Proportions (cont’d) 
& Transmission DNA

(CHAPTE 2 & 3- Brooker Text)

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BIO 184
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The Chi Square Test

• The general formula is
\[ \chi^2 = \sum \frac{(O - E)^2}{E} \]

• where
  - \(O\) = observed data in each category
  - \(E\) = observed data in each category based on the experimenter’s hypothesis
  - \(\Sigma\) = Sum of the calculations for each category

• Consider the following example in *Drosophila melanogaster*

  • Gene affecting wing shape
    - \(c^+\) = Normal wing
    - \(c\) = Curved wing
  
  • Gene affecting body color
    - \(e^+\) = Normal (gray)
    - \(e\) = ebony

• Note:
  - The wild-type allele is designated with a + sign
  - Recessive mutant alleles are designated with lowercase letters

• The Cross:
  - A cross is made between two true-breeding flies (\(c^+c^+e^+e^+\) and \(ccee\)). The flies of the \(F_1\) generation are then allowed to mate with each other to produce an \(F_2\) generation.

• The outcome
  - \(F_1\) generation
    - All offspring have straight wings and gray bodies
  - \(F_2\) generation
    - 193 straight wings, gray bodies
    - 69 straight wings, ebony bodies
    - 64 curved wings, gray bodies
    - 26 curved wings, ebony bodies
    - 352 total flies

• Applying the chi square test
  - Step 1: Propose a hypothesis that allows us to calculate the expected values based on Mendel’s laws
    - The two traits are independently assorting
Step 2: Calculate the expected values of the four phenotypes, based on the hypothesis

- According to our hypothesis, there should be a 9:3:3:1 ratio on the F2 generation

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Expected probability</th>
<th>Expected number</th>
</tr>
</thead>
<tbody>
<tr>
<td>straight wings, gray bodies</td>
<td>9/16</td>
<td>9/16 X 352 = 198</td>
</tr>
<tr>
<td>straight wings, ebony bodies</td>
<td>3/16</td>
<td>3/16 X 352 = 66</td>
</tr>
<tr>
<td>curved wings, gray bodies</td>
<td>3/16</td>
<td>3/16 X 352 = 66</td>
</tr>
<tr>
<td>curved wings, ebony bodies</td>
<td>1/16</td>
<td>1/16 X 352 = 22</td>
</tr>
</tbody>
</table>

Step 3: Apply the chi square formula

\[
\chi^2 = \frac{(O_1 - E_1)^2}{E_1} + \frac{(O_2 - E_2)^2}{E_2} + \frac{(O_3 - E_3)^2}{E_3} + \frac{(O_4 - E_4)^2}{E_4}
\]

\[
\chi^2 = \frac{(193 - 198)^2}{198} + \frac{(69 - 66)^2}{66} + \frac{(64 - 66)^2}{66} + \frac{(26 - 22)^2}{22}
\]

\[
\chi^2 = 0.13 + 0.14 + 0.06 + 0.73
\]

\[
\chi^2 = 1.06
\]

Step 4: Interpret the chi square value

- Before we can use the chi square table, we have to determine the degrees of freedom (df)
  - The df is a measure of the number of categories that are independent of each other
    - df = n – 1
    - where n = total number of categories
  - In our experiment, there are four phenotypes/categories
    - Therefore, df = 4 – 1 = 3
  - Refer to Table 2.1
### Table 2.1
Chi-Square Values and Probability

<table>
<thead>
<tr>
<th>Degrees of Freedom</th>
<th>P = 0.05</th>
<th>0.05</th>
<th>0.10</th>
<th>0.50</th>
<th>2.00</th>
<th>0.05</th>
<th>0.60</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00157</td>
<td>0.0235</td>
<td>0.042</td>
<td>0.453</td>
<td>1.842</td>
<td>3.841</td>
<td>6.635</td>
</tr>
<tr>
<td>2</td>
<td>0.022</td>
<td>0.123</td>
<td>0.446</td>
<td>7.385</td>
<td>3.239</td>
<td>5.991</td>
<td>9.210</td>
</tr>
<tr>
<td>3</td>
<td>0.048</td>
<td>0.215</td>
<td>1.06</td>
<td>10.235</td>
<td>9.489</td>
<td>13.277</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.220</td>
<td>0.711</td>
<td>2.37</td>
<td>14.865</td>
<td>14.065</td>
<td>13.277</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.554</td>
<td>1.145</td>
<td>2.74</td>
<td>16.812</td>
<td>15.065</td>
<td>15.065</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.872</td>
<td>1.635</td>
<td>3.09</td>
<td>18.612</td>
<td>14.065</td>
<td>16.812</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1.219</td>
<td>2.167</td>
<td>3.42</td>
<td>20.385</td>
<td>13.277</td>
<td>18.612</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1.646</td>
<td>2.733</td>
<td>4.59</td>
<td>22.070</td>
<td>12.385</td>
<td>20.070</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2.108</td>
<td>3.25</td>
<td>5.88</td>
<td>23.758</td>
<td>11.507</td>
<td>21.666</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>15.051</td>
<td>18.183</td>
<td>23.164</td>
<td>29.136</td>
<td>36.270</td>
<td>43.733</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>19.865</td>
<td>21.683</td>
<td>33.936</td>
<td>36.936</td>
<td>43.733</td>
<td>50.893</td>
<td></td>
</tr>
</tbody>
</table>

### Step 4: Interpret the chi square value

- With df = 3, the chi square value of 1.06 is slightly greater than 1.005 (which corresponds to P = 0.80)
- A P = 0.80 means that values equal to or greater than 1.005 are expected to occur 80% of the time based on random chance alone
- Therefore, it is quite probable that the deviations between the observed and expected values in this experiment can be explained by random sampling error

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### 3.1 General Features of Chromosomes

- **Chromosomes** are structures within living cells that contain the genetic material
  - They contain the genes
- Biochemically, chromosomes are composed of
  - DNA, which is the genetic material
  - Proteins, which provide an organized structure

**Transmission DNA**
First, let’s consider the distinctive cellular differences between the two types of cells:

1. **Prokaryotes**
   - **Bacteria**

2. **Eukaryotes**

### 3.1 GENERAL FEATURES OF CHROMOSOMES

- **Prokaryotes**
  - Do not contain a nucleus
  - Usually contain a single type of circular chromosome
    - Found in the nucleoid
  - Contain a cell membrane
    - For nutrient uptake and waste excretion
  - Contain a rigid cell wall
    - For protection
  - May contain other structures
    - Outer membrane
    - Flagella

- **Eukaryotes**
  - Have a nucleus
    - Contains two or more linear chromosomes
  - Have membrane-bounded organelles with specific functions
    - Mitochondria
      - Play a role in ATP synthesis
      - Contain their own DNA
    - Lysosomes
      - Play a role in degradation of macromolecules
    - Golgi apparatus
      - Plays a role in protein modification and trafficking
Figure 3.1 (a) Animal cell

Cytogenetics
- The field of genetics that involves the microscopic examination of chromosomes
- A cytogeneticist typically examines the chromosomal composition of a particular cell or organism
  - This allows the detection of individuals with abnormal chromosome number or structure
  - This also provides a way to distinguish between two closely-related species
  - A karyotype is the photographic representation of the chromosomes within a cell

Eukaryotic Chromosomes Are Inherited in Sets
- Most eukaryotic species are diploid
  - Have two sets of chromosomes
- For example
  - Humans
    - 46 total chromosomes (23 per set)
  - Dogs
    - 78 total chromosomes (39 per set)
  - Fruit fly
    - 8 total chromosomes (4 per set)

• Animal cells are of two types
  - Somatic cells
    - Body cells, other than gametes
      - Blood cells, for example
  - Germ cells
    - Gametes
      - Sperm and egg cells
Eukaryotic Chromosomes Are Inherited in Sets

- Members of a pair of chromosomes are called homologues
  - The two homologues form a homologous pair
- The two chromosomes in a homologous pair
  - Are nearly identical in size
  - Have the same banding pattern and centromere location
  - Have the same genes
    - But not necessarily the same alleles

- The DNA sequences on homologous chromosomes are also very similar
  - There is usually less than 1% difference between homologues
- Nevertheless, these slight differences in DNA sequence provide the allelic differences in genes
  - Eye color gene
    - Blue allele vs brown allele

Eukaryotic Chromosomes Are Inherited in Sets

- The sex chromosomes (X and Y) are not homologous
  - They differ in size and genetic composition
- They do have short regions of homology, though

Figure 3.3

The physical location of a gene on a chromosome is called its locus.

Genotype:
- AA: Homozygous for the dominant allele
- bb: Homozygous for the recessive allele
- Cc: Heterozygous
3.2 CELLULAR DIVISION

- One purpose of cell division is **acellular reproduction**
  - This is the means by which some unicellular organisms produce new individuals
  - Examples
    - Bacteria
    - Amoeba
    - Yeast
      - *Saccharomyces cerevisiae* (Baker’s yeast)

- A second important reason for cell division is ** multicellularity**
  - Plants, animals and certain fungi are derived from a single cell that has undergone repeated cell divisions
  - For example
    - Humans start out as a single fertilized egg
    - End up as an adult with several trillion cells

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**Prokaryotes Reproduce Asexually by Binary Fission**

- The capacity of bacteria to divide is really quite astounding
  - *Escherichia coli*, for example, can divide every 20 minutes
- Prior to division, the bacterial cell replicates its chromosome
- Then the cell divides into two daughter cells by a process termed **binary fission**
- Binary fission does not involve genetic contributions from two different gametes
Mitosis
Eukaryotic cells that are destined to divide progress through a series of stages known as the cell cycle.

**MITOSIS**

- During the G₁ phase, a cell prepares to divide
- The cell reaches a restriction point and is committed on a pathway to cell division
- Then the cell advances to the S phase, where chromosomes are replicated
  - The two copies of a replicated chromosome are termed chromatids
  - They are joined at the centromere to form a pair of sister chromatids

- In actively dividing cells, G₁, S and G₂ are collectively known as interphase
- A cell may remain for long periods of time in the G₀ phase
  - A cell in this phase has
    - Either postponed making a decision to divide
    - Or made the decision to never divide again
      - Terminally differentiated cells (e.g., nerve cells)
• Note that at the end of S phase, a cell has twice as many chromatids as there are chromosomes in the G\textsubscript{1} phase
  – A human cell for example has
    • 46 distinct chromosomes in G\textsubscript{1} phase
    • 46 pairs of sister chromatids in S phase
• Therefore the term chromosome is relative
  – In G\textsubscript{1} and late in the M phase, it refers to the equivalent of one chromatid
  – In G\textsubscript{2} and early in the M phase, it refers to a pair of sister chromatids

• During the G\textsubscript{2} phase, the cell accumulates the materials that are necessary for nuclear and cell division
• It then progresses into the M phase of the cycle where mitosis occurs
• The primary purpose of mitosis is to distribute the replicated chromosomes to the two daughter cells
  – In humans for example,
    • The 46 pairs of sister chromatids are separated and sorted
    • Each daughter cell thus receives 46 chromosomes

• Mitosis is subdivided into five phases
  – Prophase
  – Prometaphase
  – Metaphase
  – Anaphase
  – Telophase

• Chromosomes are decondensed
• By the end of this phase, the chromosomes have already replicated
  – But the six pairs of sister chromatids are not seen until prophase
• The centrosome divides
• Nuclear envelope dissociates into smaller vesicles

• Centrosomes separate to opposite poles

• The mitotic spindle apparatus is formed
  – Composed of microtubules (MTs)

  ![Diagram of mitotic spindle](image)

  **PROPHASE**

  - Microtubules (MTs) forming mitotol spindle
  - Sister chromatid

  **CENTROMERE**

  - Contacts the centromere
  - Contacts the other two
  - Contacts the kinetochore microtubule

  **Figure 3.8**

• Microtubules are formed by rapid polymerization of tubulin proteins

• There are three types of spindle microtubules
  – 1. Aster microtubules
    • Important for positioning of the spindle apparatus
  – 2. Polar microtubules
    • Help to “push” the poles away from each other
  – 3. Kinetochore microtubules
    • Attach to the **kinetochore**, which is bound to the centromere of each individual chromosome

  ![Diagram of spindle microtubules](image)

  **PROMETAPHASE**

  - Spindle fibers interact with the sister chromatids
  - Kinetochore microtubules grow from the two poles
    – If they make contact with a kinetochore, the sister chromatid is “captured”
    – If not, the microtubule depolymerizes and retracts to the centrosome
  - The two kinetochores on a pair of sister chromatids are attached to kinetochore MTs on opposite poles

  ![Diagram of prometaphase spindle](image)
• Pairs of sister chromatids align themselves along a plane called the metaphase plate

• Each pair of chromatids is attached to both poles by kinetochore microtubules

• The connection holding the sister chromatids together is broken

• Each chromatid, now an individual chromosome, is linked to only one pole

• As anaphase proceeds
  – Kinetochore MTs shorten
    • Chromosomes move to opposite poles
  – Polar MTs lengthen
    • Poles themselves move further away from each other

• Chromosomes reach their respective poles and decondense

• Nuclear membrane reforms to form two separate nuclei

• In most cases, mitosis is quickly followed by cytokinesis
  – In animals
    • Formation of a cleavage furrow
  – In plants
    • Formation of a cell plate
    • Refer to Figure 3.9

• Mitosis and cytokinesis ultimately produce two daughter cells having the same number of chromosomes as the mother cell

• The two daughter cells are genetically identical to each other
  – Barring rare mutations

• Thus, mitosis ensures genetic consistency from one cell to the next

• The development of multicellularity relies on the repeated process of mitosis and cytokinesis