Outline

I. DNA
   A. Structure
   B. Replication

II. RNA

III. Protein Production

DNA

- Deoxyribonucleic acid – DNA
- The blueprint to making proteins!!!
- Chromosomes located inside the nucleus contains long coiled strands of DNA

DNA's Discovery

Watson and Crick

The Players

- **Crick**: Ph.D. student at Cambridge in England working on X-ray Crystallography of the protein hemoglobin
- **Watson**: Young American scientist visiting the lab to do some work on a protein
- Both were interested in unraveling the secret of DNA's structure – it was not what they were supposed to be working on

- **Wilkins**: Working on DNA structure, had crystallized DNA fibers
- **Franklin**: Working at the same university as Wilkins, just down the hall. Did the X-ray Crystallography on Wilkins DNA fibers
- **Linus Pauling**: discovered the three dimensional structure of proteins know as alpha helixes
- **Chargaff**: Discovered that A=T and G=C Adenine levels always equal thymine levels
Franklin gave a talk describing her work with the X-Ray Crystallography. Watson attended but he was not the crystallographer and did not see the implications of her work.

Watson and Crick met with Wilkins and he shared Franklin's work with both of them (without her permission or knowledge).

Watson and Crick put all the pieces of information together. They built models to help them come up with the structure. They knew it was a race so they published a one page article in Nature (1953) with their ideas – they performed no experiments but were able to see the big picture.

Crick, Watson and Wilkins received the Nobel Prize for their work. Rosalind received no credit until much later. She died before the Nobel Prize.

Nucleic acids (DNA and RNA) are made of nucleotides.

Nucleotides have:
- One phosphate (ATP has three)
- One sugar
- One base.

The nucleotides vary in the type of base.

DNA has four different bases:
- Adenine (A), Thymine (T), Guanine (G), Cytosine (C)
**DNA Is a Double Helix**

- The sugars and phosphates link together by covalent bonds to form the rail on the outside.
- The sugars are covalently bound to a base.
- The bases hydrogen bond together to keep the two strands together = double helix.
- **Base pairs** are two nucleotides, one on each complementary strand of a DNA molecule.

---

**Double Helix Structure**

- Two strands bonded together by hydrogen bonds between the bases = weak bonds.
- Each strand has nucleotides bonded together covalently by the phosphate and the sugar.

---

**Base Pairs**

- The bases pair up in a specific manner:
  - Adenine (A) pairs with Thymine (T)
  - Guanine (G) pairs with Cytosine (C)

---

**Bases**

- Adenine (A)
- Thymine (T)
- Guanine (G)
- Cytosine

**Thymine**

- SUGAR

**Adenine**

- SUGAR
Remember that on one strand:
- The base is covalently bonded to the sugar, which is covalently bonded to the phosphate
- Between the two strands the bases are bonded together by hydrogen bond
  - A – T
  - C – G

Before the structure of DNA was discovered, no one could explain how a cell could divide and replicate the whatever the inheritance molecule was.

When the structure of DNA was worked out it became apparent how it happens.

Before a cell divides, the parent cell needs to make a copy of the DNA.

Each daughter cell receives a copy of the DNA.
DNA Replication

1. An enzyme, helicase, unwinds the DNA molecule and breaks the hydrogen bonds between the base pairs.

2. Enzymes called DNA polymerases add new nucleotides to pair with the old DNA.

Replication of DNA

- Now there are two double strands of DNA.
  - One strand in each is the original parental strand.
  - One strand in each is a new strand that was copied off of the parental strand.

- This is called semi-conservative replication.
  - Each new DNA molecule contains one strand of the original DNA and one strand of new DNA.

Energy to power binding

- The incoming nucleotides have three phosphates, only one is used to bond to the sugar molecule.
- The energy needed to build the new DNA strand comes from taking the other two phosphates off.
- The energy gained from breaking the bonds is used to build the new bond.
Pairing

Remember that T pairs with A
G pairs with C

If the original DNA strand was: TCAT
then the complimentary strand would be AGTA

Mistakes – repair mechanisms

- Before a cell can divide, it must make a complete copy of itself
- There are millions of bases that need to be added to the DNA strands – many chances for something to go wrong
- Enzymes will take out the wrong nucleotide and replace it with the correct one

Mutations – when replication goes wrong

- The repair mechanisms don’t correct all the mistakes
- There are errors in replications: one example is a point mutation
- A point mutation is when one base pair is paired incorrectly

Point Mutations

Causes of Mutations

- Random error – sometimes things just go wrong.
- Mutagens – chemicals that damage the DNA and cause mutations in replication
  - Cigarette smoke
  - Sunlight
  - Many chemicals (benzene)
Results of Mutations

- A few things can happen if DNA mutates before the cell replicates:
  1. Enzymes can repair the damage
  2. Or – The cell may commit suicide (apoptosis)
  3. Or – The cell may replicate and the mutation becomes permanent

Good mutations - Evolution

- Evolution occurs because there is variation in DNA, sometime a mutation can produce changes that are better
  - If these mutations are better they may allow the organism to survive longer and produce more offspring – the change can spread throughout the population

DNA contains the code for proteins

- How does DNA code for proteins?
- Remember that DNA is stored in the nucleus, it is too valuable to leave the nucleus so it makes a copy of itself (RNA) which leaves the nucleus and goes into the cytosol to make the protein.

DNA codes for RNA, which codes for protein

- A gene directs the production of a specific protein
  - DNA \[\rightarrow\] RNA \[\rightarrow\] Protein

Paternity test for the father of a baby

DNA analysis from blood taken from a crime scene. Match the blood to suspects
DNA and RNA

### Table 21.1 Comparisons of DNA and RNA

<table>
<thead>
<tr>
<th>DNA</th>
<th>RNA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Similarities</strong></td>
<td><strong>Differences</strong></td>
</tr>
<tr>
<td>Are nucleic acids</td>
<td>Is a single-stranded molecule</td>
</tr>
<tr>
<td>Are composed of linked nucleotides</td>
<td>Has a sugar ribose</td>
</tr>
<tr>
<td>Have a sugar phosphate backbone</td>
<td>Contains the bases adenine, guanine, cytosine, and thymine (instead of uracil)</td>
</tr>
<tr>
<td>Have four types of bases</td>
<td>Functions primarily in the nucleus</td>
</tr>
</tbody>
</table>

**mRNA is only a single strand**

**RNA has same “handrail” structure with the phosphates covalently bound to the sugars.**

**The sugars are bound covalently to bases**

---

### DNA and RNA

1. The sugar is slightly different from DNA’s sugar (has an OH vs H)
   - RNA – ribose
   - DNA – deoxyribose

(a) Comparison of RNA and DNA nucleotides

<table>
<thead>
<tr>
<th>DNA nucleotide</th>
<th>RNA nucleotide</th>
</tr>
</thead>
<tbody>
<tr>
<td>base: guanine (G) adenine (A) uracil (U)</td>
<td>base: guanine (G) adenine (A) thymine (T)</td>
</tr>
<tr>
<td>sugar-phosphate handrails</td>
<td>sugar-phosphate handrails</td>
</tr>
<tr>
<td>sugar ribose</td>
<td>sugar ribose</td>
</tr>
</tbody>
</table>

RNA strand: sugar-phosphate handrails bases: cytosine (C) guanine (G) adenine (A) uracil (U)

DNA strand: sugar-phosphate handrails bases: cytosine (C) guanine (G) adenine (A) thymine (T)

---

2. One base is different
   - RNA has four bases: RNA has Cytosine (C), Guanine (G), Adenine (A) and Uracil (U)
   - Uracil is paired to Adenine
   - DNA has CGAT

DNA and RNA

---

RNA

- mRNA is only a single strand
- RNA has same “handrail” structure with the phosphates covalently bound to the sugars.
- The sugars are bound covalently to bases

DNA and RNA
**DNA and RNA**

3. RNA is single stranded, DNA is double stranded

**RNA vs DNA**

<table>
<thead>
<tr>
<th>Sugar</th>
<th>RNA</th>
<th>DNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>Ribose</td>
<td>Deoxyribose</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bases</th>
<th>AUCG</th>
<th>ATCG</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th># of Strands</th>
<th>Single</th>
<th>Double</th>
</tr>
</thead>
</table>

---

**1. Transcription:** DNA is copied to produce mRNA

2. mRNA leaves nucleus

3. **Translation:** At the ribosome, the amino acids are chained together to form a polypeptide chain.

**DNA Codes for RNA - Transcription**

- **Transcription:**
  - Synthesis of *messenger RNA (mRNA)* using DNA as a template
  - The product of transcription is RNA
  - Transcription happens in the nucleus

**Transcription**

- **RNA polymerase** (similar to DNA polymerase) binds to a region on the DNA upstream from the gene called the promoter region.

- **RNA polymerase** brings complementary RNA nucleotides together and binds them together into a chain

- The nucleotide containing uracil is complementary to adenine
DNA Codes for RNA - Transcription

- RNA polymerase links together the RNA nucleotides
- Until it reaches a sequence of bases on the DNA that is the stop signal
- When the RNA transcript is completed, it is released from the DNA
- The DNA closes again

DNA Codes for RNA - Transcription

- Final processing of the mRNA includes removal of introns, leaving the exons to direct protein synthesis

DNA Codes for RNA - Transcription

Figure 21.4

Transcription

Animation—Transcription

RNA to Protein - Translation

- Translation – the process of converting the code in mRNA into a polypeptide chains (proteins)

RNA to Protein - Translation

- Remember that mRNA is a chain of nucleotides with four different bases: U, A, G, and C
- So it could be a chain of: UGCCAGUGC….
- These nucleotides will be read in groups of three = codons to code for one amino acid
RNA to Protein - Translation

- **A codon**
  - A three-base sequence that translates into one amino acid

Translation

- **Translation:**
  1. The mRNA leaves the nucleus and enters the cytosol.
  2. mRNA docks with ribosomes.
  3. tRNA brings amino acids to the ribosome.
  4. The amino acids are bound together by a peptide bond by the ribosome.

The Genetic Code

- **Codons**
  - Three mRNA bases code for one amino acid
  - The three mRNA bases together are called a codon
  - So when CGU are next to each other as a codon then that will be read as arginine
  - How does this happen?
RNA Codes for Protein - Translation

- Translation uses transfer RNA (tRNA) to identify and transport amino acids to the ribosome

Transfer RNA (tRNA)

- The mRNA that codes for which amino acids go in what order
- The ribosome is where the amino acids are bound together
- tRNA (transfer RNA) brings the amino acids to the ribosomes

Transfer RNA (tRNA)

- One side of tRNA attaches to an amino acid
- The other side of tRNA has complementary nucleotides to the codon
- Anticodon
  - A three base sequence on the other end of the tRNA that is complementary to the codon of the mRNA

Ribosomes

- Ribosomal RNA (rRNA)
  - Ribosomes consist of two rRNA molecules and a protein
  - It is the ribosome that forms the peptide bond
  - rRNA is the enzymatic portion of the ribosome

Types of RNA and their Functions

<table>
<thead>
<tr>
<th>TABLE 21.2 Review of the Functions of RNA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Molecule</strong></td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>Messenger RNA (mRNA)</td>
</tr>
<tr>
<td>Transfer RNA (tRNA)</td>
</tr>
<tr>
<td>Ribosomal RNA (rRNA)</td>
</tr>
<tr>
<td>Type of RNA</td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td>mRNA</td>
</tr>
<tr>
<td>tRNA</td>
</tr>
<tr>
<td>rRNA</td>
</tr>
</tbody>
</table>

**Ribosomes**

Note: there are three tRNA binding sites: E, P, A

**Steps of Translation**

1. mRNA binds to small subunit of ribosome
2. tRNA with methionine (MET) amino acid attached, binds to the mRNA codon AUG, at the “P site”
3. Large subunit of ribosome attaches
**Translation**

4. tRNA with the next amino acid attached binds to the mRNA codon at the “A site.” The bond between the tRNA and MET amino acid is broken.

5. A peptide bond is formed between the MET amino acid and the second amino acid.

6. The transfer RNAs all move over one space on the ribosome (translocation).

**Translation - Elongation**

7. Now the “free tRNA,” which used to hold the MET amino acid, is now in the “E site.”

8. The tRNA with two amino acids is in the “P site” and the “A site” is open.

9. The next tRNA with the 3rd amino acid is brought into the “A site.”

10. The “free tRNA” is released from the “E site.”

**Translation - Termination**

11. When translation reaches a stop codon, no tRNA binds to the stop codon.

12. Instead the polypeptide chain is released and the ribosome breaks apart, releasing the mRNA.

---

**Figure 21.5 The genetic code**

**Figure 21.5 (1 of 2) The genetic code**
Figure 21.5 (2 of 2) The genetic code

Protein production – cytosolic proteins

- All polypeptide chains are produced in the ribosomes
- Polypeptides/proteins that will be cytosolic are produced on free floating ribosomes

Protein production – membrane and export proteins

- If the polypeptides/proteins are going to become membrane proteins or are exported out of the cell
  - then the polypeptide chain will be produced in a ribosome that is brought to the rough ER

Protein Production – export proteins

1. DNA is in the nucleus. It is the instructions for making protein
2. During transcription, a copy of the DNA is made = mRNA
3. mRNA leaves the nucleus and enters the cytosol
4. Ribosomes are made in the nucleolus and also go to the cytosol
5. mRNA docks with a ribosome
   - The mRNA has the plan of which amino acids go where.
   - The ribosome is the place where the amino acids are linked together

Protein Production

6. tRNA brings the amino acids to the ribosome
7. At the ribosome, the amino acids are bound together with a peptide bond to make a polypeptide chain (translation)
8. The ribosome with the polypeptide chain docks with the Rough Endoplasmic Reticulum (RER)
9. Only the polypeptide chain enters the lumen of the RER
10. In the RER, the polypeptide chain/protein is folded by the chaperones into its final shape and the protein is given a carbohydrate tag.
11. A transport vesicle containing the new protein pinches off from the RER
12. The transport vesicle carries the protein from the RER to the Golgi Complex.
13. In the Golgi the protein is further processed, sorted and repackaged into a new transport vesicle
Protein Production

13. The protein is transported from the Golgi Complex to the plasma membrane in a new transport vesicle.

14. The protein is exported out of the cell using exocytosis.

<table>
<thead>
<tr>
<th>Organelle</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nucleus</td>
<td>DNA copied to mRNA</td>
</tr>
<tr>
<td>Ribosomes</td>
<td>“reads” mRNA to assemble amino acids into a polypeptide chain</td>
</tr>
<tr>
<td>Rough ER</td>
<td>Polypeptide chain folded and tagged with a carbohydrate chain</td>
</tr>
<tr>
<td>Golgi complex</td>
<td>Processes, sorts and repackages proteins</td>
</tr>
<tr>
<td>Vesicles</td>
<td>Transports proteins</td>
</tr>
</tbody>
</table>
Important Concepts

- What is the structure of DNA – and their nucleotides
  - What molecules are bonded together – order
  - What type of bonds holds the subunits together
  - What are the four bases
  - Which bases are paired together

- Be able to draw DNA. Use one letter abbreviations for the bases, phosphates, and sugars (you don’t need to draw the structure of the base, sugar and phosphate)

- What are the steps of DNA replication

- When does DNA replication take place

- What is helicase’s and DNA polymerase’s roll

- What supplies the energy to be used to build the new strand

- What are mutations, what are point mutations

- Be able to recognize an incorrectly paired sequence

- What are the possible outcomes of mutations

- What is a positive aspect of mutations

- What is the structure of proteins

- What are the structural differences between DNA and RNA, what are the structural similarities?

- Determine the complementary mRNA sequence from a DNA sequence.

- What are the steps of protein synthesis (production) for a cytosolic protein and for a protein that will be exported from the cell – starting in the nucleus, know the parts of the cell and their role in protein synthesis and protein modification (including the golgi, ER, etc)

- Be able to “read” the mRNA to make a protein, given the table of codons to amino acids.

- Know the types of RNA, their functions, and where in the cell do they complete their function
Definitions

- DNA polymerase, RNA polymerase, helicase, semiconservative replication, complimentary strand, point mutation, mutagens, base pairs, gene, tRNA, mRNA, rRNA, promoter region, polypeptide chain, peptide bond, transcription, translation, codon, anticodon