Big Idea 3: Living systems store, retrieve, transmit and respond to information essential to life processes.

Enduring understanding 3.A: Heritable information provides for continuity of life.

Essential knowledge 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.

a. Genetic information is transmitted from one generation to the next through DNA or RNA.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules.
2. Noneukaryotic organisms have circular chromosomes, while eukaryotic organisms have multiple linear chromosomes, although in biology there are exceptions to this rule.
3. Prokaryotes, viruses and eukaryotes can contain plasmids, which are small extra-chromosomal, double-stranded circular DNA molecules.
4. The proof that DNA is the carrier of genetic information involved a number of important historical experiments. These include:
    i. Contributions of Watson, Crick, Wilkins, and Franklin on the structure of DNA
    ii. Avery-MacLeod-McCarty experiments
    iii.Hershey-Chase experiment

What determines an organism's traits?

DNA → **Genes** → Proteins → Traits

OK, What exactly is a gene?

- (Basic Definition) A unit of inheritance that controls a phenotypic character.
- (Better Definition) A nucleotide sequence along a molecule of DNA that codes for a protein.
- **(Best Definition) A region of DNA that can be expressed to produce a final functional product that is either a polypeptide or an RNA molecule.**

DNA…"The Blueprints of Life"

DNA → **Genes** → Proteins → Traits

DNA is the molecule of inheritance!

- This idea was hotly contested through half of the 20th century.
- Finally in 1953 James Watson and Francis Crick not only confirmed that DNA was in fact the molecule of inheritance but they described its structure and hypothesized a replicating mechanism.
- **The story begins in the early 1900's...**

DNA…"The Story"

After the work of Darwin and Mendel the race was on to clarify the vague meaning of "units of heredity"…What exactly were the units of heredity?

- Two leading suspects were nucleic acids and proteins.
- Most thought proteins were more likely suspect.
  - with 20 subunits making up protein and only 4 subunits making up nucleic acids, protein diversity was enormous

DNA…"The Story"

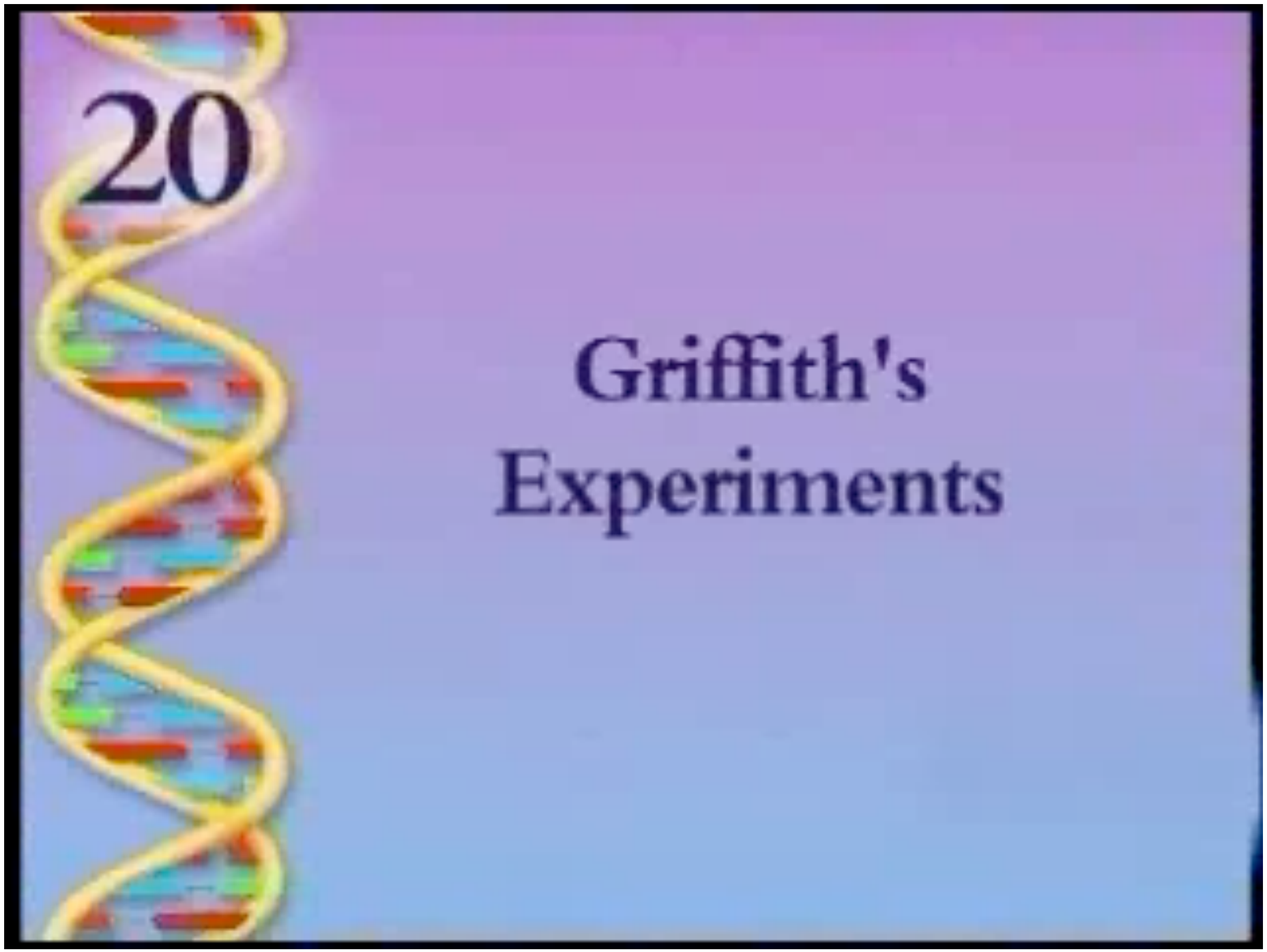
1928 Frederick Griffith

- While trying to develop a vaccine against *Streptoccocus pneumoniae,* he made a rather interesting observation.
- He later explained his observation by a term he coined...
  - ***Transformation*** a chemical component moved from one cell to another and changed the phenotype of the recipient cell.
  - Today we know that external DNA was taken up and assimilated by the bacteria whose phenotype was altered

Griffith's Experiment is described on the next slide

DNA…"The Story"

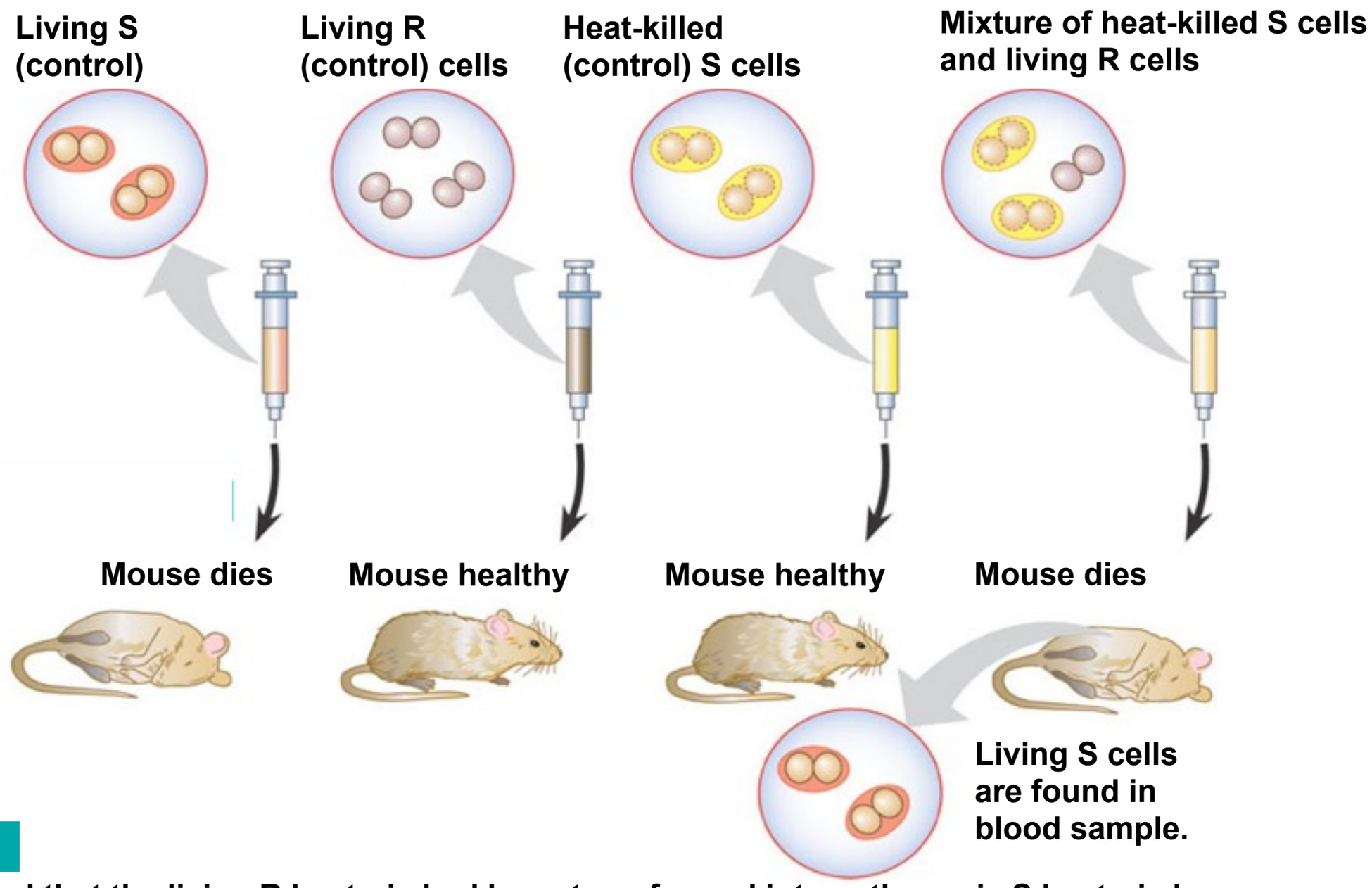
1928 Frederick Griffith



1928 Frederick Griffith

EXPERIMENT

Bacteria of the "S" (smooth) strain of *Streptococcus pneumoniae* are pathogenic because they have a capsule that protects them from an animal's defense system. Bacteria of the "R" (rough) strain lack a capsule and are nonpathogenic. Frederick Griffith injected mice with the two strains as shown below:



RESULTS

CONCLUSION

Griffith concluded that the living R bacteria had been transformed into pathogenic S bacteria by an unknown, heritable substance from the dead S cells.

DNA…"The Story"

1944 Avery, McCarty & Macleod

- For 14 years Oswald Avery tried to determine the identity of Griffith's "transforming" agent.
- Avery's work centered around purifying molecules from the heat killed bacteria
- Finally in 1944 he and his colleagues identified the agent... DNA!
  - Ironically the results generated interest but many were skeptical and felt that protein was a better suspect.
  - Also many felt even if this were true of bacteria surely "humans" would have a different molecule of inheritance.

DNA…"The Story"

1947-1950 Erwin Chargaff

- A biochemist, Chargaff was analyzing and comparing DNA from different species.
- From his work he two observations emerged which later became known as "Chargaff's Rules"
  - (ironically there was no basis for them at the time)
- **Rule 1: nucleic acid bases vary between species**
  - this was somewhat unexpected
- **Rule 2: within a species the number of A bases are equal to T bases and C bases are equal to G bases**

DNA…"The Story"

Early 20th Century Circumstantial Evidence

- Biologists had noted that the amount of DNA in a cell prior to cell division was "X", prior to mitosis the amount was "2X" and after cell division the amount of DNA returned to "X" amount.
  - It was a fact that biologists could not explain at the time, with their current understandings.
  - Obviously later with new perspectives this makes perfect sense

Makes you wonder… what knowledge today is floating around, going unnoticed, waiting to help us answer one of our many unanswered questions.

DNA…"The Story"

1952 Alfred Hershey & Martha Chase

- Hershey and Chase continued the search for the elusive "unit of heredity".
- Hershey and Chase designed simple, elegant and powerful experiment using bacteriophages and radioactive elements.
- Their experiment definitively showed that DNA was in fact the unit of heredity used by viruses
  - many began to contemplate the idea that DNA may be the unit of heredity for all living organisms
  - The tide was changing!

Hershey and Chase's Experiment is described on the next slide

1952 Alfred Hershey & Martha Chase

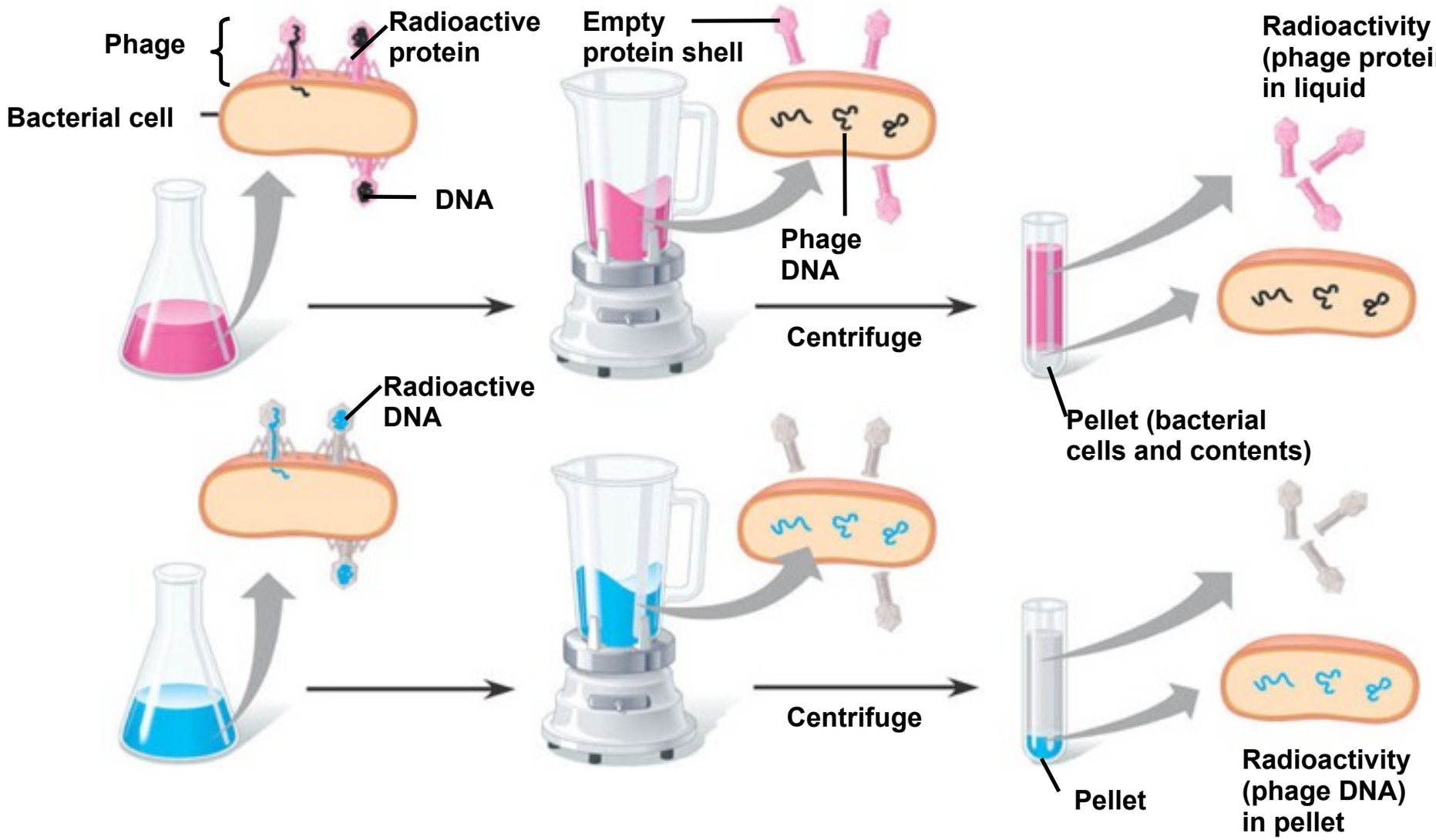
EXPERIMENT

In their famous 1952 experiment, Alfred Hershey and Martha Chase used radioactive sulfur and phosphorus to trace the fates of the protein and DNA, respectively, of T2 phages that infected bacterial cells.

1. Mixed radioactively labeled phages with bacteria. The phages infected the bacterial cells.
2. Agitated in a blender to separate phages outside the bacteria from the bacterial cells.
3. Centrifuged the mixture so that bacteria formed a pellet at the bottom of the test tube.
4. Measured the radioactivity in the pellet and the liquid

Batch 1: Phages were grown with radioactive sulfur (^{35}S), which was incorporated into phage protein (pink).

Batch 2: Phages were grown with radioactive phosphorus (^{32}P), which was incorporated into phage DNA (blue).



RESULTS

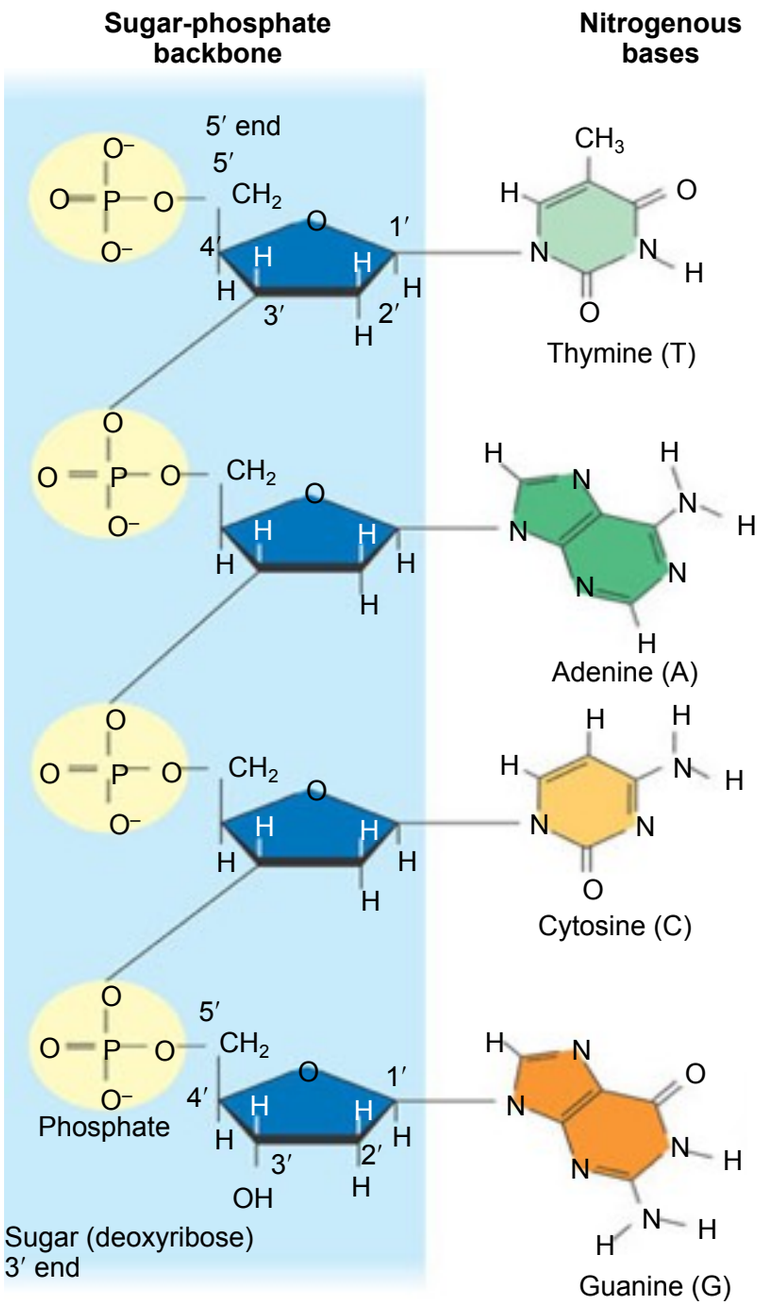
Phage proteins remained outside the bacterial cells during infection, while phage DNA entered the cells. When cultured, bacterial cells with radioactive phage DNA released new phages with some radioactive phosphorus.

CONCLUSION

Hershey and Chase concluded that DNA, not protein, functions as the T2 phage's genetic material.

DNA…"The Story"

1950's Rosalind Franklin, Linus Pauling, Maurice Wilkins



- By now many felt that DNA was the elusive "unit of heredity" and the next step would be to determine its structure.

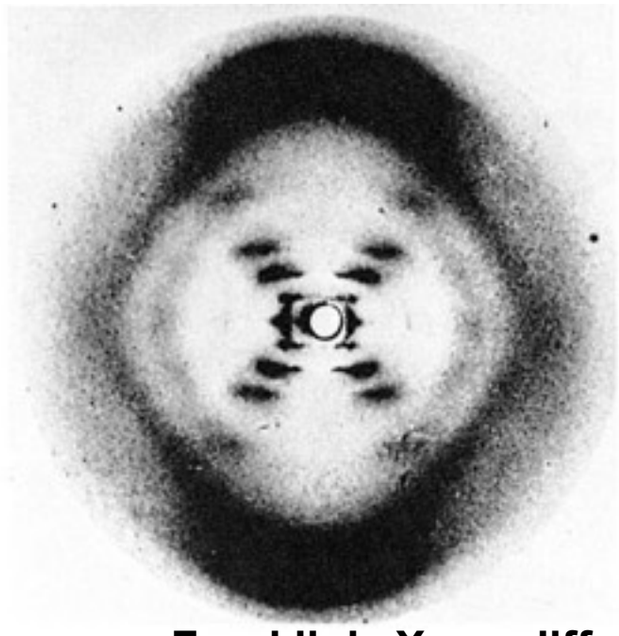
- Prior to the 1950's chemists already knew that DNA is a polymer of nucleotides, each consisting of three components: a nitrogenous base, a sugar, and a phosphate group.

DNA…"The Story"

1950's Rosalind Franklin, Linus Pauling, Maurice Wilkins

- Rosalind Franklin wrote that the sugar-phosphate groups made up the backbone on DNA.
- Wilkins and Franklin used X-ray crystallography to determine DNA's 3-D shape but could interpret the images

(a) Rosalind Franklin

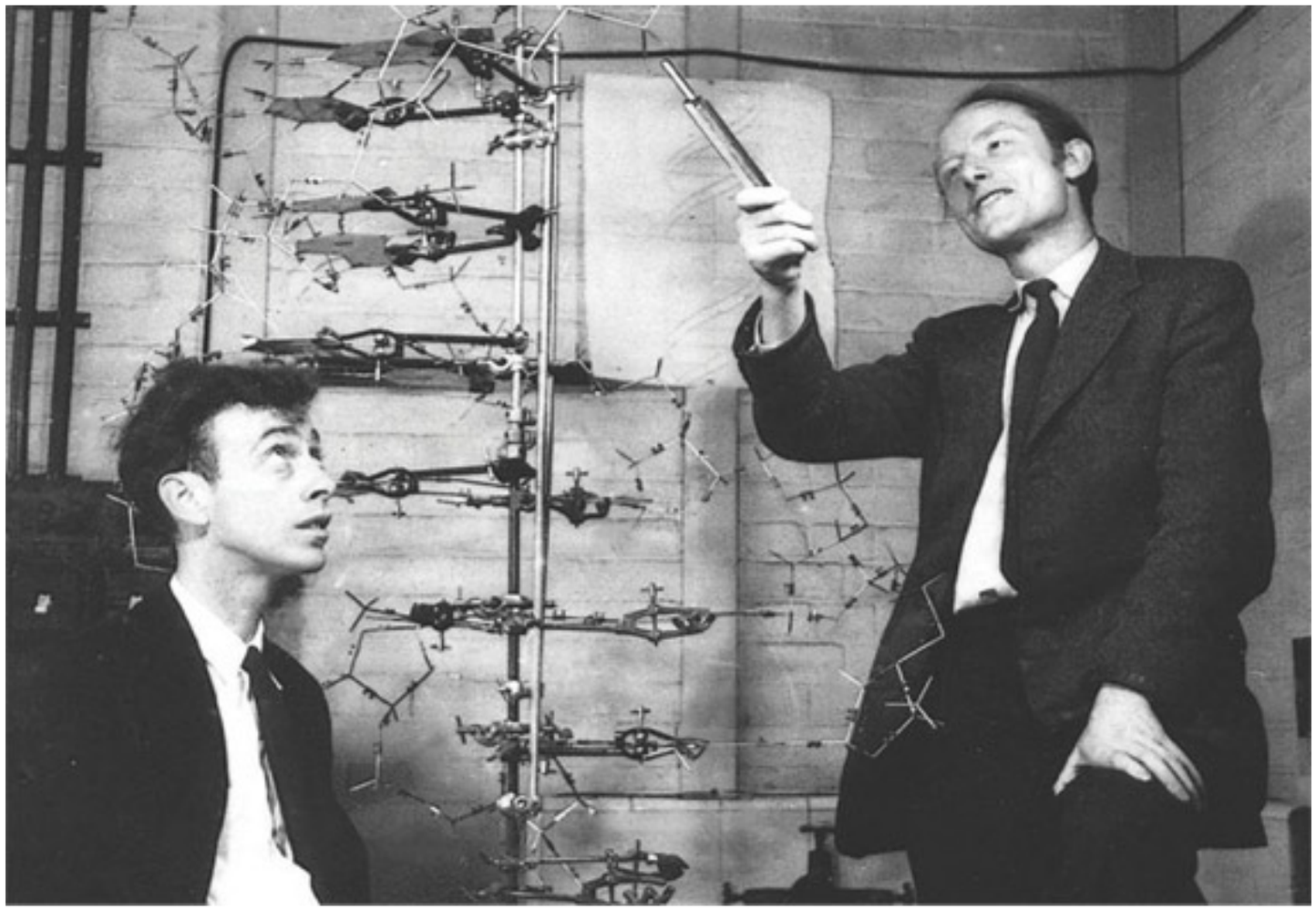


(b) Franklin's X-ray diffraction Photograph of DNA

DNA…"The Conclusion"

1953 James Watson & Francis Crick

- Watson & Crick put all the puzzle pieces together in a 1 page paper that described the structure of DNA.
  - They won Nobel Prize



DNA…"The Conclusion"

The Puzzle Pieces

- Watson recognized the x-ray image from Wilkin's lab as a helix.
- They used what chemists already knew about DNA
- They used Chargaff's observations
- They read Franklin's paper suggesting a sugar-phosphate backbone
    - From these pieces Watson & Crick deduced the following structure of DNA as seen on the next few slides

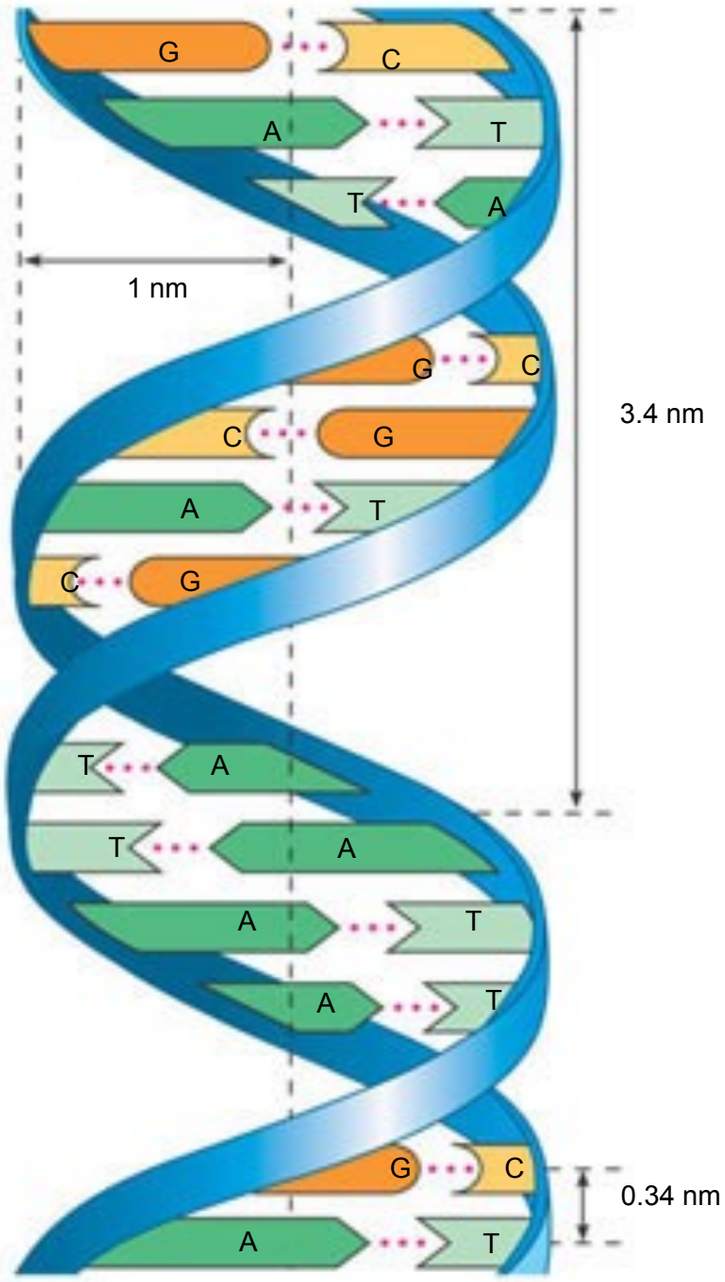
DNA

They knew...

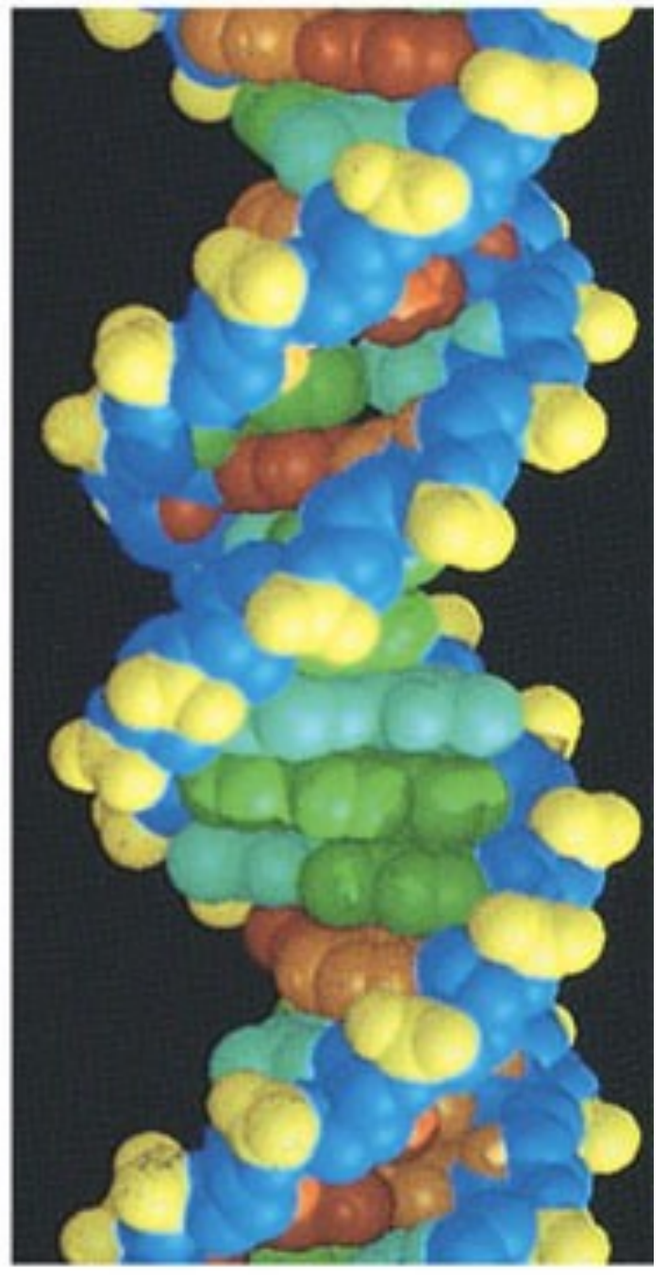
its width

its length

its shape



(a) Key features of DNA structure



(c) Space-filling model

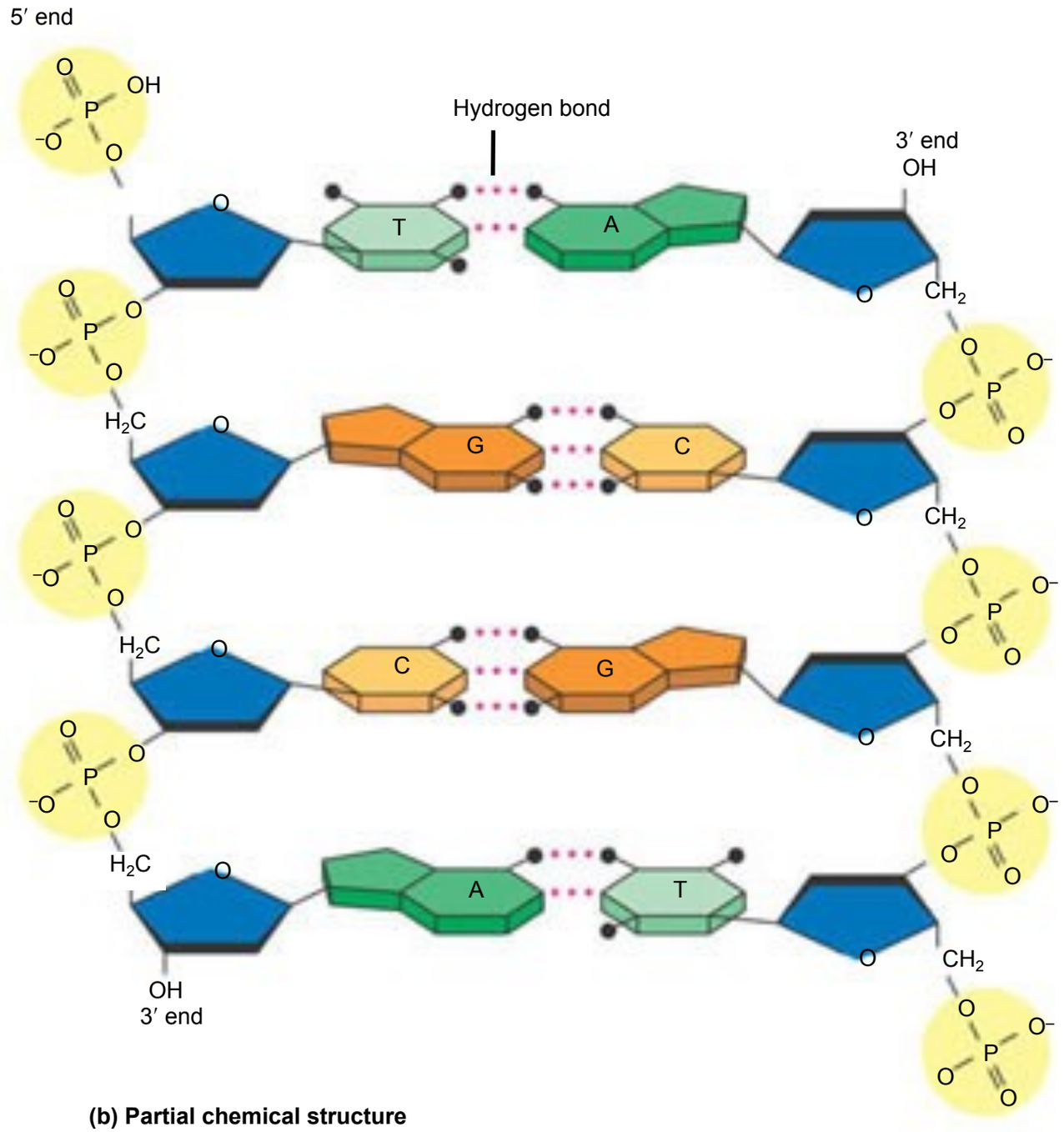
DNA

the structure of the backbone

its anti-parallel nature

in fact they even hypothesized a replicating mechanism

They knew...



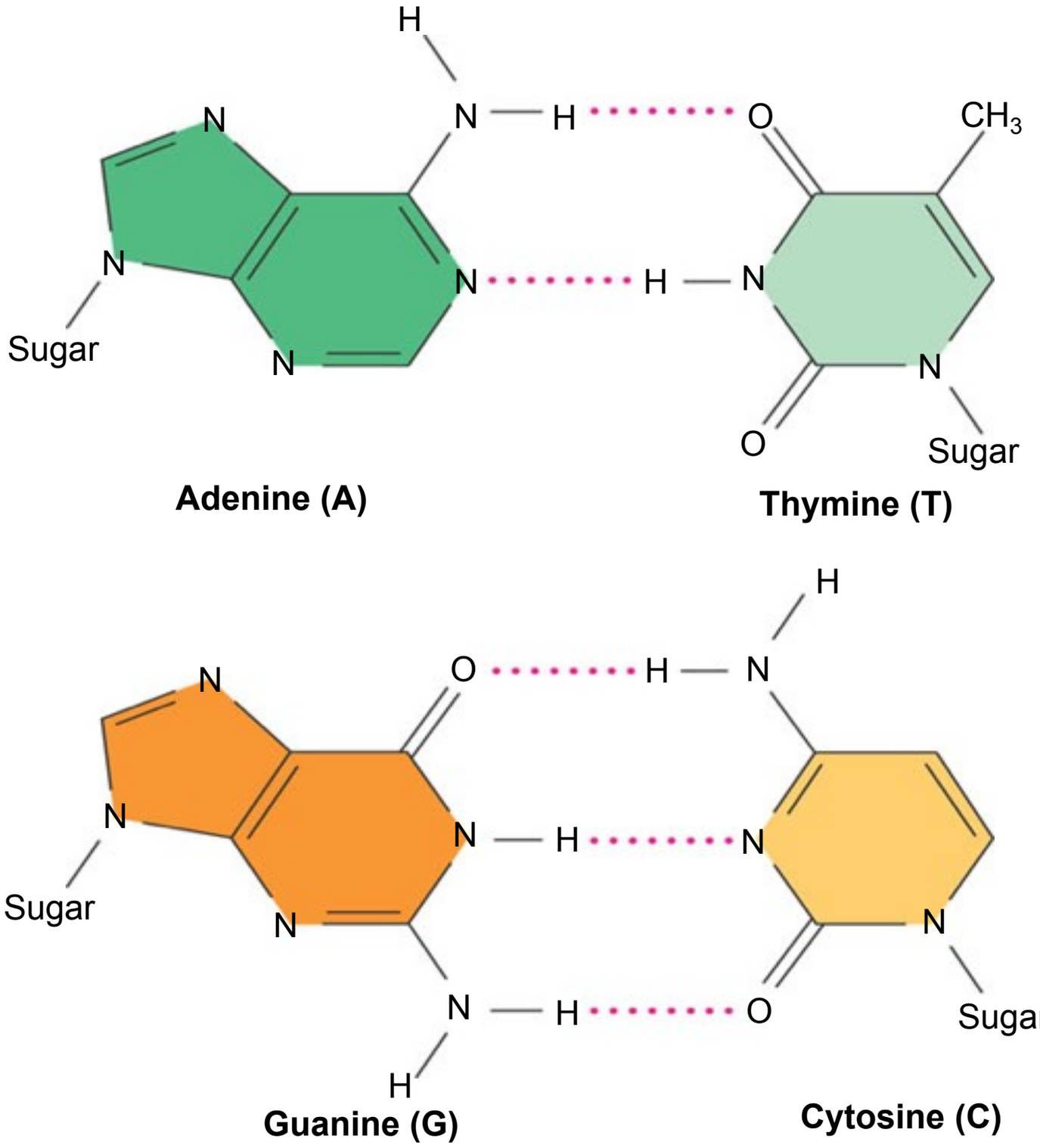
(b) Partial chemical structure

DNA

They knew...

base pairing rules

bonds between the bases



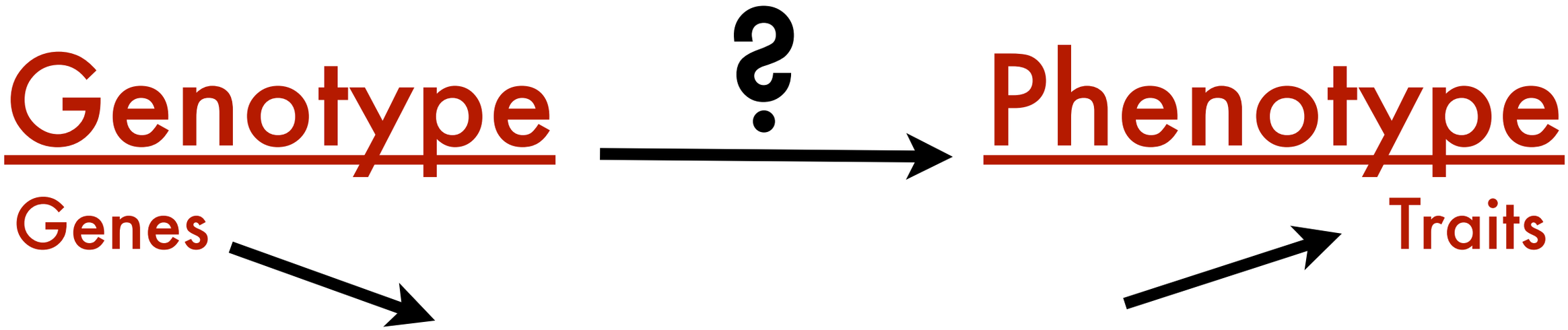
Revisit this idea…

DNA → **Genes** → Proteins → Traits

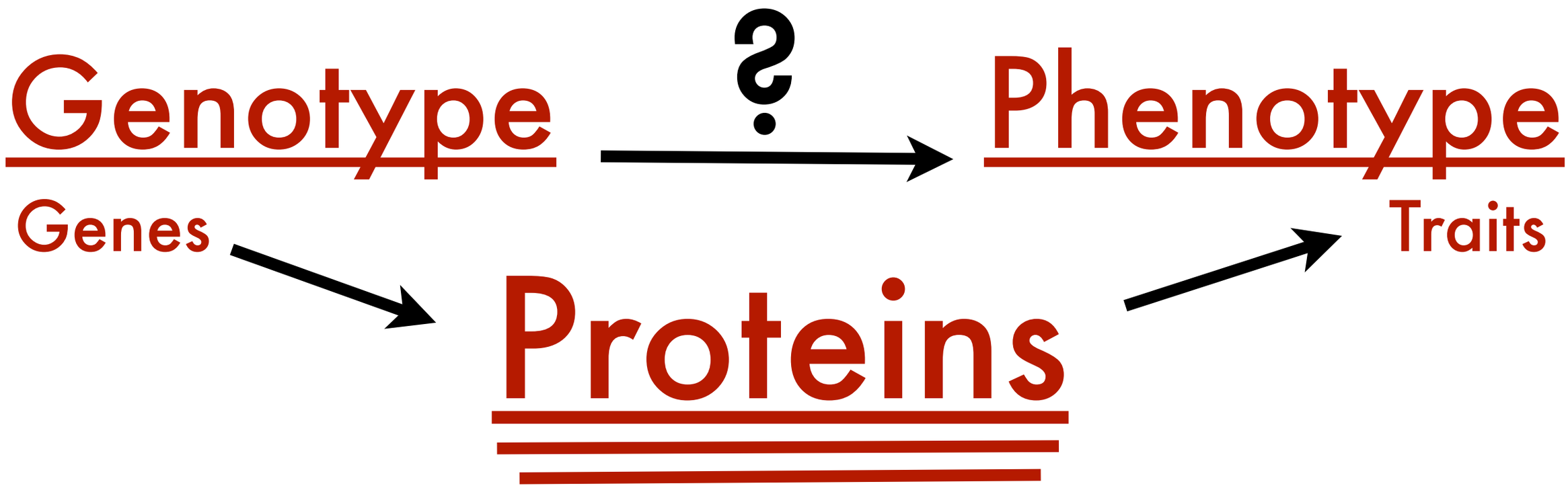
OK, What exactly is a gene?

- (Basic Definition) A unit of inheritance that controls a phenotypic character.
- (Better Definition) A nucleotide sequence along a molecule of DNA that codes for a protein.
- **(Best Definition) A region of DNA that can be expressed to produce a final functional product that is either a polypeptide or an RNA molecule.**

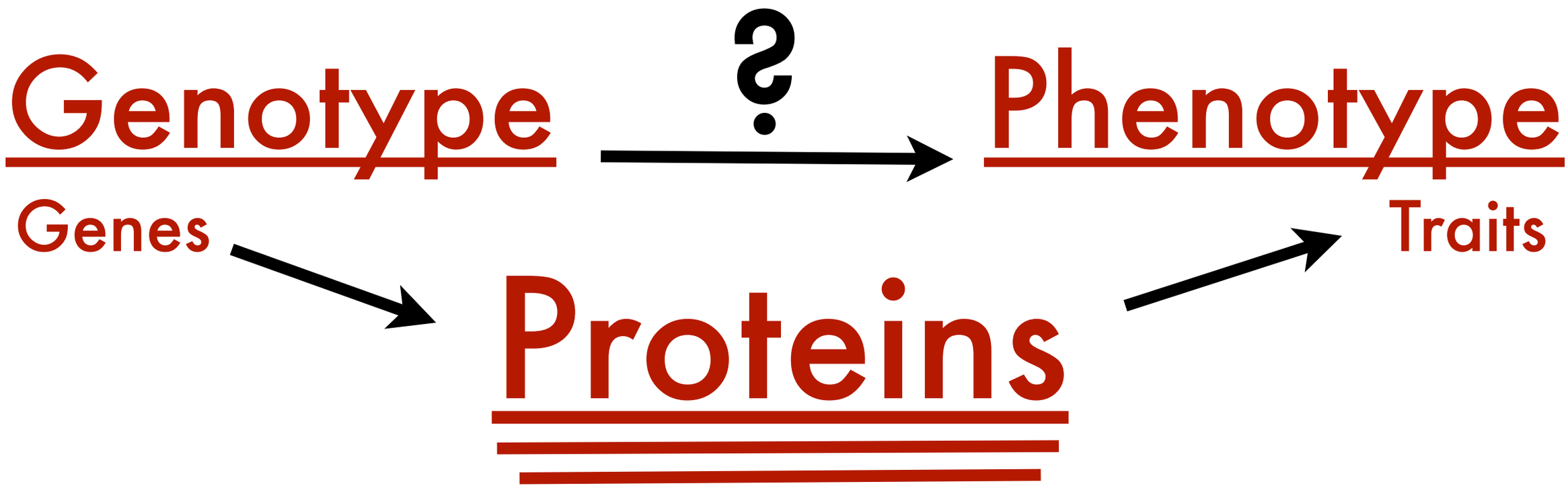
How do genes produce traits?



How do genes produce traits?



How do genes produce traits?



Proteins are the link between genotypes and phenotypes
Proteins are the link between genotypes and phenotypes
Proteins are the link between genotypes and phenotypes
Proteins are the link between genotypes and phenotypes

How do genes produce traits?

Global Flow of Information

DNA → **RNA** → **Protein**

- The flow of genetic information involves two processes.
  - Transcription
  - Translation
- Together these two processes represent gene expression.

Viral Structure

- A virus has only 2-4 parts.
  - ALL have a nucleic acid (DNA or RNA)
  - ALL have a protein shell (*capsids*)
    - Some have membranous envelopes around them
    - Some carry enzymes like reverse transcriptase

Viral Structure

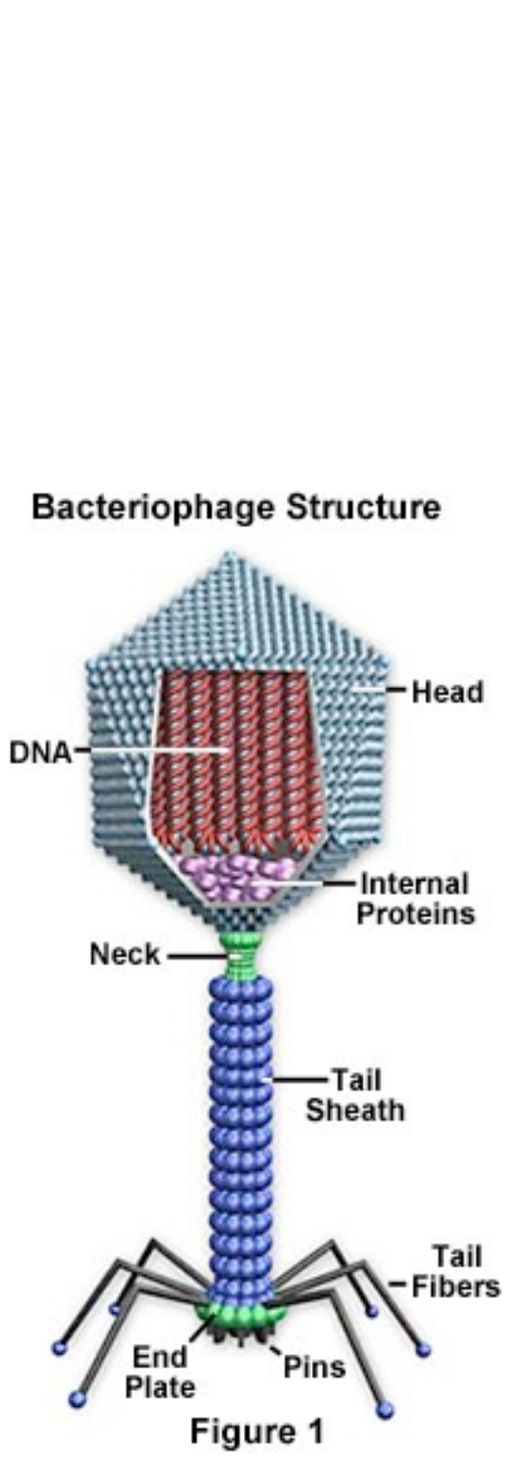
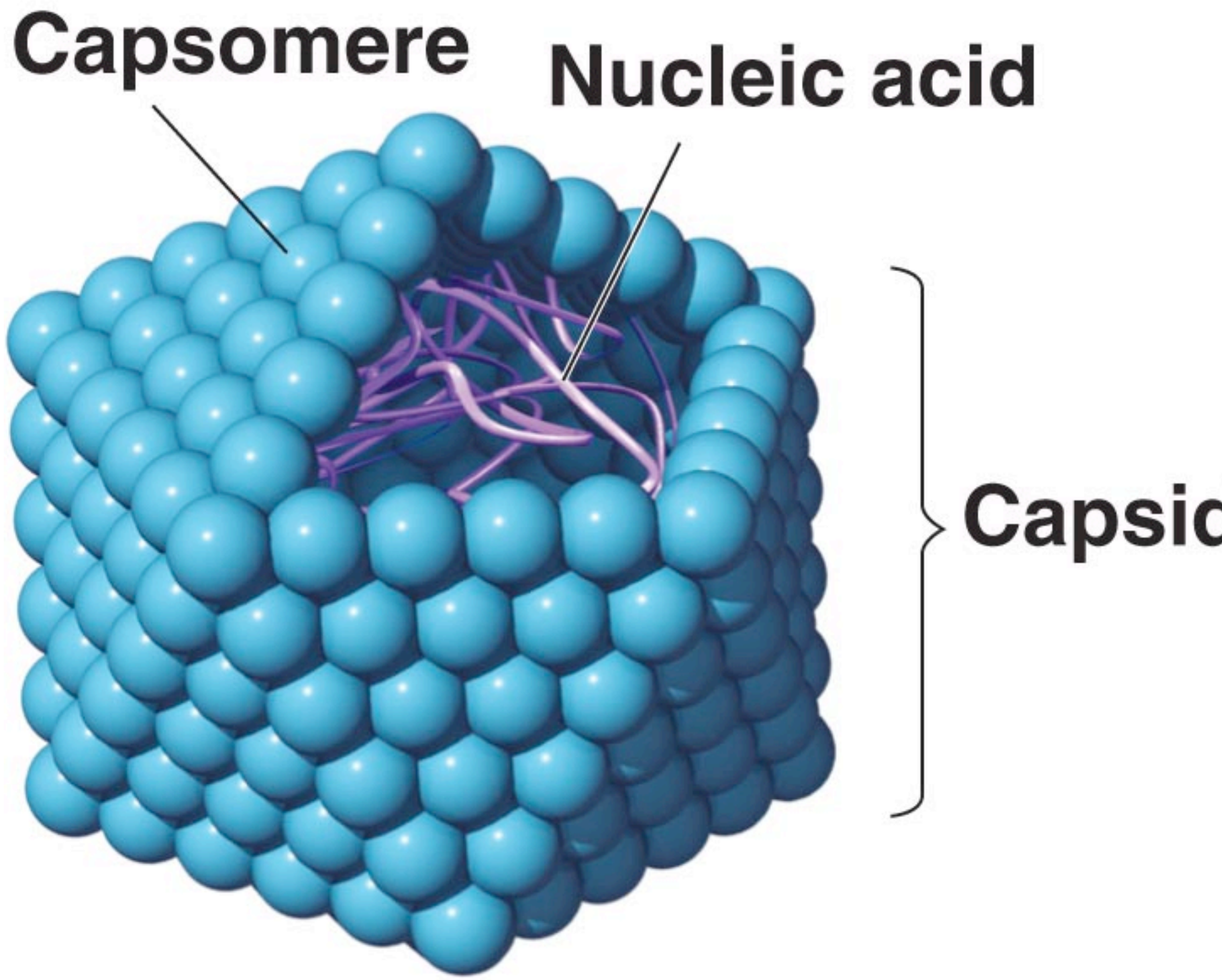


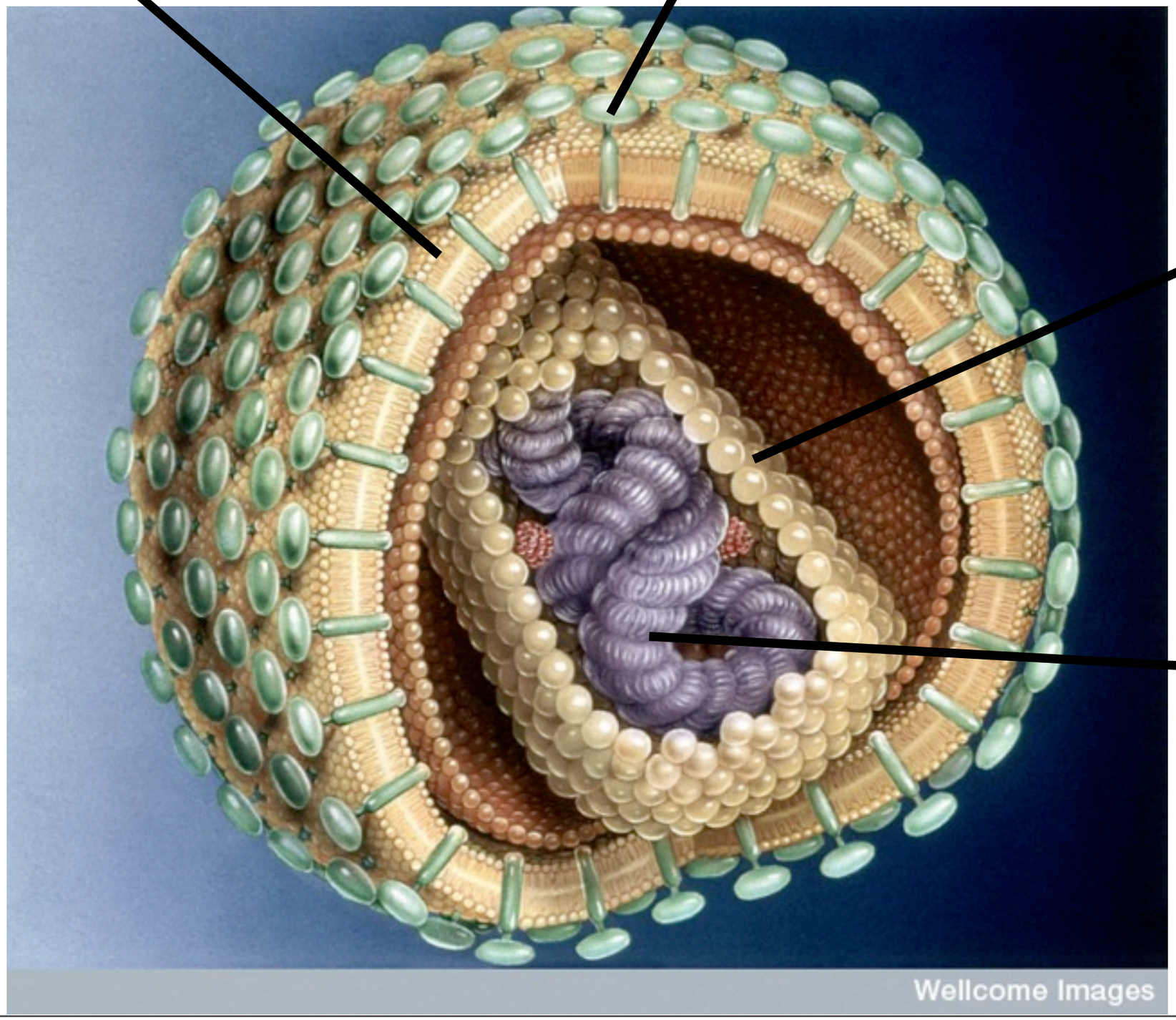
Figure 1



Viral Structure

Membranous Envelope

Glycoproteins



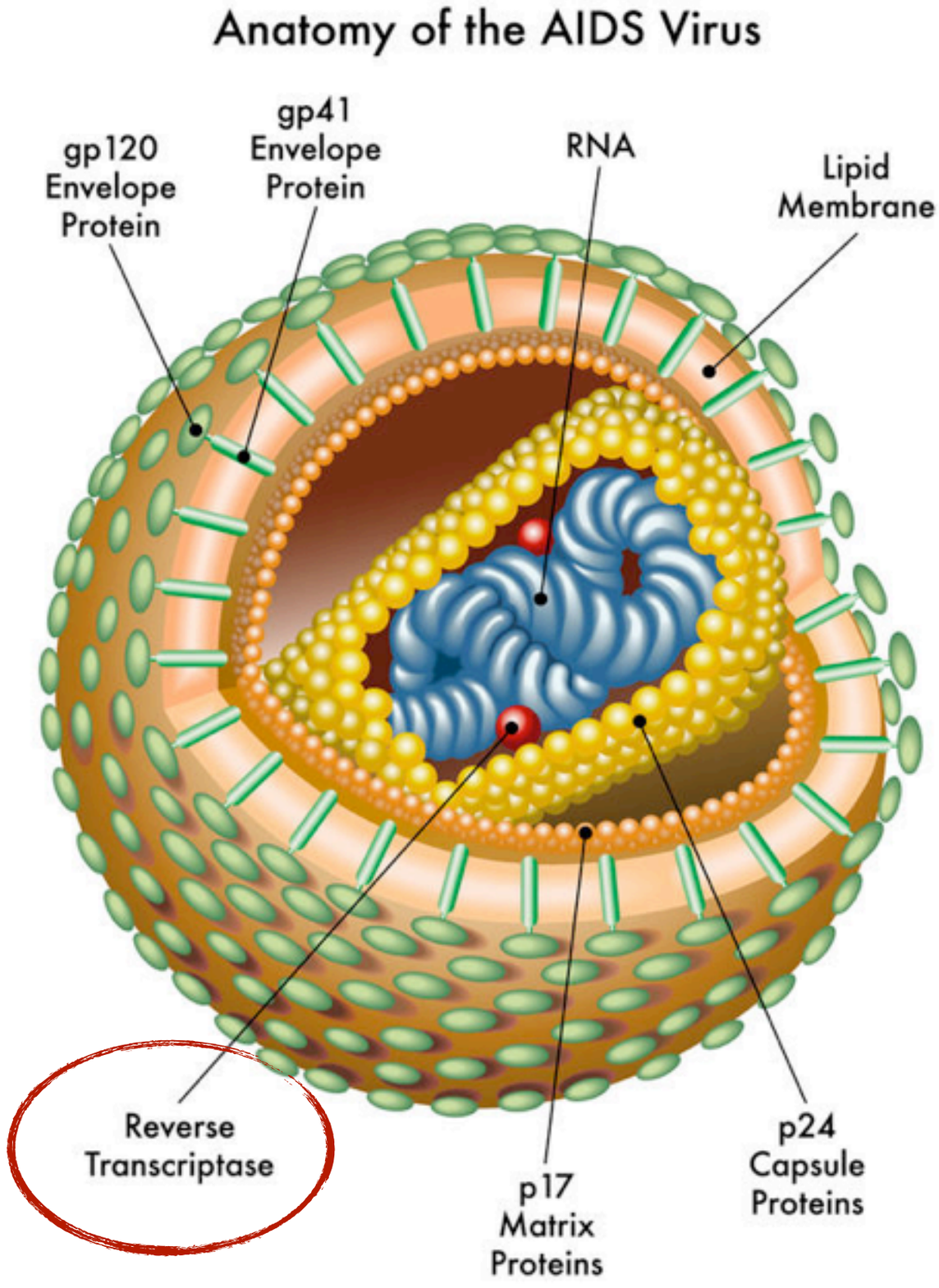
Capsid

DNA
or
RNA

Viral Structure

A retrovirus carries reverse transcriptase to copy its RNA into DNA.

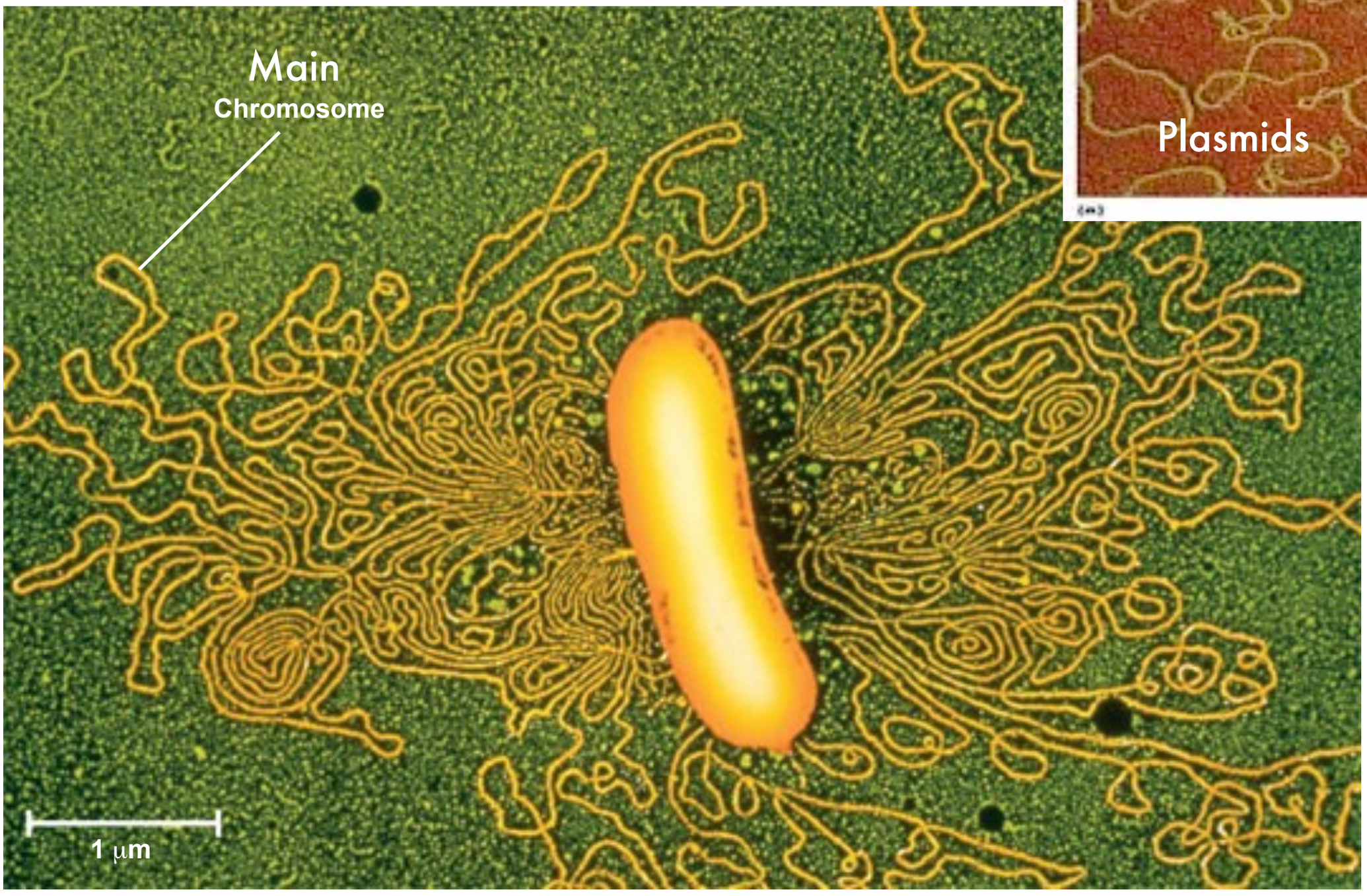
This allows the virus to incorporate its genes into the hosts genome.



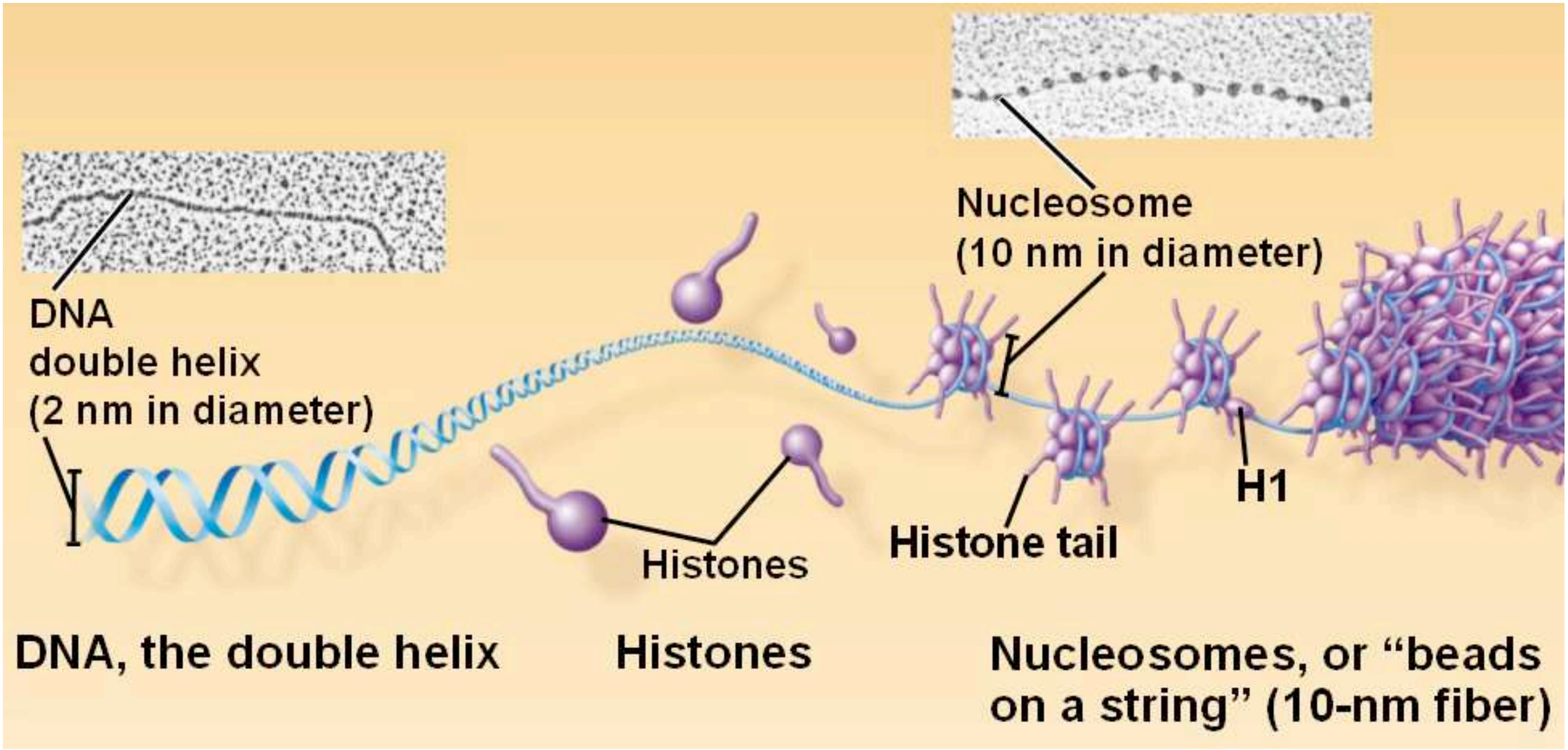
Where do bacteria store their DNA?

- Bacterial DNA is found in a large circular chromosome with very few proteins.
- The chromosome is located in a nucleoid region.
  - *remember no membrane bound organelles like a nucleus*
- Some bacteria have small circular accessory chromosome called plasmids.
  - *these reproduce independent from the main chromosome*
  - *these are often utilized in the biotech industry*
  - *they often carry resistant type genes (called r plasmids)*

Bacterial Chromosome

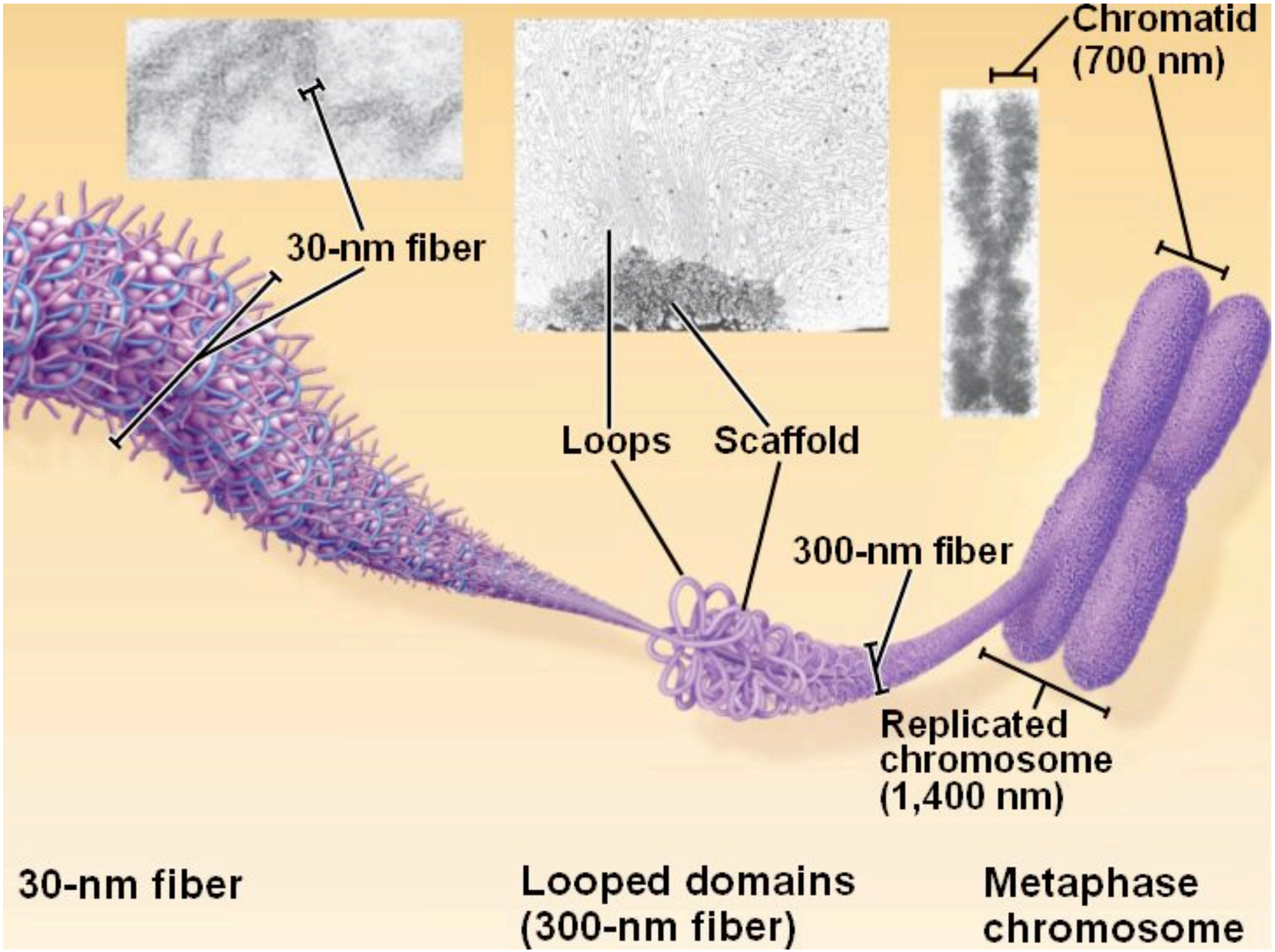


Eukaryotic DNA & Chromatin



All the DNA in one cell, when stretched out would be 4cm in length, thousands of times longer than the cells diameter. It fits only because it folded over and over.

Chromatin & Chromosomes



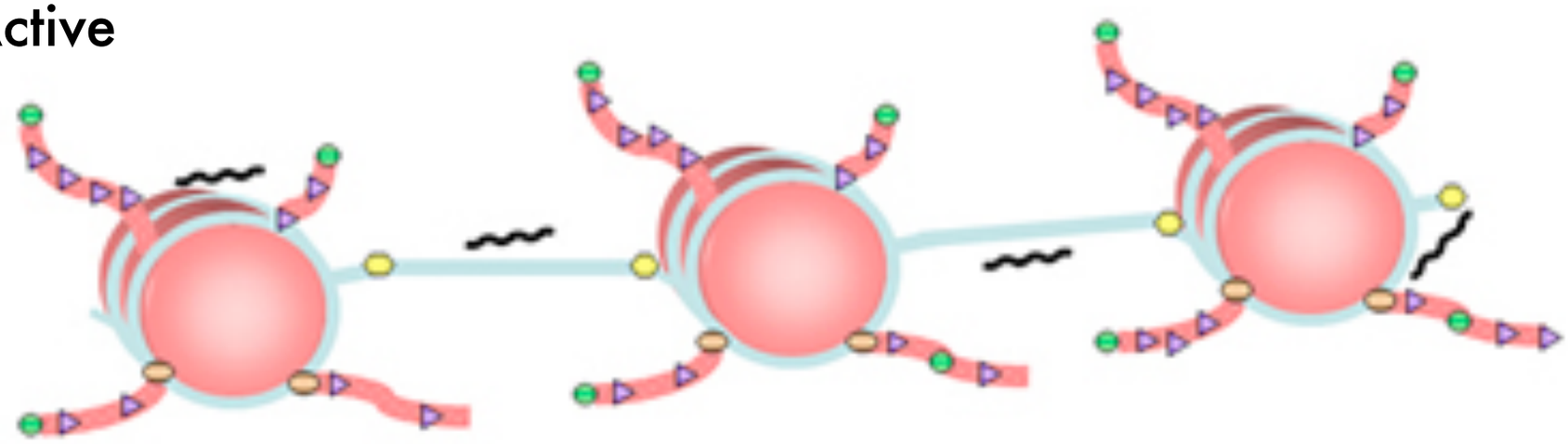
Euchromatin & Heterochromatin

Euchromatin

Gene Rich, Transcriptionally Active

Dispersed Appearance

Unique DNA sequences



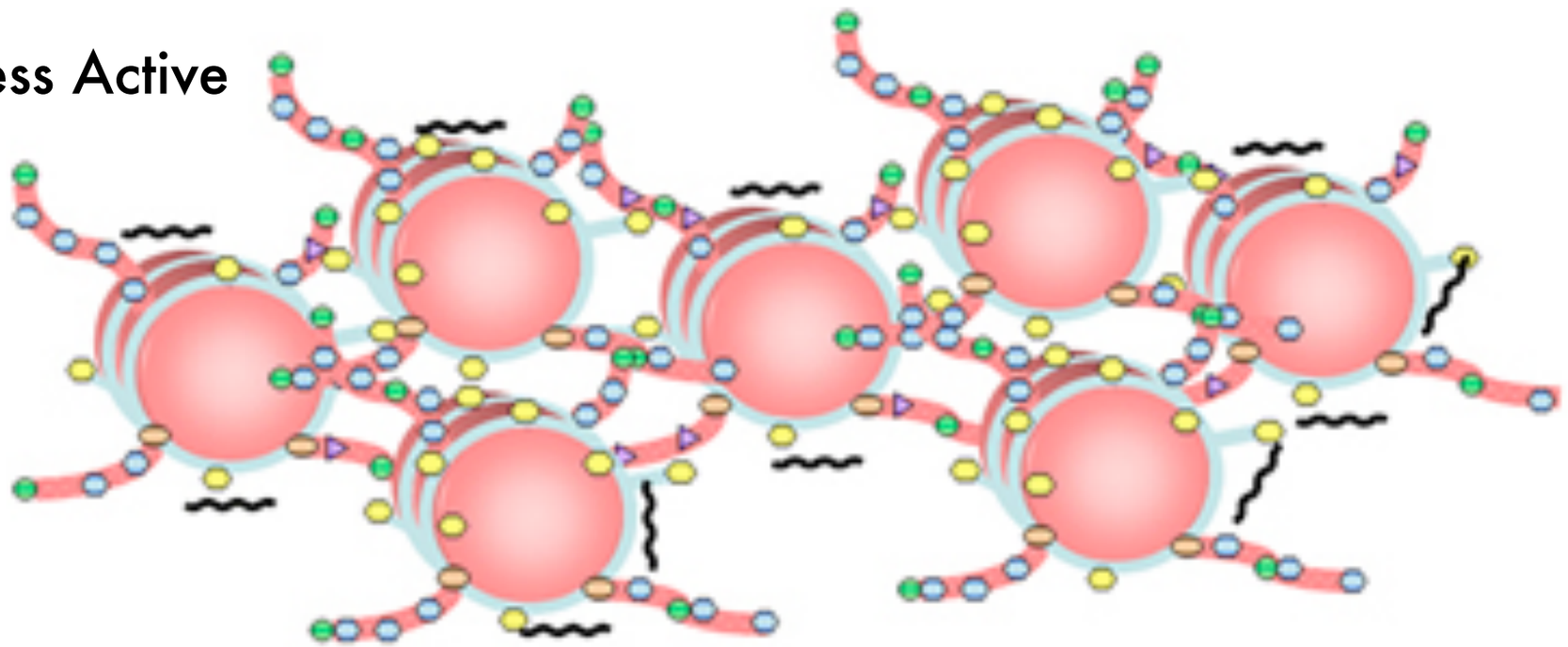
Interphase DNA

Heterochromatin

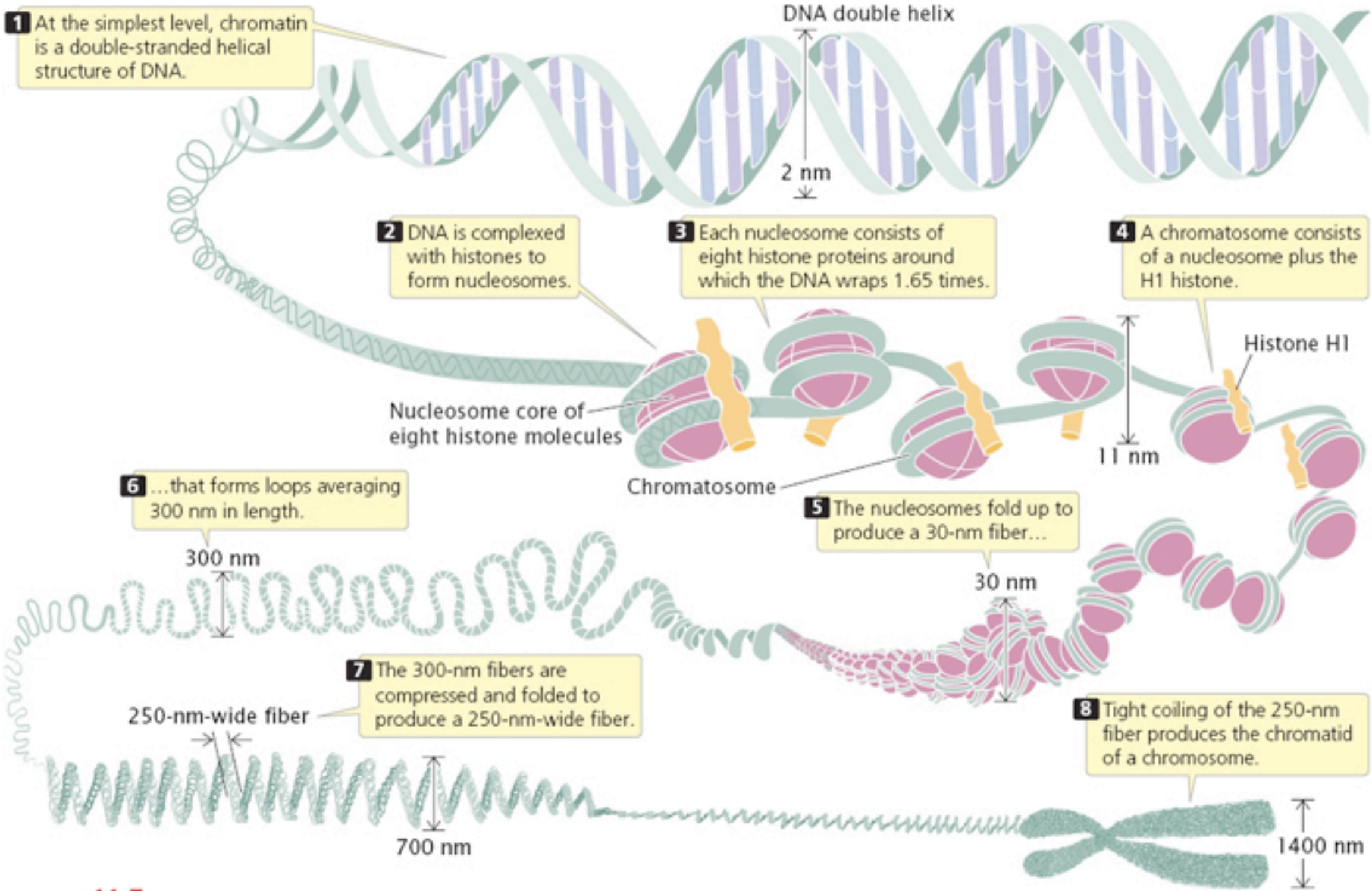
Gene Poor, Transcriptionally Less Active

Condensed Appearance

Repetitive DNA sequences



Chromatin & Chromosomes



Organization of Genetic Material

- **Genome-** a cell's endowment of genetic information (DNA)
  - Eukaryotes have far more DNA than prokaryotes.
- **Chromosomes-** are structures that package the DNA molecules.
  - each consists of a very long DNA molecule associated with proteins
    - the DNA contains the genes that code inherited traits
    - the proteins maintain structure and help to control the activity genes
  - together the DNA and the protein make up that make up the chromosome is called **chromatin.**

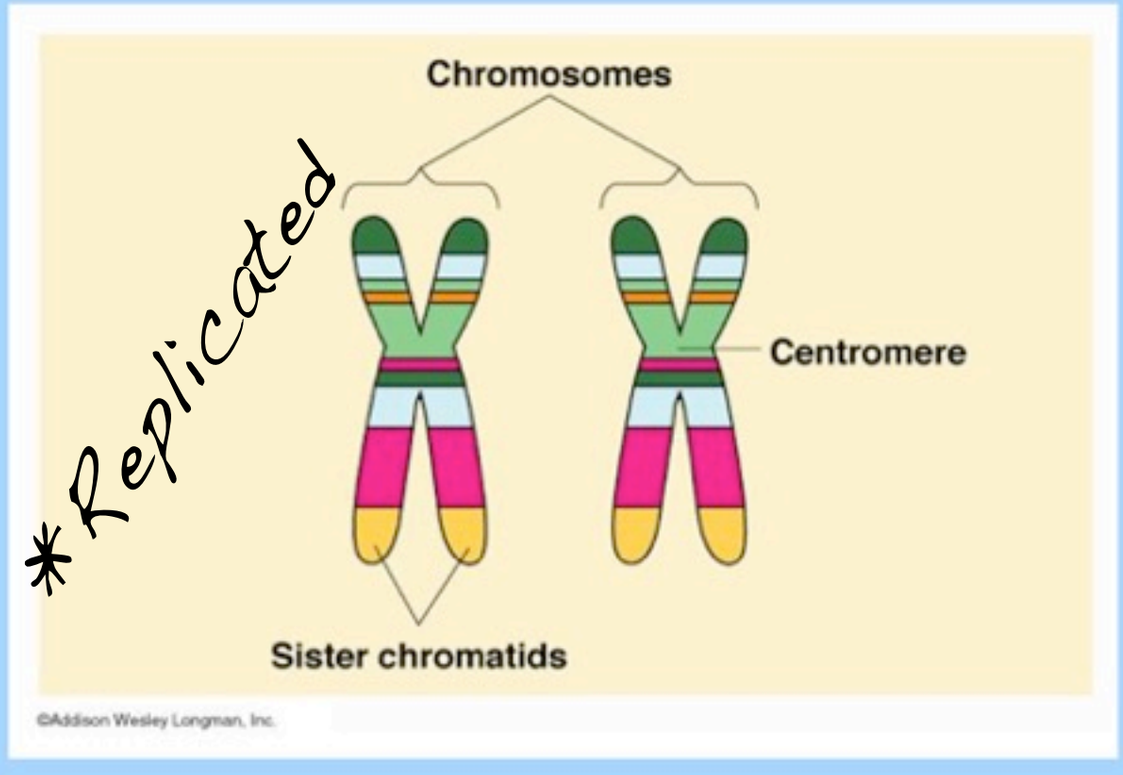
Chromosomes vs. Chromatin

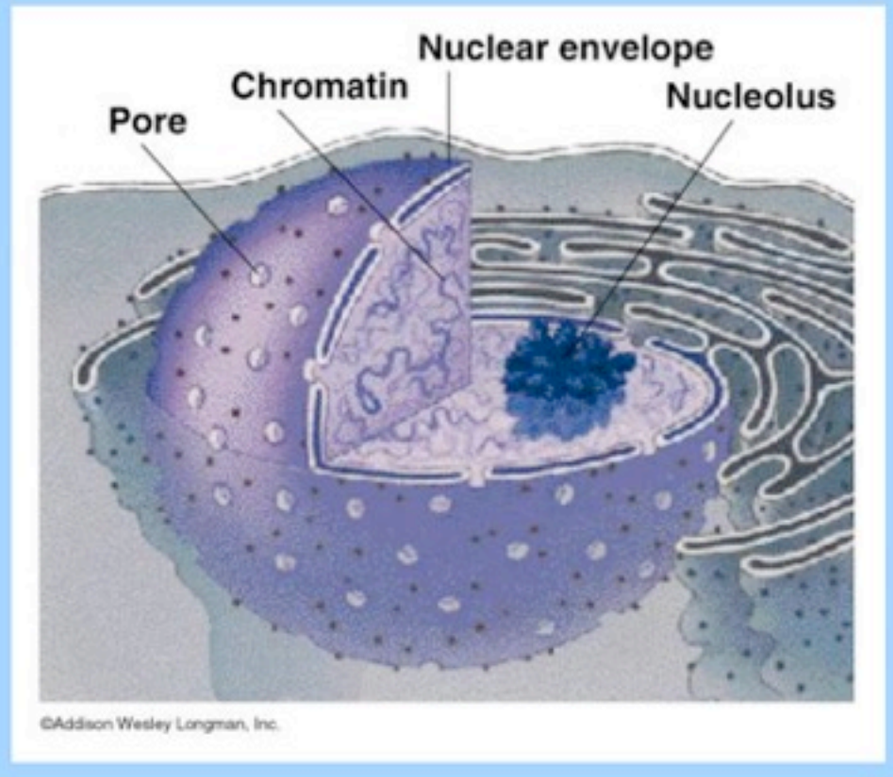
Chromosomes

- Tightly packaged DNA
- Found only during cell division
- DNA is not being used for macromolecule synthesis

Chromatin

- Unwound DNA
- Found throughout Interphase
- DNA *is* being used for macromolecule synthesis





Organization of Genetic Material

- Every eukaryotic species has a characteristic number of chromosomes in each cell's nucleus.
    - *varies greatly in eukaryotes: Jack Jumper female ant has 2 and the Adders-tongue fern has 1440*

Somatic Cells- body cells, all cells excluding sperm and egg have TWO sets of chromosomes.

- One from mom, One from dad
- 46 in humans

Reproductive Cells- only sperm and egg have ONE set of chromosomes.

- 23 in humans

Distribution of Chromosomes During Cell Division

- Most of the time the cells chromosomes are "unravelled" and referred to as chromatin.
  - This "accessible" form makes gene transcription and DNA replication possible
- After DNA replication (in preparation for cell division) the chromatin folds over and over again on itself.
  - This condensed form is more easily "moveable".
  - It is this form that cells manipulate during cell division.
  - *This condensed form is more easily seen under the microscope and consequently it is the form most commonly referred to by the name chromosome.*

Evidence of student learning is a demonstrated understanding of each of the following:

5. DNA replication ensures continuity of hereditary information.

   i. Replication is a semiconservative process; that is, one strand serves as the template for a new, complementary strand.

   ii. Replication requires DNA polymerase plus many other essential cellular enzymes, occurs bidirectionally, and differs in the production of the leading and lagging strands.

6. Genetic information in retroviruses is a special case and has an alternate flow of information: from RNA to DNA, made possible by reverse transcriptase, an enzyme that copies the viral RNA genome into DNA. This DNA integrates into the host genome and becomes transcribed and translated for the assembly of new viral progeny. [See also **3.C.3**]

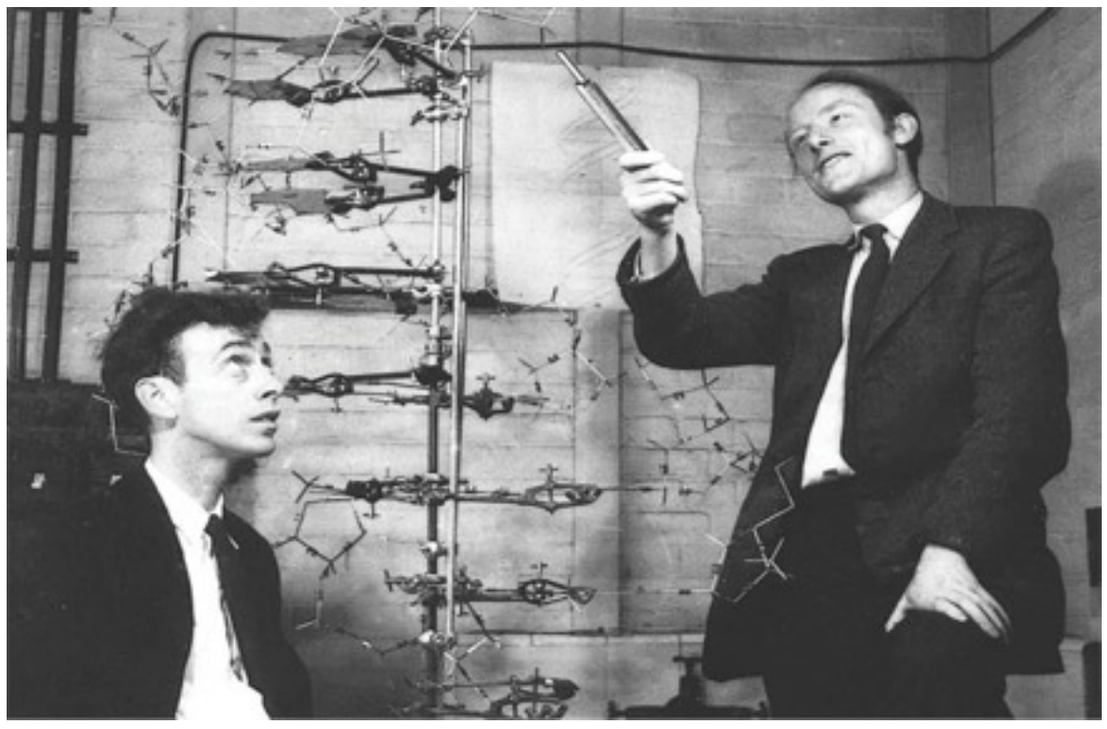
✘✘ *The names of the steps and particular enzymes involved, beyond DNA polymerase, ligase, RNA polymerase, helicase and topoisomerase, are outside the scope of the course for the purposes of the AP Exam.*

DNA Replication

1953 James Watson & Francis Crick

- Watson and Crick ended their classic paper with the following "It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material".

- Watson and Crick wrote a second paper describing their hypothesis for DNA replication.
- Their basic explanation can see on the next slide...
- Their model however remained untested for years!



DNA Replication

The basic principle behind DNA replication is that each of the two complimentary strands serves as a template for the replication of new strands

(a) Before replication, the parent molecule has two complementary strands of DNA. Each base is paired by hydrogen bonding with its specific partner, A with T and G with C.

(b) The first step in replication is separation of the two DNA strands.

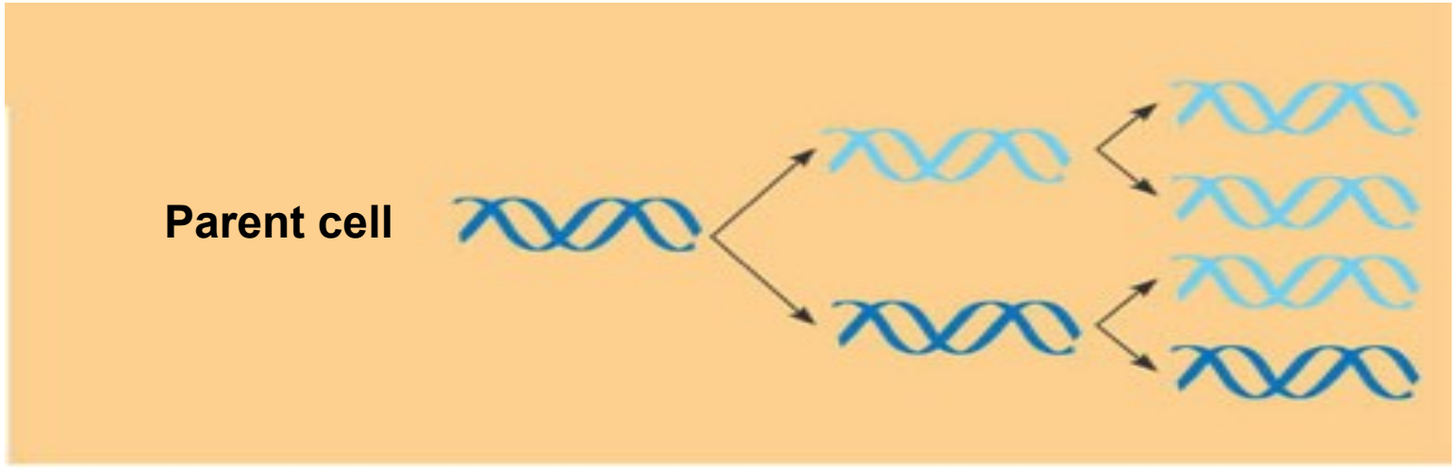
(c) Each "old" strand now serves as a template that determines the order of nucleotides along "new" complementary strands. Nucleotides plug into specific sites along the template surface according to the base-pairing rules.

(d) The nucleotides are connected to form the sugar-phosphate backbones of the new strands. Each DNA molecule now consists of one "old" strand and one "new" strand. We have two DNA molecules identical to the one molecule with which we started.

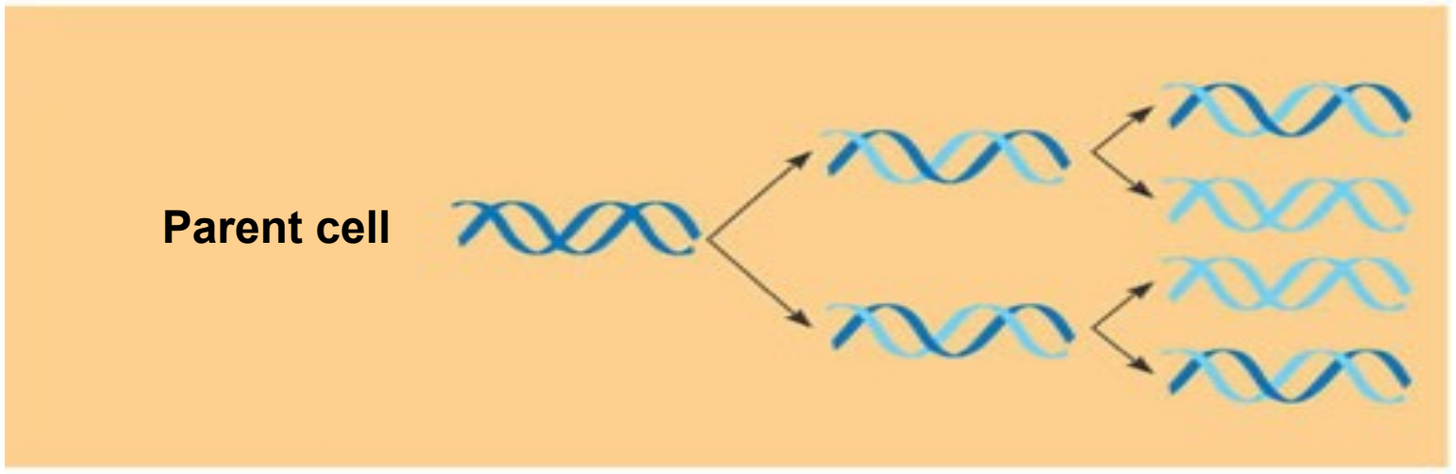
Additional Models DNA Replication

3 possible copying mechanisms

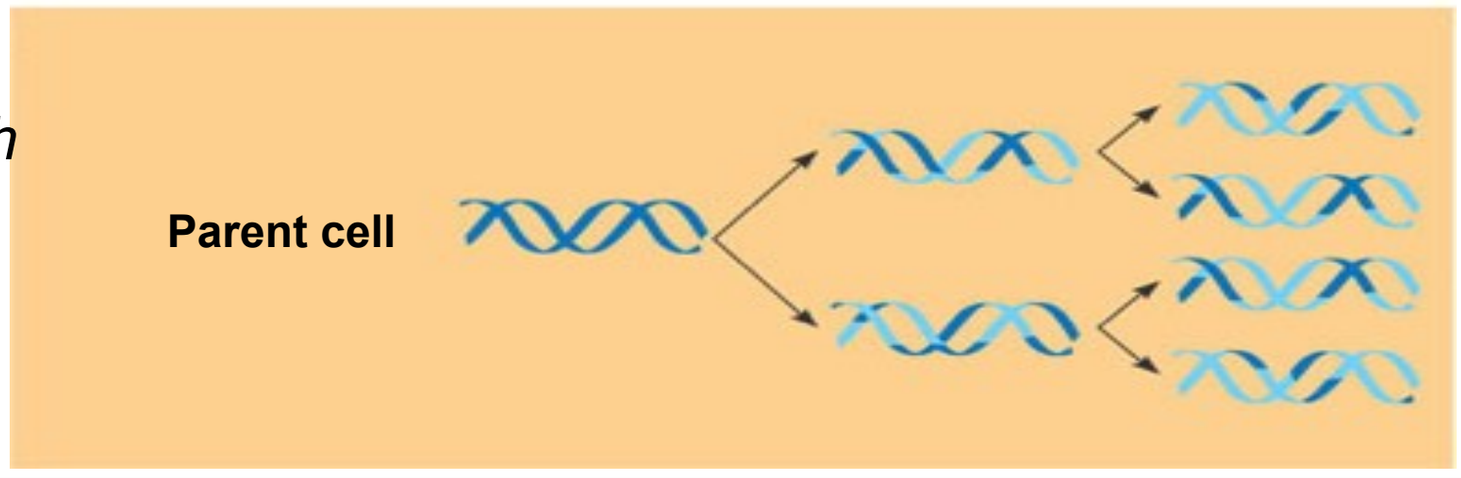
Conservative model. The two parental strands reassociate after acting as templates for new strands, thus restoring the parental double helix.



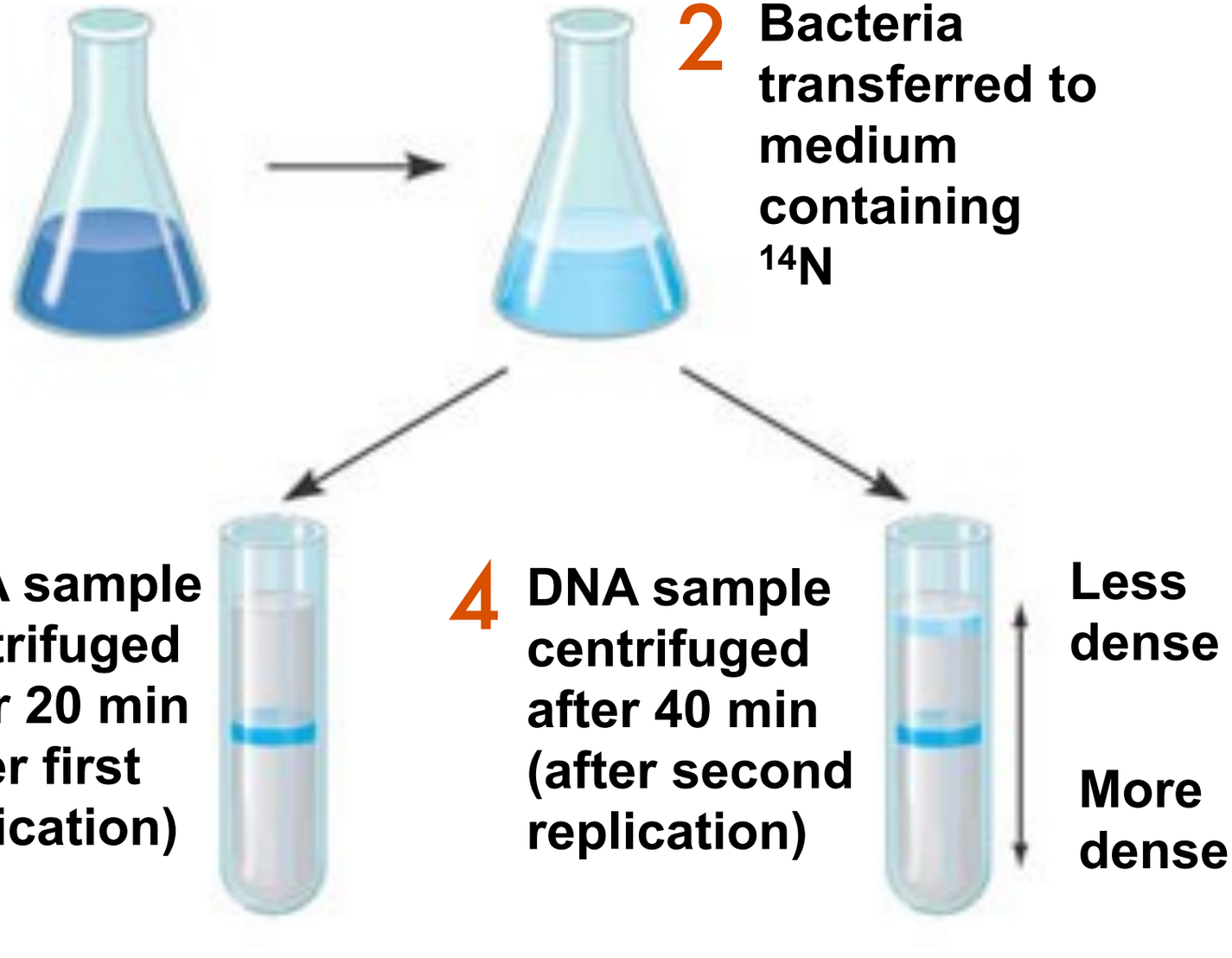
Semiconservative model. The two strands of the parental molecule separate, and each functions as a template for synthesis of a new, complementary strand.



Dispersive model. Each strand of *both* daughter molecules contains a mixture ofold and newly synthesized DNA.



EXPERIMENT Matthew Meselson and Franklin Stahl cultured *E. coli* bacteria for several generations on a medium containing nucleotide precursors labeled with a heavy isotope of nitrogen, ^{15}N. The bacteria incorporated the heavy nitrogen into their DNA. The scientists then transferred the bacteria to a medium with only ^{14}N, the lighter, more common isotope of nitrogen. Any new DNA that the bacteria synthesized would be lighter than the parental DNA made in the ^{15}N medium. Meselson and Stahl could distinguish DNA of different

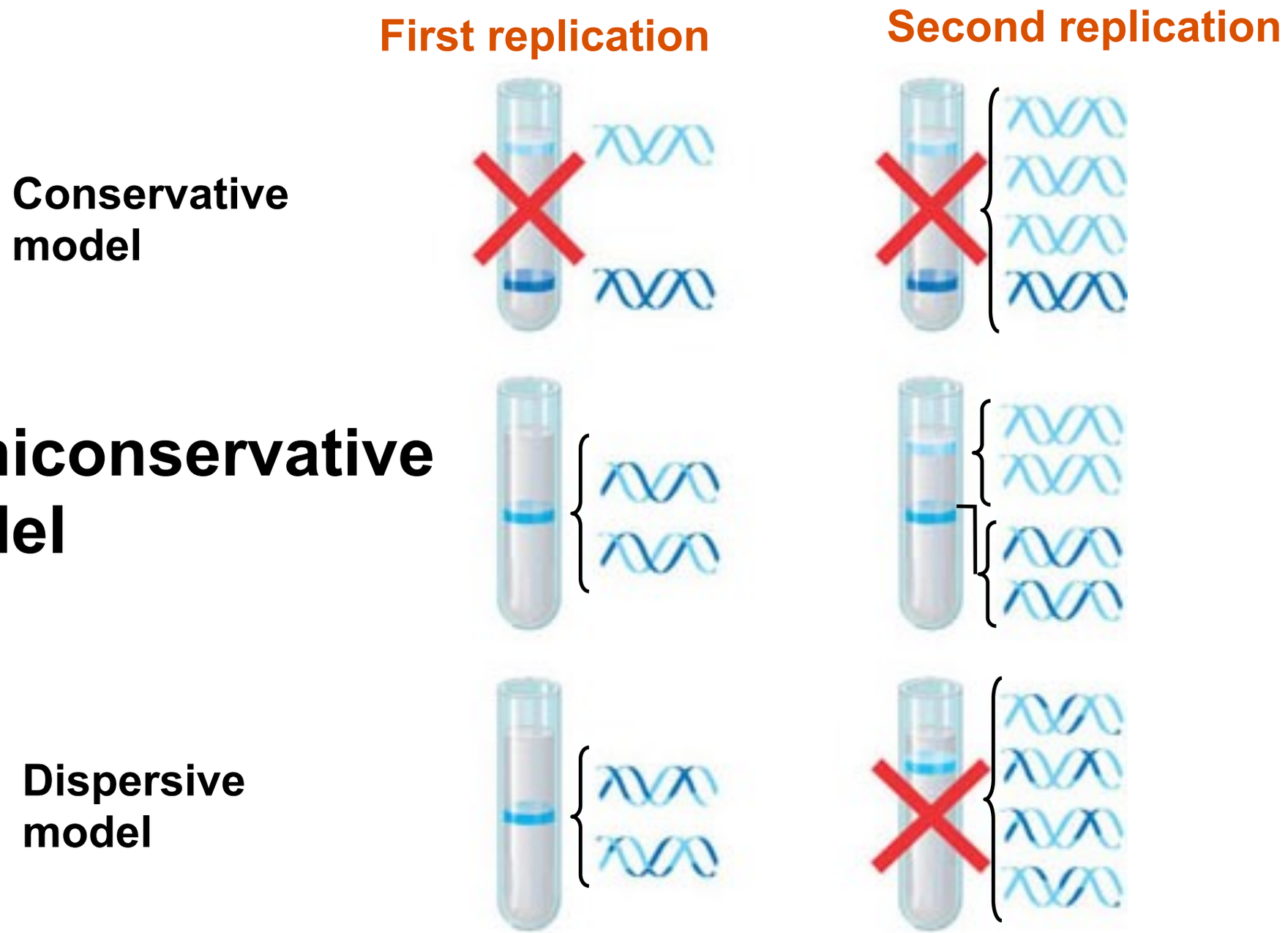


RESULTS

The bands in these two centrifuge tubes represent the results of centrifuging two DNA samples from the flask

CONCLUSION

Meselson and Stahl concluded that DNA replication follows the semiconservative model by comparing their result to the results predicted by each of the three models. The first replication in the ^{14}N medium produced a band of hybrid (^{15}N–^{14}N) DNA. This result eliminated the conservative model. A second replication produced both light and hybrid DNA, a result that eliminated the dispersive model and supported the semiconservative model.



DNA Replication

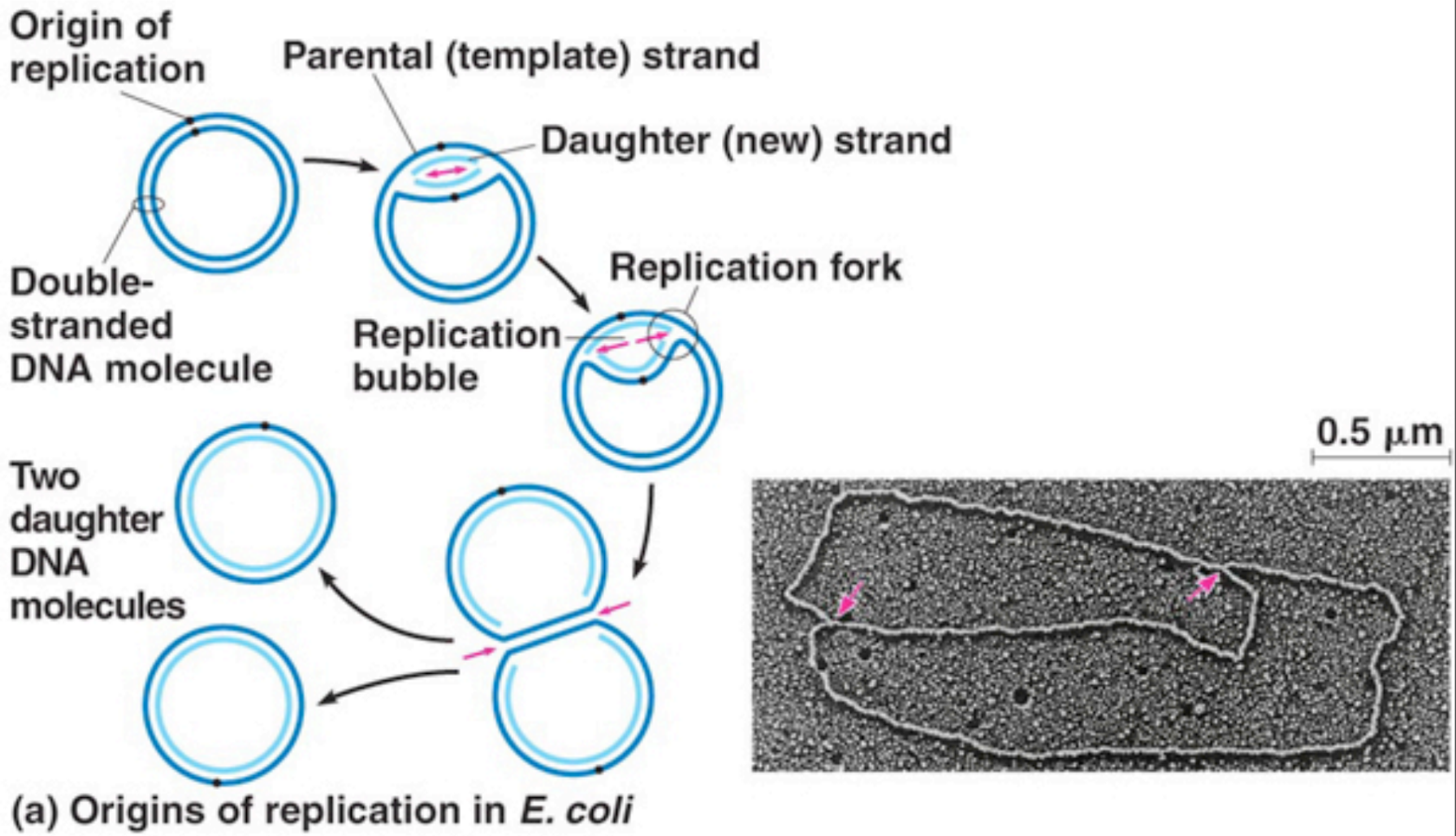
- Many proteins work together in DNA replication and repair
- The parent molecule unwinds, and two new daughter strands are built based on base-pairing rules
- Copying DNA Is done with remarkable in its speed and accuracy
- The replication of DNA begins at special sites called **origins of replication**, where the two strands are separated

Please note even though this powerpoint's focus lies on eukaryotes, we know much more about prokaryotic replication. As a result we focus primarily on prokaryotic replication since it is fundamentally the same. Along the way I will point that important distinctions between the two.

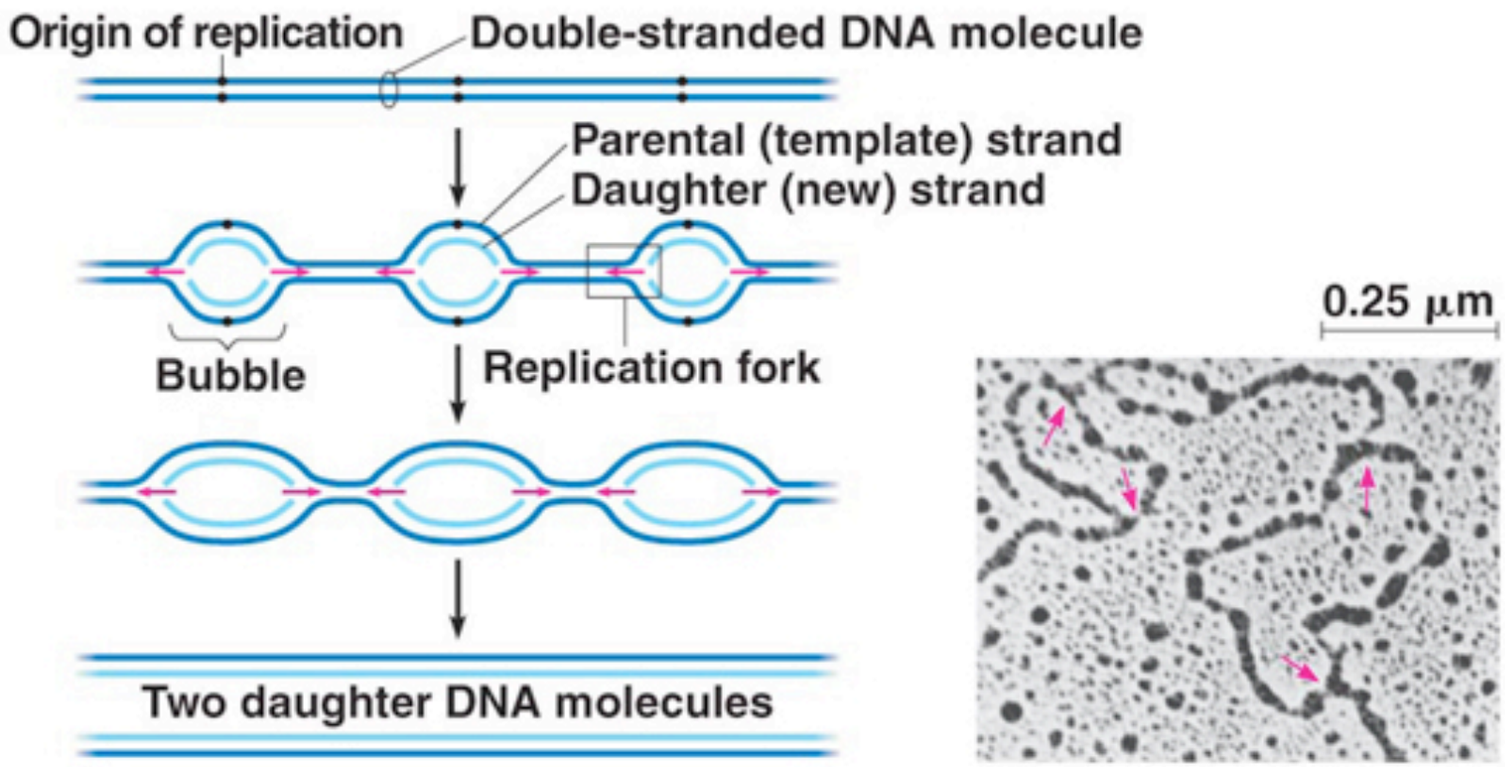
DNA Replication

Our first important distinction-

prokaryotes have only one origin of replication, where eukaryotes have hundreds or even thousands



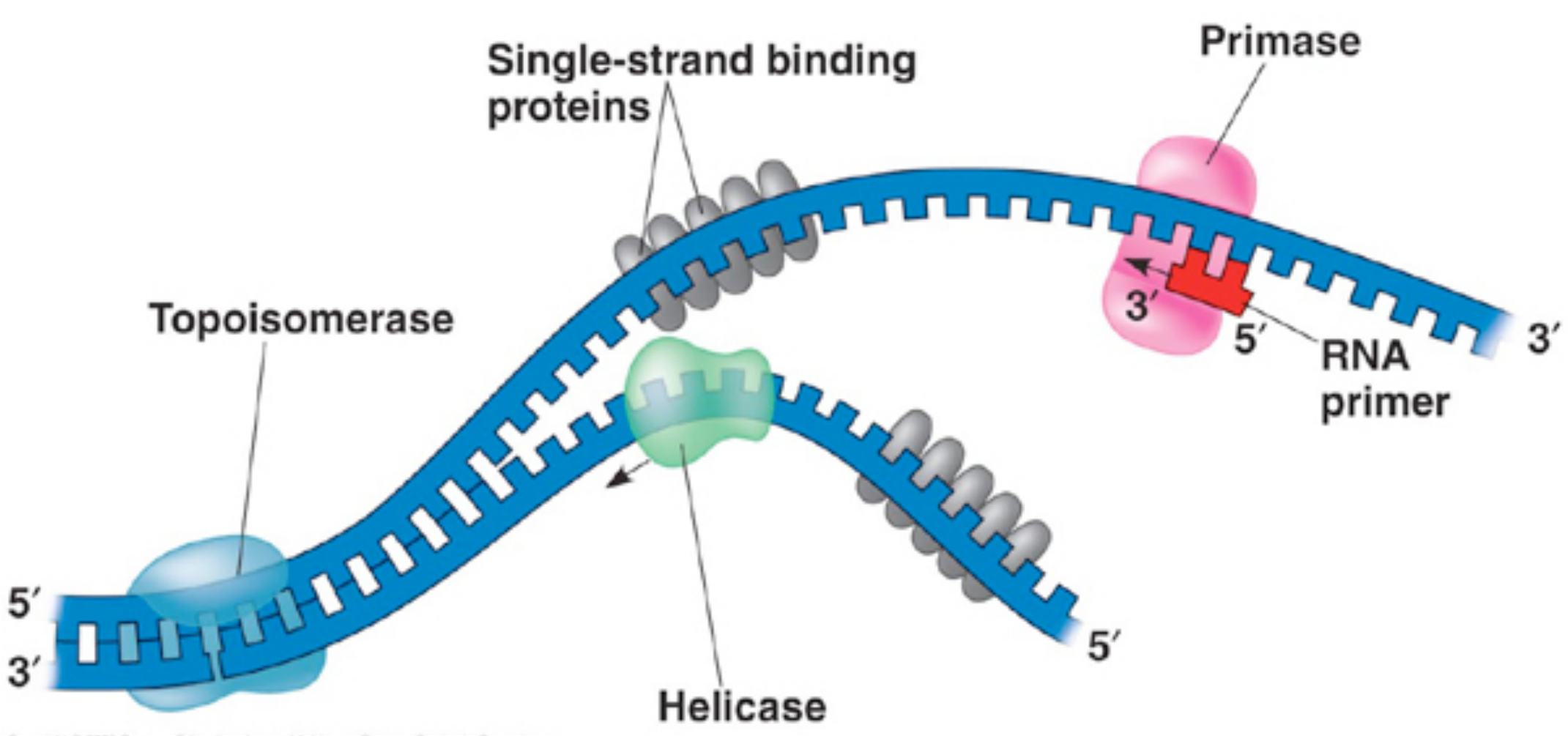
(a) Origins of replication in *E. coli*



(b) Origins of replication in eukaryotes

DNA Replication

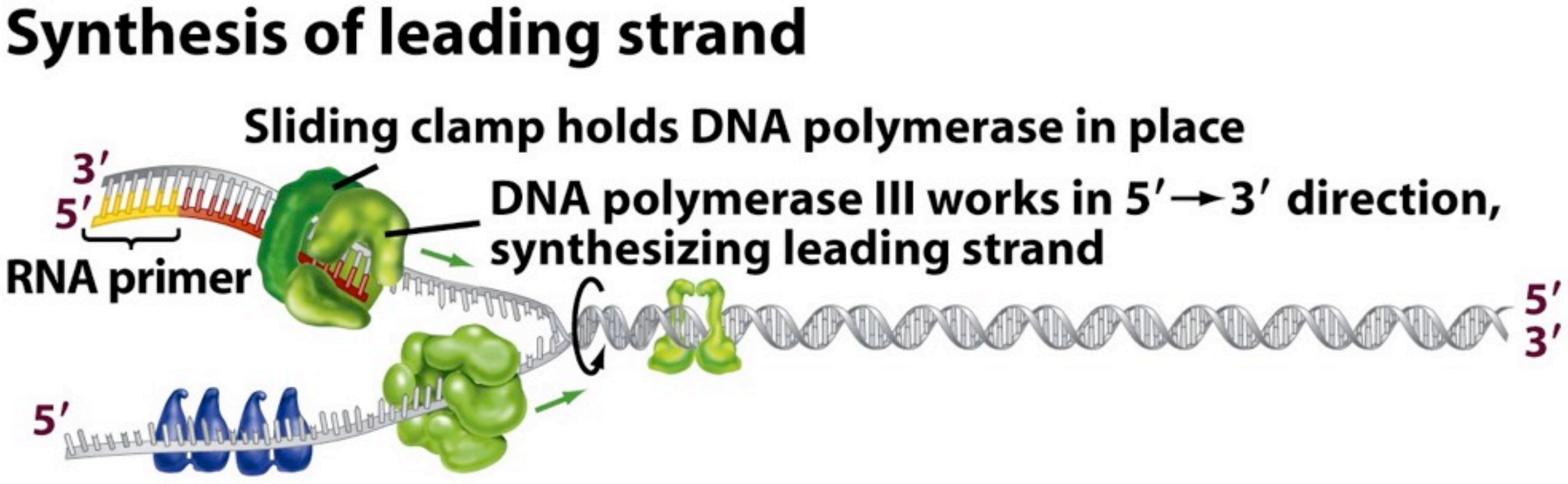
Topoisomerase- *relaxes the supercoils and unwinds DNA*
Helicase- *separates DNA strands (requires ATP)*
Single Strand Binding Proteins- holds the two strands apart
Primase- *special RNA polymerase that lays down 15-50 nucleotides, that serve as a starting point for replication*



DNA Replication

DNA Polymerase III- *large protein/enzyme complex that synthesizes new DNA strands from the template strands by adding one nucleotide at a time according to base pair rules*

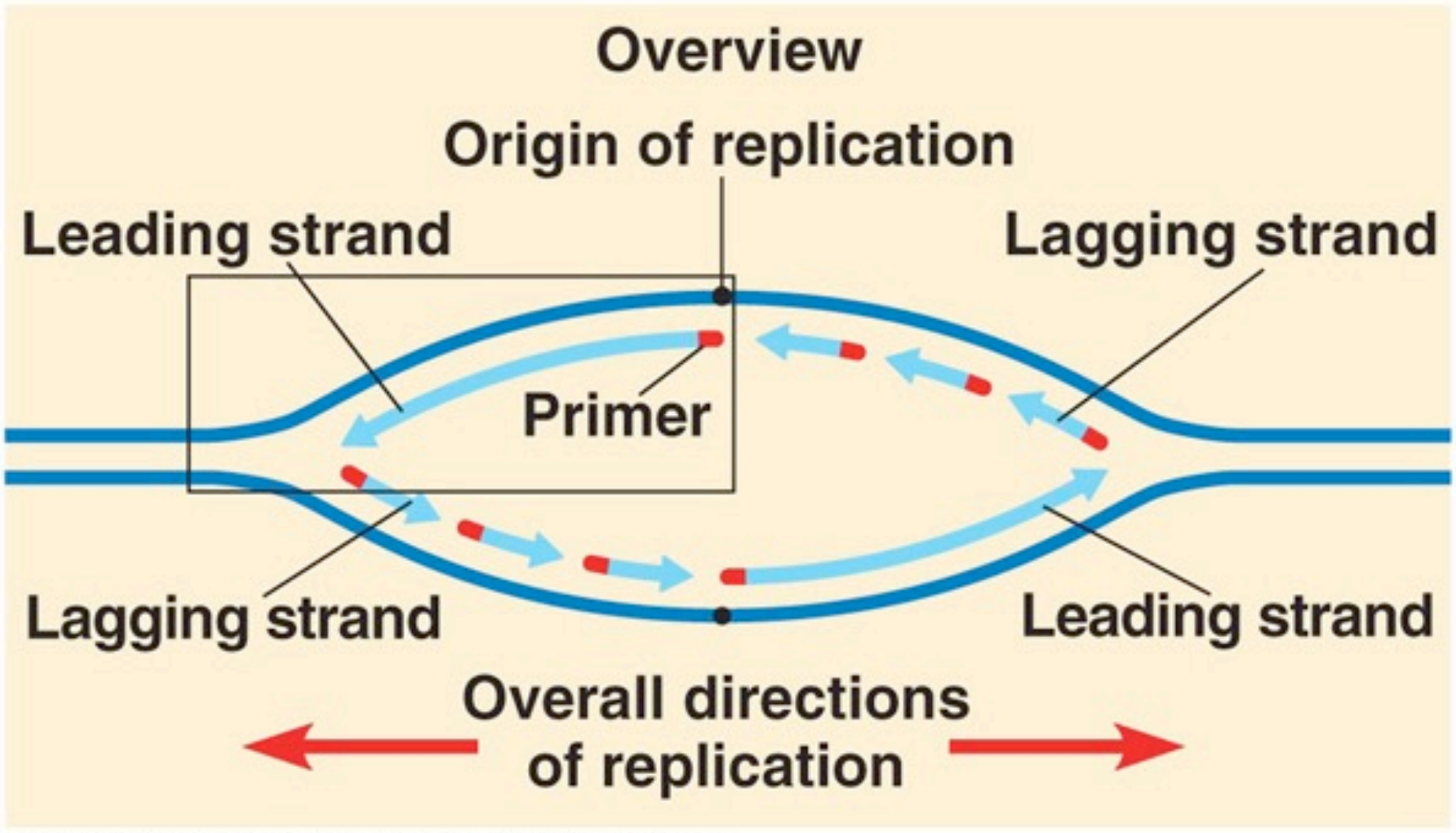
DNA Replication- always adds nucleotides to the 3' end of the growing DNA strand



DNA Replication

Leading Strand- *works towards the replication fork*

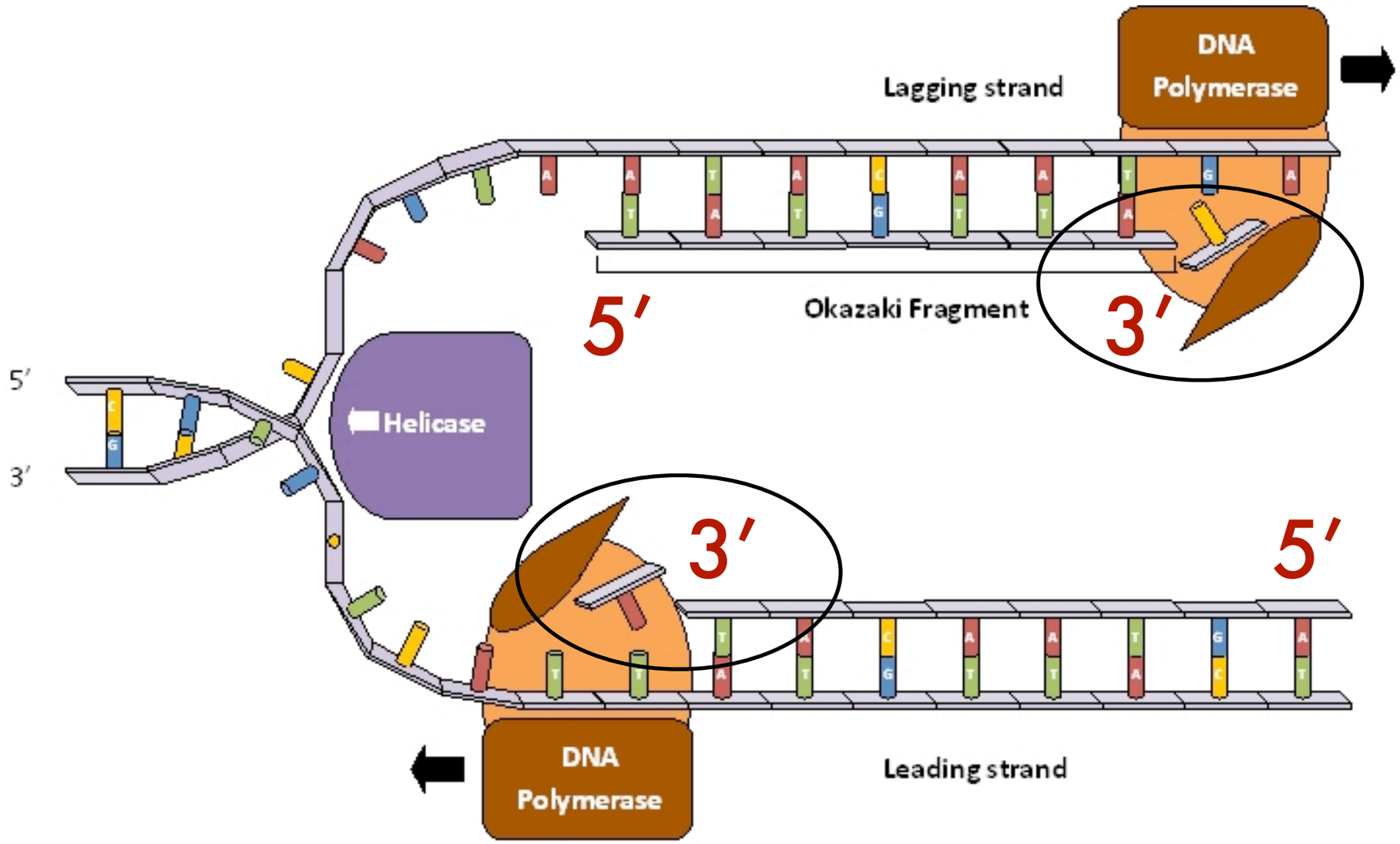
Lagging Strand- *works away from the replication fork*



DNA Replication

Leading Strand- *is produced continuously*

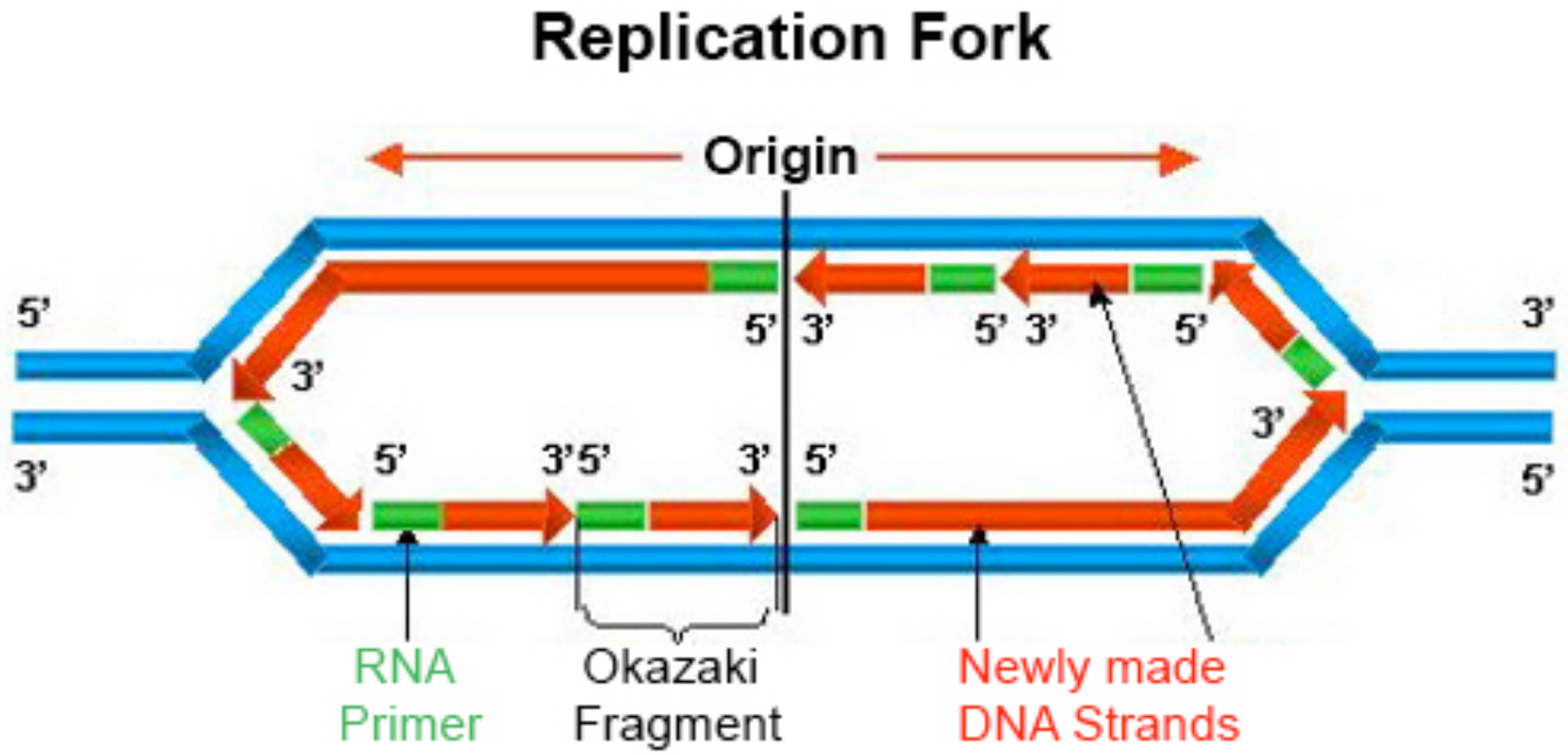
Lagging Strand- *is produced in pieces called Okazaki Fragments*



DNA replication always adds nucleotides to the 3′ end of the growing DNA strand

DNA Replication

DNA Polymerase I- *replaces RNA primers with DNA nucleotides*

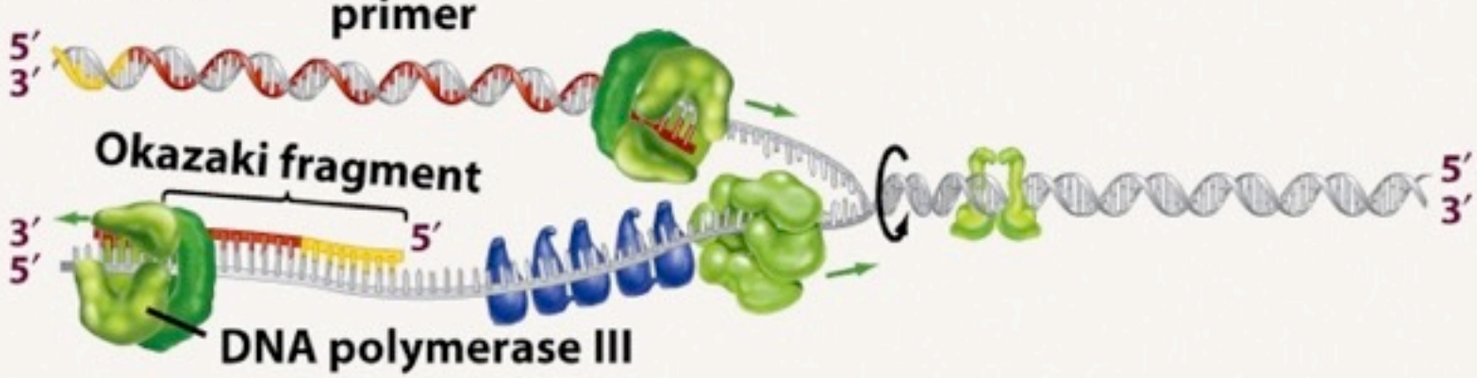


Ligase- *forms covalent bonds between Okazaki fragments in the lagging strand*

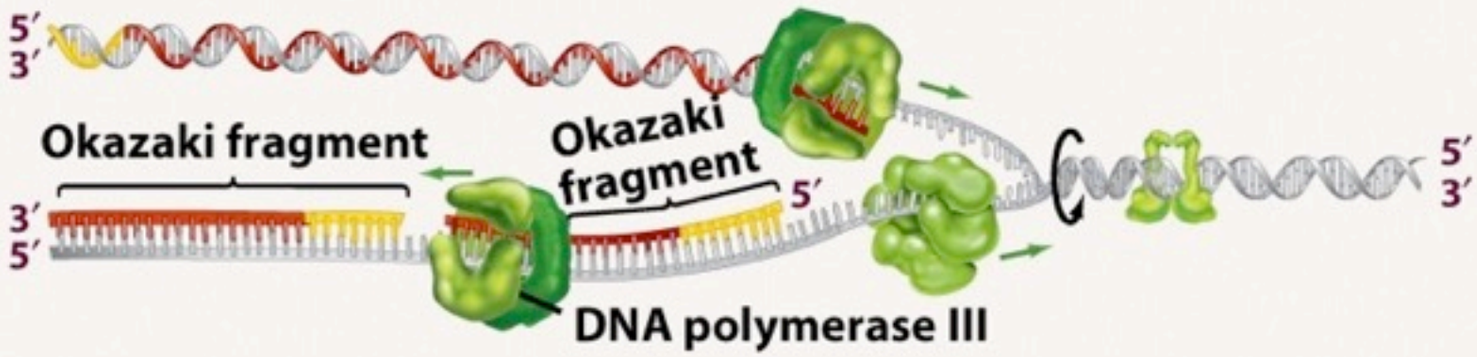
SYNTHESIS OF LAGGING STRAND

1. Primase synthesizes RNA primer.

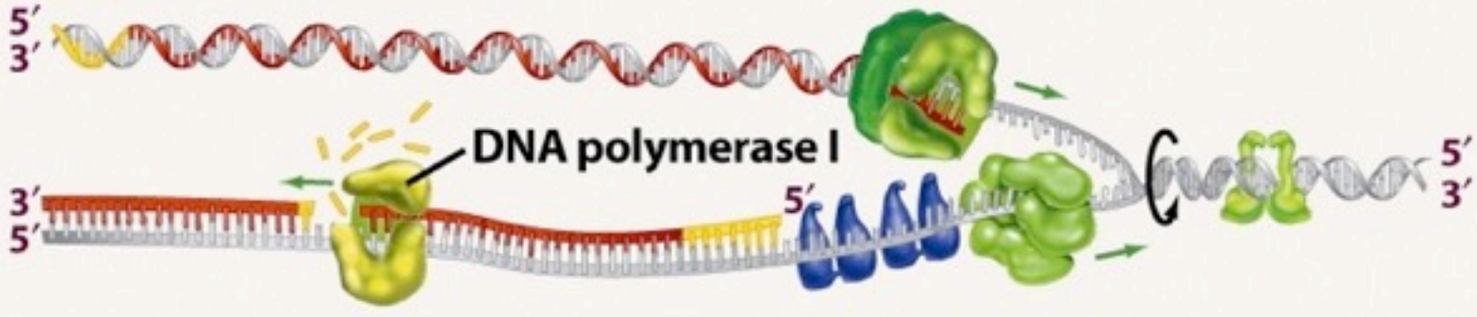
2. DNA polymerase III works in 5′→3′ direction, synthesizing lagging strand.



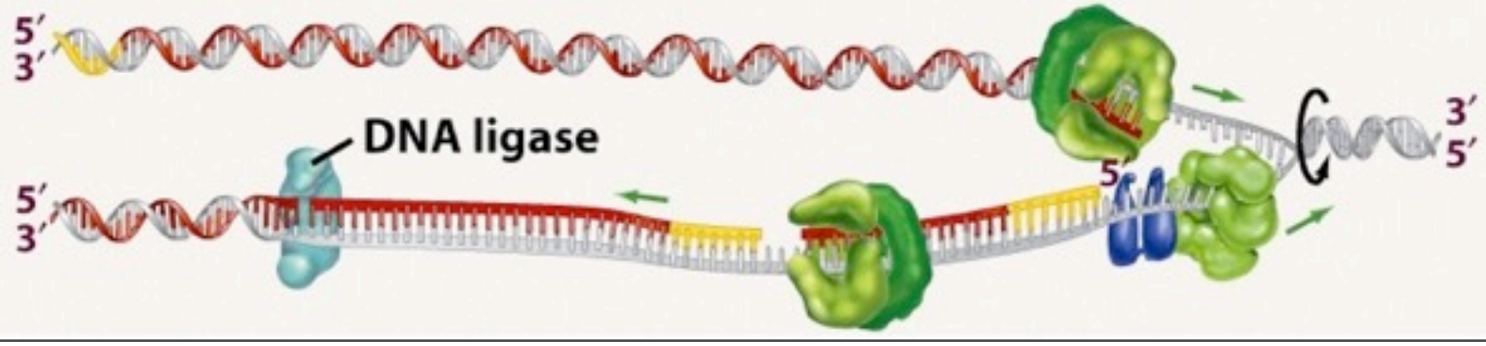
3. DNA polymerase III synthesizes another fragment.



4. DNA polymerase I removes ribonucleotides of primer, replaces them with deoxyribonucleotides in 5′→3′ direction.



5. DNA ligase closes gap in sugar-phosphate backbone.



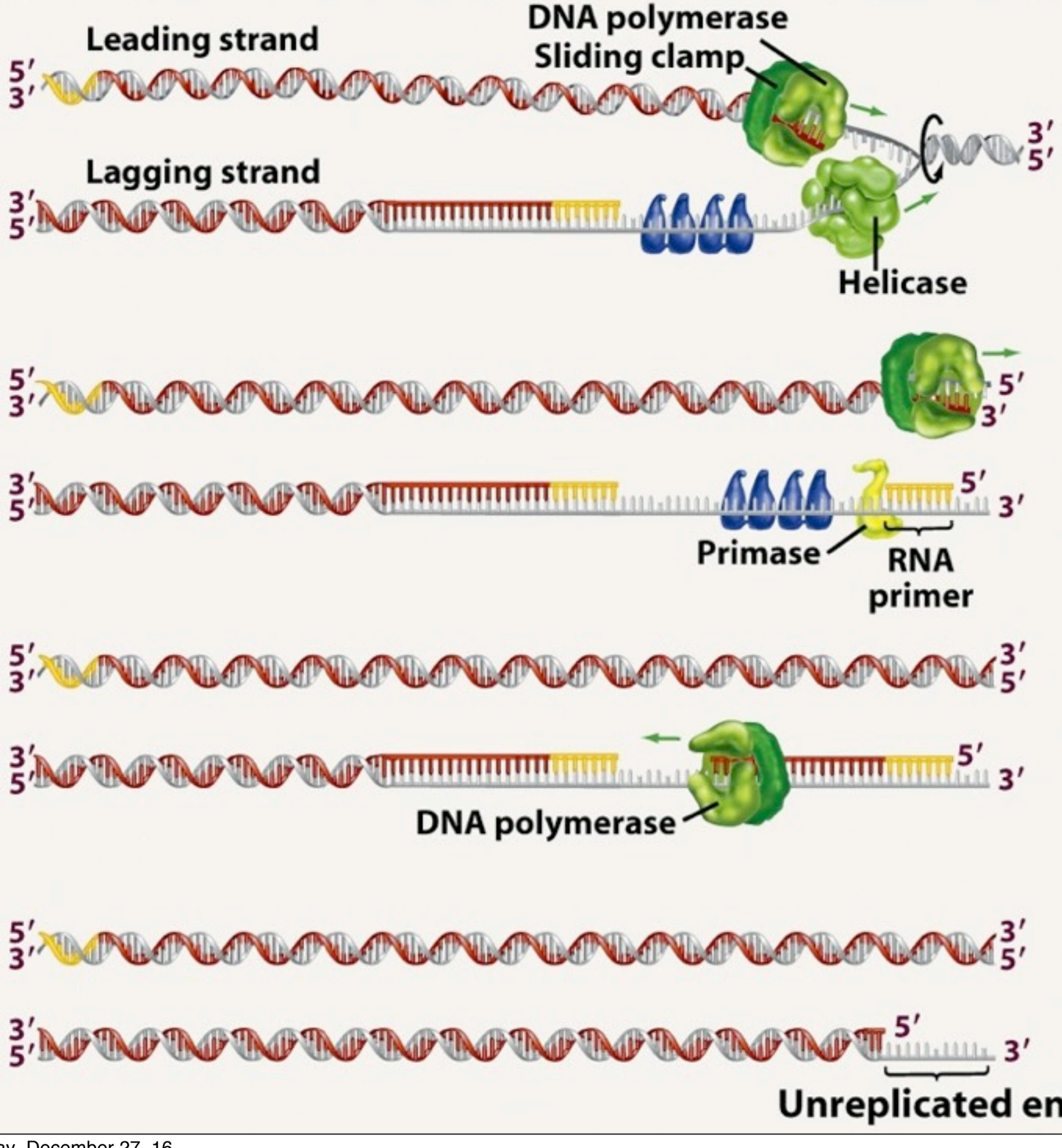
DNA Replication

Another important distinction- *prokaryotes have circular chromosomes, while eukaryotes have linear chromosomes.*

Replicating the ends of linear eukaryotic DNA presents its own unique set of problems.

The next slide illustrates the problem more clearly.

CHROMOSOME SHORTENING DURING NORMAL DNA REPLICATION



1. Helicase unwinds end of DNA helix (at end of chromosome).

2. DNA polymerase completes the leading strand. Primase synthesizes RNA primer at end of lagging strand.

3. DNA polymerase synthesizes the last Okazaki fragment in lagging strand.

4. No DNA synthesis occurs after primer is removed (no free 3′ end for DNA polymerase); chromosome is shortened.

As you can see one strand of DNA remains unfinished and the over hanging end will be removed, which completes replication.

This will however result in the DNA becoming shorter over time and eventually “eating away” important sequences that code for polypeptides.

Eukaryotes avoid this problem because the ends of their DNA has has about 6 nucleotides repeated hundreds of times, this creates long noncoding sequences called **telomeres** at the ends of linear chromosomes.

Of course, the length of the telomere will limit the number of times a molecule of DNA can be replicated.

DNA Replication

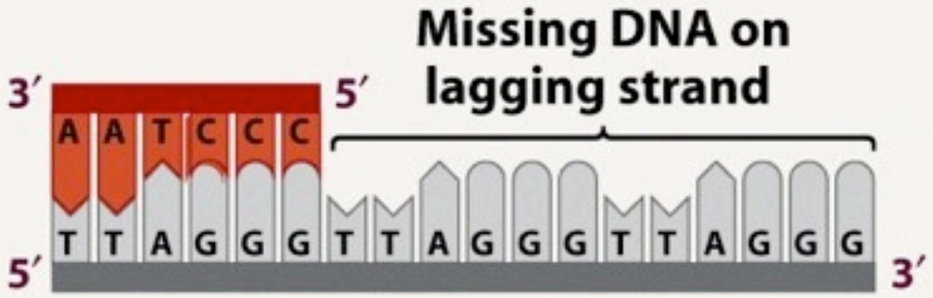
But what about germ cells, whose genome must persist virtually unchanged over the generations?

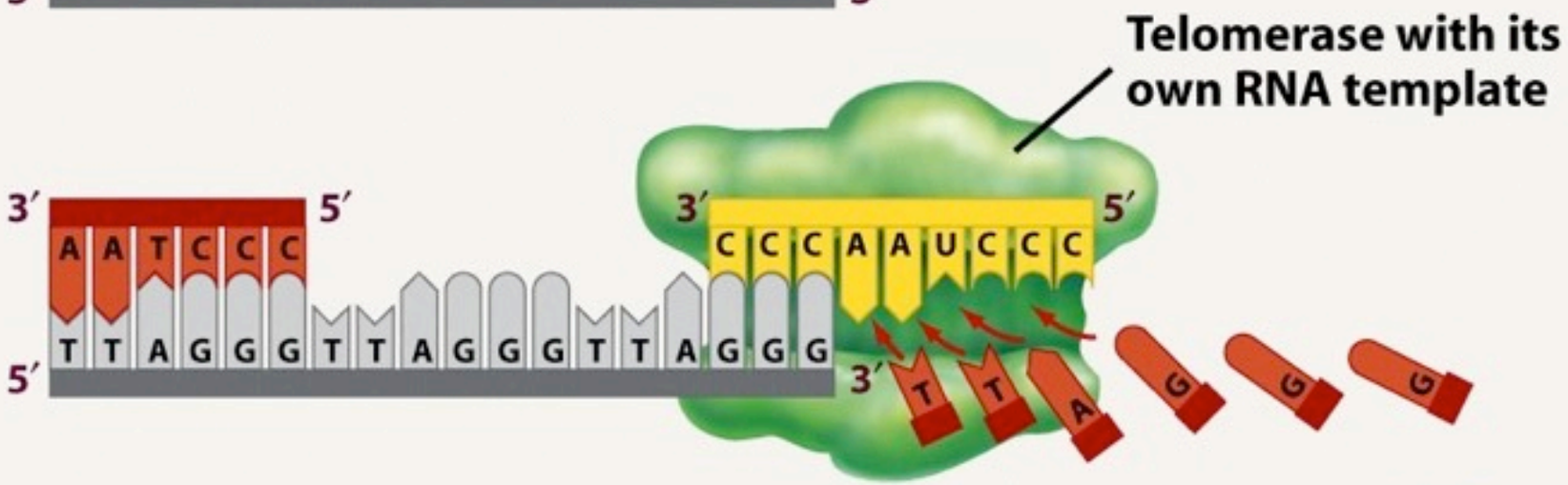
Think about it...If germ cells DNA got shorter with each replication the gametes would eventually lose all their DNA.

Germ cells have an enzyme called telomerase, that rebuilds the telomeres so that the length of the DNA remains constant over time.

Telomerase is not active in most somatic cells, in fact this may play a protective role in preventing cells that become cancerous from replicating indefinitely.

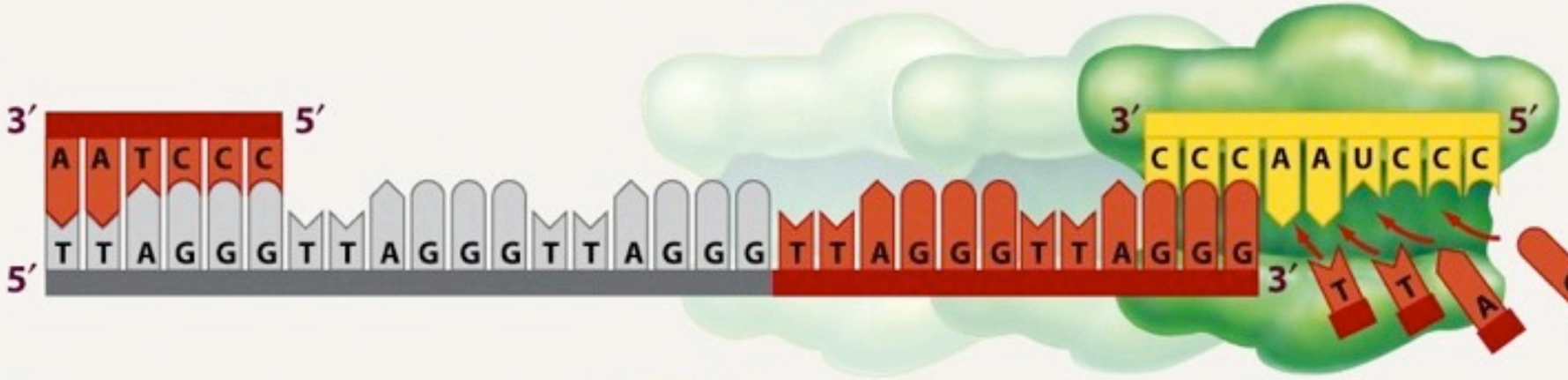
TELOMERE REPLICATION



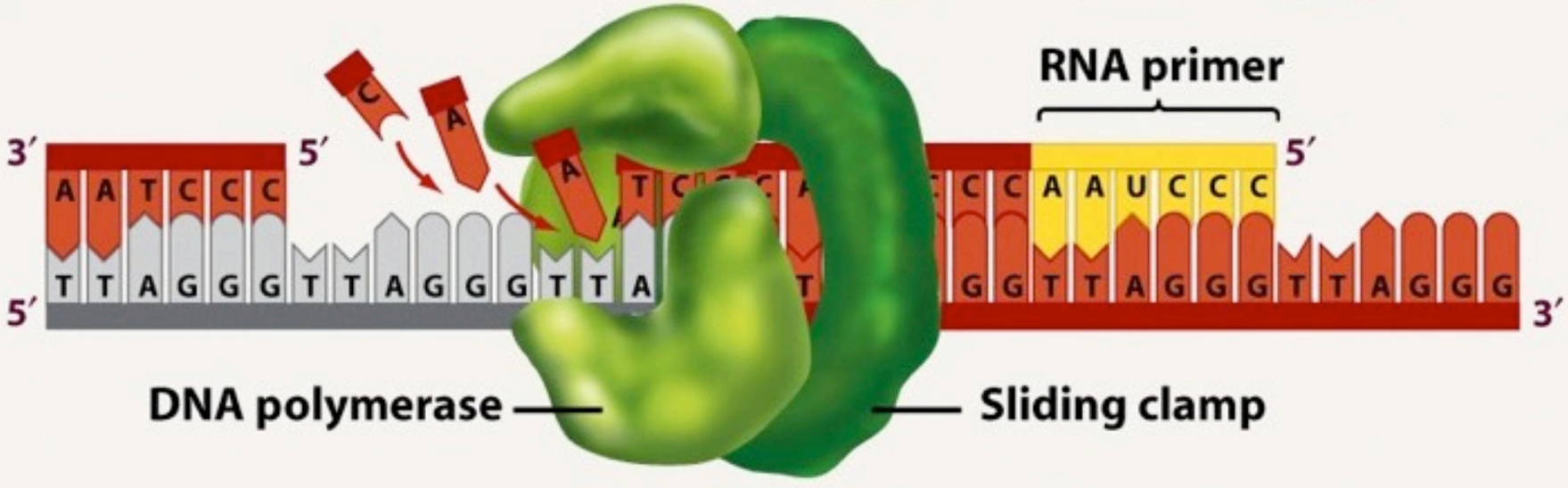


1. When the RNA primer is removed from the 5′ end of the lagging strand (see Figure 14.14), a strand of parent DNA remains unreplicated.

2. Telomerase binds to the "overhanging" section of single-stranded DNA. Telomerase adds deoxyribonucleotides to the end of the parent DNA, extending it.



3. Telomerase moves down the DNA strand and adds additional repeats.



4. Primase, DNA polymerase, and ligase then synthesize the lagging strand in the 5′→3′ direction, restoring the original length of the chromosome.

DNA Replication: Enzymes

Bacterial DNA replication proteins and their functions

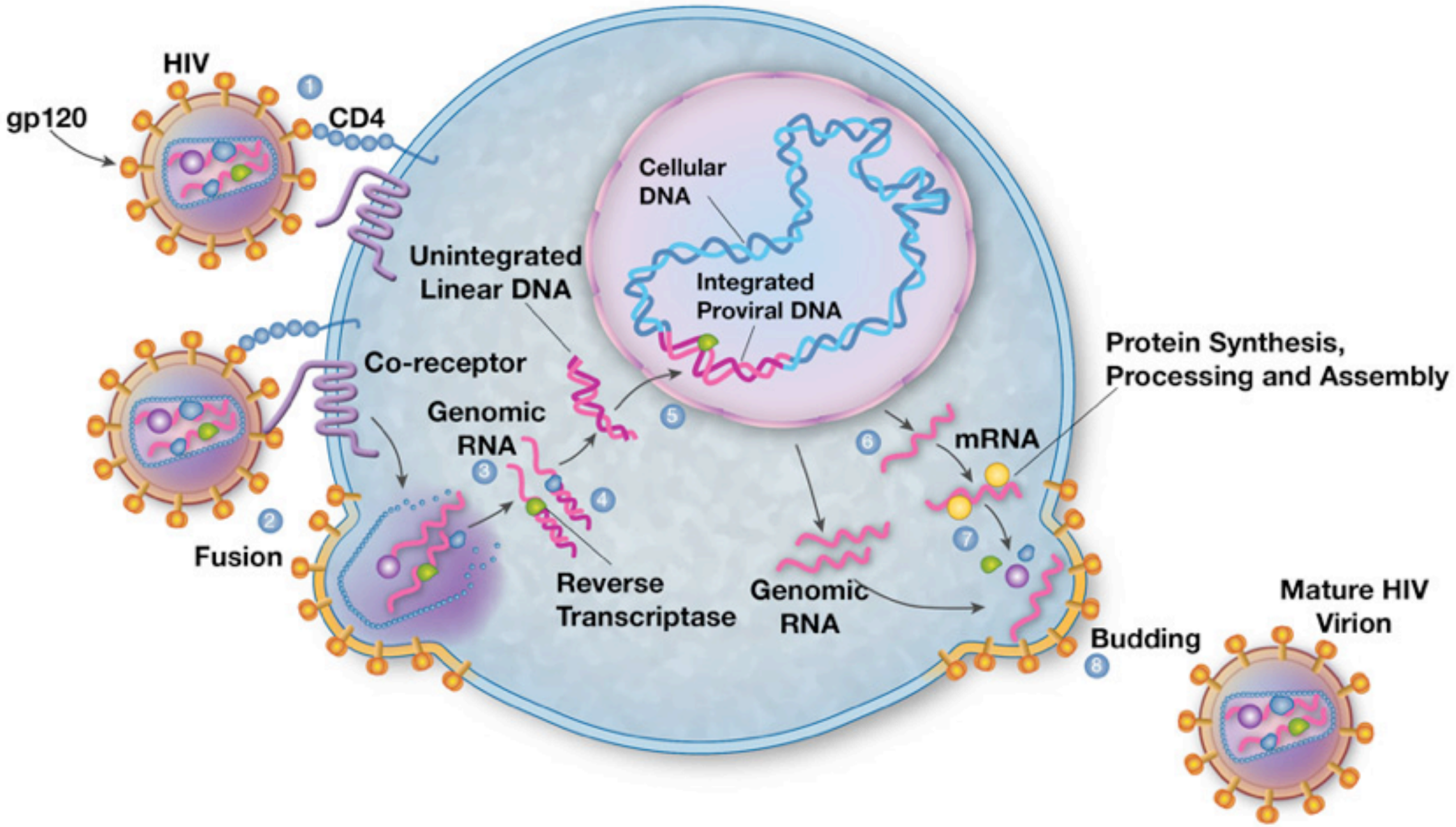
Protein	Function for Leading and Lagging Strands
Helicase	Unwinds parental double helix at replication forks
Single-strand binding protein	Binds to and stabilizes single-stranded DNA until it can be used as a template
Topoisomerase	Corrects "overwinding" ahead of replication forks by breaking, swiveling, and rejoining DNA strands

	Function for Leading Strand	Function for Lagging Strand
Primase	Synthesizes a single RNA primer at the 5′ end of the leading strand	Synthesizes an RNA primer at the 5′ end of each Okazaki fragment
DNA pol III	Continuously synthesizes the leading strand, adding on to the primer	Elongates each Okazaki fragment, adding on to its primer
DNA pol I	Removes primer from the 5′ end of leading strand and replaces it with DNA, adding on to the adjacent 3′ end	Removes the primer from the 5′ end of each fragment and replaces it with DNA, adding on to the 3′ end of the adjacent fragment
DNA Ligase	Joins the 3′ end of the DNA that replaces the primer to the rest of the leading strand	Joins the Okazaki fragments

Another important distinction- Eukaryotes have a least 11 different DNA polymerases involved in replication

Viral Reproduction: Animal (Retrovirus)

HIV Replication Cycle



Essential knowledge 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.

b. DNA and RNA molecules have structural similarities and differences that define function. [See also **4.A.1**]

Evidence of student learning is a demonstrated understanding of each of the following:

1. Both have three components — sugar, phosphate and a nitrogenous base — which form nucleotide units that are connected by covalent bonds to form a linear molecule with and ends, with the nitrogenous bases perpendicular to the sugar-phosphate backbone.

2. The basic structural differences include:
   i. DNA contains deoxyribose (RNA contains ribose).
   ii. RNA contains uracil in lieu of thymine in DNA.
   iii. DNA is usually double stranded, RNA is usually single stranded.
   iv. The two DNA strands in double-stranded DNA are antiparallel in directionality.

3. Both DNA and RNA exhibit specific nucleotide base pairing that is conserved through evolution: adenine pairs with thymine or uracil (A-T or A-U) and cytosine pairs with guanine (C-G).

i. Purines (G and A) have a double ring structure.

ii. Pyrimidines (C, T and U) have a single ring structure.

4. The sequence of the RNA bases, together with the structure of the RNA molecule, determines RNA function.

iii. mRNA carries information from the DNA to the ribosome.

iv. tRNA molecules bind specific amino acids and allow information in the mRNA to be translated to a linear peptide sequence.

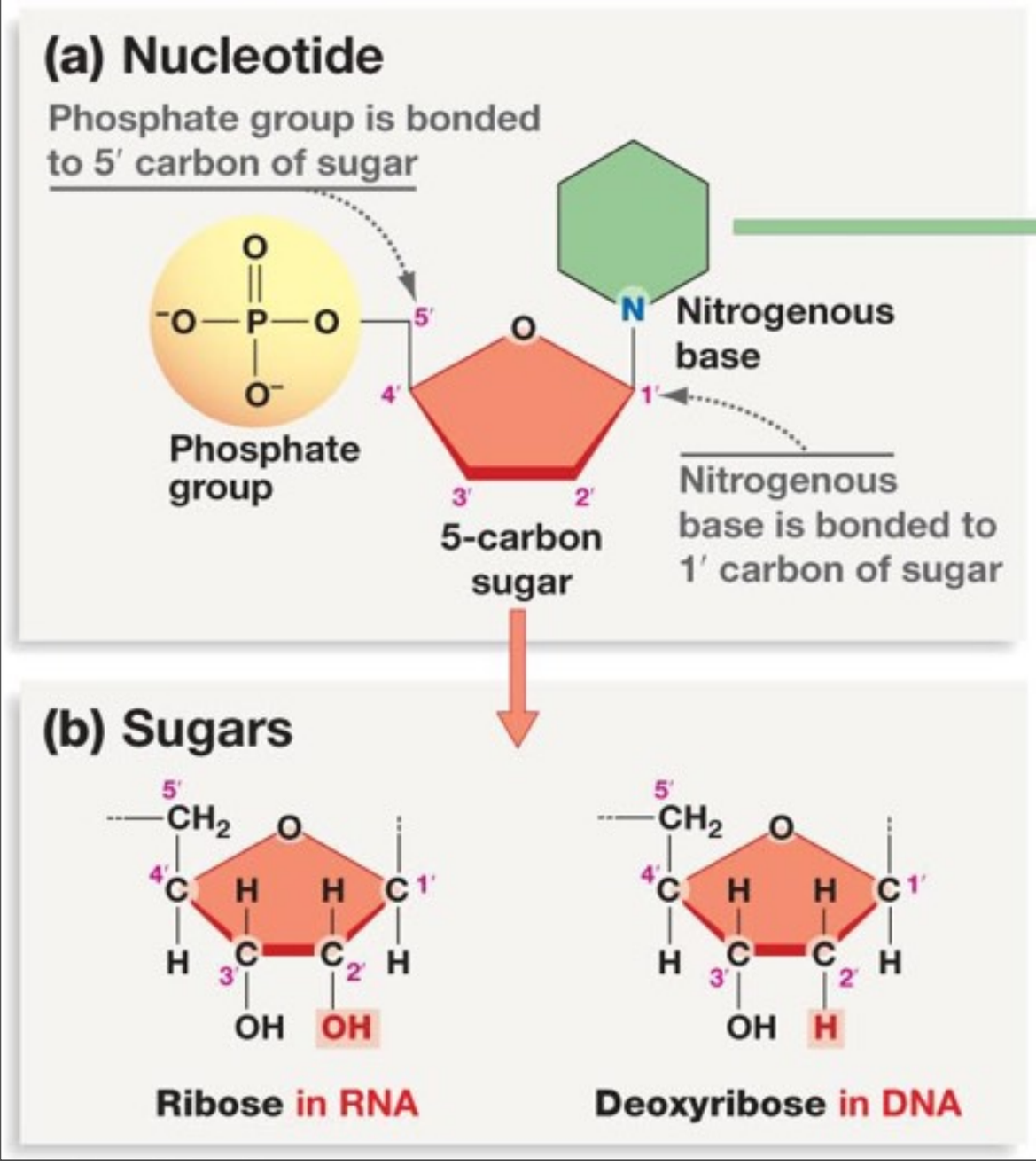
v. rRNA molecules are functional building blocks of ribosomes.

vi. The role of RNAi includes regulation of gene expression at the level of mRNA transcription.

mRNA (vs DNA)

different sugars in the backbone

Uracil instead of thymine



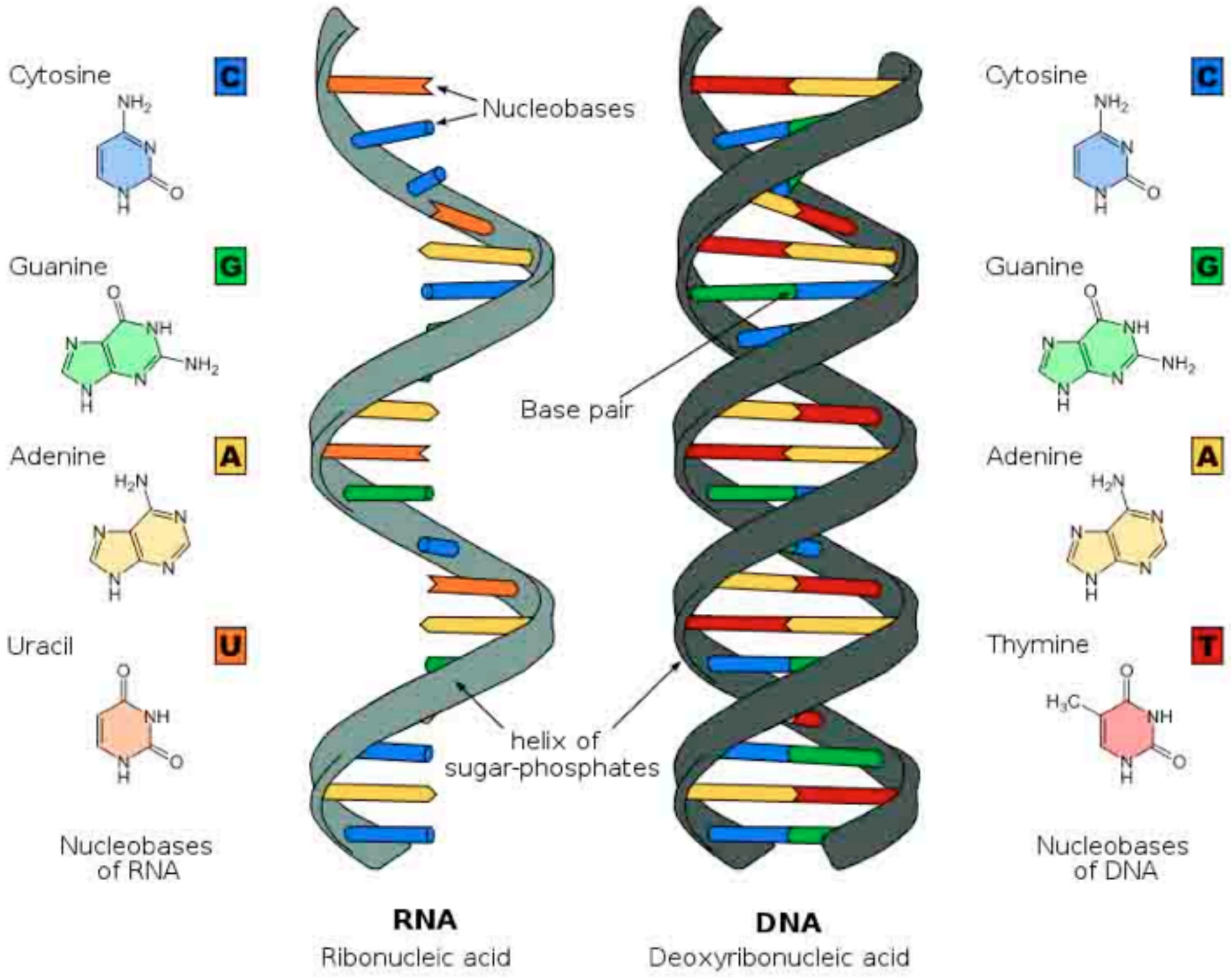
mRNA

"Our Cast of Characters"

single stranded

Uracil

ribose sugar in the backbone



Essential knowledge 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.

c. Genetic information flows from a sequence of nucleotides in a gene to a sequence of amino acids in a protein.

Evidence of student learning is a demonstrated understanding of each of the following:

1. The enzyme RNA-polymerase reads the DNA molecule in the to direction and synthesizes complementary mRNA molecules that determine the order of amino acids in the polypeptide.
2. In eukaryotic cells the mRNA transcript undergoes a series of enzyme-regulated modifications. *To foster student understanding of this concept, instructors can choose an illustrative example such as:*
    - Addition of a poly-A tail
    - Addition of a GTP cap
    - Excision of introns
3. Translation of the mRNA occurs in the cytoplasm on the ribosome.
4. In prokaryotic organisms, transcription is coupled to translation of the message. Translation involves energy and many steps, including initiation, elongation and termination.

✘✘ *The details and names of the enzymes and factors involved in each of these steps are beyond the scope of the course and the AP® Exam.*

The salient features include:

i. The mRNA interacts with the rRNA of the ribosome to initiate translation at the (start) codon.

ii. The sequence of nucleotides on the mRNA is read in triplets called codons.

iii. Each codon encodes a specific amino acid, which can be deduced by using a genetic code chart. Many amino acids have more than one codon.

✘✘ *Memorization of the genetic code is beyond the scope of the course and the AP Exam.*

i. tRNA brings the correct amino acid to the correct place on the mRNA.

ii. The amino acid is transferred to the growing peptide chain.

iii. The process continues along the mRNA until a "stop" codon is reached.

iv. The process terminates by release of the newly synthesized peptide/protein.

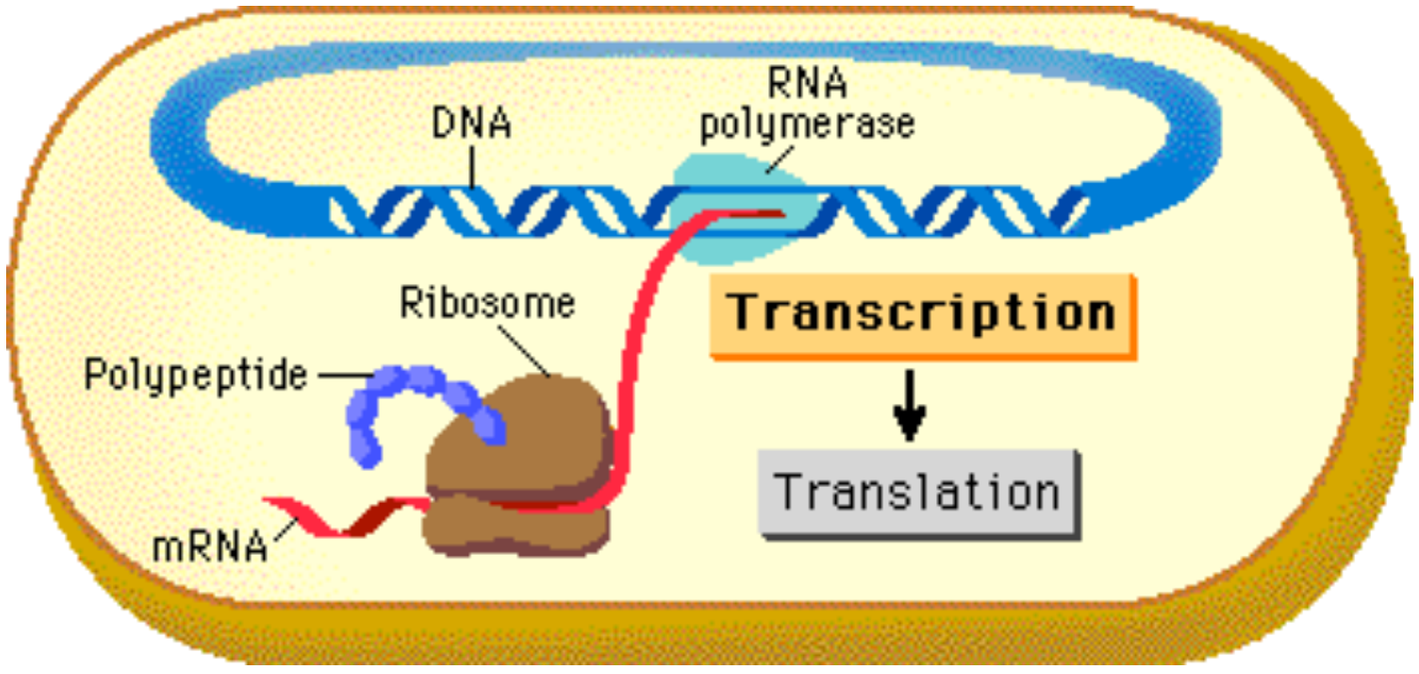
Protein Synthesis (The Basics)

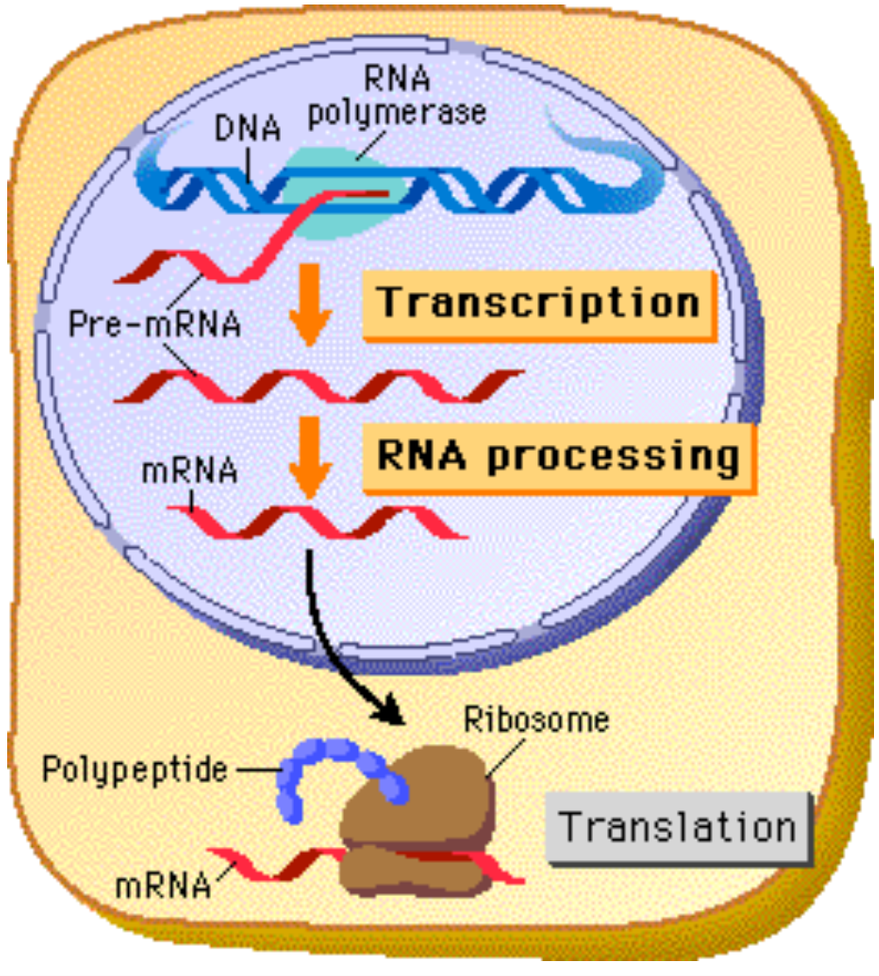
- The flow of genetic information involves two processes.
  - ***Transcription*, the synthesis of RNA using info stored in the DNA**
    - DNA serves as a template for mRNA
    - Their forms differ but their language is the same
  - ***Translation*, is the building of a polypeptide using the info stored in mRNA**
    - The language differs between nucleic acids and proteins
    - The cell must translate a nucleotide sequence into an amino acid sequence of the polypeptide

The Central Dogma

DNA → RNA → Protein

- **Transcription & Translation occurs in every organism.**
  - ***The mechanics are the same or very similar in all cells***
  - ***However, one very important difference exists between prokaryotes and eukaryotes***





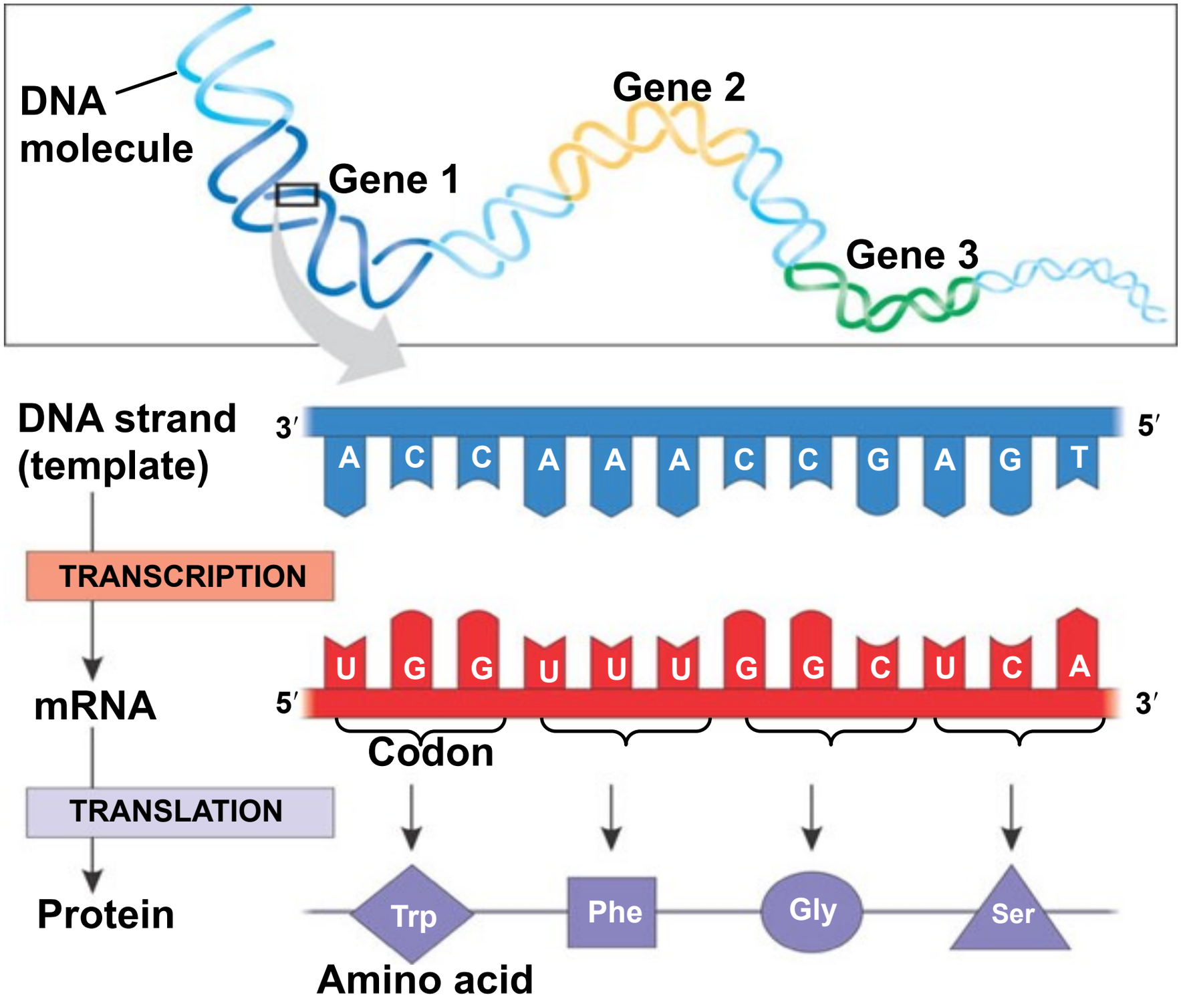
The Genetic Code

- **Once science agreed that DNA was the elusive "unit of inheritance"the next was to "crack the code".**
- **Both nucleic acids and proteins are long polymers made of molecular subunits BUT nucleic acids are built with only 4 nucleotides (subunits) and proteins are built using 20 amino acids (subunits).**
- **How does a language with 4 characters translate into a language with 20 characters?**

The Genetic Code

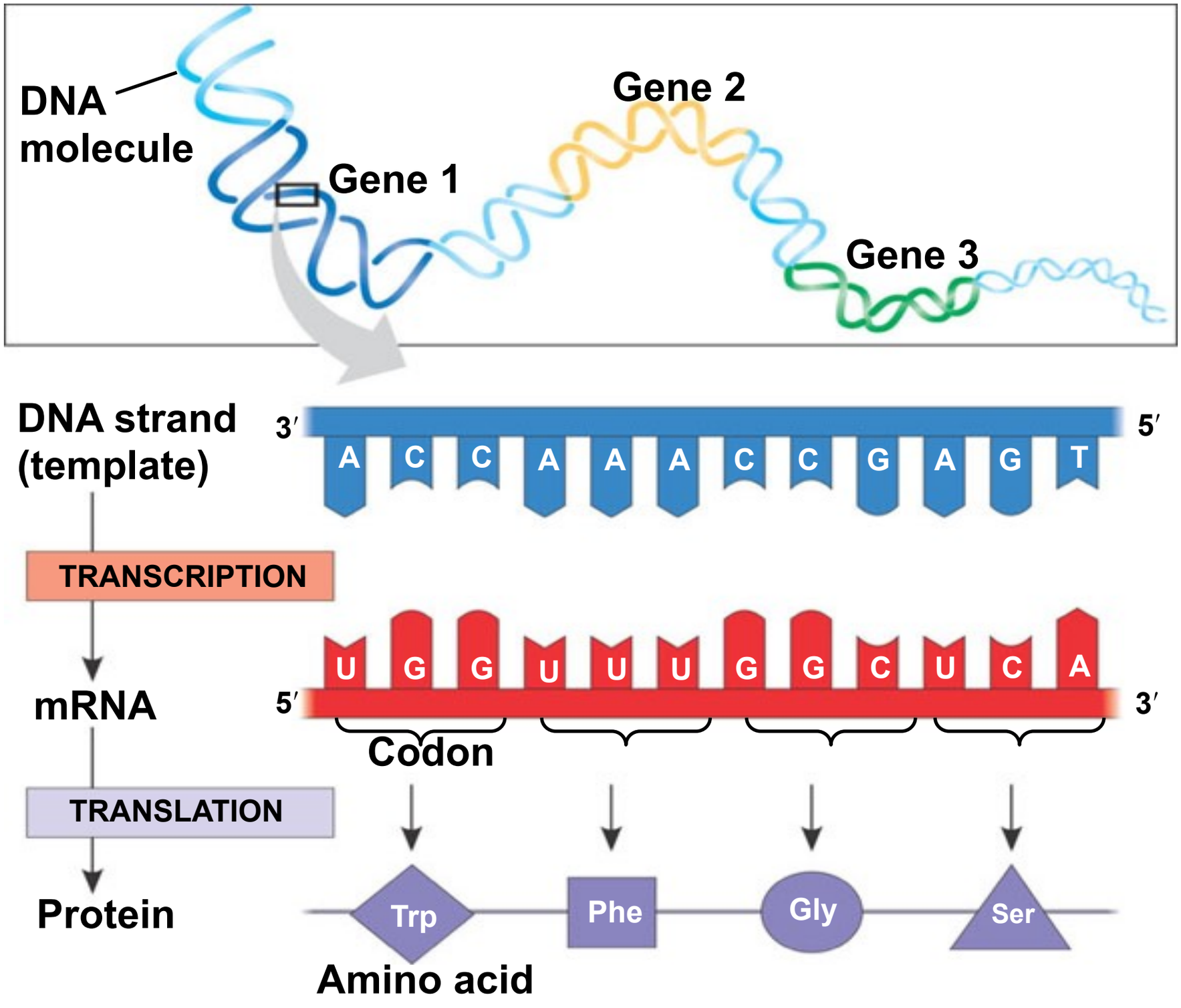
- 1 nucleotide could not code for 1 amino acid it would not be enough. $4^1 = 4 < 20$
- 2 nucleotides could not code for 2 amino acids it would not be enough. $4^2 = 16 < 20$
- 3 nucleotides could not code for 3 amino acids it would be more than enough. $4^3 = 64 > 20$
- We know that the language of life (nucleic acids) is written in a ***triplet code***.
- ***DNA uses three non-overlapping nucleotides to code for three non-overlapping nucleotides (codons) of mRNA which in turn codes for a single amino acid.***

The Genetic Code



How many nucleotides would it take to build a protein with 250 amino acids?

The Genetic Code



How many nucleotides would it take to build a protein with 250 amino acids?

750 (at least)

The Genetic Code

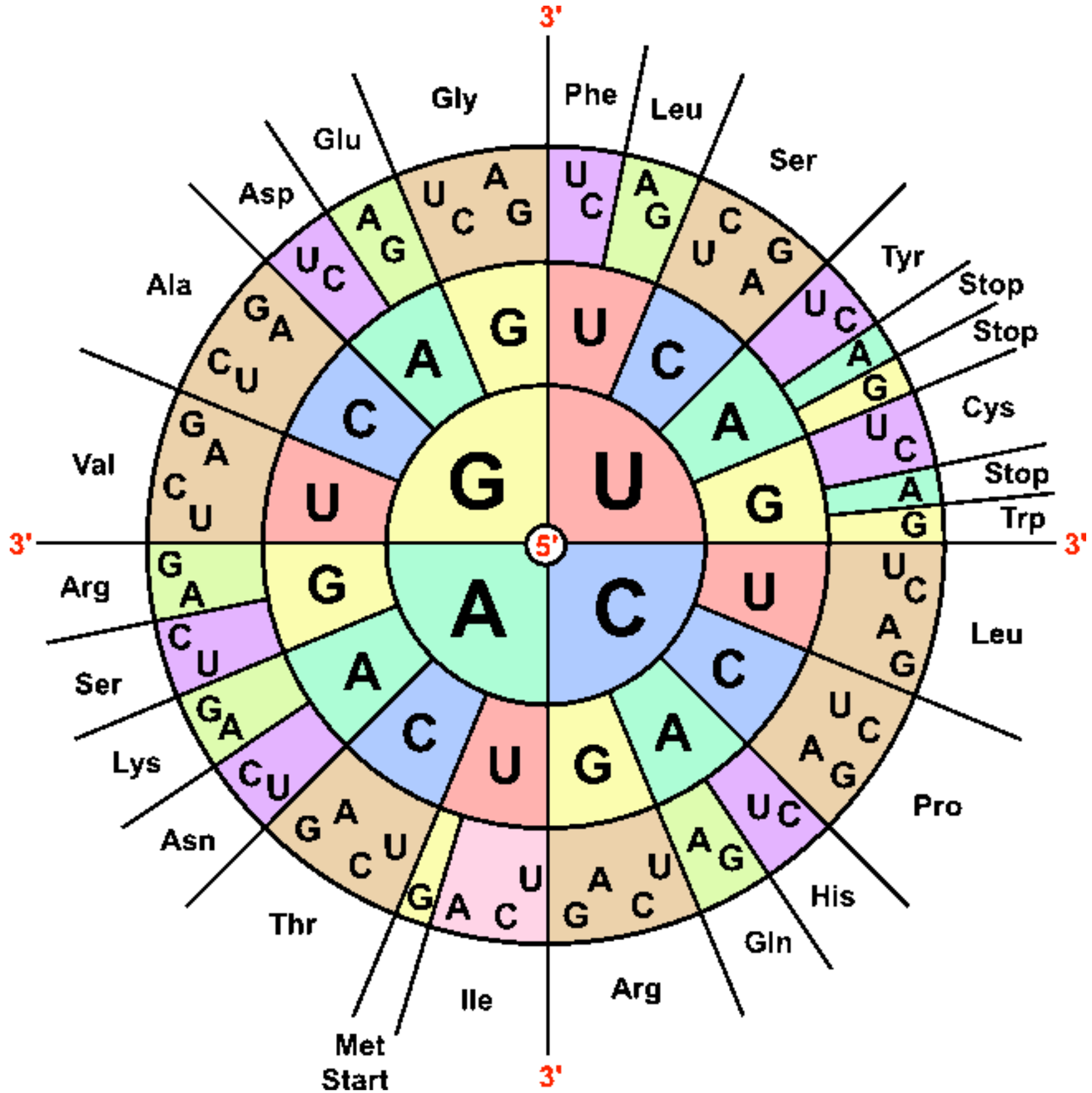
1961 Marshall Nirenberg

- Determined that UUU coded for the amino acid phenyalanine.
  - By the mid 1960's all 64 codons were deciphered.

Second Position

First Position	U		C		A		G		Third Position
U	UUU	Phe / F	UCU	Ser / S	UAU	Tyr / Y	UGU	Cys / C	U
	UUC		UCC		UAC		UGC		C
	UUA	Leu / L	UCA		*UAA*	*STOP*	*UGA*	*STOP*	A
	UUG		UCG		*UAG*	*STOP*	UGG	Trp / W	G
C	CUU	Leu / L	CCU	Pro / P	CAU	His / H	CGU	Arg / R	U
	CUC		CCC		CAC		CGC		C
	CUA		CCA		CAA	Gln / Q	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU	Ile / I	ACU	Thr / T	AAU	Asn / N	AGU	Ser / S	U
	AUC		ACC		AAC		AGC		C
	AUA		ACA		AAA	Lys / K	AGA	Arg / R	A
	AUG	Met / M	ACG		AAG		AGG		G
G	GUU	Val / V	GCU	Ala / A	GAU	Asp / D	GGU	Gly / G	U
	GUC		GCC		GAC		GGC		C
	GUA		GCA		GAA	Glu / E	GGA		A
	GUG		GCG		GAG		GGG		G

Another Amino Acid Look Up Table



The Genetic Code

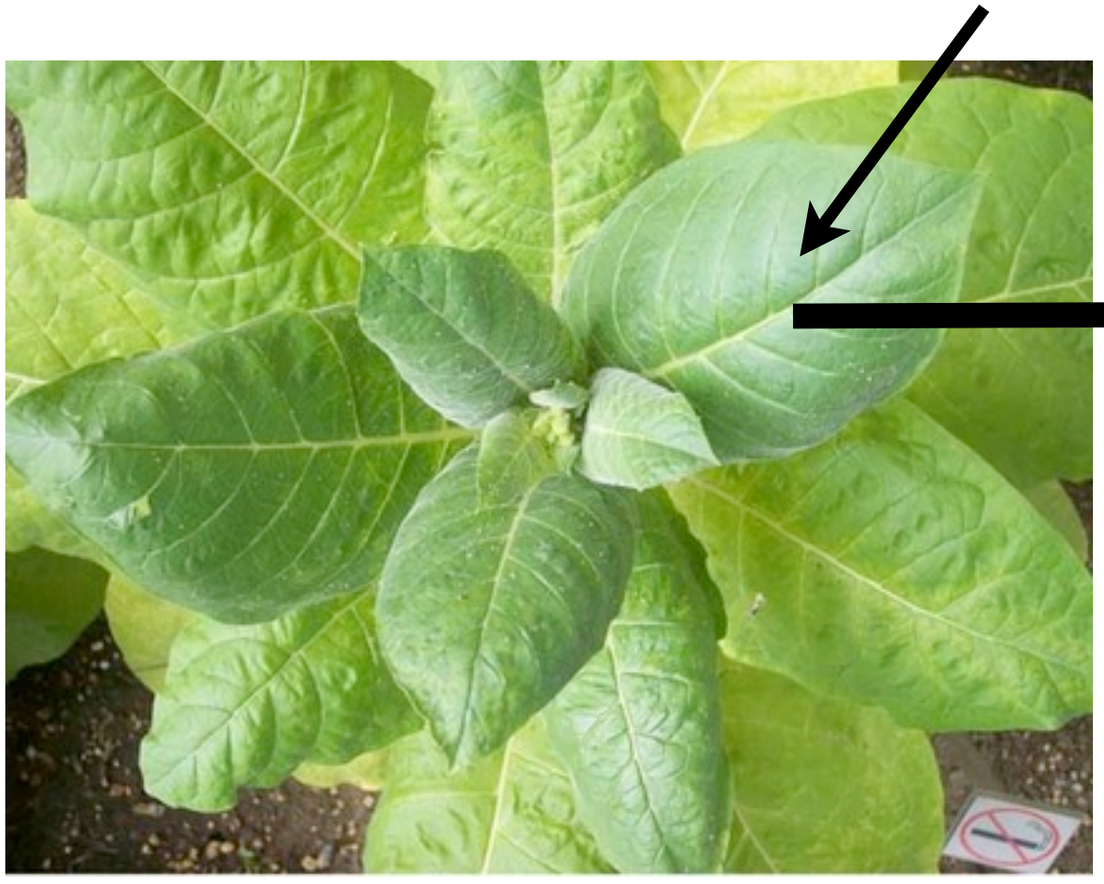
- The genetic code has some noteworthy characteristics.
  - **Redundancy**
    - AGU = serine, AGC = serine, multiple codons exist for the same amino acid
  - **No Ambiguity**
    - AGU = serine, any codon always codes for the same amino acid, it never changes
  - **Universal* (nearly)**
    - This code is identical from bacteria to blue whales!

*A shared genetic code supports the idea common ancestry among all living organisms

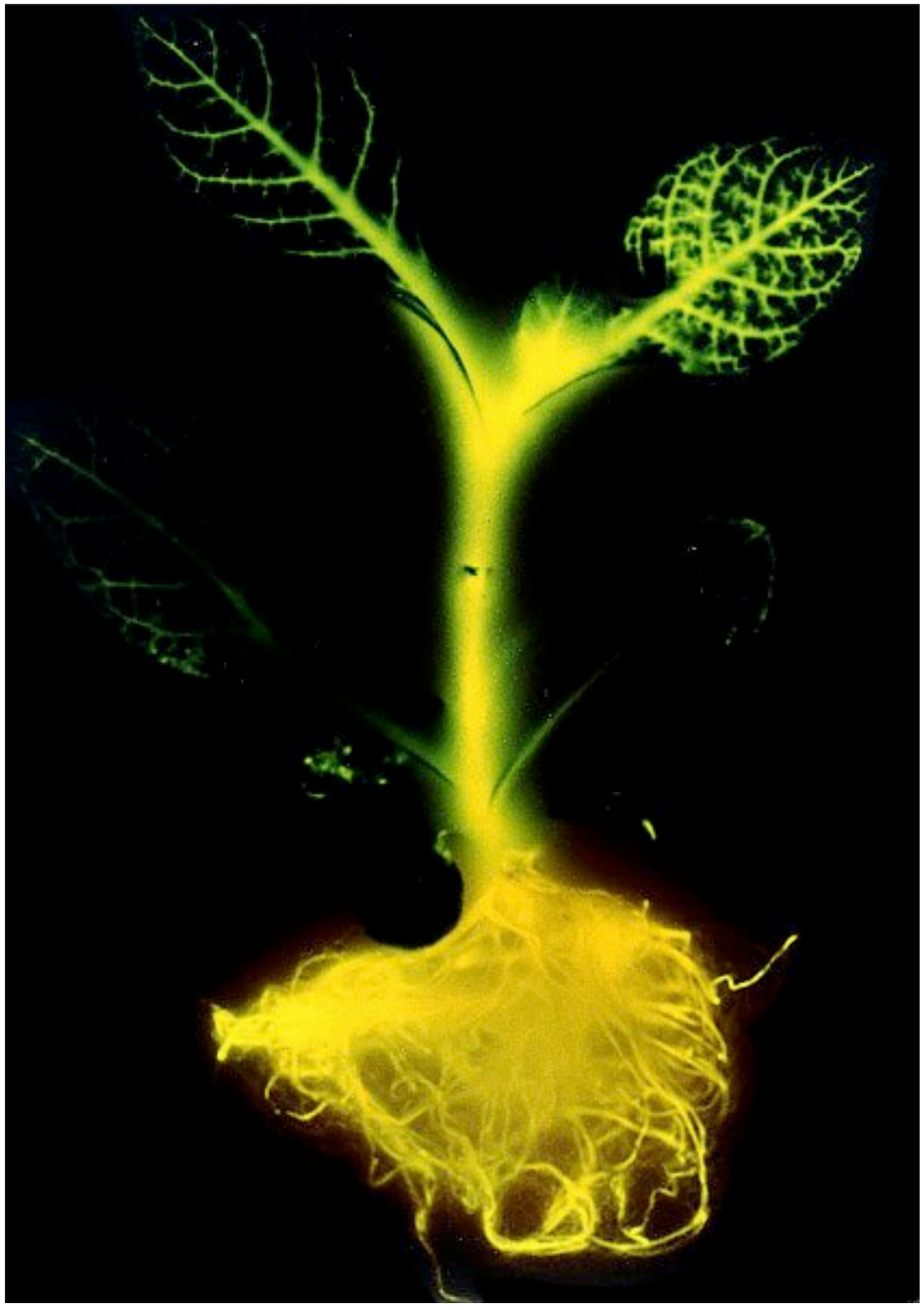
Universal Genetic Code

Firefly

Luciferase Gene



Tobacco



Prokaryotic Transcription

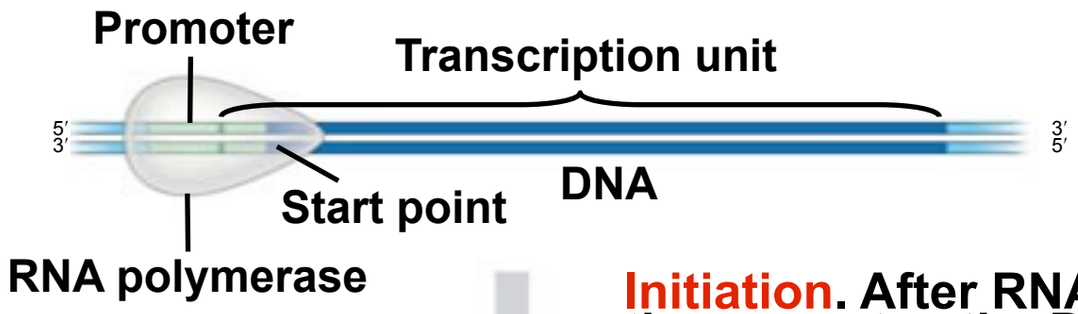
Initiation. After RNA polymerase binds to the promoter, the DNA strands unwind, and the polymerase initiates RNA synthesis at the start point on the template strand.

Elongation. The polymerase moves downstream, unwinding the DNA and elongating the RNA transcript 5′ → 3 ′. In the wake of transcription, the DNA strands re-form a double helix

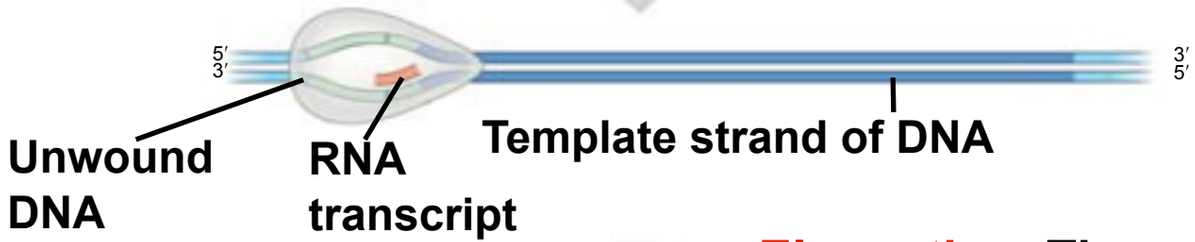
Termination. Eventually, the RNA transcript is released, and the polymerase detaches from the DNA.

As soon as one RNA polymerase moves off of promoter another one can bind and so forth like a convoy of trucks

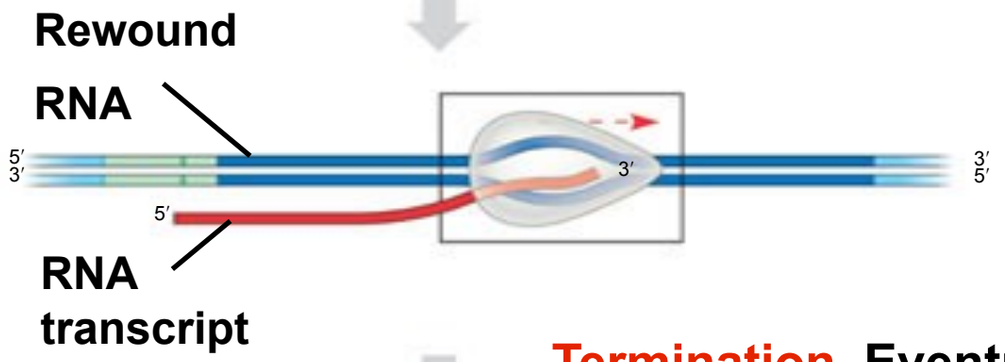
Prokaryotic Transcription



Initiation. After RNA polymerase binds to the promoter, the DNA strands unwind, and the polymerase initiates RNA synthesis at the start point on the template strand.



Elongation. The polymerase moves downstream, unwinding the DNA and elongating the RNA transcript 5′ → 3′. In the wake of transcription, the DNA strands re-form a double helix



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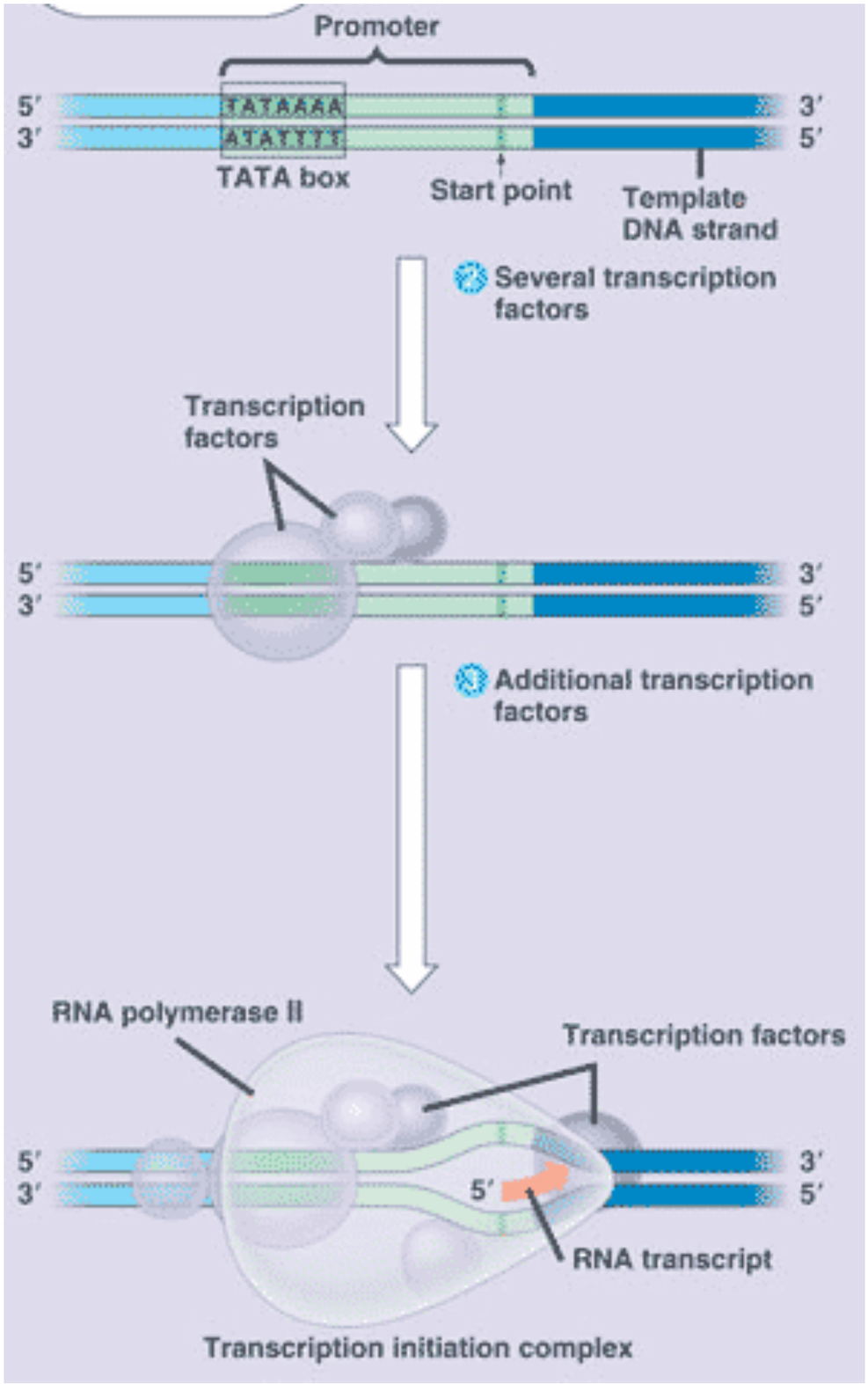
As soon as one RNA polymerase moves off of promoter another one can bind and so forth like a convoy of trucks

Eukaryotic Transcription (Initiation)



Eukaryotic Promoter- *includes TATA box a nucleotide sequence of TATA about 25 nucleotides upstream from the transcriptional starting point*

Several Transcription Factors- *one recognizing the TATA, must bind to the DNA before RNA polymerase II can bind correctly*

Additional Transcription Factors- *bind to DNA along with RNA polymerase II, forming the initiation complex, only then can RNA polymerase II begin to do its work.*

Prokaryotic Transcription (Elongation)

Elongation

RNA polymerase

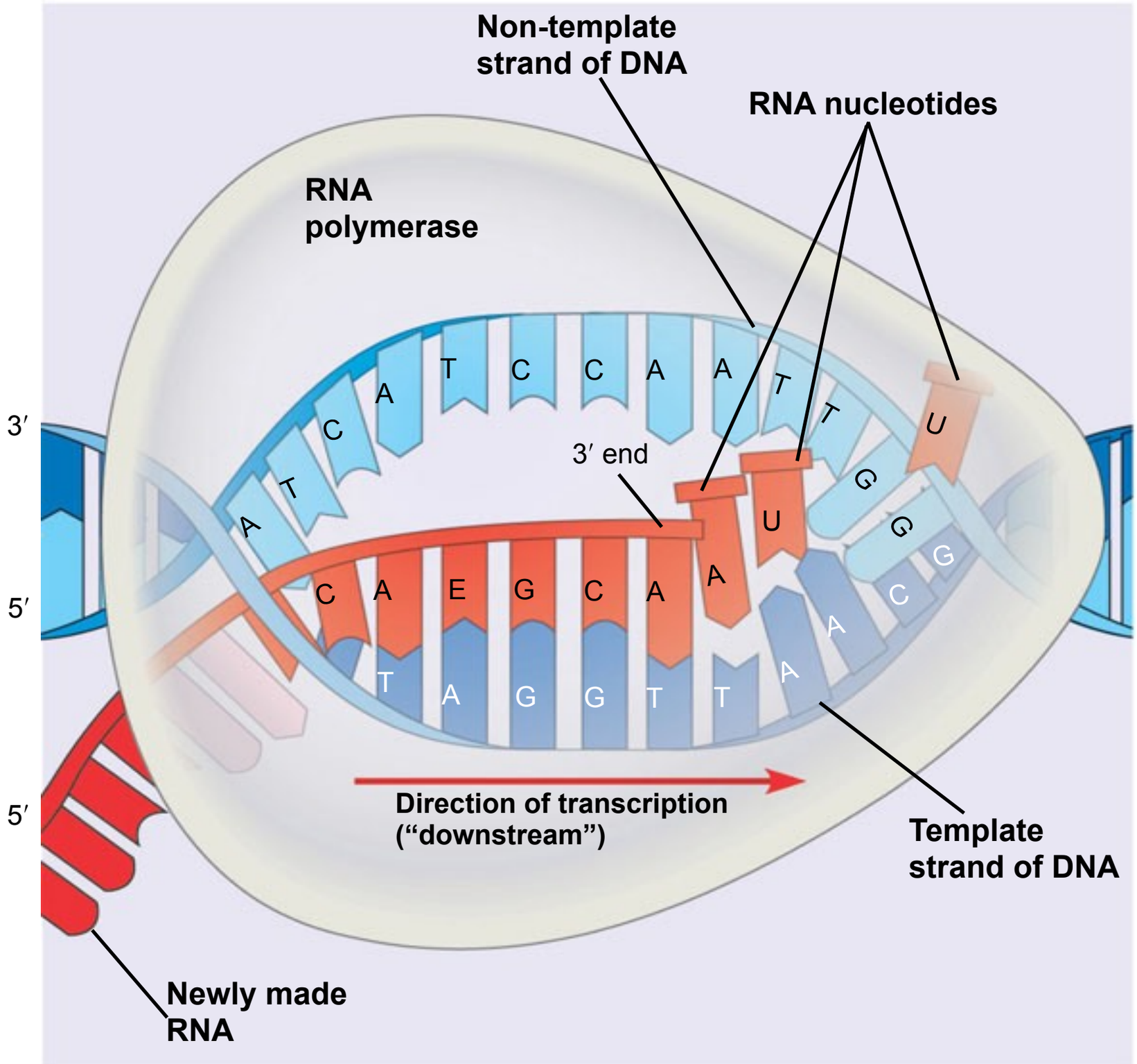
-uncoils DNA

-splits DNA

-holds DNA open

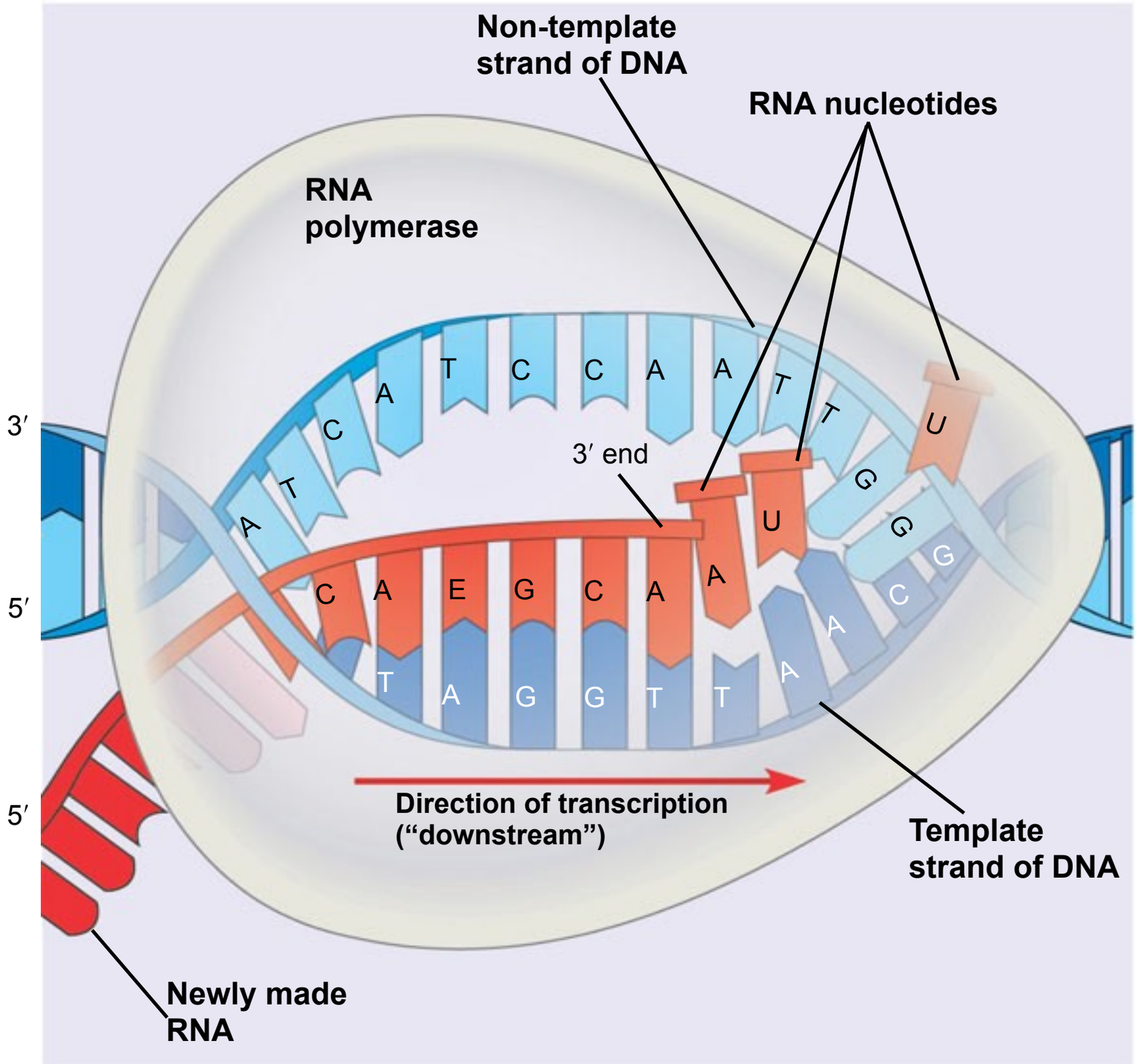
-adds RNA nucleotides

proceeds at a rate of approx. 40 nucleotides per second



Eukaryotic Transcription (Elongation)

No significant differences between prokaryotic and eukaryotic elongation



RNA polymerase

-uncoils DNA

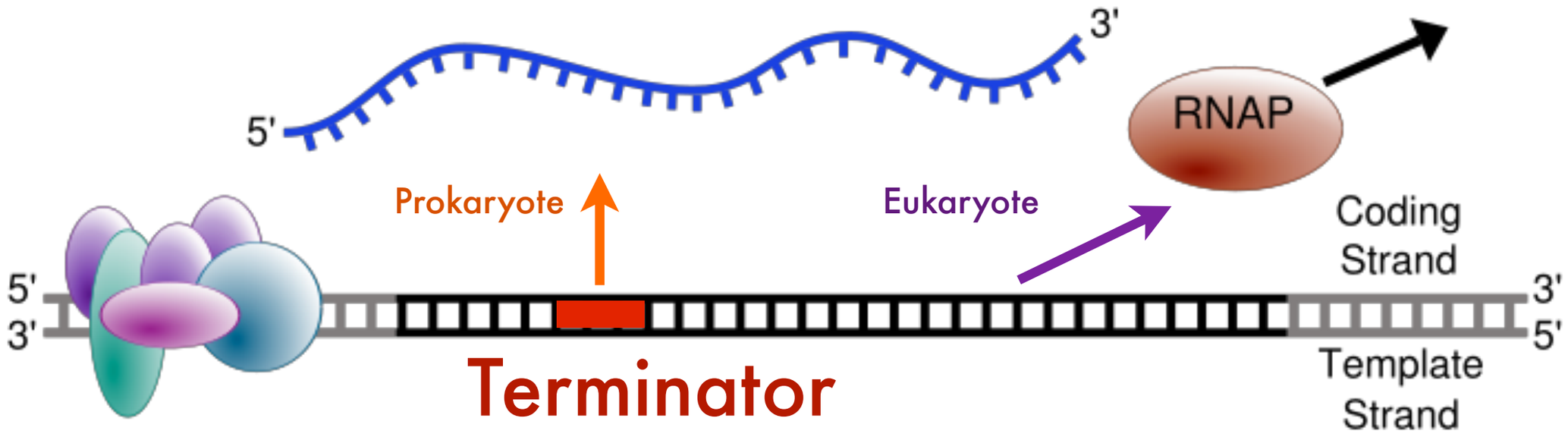
-splits DNA

-holds DNA open

-adds RNA nucleotides

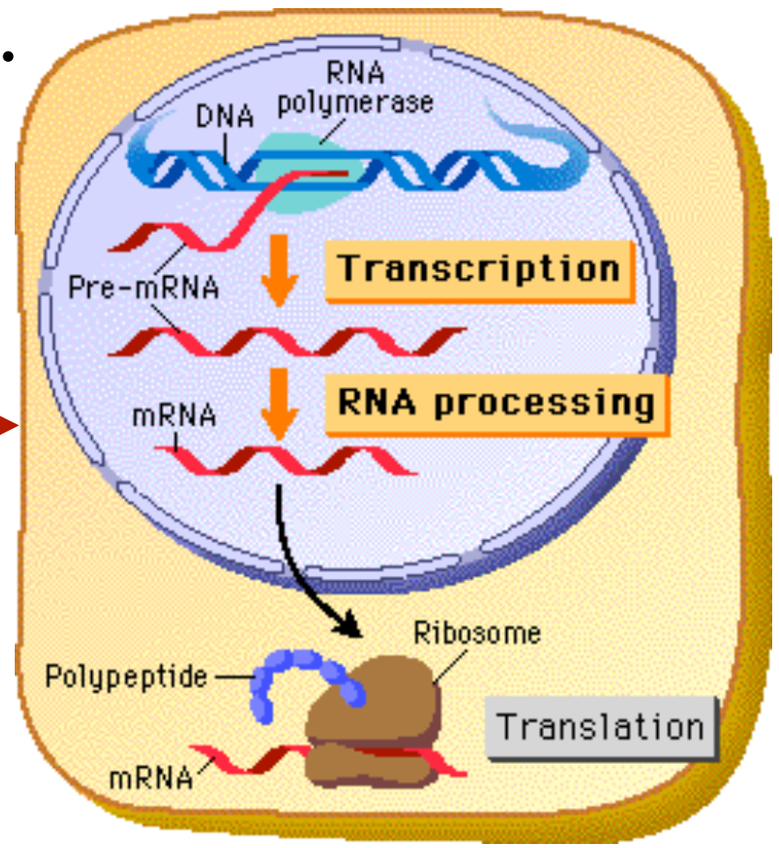
Transcription (Termination)

- Transcription stops when the RNA polymerase reaches a region on the DNA known as the terminator.
  - *This is generally true in both prokaryotes and eukaryotes.*
  - **The difference lies in the details, in prokaryotes the RNA polymerase falls off at the terminator.**
- **In Eukaryotes the RNA polymerase proceeds past the terminator for about 10-35 nucleotides downstream from the terminator and then it falls off.**



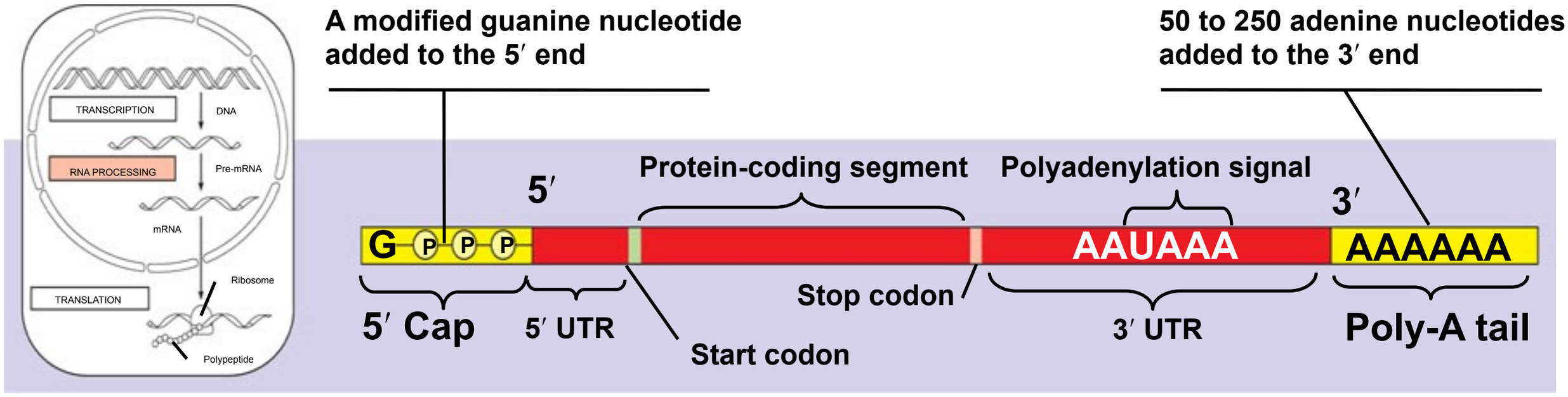
RNA Processing (eukaryotic only)

- The mRNA transcribed in eukaryotes must be modified before translation.
  - *Both ends of the mRNA need to modified and the internal portion of the mRNA must be cut and spliced.*
  - These modifications that ready eukaryotic mRNA for translation are called **RNA Processing**.



RNA Processing

- **Alteration of the Ends**
  - The 5′ prime end of mRNA receives a **5′ cap,** a modified form of guanine (G).
  - The 3′ end receives a **poly-A tail**. Several enzymes add a string of 50-250 adenines (A) after the polyadenylation signal that terminated transcription.

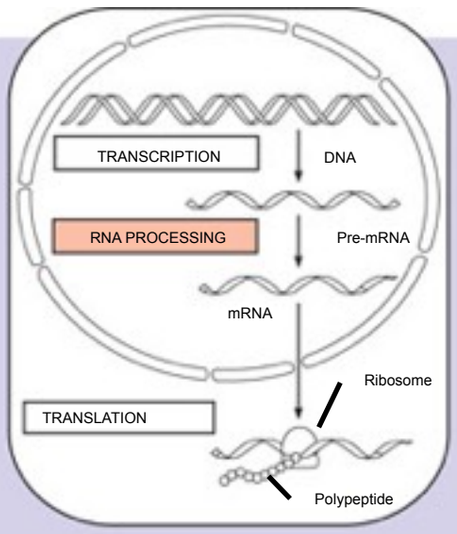


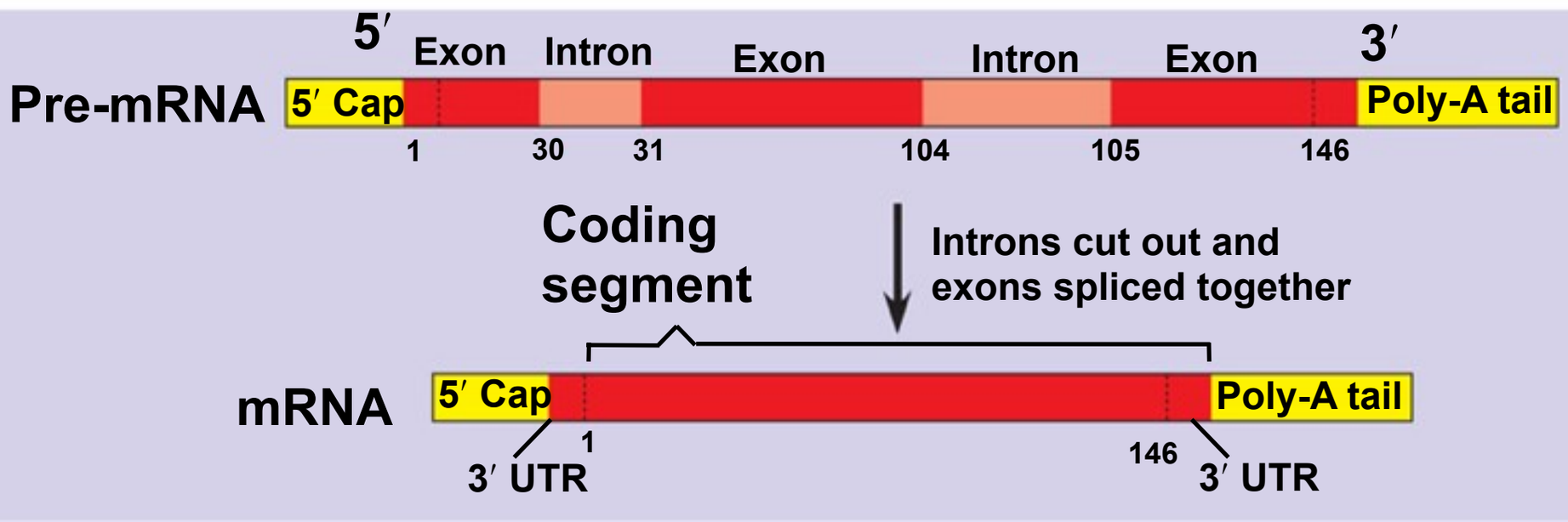
RNA Processing

- **Important Functions in the Alteration of Ends**
  - First, both *5′ cap* and *poly-A tail* facilitate the export of the mRNA from the nucleus.
  - Second, *5′ cap* and *poly-A tail* protect mRNA from the degradative enzymes found in the cytosol.
  - Third, the *5′ cap* helps orient ribosomes to the proper starting point for translation, while UTR regions help facilitate enzyme binding.

RNA Splicing

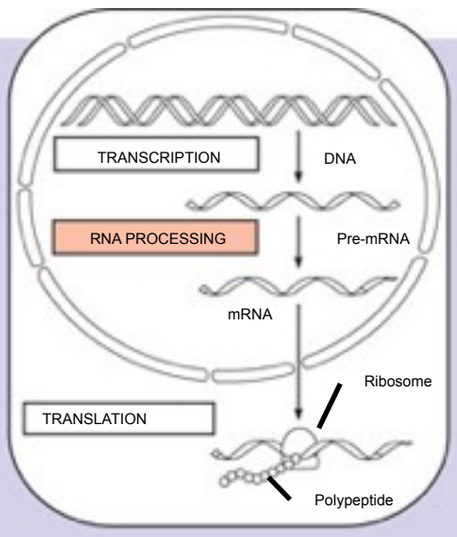
- **Gene Splicing**
  - The original mRNA that was transcribed is now highly modified in a "cut & paste" job called **RNA splicing**.
  - *The original transcript averages some 27,000 base pairs, however the average-sized protein requires only 1,200 base pairs. Most of eukaryotic mRNA is non-coding!*

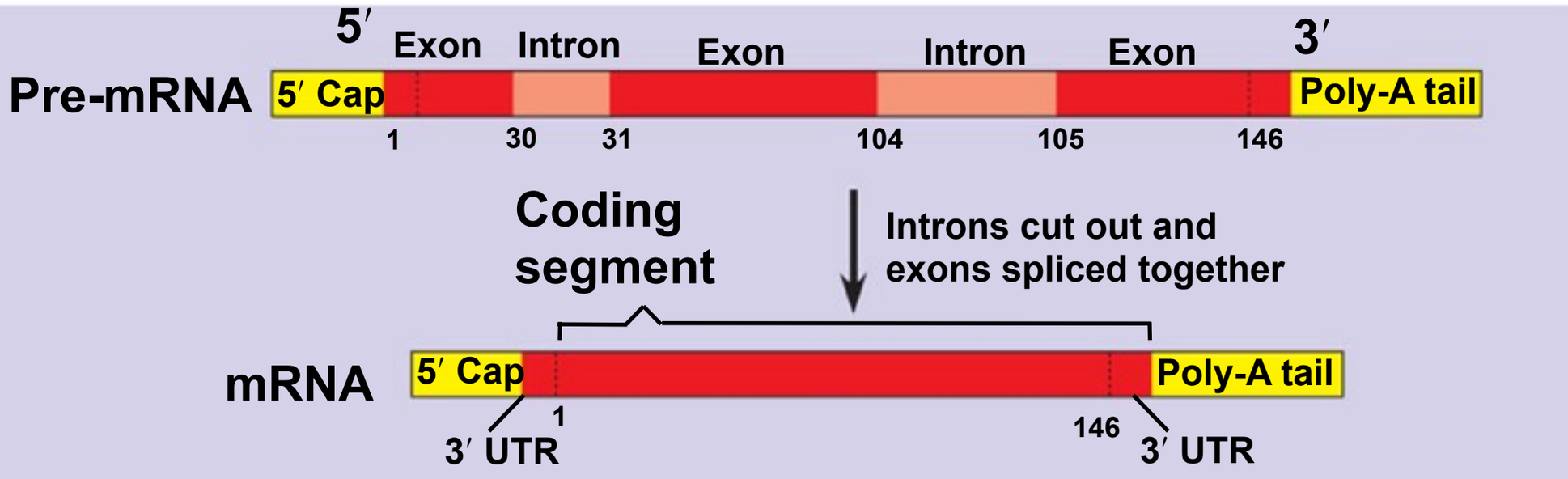




RNA Splicing

- The non-coding, "intervening" segments that lie between the coding regions are **introns**.
- The coding segments are called **exons**, because these regions are "expressed" as they get translated into amino acid sequences.
- *The exception are the UTR's which are necessary for translation but they not part of the polypeptide product.*





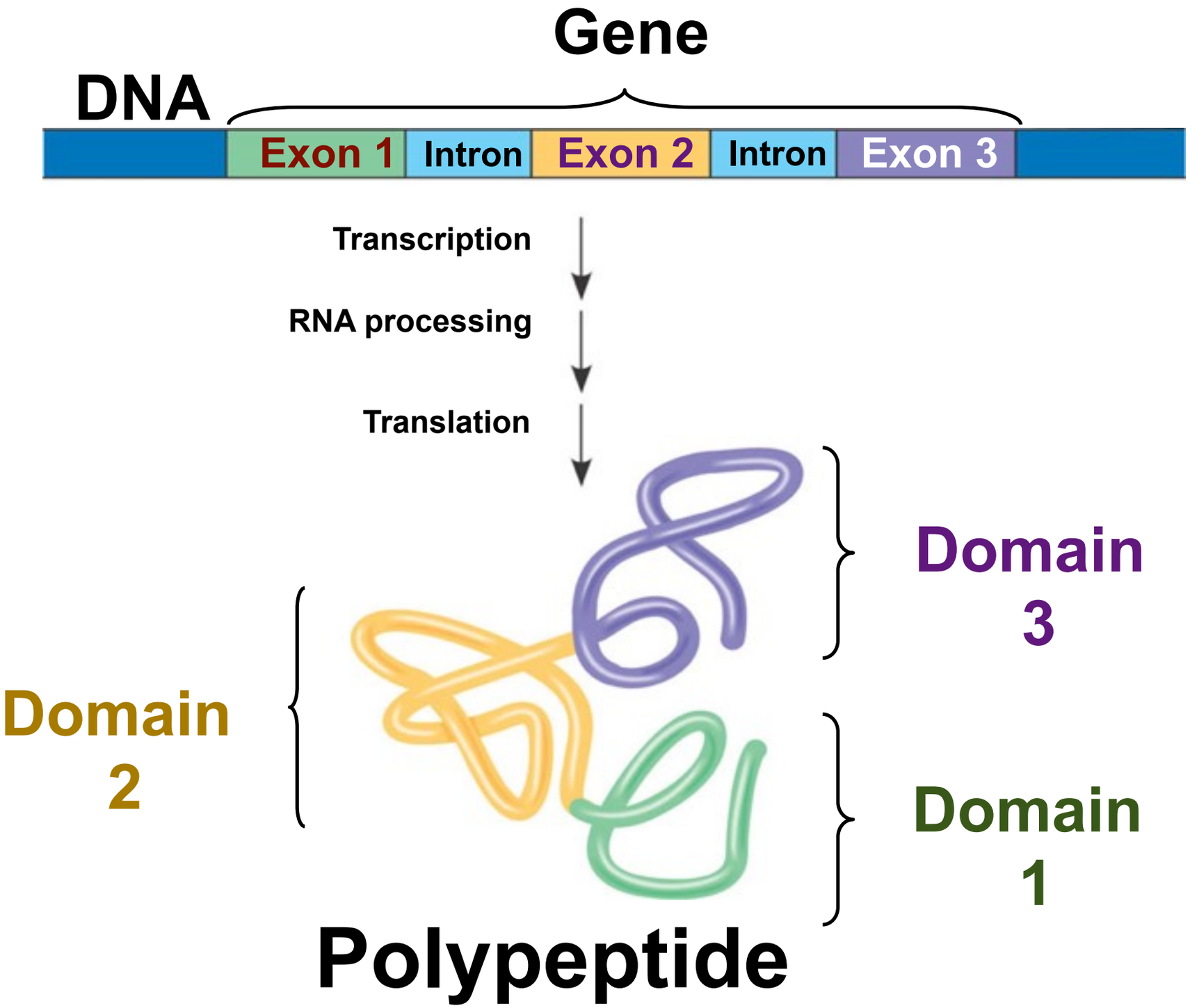
Ribozymes

- **Ribozymes**, RNA molecules that function as enzymes.
  - *This discovery made the idea that only proteins could be biological catalysts obsolete.*
- Three Properties are responsible for its ability to catalyze reactions:
  - *1. since RNA is single stranded it can base pair with itself and thus fold into unique 3-dimensional shapes*
  - *2. some of the bases can have functional groups that participate in the catalysis*
  - *3. the ability of RNA to base pair (form hydrogen bonds) with other nucleic acids adds specificity to its catalytic activity*

Functional & Evolutionary Role of Introns

- One important consequence of introns, is that a single gene can code for multiple polypeptides, depending on which segments are treated as exons during RNA processing.
  - *This alternative splicing may explain why humans get by with the same number of genes as a nematode.*
- Proteins are often built in modular architecture, consisting of discrete structural and functional regions called **domains**.
  - *In many cases each exon codes for a different domain.*

Functional & Evolutionary Role of Introns

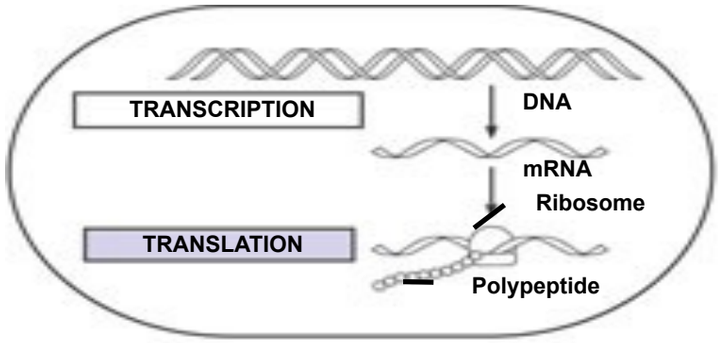


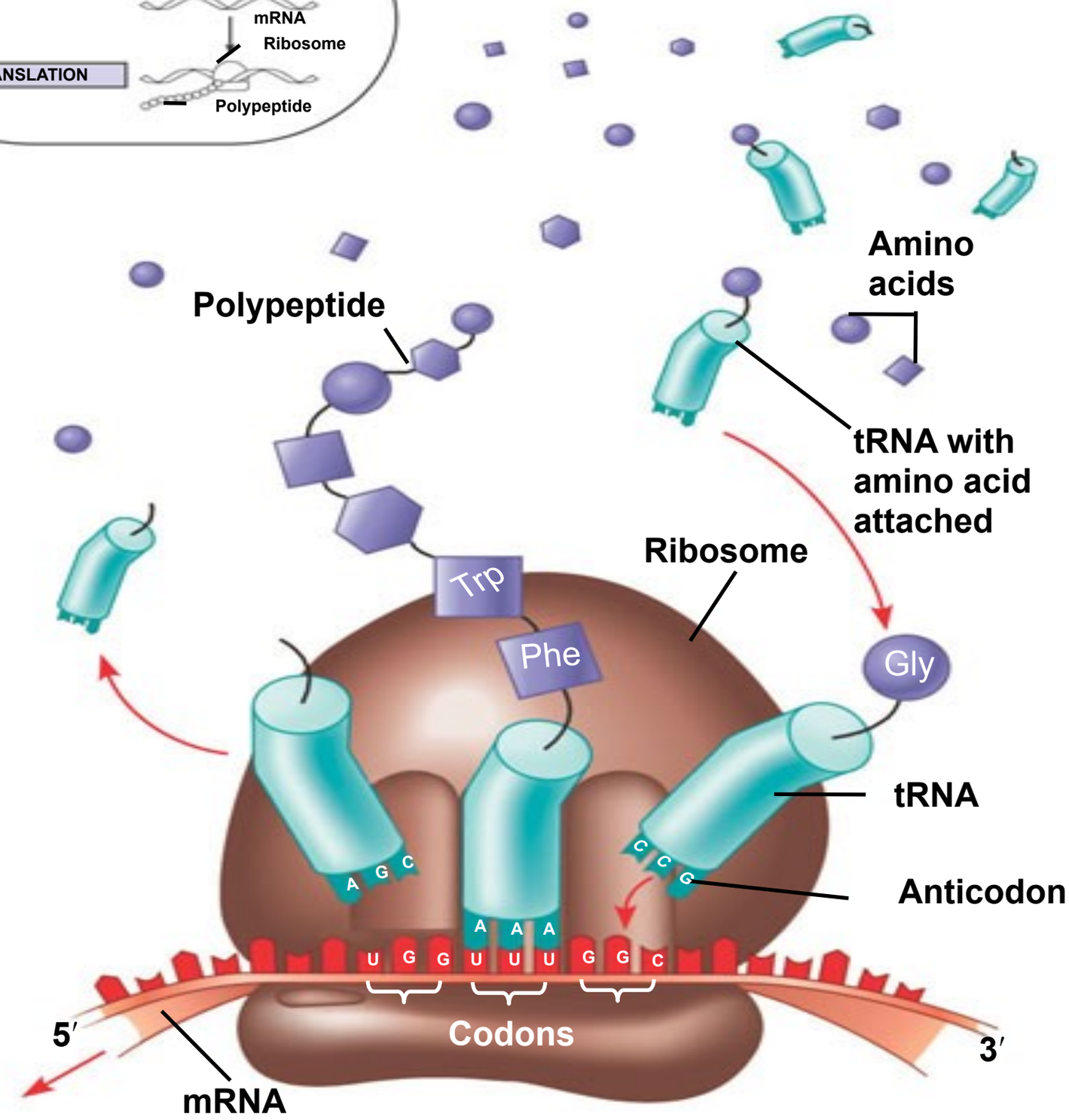
Exon Shuffling

- generates combinations resulting in new and novel proteins

- increases crossing over frequency by pushing exons farther apart

Prokaryotic Translation





the cytosol is stocked with free floating amino acids

tRNA's are also floating freely

every specific amino acid is carried by a tRNA carrying specific anticodon

Prokaryotic Translation

- Translation involves 3 steps, also named...
  - **Initiation**
  - **Elongation**
  - **Termination**
- Translation involves a number of different "characters"...
  - **tRNA**
  - **ribosomes (small & large subunits)**
  - **mRNA**
  - **amino acids**

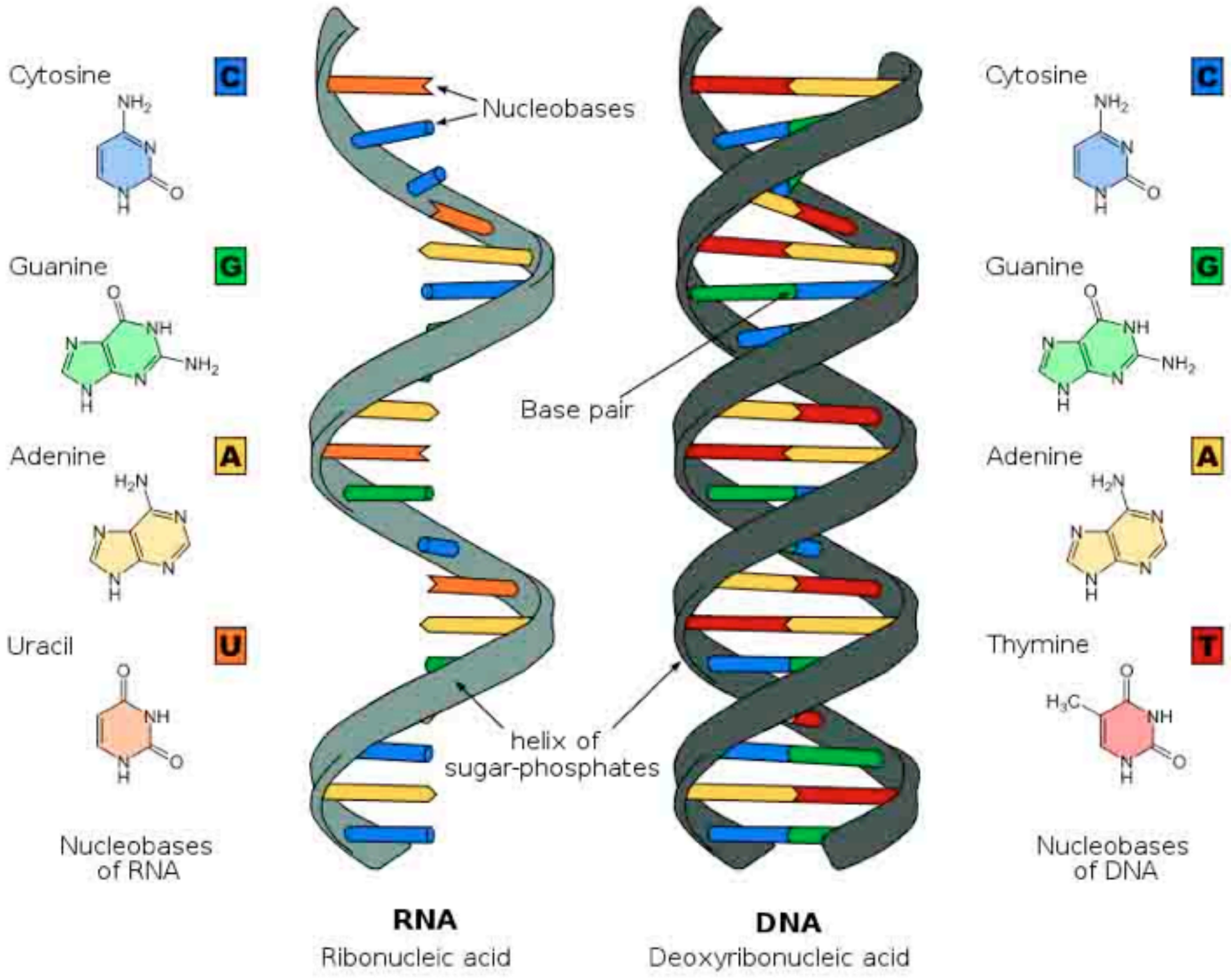
mRNA

"Our Cast of Characters"

single stranded

Uracil

ribose sugar in the backbone

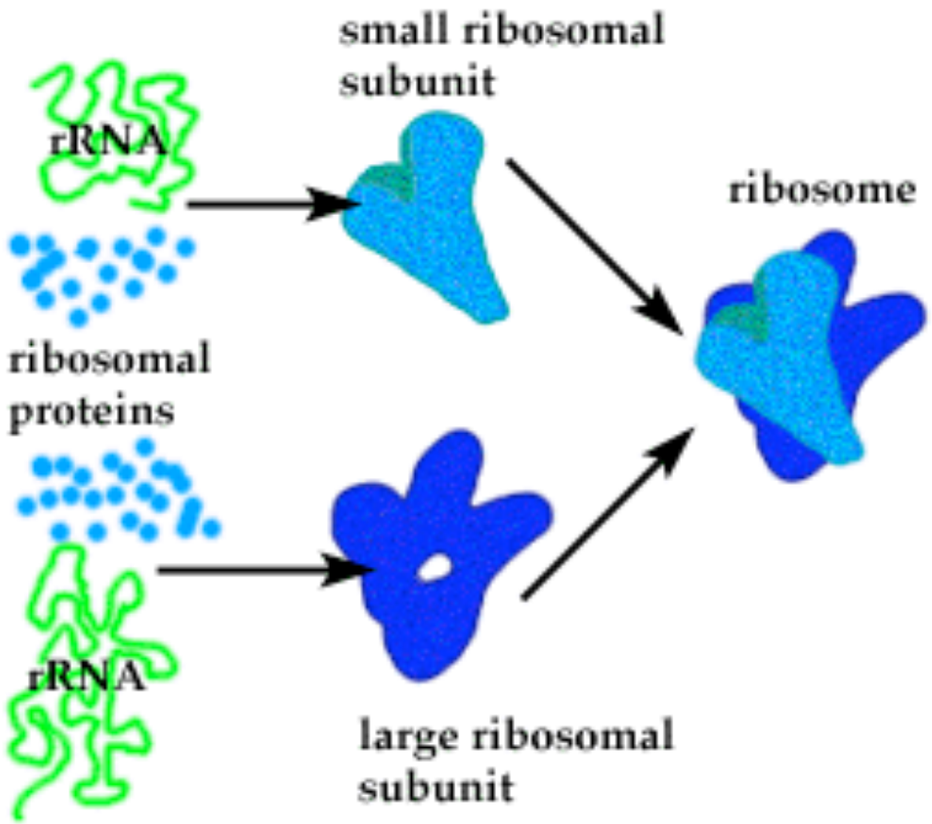


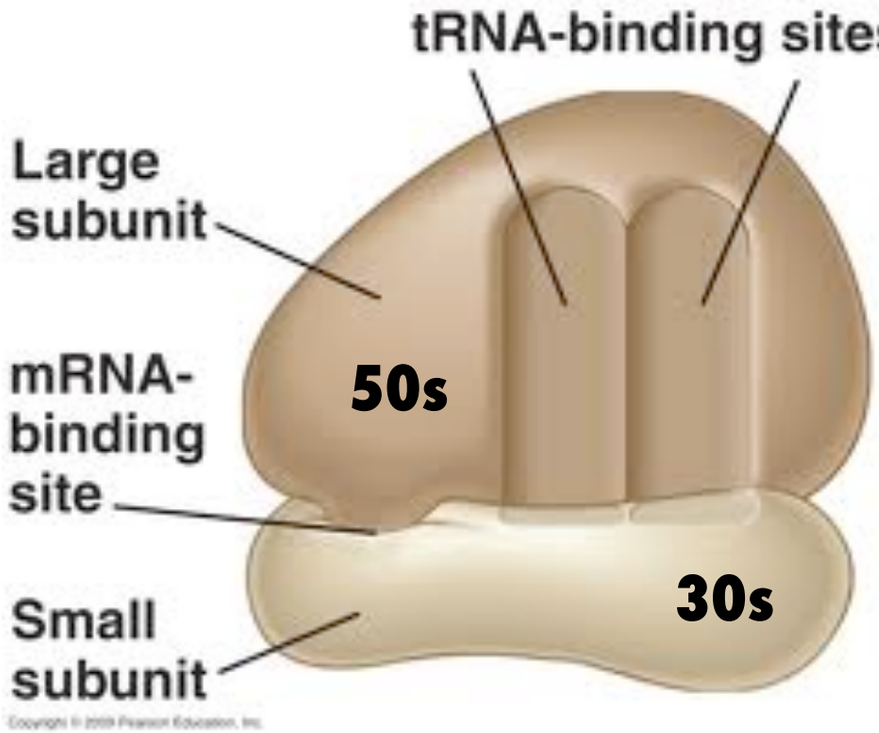
Ribosomes

"Our Cast of Characters"

Translation :

the ribosome



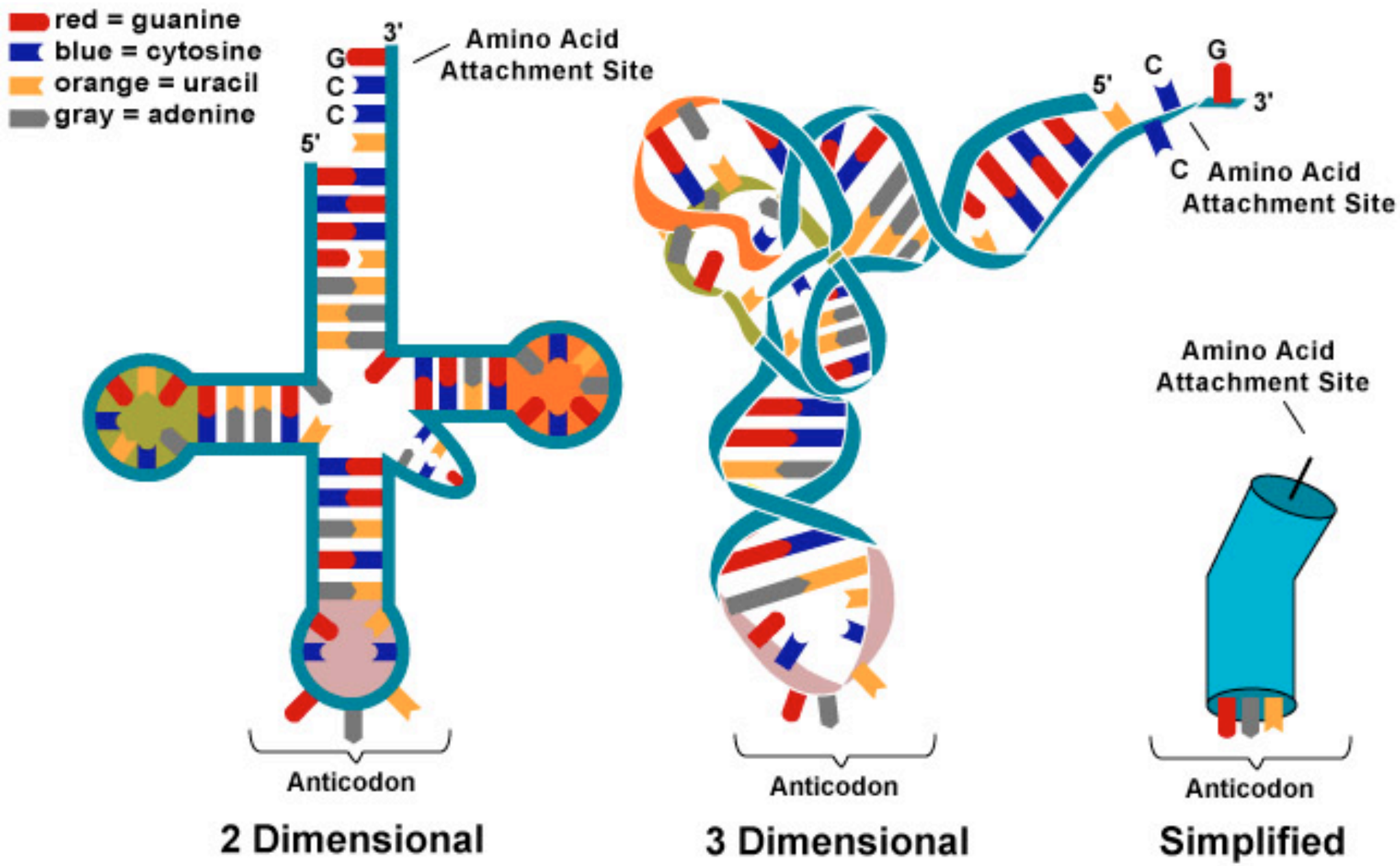


70s

rRNA is the most abundant type of cellular RNA

tRNA

"Our Cast of Characters"

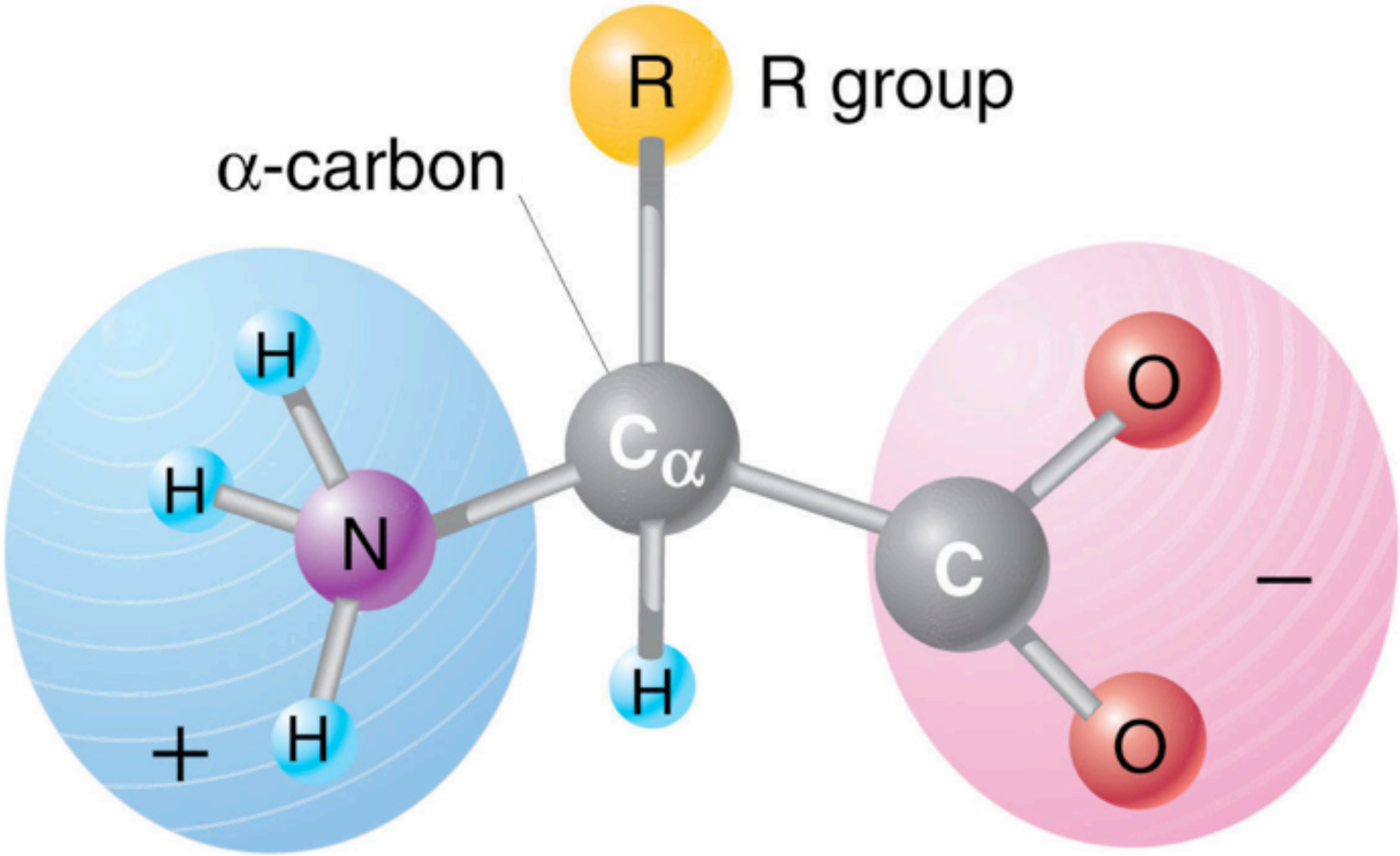


~80 nucleotides

"L" shaped

Amino Acids

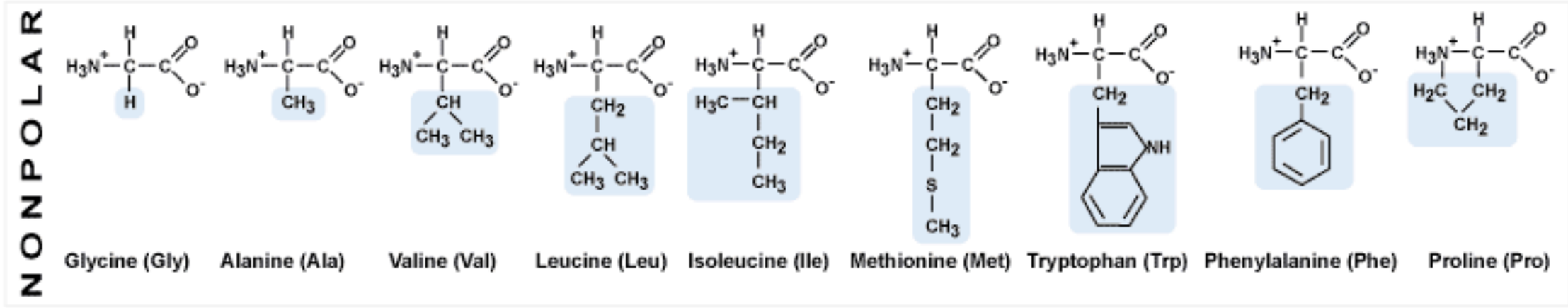
"Our Cast of Characters"

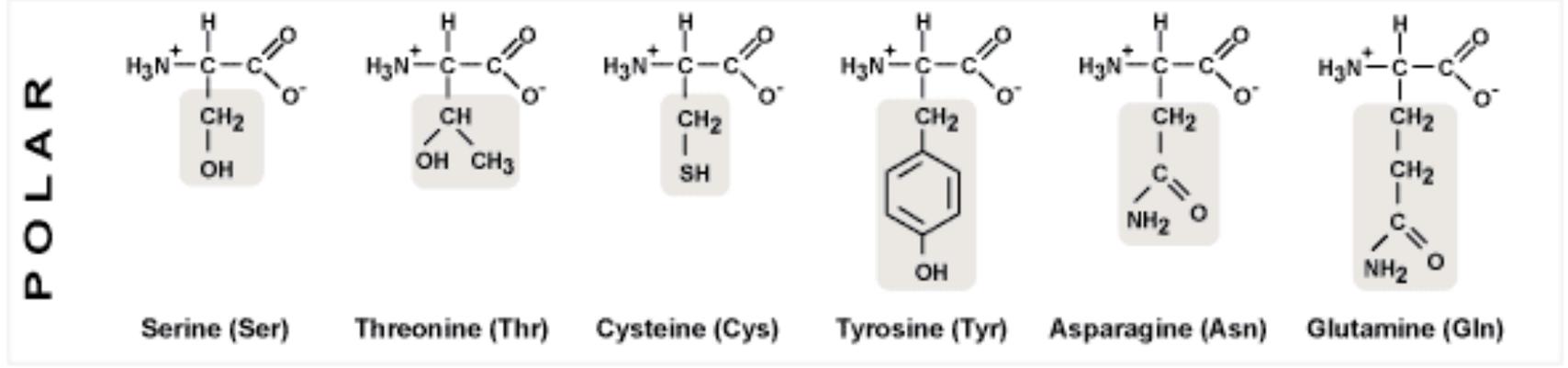


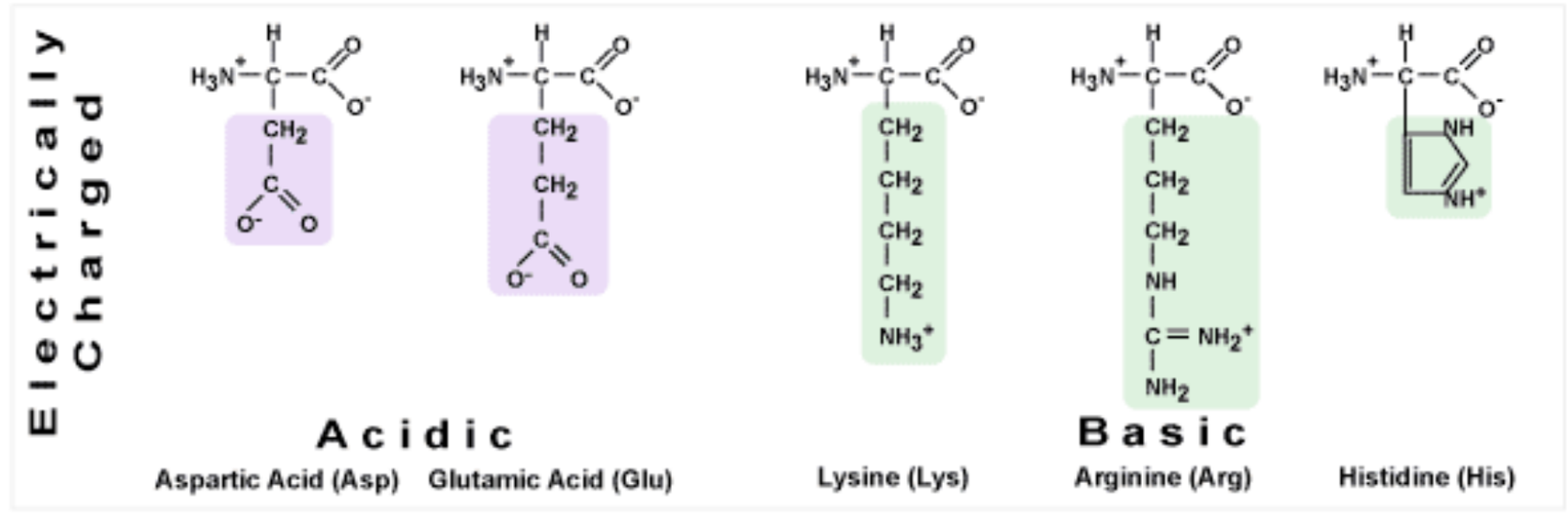
General Amino Acid Structure in Solution

Amino Acids

"Our Cast of Characters"

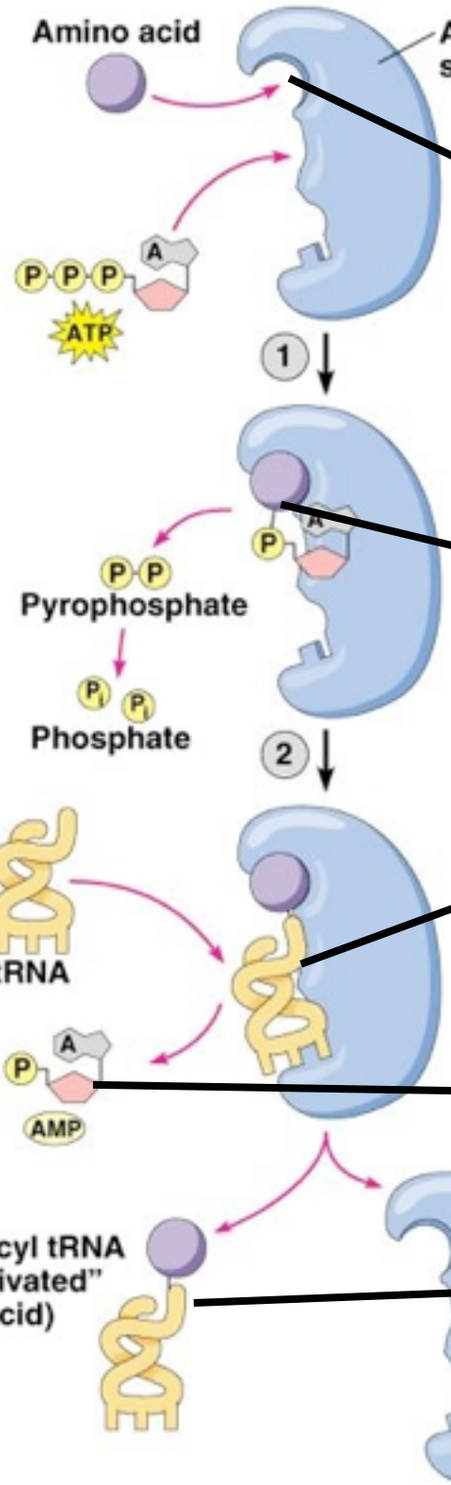






tRNA

"The Processes"



20 different enzymes one for each amino acid

active site binds amino acid and ATP

ATP loses two phosphate groups

tRNA binds to active site

tRNA displaces AMP

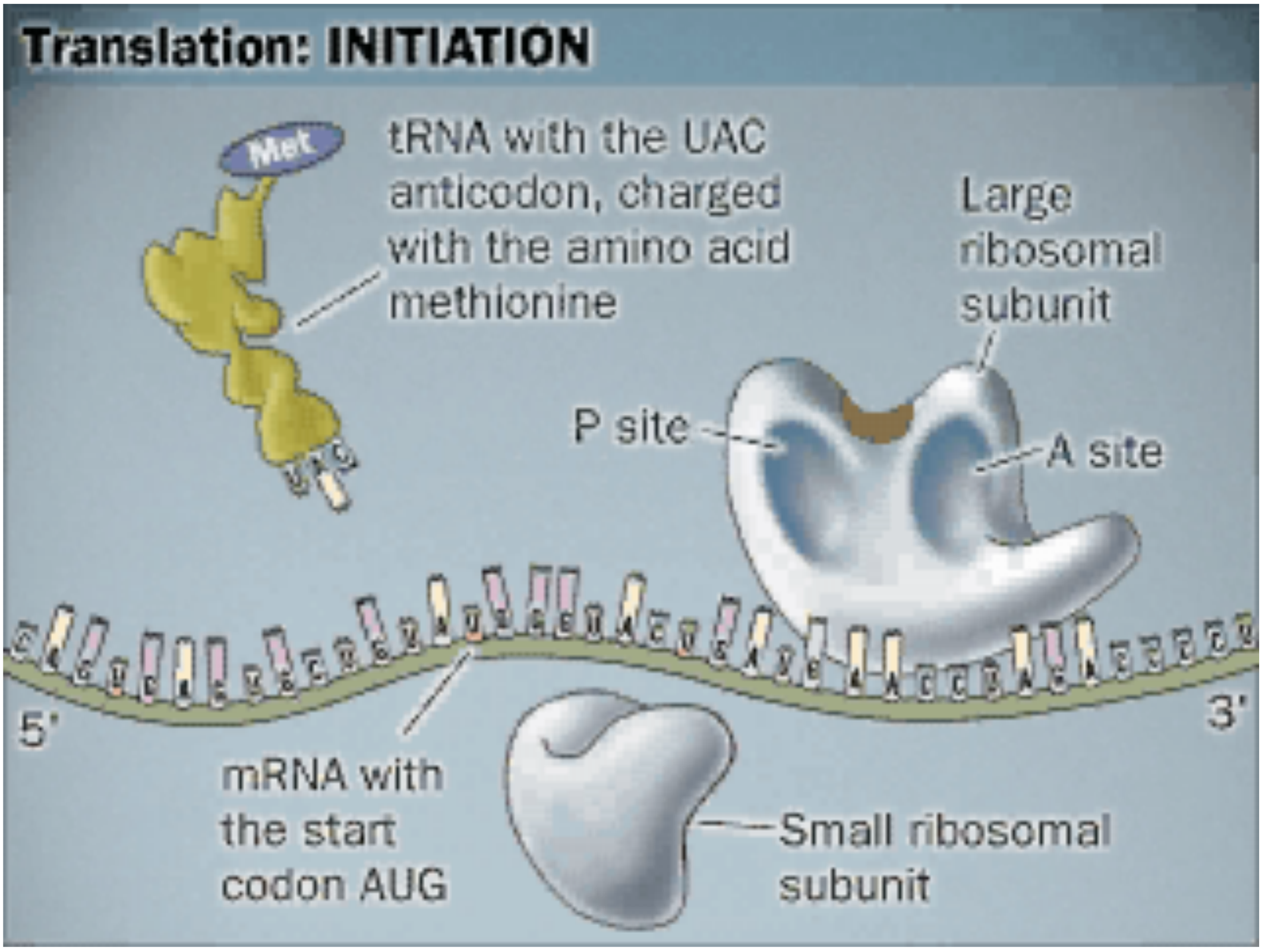
enzyme releases loaded tRNA

Only 45 different tRNA's (not 61) some tRNA's bind more than one amino acid.

This flexibility, called "wobble" occurs at the third position of the codon/anticodon

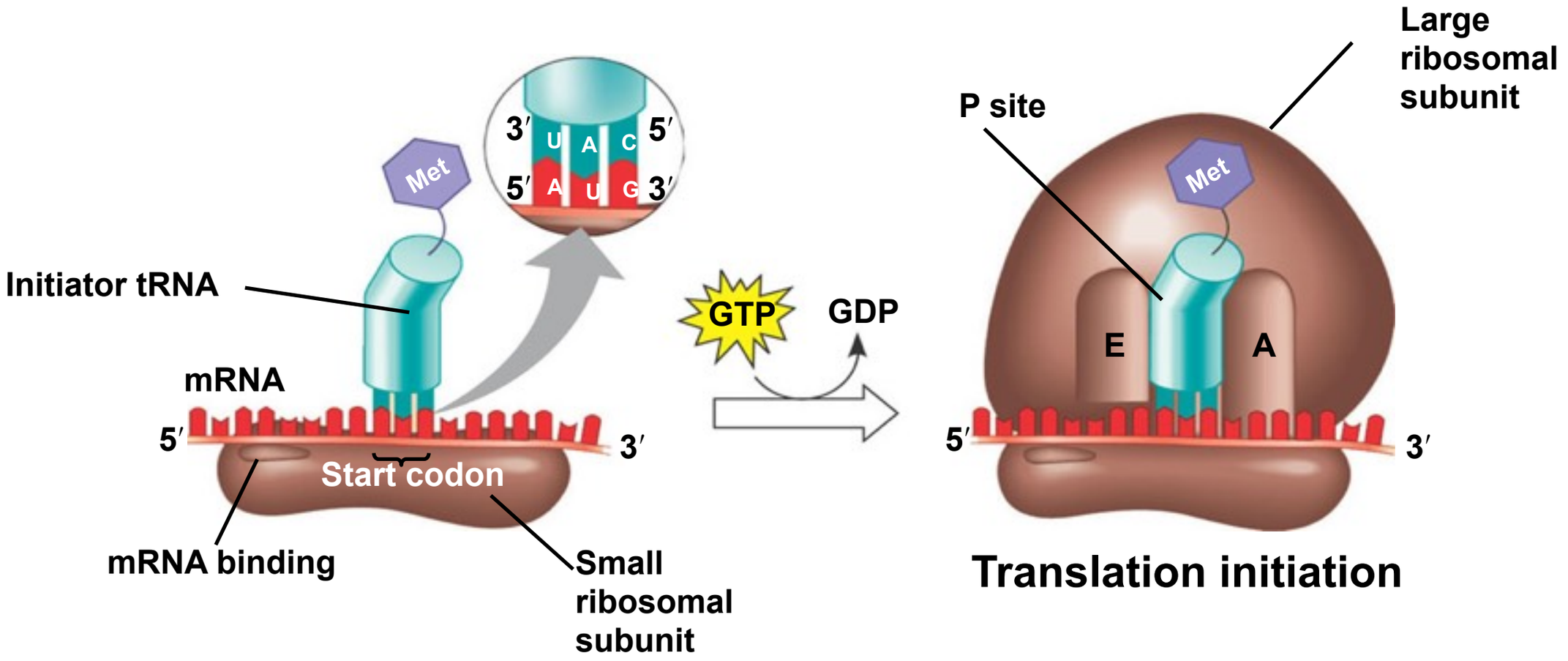
Ex. anticodon 3′-UCU-5′ can bind to either 3′-AGA-5′ or 3′-AGG-5′ both code for arginine

Translation



Translation- Initiation

"The Processes"



Translation initiation

1.

A small ribosomal subunit binds to a molecule of mRNA. In a prokaryotic cell, the mRNA binding site on this subunit recognizes a specific nucleotide sequence on the mRNA just upstream of the start codon. An initiator tRNA, with the anticodon UAC, base-pairs with the start codon, AUG. This tRNA carries the amino acid methionine (Met).

2.

The arrival of a large ribosomal subunit completes the initiation complex. Proteins called initiation factors (not shown) are required to bring all the translation components together. GTP provides the energy for the assembly. The initiator tRNA is in the P site; the A site is available to the tRNA bearing the next amino acid.

Translation- Elongation

"The Processes"

1.

Codon recognition. The anticodon of an incoming aminoacyl tRNA base-pairs with the complementary mRNA codon in the A site. Hydrolysis of GTP increases the accuracy and efficiency of this step.

2.

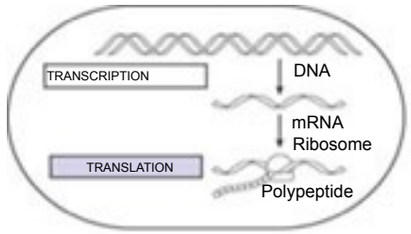
Peptide bond formation. An rRNA molecule of the large subunit catalyzes the formation of a peptide bond between the new amino acid in the A site and the carboxyl end of the growing polypeptide in the P site. This step attaches the polypeptide to the tRNA in the A site.

3.

Translocation. The ribosome translocates the tRNA in the A site to the P site. The empty tRNA in the P site is moved to the E site, where it is released. The mRNA moves along with its bound tRNAs, bringing the next codon to be translated into the A site.

Translation- Elongation

"The Processes"



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Translation- Termination

"The Processes"

Keep in mind this polypeptide now must fold into a 3-D molecule before it becomes functional

When a ribosome reaches a stop codon on mRNA, the A site of the ribosome accepts a protein called a release factor instead of tRNA.

1.

The release factor hydrolyzes the bond between the tRNA in the P site and the last amino acid of the polypeptide chain. The polypeptide is thus freed from the ribosome.

2.

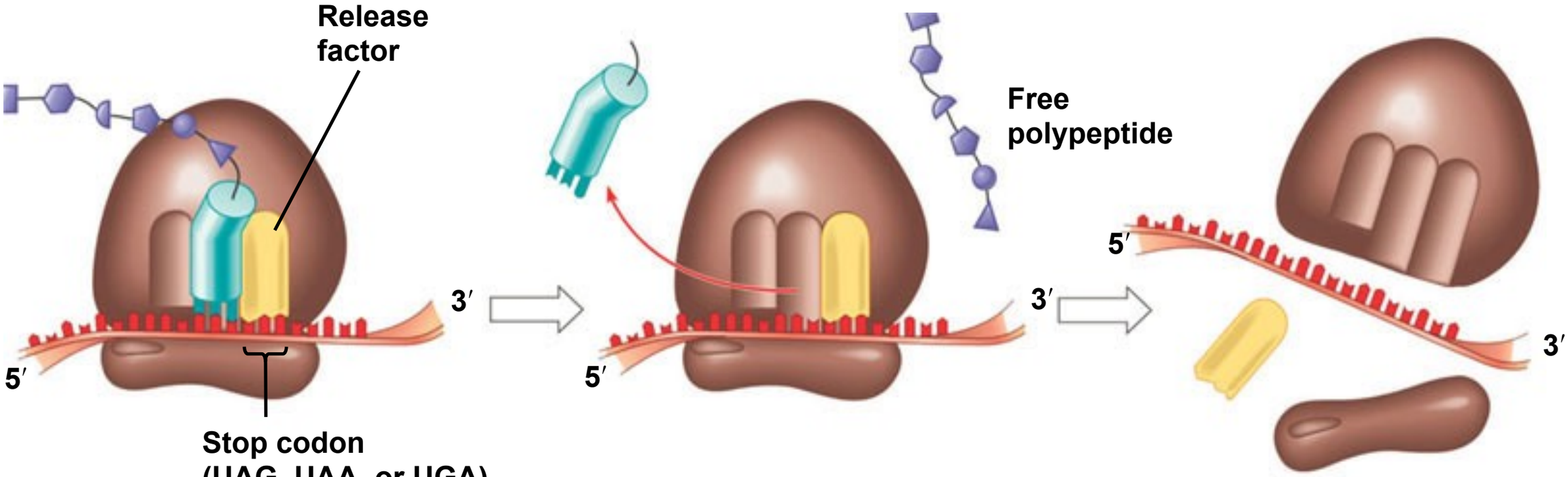
The two ribosomal subunits and the other components of the assembly dissociate. This also requires energy- 2GTP molecules.

3.

Translation- Termination

"The Processes"

Keep in mind this polypeptide now must fold into a 3-D molecule before it becomes functional



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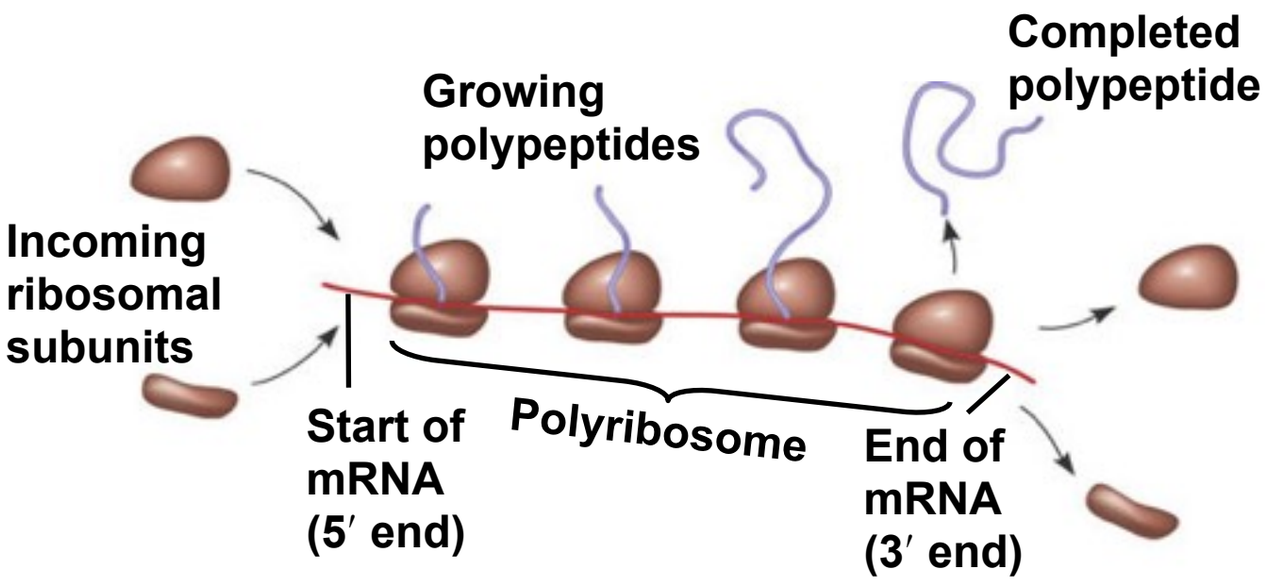
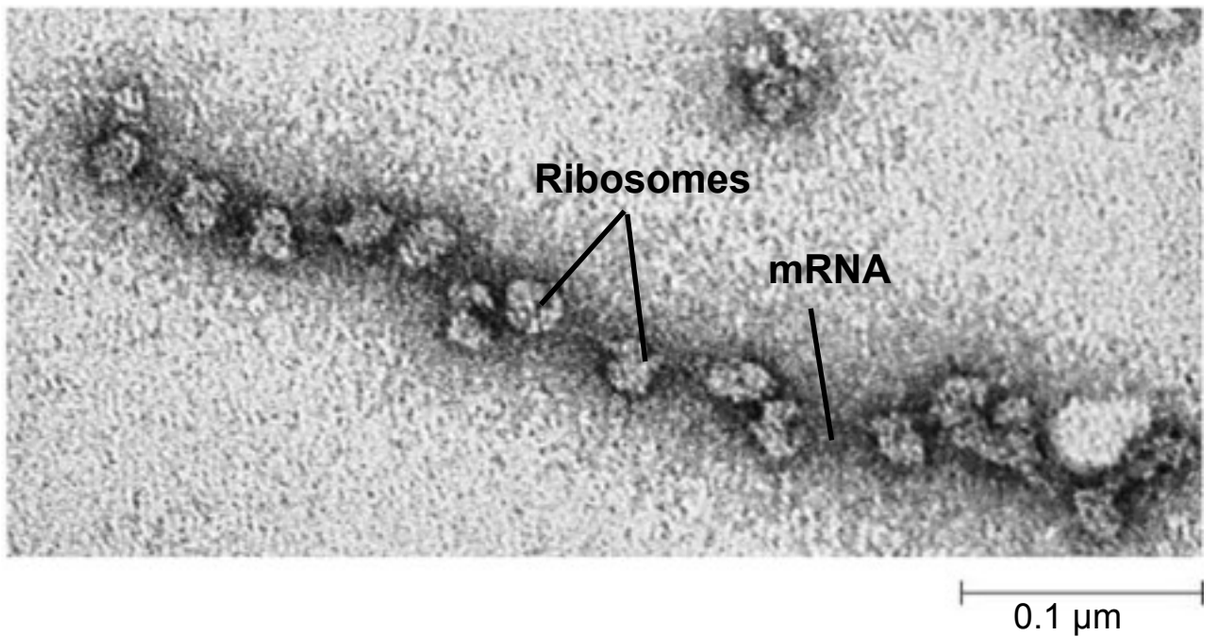
3.

Translation- Side Note

"The Processes"



(a) An mRNA molecule is generally translated simultaneously by several ribosomes in clusters called polyribosomes.



(b) This micrograph shows a large polyribosome in a prokaryotic

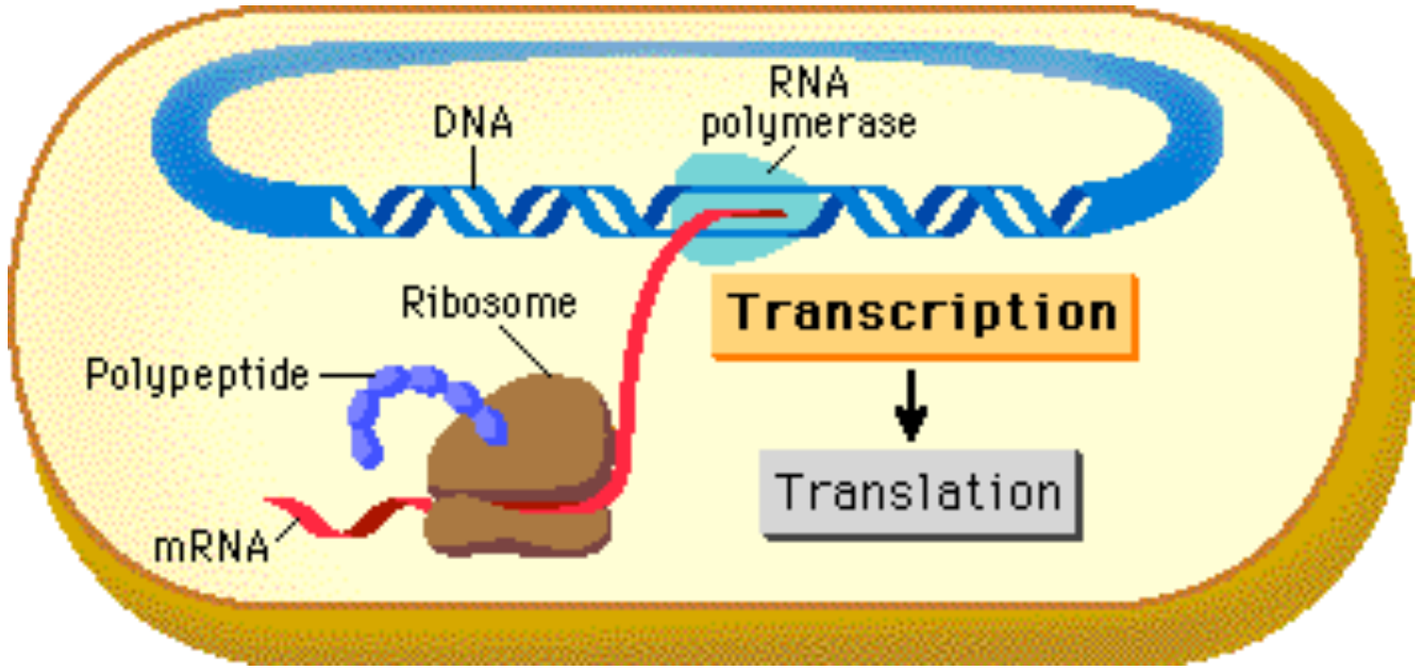
Recall- As soon as one RNA polymerase moves off of promoter another one can bind and so forth like a convoy of trucks

New- As soon as one ribosome moves off of start codon another one can bind and so forth like a convoy of trucks

Both help to increase the number of polypeptides a bacteria can make per unit time!

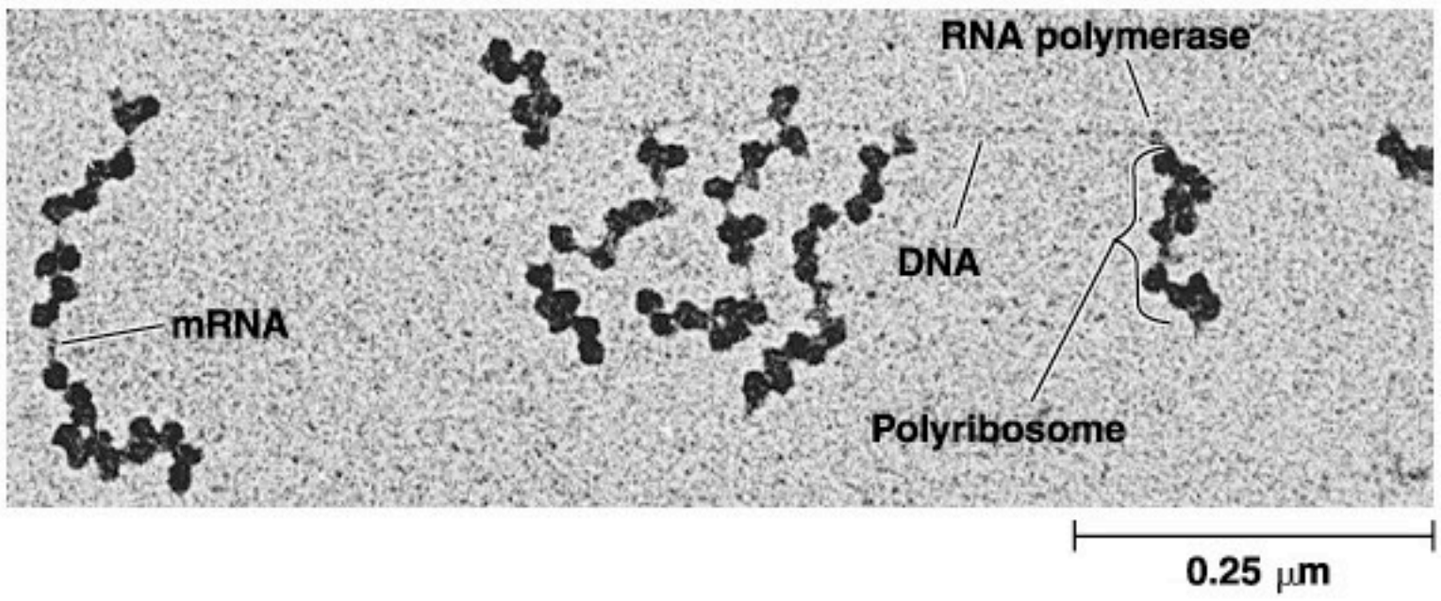
A Final Reminder

- **Transcription & Translation occurs in every organism.**
  - ***The mechanics are the same or very similar in all cells***
  - ***However, one very important difference exists between prokaryotes and eukaryotes***

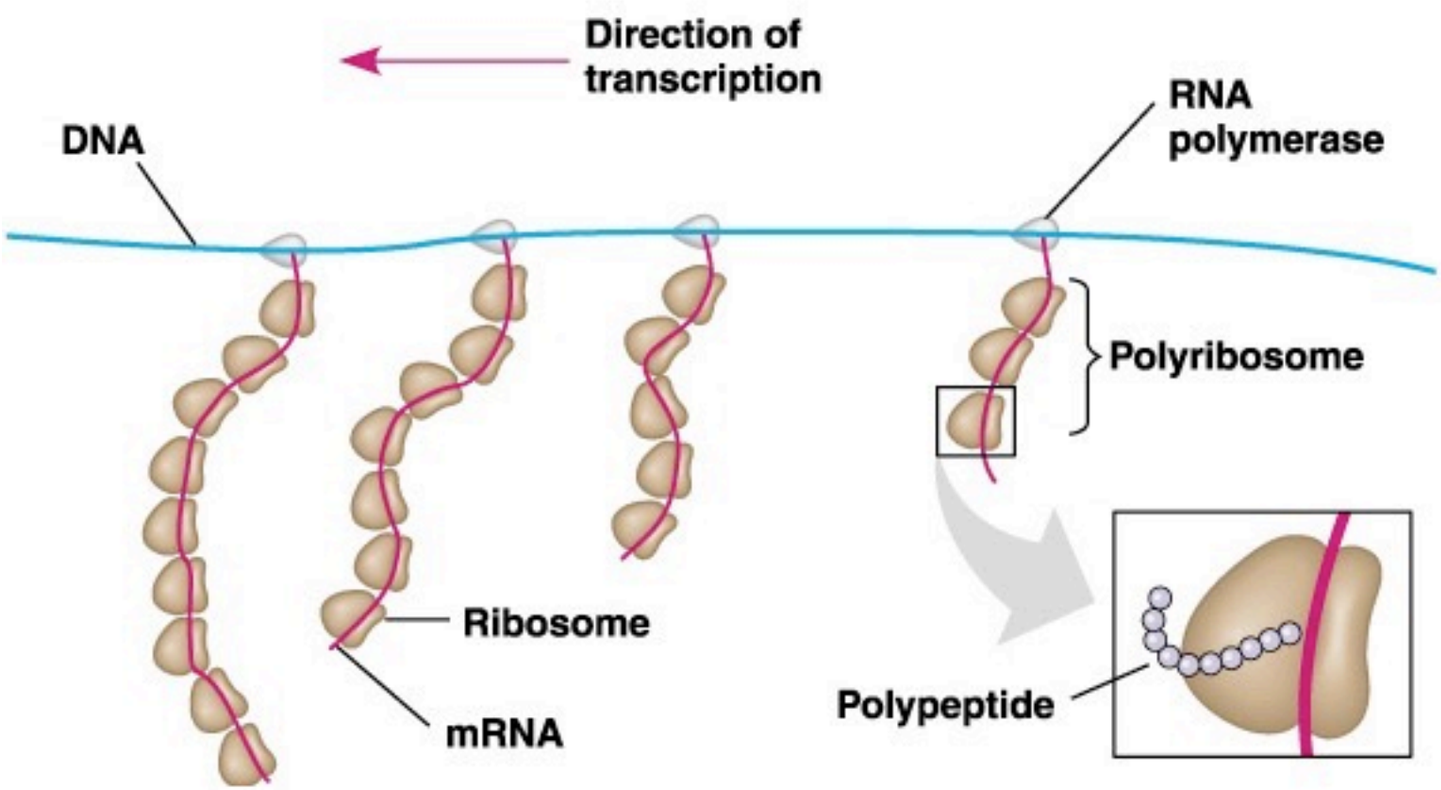


Prokaryotic Transcription and Translation are not separated by time and space

Prokaryotic Protein Synthesis



Prokaryotic Transcription and Translation occur simultaneously



Final Summary

TRANSCRIPTION

RNA is transcribed from a DNA template.

DNA

3′

Poly-A

5′ RNA transcript

RNA polymerase

RNA PROCESSING

In eukaryotes, the RNA transcript (pre-mRNA) is spliced and modified to produce mRNA, which moves from the nucleus to the cytoplasm.

Exon

RNA transcript (pre-mRNA)

Intron

Cap

NUCLEUS

CYTOPLASM

FORMATION OF INITIATION COMPLEX

After leaving the nucleus, mRNA attaches to the ribosome.

mRNA

Growing polypeptide

Poly-A

Ribosomal subunits

Cap

5′

A C C

E

A

U A C

A A A

U G G U U U A U G

Anticodon

Codon

Ribosome

Aminoacyl-tRNA synthetase

Amino acid

tRNA

AMINO ACID ACTIVATION

Each amino acid attaches to its proper tRNA with the help of a specific enzyme and ATP.

Activated amino acid

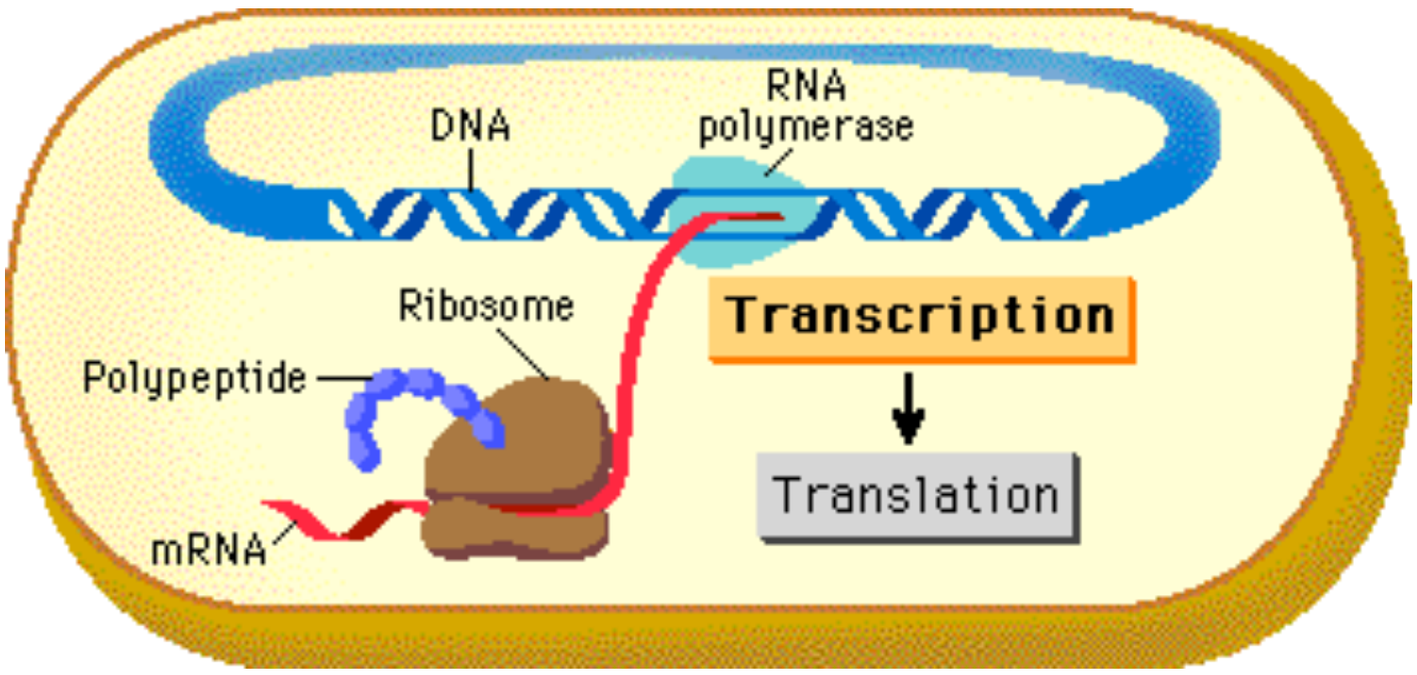
Poly-A

TRANSLATION

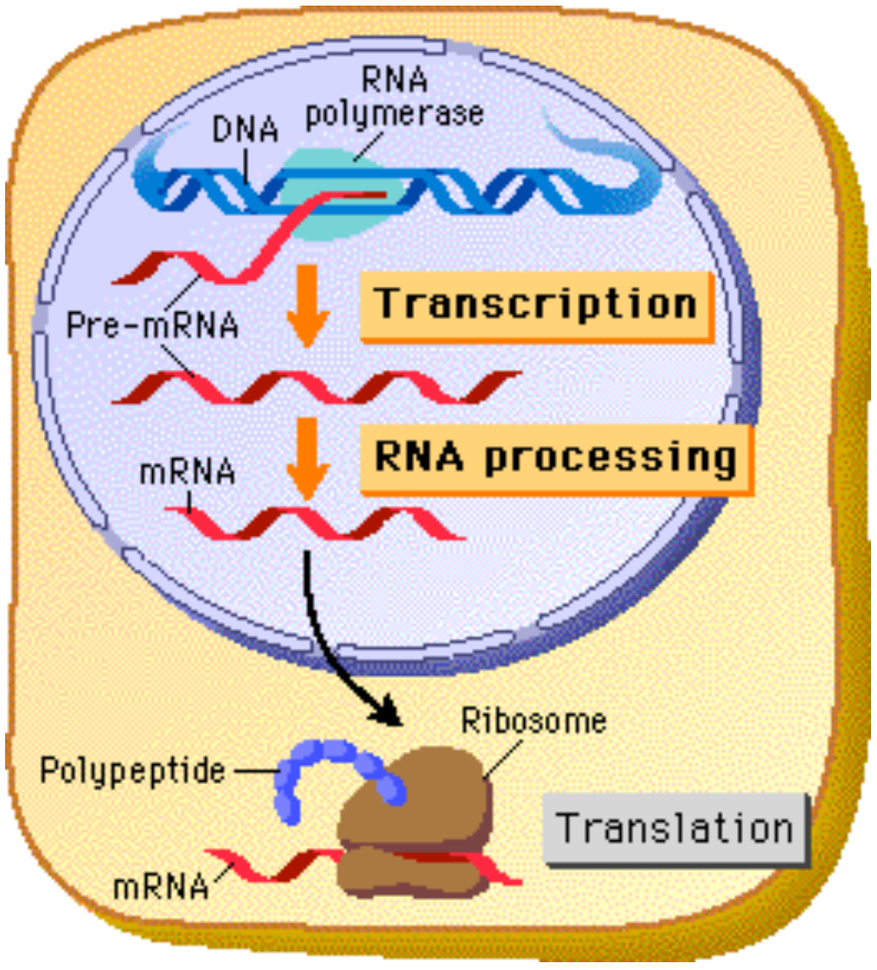
A succession of tRNAs add their amino acids to the polypeptide chain as the mRNA is moved through the ribosome one codon at a time. (When completed, the polypeptide is released from the ribosome.)

Final Comparisons

- **Transcription & Translation occurs in every organism.**
  - ***However, one very important difference exists between prokaryotes and eukaryotes***



Prokaryotic T&T are not separated by time and space



Eukaryotic T&T separated by time and space

Final Comparisons

Feature	Bacteria	Archaea	Eukaryotes
Chromosome Structure	circular	circular	linear
RNA polymerase type	I	II	I, II, III
Transcription Factors	few, simple ones	complex set	complex set
Transcription Termination	falls off at terminator	continues past terminator	continues past terminator
mRNA introns	absent	absent	present
RNA processing	absent	absent	present
Ribosome size	70s	70s	80s

A Review of Different RNA's

Type of RNA	Functions
Messenger RNA (mRNA)	Carries information specifying amino acid sequences of proteins from DNA to ribosomes.
Transfer RNA (tRNA)	Serves as adapter molecule in protein synthesis; translates mRNA codons into amino acids.
Ribosomal RNA (rRNA)	Plays catalytic (ribozyme) roles and structural roles in ribosomes.
Primary transcript	Serves as a precursor to mRNA, rRNA, or tRNA, before being processed by splicing or cleavage. Some intron RNA acts as a ribozyme, catalyzing its own splicing.
Small nuclear RNA (snRNA)	Plays structural and catalytic roles in spliceosomes, the complexes of protein and RNA that splice pre-mRNA.
SRP RNA	Is a component of the signal-recognition particle (SRP), the protein-RNA complex that recognizes the signal peptides of polypeptides targeted to the ER.
Small nucleolar RNA (snoRNA)	Aids in processing of pre-rRNA transcripts for ribosome subunit formation in the nucleolus.
Small interfering RNA (siRNA) and microRNA (miRNA)	Are involved in regulation of gene expression.

Essential knowledge 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.

d. Phenotypes are determined through protein activities.

To foster student understanding of this concept, instructors can choose an illustrative example such as:

- Enzymatic reactions
- Transport by proteins
- Synthesis
- Degradation

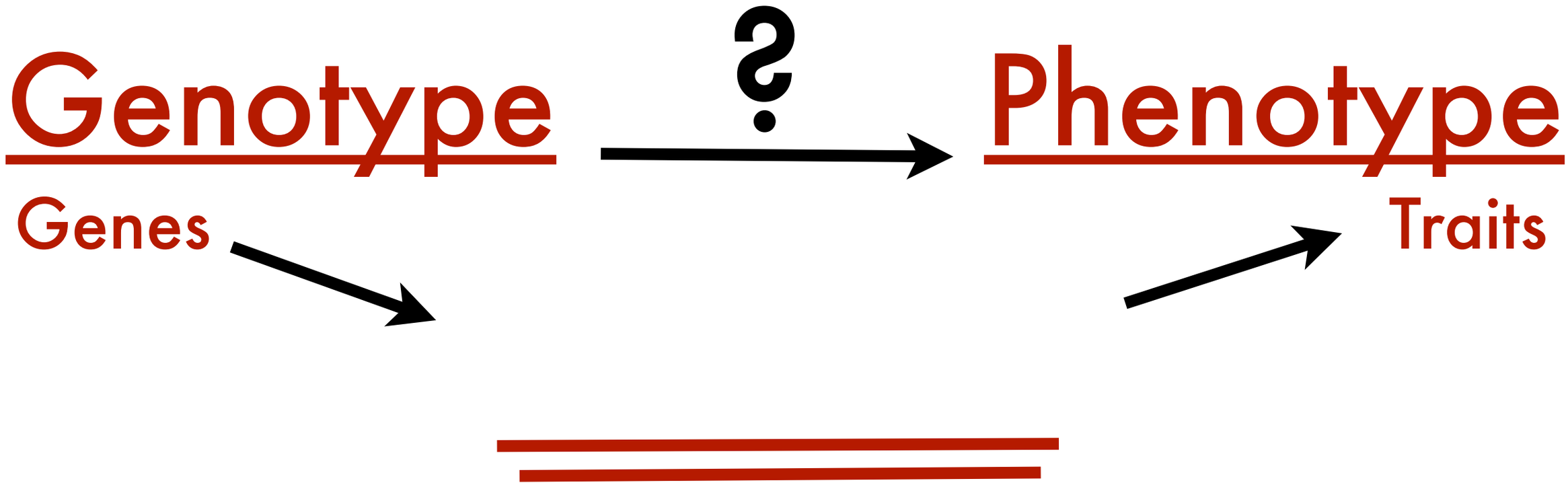
Now Lets Revisit this idea…

DNA → **Genes** → Proteins → Traits

OK, What exactly is a gene?

- (Basic Definition) A unit of inheritance that controls a phenotypic character.
- (Better Definition) A nucleotide sequence along a molecule of DNA that codes for a protein.
- **(Best Definition) A region of DNA that can be expressed to produce a final functional product that is either a polypeptide or an RNA molecule.**

How do genes produce traits?



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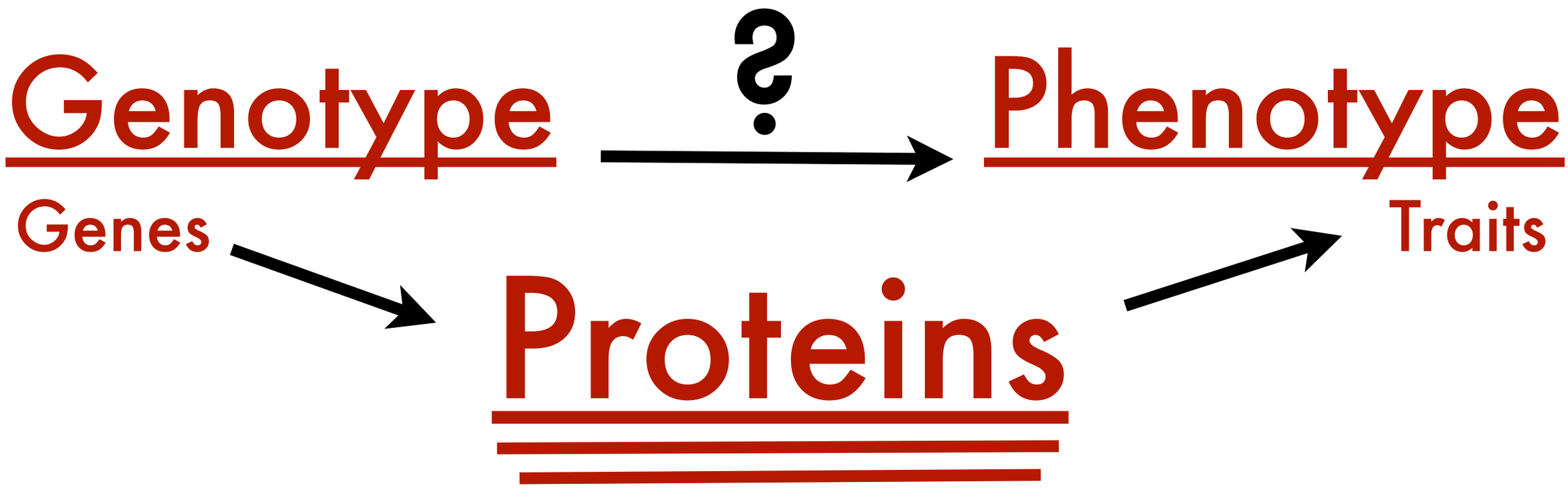

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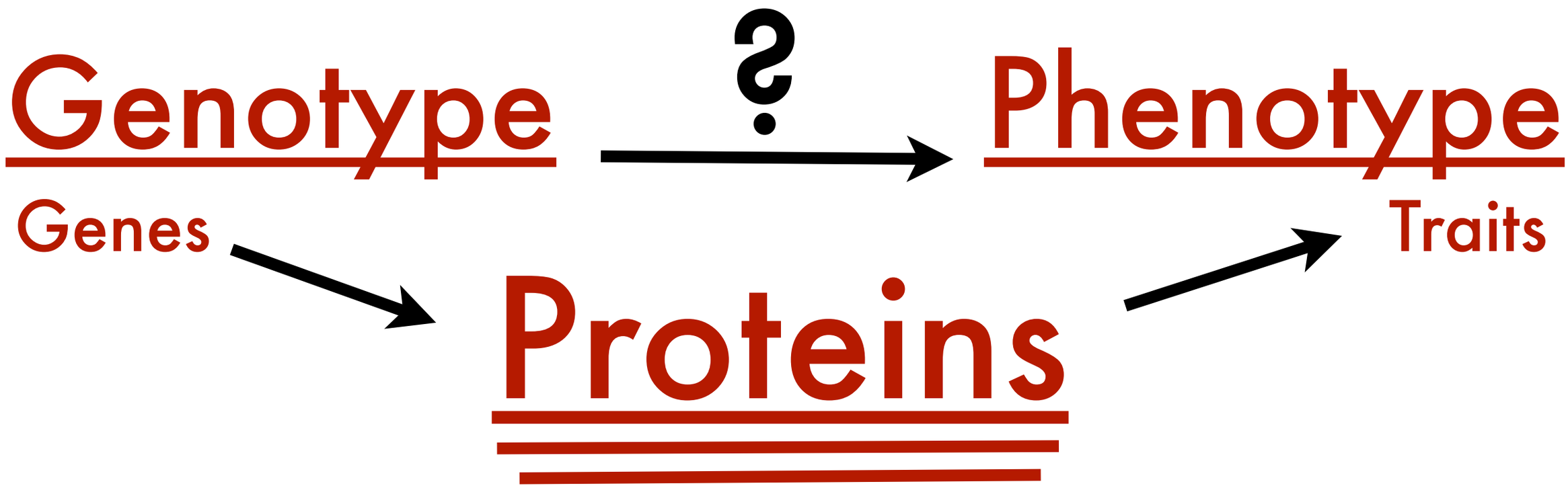

Proteins are the link between genotypes and phenotypes
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Proteins are the link between genotypes and phenotypes

How do genes produce traits?

Global Flow of Information

DNA → RNA → Protein

- The flow of genetic information involves two processes.
  - Transcription
  - Translation
- Together these two processes represent gene expression.

Recall Gene Expression…"The Story"

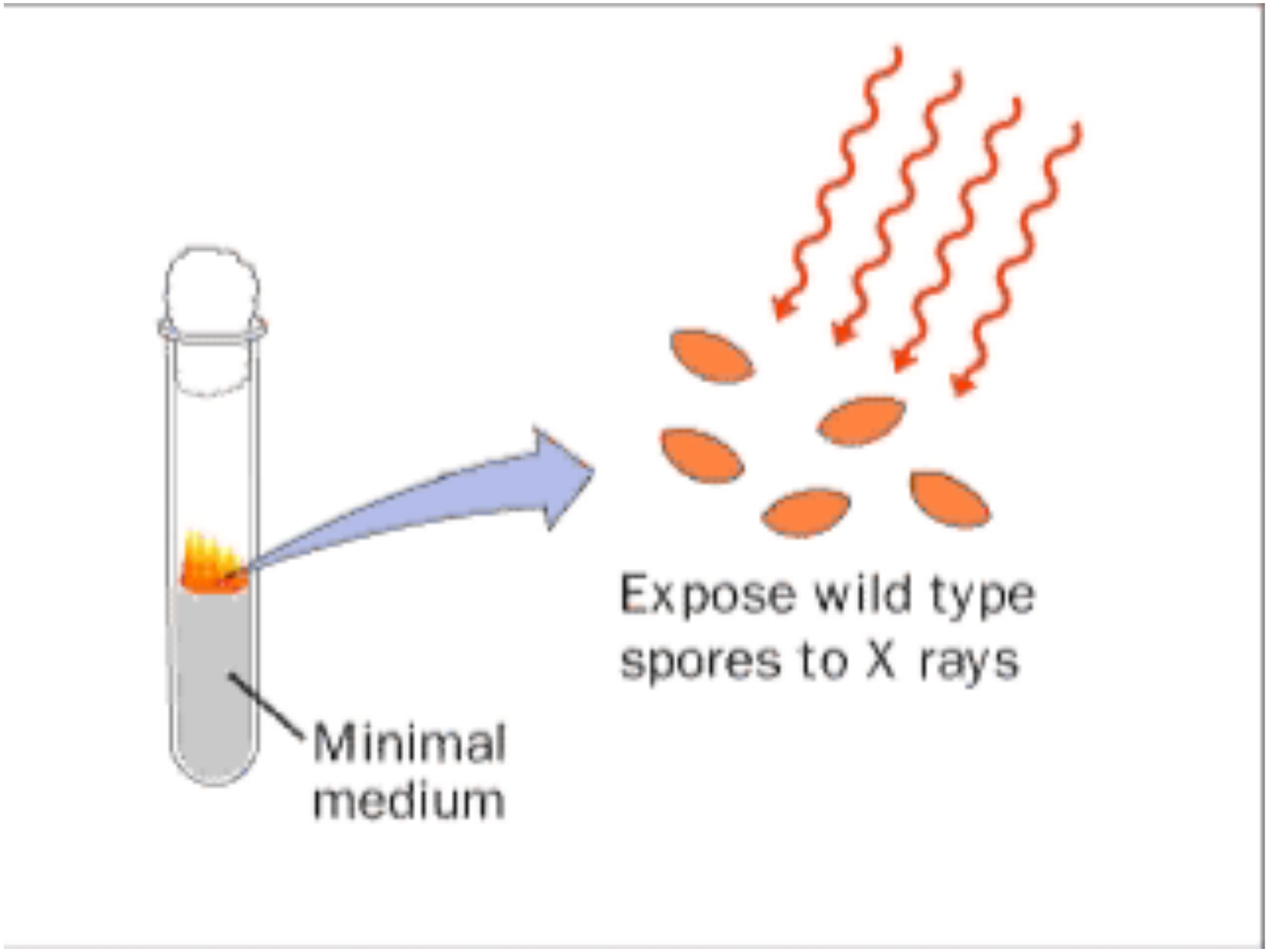
Early 1940's George Beadle & Edward Tatum

- The work of Beadle and Tatum supported the claims made decades earlier by Archibold Garrod.
- **Beadle & Tatums's experimental results supported their *one gene - one enzyme hypothesis* (which states that one dictates the production of a specific enzyme).**
- Beadle and Tatum shared the 1958 Nobel Prize for their work

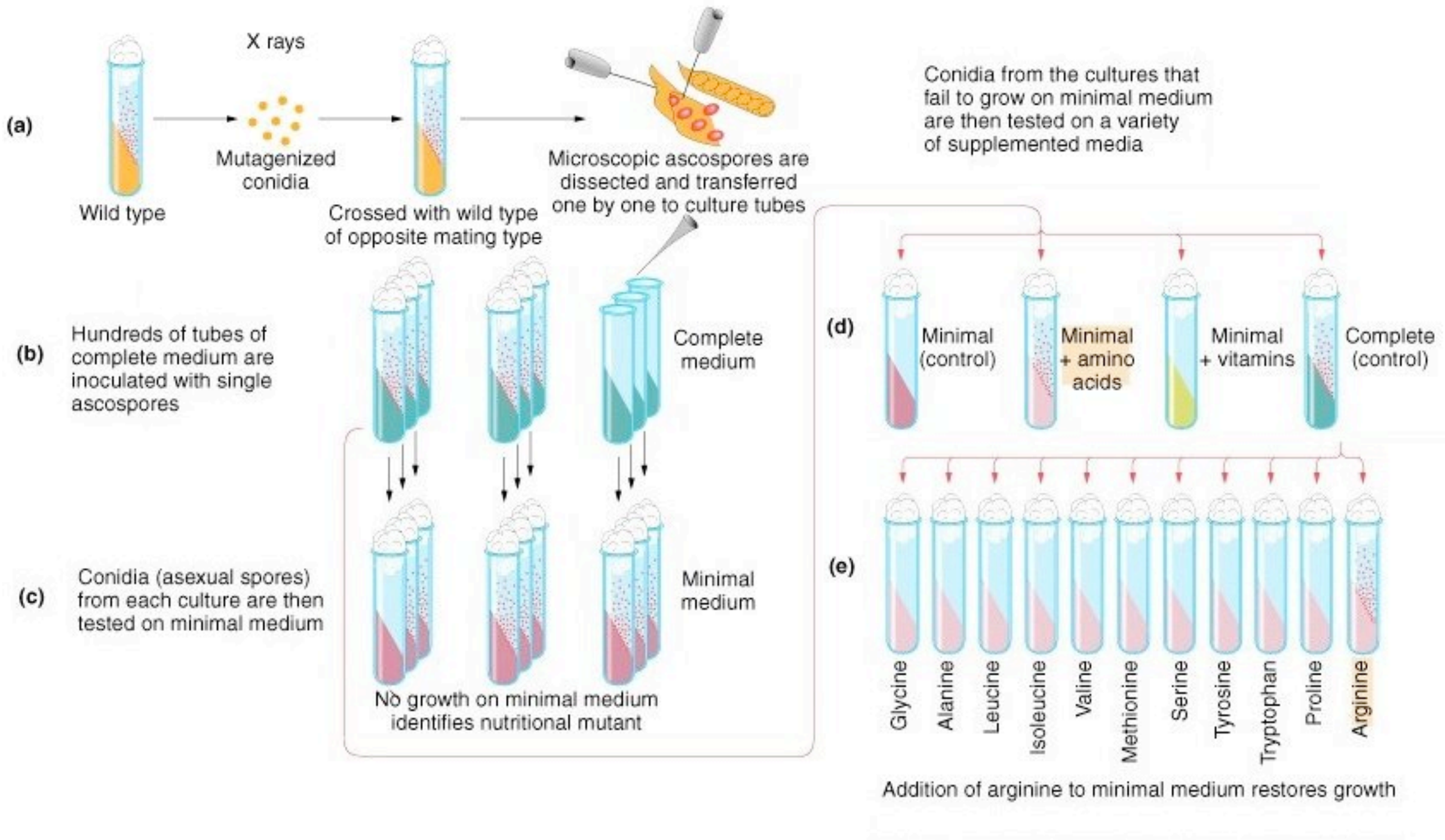
Beadle & Tatum's Experiment is described on the next slide

Recall Gene Expression…"The Story"

Early 1940's George Beadle & Edward Tatum



George Beadle & Edward Tatum Experiment



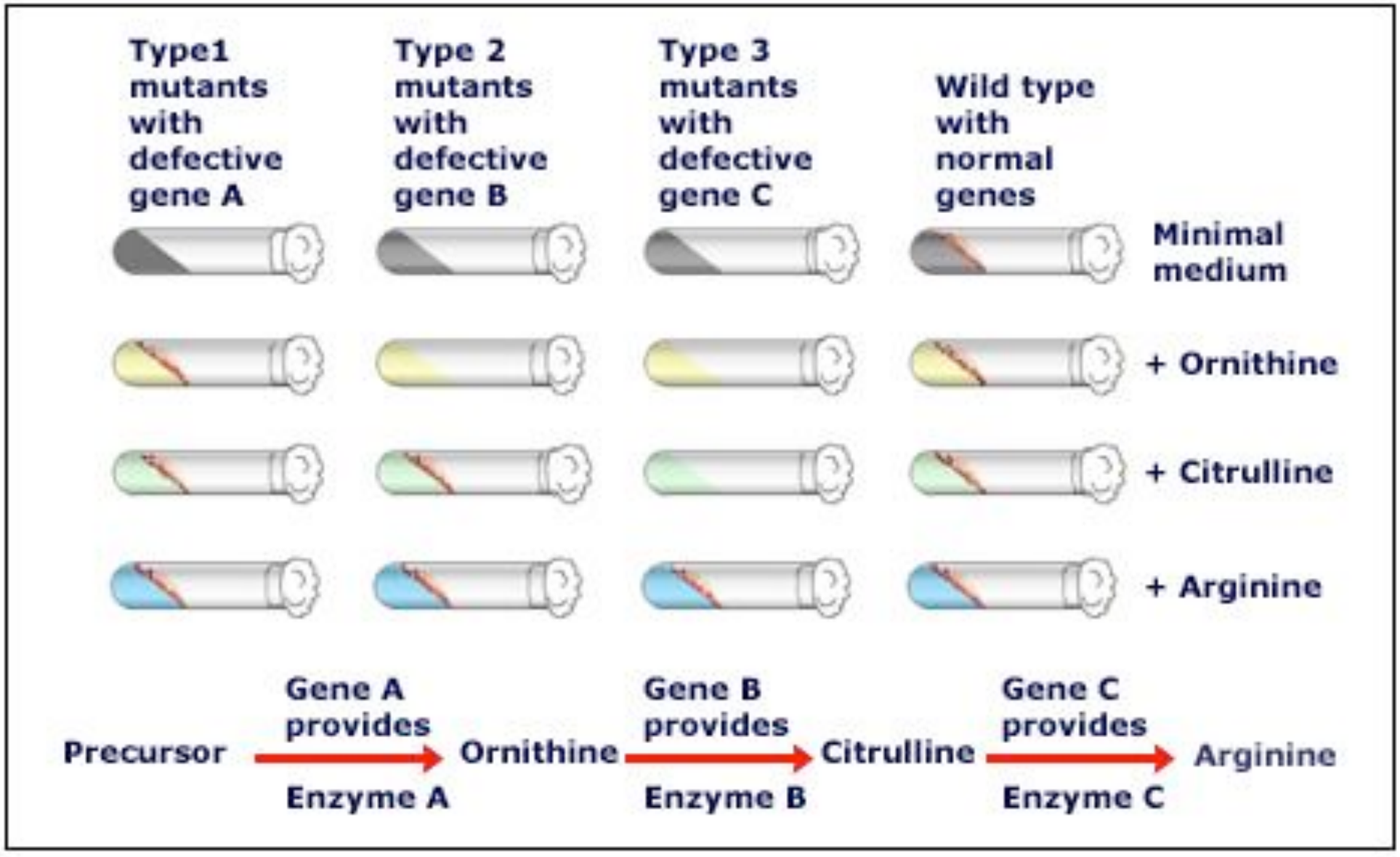
Recall Gene Expression…"The Story"

Early 1940's Adrian Srb & Norman Horowitz

- Colleagues of Beadle and Tatum, Srb and Horowitz used a similar approach to investigate the specific biochemical pathway for *Arginine*.
- **Srb and Horowitz's experimental results provided additional support for the *one gene - one enzyme hypothesis*.**

Srb & Horowitz's Experiment is described on the next slide

Adrian Srb & Norman Horowitz Experiment



Dominance & Phenotype

Unbranched Starch

r= ↓ **Defective Enzyme**

Unbranched Starch

↓

Excessive Water Enters

↘

seed dries

Having one dominant allele results in 50% of the "enzymes" being effective. As we can see having at least 50% of the enzymes effective converts enough unbranched starch that we see the smooth phenotype.

Unbranched Starch

R= ↓ **Effective Enzyme**

Branched Starch

↓

Normal Amount Water Enters Seed

↙

seed dries

Dominance & Phenotype

- In fact this relationship is even more intriguing.
- For any character, the observed dominant/recessive relationship of alleles depends on the level at which we examine the phenotype.
- Consider **Tay-Sachs Disease**, an inherited disorder in humans that results in seizures, blindness, degeneration of motor and mental skills all followed by death because a faulty enzyme in brain cells allows lipids to accumulate to dangerous levels.

Carrier Statistics

1 in 27 Ashkenazi Jews, French Canadians, or Louisiana Cajuns...

1 in 50 Irish-Americans...

1 in 250 from the general population...

Carries the Tay-Sachs gene!

Tay-Sachs Genetics

Consider a carrier for the disease: **Aa**

- Organismal Level: The genotype of **Aa** is free of disease,
  - *thus the **A** to **a** relationship is simple and complete dominance.*

Tay-Sachs Genetics

Consider a carrier for the disease: **Aa**

- Biochemical Level: The **AA** shows no lipid accumulation, the **aa** shows deadly levels of lipid accumulation and the **Aa** shows lipid accumulation but not to deadly levels,
  - *thus the **A** to **a** relationship is incomplete dominance.*

Tay-Sachs Genetics

Consider a carrier for the disease: **Aa**

- Molecular Level: The **AA** shows 100% effective enzymes, the **aa** shows 0% effective enzymes and the **Aa** shows 50% effective enzymes,
- *thus the **A** to **a** relationship is codominance.*

Essential knowledge 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.

e. Genetic engineering techniques can manipulate the heritable information of DNA and, in special cases, RNA.

To foster student understanding of this concept, instructors can choose an illustrative example such as:

- Electrophoresis
- Plasmid-based transformation
- Restriction enzyme analysis of DNA
- Polymerase Chain Reaction (PCR)

PREFACE

- BIOTECHNOLOGY-
  - manipulating organisms to make useful products
  - includes age old selective breeding
  - use of microorganisms to produce food/other products
  - includes modern genetic engineering
  - has sequenced the entire human genome
  - will continue to have direct impacts on human society

DNA CLONING

- Most DNA cloning techniques share common features
- **Gene cloning**- is the production of multiple copies of a single gene
- Gene cloning is useful for two reasons: 1. to make more copies of gene OR 2. to produce a protein product.

DNA CLONING

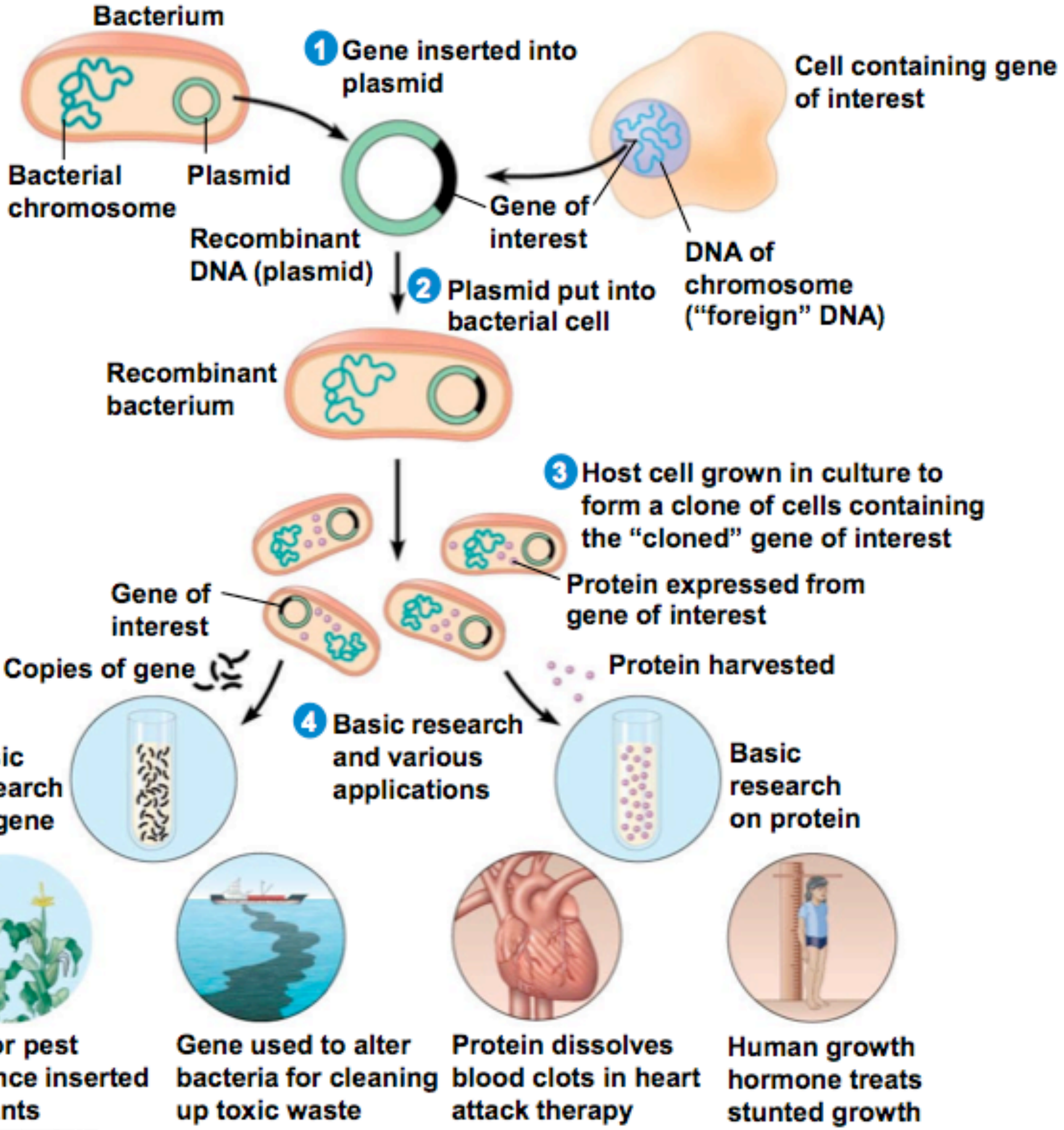
- **Gene cloning** involves using bacteria to make multiple copies of a gene

- Foreign DNA is inserted into a plasmid, and the recombinant plasmid is inserted into a bacterial cell

- **Plasmids** are small circular DNA molecules that replicate separately from the bacterial chromosome

- Reproduction in the bacterial cell results in cloning of the plasmid including the foreign DNA

- This results in the production of multiple copies of a single gene


Bacterium
1 Gene inserted into plasmid
Cell containing gene of interest
Bacterial chromosome
Plasmid
Gene of interest
Recombinant DNA (plasmid)
DNA of chromosome ("foreign" DNA)
2 Plasmid put into bacterial cell
Recombinant bacterium
3 Host cell grown in culture to form a clone of cells containing the "cloned" gene of interest
Protein expressed from gene of interest
Gene of interest
Copies of gene
Protein harvested
4 Basic research and various applications
Basic research on gene
Basic research on protein
Gene for pest resistance inserted into plants
Gene used to alter bacteria for cleaning up toxic waste
Protein dissolves blood clots in heart attack therapy
Human growth hormone treats stunted growth

RESTRICTION ENZYMES

- Gene cloning and genetic engineering rely on **restriction enzymes** that cut DNA at limited and specific locations.

- *Restriction enzymes are used by bacteria to protect themselves from phages by cutting up the foreign DNA before it damages the bacteria*

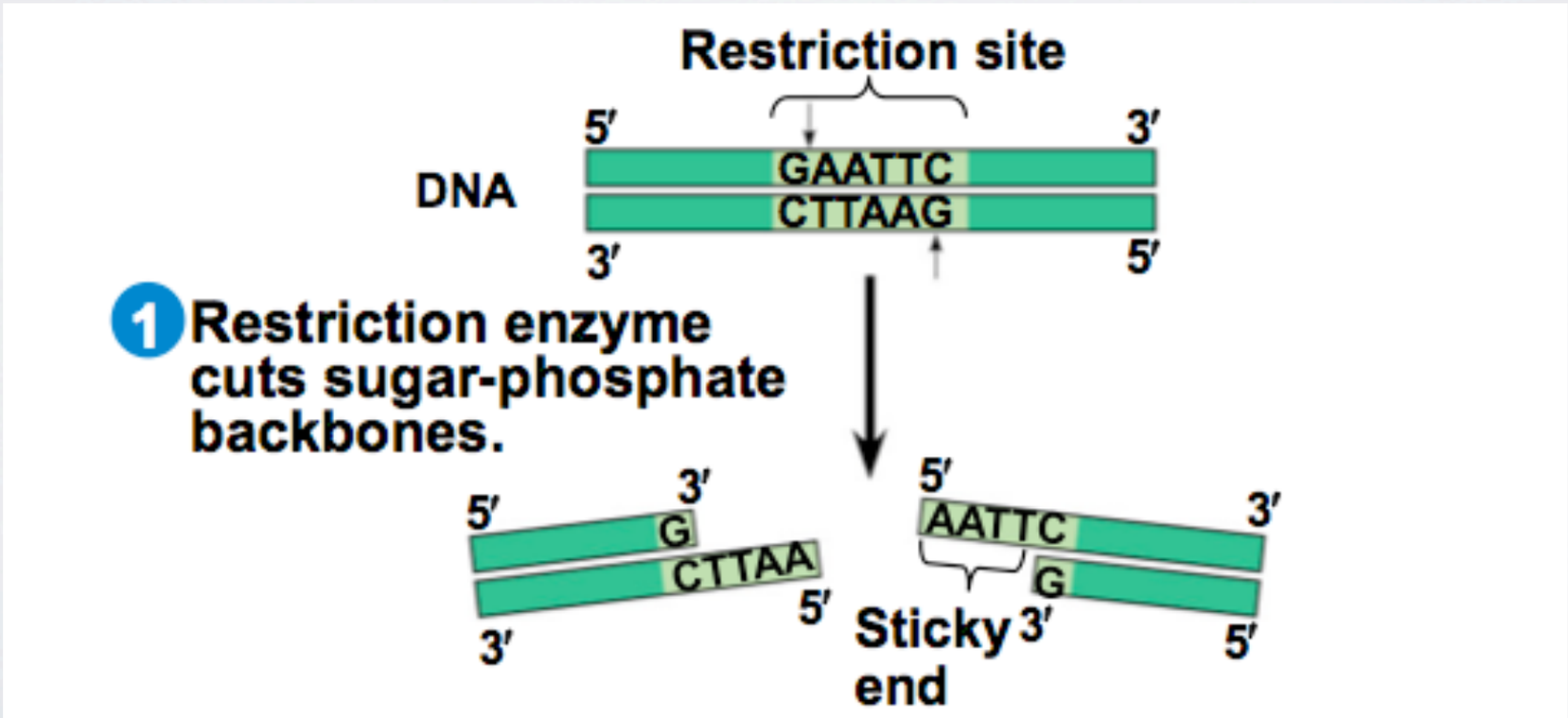
- *Bacteria protects its own DNA from restriction enzymes by methylating its DNA*

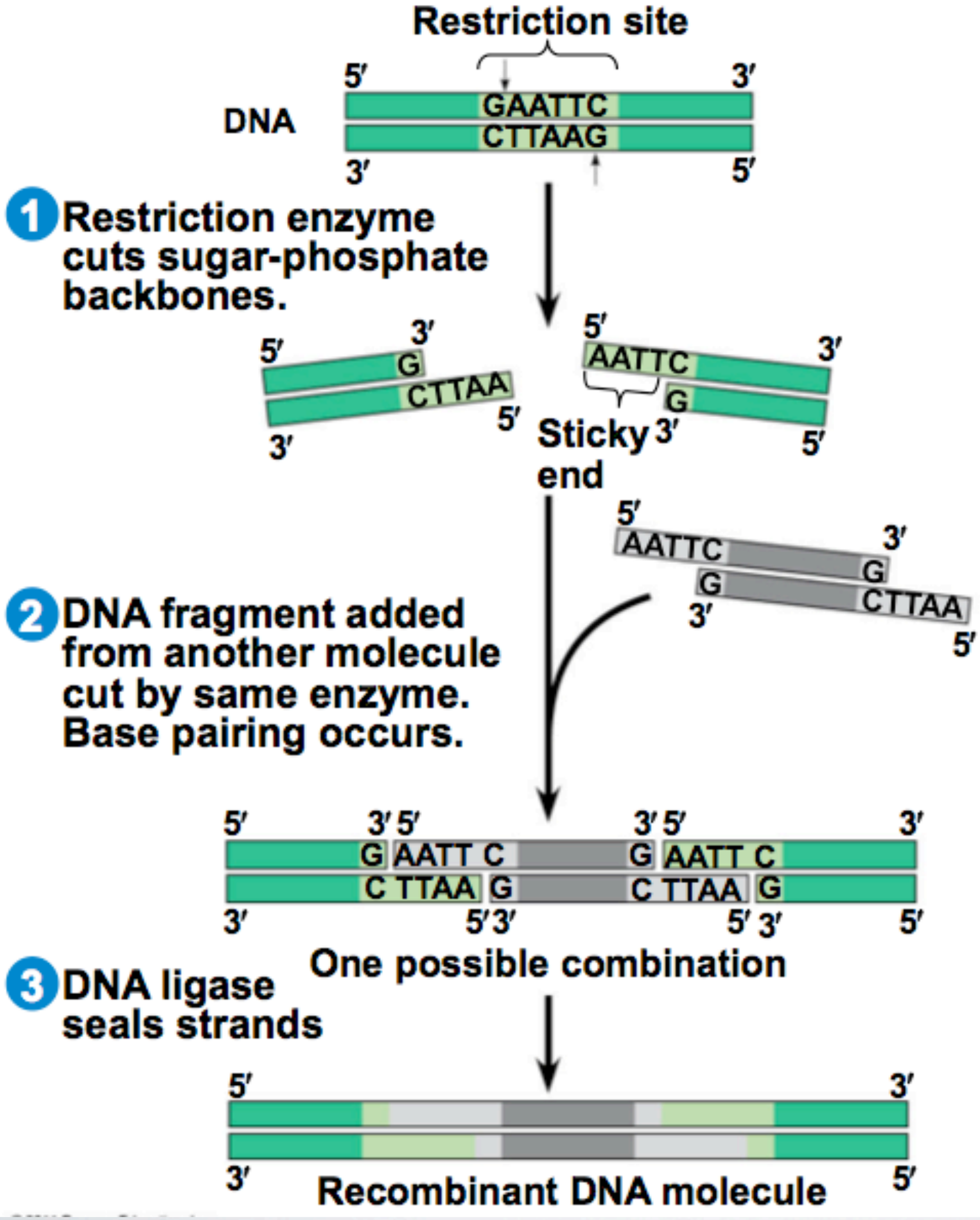
- *Hundreds of restriction enzymes have been identified and isolated, each recognizing a specific restriction site.*

- Bacterial restriction enzymes cut DNA molecules at specific DNA sequences called **restriction sites**

RESTRICTION ENZYMES

- Bacterial **restriction enzymes** cut DNA molecules at specific DNA sequences called **restriction sites**
- A restriction enzyme usually makes many cuts, yielding **restriction fragments**
- The most commonly used restriction enzymes recognize and cut DNA into sequences of 4-8 nucleotides in length





- The most useful restriction enzymes cut DNA in a staggered way, producing fragments with "**sticky ends**"

- Sticky ends can bond with complementary sticky ends of other fragments

- **DNA ligase** is an enzyme that seals the bonds between restriction fragments

RESTRICTION ENZYMES

- Restriction sites are specific but their number and location throughout an entire molecule is random.

- A restriction enzymes will cut every restriction site it finds.

- This results in hundreds or thousands of restriction fragments, each its own unique length and sequence but each with exactly the same "sticky ends".

- Imagine, only one of these fragments represents our "gene of interest", later we ill learn how to find our "needle in the haystack"

CLONING EUKARYOTIC GENES USING PLASMIDS

- Recall, the main idea behind gene cloning involves finding a gene of interest in one organism, cutting the gene out and then pasting this gene into another cell/organism.
- The restriction enzymes act like "scissors"
- DNA ligase acts like the "glue"

But we still need something to carry the gene into the host cell

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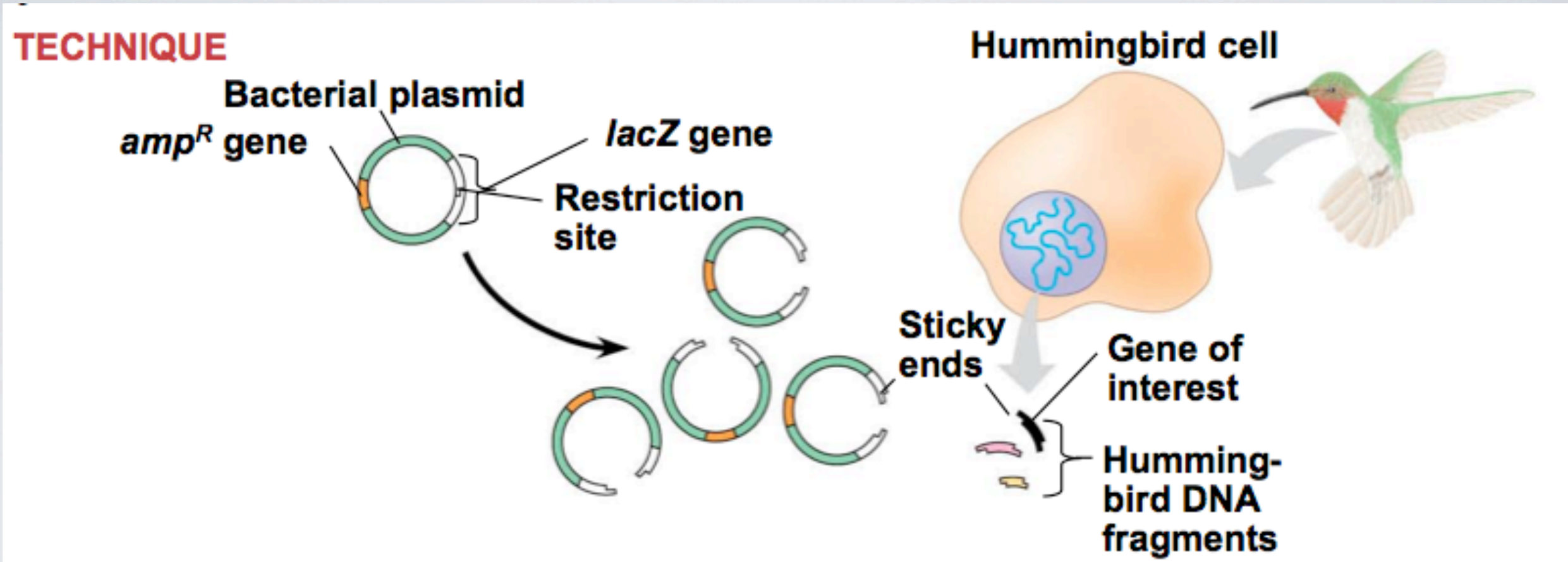
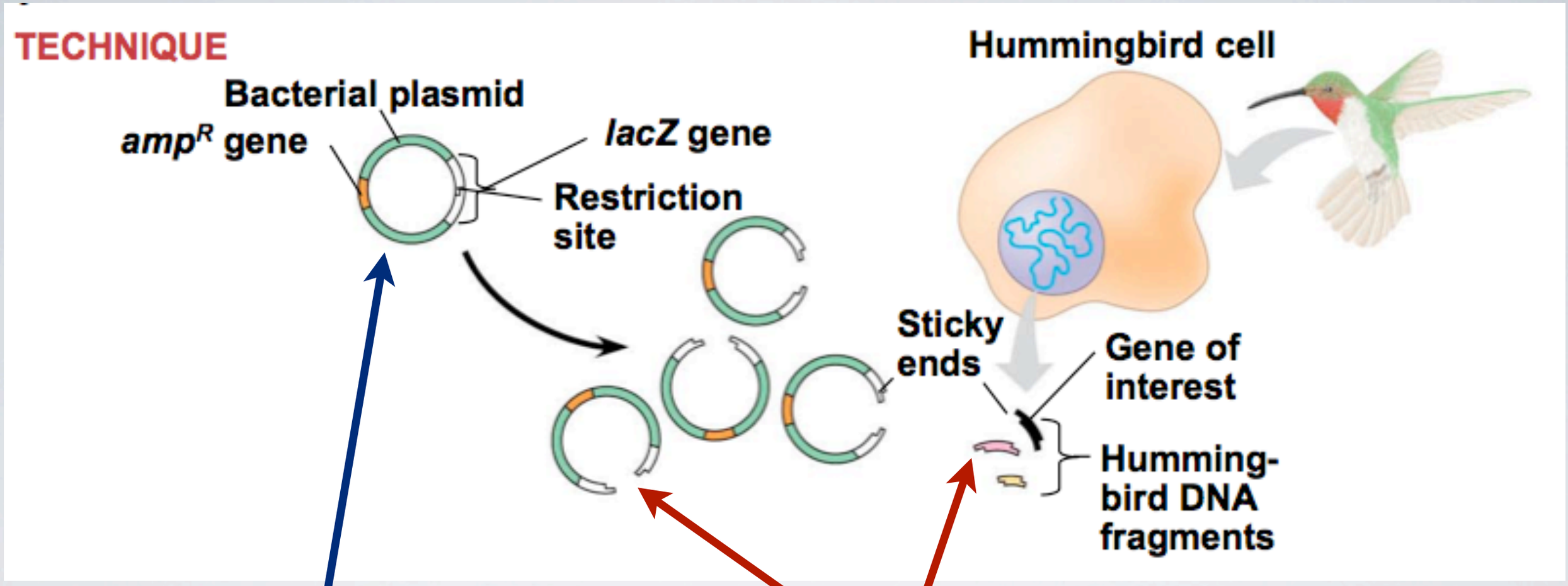
But we still need something to carry the gene into the host cell

- A **cloning vector** is a molecule of DNA that can carry foreign DNA into a host cell and replicate there.
- Bacterial plasmids are widely used as cloning vectors

CLONING EUKARYOTIC GENES USING PLASMIDS



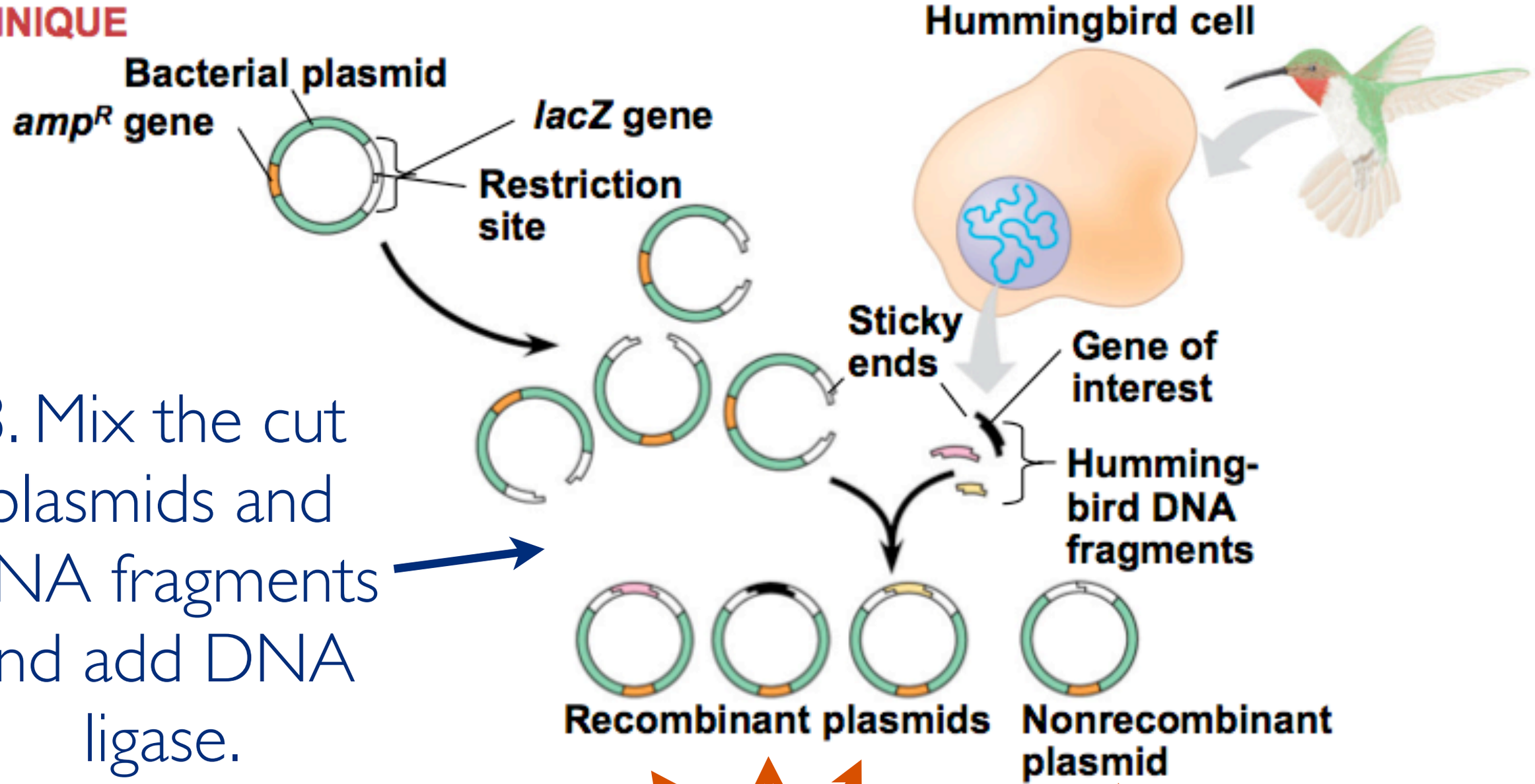
In this example we are going to learn how we might insert hummingbird genes into E. coli.



1. Obtain an engineered plasmid, today this means purchasing it from a biotech supply company.

2. Cut plasmid and Hummingbird's DNA with the same restriction enzyme, one that makes a single cut in the Lac Z gene of the engineered plasmid .

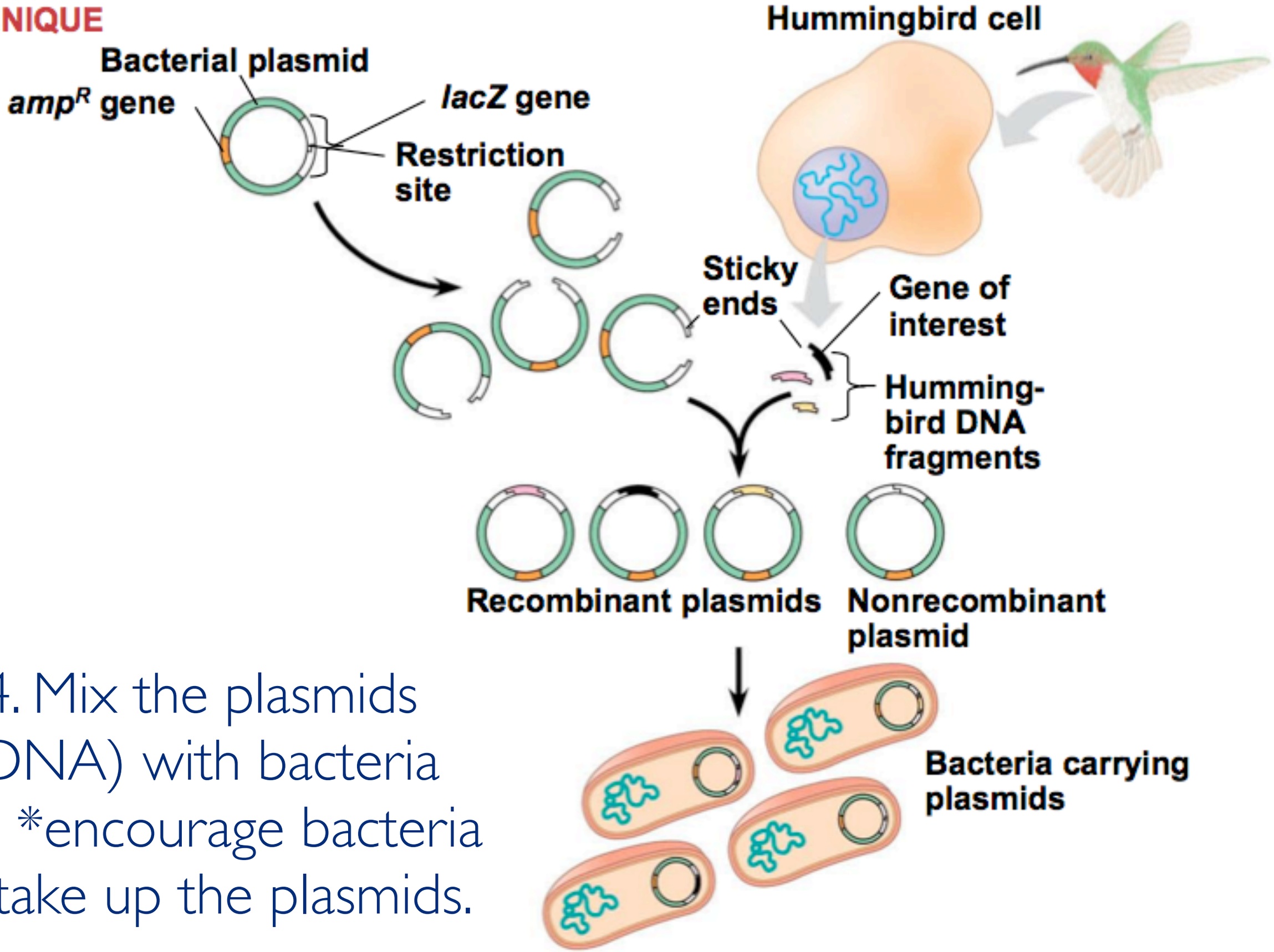
TECHNIQUE



3. Mix the cut plasmids and DNA fragments and add DNA ligase.

Some plasmids will be recombinants while others are not recombinants.

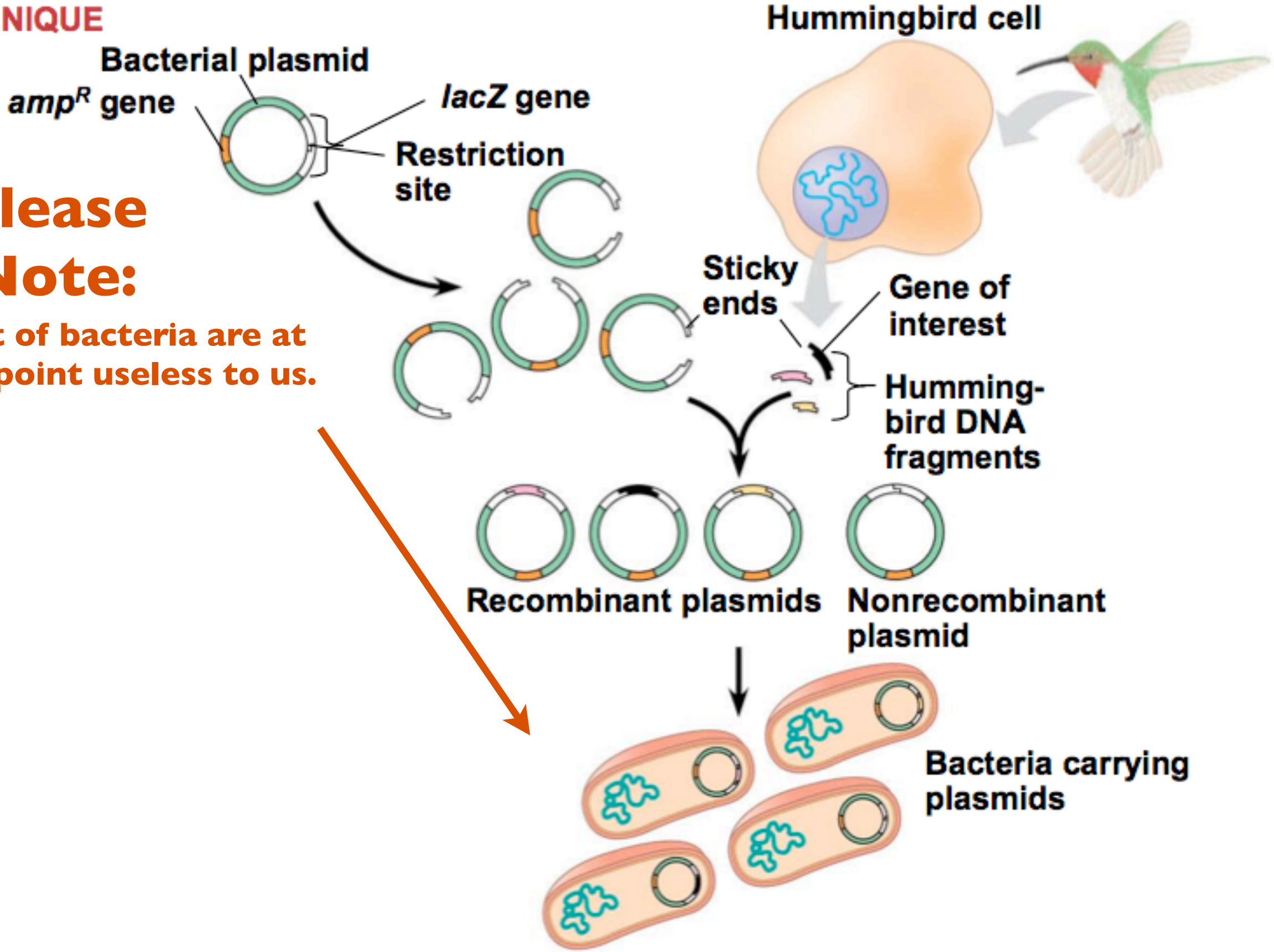
TECHNIQUE



4. Mix the plasmids (DNA) with bacteria and *encourage bacteria to take up the plasmids.

*lab techniques such as cold to hot water bath transfers.

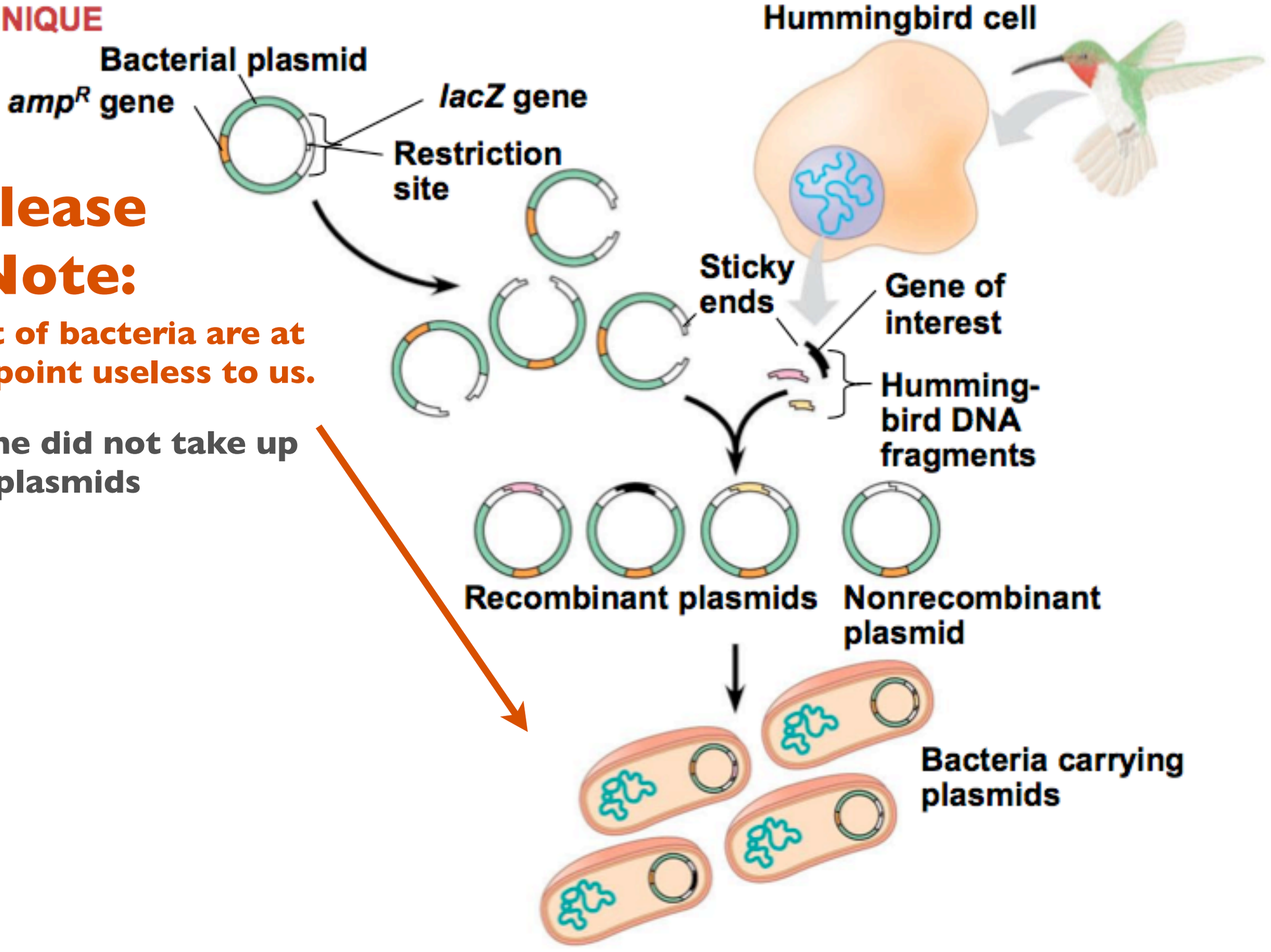
TECHNIQUE



Please Note:

Most of bacteria are at this point useless to us.

TECHNIQUE

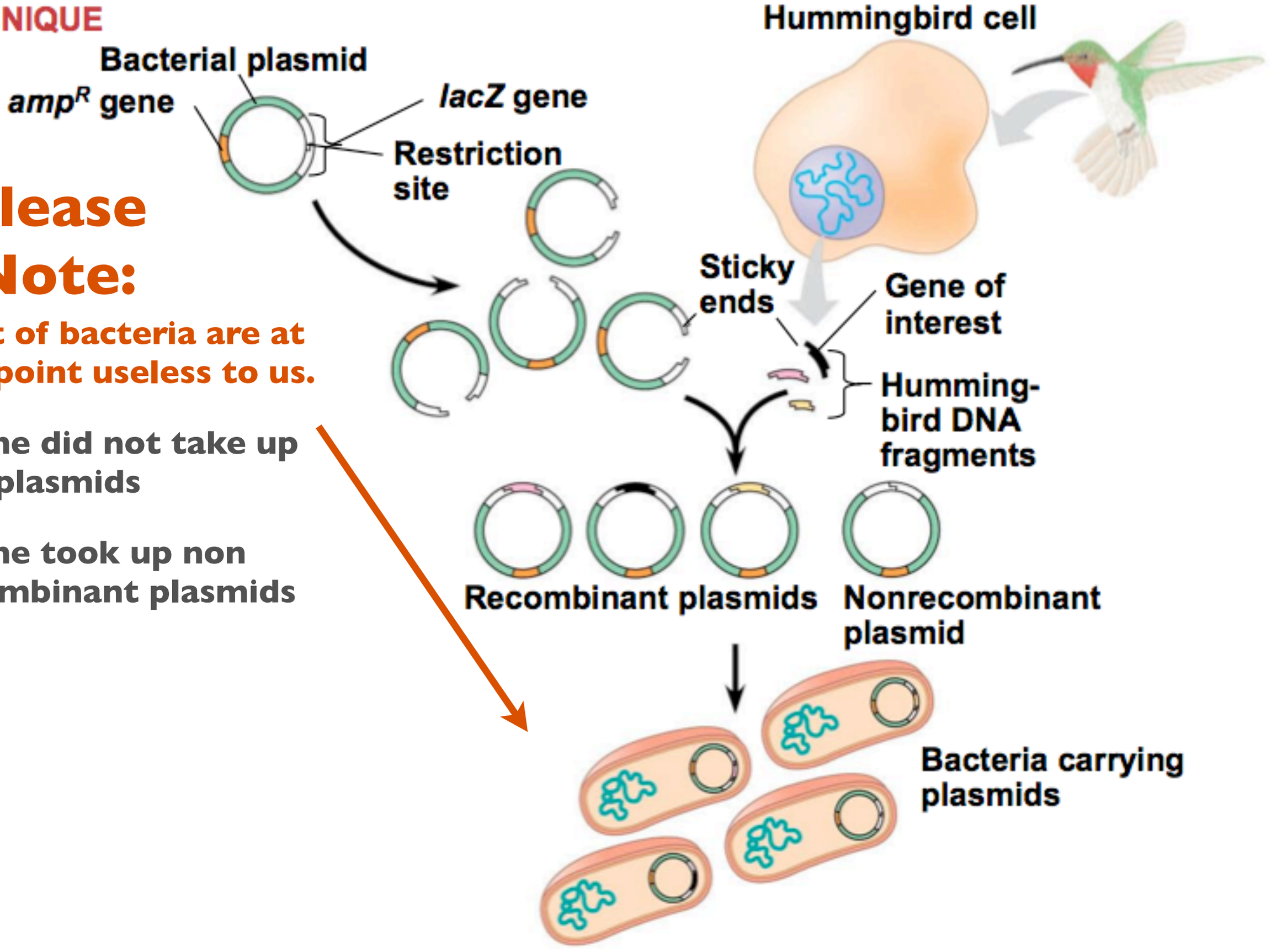


Please Note:

Most of bacteria are at this point useless to us.

-some did not take up any plasmids

TECHNIQUE



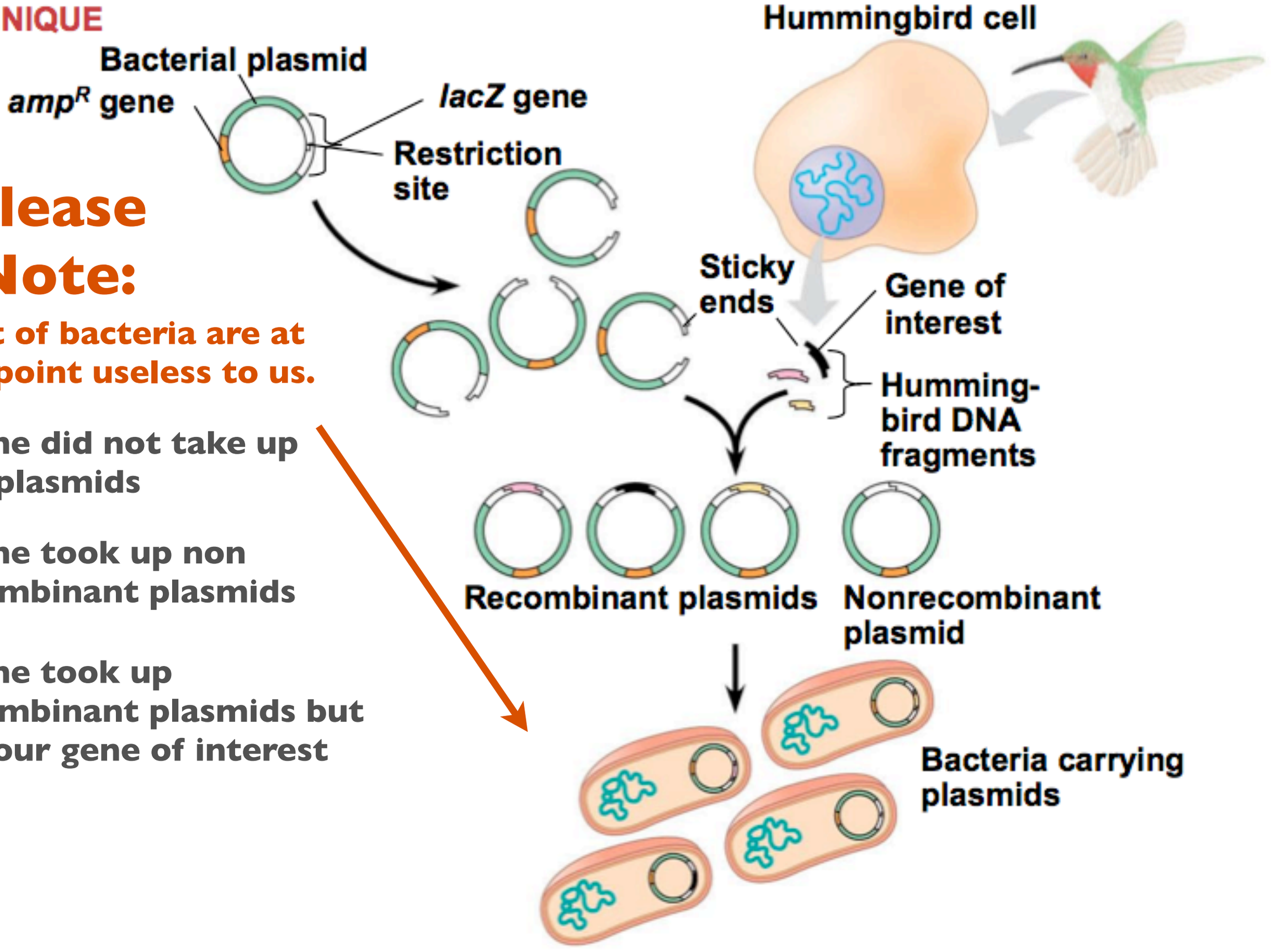
Please Note:

Most of bacteria are at this point useless to us.

-some did not take up any plasmids

-some took up non recombinant plasmids

TECHNIQUE



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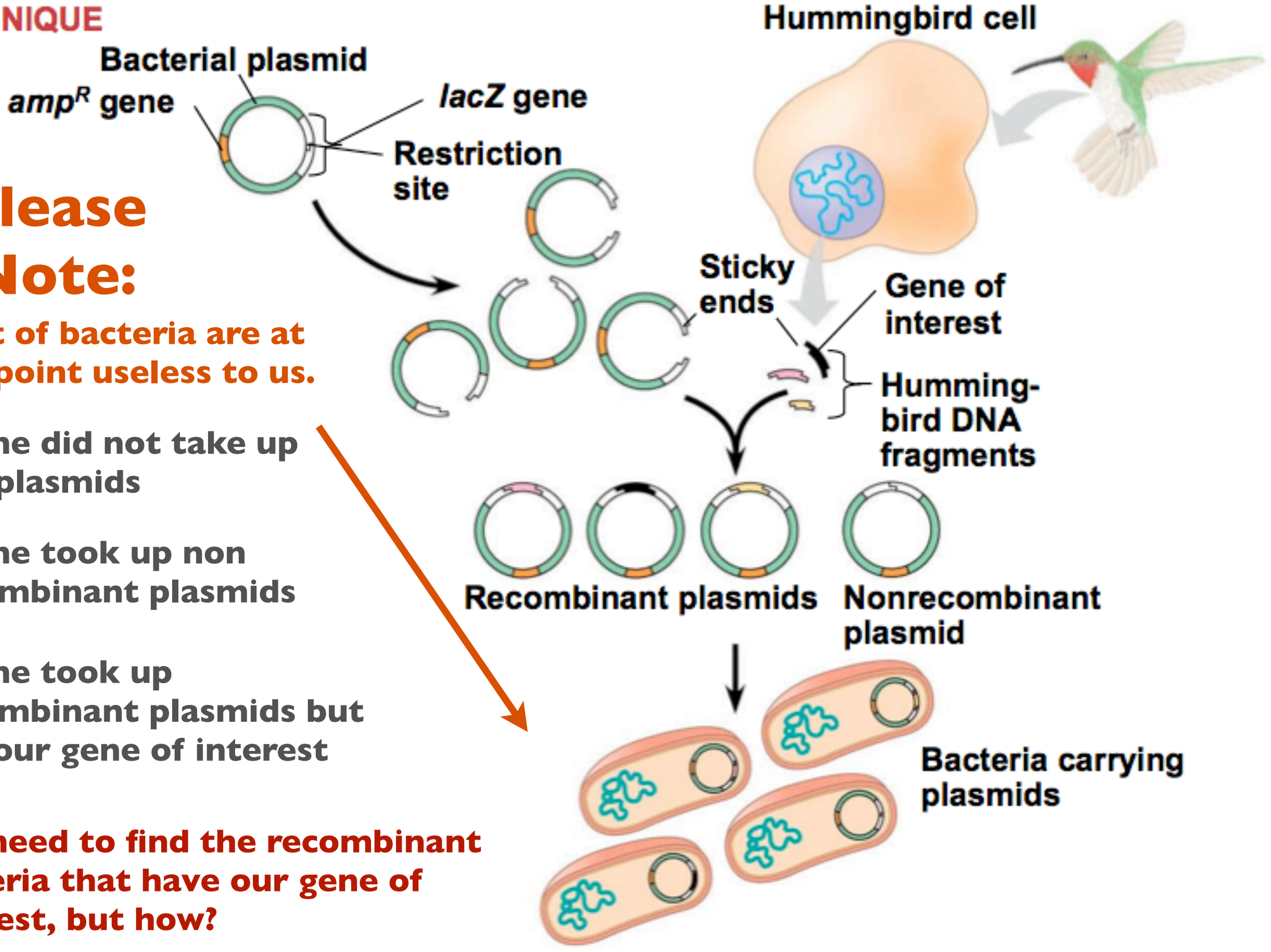
-some did not take up any plasmids

-some took up non recombinant plasmids

-some took up recombinant plasmids but not our gene of interest

TECHNIQUE



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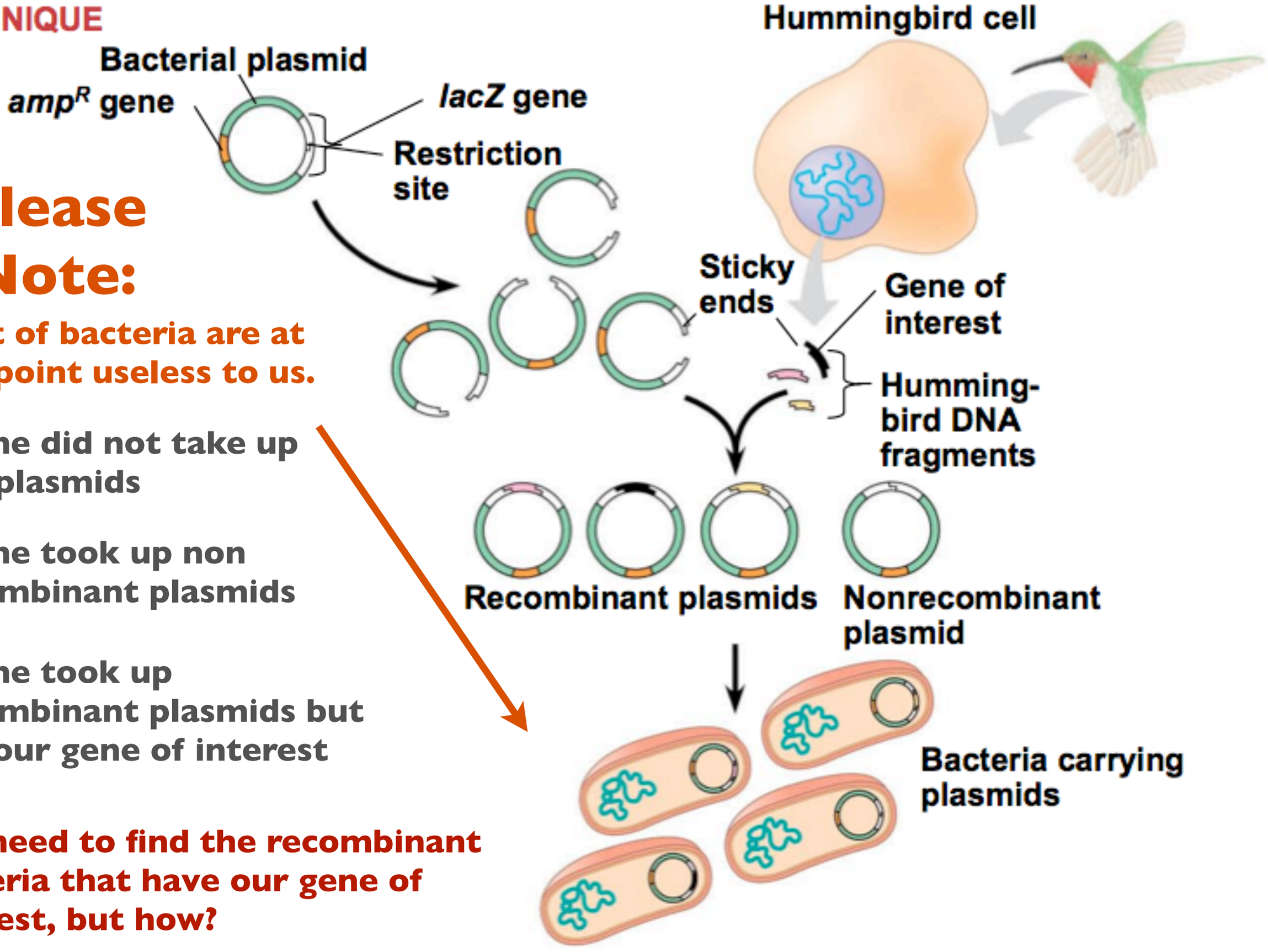
-we need to find the recombinant bacteria that have our gene of interest, but how?

TECHNIQUE



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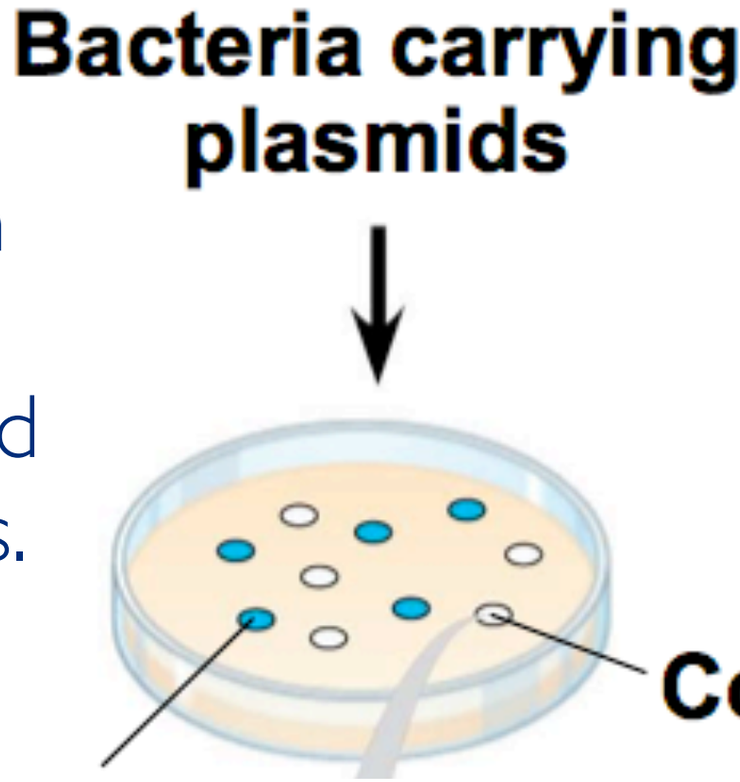
-we need to find the recombinant bacteria that have our gene of interest, but how?

...the amp^R gene and the Lac Z gene will help us

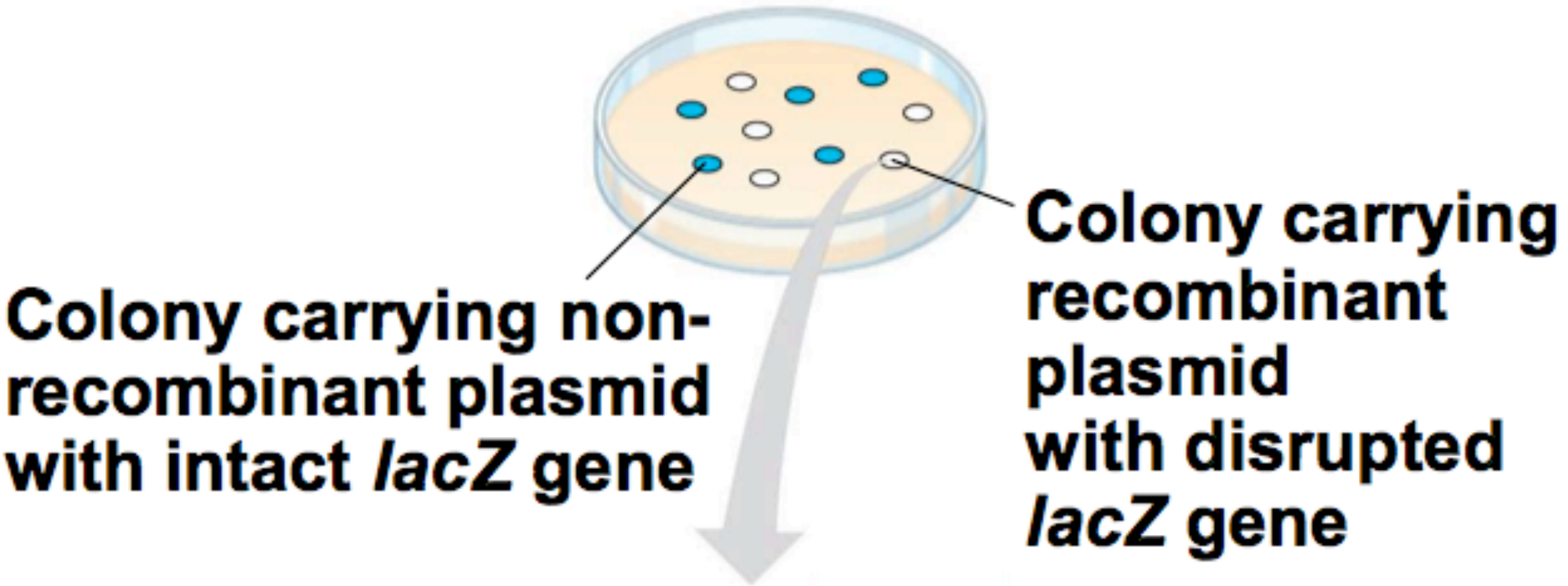
CLONING EUKARYOTIC GENES

5. Grow the bacteria on agar with penicillin, this eliminates all cells that did not take up any plasmids.



CLONING EUKARYOTIC GENES

5. Grow the bacteria on agar with X-gal. This will help to distinguish between (white) recombinant and (blue) non recombinant plasmids.



An intact Lac Z gene (non recombinant plasmid) can produce a functional enzyme beta-galactosidase that will hydrolyze X-gal and turn it blue.

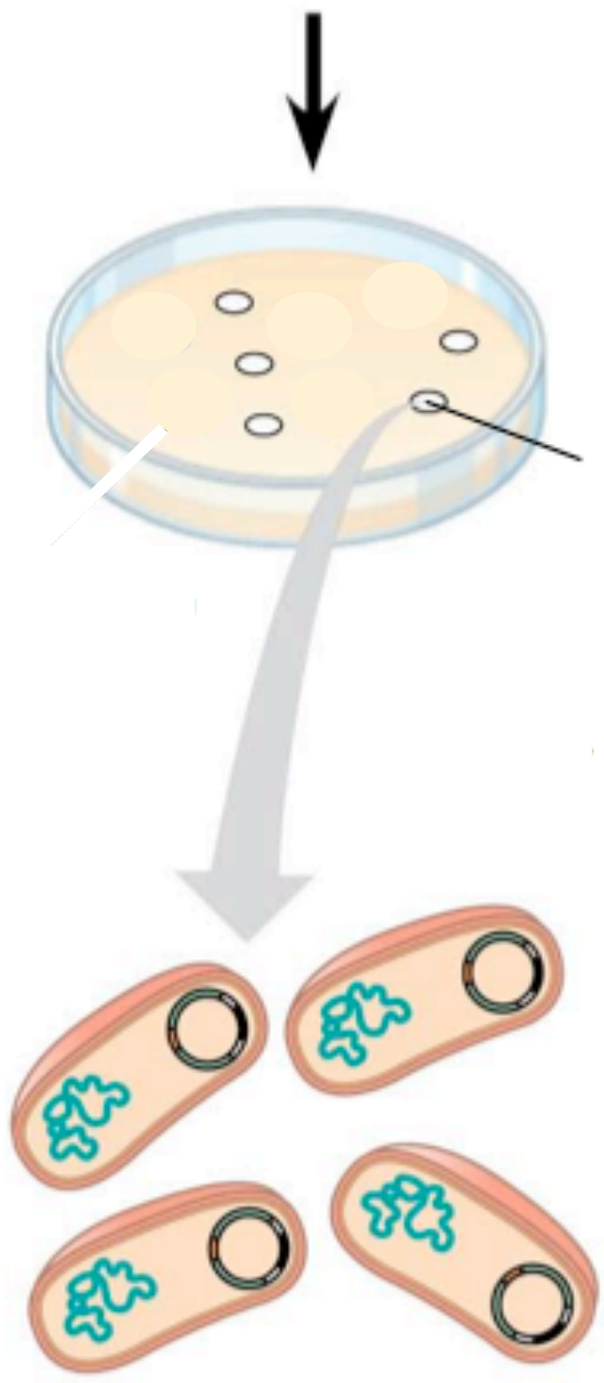
A disrupted Lac Z gene (recombinant plasmid) can NOT produce a functional enzyme beta-galactosidase and will NOT hydrolyze X-gal and remains white.

CLONING EUKARYOTIC GENES

At this point, we know the bacteria have our plasmids, we know that a piece of Hummingbird DNA is in the correct position

RESULTS

Most of these colonies are carrying other genes, or pieces of genes or even even noncoding pieces of DNA...not our single gene of interest!



Shortly, we will learn how to find the colony carrying our gene interest.

One of many bacterial clones

Essential knowledge 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.

f. Illustrative examples of products of genetic engineering include:

- Genetically modified foods
- Transgenic animals
- Cloned animals
- Pharmaceuticals, such as human insulin or factor X

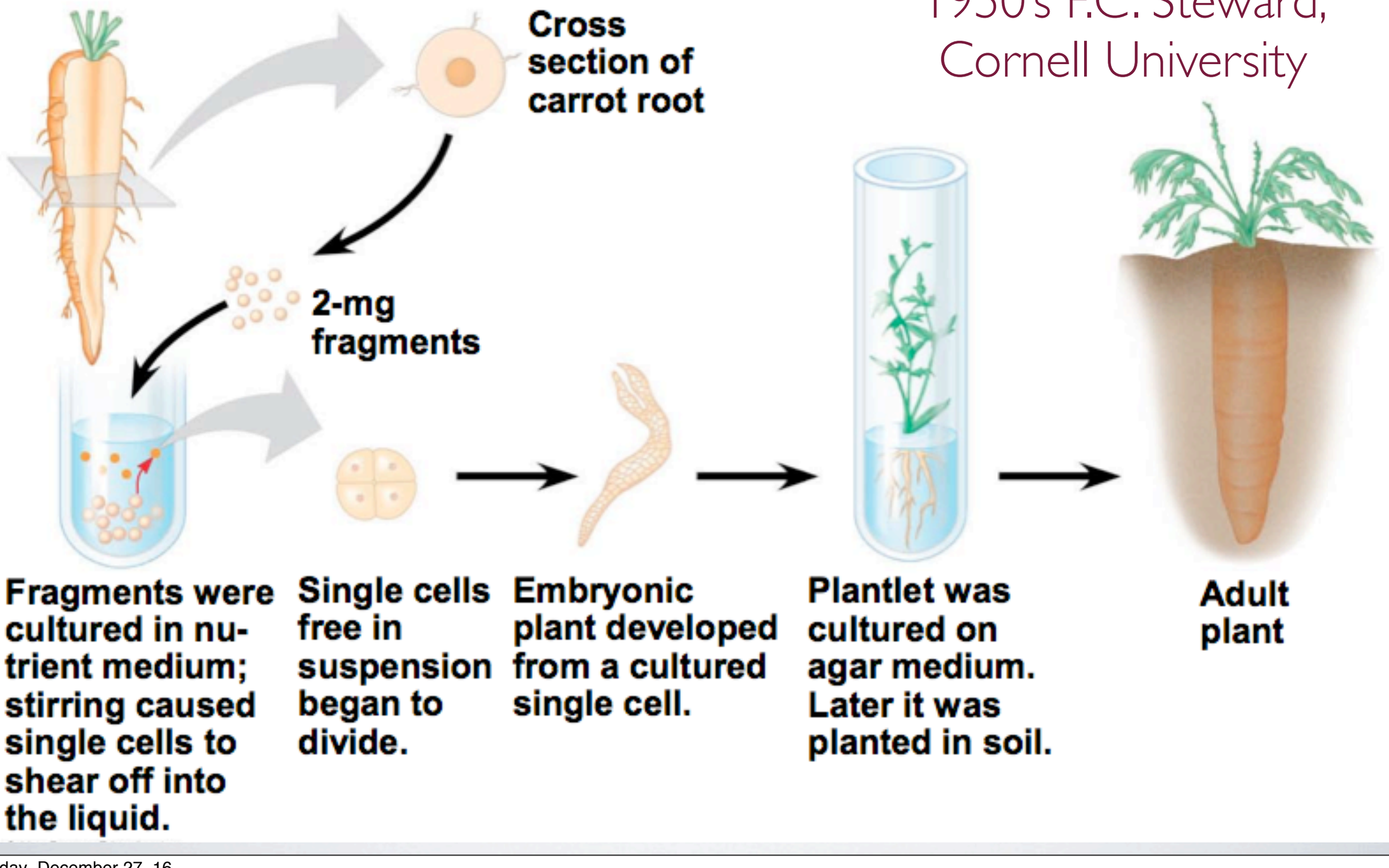
BIOTECHNOLOGY

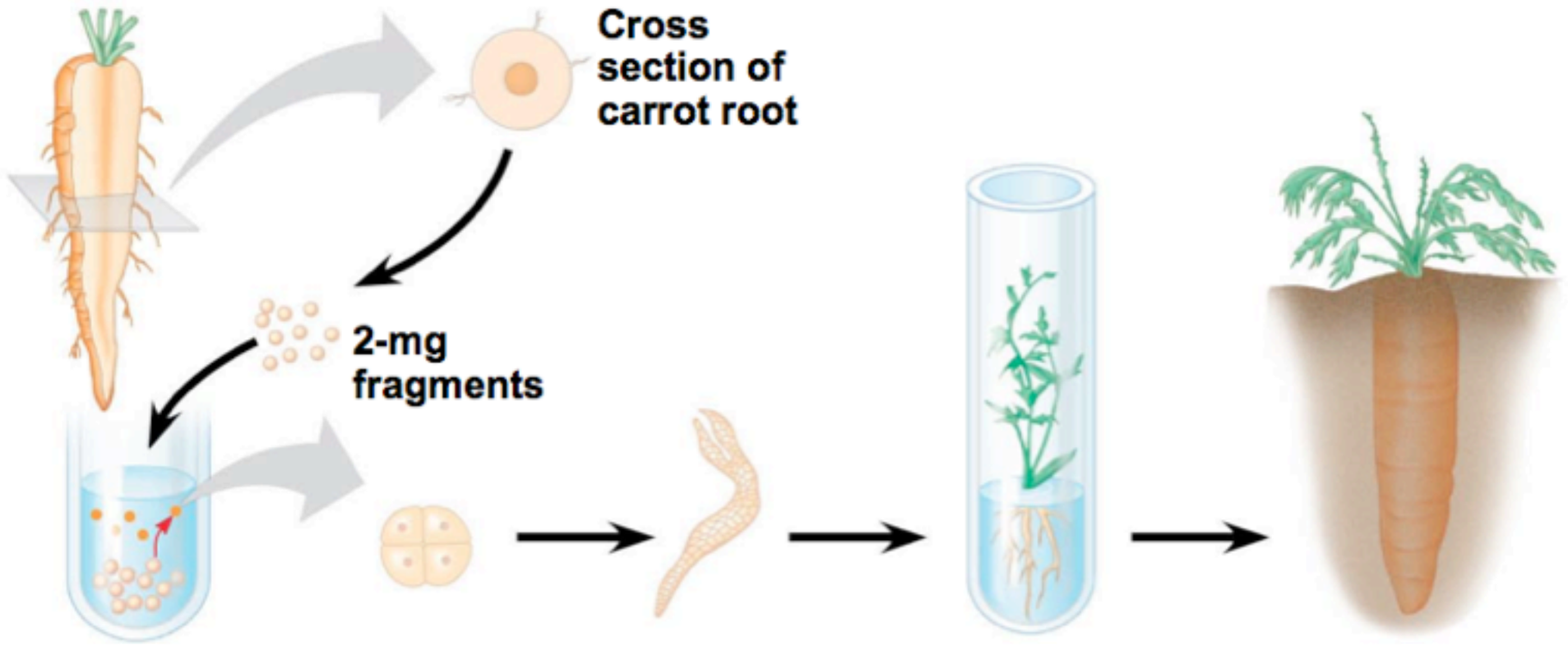
III. Main Idea

Cloning organisms has many potential applications, one of which is the production of stem cells.

CLONING PLANTS

1950's F.C. Steward, Cornell University





Plant cloning is used extensively today in agriculture!

Found that differentiated cells taken from root, grown in culture could develop into a normal adult plant!

These results showed that cell differentiation does not necessarily involve irreversible changes in the DNA.

Further...in plants some cells can "dedifferentiate" and "re-differentiate" into another cell type...these cells are totipotent!

CLONING ANIMALS

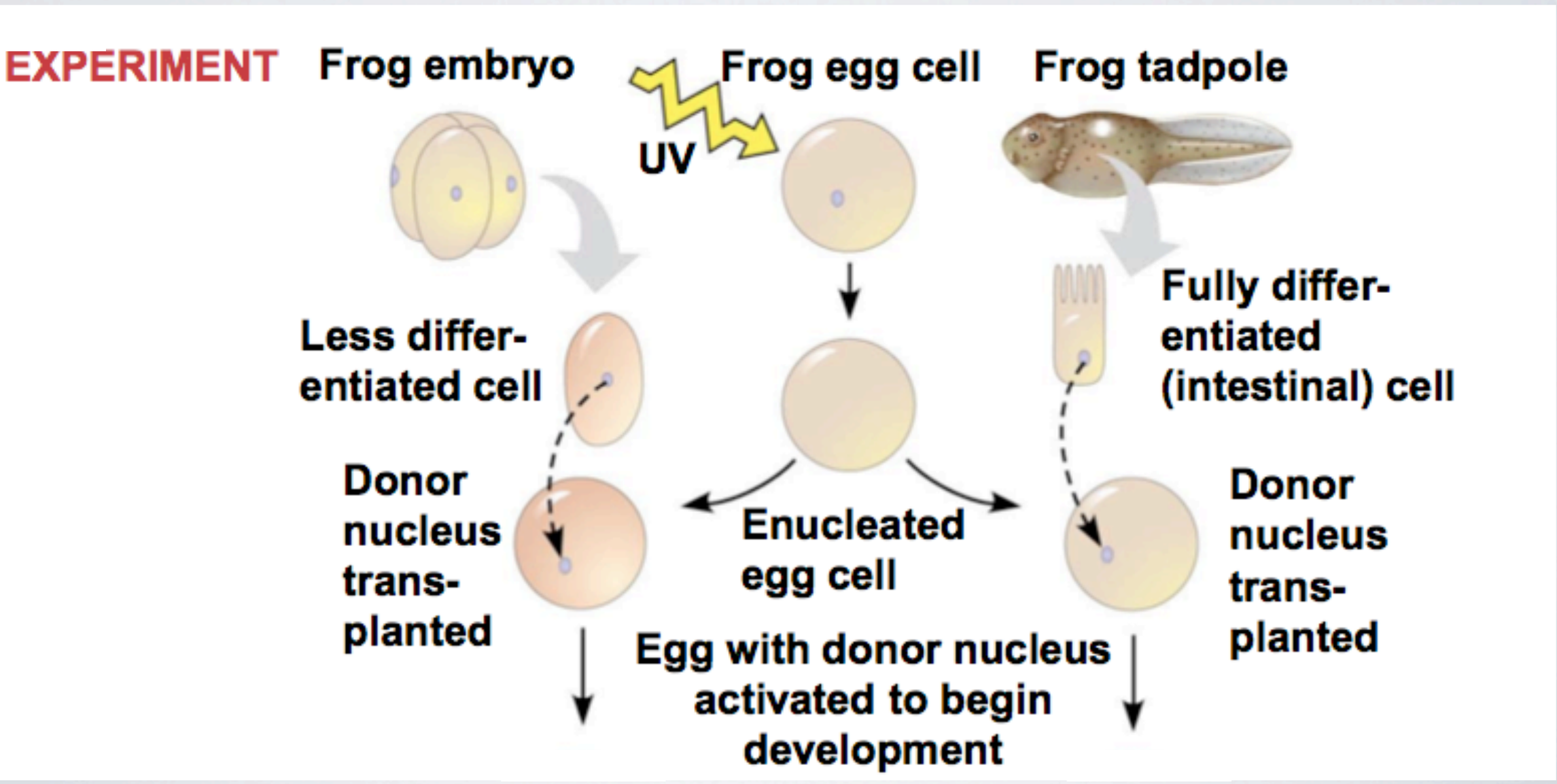
- Differentiated animal cells do not generally divide in culture.

- Differentiated animals cells will develop into other cell types or complete organisms.

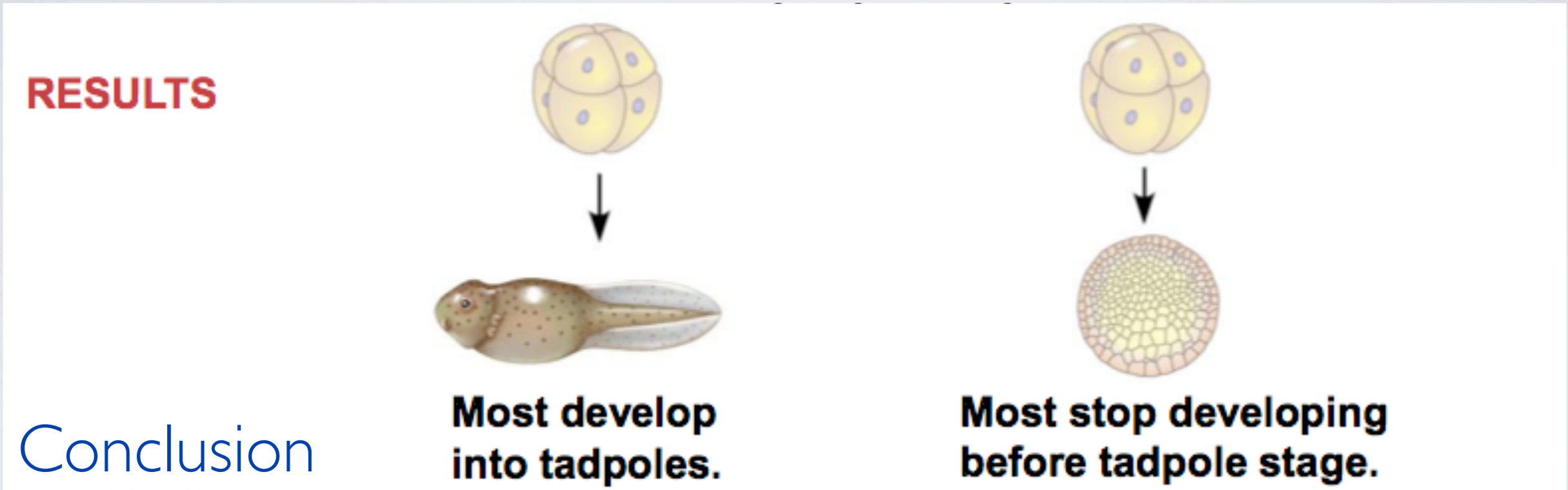
- The search for totipotent animal cells requires a different approach, called **nuclear transplantation**.

- *Nuclear transplantation*, removes the nucleus from an egg and replaces it with the nucleus of a differentiated cell.

John Gurdon and colleagues at Oxford University, destroyed the nuclei of frog eggs by exposing the eggs to UV light. They then transplanted the nuclei from cells of frog embryos and tadpoles into the enucleated eggs.



When the transplanted nuclei came from an early embryo, whose cells were relatively undifferentiated, most of the recipient eggs developed into tadpoles. BUt when the nuclei was came from fully differentiated intestinal cells of a tadpole, fewer than 2% of the eggs developed into into tadpoles, and most stopped developing at a much earlier stage.



Conclusion

The nucleus from a differentiated frog cell can direct the development of a tadpole. However, its ability to do so decreases as the donor cell becomes more differentiated, presumably because of changes in the nucleus.

REPRODUCTIVE CLONING OF MAMMALS

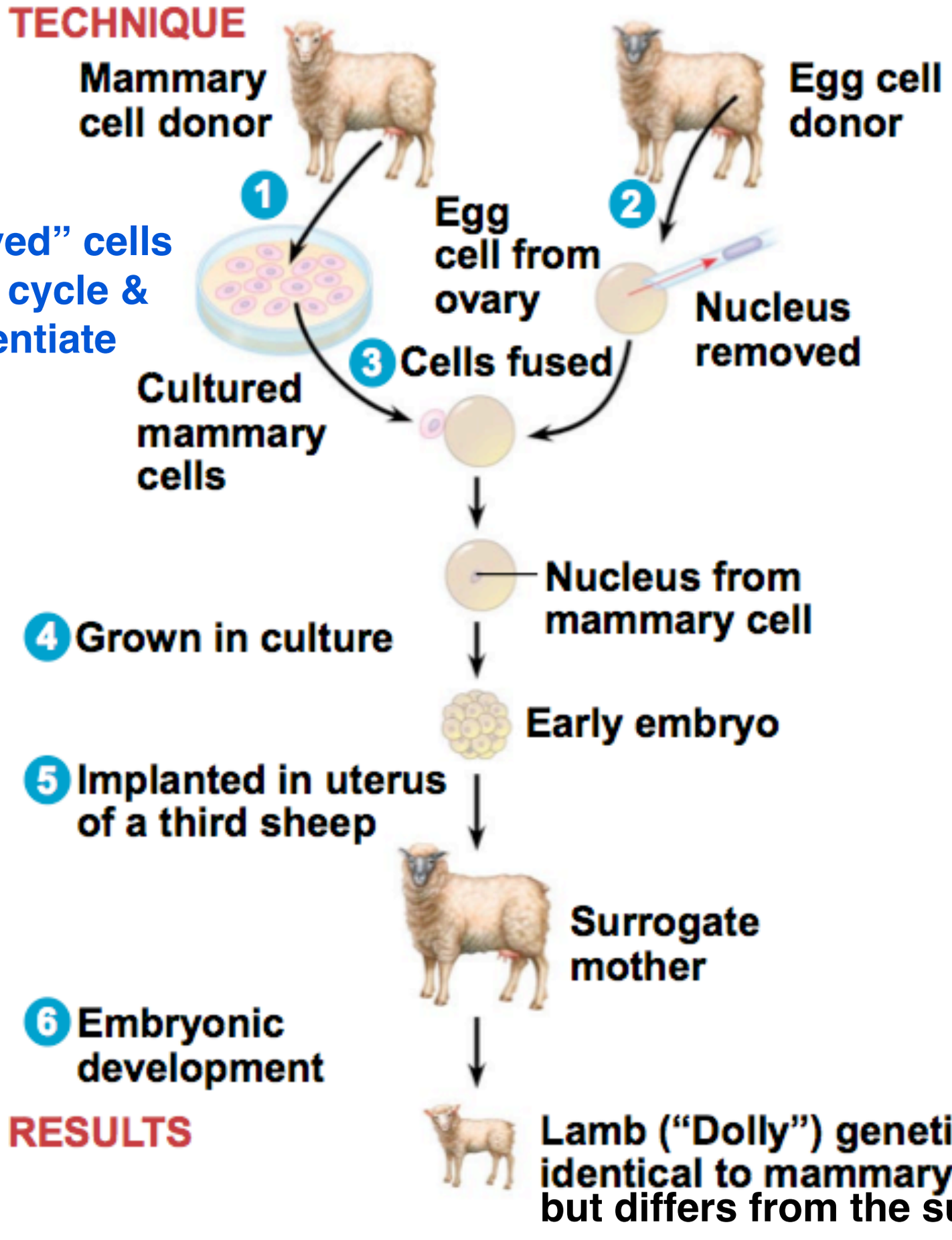
- Researchers now wondered whether nuclei of differentiated cells **could** be reprogrammed and act like as a donor nucleus.

- The answer came in 1997, when scientists from Roslin Institute in Scotland made the headlines.

- They announced the birth of "Dolly" a lamb cloned from an adult sheep by nuclear transplantation from a differentiated cell.

- They were able to dedifferentiate the donor nuclei by culturing the cells in a nutrient poor medium and then fusing these cells with enucleated sheep eggs.

TECHNIQUE



RESULTS

Lamb ("Dolly") genetically identical to mammary cell donor but differs from the surrogate mother

APPLICATION

This method is used to produce cloned animals whose nuclear genes are identical to those of the animal supplying the nucleus.

REPRODUCTIVE CLONING OF MAMMALS

- Speculation arose regarding the success of Dolly, since she did suffer a seemingly high number of health complications and was consequently euthanized at age 6.

- However since 1997 many other mammals have been successfully cloned including: mice, cats, cows, horses, pigs, dogs and monkeys.

- The goal is usually reproductive cloning, that is simply making new individuals.

- Our knowledge of cloning continues to grow.

- CC (forCarbonCopy) was the first cat cloned; however, CC differed somewhat from her female “parent”

- Cloned animals do not always look or behave exactly the same

- Illustrating the importance of environmental influences and random phenomena in development.

Speculation abounds about cloning humans!

Researchers are getting closer, but the prospect raises unprecedented ethical issues.

PROBLEMS: IN CLONING ANIMALS

- Most clones like, "Dolly" exhibit defects of some sort or another, recent research has started to uncover reasons for these issues.

- The biggest problem in cloning animals relates to the epigenetic changes in chromatin.

- The methylation and acetylation patterns found on DNA must be reversed in the donors genes or the donors genes must be appropriately repressed or expressed *early* in development.

Remember DNA methylation/acetylation regulate gene expression, in fact we are finding much of cloning success resides in the ability to artificially manipulate these epigenetic patterns.

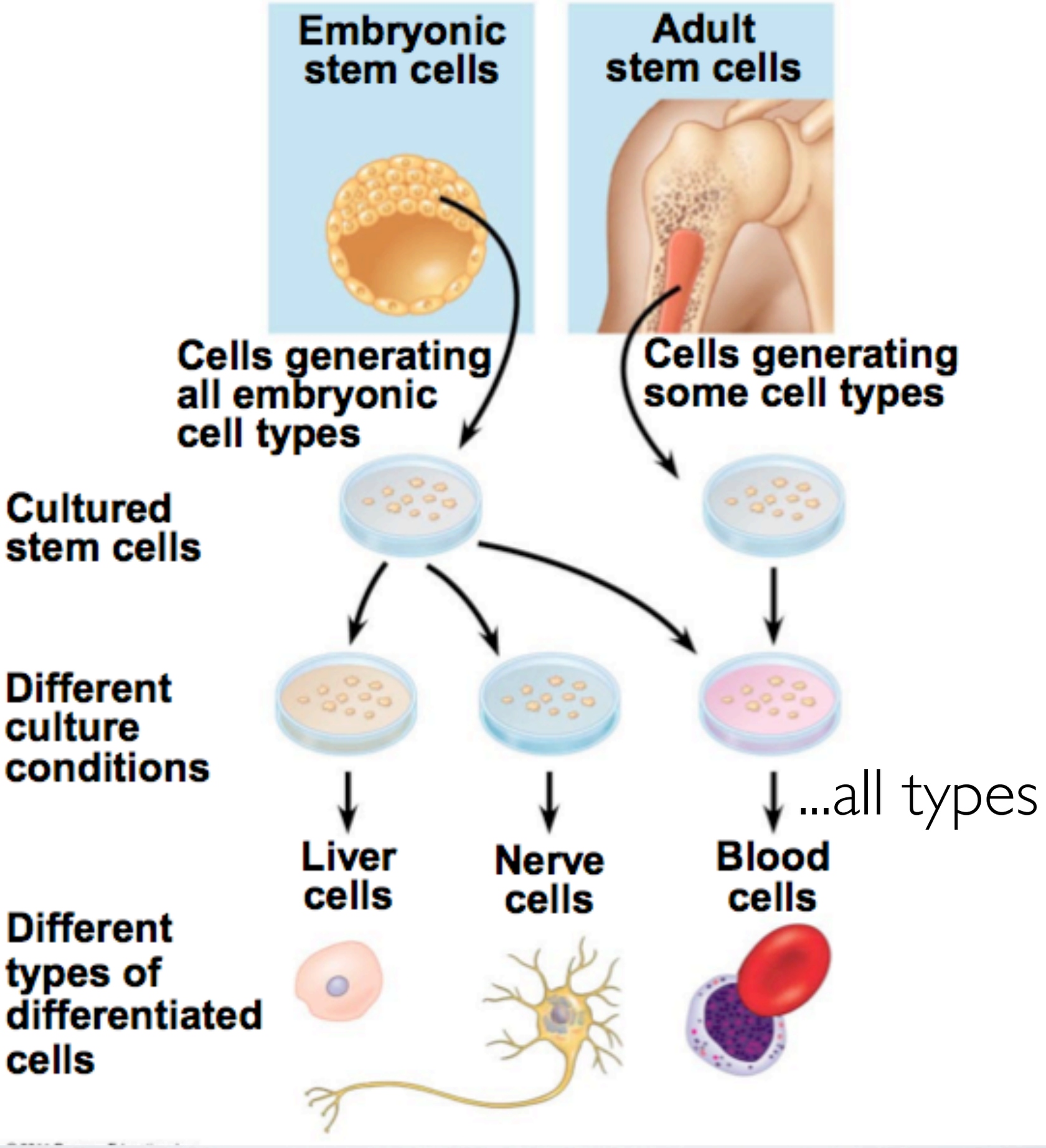
ANIMAL STEM CELLS

- A major goal of cloning human embryos is not reproduction, but production, the production of *stem cells* for treating human diseases.

- A **stem cell** is a relatively unspecialized cell that can both reproduce itself indefinitely and, under certain conditions, differentiate into specialized cells of one or more types.

- Early animal embryos (blastocyst stage) contain stem cells called **embryonic stem cells**, they are capable of producing any cell type.

- In contrast, **adult stem cells**, serve to replace non-reproducing specialized cells, including many different cell types BUT not ALL cell types.


Embryonic stem cells
Adult stem cells
Cells generating all embryonic cell types
Cells generating some cell types
Cultured stem cells
Different culture conditions
...all types
Liver cells
Nerve cells
Blood cells
Different types of differentiated cells

ANIMAL STEM CELLS

- Researchers continue more and more *adult stem cells*.

- *Adult stem cells* have been found in the brain, skin, hair, eyes, dental pulp and bone marrow.

- Scientists are getting better at finding, isolating and culturing these *adult stem cells*, but none are more versatile or promising than the *embryonic stem cells*.

- The ultimate goal behind stem cell research is to supply new operative cells to damaged or diseased organs.

ANIMAL STEM CELLS

- *Adult stem cells* are limited to certain tissue types, *embryonic stem cells* hold more promise because they are **pluripotent** (they can develop into many types of cells).

- The only way thus far to acquire ES cells is through embryos, which raises political and ethical issues.

- ES cells are currently obtained through embryos donated by patients undergoing infertility treatments.

- Scientists would like to clone the human embryos and use the embryos as a source of stem cells.

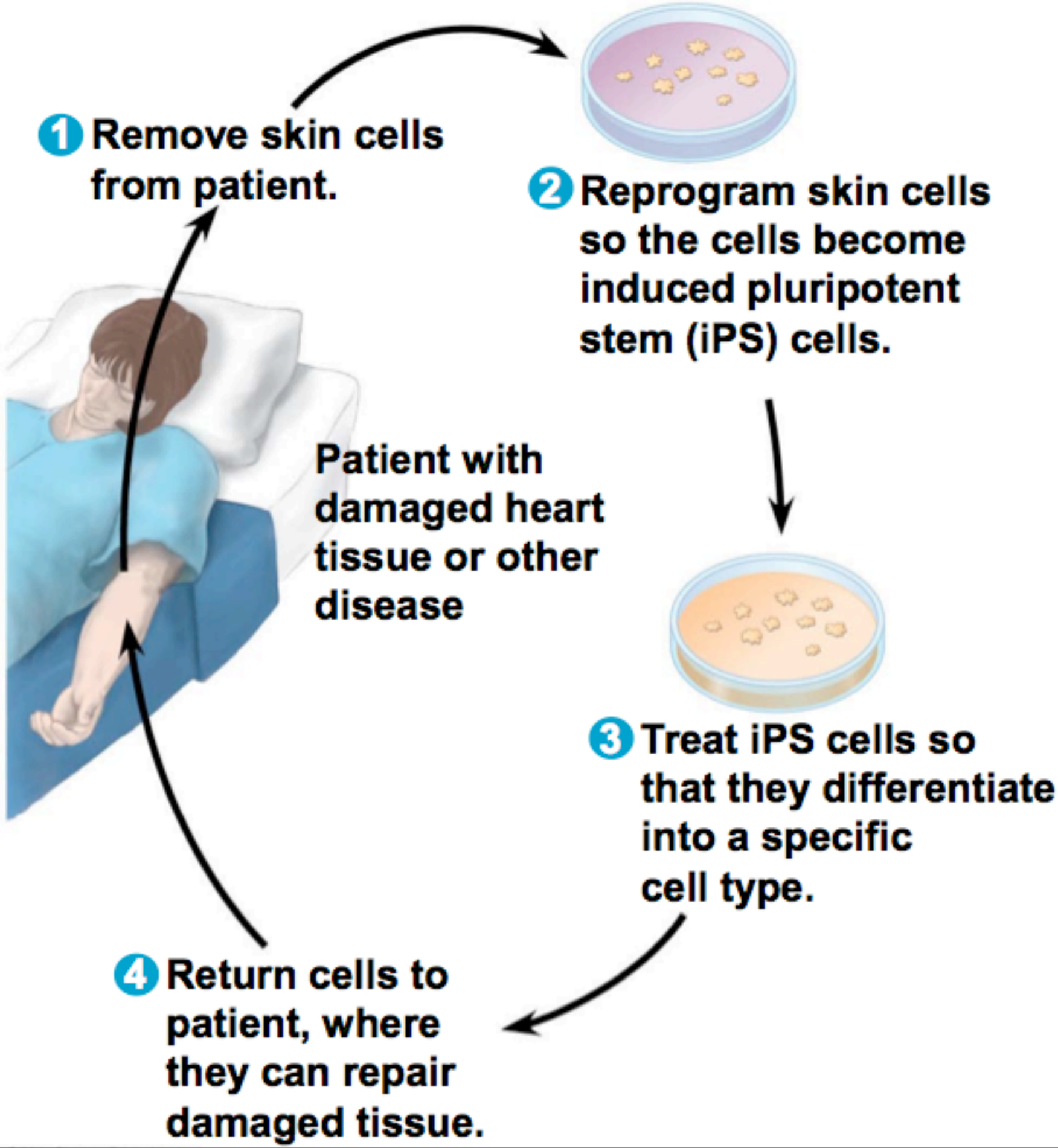
- A donor nucleus could from a diseased person, implanted into stem cell and used for therapeutic purposes.

ANIMAL STEM CELLS

- In 2007 researchers were able to reprogram differentiated cells to act like ES cells, they used retroviruses to introduce 4 stem cell regulatory master genes.

- Initially it look like the debate would be less imperative because these **induced pluripotent stem cells (iPS)** could do everything that ES cells could do.

- Recently however, differences between the iPS and ES cells are coming to light particularly with respect to gene expression and cell division.



Potential Treatments:

Cancers
Diabetes
Heart Disease
Alzheimer's
Parkinson's
Huntington's
Sickle Cell
Spinal Cord Injuries

BIOTECHNOLOGY

IV. Main Idea

The practical applications of DNA technology affect our lives in many areas such as medicine, forensics, agriculture and environmental science.

MEDICAL APPLICATIONS

- DNA technology has allowed us to identify the genes that play a role direct role in disease.

- It has even helped our understanding of "non-genetic" diseases and the indirect roles that certain genes play.

- Furthermore by comparing diseased and normal tissue we can identify gene expression patterns that could help to develop targets for prevention or therapy.

DIAGNOSIS

- PCR and gene probes are now used to diagnose and track down pathogens such as HIV.

- PCR and gene probes can also diagnose genetic disorders such as sickle cell, Huntington's, cystic fibrosis, hemophilia and Duchenne muscular dystrophy.

- Southern blotting is used to determine carriers of these genetic disorders.

- SNP's associated with increased risk of cancers, Alzheimer's or heart disease can be identified so that patients better understand their personal health risks.

TREATMENT

- Genome wide association studies have looked at gene expression patterns in cancers and has consequently affected the treatment protocols selected by patients and doctors.

- Many envision a future of "personalized medicine" where your treatment is dependent upon you specific genetic profile.

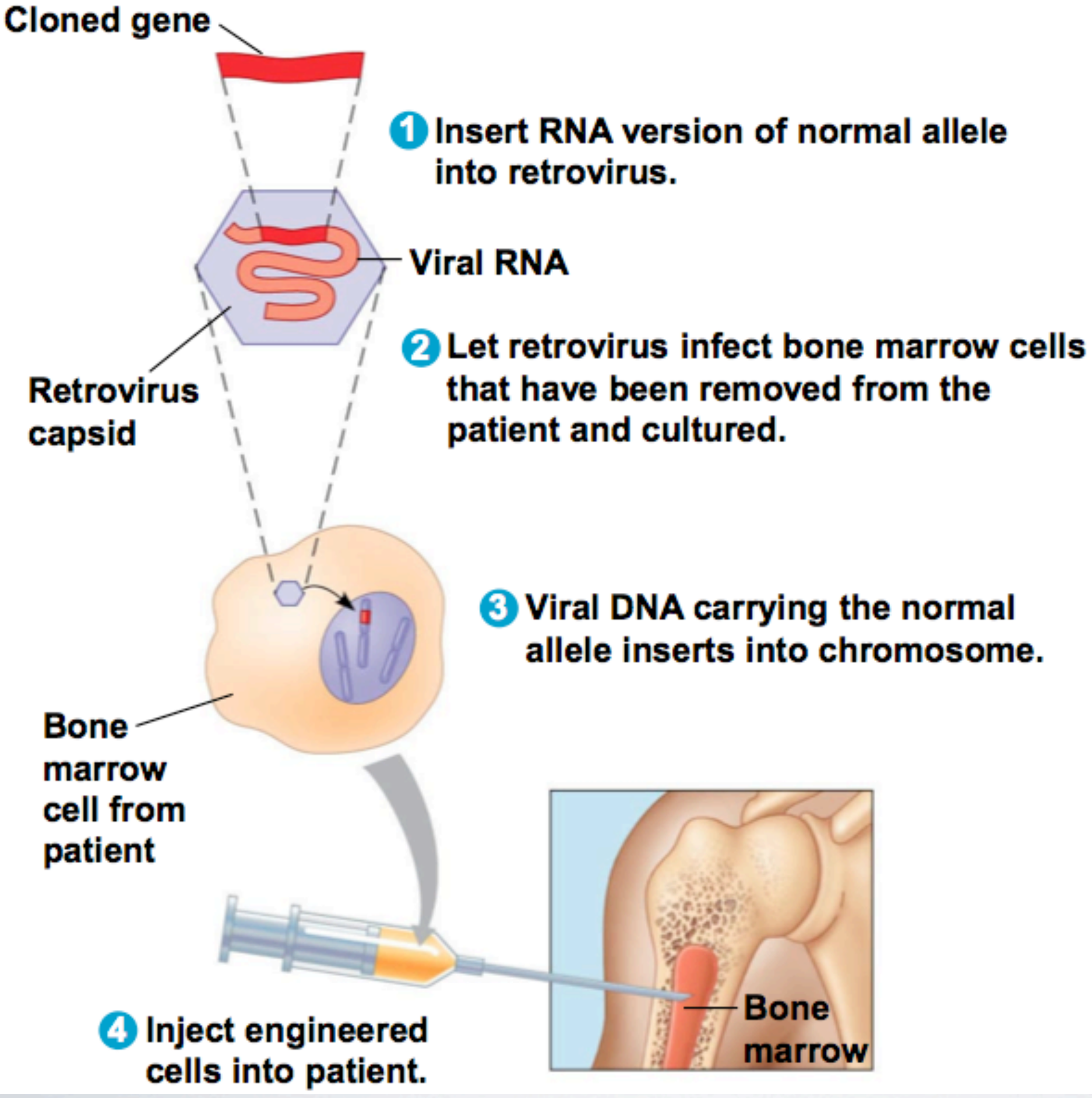
- This era of "personalized medicine" will likely become reality when complete genome sequencing technology becomes rapid (hours) and inexpensive (<1000$ per person).

HUMAN GENE THERAPY

- **Gene Therapy**- injecting genes into an afflicted individual for therapeutic purposes-holds great promise.

- For gene therapy in somatic cells to become permanent the cells that receive the "normal copy" must be the ones that replicate throughout life.

- Bone marrow cells, which include stem cells are prime candidates.



France, 2000
a trial begins with ten kids suffering from a blood disease (SCID), the results were mixed as 9/10 improved after 2 years but 3 subsequently developed leukemia, one of which died.

HUMAN GENE THERAPY

- Since the France 2000 trial, two other diseases have been treated using this method: one that causes blindness and the other a degeneration of the nervous system.

- Both were successful but had limited participants so researchers remain cautiously optimistic.

- Keep in mind, human gene therapy comes with its own set of technical and ethical issues.

PHARMACEUTICAL PRODUCTS

- Determining the sequence and structure of proteins crucial for tumor cell survival has lead to identification and production of small molecules that combat cancers by blocking the functions of these proteins.

- Recall the drug "Gleevec" used to treat chronic myelogenous leukemia, those treated in the early stages show almost complete and sustained remission.

- *Pharmaceutical products* are proteins that can be made on a large scale, using cells or whole organisms.

PROTEIN PRODUCTION IN CELLS

- DNA cloning and gene expression systems have engineered cells to secrete the "farmed protein" as it is being made, which drastically cuts time and cost of production.

- Today insulin created this way is used to manage diabetes in over 2 million people in the U.S.

- Other examples include human growth hormone (HGH) and tissue plasminogen activator (TPA), given to heart attack patients to reduces risk of subsequent heart attacks.

PROTEIN PRODUCTION BY "PHARM" ANIMALS

- By introducing a gene from one animal into another animal (often different species) that **transgenic** animal can act as a pharmaceutical factory for the protein of interest.

- The human gene for antithrombin was inserted into a goat and the engineered goats now secrete antithrombin in their milk.

- Details are still being worked out as sometimes the transgenic animal produces human proteins that are slightly different, so allergic reactions and contamination must be addressed.

ENVIRONMENTAL CLEANUP

- Scientists can transfer genes for remarkable metabolic capabilities into other microorganisms that then can be used to treat environmental problems.
- Some bacteria can extract heavy metals such as copper, lead or nickel and incorporate them into compounds that we ca easily recover.
- Microbes may become important in mining metals as well as the clean-up of toxic mine waste.
- Microbes are being engineered to clean-up dangerous chlorinated hydrocarbons.
- Microbes are used regularly in waste water treatment facilities.

AGRICULTURAL APPLICATIONS

- For thousands of years people have employed selective breeding of livestock (animal husbandry) and crops.

- Today DNA technology looks to speed this up this selective process by creating transgenic organisms.

- The goal is essentially the same as traditionally breeding, create desirable traits in the livestock or crop.

- We want sheep with better wool, cows that grow faster, pigs with leaner meat, crops that pest resistant, crops that need little water or crops that can grow in salty soil.

AGRICULTURAL APPLICATIONS

- The most commonly used vector in plants is the **Ti plasmid** from the soil bacterium *Agrobacterium tumefaciens*.

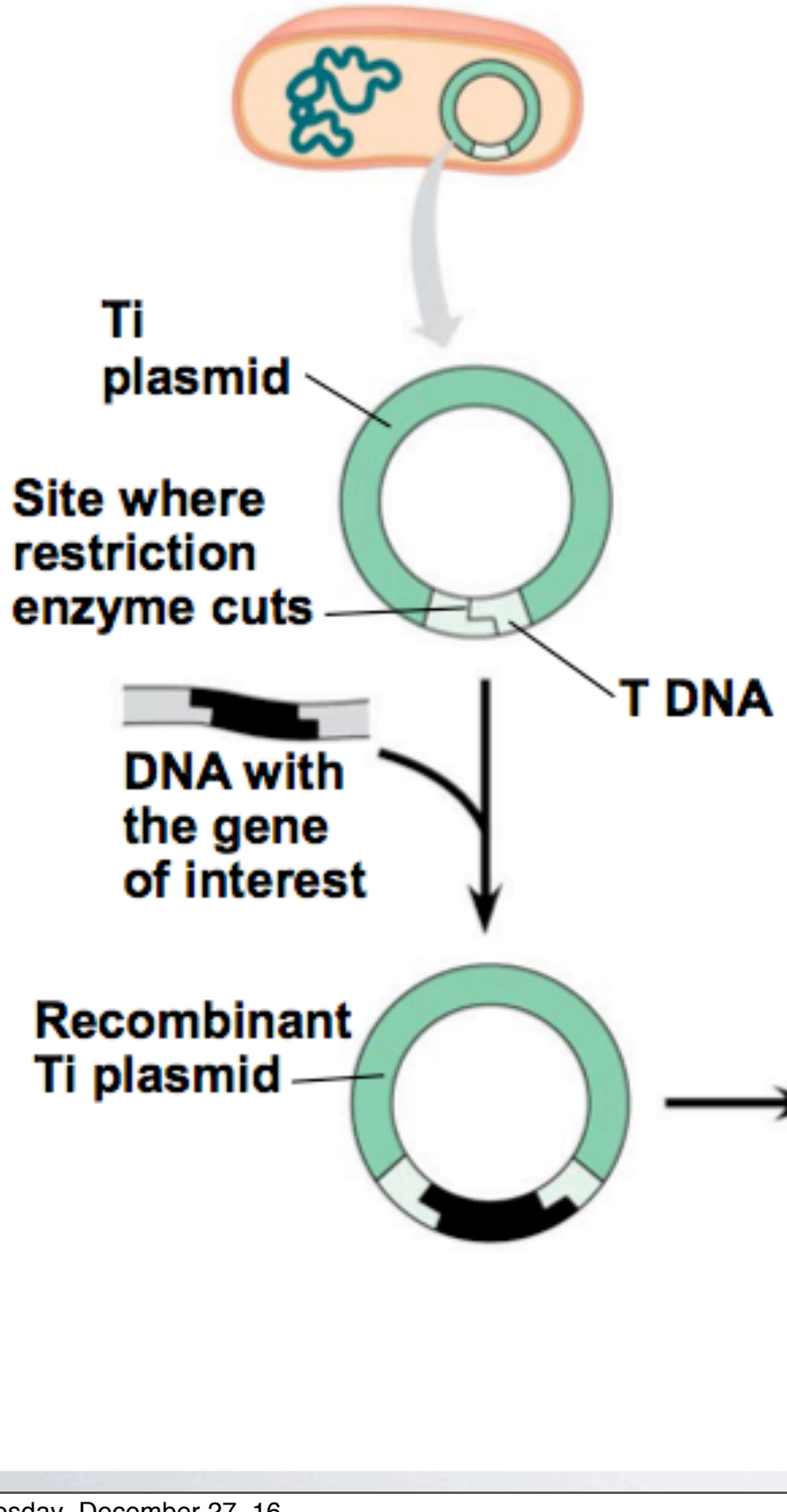
- The vectors are engineered to carry genes of interest while at the same time not causing disease (which wild type does).

- Genetic engineering is replacing traditional breeding by inserting useful genes/traits into the plants.

- The most common traits being engineered today involve pest resistance, herbicide resistance, delayed ripening, improved nutritional content and salinity resistance.

TECHNIQUE

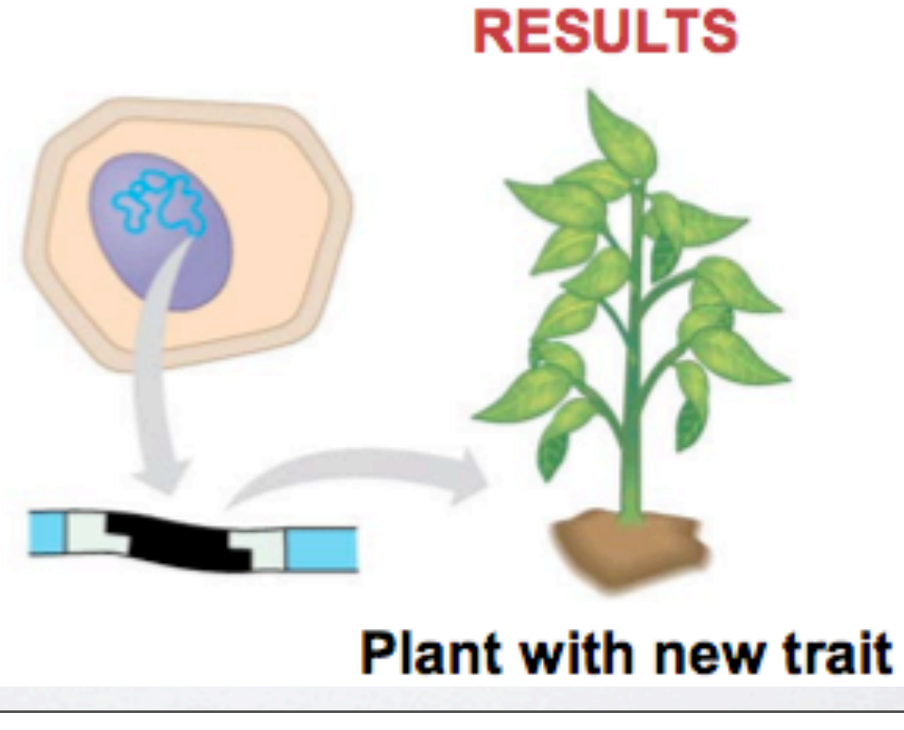
Agrobacterium tumefaciens



APPLICATION

Genes conferring useful traits can be transferred from one plant variety or species to another using the Ti plasmid vector.

RESULTS



RESULTS

Transformed cells carrying the gene of interest can regenerate complete plants that exhibit the new trait.

SAFETY & ETHICS

- The earliest and greatest concerns with recombinant technology was the possibility that hazardous new pathogens might be created.
- Today, strict global regulations and guidelines are in place.
- FIRST- Strict lab procedures are in place to protect researchers and the accidental escape of microbes from the lab.
- SECOND- Recombinant strains are often crippled so that they can not live outside of the artificial conditions created by the lab.
- THIRD- Some experiments or types of experiments have been banned altogether.

SAFETY & ETHICS

- Today the greatest concerns revolve around **genetically modified organisms (GMOs)** used as food.

- Today, some GMO animals exist but most GMOs are crops.

- Most GMO crops are grown in the U.S., Brazil and Argentina. Together they make up 80% of worldwide GMO crops

- In the U.S. most soybean, corn and canola crops are genetically modified.

- **Also, in the U.S. GM foods are NOT required to be labeled, and this is a growing point of contention for many people.**

SAFETY & ETHICS

- The GM revolution has been met with strong opposition in Europe, citizens have expressed health and environmental concerns regarding these plants.

- In 2000, 130 countries signed the Biosafety Protocol (which the U.S. under George Bush failed to sign) went affect.

- The Biosafety Protocol requires exporters to identify GM organisms present in food shipments and allows importing countries whether they pose health or environmental risks.

- Since 2000, GM crops grown in Europe have failed in local markets and they have on occasion refused U.S. imports of GM organisms, leading to trade disputes.

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SAFETY & ETHICS

- Additional concerns around GM crops involve the production of "superweed" and allergic reactions.

- If a gene conferring herbicide resistant in the crop plant makes its way to a weed we could have very difficult problem to, control.

- We know that pollen transfer can and will occur and that the division between plant species is not near as distinct as that between animals which increases the plausibility even more.

- Also, they is evidence that GM crops contain slightly altered molecules, which can and have caused severe allergic reactions.

SAFETY & ETHICS

- Today governments and regulatory agencies are struggling with the facilitation of biotechnology.

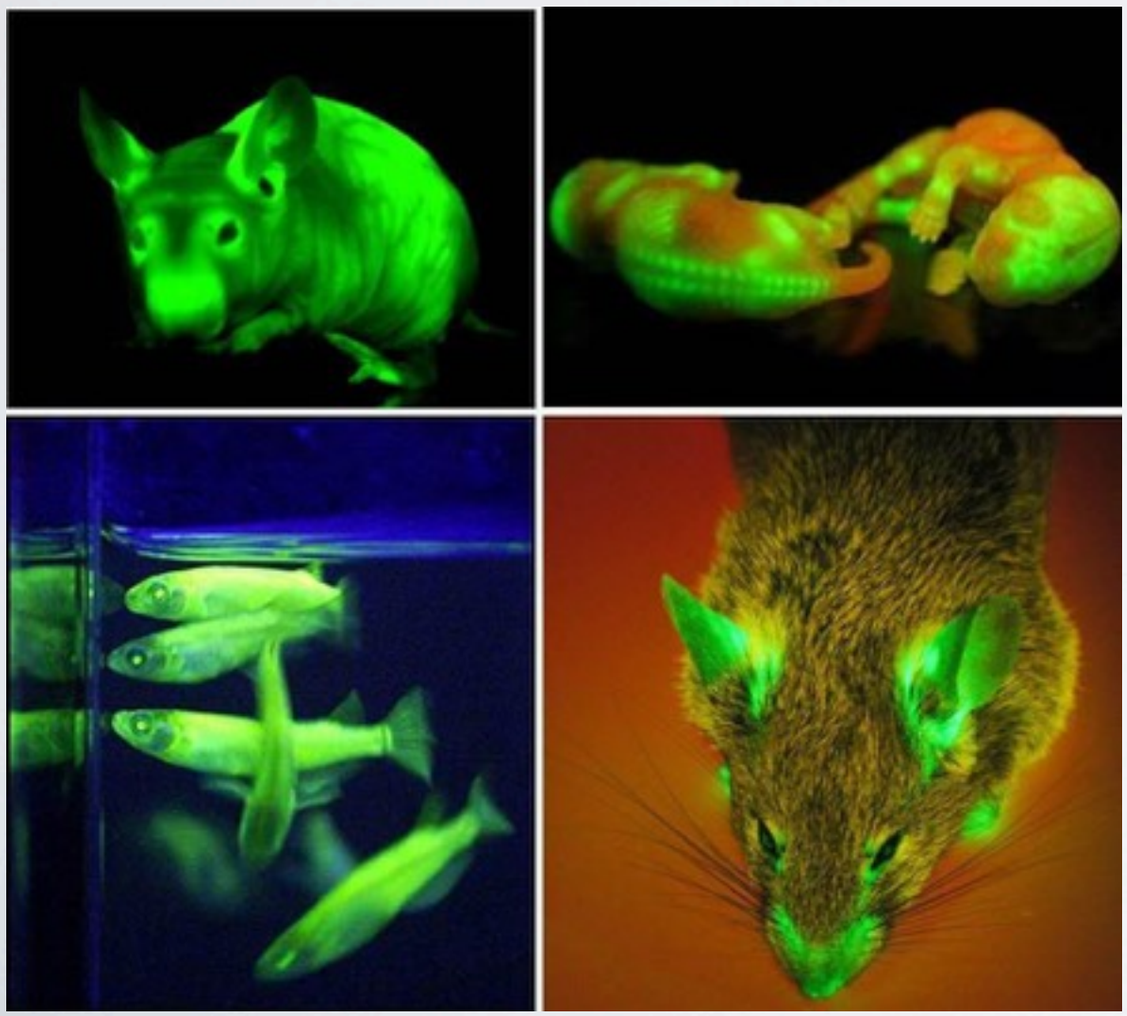
- In the U.S. biotech applications and products are evaluated through the Food & Drug Administration, Environmental Protection Agency, Department of Agriculture and The National Institutes of Health.

- Unfortunately many of the people running these regulatory agencies have worked for or have close ties to the very companies that are producing the GM products.

- As result, non-profit organizations and watch groups along with social media play an increasingly important role our health, safety and decision making.

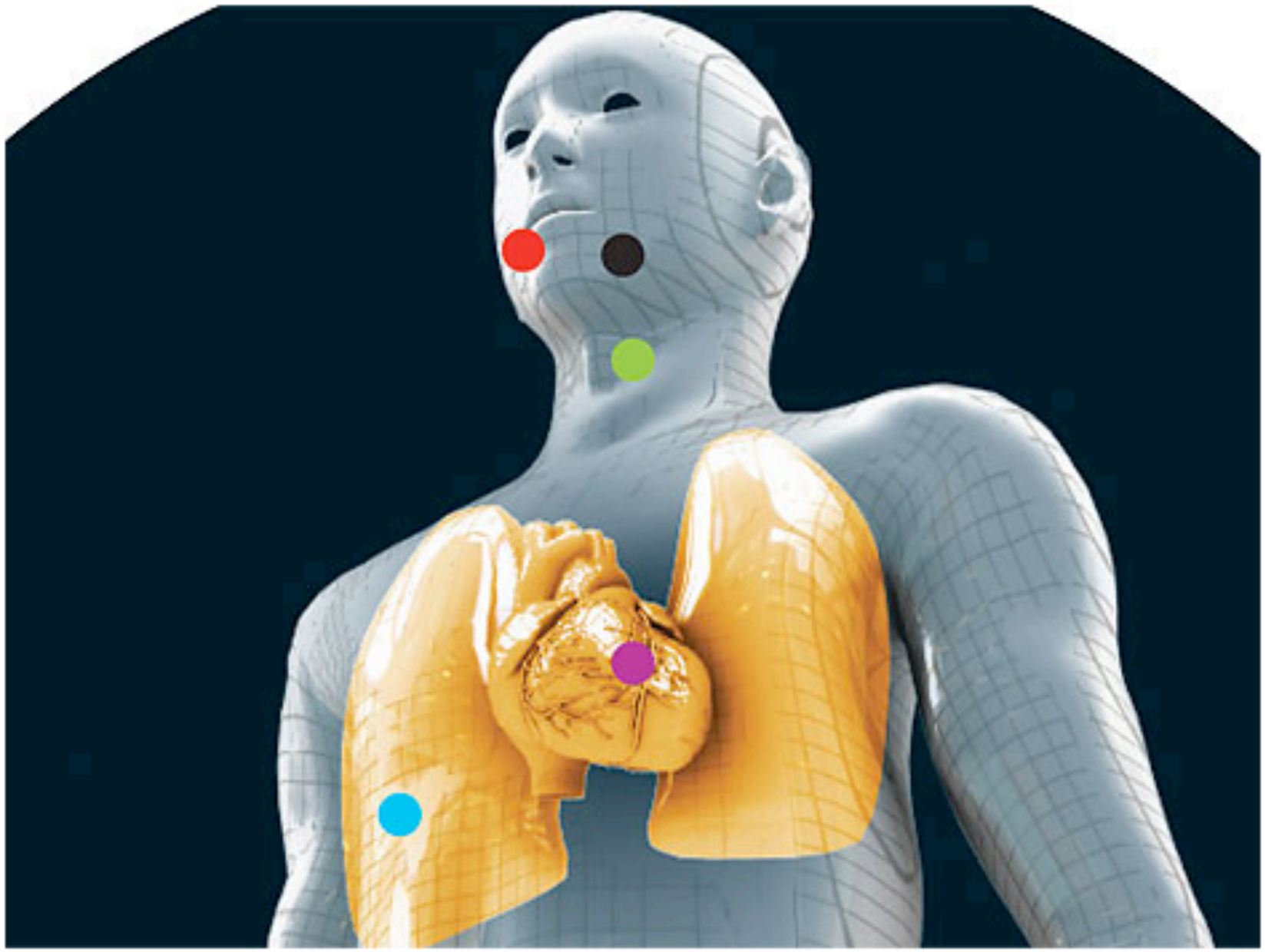
HERE WE GO...


To: Mom
23andMe




Carrier
3:22 PM
100%
MyGenome
Health
Show All
My Variants
breast
Hereditary Breast and Ovarian Cancer
Genetic Disease | Cancers
Hereditary breast and ovarian cancer (HBOC) is a hereditary cancer syndrome. Two genes, BRCA1 and BRCA2, account for the majority of known genetic causes of this syndrome. Individuals with HBOC syndrome have a significantly increased risk of breast, ovarian, pancreatic, prostate and male breast cancers. Early ages of onset, bilateral disease and multiple primary cancers are also characteristic of HBOC syndrome.
Causal Variants
BRCA1
BRCA2
mygenome app .99$
21/251
Familial Mediterranean Fever
Fanconi Anemia
Fucosidosis
Hereditary Breast and Ovarian Cancer
Hereditary Spherocytosis
Krabbe Disease
LCAD Deficiency
Unknown

HERE WE GO...



* 1. Decay-Fighting Microbes

Bacteria living on teeth convert sugar into lactic acid, which erodes enamel and causes tooth decay. Florida-based company ONI BioPharma has engineered a new bacterial strain, called SMaRT, that cannot produce lactic acid—plus, it releases an antibiotic that kills the natural decay-causing strain. Dentists will only need to swab SMaRT, now in clinical trials, onto teeth once to keep them healthy for a lifetime.

* 2. Artificial Lymph Nodes

Scientists from Japan's RIKEN Institute have developed artificial versions of lymph nodes, organs that produce immune cells for fighting infections. Though they could one day replace diseased nodes, the artificial ones may initially be used as customized immune boosters. Doctors could fill the nodes with cells specifically geared to treat certain conditions, such as cancer or HIV.

* 3. Asthma Sensor

Asthma accounts for a quarter of all emergency room visits in the U.S., but a sensor developed at the University of Pittsburgh may finally cause that number to plummet. Inside the handheld device, a polymer-coated carbon nanotube —100,000 times thinner than a human hair—analyzes breath for minute amounts of nitric oxide, a gas that lungs produce prior to asthma attacks.

* 4. Cancer Spit Test

Forget biopsies—a device designed by researchers at the University of California-Los Angeles detects oral cancer from a single drop of saliva. Proteins that are associated with cancer cells react with dyes on the sensor, emitting fluorescent light that can be detected with a microscope. Engineer Chih-Ming Ho notes that the same principle could be applied to make saliva-based diagnostic tests for many diseases.

* 5. Biological Pacemaker

Electronic pacemakers save lives, but use hardware that eventually wears out. Now, researchers at several universities are developing a batteryless alternative: pacemaker genes expressed in stem cells that are injected into damaged regions of the heart. Better suited for physical exertion, biological pacemakers have been shown to bring slow canine hearts back up to speed without complications.

6. Prosthetic Feedback

One challenge of prosthetic limbs is that they're difficult to monitor. "You and I sense where our limbs are spatially without having to look at them, whereas amputees don't," says Stanford University graduate student Karlin Bark. Skin is sensitive to being stretched—it can detect even small changes in direction and intensity—so Bark is developing a device that stretches an amputee's skin near the prosthesis in ways that provide feedback about the limb's position and movement.

7. Smart Contact Lens

Glaucoma, the second-leading cause of blindness, develops when pressure builds inside the eye and damages retinal cells. Contact lenses developed at the University of California-Davis contain conductive wires that continuously monitor pressure and fluid flow within the eyes of at-risk people. The lenses then relay information to a small device worn by the patient; the device wirelessly transmits it to a computer. This constant data flow will help doctors better understand the causes of the disease. Future lenses may also automatically dispense drugs in response to pressure changes.

8. Speech Restorer

For people who have lost the ability to talk, a new "phonetic speech engine" from Illinois-based Ambient Corporation provides an audible voice. Developed in conjunction with Texas Instruments, the Audeo uses electrodes to detect neuronal signals traveling from the brain to the vocal cords. Patients imagine slowly sounding out words; then the quarter-size device (located in a neck brace) wirelessly transmits those impulses to a computer or cellphone, which produces speech.

9. Absorbable Heart Stent

Stents open arteries that have become narrowed or blocked because of coronary artery disease. Drug-eluting stents release medication that keeps the artery from narrowing again. The bio-absorbable version made by Abbott Laboratories in Illinois goes one step further: Unlike metal stents, it does its job and disappears. After six months the stent begins to dissolve, and after two years it's completely gone, leaving behind a healthy artery.

10. Muscle Stimulator

In the time it takes for broken bones to heal, nearby muscles often atrophy from lack of use. Israeli company StimuHeal solves that problem with the MyoSpare, a battery-operated device that uses electrical stimulators—small enough to be worn underneath casts—to exercise muscles and keep them strong during recovery.

11. Nerve Regenerator

Nerve fibers can't grow along injured spinal cords because scar tissue gets in the way. A nanogel developed at Northwestern University eliminates that impediment. Injected as a liquid, the nanogel self-assembles into a scaffold of nanofibers. Peptides expressed in the fibers instruct stem cells that would normally form scar tissue to produce cells that encourage nerve development. The scaffold, meanwhile, supports the growth of new axons up and down the spinal cord.

12. Stabilizing Insoles

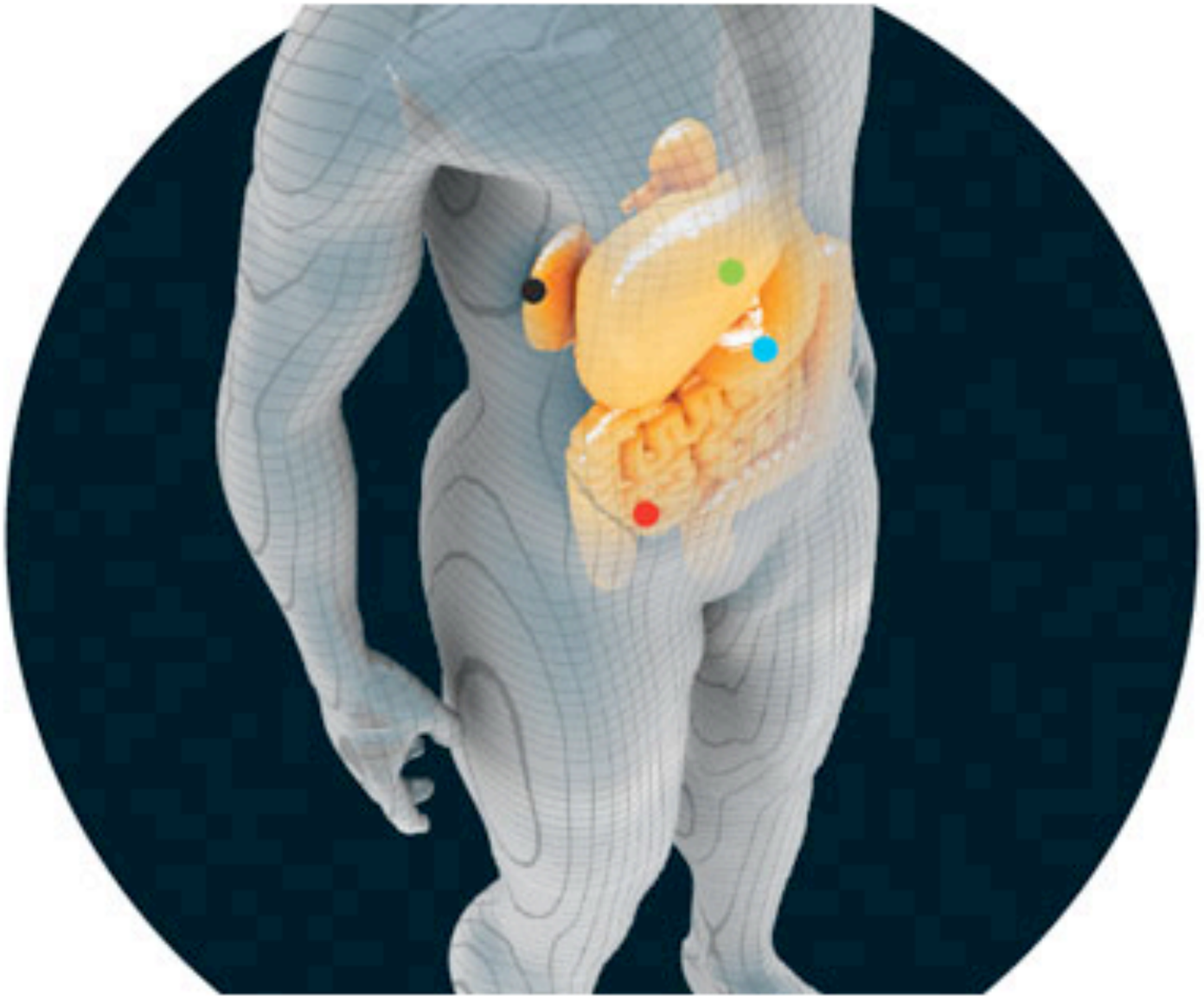
When Erez Lieberman's grandmother suffered a dangerous fall, he wanted to ensure it never happened again. "But it wasn't till a few years later at NASA that I found a way to channel that into something tangible," says the MIT graduate student. Using technology developed to monitor the balance of astronauts who have just returned from space, Lieberman's iShoe analyzes the pressure distribution of the feet. Doctors can use the insole to diagnose balance problems in elderly patients before falls occur.

13. Smart Pill

California-based Proteus Biomedical has engineered sensors that track medication use by recording the exact time drugs are ingested. Sand-grain-size microchips emit high-frequency electrical currents that are logged by Band-Aid-like receivers on the skin. The receivers also monitor heart rate and respiration and wirelessly transmit the data to a computer. "To really improve pharmaceuticals, we need to do what is now common in every other industry—embed digital technology into existing products and network them," says David O'Reilly, senior vice president of corporate development.

14. Autonomous Wheelchair

MIT researchers have developed an autonomous wheelchair that can take people where they ask to go. The chair learns about its environment by listening as a patient identifies locations—such as "this is my room" or "we're in the kitchen"—and builds maps using Wi-Fi, which works well indoors (unlike GPS). The current model, which is now being tested, may one day be equipped with cameras, laser rangefinders and a collision- avoidance system.



* 15. Gastrointestinal Liner

Obesity is associated with type II diabetes, which over time wears out the pancreas. A gastrointestinal liner developed by Massachusetts-based GI Dynamics may restore the obese to a healthy weight by preventing food from contacting the intestinal wall. The Endobarrier is routed endoscopically through the mouth—unlike a gastric bypass, no surgery is necessary—and lines the first 2 ft of the small intestine, where the most calories are absorbed (nutrients are still absorbed farther down the intestine).

* 16. Liver Scanner

How healthy is your liver? Until recently, answering that question often required a painful biopsy. French company EchoSens has developed a machine that scans the organ for damage in just 5 minutes. Studies have shown that damaged livers become stiffer and less elastic, so the scanner, called the Fibroscan, measures the organ's elasticity using ultrasound.

* 17. Nanoscale Adhesive

Gecko feet are covered with nano-size hairs that exploit intermolecular forces, allowing the lizards to stick firmly to surfaces. By replicating this nanoscale topography, MIT scientists have developed an adhesive that can seal wounds or patch a hole caused by a stomach ulcer. The adhesive is elastic, waterproof and made of material that breaks down as the injury heals.

* 18. Portable Dialysis

More than 15 million adult Americans suffer from diseases of the kidneys, which often impair the ability of the organs to remove toxins from the blood. Standard dialysis involves three long sessions at a hospital per week. But an artificial kidney developed by Los Angeles-based Xcorporeal can clean blood around the clock. The machine is fully automated, battery-operated, waterproof and, at less than 5 pounds, portable.

19. Walking Simulator

Stroke victims are being tricked into recovering more quickly with a virtual-reality rehabilitation program developed at the University of Portsmouth in Britain. As patients walk on a treadmill, they see moving images that fool their brains into thinking they are walking slower than they are. As a result, patients not only walk faster and farther, but experience less pain while doing so.

20. Rocket-Powered Arm

Adding strength to prosthetic limbs has typically required bulky battery packs. Vanderbilt University scientist Michael Goldfarb came up with an alternative power source: rocket propellant. Goldfarb's prosthetic arm can lift 20 pounds —three to four times more than current prosthetics—thanks to a pencil-size version of the mono-propellant rocket-motor system used to maneuver the space shuttle in orbit. Hydrogen peroxide powers the arm for 18 hours of normal activity.

POST SCRIPT

- We expect science to proceed with humility and caution. As citizens we must be educated and aware of the issues that confront us. We have to include these issues in our social dialogue. It will be more important than ever to question the sources of information and the bias they carry. Regardless of the intent, many of these biotech advancements they will likely become huge money makers. We have seen the oil industry invest a large amount of money on a misinformation campaign intended to misguide the public regarding carbon emissions and global climate change. Climate change is not something to debate, science supports hypotheses through data and right now the data and 99% of PhD's who study climate science tell us the earth is warming to dangerous levels and our actions are contributing to it. One thing is for certain, the advancements made in biotechnology will come fast and the world we know today will be very different than the one in ten years, let's make it a better than it is today for my kids and yours. Understand the issues, stay informed, discuss issues, use knowledge to guide your decisions and vote for those who do the same.

Learning Objectives:

LO 3.1 The student is able to construct scientific explanations that use the structures and mechanisms of DNA and RNA to support the claim that DNA and, in some cases, RNA are the primary sources of heritable information. [See SP 6.2, 6.5]
LO 3.2 The student is able to justify the selection of data from historical investigations that support the claim that DNA is the source of heritable information. [See SP 4.1]
LO 3.3 The student is able to describe representations and models that illustrate how genetic information is copied for transmission between generations. [See SP 1.2]
LO 3.4 The student is able to describe representations and models illustrating how genetic information is translated into polypeptides. [See SP 1.2]
LO 3.5 The student can explain how heritable information can be manipulated using common technologies. [See SP 6.2, 6.4]
LO 3.6 The student can predict how a change in a specific DNA or RNA sequence can result in changes in gene expression. [See SP 6.4]