Grade 11 Biology

Genetic Processes

Class 5

Pedigrees – Tracking Inheritance

- Pedigree – a diagram of an individual's ancestors used in human genetics to analyze the Mendelian inheritance of a certain trait
- Shows:
  - Connections between parents and offspring
  - Sex of individuals in each generation
  - Presence or absence of trait
- Useful for genetic counselors and animal/plant breeders

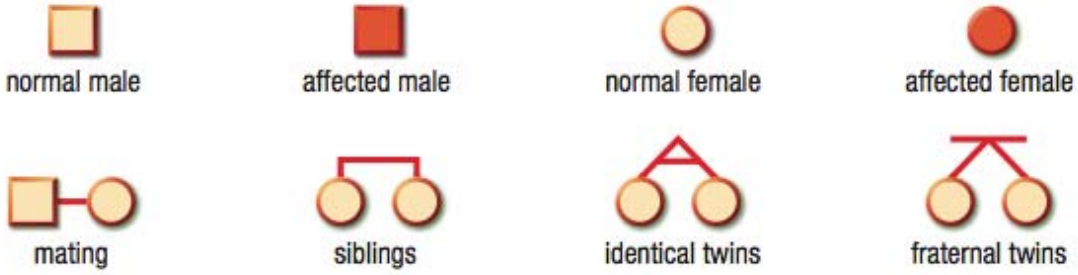


Figure 1 Squares represent males and circles represent females. Individuals who express a trait are shown in a shaded circle or square. Mating between two individuals is shown by a horizontal line, and children are connected to their parents with vertical lines.

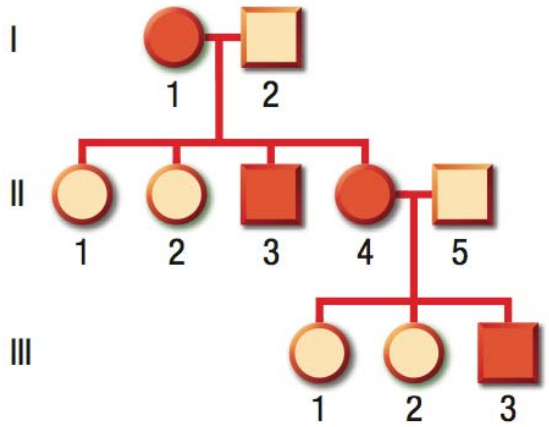


Figure 2 An example of a pedigree chart spanning three generations. In this pedigree, the grandmother (I-1), one of her sons (II-3), one of her daughters (II-4), and her grandson (III-3) have freckles. The allele for freckles (*F*) is dominant over the allele for no freckles (*f*).

- Each generation is identified by a Roman numeral
- Arabic numbers symbolize individuals within a given generation
- Birth order is drawn from left (oldest) to right (youngest)

Checkpoint

Marfan syndrome is a genetic disorder that affects the body's connective tissue. When the dominant allele (*M*) is expressed, an individual will have Marfan syndrome. People with no defect in the Marfan allele are homozygous recessive (*mm*). Individuals with the syndrome are typically very tall, with disproportionately long limbs and fingers, and sometimes have problems with their hearts and eyes. Use the pedigree chart (**Figure 3**) to determine the genotypes of all individuals, if possible.

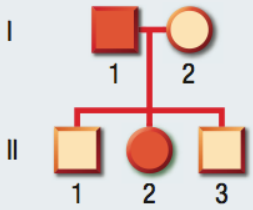


Figure 3 A family's pedigree showing the inheritance of Marfan syndrome

Checkpoint

Individuals with albinism have a defect in an enzyme that is involved in the production of melanin, a pigment normally found in the skin. These individuals have little or no pigment in their skin, hair, and eyes. The characteristic is governed by only two alleles: the normal allele and the albinism allele. Analyze the pedigree chart at right (**Figure 7**) to determine whether the albinism allele is a dominant or a recessive allele. Then determine the genotypes of each individual. Use *P* and *p* to represent the dominant and recessive alleles, respectively.

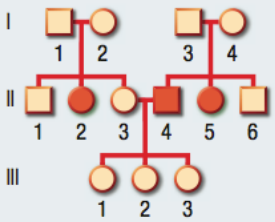
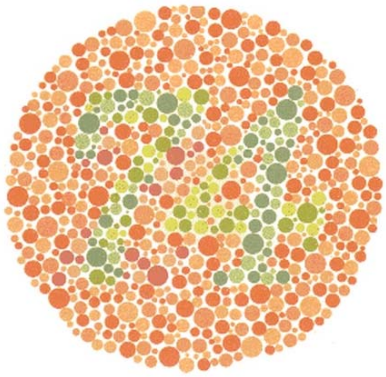


Figure 7 A family's pedigree chart for albinism

Sex Linkage

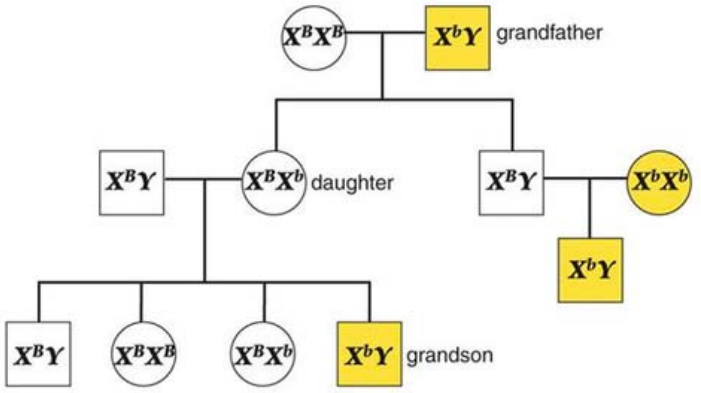
- Autosomal inheritance – Inheritance of alleles located on autosomal (non-sex) chromosomes
  - Both males and females are affected equally
- Sex-linked – Inheritance of alleles location on either the X or Y chromosome
  - Affects a disproportionate number of males to females

- Females have XX but males have XY and only one copy of the X chromosome
- If allele with the disorder is found on the X chromosome and is recessive in the mother, the male will inherit the affected X chromosome and express the phenotype
- Y chromosome cannot the effects of the X chromosome
- Female must inherit two copies of the affected X chromosome to express the phenotype



	X^c	X^+
X^+	$X^c X^+$	X^+X^+
Y	X^cY	X^+Y

- Red-Green Colour-blindness due to abnormal photopigments
- X^+ = normal allele
- X^C = colourblind allele
- Daughters of a carrier mother will not express the phenotype
- 25% chance that the son will have colour-blindness



Key

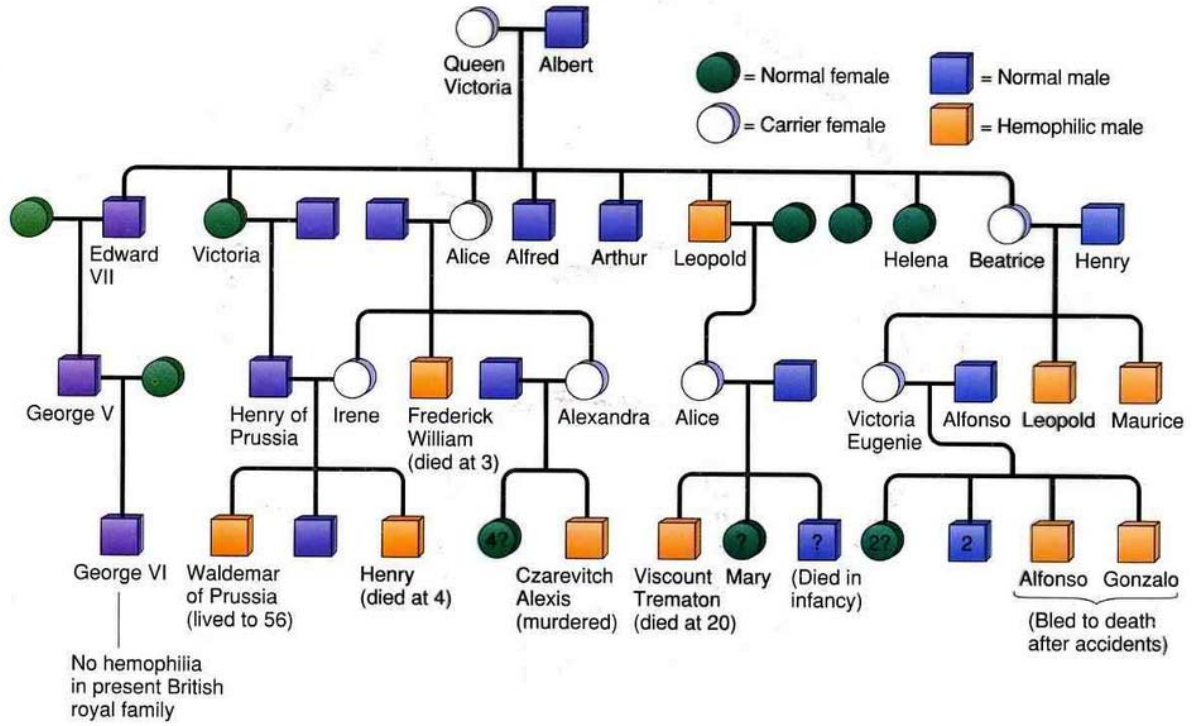
X^BX^B = Unaffected female
X^BX^b = Carrier female
X^bX^b = Color-blind female
X^BY = Unaffected male
X^bY = Color-blind male

X-linked Recessive Disorders

- More males than females are affected.
- An affected son can have parents who have the normal phenotype.
- For a female to have the characteristic, her father must also have it. Her mother must have it or be a carrier.
- The characteristic often skips a generation from the grandfather to the grandson.
- If a woman has the characteristic, all of her sons will have it.

mother $X^H X^h$		X^H	X^h
father $X^H Y$	X^H	$X^H X^H$	$X^H X^h$
	Y	$X^H Y$	$X^h Y$

- Hemophilia A – inability to form a clot leading to extensive bleeding
- X^H = normal allele
- X^h = hemophilia allele
- 25% chance that son will have hemophilia
- 25% chance that daughter will be a carrier
- 50% chance that son or daughter will not inherit hemophilia



- Y-linked disorders – passed from father to son
- Fewer Y-linked than X-linked disorders because Y chromosome is small and does not carry as much genetic information as X-chromosome
- Y-linked disorders usually lead to reduced fertility leading to less inheritance of Y-linked disorders

Genetic Disorders

- Cystic fibrosis – Disease that causes the body to produce a thick, sticky mucus that clogs the lungs and blocks the enzymes in the pancreas

Figure 1 A child undergoing physical therapy for cystic fibrosis. The child's chest or back is tapped repeatedly to loosen the mucus in the lungs. This makes it easier for the child to rid his body of the mucus.

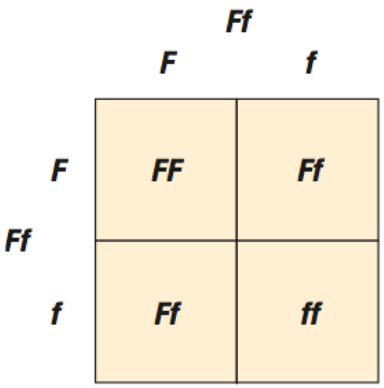
- Due to mutated CFTR gene which is recessive
- Child must have both copies of the defective allele passed by carrier parents to have cystic fibrosis

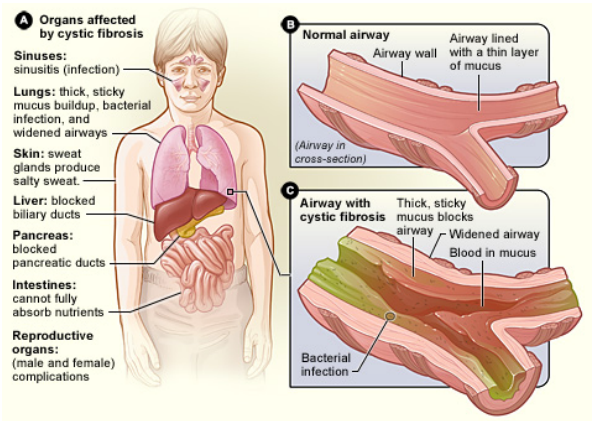
- Carrier testing – a genetic test to identify individuals who carry disorder-causing recessive genes that may be inherited by their children
- Genetic screening – tests used to identify the presence of a defective allele that leads to a genetic disorder

Table 1 Risk of Having a Child with Cystic Fibrosis before and after Carrier Testing in Canada

Test status of parents	Risk of having a child with CF
No test performed	1 in 2500
Both partners tested: results show one positive, one negative	1 in 600
Both partners tested: results show both positive	1 in 4

Source: Canadian Cystic Fibrosis Foundation, Carrier Testing for Cystic Fibrosis





- F = normal gene
- f = cystic fibrosis gene
- 25% chance of conceiving a child with CF (ff)
- 50% chance that the child is a carrier (Ff)
- 25% chance that the child is unaffected (FF)

- Breast Cancer – if genetic disorders appear later in life, the harmful allele may have been passed on to offspring
- BRCA1 and BRCA2 are human genes that inhibit the growth of tumours
- If a woman carries a defective copy of these genes, she has an increased chance of developing breast or ovarian cancer at an early age
- If genetic screening shows a mutation in the BRCA1 and BRCA2 genes, she may decide to have a mastectomy – removal of part or all of the breast tissue

- Phenylketonuria (PKU) – autosomal, recessive genetic disorder that results in the accumulation of phenylalanine in the tissues and blood
- Lack the enzyme to break down phenyalanine to make proteins and essential brain chemicals
- Brain function does not develop normally if phenylalanine builds up
- PKU-positive child must have their diet tightly regulated to limit intake of high-protein foods such as meat, fish, eggs and milk

Table 2 Genetic Disorders and Their Mechanism of Inheritance

Disorder	Adverse health effects	Mechanism of inheritance
alkaptonuria the accumulation of alkapton in the body	kidney stones, damage to cartilage	recessive allele
cystic fibrosis causes the body to produce thick, sticky mucus that clogs the lungs and pancreatic duct	infections; blocks the release of enzymes from the pancreas	recessive allele
galactosemia the inability to digest galactose	infants experience jaundice, failure to thrive, vomiting, and diarrhea; may lead to death if undiagnosed	recessive allele
hemophilia body cannot form blood clots	excessive bleeding	recessive allele
Lesch–Nyhan syndrome buildup of uric acid in the body	gout, kidney problems, self-injuring behaviour	recessive allele
phenylketonuria accumulation of phenylalanine in blood	poor mental development and growth, weak tooth enamel	recessive allele
Tay–Sachs disease nerve cells in the brain are affected by the accumulation of gangliosides	deterioration of muscle and physical abilities	recessive allele
Huntington's disease progressive, irreversible degeneration of nervous system	loss of muscle control and cognitive abilities	dominant allele
hypercholesterolemia high levels of cholesterol accumulate in the blood	premature heart disease	dominant allele
neurofibromatosis nerve cells grow tumours	tumours may be harmless or may cause damage by pushing on other nerves	dominant allele

Newborn Screening Program

- In Ontario, newborns are currently screened for at least 28 genetic disorders
  - Screen for Cystic Fibrosis, PKU, Sickle-cell anemia and disorders of the endocrine system
- Every year, more than 140 000 newborns are tested and 150 test positive for rare genetic disorders
- Early diagnosis enables doctors to begin treatment that may eliminate or reduce serious health consequences and prevent infant death

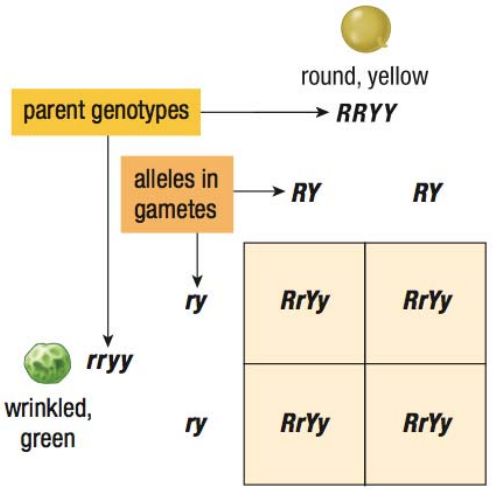
Ethics of Genetic Testing

- The decision to have a genetic test is personal however what if it becomes compulsory?
- How much information should be available about an individual's genetic profile?
- Who should have access to it?
- Who should you disclose to?
- How will the results of the genetic test affect the way you live your life?

- **Parenting** – should parents be able to test their children for any genetic disorder regardless of evidence of risk?
- **Relationships** – should people have access to a potential partner's genetic information? If you are carrying a lethal gene, should the law require you to disclose this information to your prospective spouse?
- **Employment** – should employers have access to genetic information about an applicant?
- **Insurance** – should insurance companies request a genetic test based on the probability of having a disease?

Multi-trait Inheritance

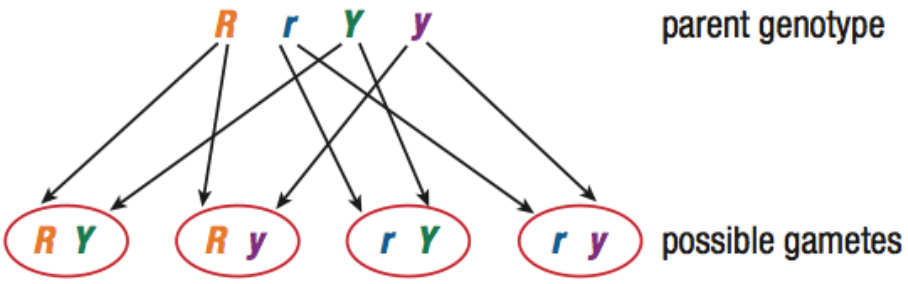
- Dihybrid Cross – A cross that involves two genes, each consisting of heterozygous alleles



Seed Shape
- R = round
- r = wrinkled

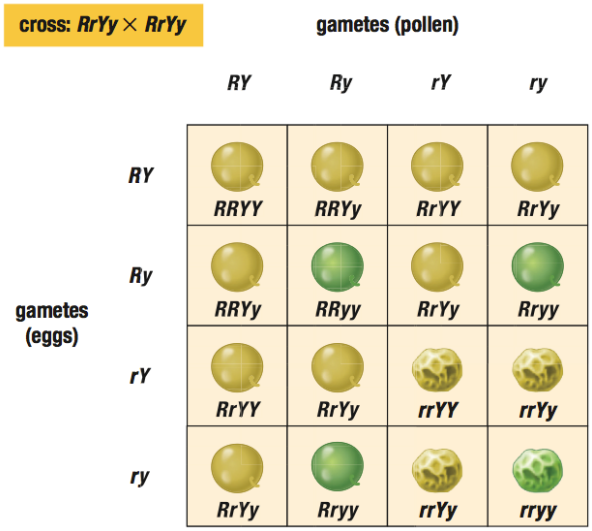
Seed Colour
- Y = yellow
- y = green

- Heterozygous individual for two characteristics will produce 4 possible gametes which are all equally likely



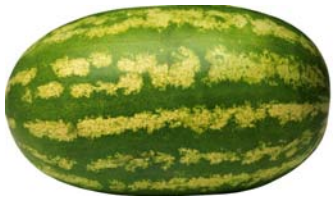
- Law of Independent Assortment – if genes are located on separate chromosomes, they will be inherited independently of one another

- Mendel found that characteristics he tested were not linked, for example, seed shape had no influence on seed colour
- Result is a 9:3:3:1 phenotypic ratio



Checkpoint

In watermelons, the green colour gene (*G*) is dominant over the striped colour gene (*g*), and round shape (*R*) is dominant over long shape (*r*). A heterozygous round green colour (*GgRr*) watermelon plant is crossed with another heterozygous round green colour (*GgRr*) plant. Determine the expected phenotypic ratio of the F_1 generation.



Checkpoint

Assume that in guinea pigs, black fur (*B*) is dominant over white fur (*b*), and a rough coat (*R*) is dominant over a smooth coat (*r*). If a black, rough-furred guinea pig that is homozygous dominant for both traits (*BBRR*) is crossed with a white, smooth-furred guinea pig (*bbrr*), what are the expected phenotypes in a large litter?

The Product Law

- The probability of two independent random events both occurring is the product of the individual probabilities of the events
- Ex: Probability of giving birth two two boys
  - Probability of giving birth to first boy = ½
  - Probability of giving birth to second body = ½

$$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

Table 1 Using the Product Law to Determine Probabilities of a Dihybrid Cross When Both Genes Are Heterozygous

Round or wrinkled seed: probability from monohybrid cross	Yellow or green seed: probability from monohybrid cross	Dihybrid cross probability
Round seed ($Rr \times Rr$) $\frac{3}{4} = 75\ \%$	Yellow seed ($Yy \times Yy$) $\frac{3}{4} = 75\ \%$	round, yellow seed ($RrYy \times RrYy$) $\frac{3}{4} \times \frac{3}{4} = \frac{9}{16}$ $75\ \% \times 75\ \% = 56.25\ \%$
round seed ($Rr \times Rr$) $\frac{3}{4} = 75\ \%$	green seed ($Yy \times Yy$) $\frac{1}{4} = 25\ \%$	round, green seed ($RrYy \times RrYy$) $\frac{3}{4} \times \frac{1}{4} = \frac{3}{16}$ $75\ \% \times 25\ \% = 18.75\ \%$
wrinkled seed ($Rr \times Rr$) $\frac{1}{4} = 25\ \%$	yellow seed ($Yy \times Yy$) $\frac{3}{4} = 75\ \%$	wrinkled, yellow seed ($RrYy \times RrYy$) $\frac{1}{4} \times \frac{3}{4} = \frac{3}{16}$ $25\ \% \times 75\ \% = 18.75\ \%$
wrinkled seed ($Rr \times Rr$) $\frac{1}{4} = 25\ \%$	green seed ($Yy \times Yy$) $\frac{1}{4} = 25\ \%$	round, green seed ($RrYy \times RrYy$) $\frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$ $25\ \% \times 25\ \% = 6.25\ \%$

Discontinuous vs. Continuous Variation

- Discontinuous variation – when the expression of the characteristics do not interact with each other; no in-between values
- Continuous variation – when the expression of the characteristic is affect by other genes; effect can be additive or can negate the other effect; ex: skin colour, height, hair colour, eye colour