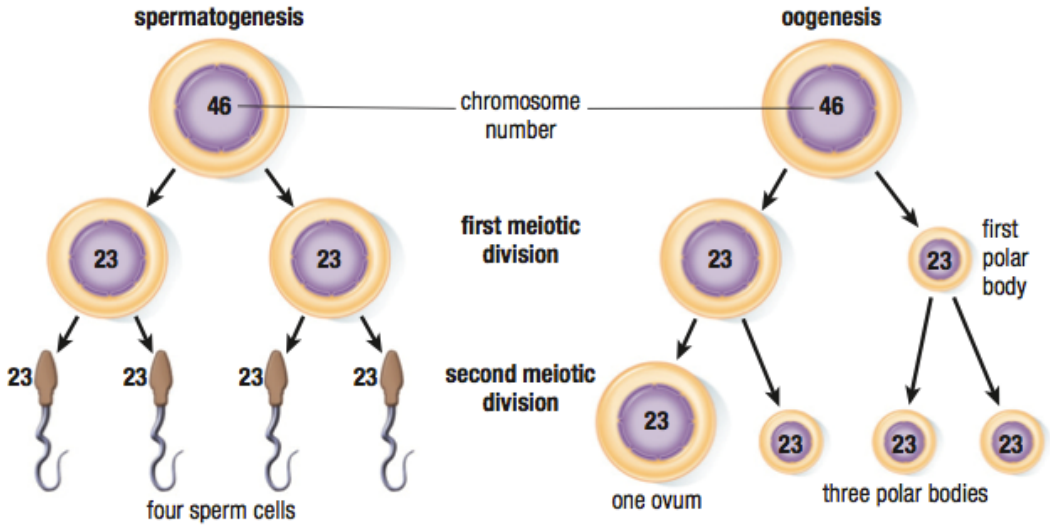


- When homologous chromosomes pair up and separate during meiosis I, the chromosomes in each pair are assorted independently to form 8 possible combinations

- For any diploid (2*n*) organisms, the number of combination is 2^n
  - Ex: 3 pairs of chromosomes = 2^3 = 8 combinations
  - Ex: 23 pairs of chromosomes = 2^{23} = 8 388 608
- This variation does not include the added variation from crossing over

Gametogenesis

- Gametogenesis is the formation of sex cells through the process of meiosis
- Takes place in the testes and ovaries
- Spermatogenesis – production of sperm cells
  - Cytoplasm is equally divided during each cell division
- Oogenesis – production of egg cells
  - Cytoplasm does not divide equally and one of the daughter cells receives most of the cytoplasm while the other cells called polar bodies die



Sperm

- Small shape and flagellum allows for motility to swim towards the egg

Egg

- Large cytoplasm contains nutrients and organelles for future cell division after fertilization

- Males can produce hundreds of millions of sperm cells every day
- Females stop developing eggs after birth; some eggs go to complete meiosis after puberty
  - Female human produces between 400-500 eggs in a lifetime

Karyotypes

- Chromosomes can be stained, viewed and photographed under a microscope during cell division

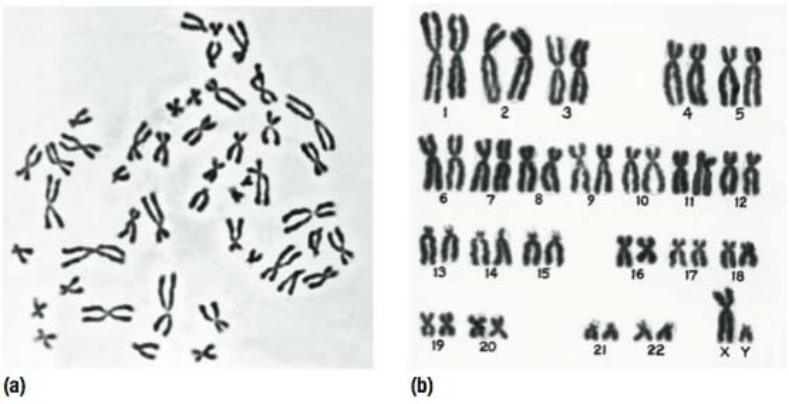
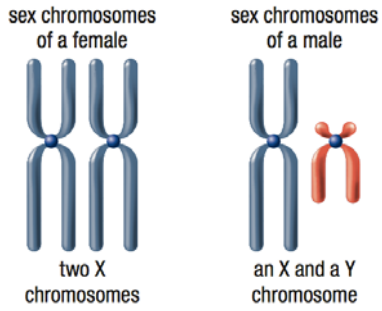


Figure 11 (a) After all chromosomes from a single human cell are stained and photographed, (b) they can be arranged into a karyotype based on their characteristics.

Sex Chromosomes and Sex Determination

- Sex Chromosomes – chromosomes that differ in males and females of the same species
- Females – XX chromosome
- Males – XY chromosome

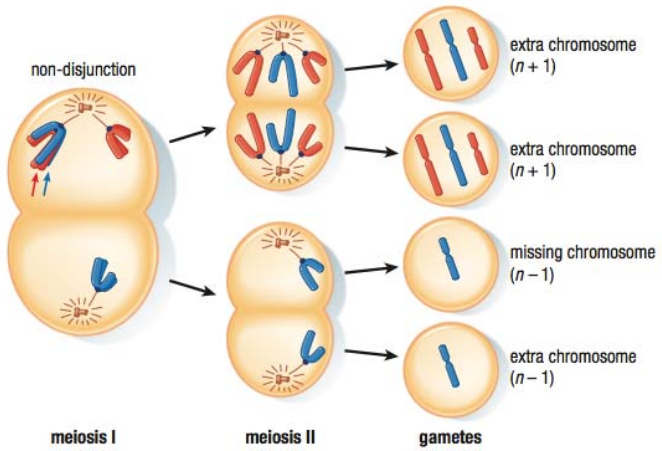


- Autosomes – chromosomes that are not sex chromosomes

Sex determination	Examples	Description
XX/XY	mammals, some insects	XX females, XY males
ZW/ZZ	birds	ZW females, ZZ males
temperature	turtles, crocodiles	If the eggs are kept relatively warm, most or all eggs hatch as females. If the eggs are kept relatively cool, most or all eggs hatch as males.
age	some fish, some mollusks	All young are born male. As they become older and larger, they change into females.
social structure	some fish	All young fish are females. When the dominant male fish dies, a large female changes into a male.
fertilization—haploid/diploid	bees, ants, wasps	Fertilized eggs ($2n$) become females. Unfertilized eggs (n) become males.
infection	some insects	Variable. In one form, infected individuals develop into females.
none	earthworms and other hermaphroditic organisms	All individuals have both male and female reproductive organs.

Abnormal Meiosis and Fertilization

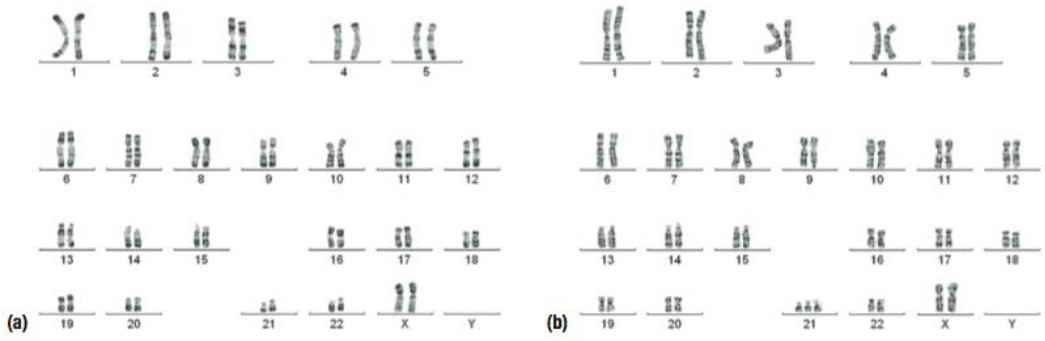
- **Non-disjunction** – the failure of homologous chromosomes to move to opposite poles of the cell during meiosis



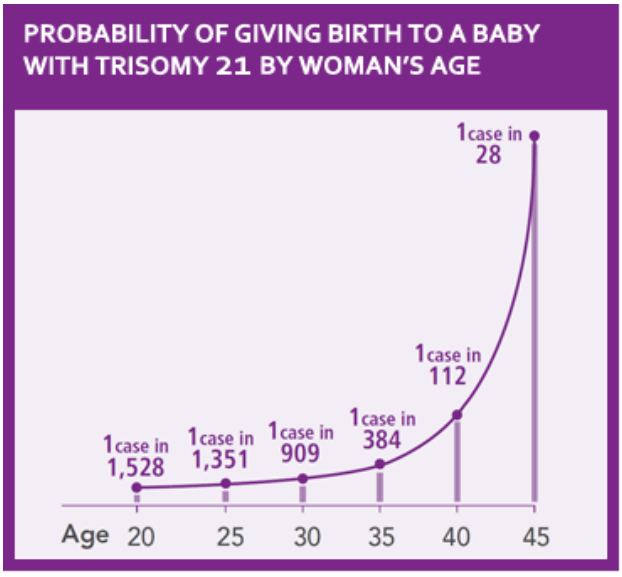
- Trisomy – the presence of three homologous chromosomes rather than two; 47 chromosomes in total
  - Ex: Down Syndrome – Trisomy 21
  - Ex: Klinefelter Syndrome – XXY chromosome
- Monosomy – the presence of a single chromosome rather than two; 45 chromosomes in total
  - Turner Syndrome – X chromosome only

Non-disjunction disorder	Chromosome abnormality	Characteristics of the disorder
Turner syndrome	one X and no Y sex chromosome	Approximately 1:2500 female births. Female in appearance but do not mature sexually and are sterile. Most Turner syndrome fetuses are miscarried before the 20th week of pregnancy.
Klinefelter syndrome	two X and one Y sex chromosome	Approximately 1:500 male births. Males are usually sterile and exhibit some feminine body characteristics, but severity varies.
Patau syndrome	trisomy of chromosome 13	Approximately 1:25 000 live births. Many serious developmental problems, including brain, kidney, and heart defects. Children rarely live more than a few months.
Edwards syndrome	trisomy of chromosome 18	Approximately 1:6000 live births. Many organ system defects. Very low survival rate. Most fetuses die before birth. Average life expectancy of live-born infants is less than one month.

Down Syndrome



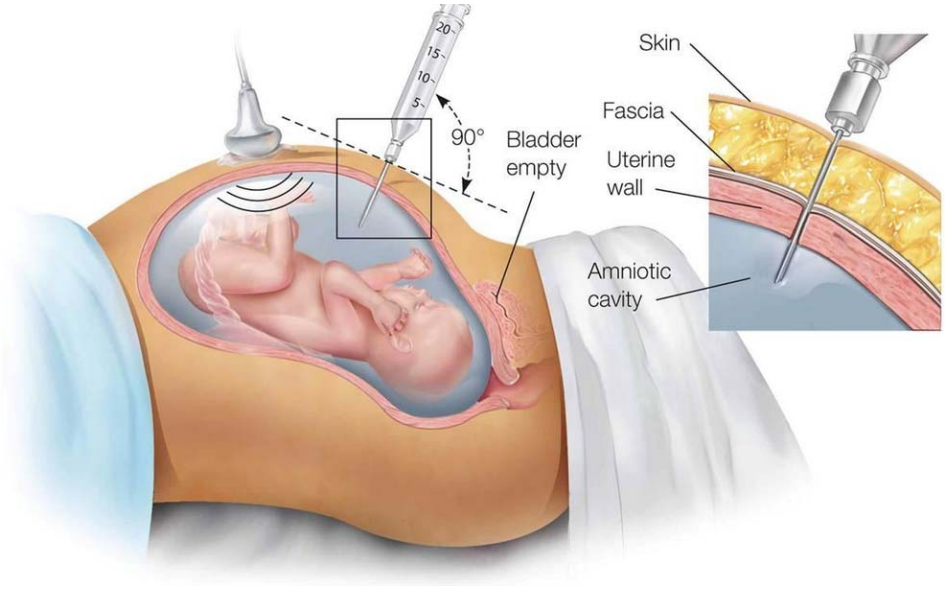
- Extra chromosome means there is excess genetic information and an unpaired chromosome in every cell
- Symptoms: Round, full face, short height, large forehead, mild developmental and intellectual disabilities



Diagnosing Non-Disjunction

- Karyotyping – obtaining a small sample of white blood cells, inducing mitotic division and creating a karyotype
- Prenatal Testing – testing for a genetic disorder before birth; recommended for pregnant women over the age of 35
  - Chorionic Villus Sampling (CVS) – used to remove cells from the outer membrane of the embryo
  - Multiple-Marker Screening – tests blood hormone levels between 15th-20th week of pregnancy

- Amniocentesis – extraction of amniotic fluid from the amniotic sac with a large syringe and an ultrasound machine

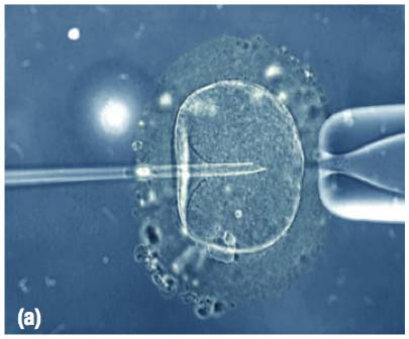


Problems with Fertilization

- In Ontario, 10% of couples have difficulty conceiving due to poor or reduced egg or sperm quality and production, blocked Fallopian tubes in females, blocked epididymus or vas deferens in males

Assisted Reproductive Technologies (ARTs)

- In Vitro Fertilization (IVF) – stimulate the ovaries to increase egg production via hormonal medication
  - Eggs are retrieved and fertilized outside the body
  - Fertilized egg is implanted back into the uterus
- Intracytoplasmic Sperm Injection (ICSI) – injects sperm directly into the cytoplasm of the egg

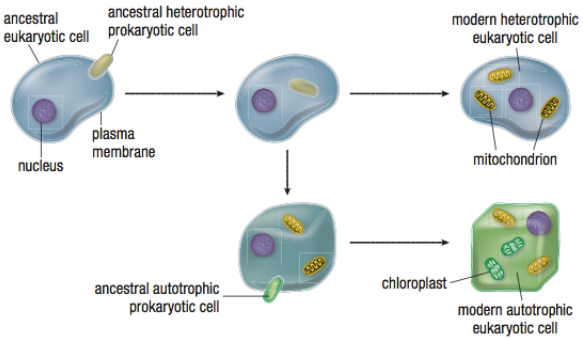


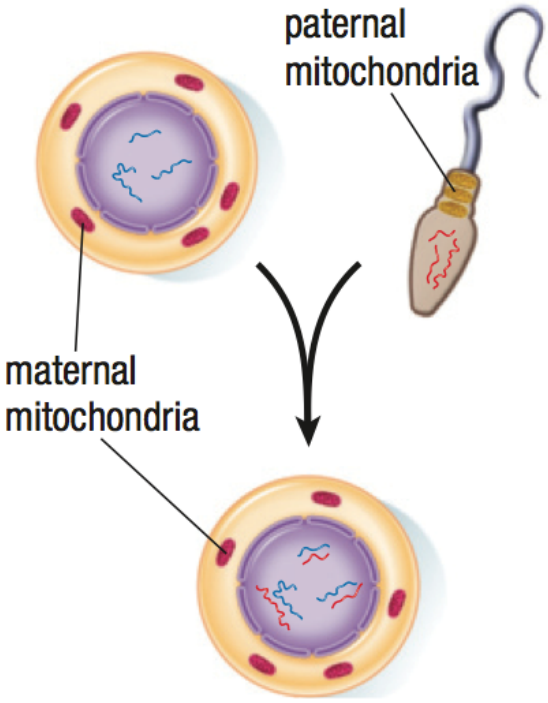
- Artificial Insemination – Placement of sperm into the reproductive tract of a female
- Reproductive technology is also used for animal breeding and wildlife conservation efforts

- Advantages of Artificial Insemination
  - Semen can be frozen and stored for long periods of time
  - A bank of genetic information can be preserved
  - Transports costs are low compared to moving the live animal for breeding
  - Permits the breeding of animals that do not breed successfully in captivity

Cytoplasmic Inheritance

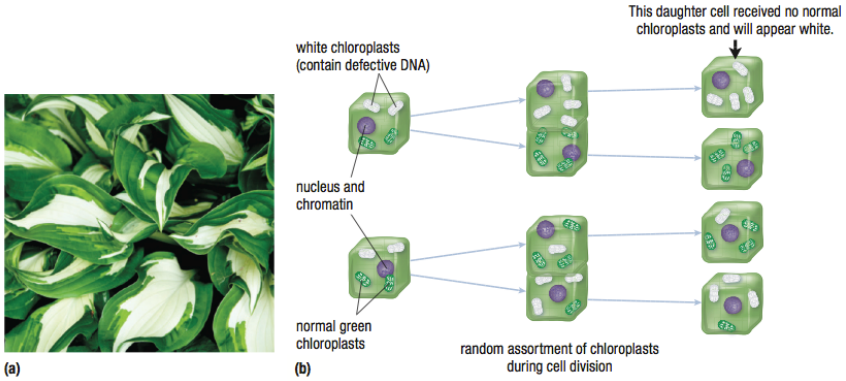
- Some DNA is also found in the mitochondria and chloroplasts – cytoplasmic DNA
- According to the Endosymbiotic Theory, both mitochondria and chloroplasts were prokaryotes with their own genetic material





- Since the ovum is large, it contains most of the organelles that are passed to the zygote
- Maternal Inheritance – zygote inherits cytoplasmic DNA from the female gamete
  - Mitochondria in any individual are always genetic clones of the mitochondria of the mother

- Although mitochondria and chloroplasts are normally inherited exclusively from the mother, the daughter cells may not be genetically identical
  - Ex: Leaves can have normal green chloroplasts and chloroplasts with a genetic mutation that makes them colourless



DNA Egg Swapping

- To avoid the inheritance of mitochondrial diseases, the nucleus of a fertilized egg can be removed and transferred to an enucleated egg with normal mitochondria

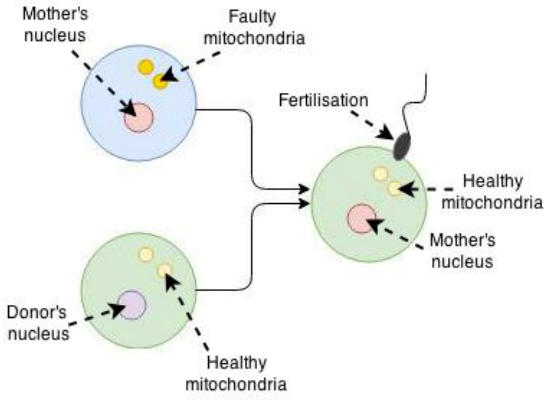


Figure 4 The green sea slug, *Elysia chlorotica*, feeds on algae cells when it is young and keeps the chloroplasts intact and within its body cells. For the remainder of its life, the slug relies on the products of photosynthesis.

- *E. chlorotica* is an animal that can perform photosynthesis
  - Feeds on algae but keep the algae chloroplast intact
  - Chloroplasts line the digestive system of the slug where they become part of the cytoplasm