

## Chapter 10: Genetics: Mendel and Beyond

### I Foundation of Genetics

- Five thousand years ago or earlier, applied genetics in the form of plant and animal breeding was used by mankind.
- The science of genetics became more defined in the period around 1866, when Gregor Mendel used variants of peas to conduct experiments on inheritance.

#### A. Plant breeders showed that both parents contribute equally to inheritance.

- Plants have some desirable characteristics for genetic studies.
  - Higher plants are diploid,  $2n$ , as are humans.
  - They can be grown in large quantities.
  - Many have both male and female reproductive organs in the same plant, which allows self-fertilization.
  - The generation time is relatively short.
  - It is easy to control which individuals mate.
- Josef Gottlieb Kölreuter made a few of the observations Mendel had made earlier.
  - Mendel's research was ignored until the turn of the 20<sup>th</sup> century.
  - Kölreuter 's research focused on the relative contribution of males and females to the genetics of plants.
  - Reciprocal crosses helped prove that both male and female parents contribute equally to the characteristics inherited by offspring.
    - An example of a reciprocal cross would be a cross of a male, white plant with a female, pink; and its reciprocal cross; a male, pink with a female white.
    - The resulting progeny have the same appearance.
  - Before the acceptance of Mendel's research, the concept of inheritance as a blending was favored. An example of this concept would be purple progeny resulting from red and blue parents.

#### B. Mendel's discoveries were overlooked for decades '

- Gregor Mendel was a monk with scientific training in mathematics, physics and biology.
- Mendel presented his nine year long project orally in 1865 and in writing in 1866.
- His theory was ignored, likely due to it being beyond the intellectual grasp of his scientific peers.
- In 1900, Hugo de Vries, Karl Correns and Erich von Tschermak each independently published papers on the quantitative outcomes from crosses. Each cited Mendel's then rediscovered 1866 paper.

## II Mendel's Experiments and the Laws of Inheritance

### A. Mendel devised a careful research plan

- Garden peas were his chosen subjects.
- He controlled pollination by manually moving pollen between plants. (*See Figure 10.1*)
- He could also allow the plants to self-pollinate.
- Mendel examined varieties of peas for heritable characters and traits for his study.
  - A character is a feature, such as flower color. (*See Table 10.1*)
  - A trait is a particular form of a character, such as white flowers.
  - Heritable means the trait is passed to progeny.
- Mendel looked for characters that had well-defined alternative traits and that were true breeding.
  - True breeding is when the trait is the only one present for many generations.
  - A true-breeding white-flowered plant would have only white-flowered progeny when crossed with others in its strain.
  - True-breeding plants, when used for crossing with other plants that have an alternate trait, are called the parental generation, designated P.
- The progeny from the cross of the P parents are called first filial generation, designated F1.
- When F1 individuals are crossed to each other or self-fertilized, their progeny are designated F2.

### B. Mendel's Experiment 1 examined a monohybrid cross

- True-breeding plants that differed in a character were crossed.
  - A monohybrid cross involves one (mono) character and different (hybrid) traits.
  - Pollen from true-breeding pea plants with wrinkled seeds was placed on stigmas of spherical-seeded plants. (*See Figure 10.2*)
  - The F1 seeds were all spherical.
  - The wrinkled trait failed to appear at all.
  - The F1 were allowed to self-pollinate.
    - This is called the monohybrid cross, because the F1, also called monohybrids, are crossed.
    - This is also called an F1 cross.
    - Self-pollination is sometimes called selfing.
  - The progeny, called F2, were examined for the presence of traits: 5,474 were spherical and 1,850, wrinkled. (*See Figure 10.3*)
  - Spherical was *dominant* to the *recessive* trait wrinkled.

- Traits that are observed in the F1 generation masking the alternative traits are called dominant traits.
  - Traits that are masked by other traits in the F1 generation are called recessive traits.
  - The ratio of expression of the dominant trait to the recessive is 1:0 in the F1 and 3:1 in the F2 generation.
  - Mendel proposed that the units responsible for inheritance were discrete particles.
    - They existed within an organism in pairs.
    - This is called the particulate theory.
  - Each pea has two units of inheritance for each character. (*See Figure 10.4*)
  - During production of gametes, only one of the pair members for a given character passes to the gamete.
  - When fertilization occurs, the zygote gets one from each parent, restoring the pair.
  - The units of inheritance are now called genes.
    - Each unit is given a symbol.
    - In the case of wrinkled seeds, *S* might represent smooth and *s* wrinkled.
    - The true-breeding wrinkled would have *ss*.
  - Different forms of a gene are called alleles.
  - These different alleles are responsible for the different traits for a character like flower color.
  - True-breeding individuals would have two copies of the same allele.
    - Wrinkled would be *ss*.
    - Smooth true-breeding would be *SS*.
  - Some smooth seeded plants could be *Ss*, although they would *not* be true-breeding.
  - Individuals that just produce wrinkled seeds are homozygous. (If they had the alternate allele, they would not be wrinkled.)
  - *SS* are homozygous for the *S* gene.
  - Those *ss* are homozygous for the *s* gene.
  - Individuals that are smooth but had a wrinkled parent are heterozygous: *Ss*.
  - When an organism is studied for three different genes and has the alleles *AABbCC*, it is homozygous for *A* and *C* but heterozygous for the *B* gene.
  - The physical appearance or metabolic functioning of an organism is its phenotype. Wrinkle-seed would be a phenotype.
  - The composition of the organism's alleles for a gene is its genotype: *Ss* is a genotype.
- Organisms have many different genes, some have thousands, and complex organisms have 10 times that number. Most of these genes are yet to be described in terms of the sequence of DNA or the amino acid sequence of the gene product.

### C. Mendel's first law says that alleles segregate

- When producing gametes, alleles separate, so each gamete receives one member of the pair.
- This is Mendel's first law, the law of segregation.
- When fertilization occurs, pairs are reestablished by receiving one copy from each parent.
- The Punnett square can provide clarity when beginning to work in Mendelian genetics:

	<b>Punnett Square</b>	
	<i>Male Gametes</i>	
<i>Female Gametes</i> ↓	<i>S</i>	<i>s</i>
<i>S</i>	<i>SS</i>	<i>Ss</i>
<i>s</i>	<i>Ss</i>	<i>ss</i>

- The column and row S and s symbols represent the single allele each gamete receives.
- A heterozygote is like a coin with a head and tail. The gamete is the outcome, either head or tail, not both.
- The fertilization provides the two alleles for the new individual.
- The individual could get two heads, or two tails or a head and a tail (or also a tail and a head).
- From the Punnett square, the genotypes and associated ratios for a monohybrid cross are 1SS:2Ss:1ss.
- Any progeny with an S would have the smooth phenotype so the phenotypic ratio is 3 smooth:1 wrinkled.
- Now it is known that a gene is a portion of the chromosomal DNA that resides at a particular site, called a locus (loci is plural).
- The gene encodes for a particular protein.
- Mendel had no knowledge of meiosis or chromosomes, which behave similarly to his particles. (See Figure 10.5)

### D. Mendel verified his hypothesis by performing a test cross

- A test cross can determine the genotype of an individual with the dominant traits. (See Figure 10.6)

- It involves crossing the individual to a true-breeding recessive (homozygous recessive).
  - If the unknown is heterozygous, half the progeny will have the dominant and half the recessive traits.
  - If the unknown is homozygous dominant, all the progeny will have the dominant trait.

**E. Mendel's second law says that alleles of different genes assort independently**

- The second law has to do with dihybrid or greater-hybrid crosses.
- A dihybrid is when two genes are heterozygous. An example would be an individual with the genotype *AaBb*.
- It states that the *Aa* alleles assort into gametes independent of the *Bb* alleles.
- This would be like having two coins, a quarter and a penny. Each has a head and tail.
- The *Aa* would be the head and tail of the quarter.
- The *Bb* would be the head and tail of the penny.
- The dihybrid, *Aa Bb*, produces gametes that have one allele of each gene.
- Flipping the coins, the quarter randomly lands on head (*A*) or tail (*a*). The same with the penny.

	<i>B</i>	<i>b</i>
<i>A</i>	<i>AB</i>	<i>Ab</i>
<i>a</i>	<i>aB</i>	<i>ab</i>

- Four different gametes are possible with a 1/4:1/4:1/4:1/4 probability.
- Random fertilization of gametes yields the outcome visible in the Punnett Square:

	<b>M</b>	<i>AB</i>	<i>Ab</i>	<i>aB</i>	<i>ab</i>
<b>F</b>					
<i>AB</i>		<i>AABB</i>			
<i>Ab</i>					
<i>aB</i>					
<i>ab</i>					

- Filling in the table and adding the like cells results in a 1:2:1:2:4:2:1:2:1 ratio.

- This is because the alleles for different genes assort independently.
- The law of independent assortment: Alleles of different genes assort independently of one another during gamete formation. (*See Figure 10.7*)
  - In fact, this law is not always true. Genes that are close to each other on the same chromosome tend to stay together.
  - The closer together on the same chromosome they are, the more they tend to stay together.
  - If far apart on the same chromosome or on different chromosomes, they assort independently. (*See Figure 10.8*)

#### **F. Punnett squares or probability calculations: a choice of methods**

- Multiplying probabilities:
  - If two coins, a penny and a quarter, are tossed, each acts independently.
  - The probability of both landing on heads would be  $1/2 \times 1/2 = 1/4$ .
  - To find the probability of joint events, the general rule is to multiply the probabilities of the individual events. (*See Figure 10.9*)
- Monohybrid cross probabilities:
  - In the example of smooth and wrinkled seeds, heterozygotes produce  $S$  and  $s$  gametes.
  - The probability of a gamete being  $S = 1/2$ .
  - The probability of that an  $F_2$  plant will be  $SS$  is  $1/2 \times 1/2 = 1/4$ .
- Adding probabilities;
  - When the probability problem includes an “either/or” statement, probabilities are added.
  - In a monohybrid cross,  $1/2$  of the sperm will have  $S$ , half the egg will have  $s$ . The probability of both events is  $1/2 \times 1/2 = 1/4$ . These progeny will be  $Ss$ . Another way  $Ss$  would be generated would be if the sperm with  $s$  combined with an egg carrying  $S$ . The probability of either of these events occurring is  $1/4 + 1/4 = 1/2$ .
  - What would be the chance of a coin landing on either heads or tails?  $1/2 + 1/2 = 1$  What is the chance that a die will land on either one or two spots?  $1/6 + 1/6 = 1/3$
- The dihybrid cross:
  - To calculate the probabilities of the outcomes of dihybrid crosses, simply use the outcomes from each of the individual monohybrid components.
  - An  $F_1$  (dihybrid) cross of  $AaBb$  generates  $1/4 AA$ ,  $1/2 Aa$ ,  $1/4 aa$  and  $1/4 BB$ ,  $1/2 Bb$ ,  $1/4 bb$ . The probability of the  $AABb$  genotype is the probability of the  $AA$ , which is  $1/4$ , times the probability of the  $Bb$  genotype, which is  $1/2$ . This would be  $1/8$  ( $1/4 \times 1/2$ ).

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- Phenotypes can be calculated independently for each gene, and combined probability can be calculated.

- If the expected outcome of traits for one character in a dihybrid cross is 3 brown and 1 white, and the expected outcome for the other is 3 tall and 1 short; the ratios for all four phenotypes are 9 brown, tall; 3 brown, short; 3 white, tall; and 1 white, short.

cells	a	b	
1	3 Brown	1 White	
2	3 Tall	1 Short	
9 Brown, Tall (1a times 2a)	3 White, Tall (1b times 2a)	3 Brown, Short (1a times 2b)	1 White, Short (1b times 2b)

- Just place one ratio over the other and progress as described from left to right in the bottom row of the above table.
- Note that the process reveals all possible combinations, and requires no adding of cells.

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#### G. Mendel's laws can be observed in human pedigrees

- Patterns for over 2,500 inherited characteristics have so far been determined.
- Humans cannot be studied using planned crosses.
- Human geneticists rely on pedigrees.
- See *Figure 10.11* for an example of a human pedigree.
- If neither parent has the phenotype, which shows up in progeny, the trait is recessive. The parents are heterozygous and the chance of other children getting the trait is 1/4.
- Half of the children from such a cross will be carriers.
- The number of affected versus unaffected is impossible to predict for a certain couple because outcomes for small samples fail to follow closely the expected outcomes.
- This is just like the likelihood of having two girls born to a family that has just two children. This would be expected in a quarter of two children families.
- The probability of a carrier (heterozygote) for a rare allele unknowingly marrying another carrier would be as likely as the frequency of the allele in the population.
- See *Figure 10.10* for a pedigree analysis of a dominant allele. For a dominant allele:
  - *Every* affected person has an affected parent.
  - Half of the offspring of an affected person are also affected.
  - The phenotype occurs equally in both sexes.
- Recessive traits:
  - Affected people usually have parents who are both not affected.
  - One-quarter of the children on average of unaffected parents would be affected, when both parents are heterozygous.

- The phenotype occurs equally in both sexes.
- Marriage between relatives yields higher likelihood for both being carriers.

### III Alleles and Their Interactions

- Differences in alleles of genes are slight differences in the DNA sequence at the locus.
- Some alleles are not simply dominant or recessive.

#### A. New alleles arise by mutation

- Different alleles exist because any gene is subject to mutation.
- Alleles can mutate to become a different allele.
- *Wild-type* is a term used for the most common allele in the population.
- Other alleles, often called mutant alleles, may produce a different phenotype.
- A genetic locus with a wild-type allele that has a frequency less than 99% is called polymorphic.

#### B. Many genes have multiple alleles

- A population might have more than two alleles.
- The ABO blood types are an example of this.
- In rabbits, coat color is determined by one gene with four different alleles.
- A dominance hierarchy exist:  $C > c^{ch} > c^h > c$
- *See Figure 10.12*
- When more than two alleles exist in a population, any given individual can have no more than two of them, one from their mother and one from their father.

#### C. Dominance is often not complete

- Instead, heterozygotes might show an intermediate phenotype.
- Red flowered snapdragons when crossed to white generate pink flowered plants.
- This might seem to support the blending theory. The F2 progeny, however, demonstrate Mendelian genetics. The F1 pink self-fertilize and the F2 have a phenotypic ratio of 1 red:2 pink:1 white.
- (The blending theory predicts pink F2 progeny.)
- This mode of inheritance is called incomplete dominance. (*See Figure 10.13*)
- The phenotypic outcomes for snapdragons flower color and incomplete dominance in general can be explained, biochemically.
  - The gene codes for an enzyme. The enzymes generate the red color.
  - The red flowered plants have two functional copies of the gene and produce enough enzyme to make red flowers.
  - The pink has one, just enough for pink. White flowered plants fail to produce functional pigment producing enzymes.

- Mendel just happened to find examples of complete dominance.

#### **D. In codominance, both alleles are expressed**

- Codominance is when two different alleles for a gene produce two different phenotypes in the heterozygotes. (*See Figure 10.13*)
- The AB of the human ABO blood group system is an example.
- The alleles for blood type are  $I^A$ ,  $I^B$  and  $I^O$ . They all occupy one locus.
- They determine which antigens are present on the surface of red blood cells.
- *See Figure 10.14.*
- Individuals with two  $I^A$  or  $I^A$  and  $I^O$  are A type.
- Individuals with two  $I^B$  or  $I^B$  and  $I^O$  are B.
- Individuals with  $I^A$  and  $I^B$  are AB.
- Individuals with  $I^O$  and  $I^O$  are O.
- Both  $I^A$  and  $I^B$  produce an antigen.
- This is why they are called codominant.
- $I^O$  is a recessive trait, and is the absence of either the A or B antigen.

#### **E. Some alleles have multiple phenotypic effects**

- Some single alleles have more than one distinguishable phenotypic effect.
- This is called pleiotropy.
- An example is the coloration pattern of Siamese cats, which is caused by an allele that also causes cross-eyes.

### **IV Gene Interactions**

#### **A. Some genes alter the effects of other genes**

- Epistasis is when the alleles of one gene cover up or alter the expression of alleles of another gene.
- An example is coat color in mice. (*See Figure 10.15*)
  - The  $B$  allele determines a banded pattern, called agouti.
  - The recessive  $b$  allele doesn't.
  - The genotypes  $BB$  or  $Bb$  are agouti. The genotype  $bb$  is solid colored (black).
  - Another locus determines if any coloration occurs. The genotypes  $AA$  and  $Aa$  have color and  $aa$  are albino
  - The mice heterozygous for both genes are agouti.
  - The F2 phenotypic ratio is 9 agouti:3 black:4 white.
  - The corresponding genotypes are: 9 agouti ( $1BBAA + 2BbAA + 4BbAa$ ):3 black ( $1bbAA + 2bbAa$ ):4 albino ( $1BBaa + 2Bbaa + 1bbaa$ ).
  - The reason is that there must be color to have a pattern.

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- Imagine that when a white flowered plant is crossed to a purple flowered plant, the F1 are all purple.
- When the purple F1 plants are crossed, 9 purple for every 7 white are observed in the F2 progeny.
  - This ratio is different from what would be expected if purple is simply dominant to white.
  - The ratio provides a clue to the relationship of two different genes.
  - A biochemical pathway could be proposed.
  - The biochemical pathway is diagrammed:



- Both a dominant A and B allele is needed to get purple color.
- This is another example of epistasis.

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#### **B. Hybrid vigor results from new gene combinations and interactions**

- For centuries, it has been known that when two homozygous strains of plants or animals are crossed, the offspring are phenotypically stronger, larger and more vigorous than either parent.
- Shull crossed two varieties of corn and the yield per acre went from 20 to 80 bushels per acre. (*See Figure 10.16*)
- This is called either hybrid vigor or heterosis.
- A hypothesis called overdominance states the heterozygous condition in certain important genes is superior to either homozygote.

#### **C. Polygenes mediate quantitative inheritance**

- Individual heritable characters are often found to be controlled by groups of several genes, called polygenes.
- Each allele intensifies or diminishes the phenotype.
- Variation is continuous.
- Examples of continuous characters are height, skin color and possibly intelligence.
- *See Figure 10.17.*

#### **D. The environment affects gene action**

- Genotype and environment interact to determine the phenotype of an organism.
- Variables such as light, temperature, diet and competition can affect the translation of genotype into phenotype.

- For example, the darkness of the fur of a Siamese cat is affected by the temperature of that region. The coloration can be manipulated, experimentally.
- The proportion of individuals in a group with a given genotype that express the corresponding phenotype can sometimes be measured, and the measure is called *penetrance*.
- The *expressivity* of the genotype is the degree to which it is expressed in an individual.

- An example is hereditary hemochromatosis.
- This disease causes abnormally high levels of iron to accumulate in the liver and other organs of affected people.
- Some people with the disease accumulate toxic levels of iron and others accumulate levels just above normal.

- The influence of environment versus genotype or phenotype can be studied with identical twins, especially when separated from birth and reared apart in substantially different environments.

## V Genes and Chromosomes

- How do we determine the order and distance between the genes that are located on the same chromosome?
- A system was first developed in Thomas Hunt Morgans fly lab in 1910.
- The biological model used was *Drosophila melanogaster*.

### A. Linked genes are on the same chromosome

- Mendel's second law, independent assortment, failed to be universal.
- One early exception was found in *Drosophila* when crossing a dihybrid fly with a double recessive (testcross).
  - The results were not the expected 1:1:1:1, but instead, two of the genotypes occurred at a frequency higher than the other two. (*See Figure 10.19*)
  - This was proved to be due to the genes being on the same chromosome.
- *Drosophila* have just 3 pairs of chromosomes (autosomal) and one pair of sex chromosomes. The normal fly is diploid, and has 8 chromosomes.
- The fly has thousands of genes. Therefore, many exist together on the same chromosome.

### B. Genes can be exchanged between chromatids

- See Figure 9.16 for a review of the recombination of chromosomal segments.
- When two homologous chromosomes physically exchange corresponding segments during prophase I of meiosis, geneticists call it crossing over.
- Recombinations occur at chiasmata. (*See Figure 10.21*)

- If just a few exchanges occur, genes that are closer together tend to stay together.
- The farther apart on the same chromosome genes are, the more likely they will separate during recombination.
- The two extremes are independent assortment, which is when a dihybrid is crossed to a double-recessive and the phenotypic ratio is 1:1:1:1; to complete linkage, which would yield a ratio of just 1:1. (*See Figure 10.20*)
  - Between these two extremes are when distances between genes can be determined.
  - The closer to 1:1, the closer the two genes; the closer to 1:1:1:1, the farther apart.
- The measure of this is called the recombination frequency. (*See Figure 10.23*)
- Again, greater recombination frequencies, i.e. alleles of separate loci tending toward independent assortment in recombination frequency, are observed for genes that are farther apart on the chromosomes.

### **C. Geneticists make maps of eukaryotic chromosomes**

- Alfred Sturtevant, an undergraduate student working in Morgan's fly room, resolved the puzzling question of the deviation of results from the expected ratio of 1:1:1:1.
- A map unit is a recombination frequency of 0.01 (or a 1% recombination). It is also referred to as a centimorgan(cM). (*See Figure 10.22*)

## **VI Sex Determination and Sex-Linked Inheritance**

- Sometimes parental origin of a chromosome does matter.
  - Reciprocal crosses give identical results when organisms are diploid.
  - Many organisms have diploid pairs of chromosomes, *except* for sex chromosomes.
- ### **A. Sex is determined in different ways.**
- In corn, every diploid adult has both male and female reproductive structures. The same is true for peas.
  - This type of organism is called monoecious.
  - Other plants and animals, which have individuals that are one or the other sex, are called dioecious.
  - In most dioecious organisms, sex is determined by differences in the chromosomes.
  - In honeybees, eggs either are fertilized with a sperm, and become diploid females, or do not, and become haploid male, drones.
  - Female grasshoppers have two X-chromosomes, and males have just one. The sperm determines the sex of the zygote. If a sperm without an X fertilizes an egg, the zygote becomes a male grasshopper.

- Humans have different sex chromosomes, X and Y. Males have X and Y, females have X and X.
- Sex is determined by the sperm.
- In humans, maleness is determined by the presence of the Y chromosome, and the genes present on it. Those with XO condition, Turner syndrome, a somewhat rare chromosomal anomaly, are female.
- Those with Klinefelter syndrome, XXY, are male.

## **B. The X and Y chromosomes have different functions**

- The gene that determines maleness was identified by studying people with chromosomal abnormalities.
  - Some XY females were found.
  - Some XX males were found.
  - The XY females had a piece missing from the Y, and the XX males had a piece of a Y on one of their X's.
  - (The X and Y chromosomes pair during meiosis I, like an autosomal pair.)
  - The fragment missing from the Y- or present on the X-chromosome contained the maleness-determining gene.
  - The gene was named *SRY* (for sex-determining region on the Y chromosome).
  - The *SRY* gene codes for a DNA binding protein involved in primary sex determination.
  - If it is present, testes develop, if not ovaries develop.
  - A gene on the X called *DAX1* produces an anti-testis factor. The *SRY* gene product inhibits the gene *DAX1*, and no maleness inhibitor is made.
  - Secondary sex traits like breast, body hair, and voice, are influenced by steroids such as testosterone and estrogen.
- *Drosophila* follow the same pattern as humans but the mechanism is different.
  - The males are XY, and females XX.
  - The ratio of X-chromosomes to the autosomal sets determines sex.
  - Two X's for each diploid set yields females.
  - One X for each diploid set yields males.
- Birds, moths and butterflies have XX males and XY females. These are called ZZ males and ZW males to help prevent confusion.

## **C. Genes on sex chromosomes are inherited in special ways**

- The Y carries very few genes.
- Females are diploid for X-linked genes; males are haploid. This partial haploid condition for males is called *hemizygous*.
- This generates a special type of inheritance called sex-linked inheritance.
- See Figure 10.25 for a description of Morgan's early research on eye color inheritance in *Drosophila*.

#### **D. Human beings display many sex-linked characters**

- The human X chromosome carries thousands of genes.
- The probability of a male having an X-link genetic disease is much higher than a female.
  - Barring inbreeding, the probability of a woman having a recessive X-linked genetic disease is the frequency disease causing allele, squared.
  - This is because it would be the probability of getting the allele twice.
  - Because men have only one X-chromosome, and express what they get, the probability of having a genetic disease *is* the frequency of the allele for the disease in the population.
- The number of lethal or severely detrimental genes on the X is kept low by the hemizygous state of the males.
- Pedigree analysis of X-linked recessive phenotypes reveal certain patterns:
  - 1). The phenotype appears much more often in males than in females.
  - 2). A male with the mutation can pass it on only to his daughters; his sons get his Y.
  - 3). Daughters who receive one mutant X are generally heterozygous carriers. They pass the allele to half of their sons.
  - 4). The mutant phenotype can skip a generation, if the mutation was passed from a male to his daughter.
- The most common form of muscular dystrophy, hemophilia, gout and red-green color blindness are a few X-linked human phenotypes. (*See Figure 10.26*)
- (Contrary to popular opinion, male-pattern baldness is not X-linked.)

#### **VII Cytoplasmic Inheritance**

- Mendelian genetics is the genetics of the nucleus.
- Mitochondria, chloroplast and other plastids possess a small circular DNA molecule.
- Humans have about 60,000 genes in the nucleus and 37 genes in mitochondria.

*<<The page 196 of the pre-press states 600,000 genes. Someone missed a decimal point. No one has estimated this great a number. Estimates are 35,000 to 130,000, and fluctuate daily within this range.>>*

- Plastid genomes are five times larger than mitochondria.
- Mitochondria and plastids are passed on by the mother only. The sperm mitochondria fail to make a significant contribution.
- Some chloroplasts are white, not green, because of a mutation in their DNA.
- Mitochondrial mutations are linked to human genetic diseases also. One causes a type of delayed blindness.