

The background features a bright yellow-to-white gradient. On the left side, there is a large, detailed DNA double helix structure. In the center and right, there are several faint, semi-transparent DNA double helix structures that appear to be receding into the distance, creating a sense of depth.

Unit 8: DNA, Gene Expression, and Biotechnology

Learning Objectives

- Describe what DNA is and what it does.
- Explain the process of DNA replication.
- Explain the process of gene expression.
- Explain the causes and effects of damage to the genetic code.
- Describe biotechnology and its implications for human health.
- Discuss biotechnology in agriculture.
- Discuss biotechnology today and tomorrow.

What is the most common reason why DNA analyses overturn incorrect criminal convictions?

- In more than three-quarters of the cases, inaccurate eyewitness testimony played an important role in the guilty verdict.
 - Julius Ruffin
 - Ken Wyniemko



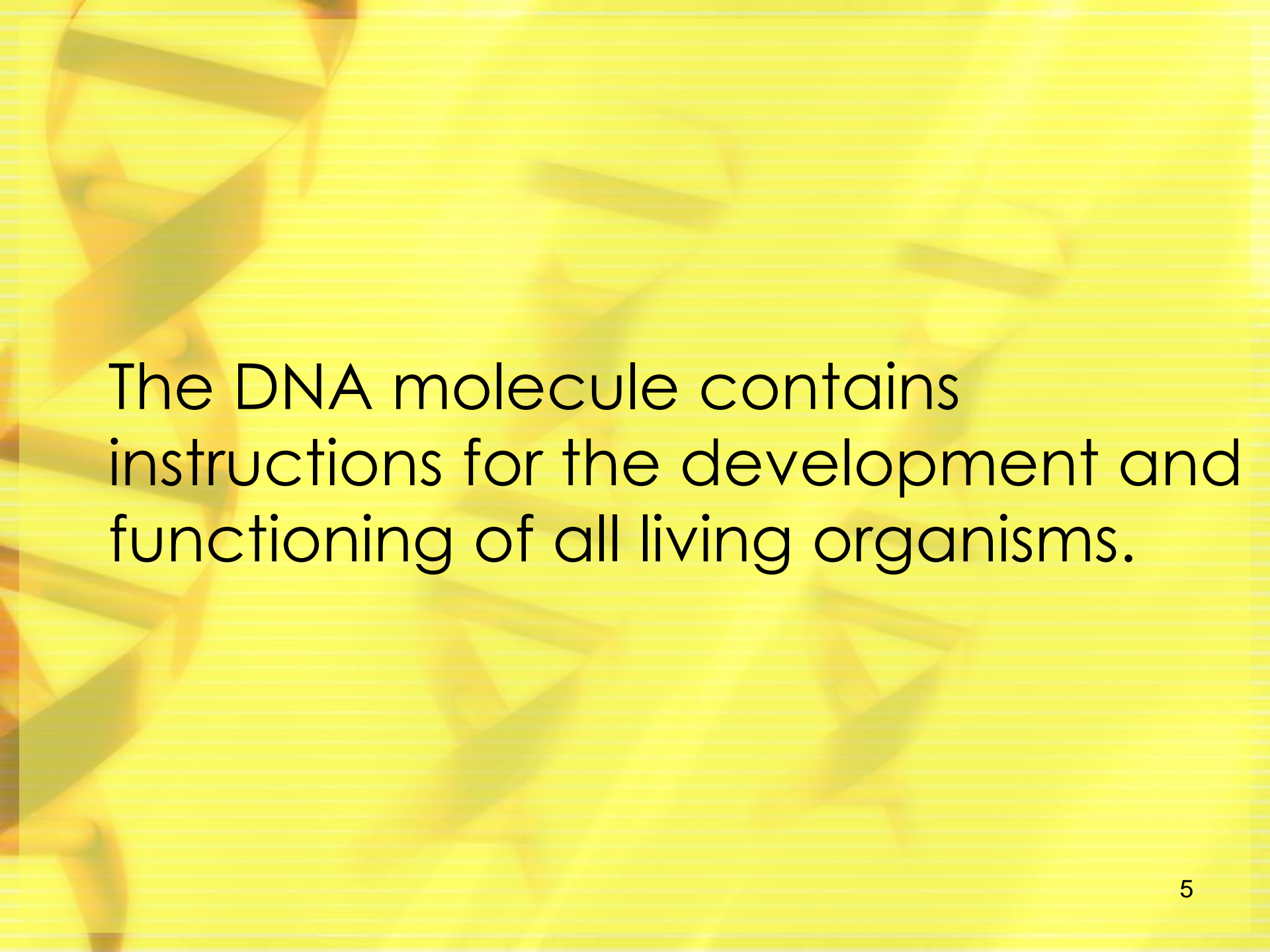
Figure 5-1
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Selfish dictators may owe their behaviour partly to their genes, according to a study that claims to have found a genetic link to ruthlessness.

–Nature, April 2008

Whether a man has one type of gene versus another could help decide whether he's good "husband material," a new study suggests.

–Washington Post, September 2008



The DNA molecule contains instructions for the development and functioning of all living organisms.



Two Important Features of DNA

1. DNA contains the instructions on how to create a body and control its growth and development.
2. The instructions encoded in the DNA molecule are passed down from parent to offspring.

Cast of Characters

- Erwin Chargaff: established base-pairing rules
- James Watson and Francis Crick: brash, young, inexperienced; not taken seriously by too many people
- Sir William Lawrence Bragg: head of the Cavendish Laboratory where Watson and Crick did their work; Nobel laureate, serious competitor to...

Cast of Characters

- Linus Pauling: wizard of Caltech; world's leading structural chemist; odds-on favorite to solve the structure of DNA
- Peter Pauling: office-mate of Watson and Crick; unofficial communications link between competing groups in California and England
- Maurice Wilkins and Rosalind Franklin, whose laboratories at King's College produced critical evidence critical.

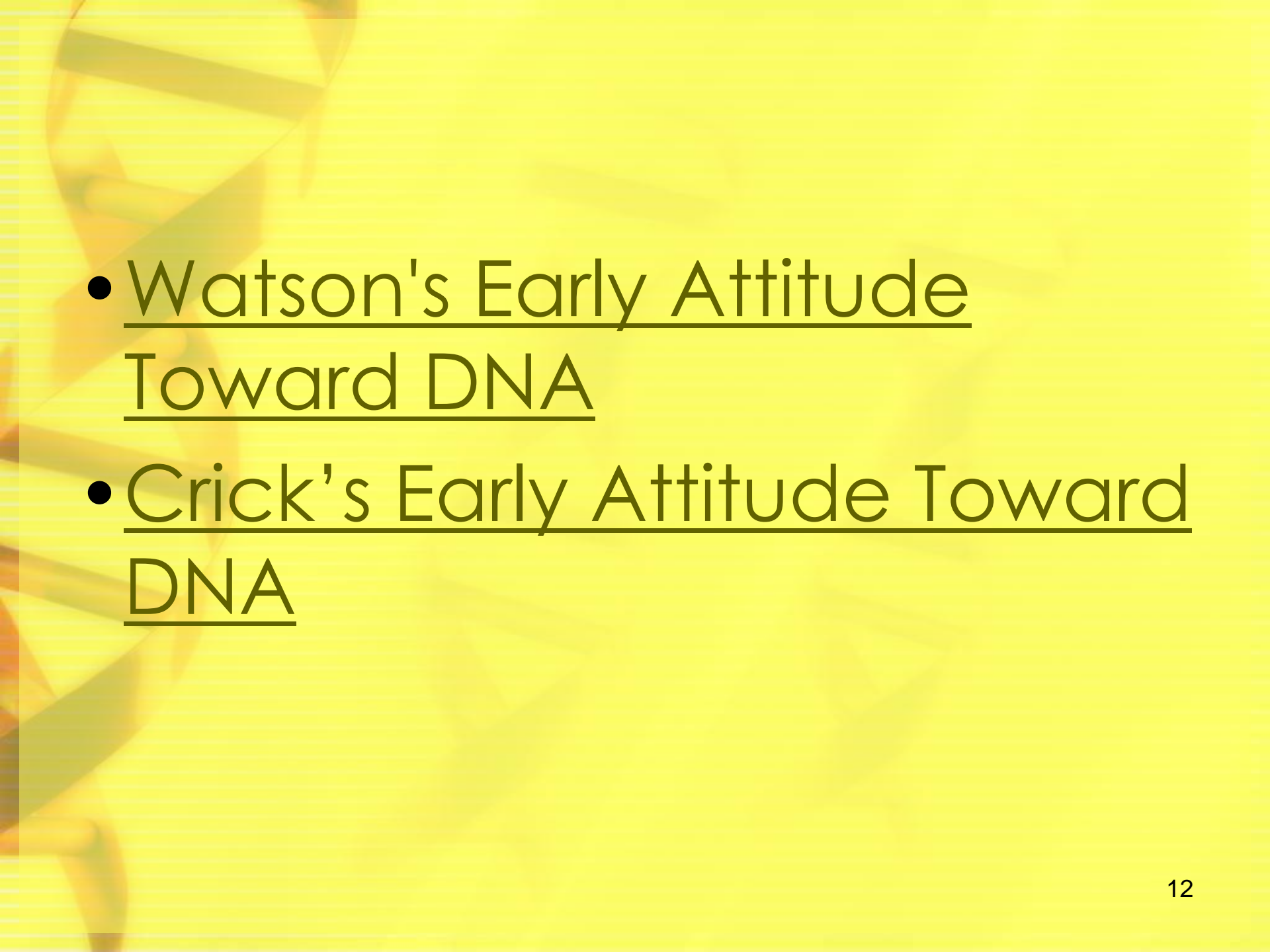


- Chargaff's Rules

- 
- A Short Summary of Pauling's Involvement with DNA.



- Denying Pauling's Request

- 
- Watson's Early Attitude Toward DNA
 - Crick's Early Attitude Toward DNA

Chargaff's Rules

- 1950 - Erwin Chargaff reported that DNA composition varies from one species → another.
- Such evidence of molecular diversity made DNA a more credible candidate for the genetic material than protein.
- In DNA of each species he studied, # adenines \approx # thymine, # guanines \approx # cytosine.



Base Pairing

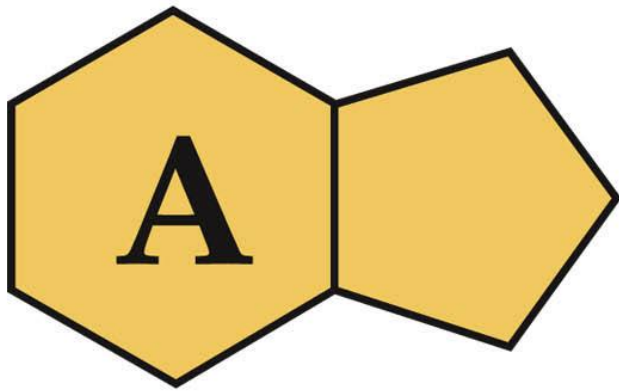
The C+G:A+T ratio varies from organism to organism (particularly among the bacteria), but within the limits of experimental error, $A = T$ and $C = G$

Relative Proportions (%) of Bases in DNA

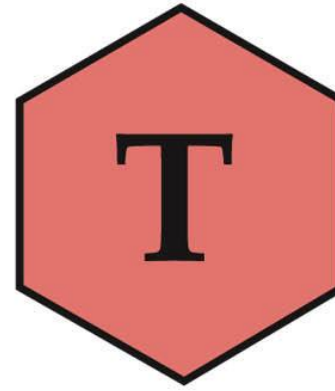
Organism	A	T	G	C
Human	30.9	29.4	19.9	19.8
Chicken	28.8	29.2	20.5	21.5
Grasshopper	29.3	29.3	20.5	20.7
Sea Urchin	32.8	32.1	17.7	17.3
Wheat	27.3	27.1	22.7	22.8
Yeast	31.3	32.9	18.7	17.1
E. coli	24.7	23.6	26.0	25.7

Base Pairing

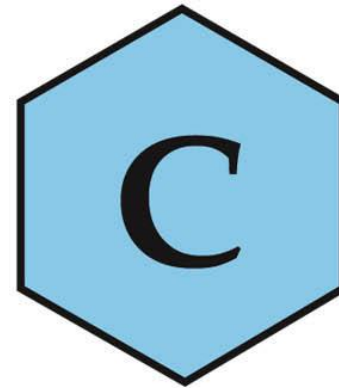
- The rules of base pairing are:
 - the purine **adenine** (A) always pairs with the pyrimidine **thymine** (T)
 - the pyrimidine **cytosine** (C) always pairs with the purine **guanine** (G)
- This is consistent with there not being enough space (20 Å) for two purines to fit within the helix and too much space for two pyrimidines to get close enough to each other to form hydrogen bonds between them.



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Purines

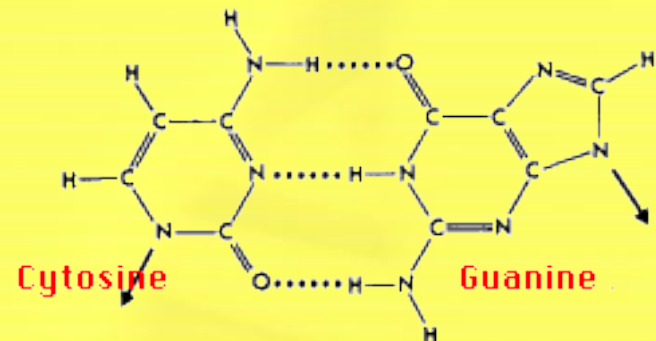
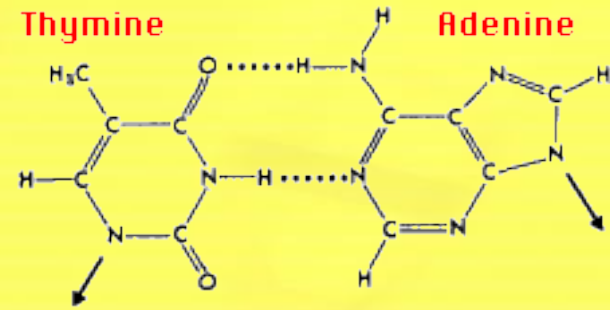
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Pyrimidines

LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 11.5 Chargaff's Rule
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Base Pairing

- Why not A with C and G with T?
 - only with A & T and with C & G are there opportunities to establish **hydrogen bonds** between them (2 between A & T; 3 between C & G).



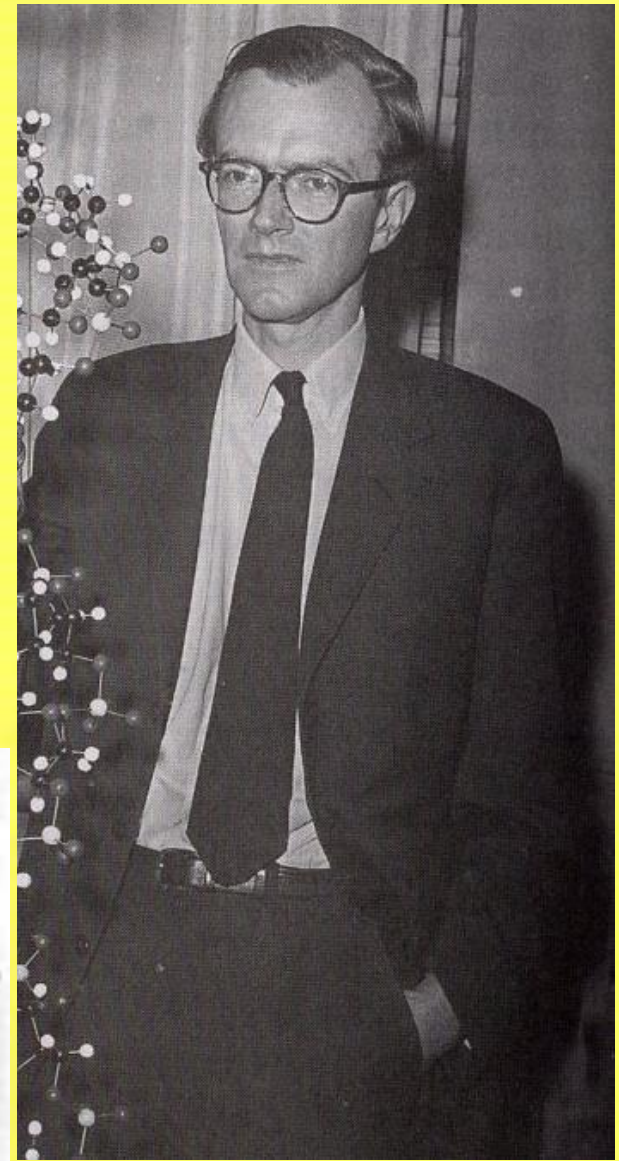
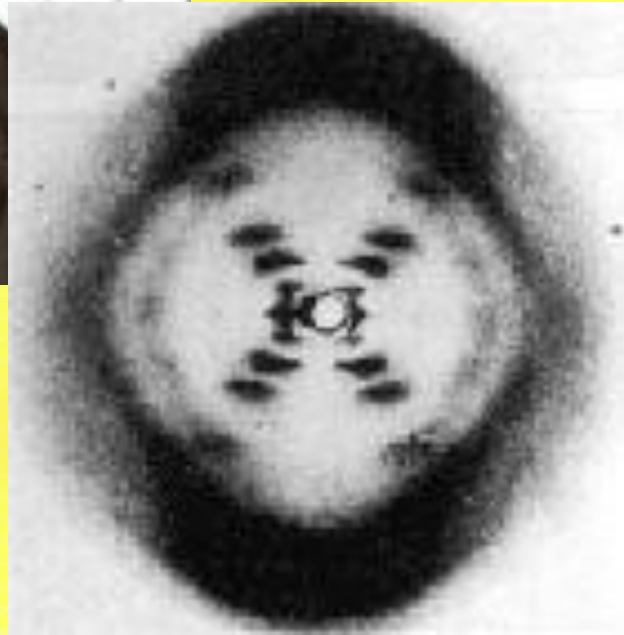


Which answer will base pair with the following sequence?

AGTTCTCATGT

1. AGTTCTCATGT
2. ACATGAGAACT
3. TCAAGAGTACA
4. UCAAGAGUACA

X-Ray Crystallography



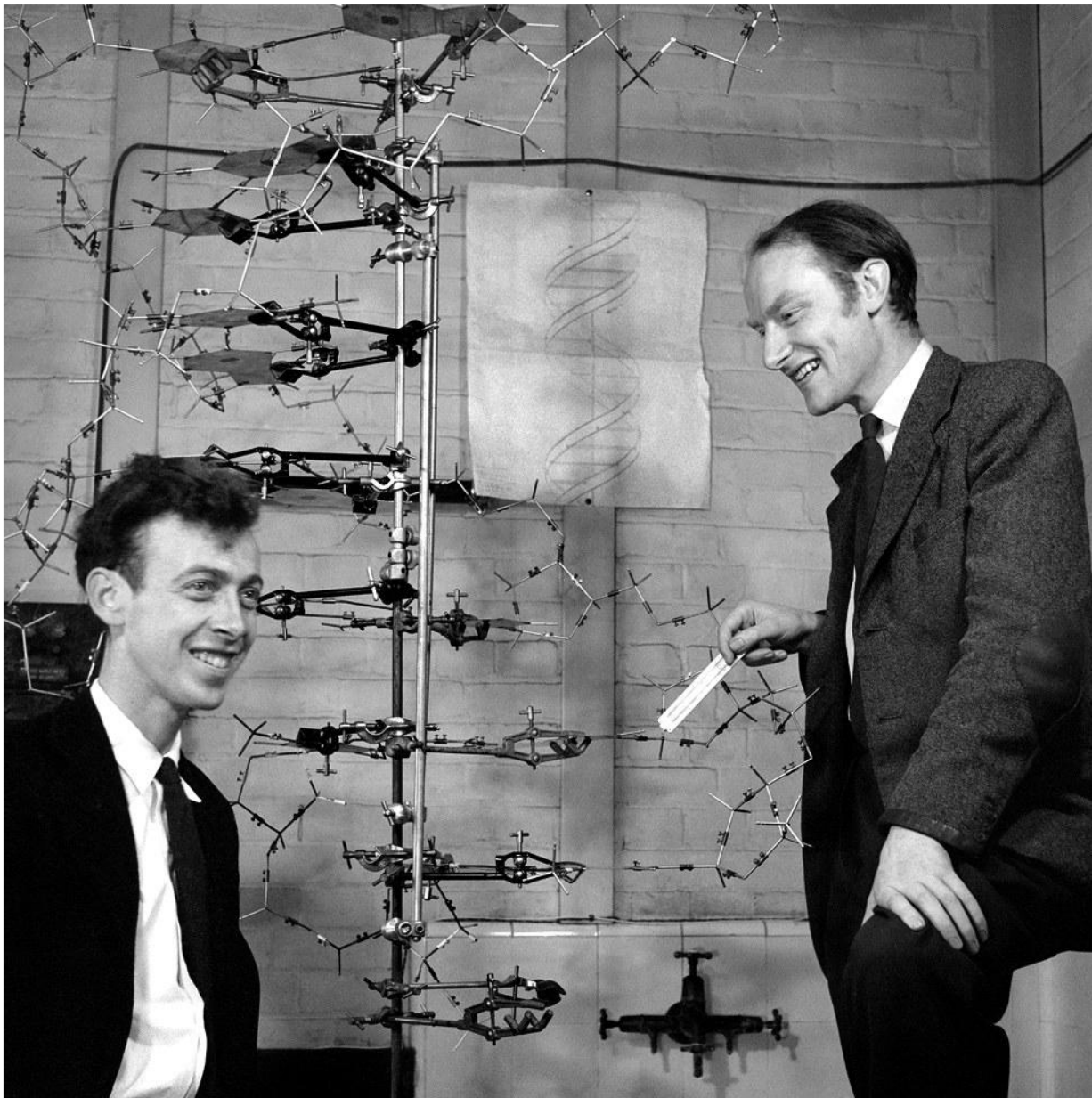


Figure 5-3a

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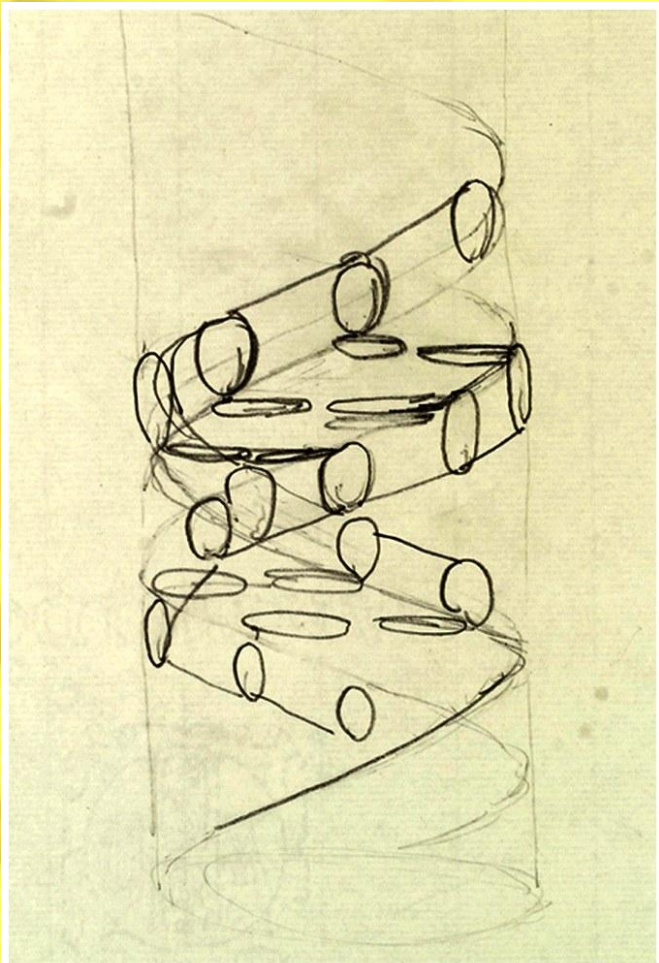
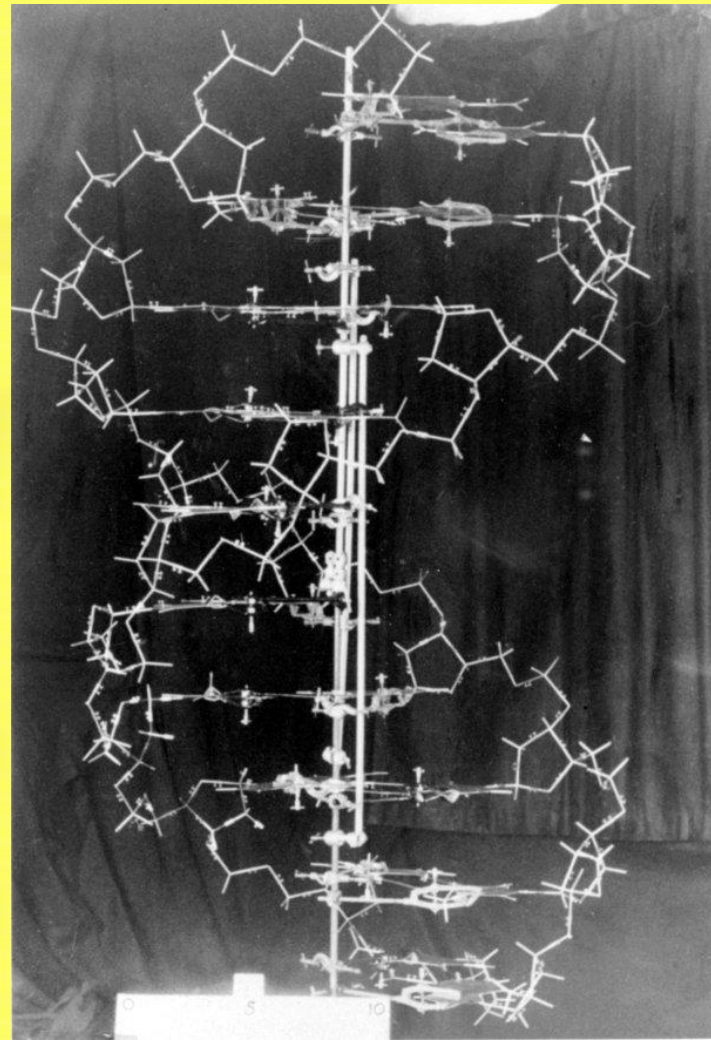


Figure 5-3b
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DNA "Double Helix"

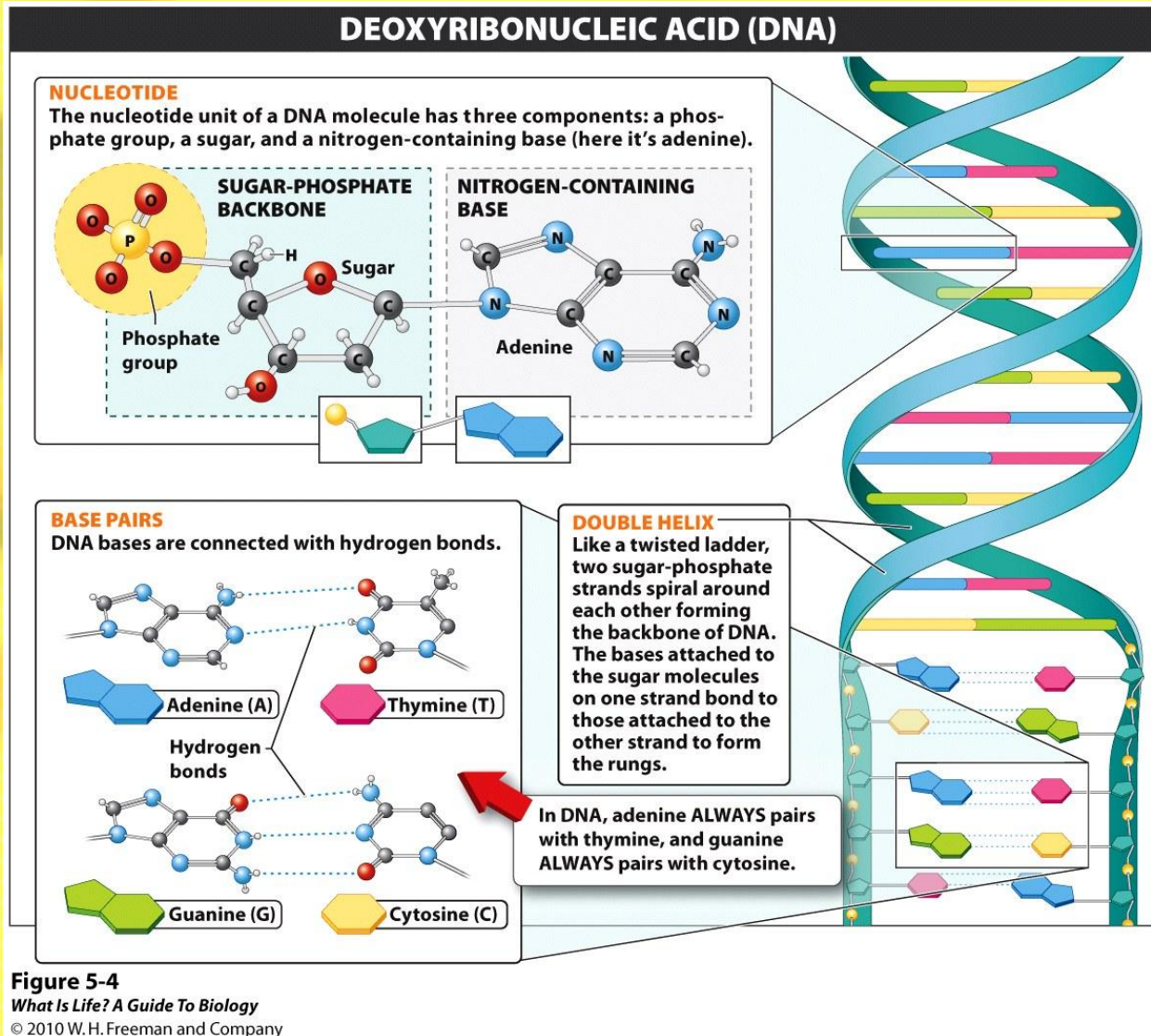



Figure 5-4
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DNA replication is a biological process that occurs in all living organisms and copies their DNA; it is the basis for biological inheritance.

DNA Replication

- ❑ Double-stranded DNA molecule produces two identical copies of the molecule
- ❑ Semiconservative replication: each strand of the original double-stranded DNA molecule serves as template for the production of the complementary strand.
- ❑ Cellular proofreading and error-checking mechanisms ensure near perfect fidelity for DNA replication.

Key Enzymes

□ DNA Helicase

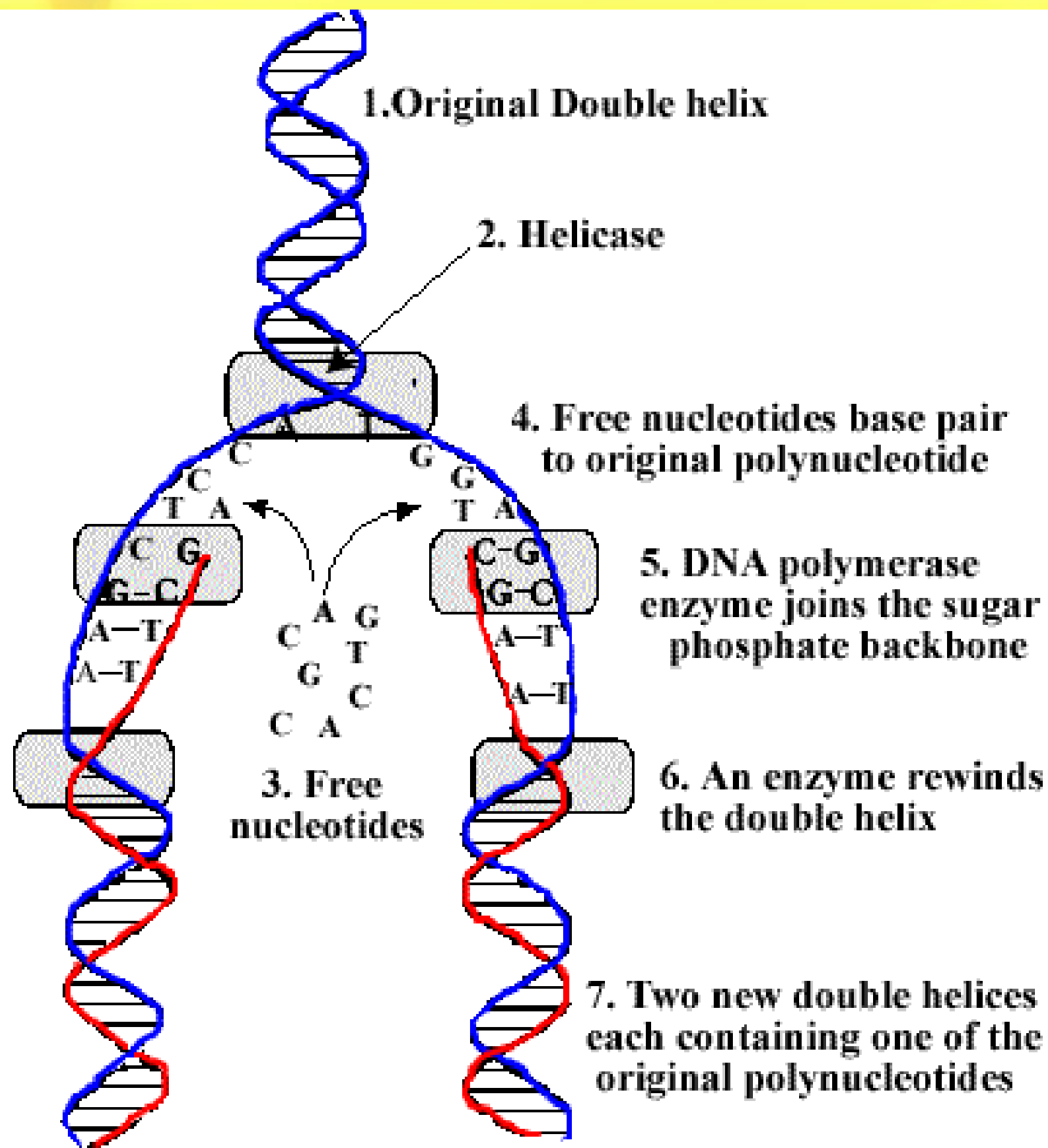
- Unwinds the DNA double helix

□ DNA Polymerase

- Builds a new duplex DNA strand by adding nucleotides.
- Also performs proof-reading and error correction.

Let's look at the details:

- ❑ Helicase unwinds the double-stranded DNA
- ❑ DNA polymerase "walks" down the DNA strands and adds new nucleotides to each strand.
- ❑ The nucleotides pair with the complementary nucleotides on the existing strand (A with T, G with C).
- ❑ A subunit of the DNA polymerase proofreads the new DNA
- ❑ DNA ligase seals up the fragments into one long continuous strand
- ❑ The new copies automatically wind up again





Genes are sections of DNA that contain instructions for making proteins.

Why is DNA considered the universal code for all life on earth?



DNA provides the instructions for building virtually every organism on earth!

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FROM GENOME TO GENE

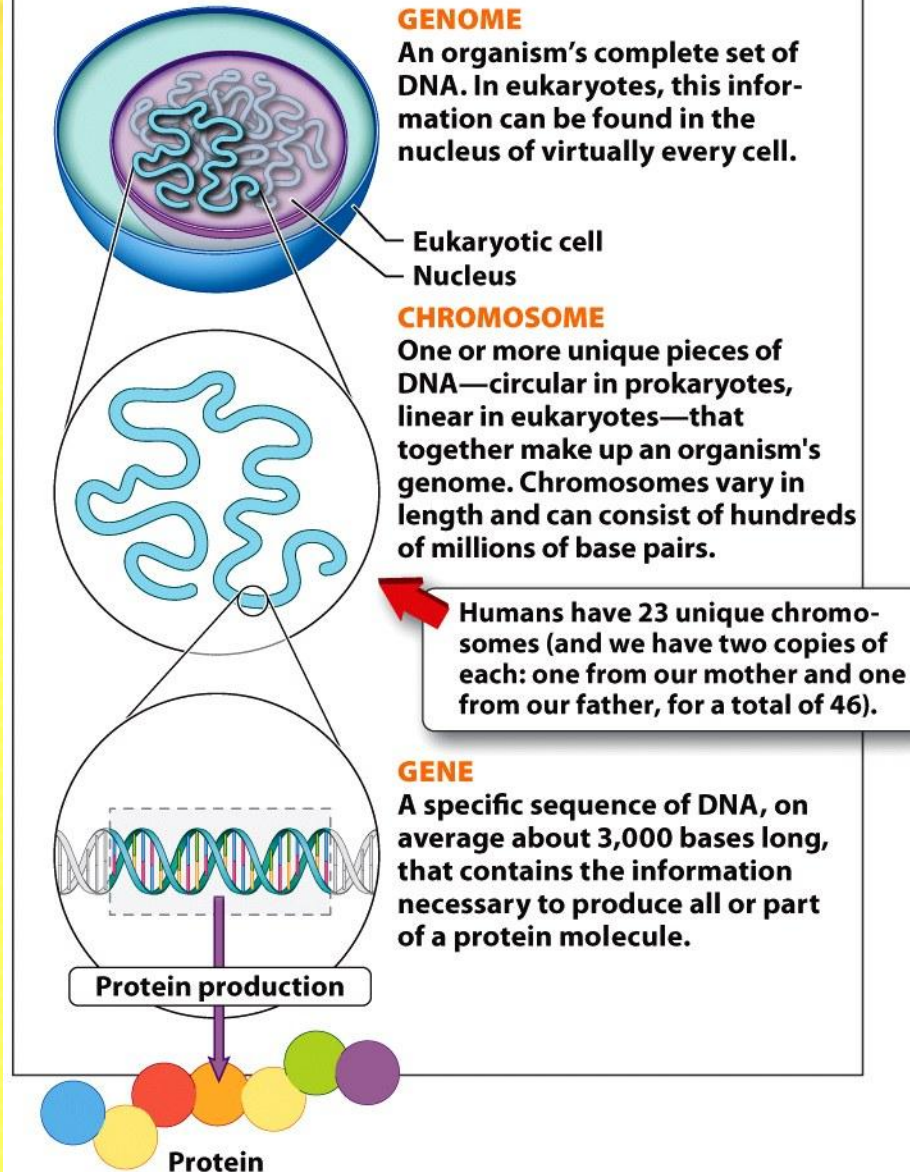


Figure 5-6

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Genes

- ❑ Sequence of bases in a DNA molecule
 - Carries information necessary for producing a functional product, usually a protein molecule or RNA
 - Average gene is 3000 bases long

ALLELES

Within a species, individuals sometimes have alternate versions of a gene for a given protein. These instructions can result in a different version of the same trait.

ALLELE

Alternate versions of a gene that code for the same trait

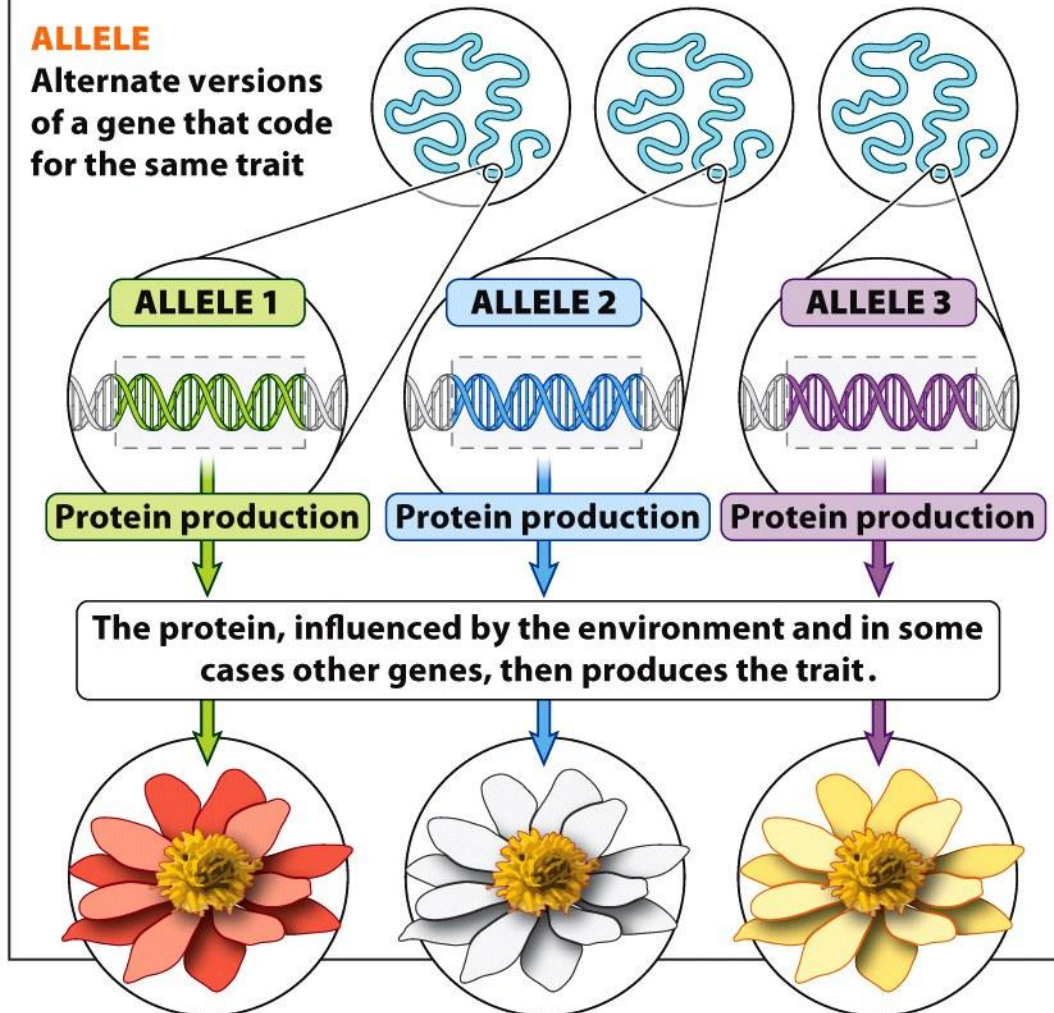


Figure 5-7

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Genes

- ❑ Instruction set for producing one particular molecule, usually a protein
- ❑ Examples
 - fibroin, the chief component of silk
 - triacylglyceride lipase (enzyme that breaks down dietary fat)

Genes

- ❑ Within a species, individuals sometimes have slightly different instruction sets for a given protein and these instructions can result in a different version of the same trait.
- ❑ These alternate versions of a gene that codes for the same character are called alleles.
- ❑ Any single feature of an organism is referred to as a trait.

Different people can have free or attached earlobes. The DNA that encodes for making free or attached earlobes is called a(n) _____, and there are two different versions of it, called _____.

1. allele; genes
2. trait; alleles
3. gene; trait
4. gene; alleles

Not all DNA contains instructions for making proteins.

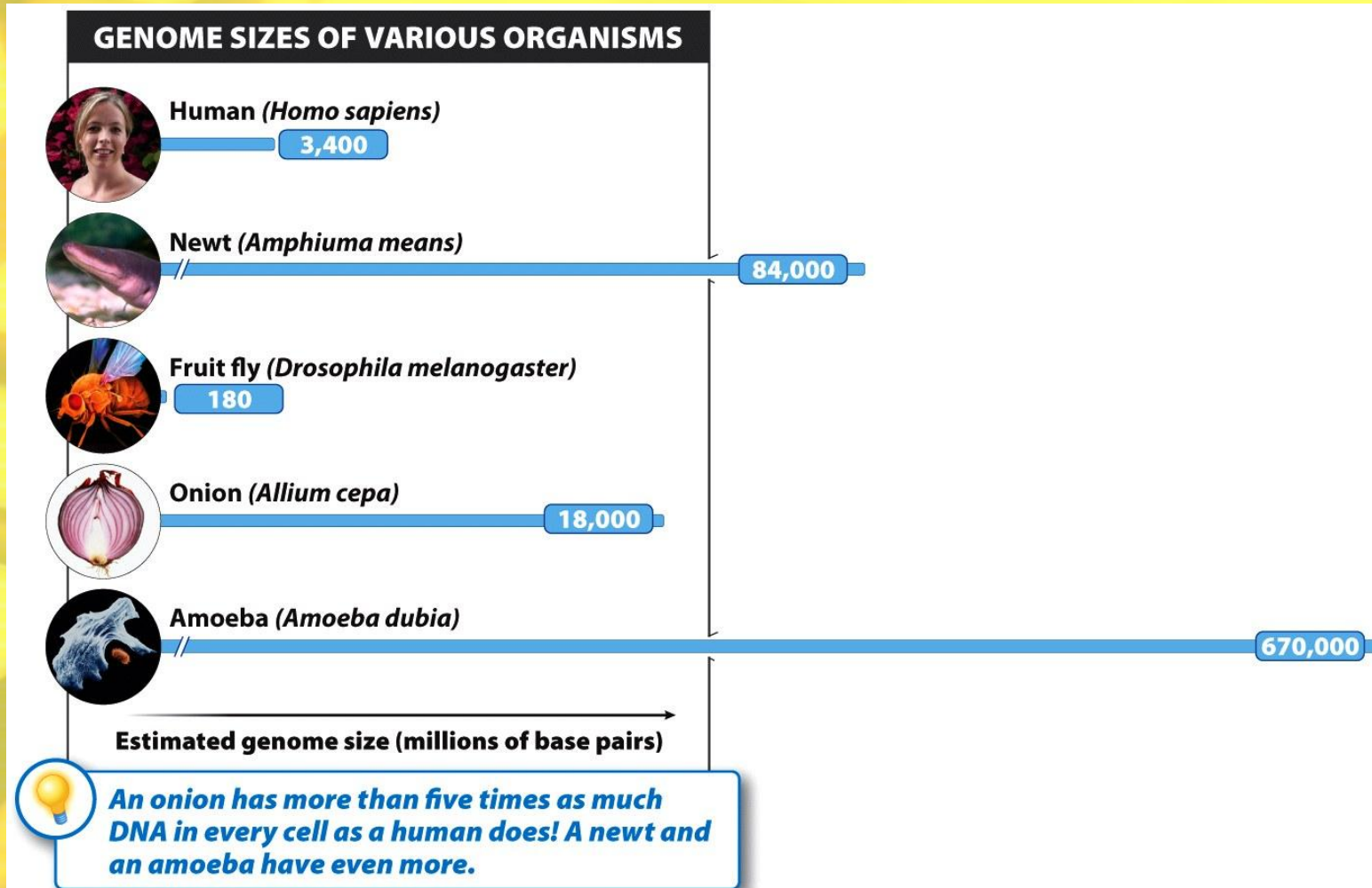


Figure 5-8

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Not all DNA contains instructions for making proteins.

- Comparing the amount of DNA present in various species reveals a paradox:
 - There does not appear to be any relationship between the size of an organism's genome and the organism's complexity
 - Complexity can be assessed in a variety of ways, such as by counting the number of different cell types in the organism

The Proportion of the DNA That Codes for Genes

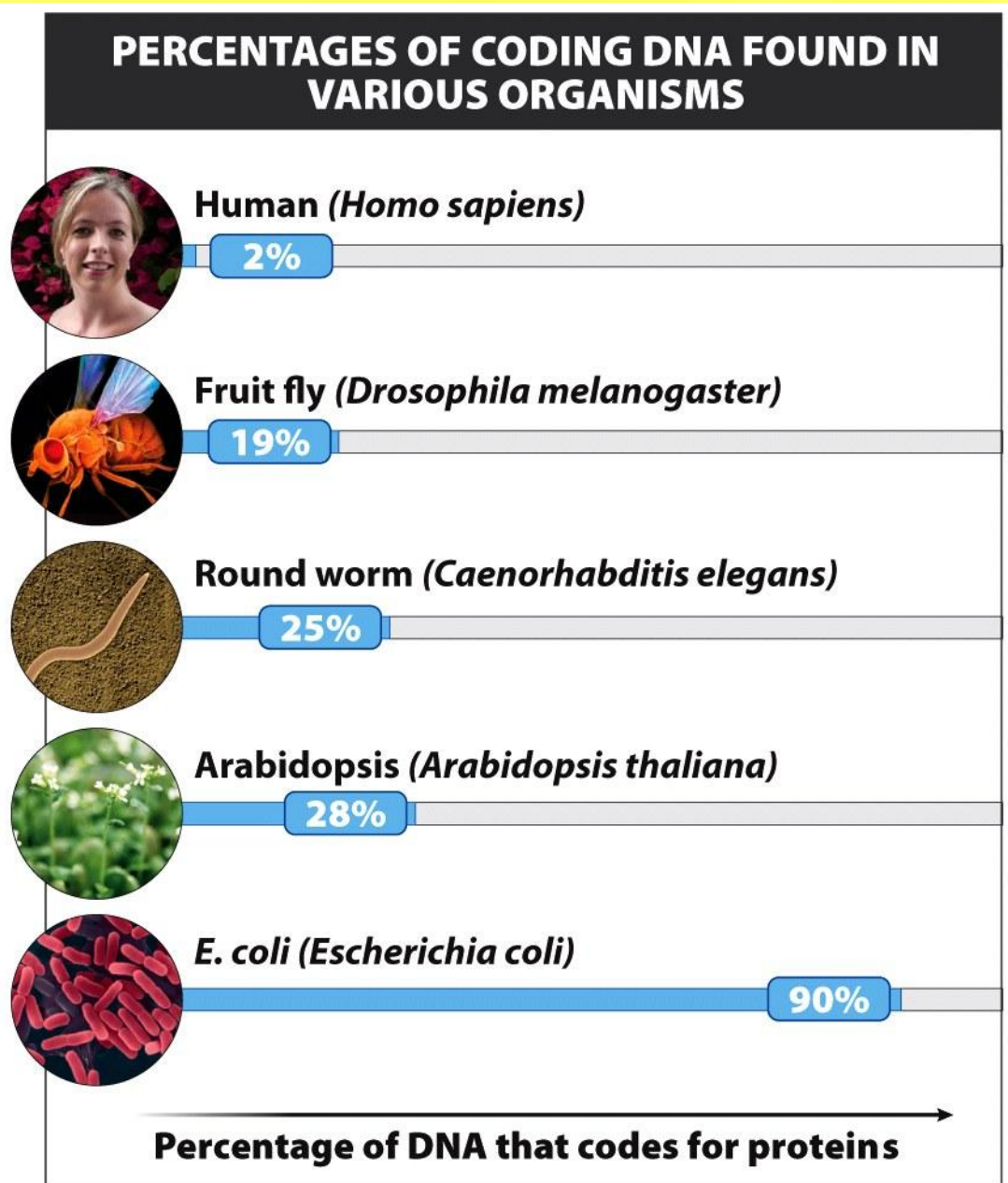


Figure 5-9

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CODING vs. NON-CODING DNA

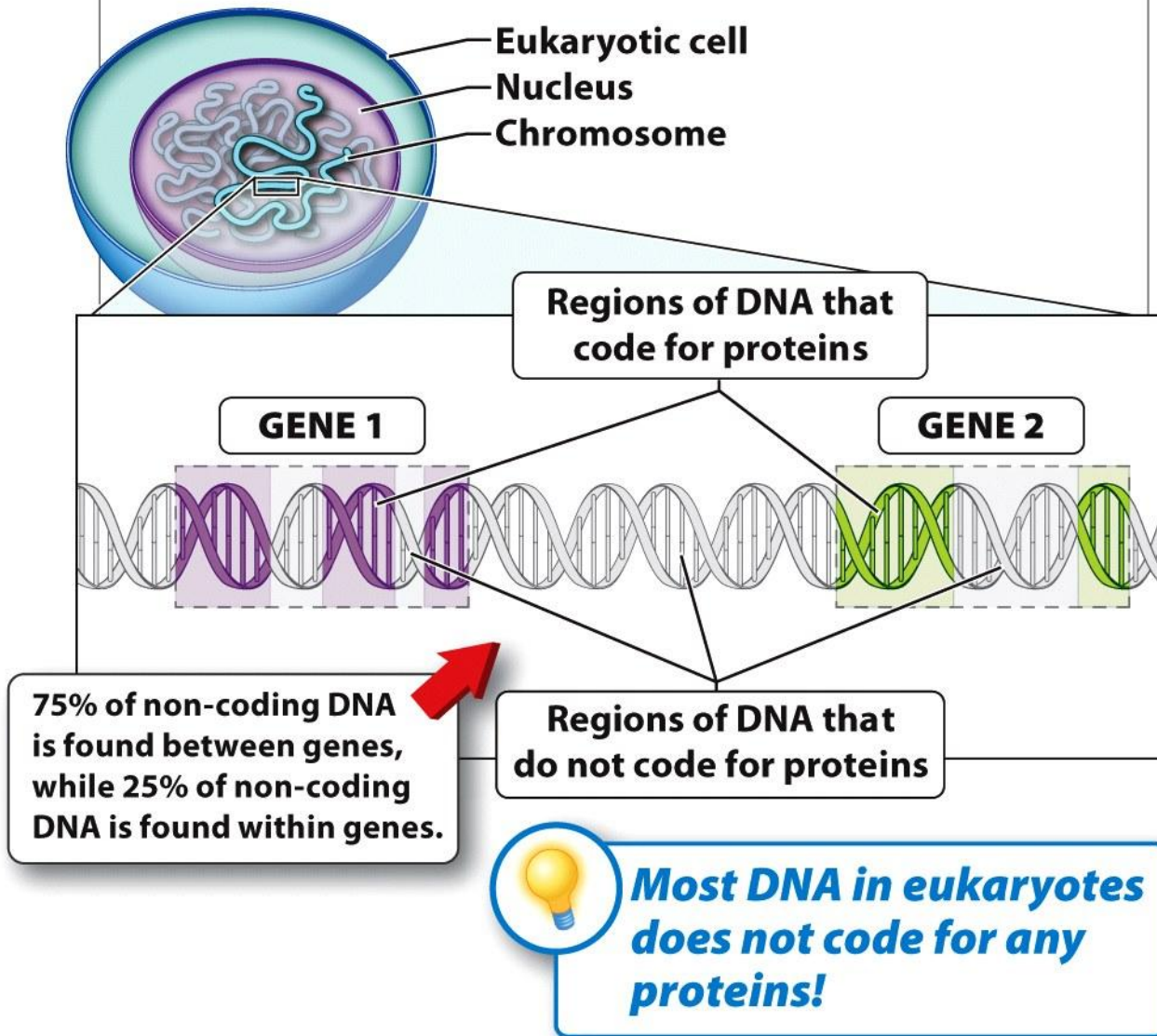


Figure 5-10

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Introns & Exons

- ❑ Introns: non-coding regions of DNA
 - may take the form of short (or long) sequences that are repeated thousands of times
 - may also consist of gene fragments, duplicate versions of genes, and pseudogenes
- ❑ Exons: protein-coding region in the DNA.
 - nucleic acid sequence in DNA OR
 - RNA transcript following genetic splicing

How do genes work?

- ❑ Every cell contains all of the information needed to manufacture every protein in the body but having the instructions is not the same as having the products
- ❑ Example: skin cells on your arm contain genes for producing liver cells, RBCS, muscle tissue—but they don't

HOW GENES WORK: AN OVERVIEW

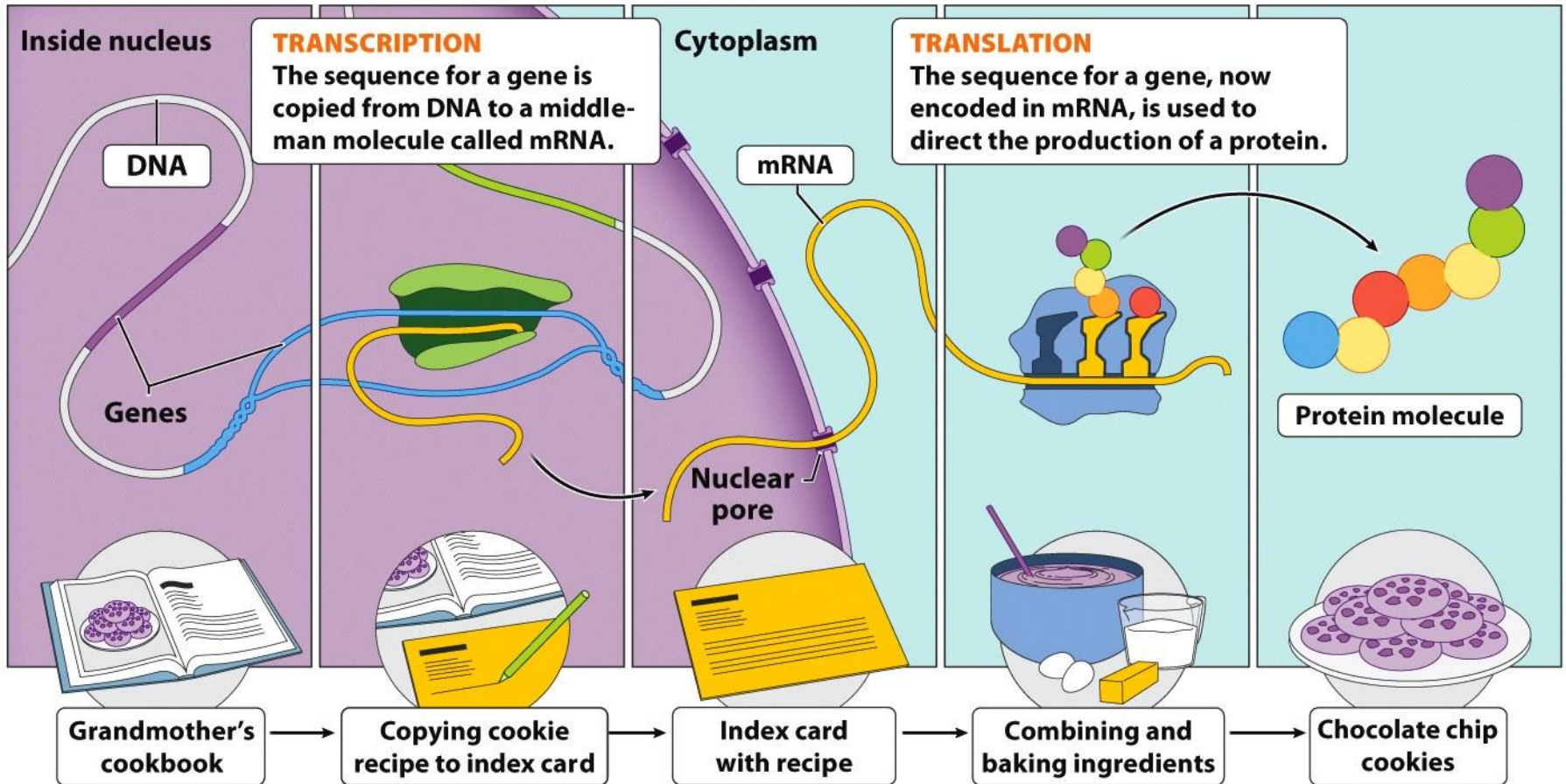


Figure 5-11
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Which molecule acts as a “middle man” between the nucleus, where transcription occurs, and the cytoplasm, where translation occurs?

1. DNA
2. mRNA
3. Protein
4. Choices 1 and 3 are correct.

Transcription

- A single copy of one specific gene within the DNA is made.
 - Recognize & bind
 - Transcribe
 - Termination
 - Capping & editing

Step 1 – Recognize, Bind, and Unwind

- ❑ RNA polymerase (enzyme) recognizes a promoter site, a part of the DNA molecule that indicates the start of a gene
- ❑ At the promoter site, the molecule binds to one strand of the DNA and, like a court reporter transcribing everything that is said in a courtroom, begins to read the gene's message
- ❑ At the point where the RNA polymerase binds to the promoter, the DNA molecule unwinds just a bit, so that only one strand of the DNA can be read

Step 2 – Transcribe

- ❑ As the DNA strand is processed through the RNA polymerase, the RNA polymerase builds a copy—called a “transcript”—of the gene from the DNA molecule.
- ❑ This copy is called messenger RNA (mRNA) because once the copy of the gene is created, it can move elsewhere in the cell and its message can be translated into a protein.

mRNA

- constructed from four different ribonucleotides, each of which pairs up with an exposed base on the now unwound and separated DNA:
 - If the DNA strand has a Thymine (T), an Adenine (A) is added to the mRNA.
 - If the DNA strand has a Adenine (A), a Uracil (U) is added to the mRNA.
 - If the DNA strand has a Guanine (G), a Cytosine (C) is added to the mRNA.
 - If the DNA strand has a Cytosine (C), a Guanine (G) is added to the mRNA.

mRNA

- ❑ Because the mRNA transcribes a specific sequence of DNA letters (the gene), the transcript carries the DNA's information.
- ❑ And because it is separate from the DNA, the mRNA transcript can move throughout the cell, to the places where the information is needed, while leaving the original information within the DNA.

Step 3 – Re-wind

- As the RNA polymerase moves down the unwound strand of DNA, the DNA that has already been transcribed twists back into its original double-helix form.

Step 4 – Terminate

- ❑ When the RNA polymerase encounters a sequence of bases on the DNA at the end of the gene (called a termination sequence), the court reporter molecule stops creating the transcript and detaches from the DNA molecule.
- ❑ At that point, the mRNA molecule is released as a free-floating single-strand copy of the gene

Step 4 – Terminate

- Prokaryotes: once the mRNA transcript separates from the DNA it is ready to be translated into a protein

Step 4 – Terminate

- ❑ Eukaryotes: transcript must first be edited
 - a) cap and tail may be added at the beginning and end of the transcript
 - b) protects the mRNA from damage and help the protein-making machinery recognize the mRNA
 - c) Introns are snipped out

- ❑ Once the mRNA transcript has been edited, it is ready to leave the nucleus for the cytoplasm where it will be translated into a protein

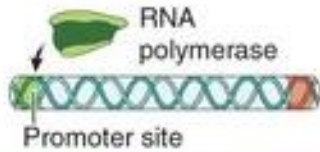
TRANSCRIPTION

DNA

1

RECOGNIZE and BIND

Once RNA polymerase recognizes a promoter site, it binds to one strand of the DNA and begins reading the gene's message.



2

TRANSCRIBE

As the DNA strand is processed through the RNA polymerase, the RNA polymerase builds a single-strand copy of the gene, called the mRNA transcript.

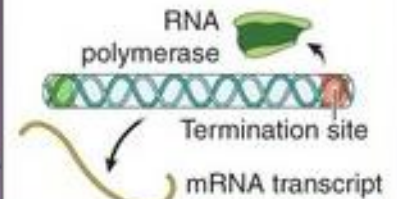
RNA polymerase

mRNA transcript

3

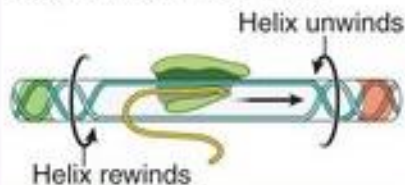
TERMINATE

When the RNA polymerase encounters a code signaling the end of the gene, it stops transcription and releases the mRNA transcript.



UNWIND and REWIND

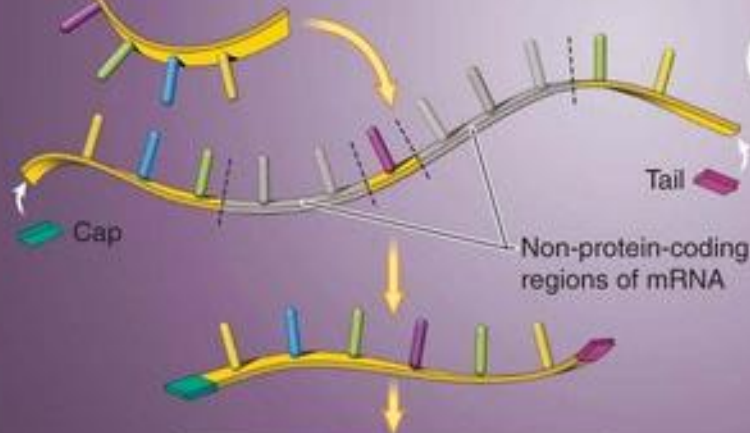
As the RNA polymerase moves down the strand of DNA, the helix unwinds so that the DNA can be read. At the same time, the DNA that has already been transcribed rewinds back to its original double-helix form.



4

CAPPING and EDITING

Before the mRNA transcript can be translated into a protein, a cap and tail are often added for protection and to promote recognition, and non-coding sections are removed.



mRNA transcript leaves nucleus to be translated into a protein.

Translation

- ❑ Once the mRNA molecule moves out of the cell's nucleus and into the cytoplasm, the translation process begins.
- ❑ In translation, the information carried by the nucleotide sequence of the mRNA is read and ingredients present in the cell's cytoplasm are used to produce a protein.

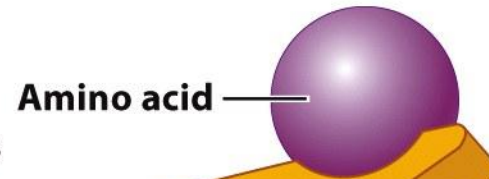


Several ingredients must be present in the cytoplasm for translation to occur.

- ❑ Free amino acids
- ❑ Ribosomal units
- ❑ Transfer RNA

TRANSFER RNA (tRNA)

Transfer RNA (tRNA) molecules translate the mRNA code, linking specific bases on the mRNA with specific amino acids that will be used to build a protein.



tRNA

Attachment site

Attachment sites consist of a three-base sequence that matches up with a three-base sequence on the mRNA transcript. Each three-base sequence in mRNA—called a codon—always matches with a tRNA that carries one particular amino acid.

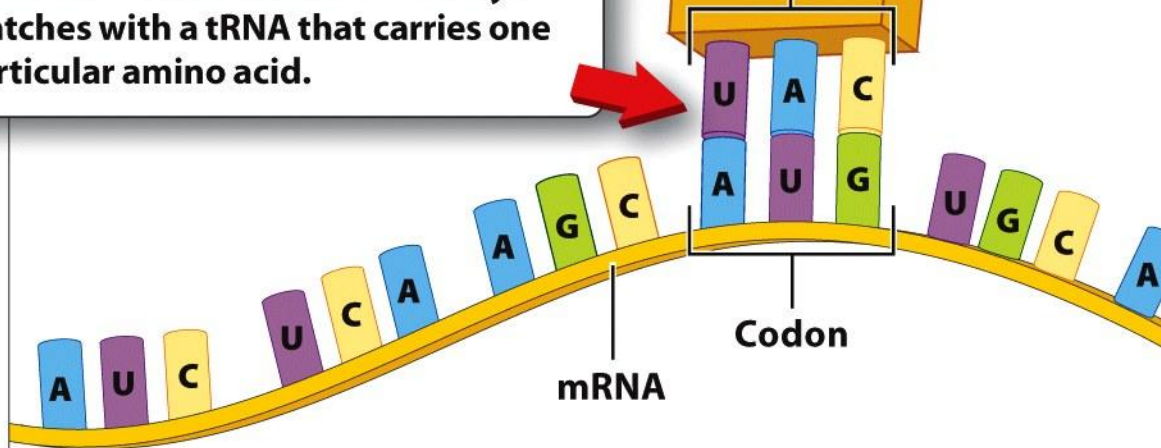


Figure 5-13

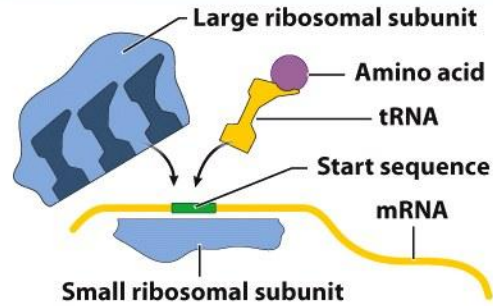
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TRANSLATION

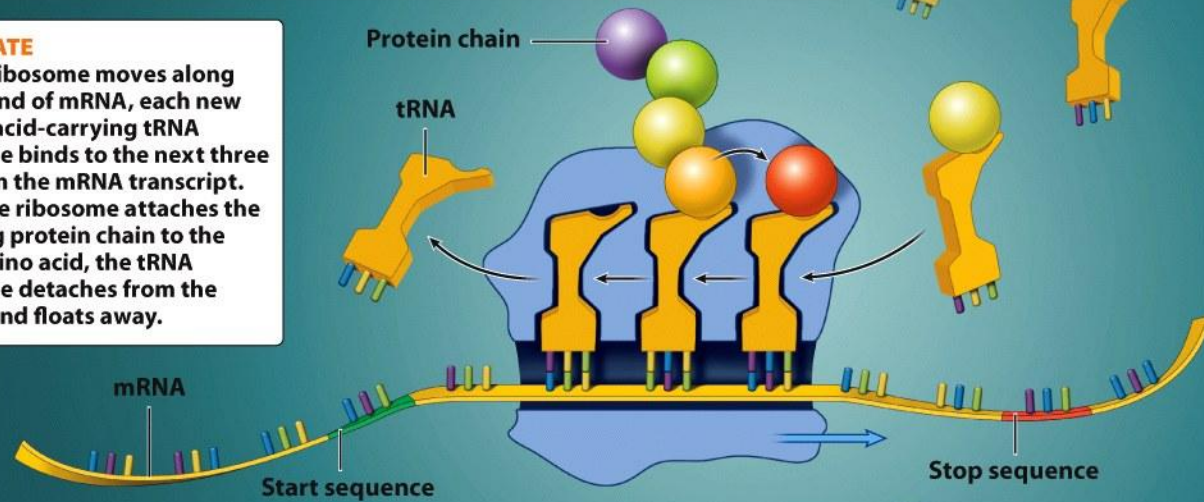
1 RECOGNIZE and INITIATE PROTEIN BUILDING

The “start sequence” of the mRNA transcript—signified by the bases A, U, and G—is recognized by a corresponding tRNA molecule and the two ribosomal subunits. The attachment site of the tRNA molecule binds to the mRNA as the ribosomal subunits assemble around them.



2 ELONGATE

As the ribosome moves along the strand of mRNA, each new amino-acid-carrying tRNA molecule binds to the next three bases on the mRNA transcript. After the ribosome attaches the growing protein chain to the new amino acid, the tRNA molecule detaches from the mRNA and floats away.



The same mRNA molecule can be translated over and over again before it is degraded, producing dozens or even hundreds of molecules of the protein.

3 TERMINATE

Once the ribosome encounters the three-base “stop sequence,” protein assembly is complete. Translation ends and both the protein and the mRNA molecule are released from the ribosome.

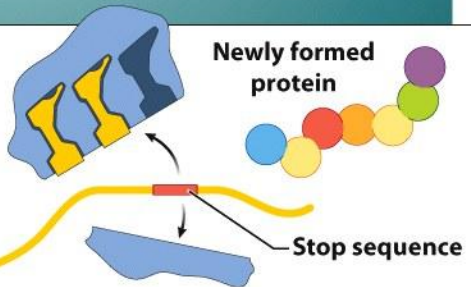


Figure 5-14 part 2

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Translation

- ❑ Step 1 – Recognize and Initiate Protein-Building
- ❑ Translation begins in the cell's cytoplasm when a ribosome, essentially a two-piece protein-building factory, recognizes and assembles around a “start sequence” – AUG – on the mRNA transcript.

Translation

- ❑ As the ribosomal subunits assemble themselves into a ribosome, one side of a tRNA molecule (anticodon) also recognizes the start sequence (codon) and binds to the mRNA at that point.
- ❑ That initiator tRNA has the amino acid methionine bound to its other side. This will be the first amino acid in the protein that is to be.

Translation

□ Step 2 – Elongate

- After the mRNA start sequence, the next (codon) three bases on the mRNA specify which amino-acid-carrying tRNA molecule should bind to the mRNA next.
- Example – If the next three bases on the mRNA transcript are GUU, a tRNA molecule that recognizes that sequence will attach to the mRNA at that point. The GUU-recognizing tRNA molecule always has the amino acid valine attached.

Translation

- ❑ The process continues in the same manner.
- ❑ This is the beginning of protein synthesis because all proteins are chains of amino acids, like beads on a string.

Translation

- ❑ The mRNA continues to be “threaded” through the ribosome, with the ribosome moving down the mRNA strand reading and translating its message in little three-base chunks.
- ❑ Each three-base sequence specifies the next amino acid, lengthening the growing amino acid strand.
- ❑ After the amino acid carried by a tRNA molecule is attached to the growing protein, the tRNA molecule detaches from the mRNA and floats away.

Translation

□ Step 3 – Terminate

- Eventually, the ribosome arrives at the three-base sequence on the mRNA that signals the end of translation.
- Once the ribosome encounters this sequence, the assembly of the protein is complete.
- Translation ends and the amino acid strand and mRNA molecule are released from the ribosome.

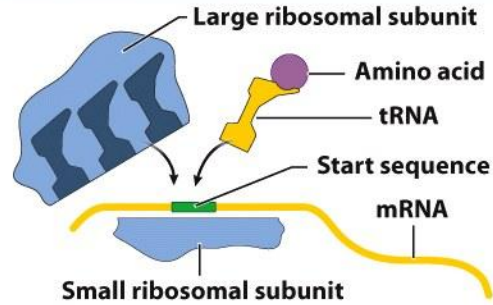
Translation

- ❑ When it is complete, the protein—such as insulin or a digestive enzyme—may be used within the cell or packaged for delivery via the bloodstream to somewhere else in the body where it is needed.
- ❑ In bacteria an mRNA strand may last from a few seconds to more than an hour; in mammals, mRNA may last several days.
- ❑ Depending on how long it lasts, the same mRNA strand may be translated hundreds of times.
- ❑ Eventually, it is broken down by enzymes in the cytoplasm.

TRANSLATION

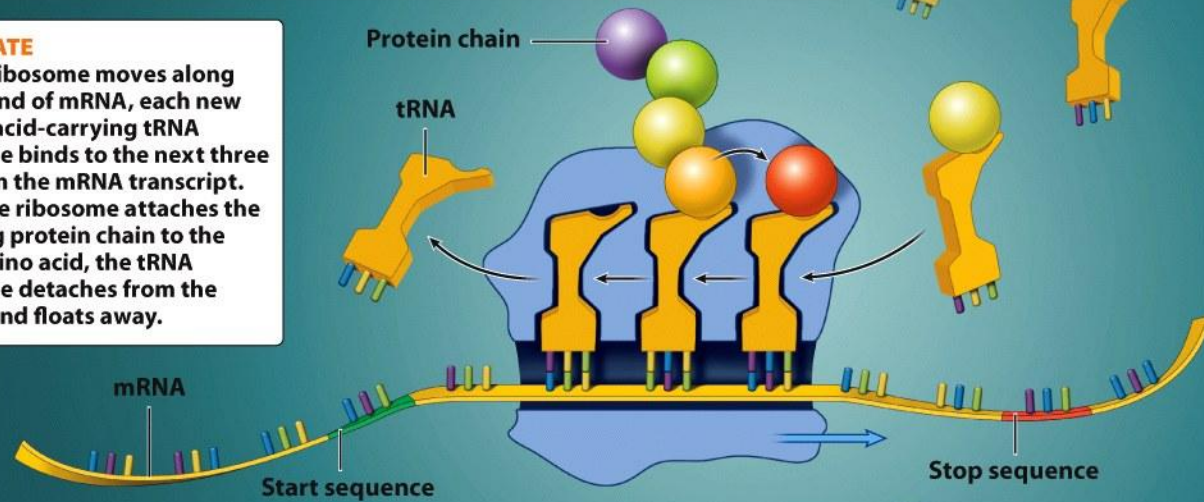
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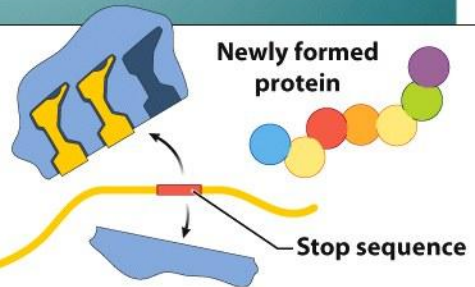


Figure 5-14 part 2

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Translation

- ❑ Protein Synthesis
- ❑ Protein Synthesis



Causes and effects of mutation

- Alteration of the sequence of bases in DNA
 - can lead to changes in the structure and function of the proteins produced
 - can have a range of effects

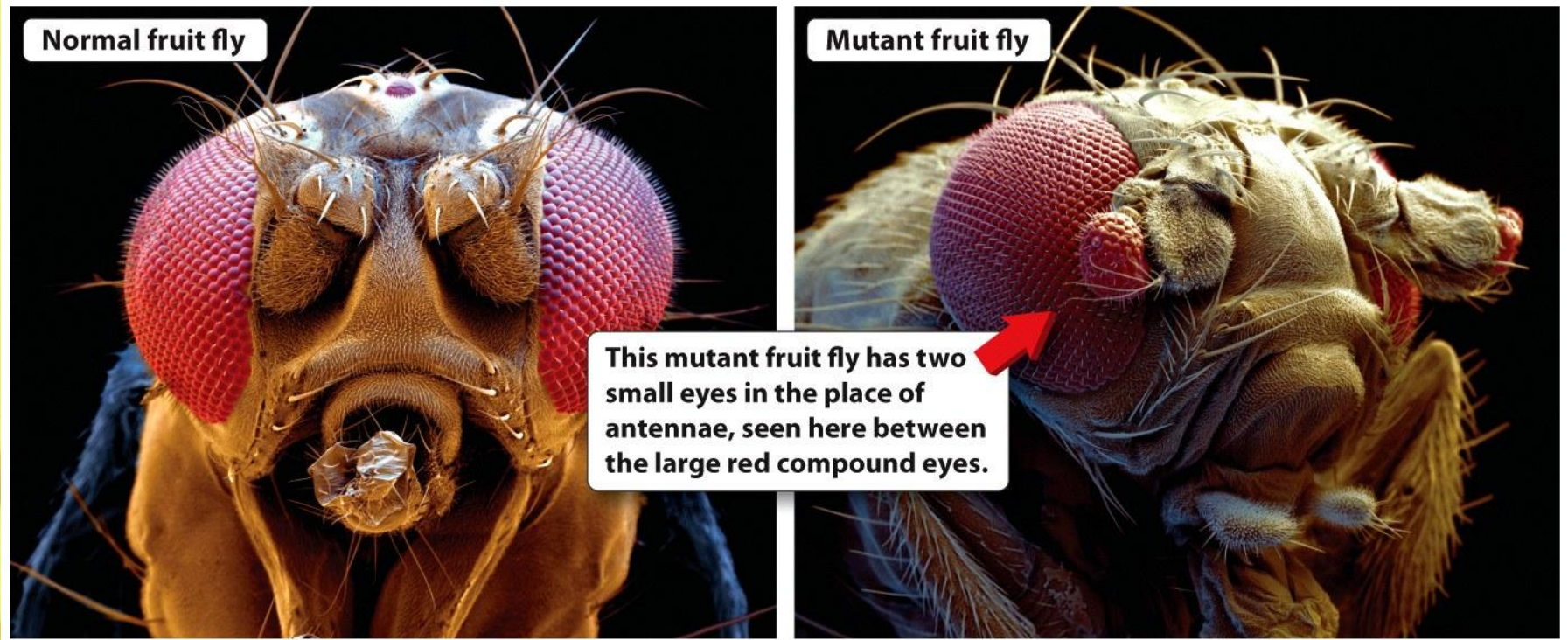


Figure 5-15
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- Mutations can have a range of effects
 - serious, even deadly, problem
 - little or no detrimental effect.
 - beneficial to the organism

Mutations

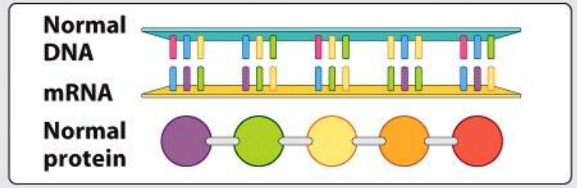
- ❑ Bad reputation
- ❑ Tend to be disruptive
- ❑ Very, very rare

Mutations

- 2 types

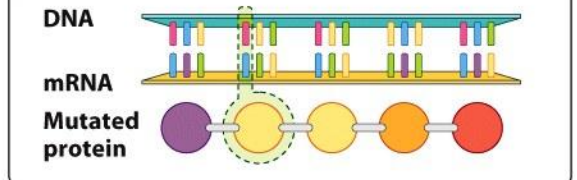
- point mutations - one base pair is changed
- chromosomal - entire sections of a chromosome are altered

TYPES OF MUTATIONS

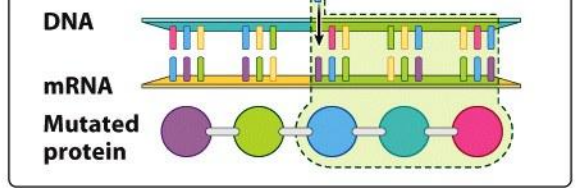


POINT MUTATIONS

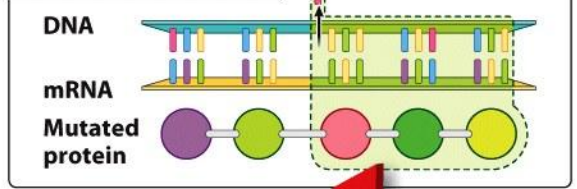
BASE-PAIR SUBSTITUTION



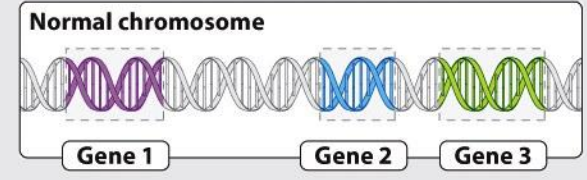
BASE-PAIR INSERTION



BASE-PAIR DELETION

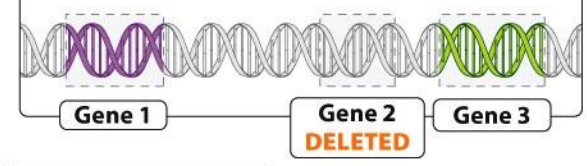


Insertions and deletions can be much more harmful than substitutions because they can alter the reading frame for the rest of the gene.

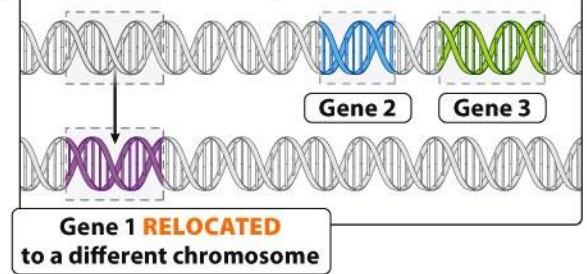


CHROMOSOMAL ABERRATIONS

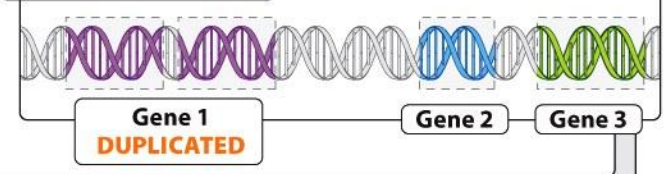
GENE DELETION



GENE RELOCATION



GENE DUPLICATION



In point mutations, one base pair is changed, whereas in chromosomal aberrations, entire sections of a chromosome are altered.

Figure 5-16
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Breast Cancer in Humans

- ❑ Two human genes, called BRCA1 and BRCA2
 - When functioning properly, help to prevent breast cancer by deterring cells from dividing uncontrollably
- ❑ More than 200 different changes in the DNA sequences of these genes have been detected, each of which results in an increased risk of developing breast cancer.



Spontaneous mutations

Some mutations arise by accident as long strands of DNA are duplicating themselves.

Most errors are repaired by DNA repair enzymes but some still slip by and there's not much we can do about them.



Chemical-induced mutations

Many chemicals, such as those found in cigarette smoke and in internal combustion engines, can also react with the atoms in DNA molecules and induce mutations.



Radiation-induced mutations

Ionizing radiation is radiation with enough energy that it can disrupt atomic structure—even breaking apart chromosomes. This is why long-term sun exposure can contribute to the development of skin cancer.

Which answer shows the mRNA transcribed from the DNA sequence below?

TTA TCC TTT ACT CAT

1. AUG AGU AAA GGA UAA
2. AAU-AGG-AAA-UGA-GUA
3. TTA-TCC-TTT-ACT-CAT
4. UUA-AGG-AAA-TGA-GUA

From mutation to illness in just four steps:

- (1) A mutated gene codes for a non-functioning protein, usually an enzyme.
- (2) The non-functioning enzyme can't catalyze the reaction as it normally would, bringing it to a halt.

From mutation to illness in just four steps:

- (3) The molecule with which the enzyme would have reacted accumulates, like a blocked assembly line.
- (4) The accumulating chemical causes sickness and/or death.

DNA as an individual identifier: the uses and abuses of DNA fingerprinting

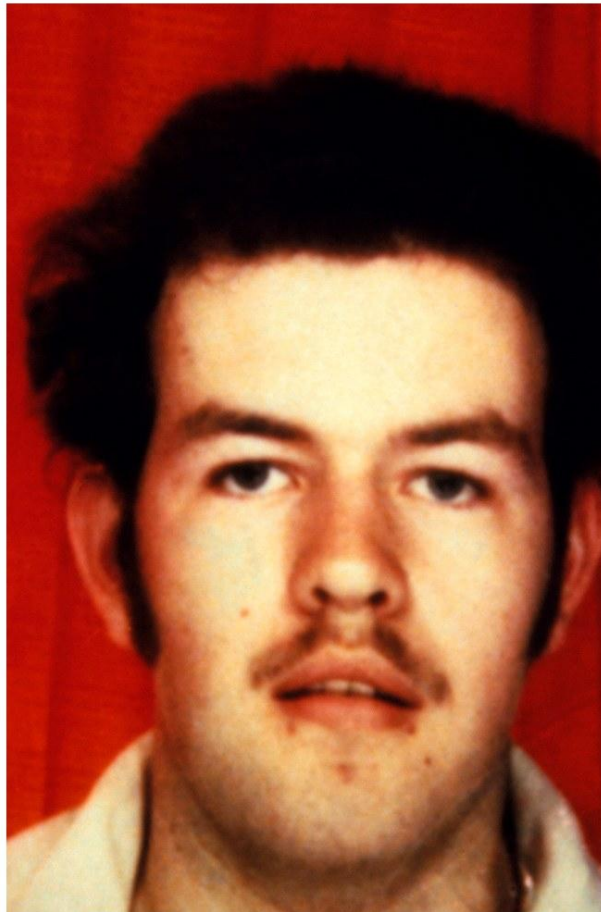


Figure 5-39a
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Figure 5-39b
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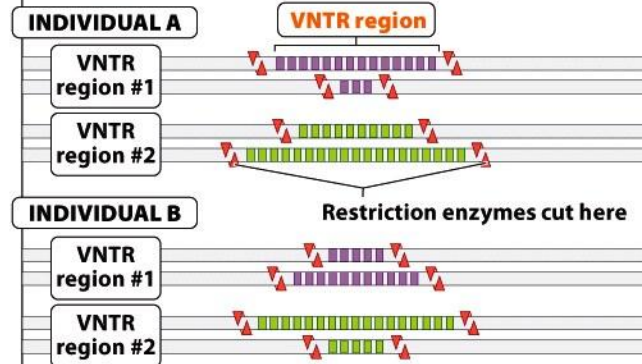


Figure 5-39c
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What is a DNA fingerprint?

CREATING A DNA FINGERPRINT GEL

1 Using restriction enzymes, DNA samples are cut on either side of the repeating sequences. Only two VNTR regions are shown here. Actual DNA fingerprints are created by sampling up to eight regions.



2 The isolated DNA sequences are then poured into a gel and an electrical charge is applied. Because DNA is a negatively charged molecule, the pieces of DNA move toward the bottom of the gel. This process causes the pieces of DNA to be separated by size. Smaller pieces—those with a small number of repeats—move more quickly than larger pieces and are found closer to the bottom.

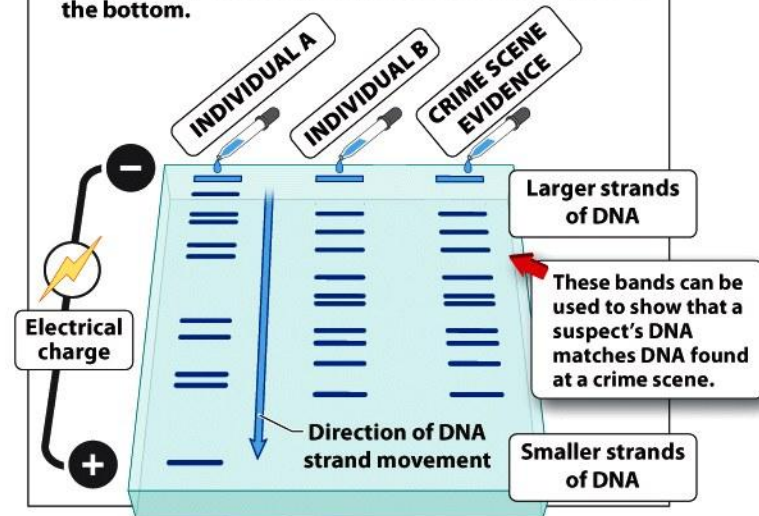


Figure 5-41

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Using the DNA fingerprint information below, determine which suspect was present at the crime scene?

1. Suspect #1
2. Suspect #2
3. Suspect #3
4. All of the above.

Crime Scene	Suspect #1	Suspect #2	Suspect #3
— —	— —	— —	— —
— —	— —	— —	— —
— —	— —	— —	— —