

## What have we done? Where are we going?

We learned about the diversity and evolution of life on the planet in the past.

What does that diversity include? (Prokaryotes-Bacteria and Archaea, Eukaryotes-Single celled “protists”, plus true multicellular fungi, plants, animals)

Unique contribution of Darwin-his proposal of natural selection as the engine of evolution.

For natural selection to work you have to have some way **of passing on your characteristics to your offspring**

(FYI: Lamarck was wrong-he thought that muscles communicate to sperm and eggs to ensure next generation has larger, longer necks.)

So how does inheritance happen !!???

*We are going to focus on how traits get passed down from one generation to the next and how a material (DNA) in cells makes this happen.*

# Chapter 5

## Raw material: heritable variation among individuals

*The central metaphor of Dawkins's new book is a river of genes, flowing through geological time rather than space. Each river is a population of genes held together by sexual interbreeding. The river may fork in time. Each branch slowly drifts apart to give rise to a new species. Some branches dry up in extinction. Others split repeatedly, generating the 30 million branches that exist today.*

**How do these genes “flow” through time?**

**How do they get copied and passed down to other cells and to new individuals during reproduction?**

A question from your reading guide....

Q1. Why is height a great place to start as we think about how traits are inherited?

Variation within a single species!



# Regents Hall Dogs

Variation within a single species!



## Chapter 5 Topics

1. Animal Life Cycles
2. Structure of DNA in Eukaryotes and Prokaryotes! (*and HGT*)
3. Replication of DNA (*copying of DNA*) in mitosis
4. Making proteins!
  - Transcription-going from DNA to mRNA
  - Translation-going from mRNA to protein
5. Gene regulation!
6. Sizing up the Genome
7. Mutations
8. Mitosis vs Meiosis (*sexual reproduction*)
9. Mendel and Punnett Squares

# 1. Animal Life Cycle (Basic pattern)

*(FYI: We are ignoring the life cycles of many other eukaryotic lineages and will focus only on animals! ☹)*

Fertilization

Zygote

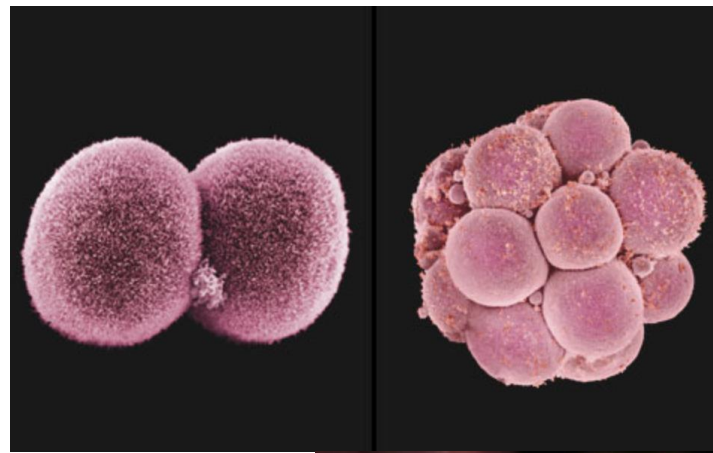
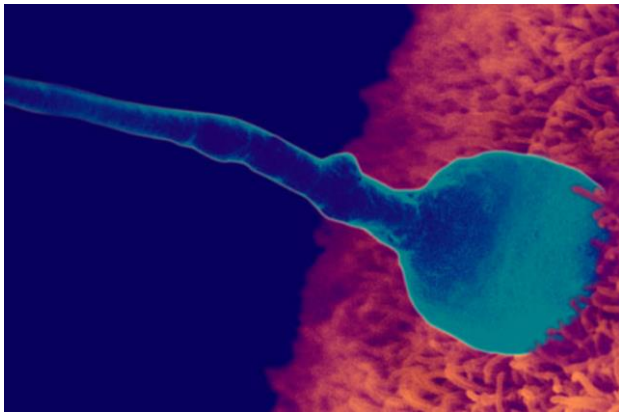
Mitosis (when cells copy themselves to make more body cells)

Meiosis (when cells copy themselves but make gametes)

Gametes

Haploid

Diploid



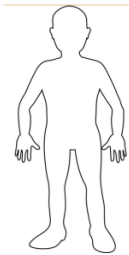
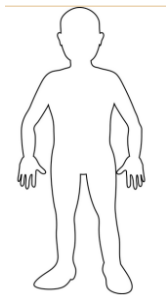
### For your Review!

- Fertilization
- Zygote
- Mitosis
- Meiosis
- Gametes
- Haploid
- Diploid



Sperm

Egg



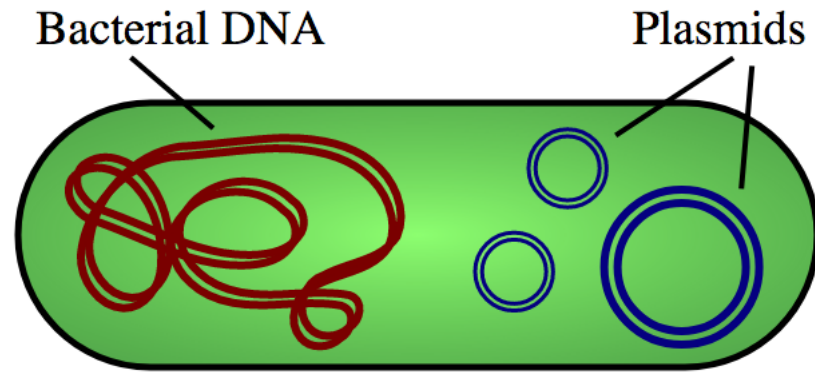
## Life Cycle Practice

*Fertilization, Zygote, Mitosis, Meiosis, Gametes, Replication*

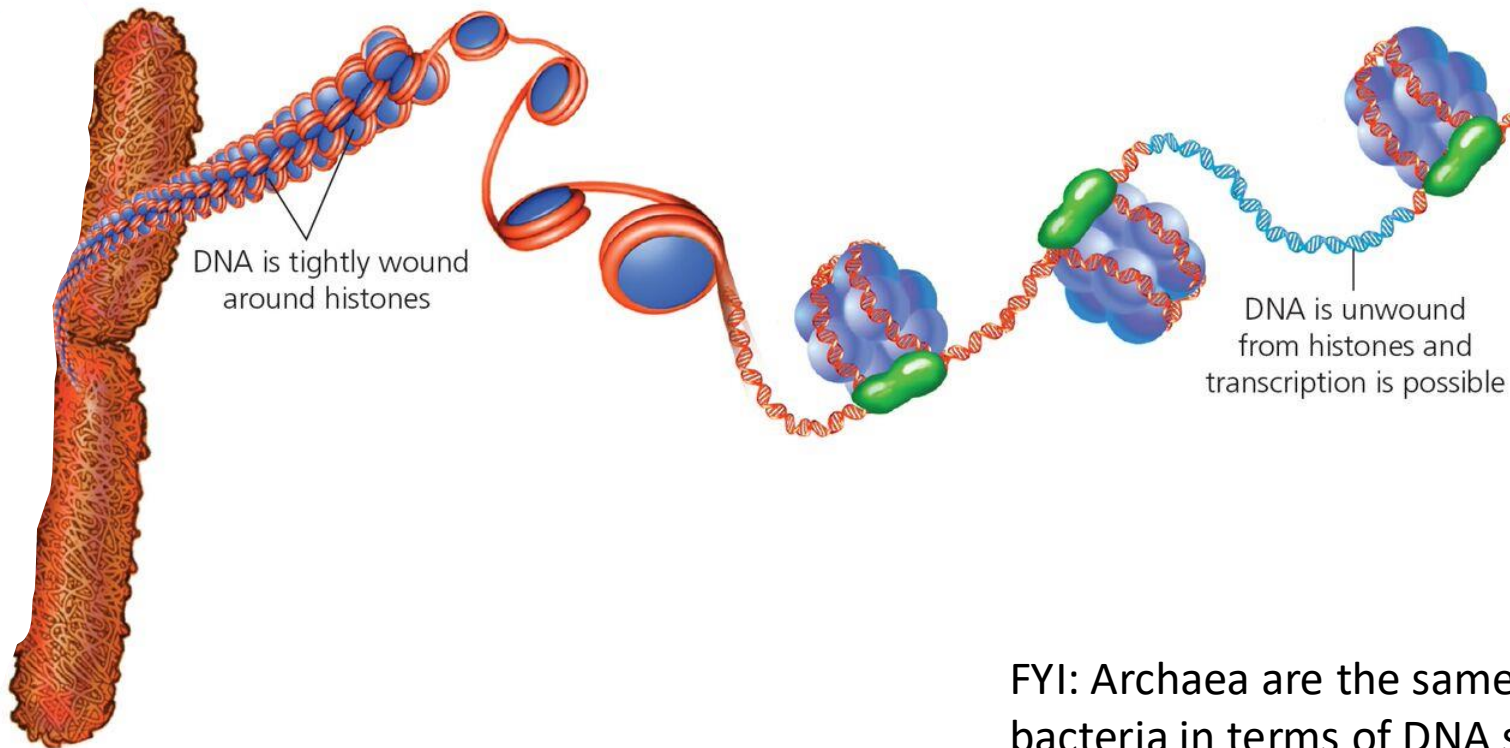
1. Sperm are gametes that are \_\_\_\_\_ (single celled/multicelled) and \_\_\_\_\_ (diploid/haploid).
2. Eggs are gametes that are \_\_\_\_\_ (single celled/multicelled) and \_\_\_\_\_ (diploid/haploid).
3. When sperm fertilizes an egg a \_\_\_\_\_ is formed which is \_\_\_\_\_ (diploid/haploid).
4. This then goes through \_\_\_\_\_ (mitosis/meiosis) over and over again to create a body that is \_\_\_\_\_ (single celled/multi-celled).
5. During this process the DNA in the cells must go through \_\_\_\_\_.
6. Once an adult multicellular organism exists it is \_\_\_\_\_ (diploid/haploid)..
7. In humans each cell will have \_\_\_\_\_ (how many) chromosomes.
8. At this point, germ cells in the multicellular body must go through \_\_\_\_\_ (mitosis/meiosis) to make \_\_\_\_\_.
9. These are \_\_\_\_\_ (diploid/haploid) and have \_\_\_\_\_ chromosomes in humans.

## 2. Structure of DNA in Eukaryotes and Prokaryotes + HGT!

(Remember we talked about viruses in CH1!)



Prokaryote



FYI: Archaea are the same as bacteria in terms of DNA structure.

Eukaryotic chromosome in the nucleus of a cell

Prokaryotic cells make new individuals by copying their genome and then dividing-making sure that each daughter cell created has a copy that is the same as the parent cell

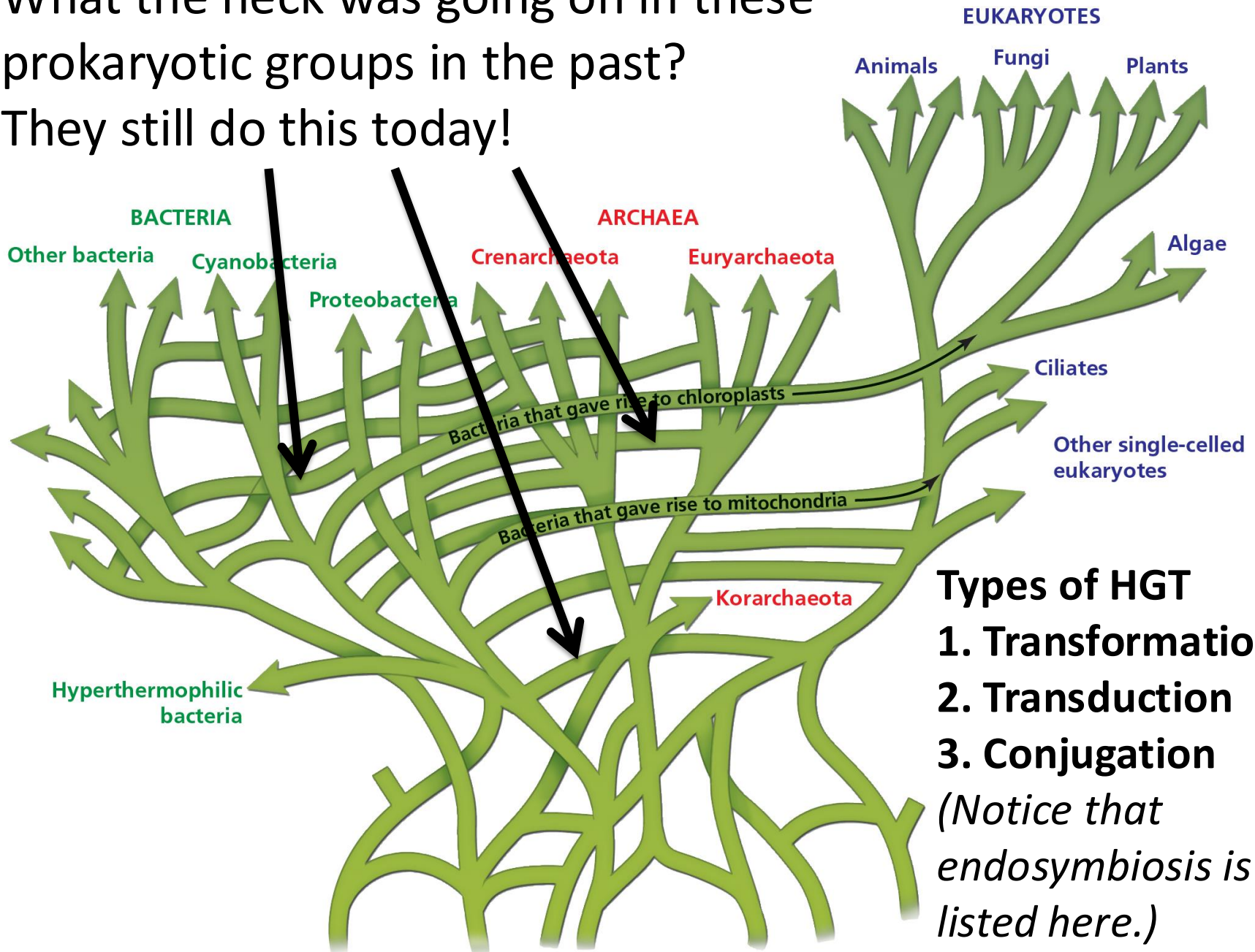
This is called Binary Fission (its kind of boring).

BUT they can do other cool things Eukaryotes can't do!

Horizontal Gene Transfer (HGT)-also known as Lateral Gene Transfer

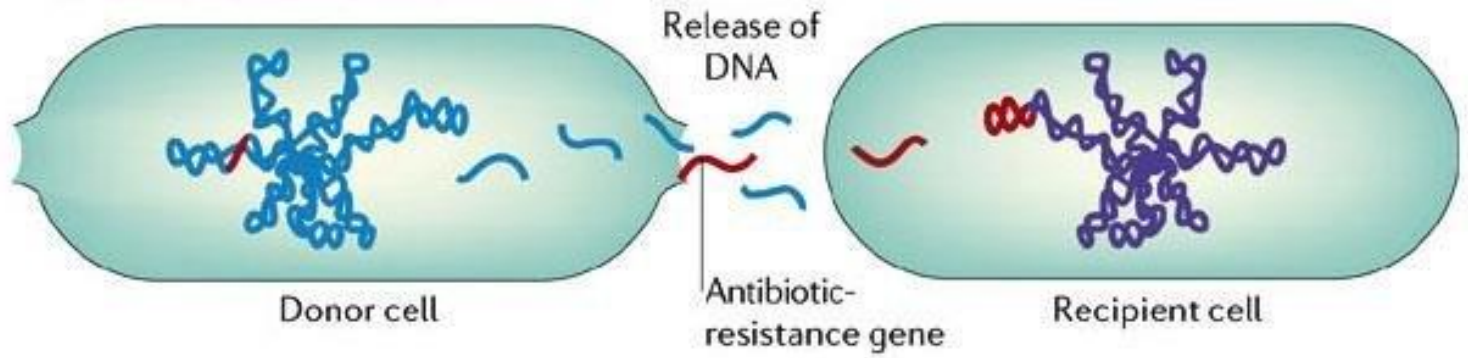
*(Remember we already talked about Endosymbiosis)*

What the heck was going on in these prokaryotic groups in the past?  
They still do this today!



COMMON ANCESTRAL COMMUNITY OF PRIMITIVE CELLS

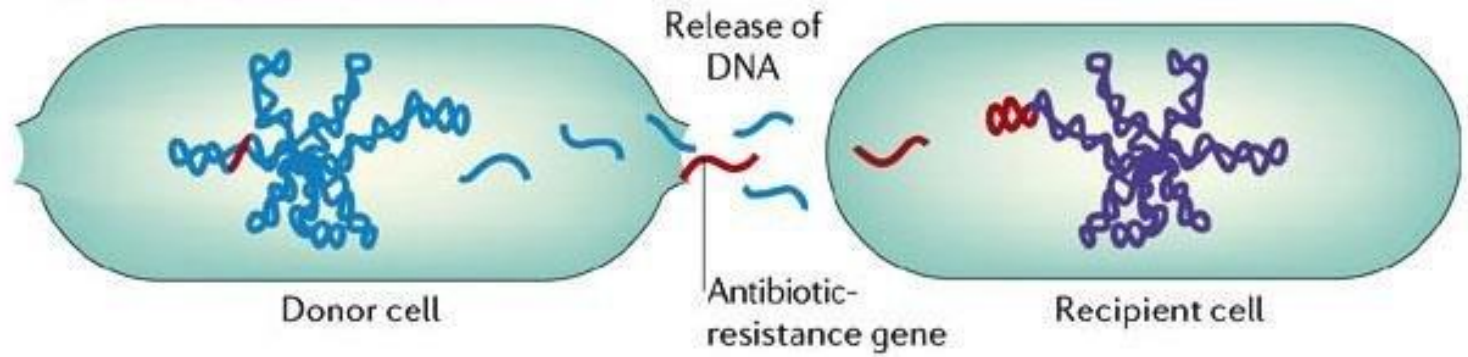
**a Bacterial transformation**



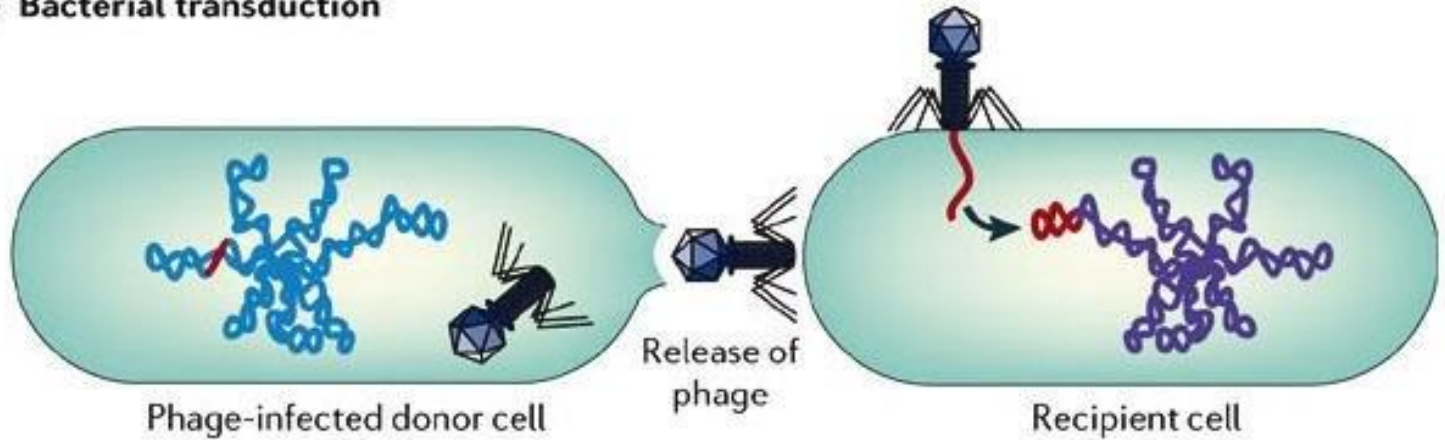
**Horizontal  
or lateral  
gene  
transfer in  
prokaryotes!**

**Horizontal  
or lateral  
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prokaryotes!**

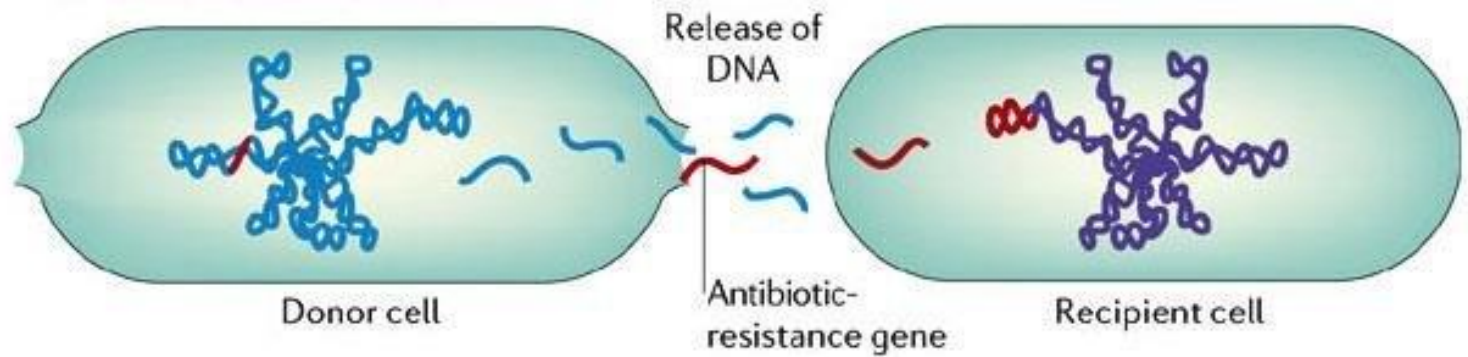
**a Bacterial transformation**



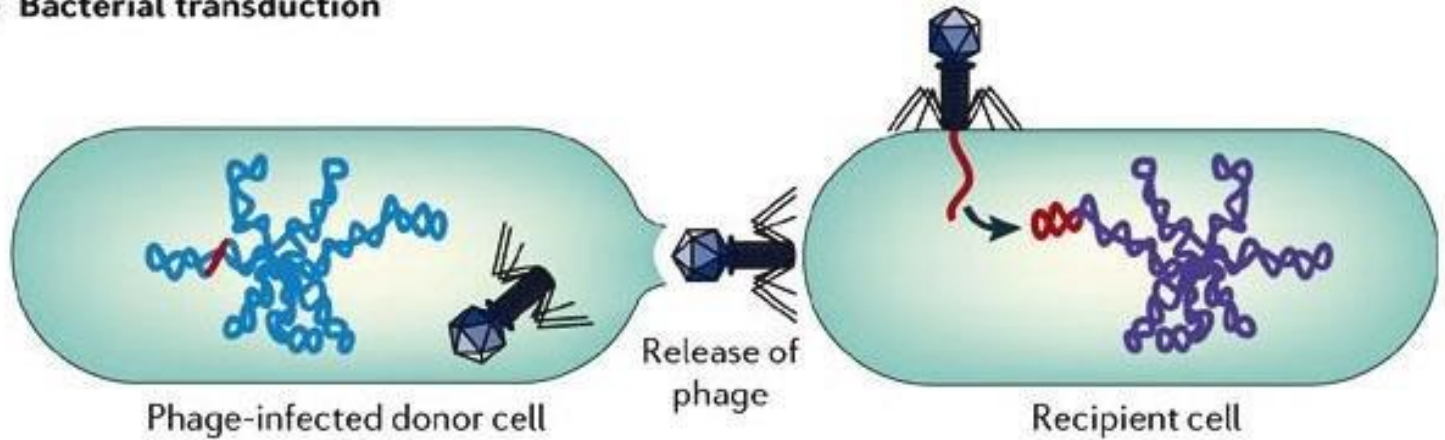
**b Bacterial transduction**



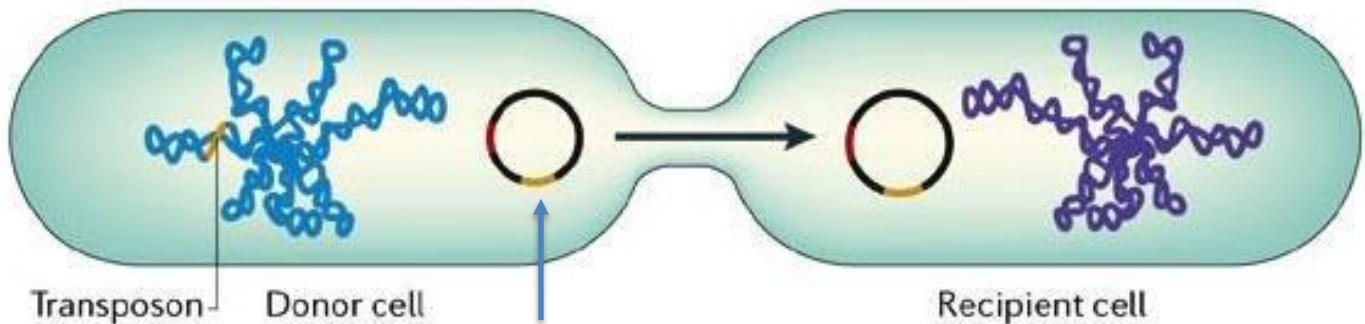
**a Bacterial transformation**



**b Bacterial transduction**



**c Bacterial conjugation**

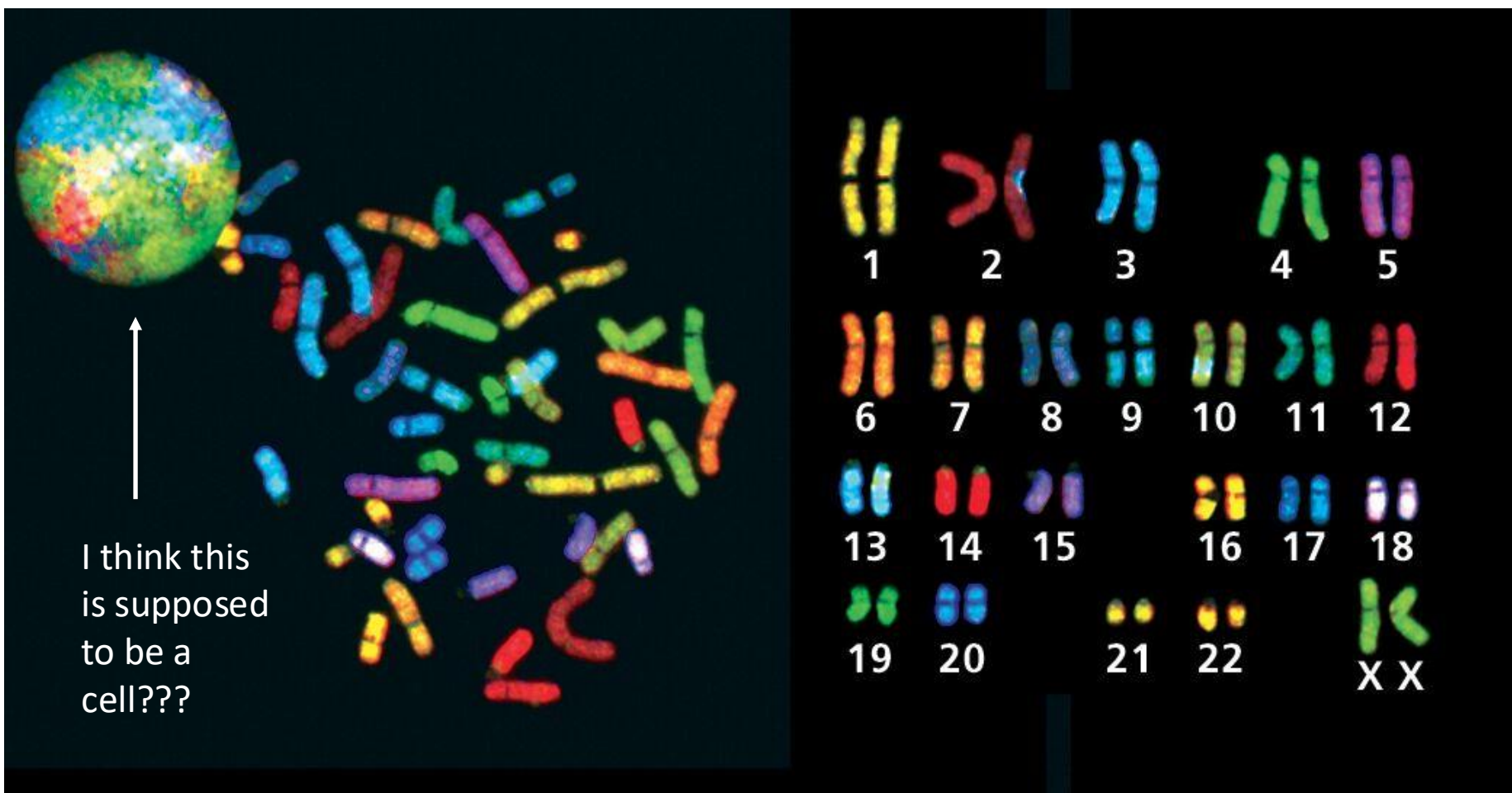


All three of these result in genetic material being moved around within populations of bacteria.

# More on Eukaryotic Structure

Linear chromosomes in eukaryotes typically come in  
**homologous pairs**

Each cell in a multicellular adult has a whole set  
(2 of each chromosome=we are “diploid” =23 pairs so  $2N=46$ )





Lets look more closely at one of these paired chromosomes.



FYI 3 snapshots of same chromosome at different levels of detail.

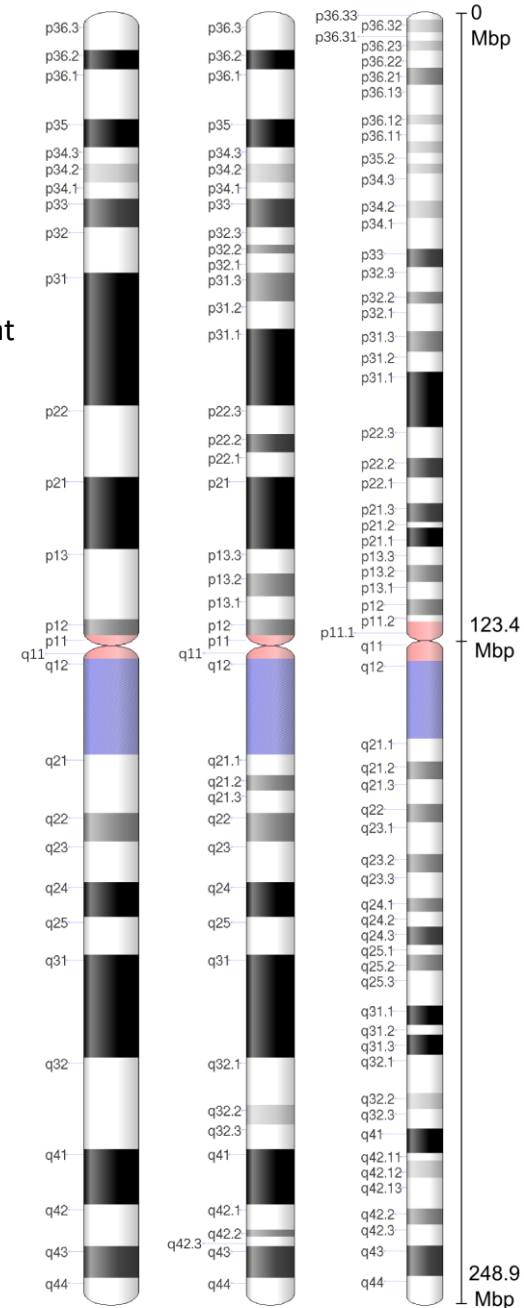
**p-arm** [ edit ]

Partial list of the genes located on p-arm (short arm) of human chromosome 1:

- **AADACL3**: Arylacetamide deacetylase-like 3
- **AADACL4**: Arylacetamide deacetylase-like 4
- **ACADM**: acyl-Coenzyme A dehydrogenase, C-4 to C-12 straight chain
- **ACTL8**: Actin-like 8
- **ADGRL2** (1p31.1): adhesion G protein-coupled receptor L2
- **ADPRHL2**: Poly(ADP-ribose) glycohydrolase ARH3
- **AMPD2**: encoding **enzyme** AMP deaminase 2
- **ARID1A** (1p36)
- **ATXN7L2**: Ataxin 7-like 2
- **AZIN2**: encoding **enzyme** Antizyme inhibitor 2 (AzI2) also known as arginine decarboxylase (ADC)
- **BCAS2**: Breast carcinoma amplified sequence 2
- **BCL10** (1p22)
- **BCL2L15** (1p13)
- **LRIF1**: encoding **protein** Ligand-dependent nuclear receptor-interacting factor 1
- **C1orf109**: chromosome 1 open reading frame 109
- **CZIB**: chromosome 1 open reading frame 123
- **CACHD1** encoding **protein** Cache domain containing 1
- **CAMTA1** (1p36)
- **CASP9** (1p36)
- **CASZ1** (1p36): Castor zinc finger 1
- **CSDE1**: Cold shock domain containing E1
- **CHD5** (1p36)
- **CLIC4** (1p36)
- **CLSPN** (1p34)

- **MEAF6**: MYST/ESA1 associated factor 6
- **MECR**: Trans-2-enoyl-CoA reductase, mitochondrial
- **MFAP2**: Microfibrillar-associated protein 2
- **MIB2** (1p36)
- **MIER1** (1p31)
- **MFN2**: mitofusin 2
- **MFSD2**: Major facilitator superfamily domain containing 2A
- **MIR6079**: microRNA 6079
- **MMEL1**: Membrane metallo-endopeptidase-like 1
- **MTFR1L**: mitochondrial fission regulator 1 like
- **MTHFR** (1p36): 5,10-methylenetetrahydrofolate reductase (NADPH)
- **MUL1**: Mitochondrial E3 ubiquitin protein ligase 1
- **MUTYH** (1p34): mutY homolog (E. coli)
- **NBPF3**: Neuroblastoma breakpoint family member 3
- **NGF**: Nerve Growth Factor
- **NOL9**: Nucleolar protein 9
- **NRAS** (1p13)
- **NOTCH2** (1p12)
- **OLFML3**: Olfactomedin-like 3
- **OMA1**: Metalloendopeptidase OMA1, mitochondrial
- **OVGP1**: Oviductal glycoprotein 1
- **PARK7** (1p36): Parkinson disease (autosomal recessive, early onset) 7
- **PINK1**: PTEN induced putative kinase 1
- **PLOD1**: procollagen-lysine 1, 2-oxoglutarate 5-dioxygenase 1
- **PRMT6**: Protein arginine methyltransferase 6

[GenBank](#) [CM00](#)



400 bps 550 bps 850 bps

**Human chromosome 1**

If we zoomed into one of these chromosomes and unraveled it we would see.....

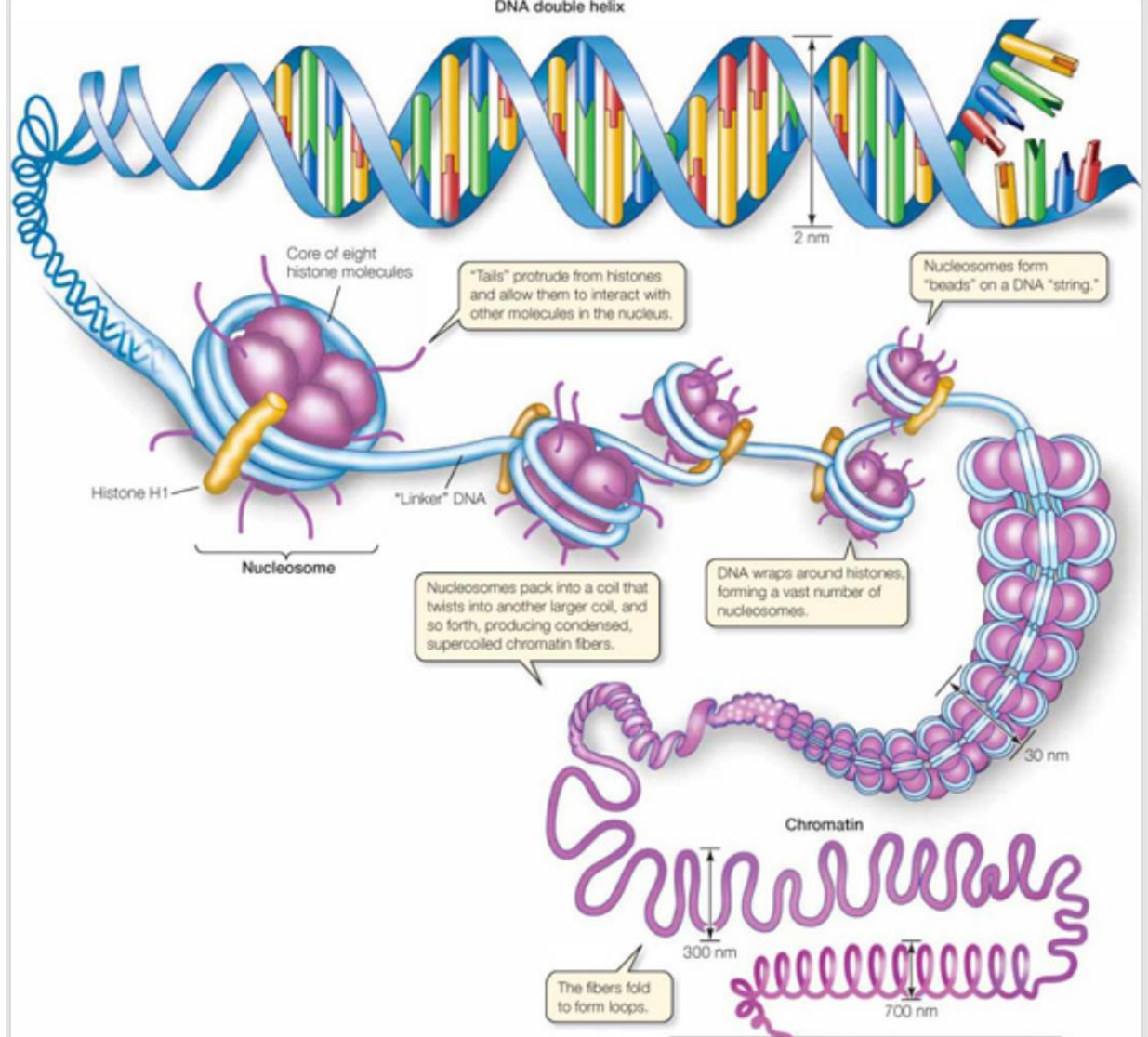
# More on Eukaryotic Structure

Double helix

Bases

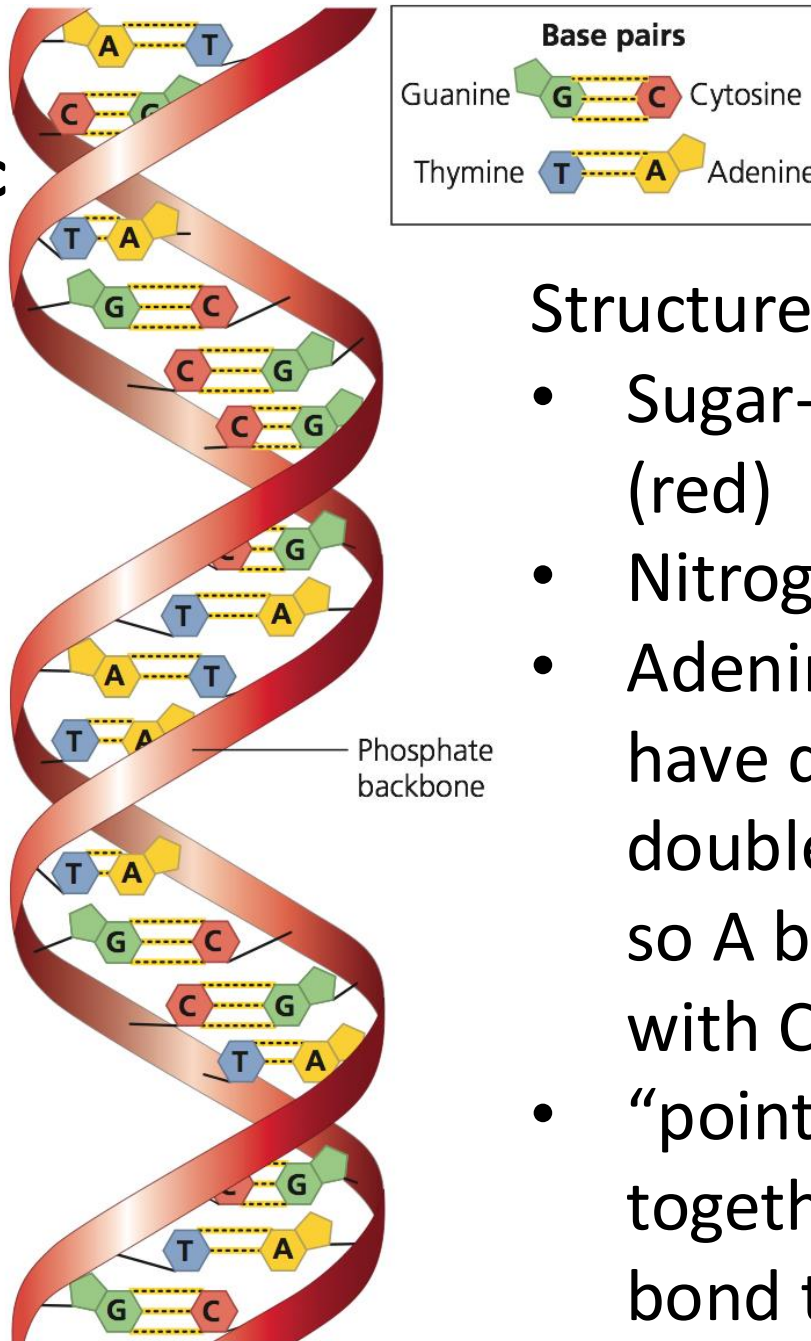
**Histone+DNA**  
wrapped around  
it= **nucleosome**.

What is with all  
the wrapping  
and coiling?



<https://www.nature.com/scitable/content/DNA-is-Packed-into-a-Mitotic-Chromosome-3497/>

# More on Eukaryotic Structure



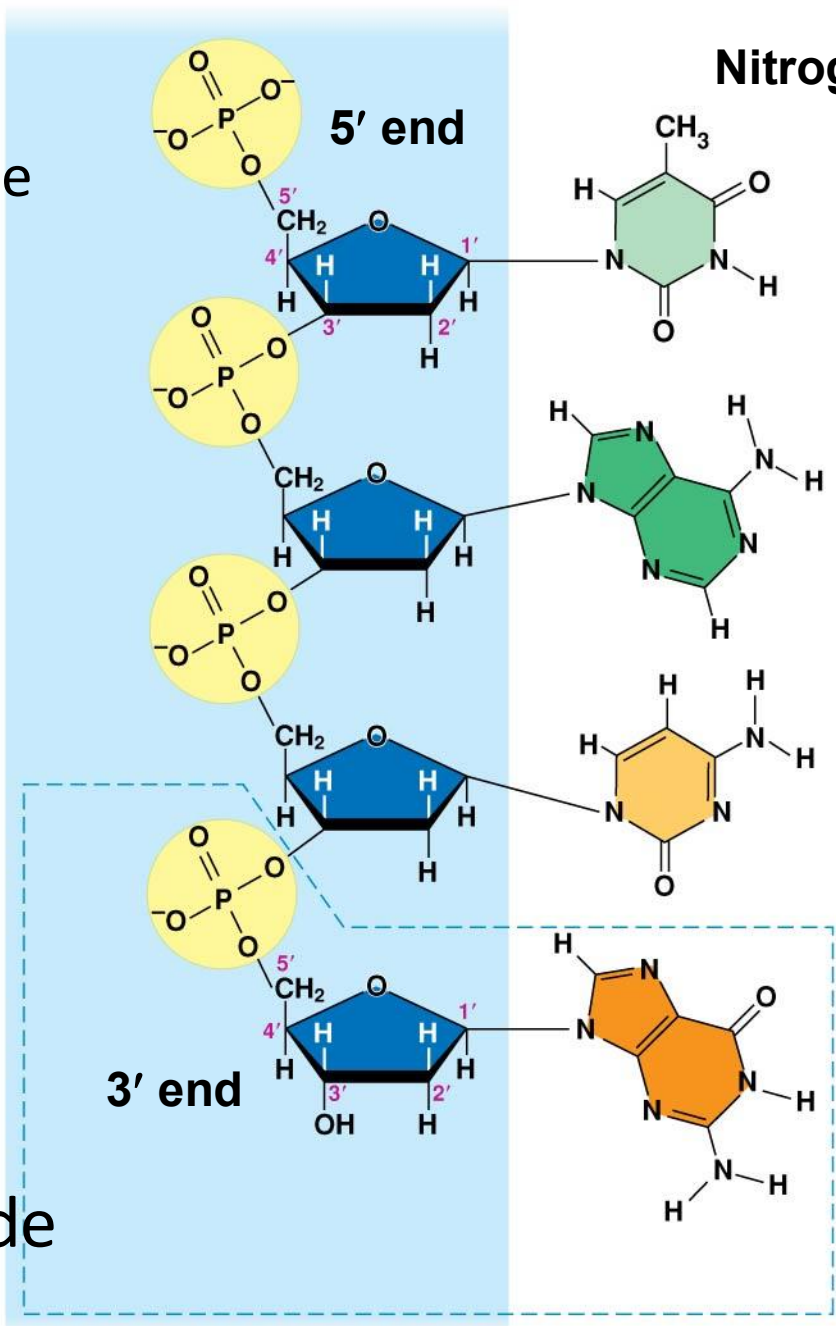
Structure in more detail....

- Sugar-Phosphate backbone (red)
- Nitrogen rich bases A, T, G, C
- Adenine and Guanine both have double rings (Two double rings would not fit .... so A bonds with T and G with C)
- “pointy” letters bond together + “curvy” letters bond together



Blue shading =

Sugar-phosphate backbone



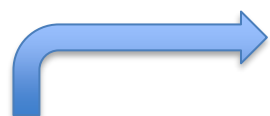
Nitrogenous bases

Thymine (T)

Adenine (A)

Cytosine (C)

Guanine (G)

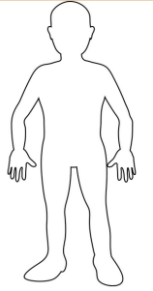


DNA nucleotide

## Chapter 5 Topics

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### 3. Replication (copying of DNA) has to happen whenever cells divide or go through MITOSIS



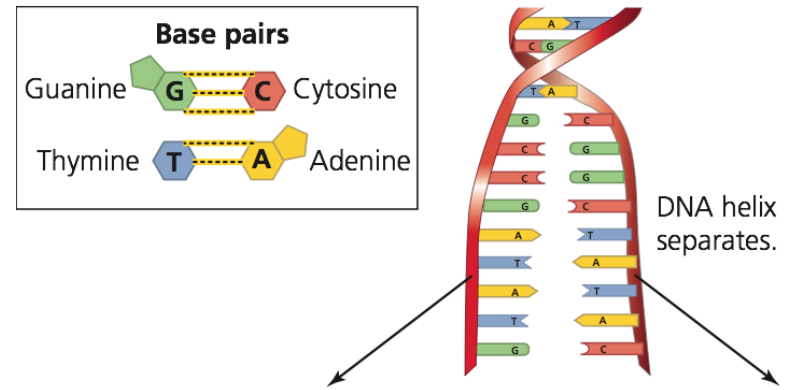
*(DNA also replicates during meiosis which we will cover later)*

When does **mitosis** take place during a life cycle?

When/where are cells in your body doing lots of **mitosis**?

When a cell divides or goes through mitosis how is the DNA copied or replicated?

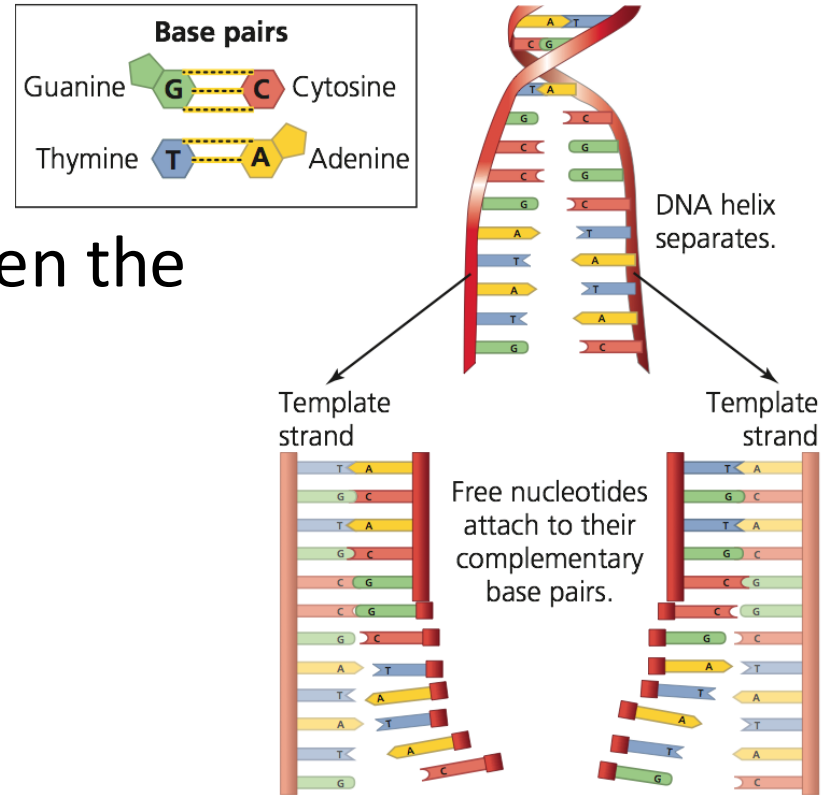
# How does DNA copy itself? (or go through replication)



# How does DNA copy itself?

What is the difference between the **template** strand and the **complementary** strand?

Where are **nucleotides**?



<https://www.yourgenome.org/video/dna-replication>

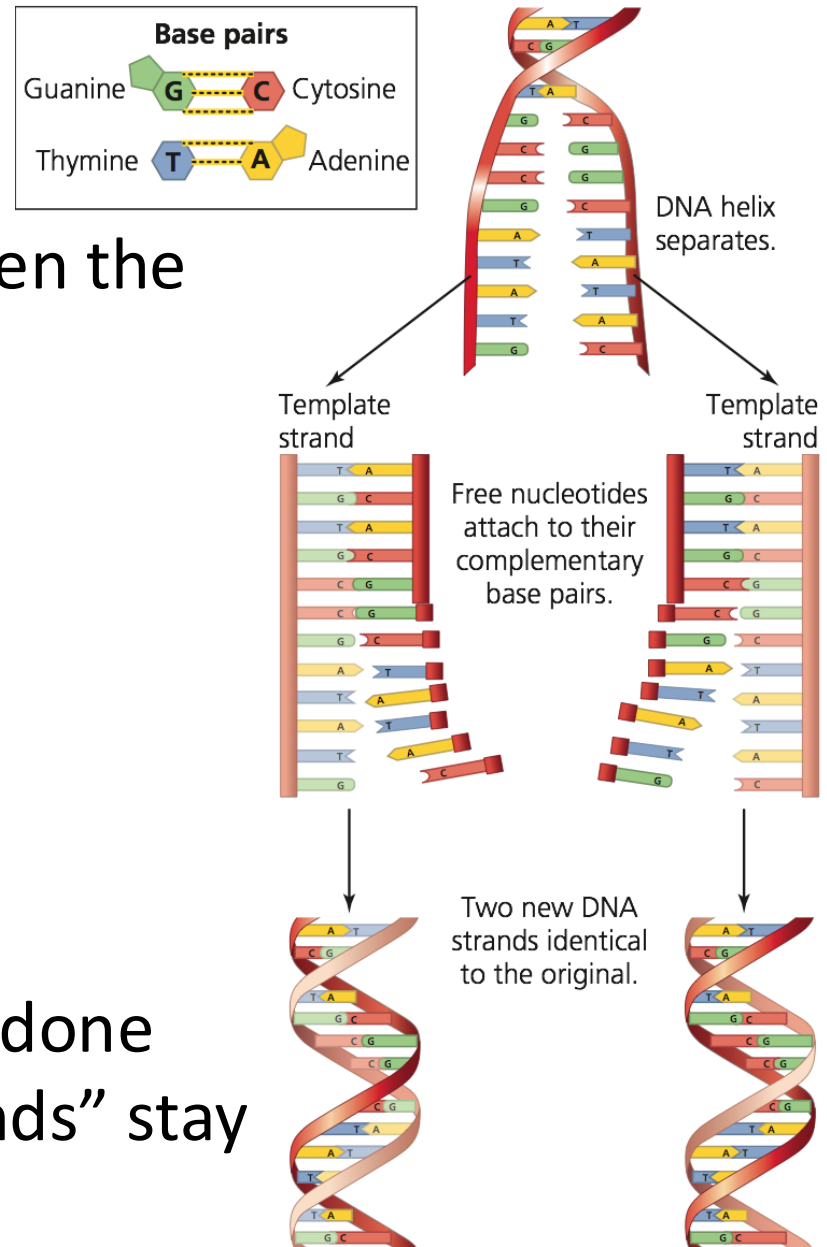
# How does DNA copy itself?

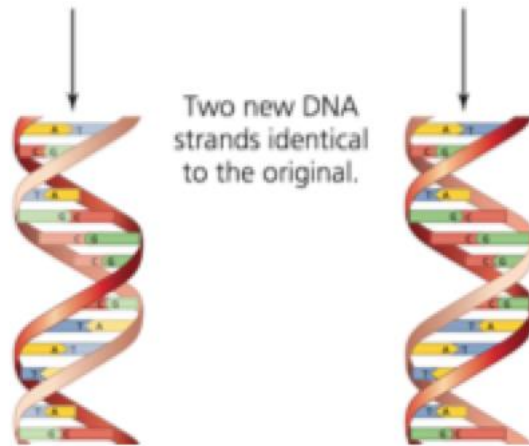
What is the difference between the **template** strand and the **complementary** strand?

Where are **nucleotides**?

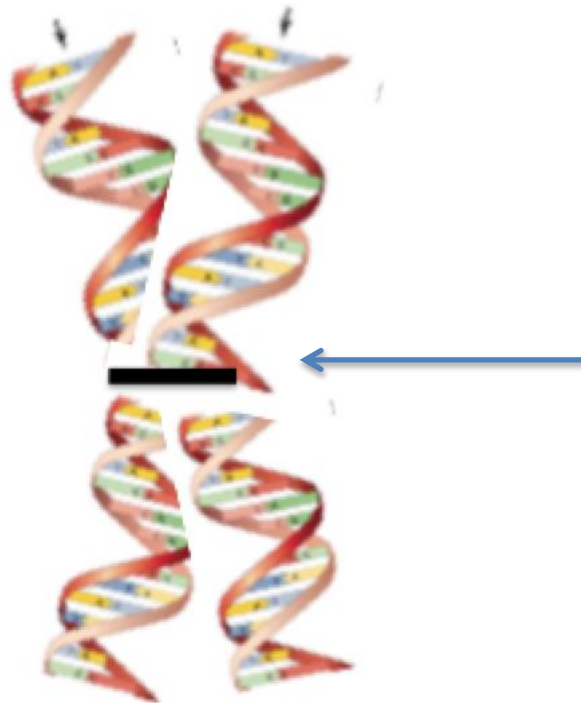
<https://www.yourgenome.org/video/dna-replication>

In reality...once replication is done the two new DNA helix “strands” stay attached.





These two new strands actually stay “attached to one another” for a bit....

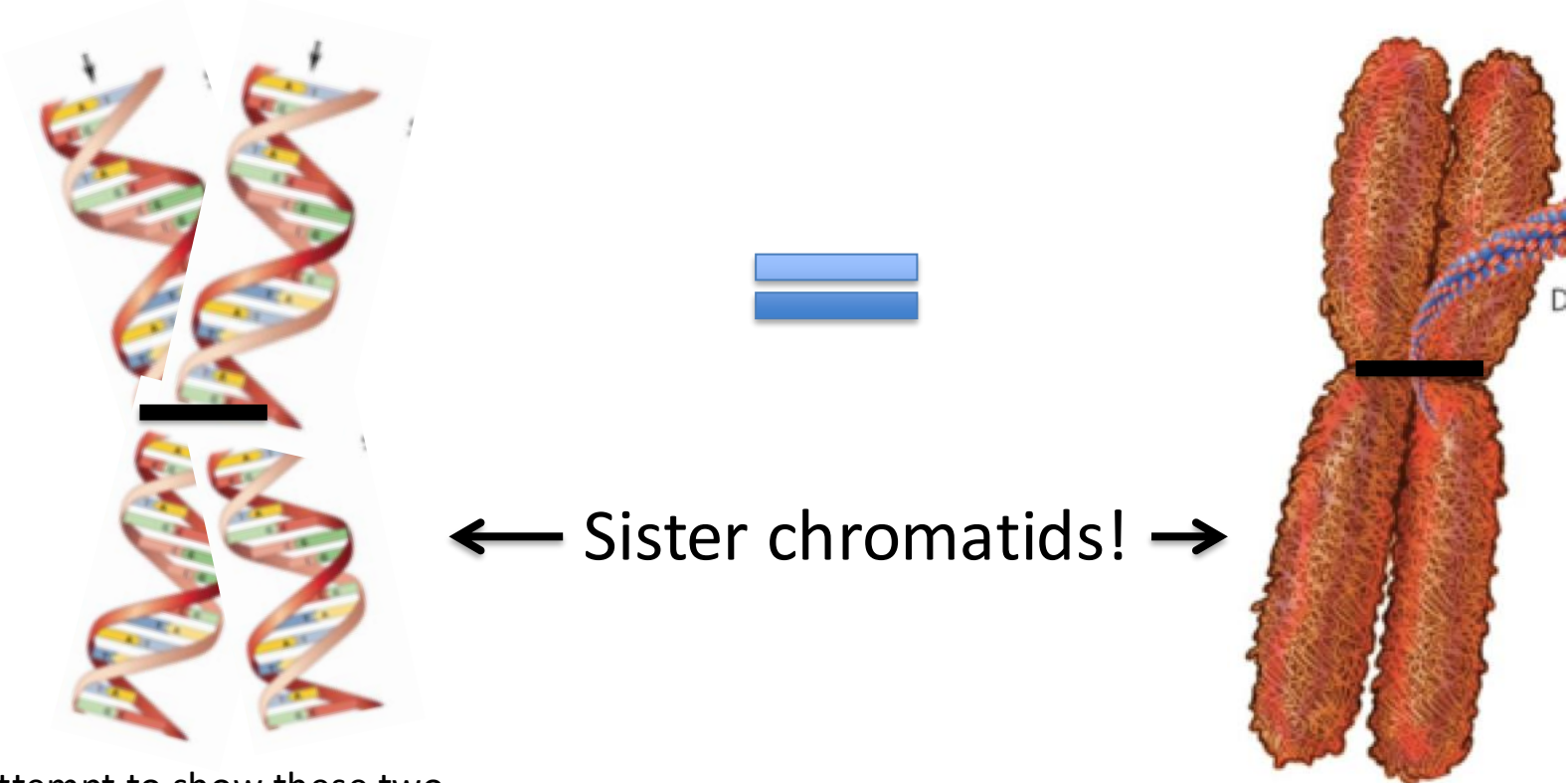


They are attached most tightly here at the centromere.

(My attempt to show that connection.)

Once replication has taken place they stay attached.  
These two strands together are called **sister chromatids**.

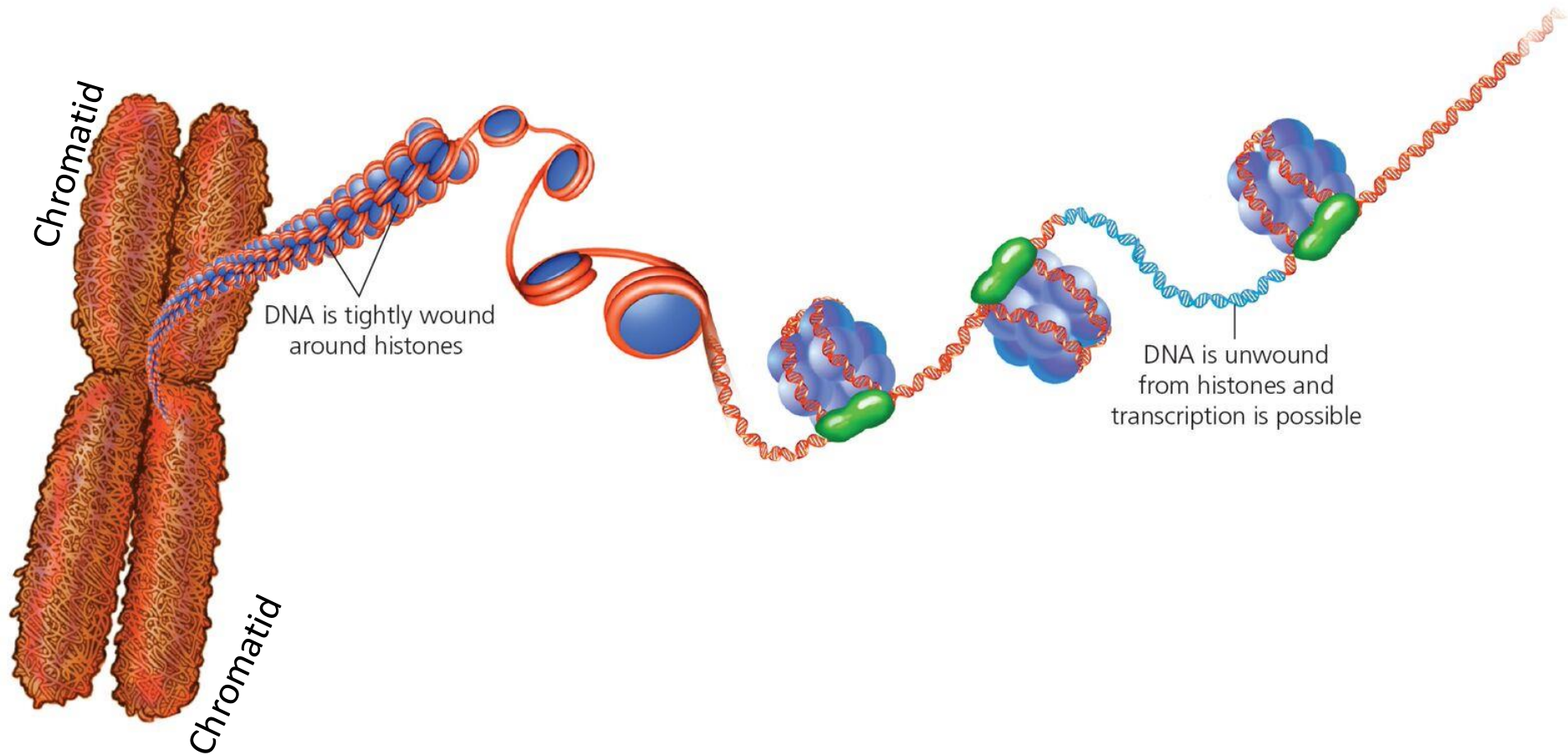
*How different are they likely to be from one another?*



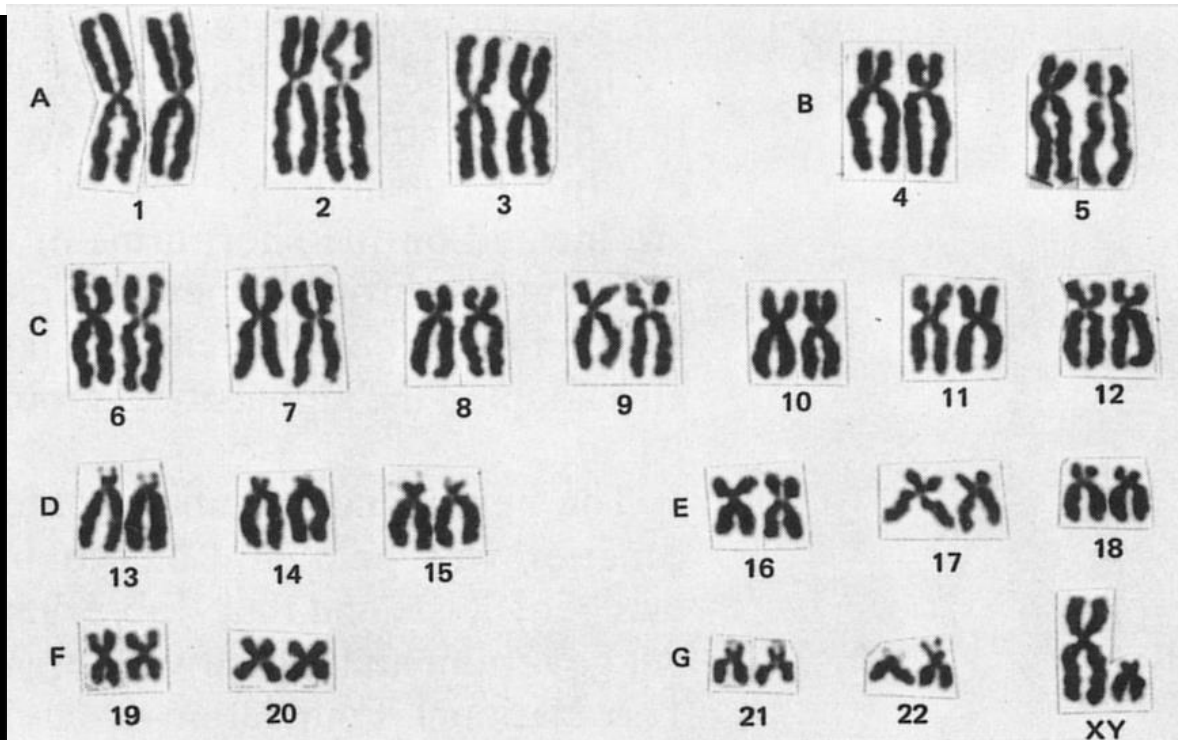
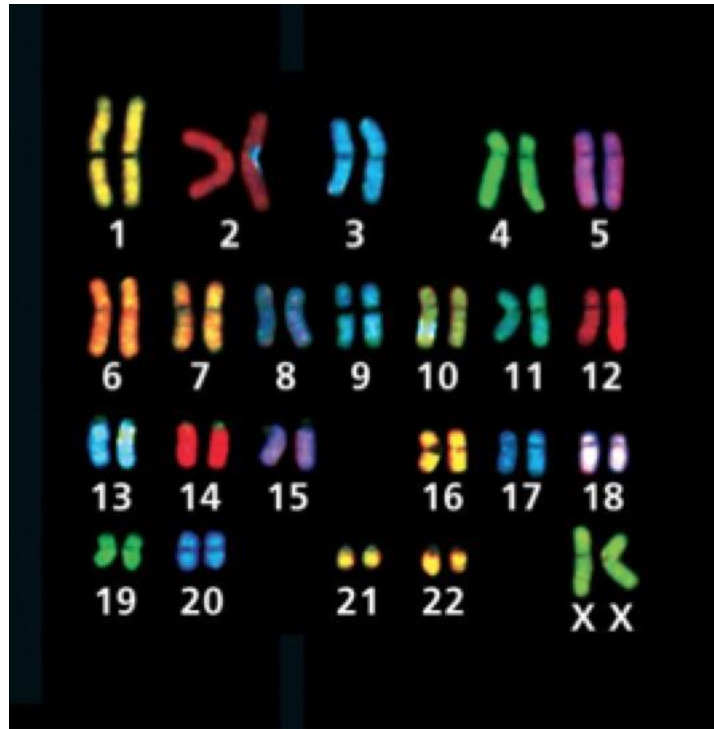
My attempt to show these two strands attached! (They are actually more coiled up than I show here.)

Sister chromatids are two giant tightly coiled strands of DNA.

“Identical Sister Chromatids”



What is going on here?  
(We often see both kinds of images.)



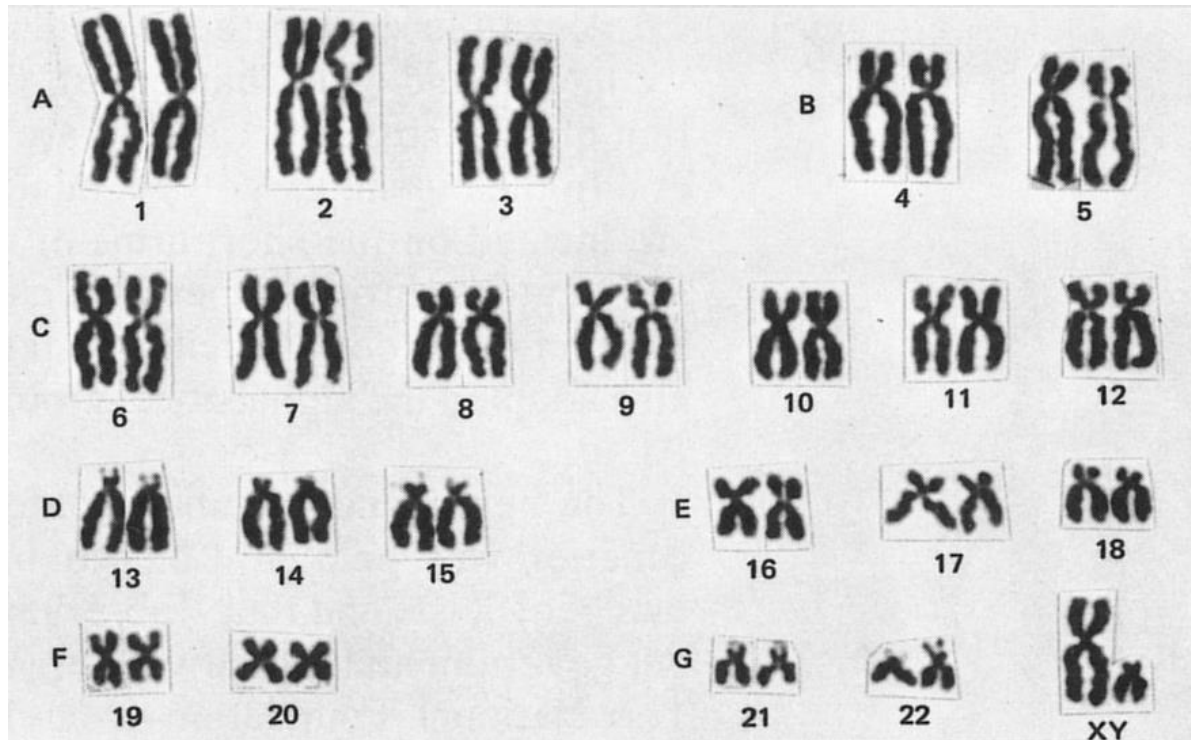
[https://www.mun.ca/biology/scarr/Human\\_Karyotype.html](https://www.mun.ca/biology/scarr/Human_Karyotype.html)

Parent #1 Parent #2

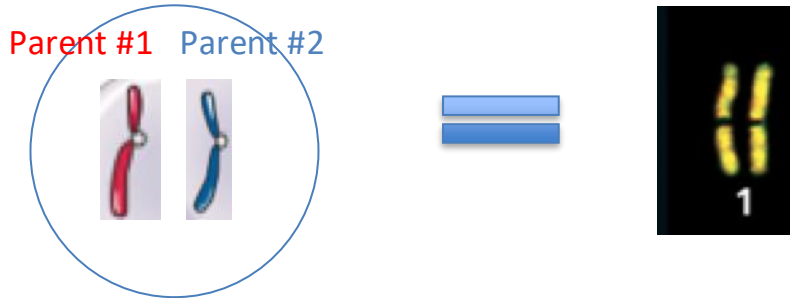


How do cells divide and distribute this copied DNA into two “daughter” cells while guaranteeing that each cell gets two of each type of chromosome?

Seems like it could get messy...  
Need a very organized process!



# They use Mitosis!

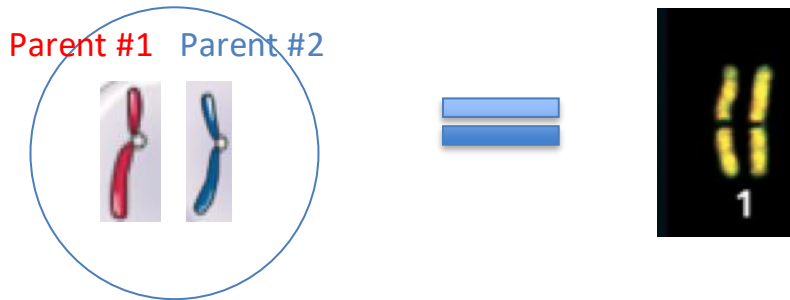


Reality check #1: There would actually be lots of chromosomes and they would actually be smaller than this since they would all have to fit in this cell.

Reality check #2: What happened to the nucleus??

Reality check #3: Why are they now different colors?

# They use Mitosis!



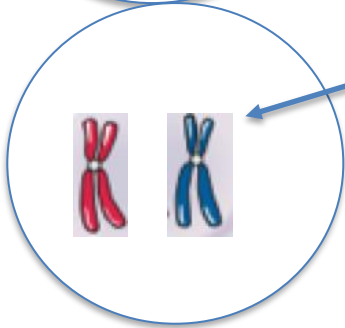
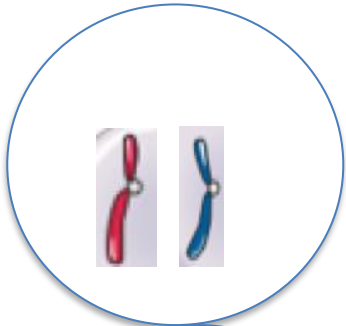
Start with one cell with one homologous pair of chromosomes!

This means it is diploid!

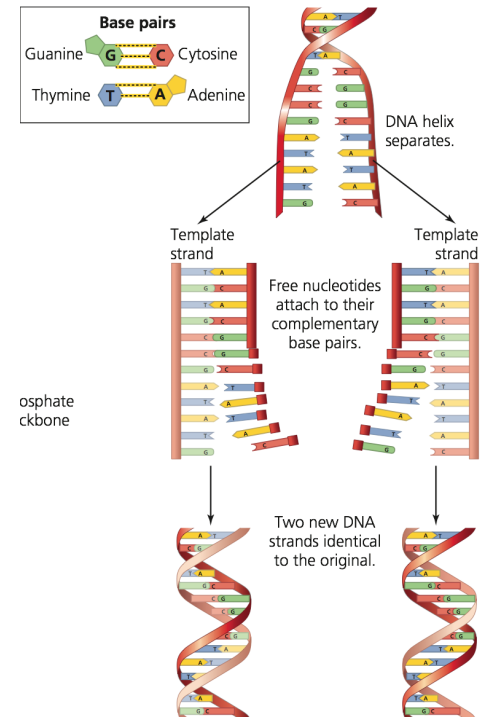
To make 2 cells from one cell what has to happen first?

Replication!

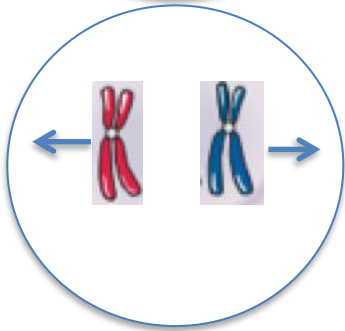
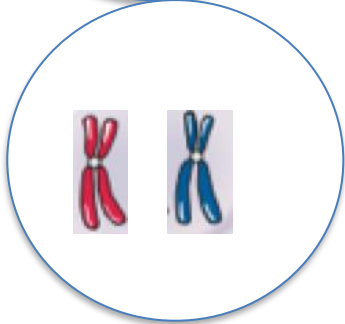
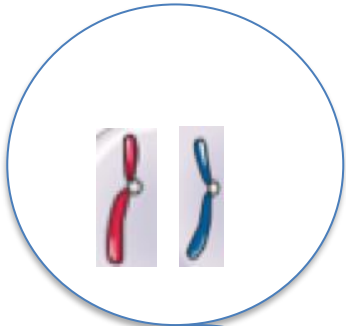
# Mitosis



What just happened??



## Mitosis

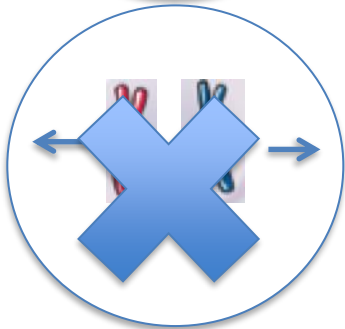
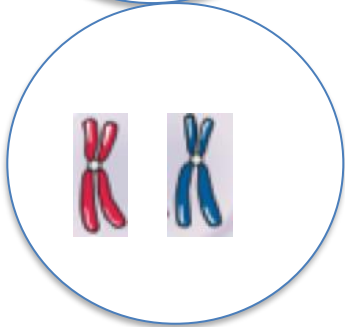
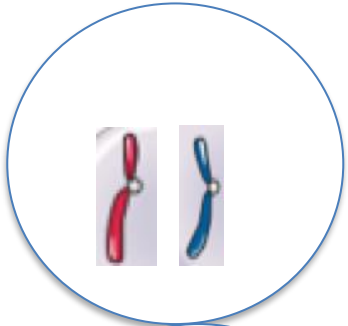


Is this a “good” way to get to two diploid cells??

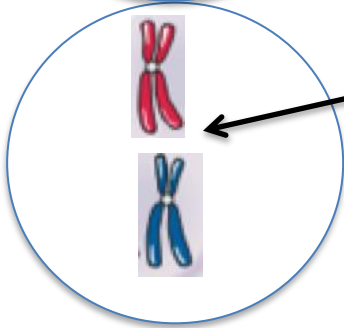
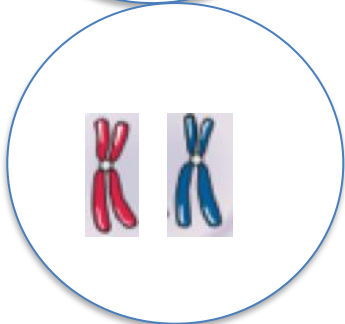
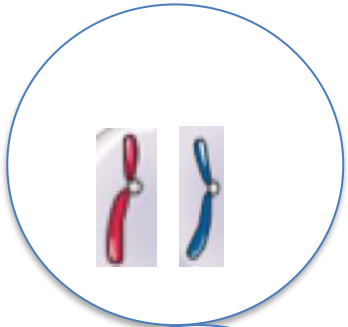
Remember we want a cell that is genetically identical to the original cell.

If you did it that way the daughter cells would not be genetically identical to the starting cell.

# Mitosis

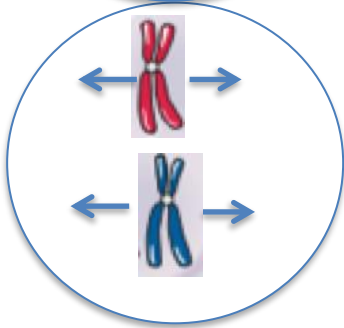
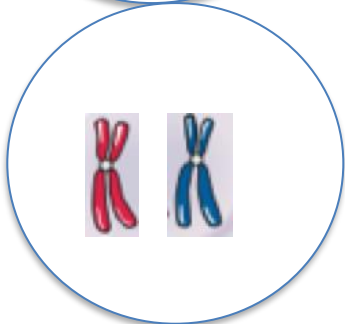
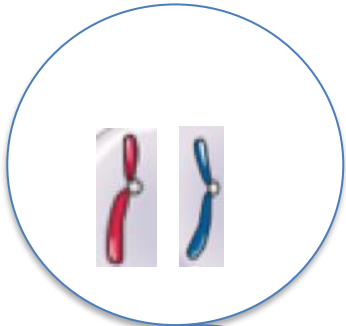


# Mitosis



Instead they line up in middle!  
(happens to be called metaphase)

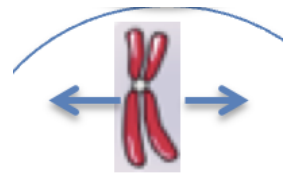
# Mitosis



Are these sister chromatids that are “separating or pulling apart”?

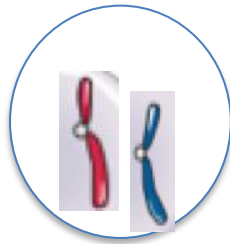
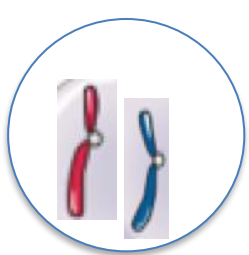
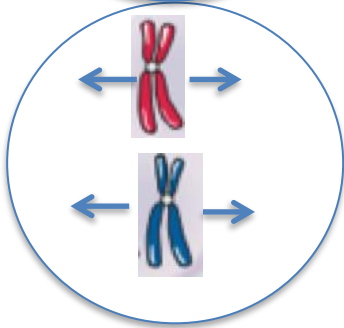
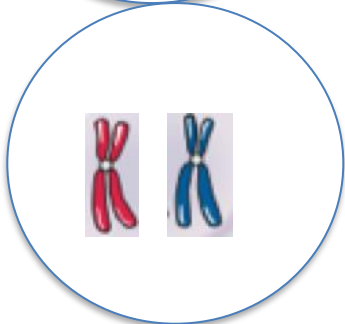
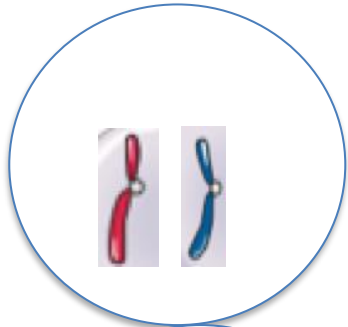
or

Are these homologous chromosomes that are “separating or pulling apart”?



They are sister chromatids!

# Mitosis



## Mitosis

One cell to two cells  
Diploid to diploid

# So where is mitosis happening?

cell type	turnover time
small intestine epithelium	2-4 days
stomach	2-9 days
blood Neutrophils	1-5 days
white blood cells Eosinophils	2-5 days
gastrointestinal colon crypt cells	3-4 days
cervix	6 days
lungs alveoli	8 days
tongue taste buds (rat)	10 days
platelets	10 days
bone osteoclasts	2 weeks
intestine Paneth cells	20 days
skin epidermis cells	10-30 days
pancreas beta cells (rat)	20-50 days
blood B cells (mouse)	4-7 weeks
trachea	1-2 months
hematopoietic stem cells	2 months
sperm (male gametes)	2 months
bone osteoblasts	3 months
red blood cells	4 months
liver hepatocyte cells	0.5-1 year
fat cells	8 years
cardiomyocytes	0.5-10% per year
central nervous system	life time
skeleton	10% per year
lens cells	life time
oocytes (female gametes)	life time

<http://book.bionumbers.org/how-quickly-do-different-cells-in-the-body-replace-themselves/>

## Chapter 5 Topics

1. Animal Life Cycles (We are kind of ignoring plants and many other groups!!! 😞)
2. Structure of DNA in Eukaryotes and Prokaryotes! (*and HGT*)
3. Replication of DNA (*copying of DNA*) in mitosis
- 4. Making proteins!**
  - Transcription-going from DNA to mRNA
  - Translation-going from mRNA to protein
5. Gene regulation!
6. Sizing up the Genome
7. Mutations
8. Mitosis vs Meiosis (*sexual reproduction*)
9. Mendel and Punnett Squares

# 4. Making proteins (transcription and translation)!

## Why do cells need to make proteins?

Function	Description	Example
Antibody	Antibodies bind to specific foreign particles, such as viruses and bacteria, to help protect the body.	<a href="#">Immunoglobulin G (IgG)</a>
Enzyme	Enzymes carry out almost all of the thousands of chemical reactions that take place in cells. They also assist with the formation of new molecules by reading the genetic information stored in DNA.	<a href="#">Phenylalanine hydroxylase</a>
Messenger	Messenger proteins, such as some types of hormones, transmit signals to coordinate biological processes between different cells, tissues, and organs.	<a href="#">Growth hormone</a>
Structural component	These proteins provide structure and support for cells. On a larger scale, they also allow the body to move.	<a href="#">Actin</a>
Transport/storage	These proteins bind and carry atoms and small molecules within cells and throughout the body.	<a href="#">Ferritin</a>

FYI...Human cells can make as many as 100,000 different proteins

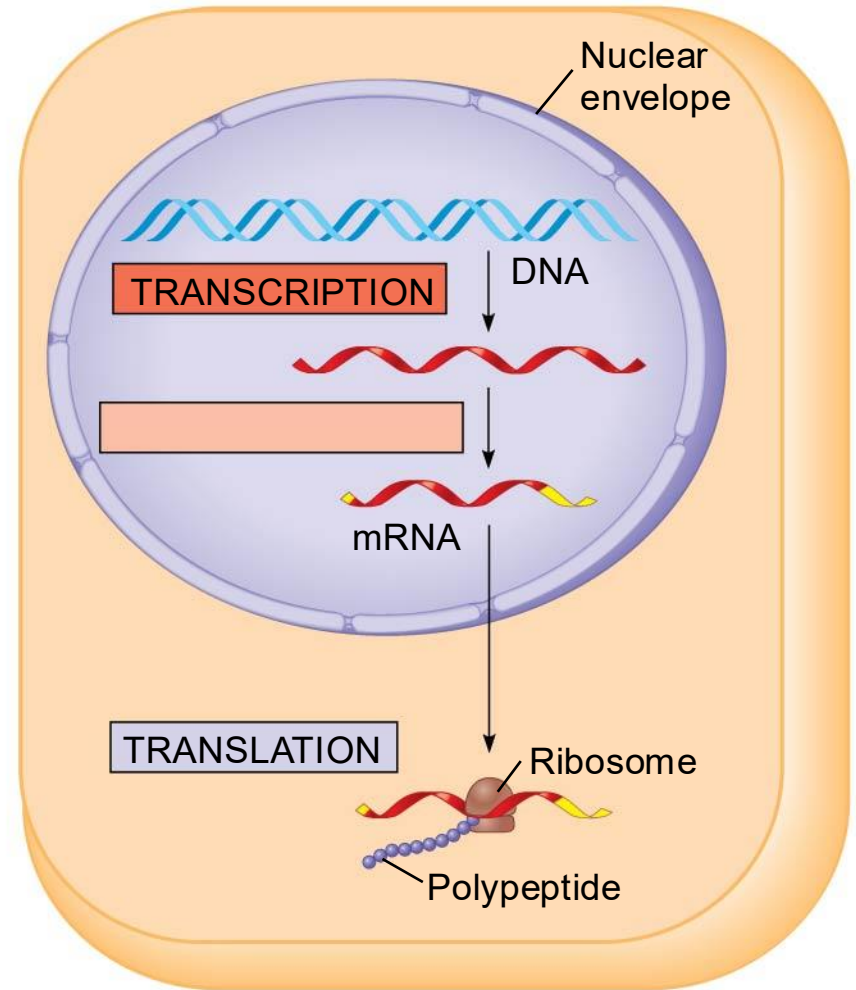
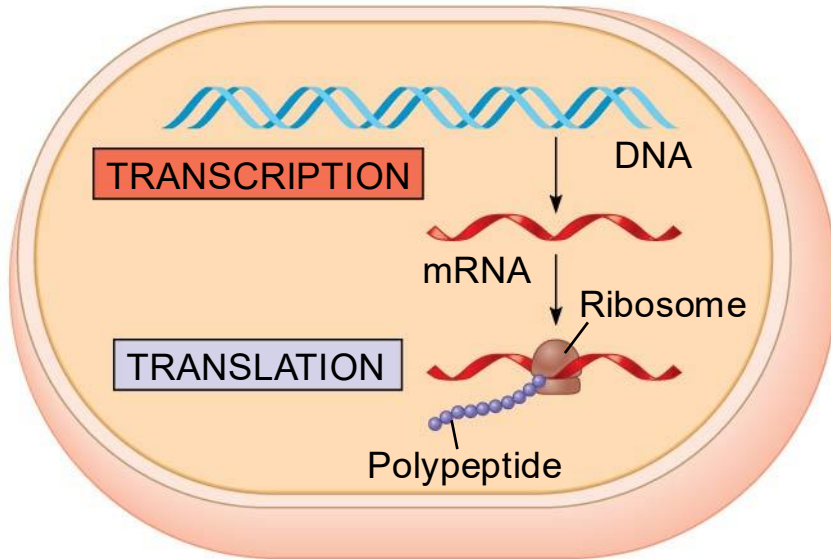
How are **proteins** “made” from the DNA molecule.  
How are genes expressed?

# **An overview of Transcription and Translation**

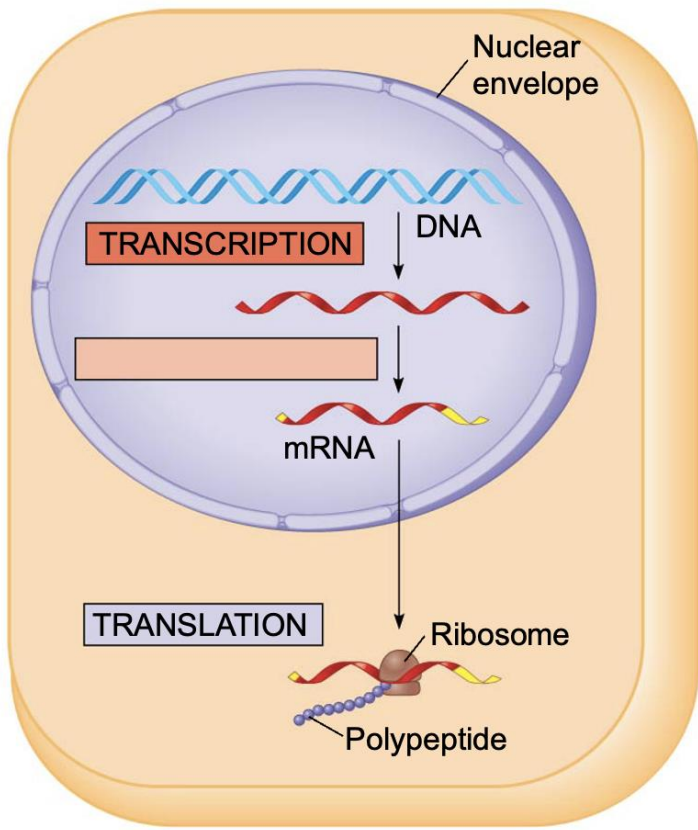
# Which is a Bacterial cell? Which is a Eukaryotic cell?

- What is transcription?
- What is translation?
- What is mRNA?

(FYI: RNA has Uracil instead of Thymine!  
RNA=C,A,U,G DNA= C,A,T,G)

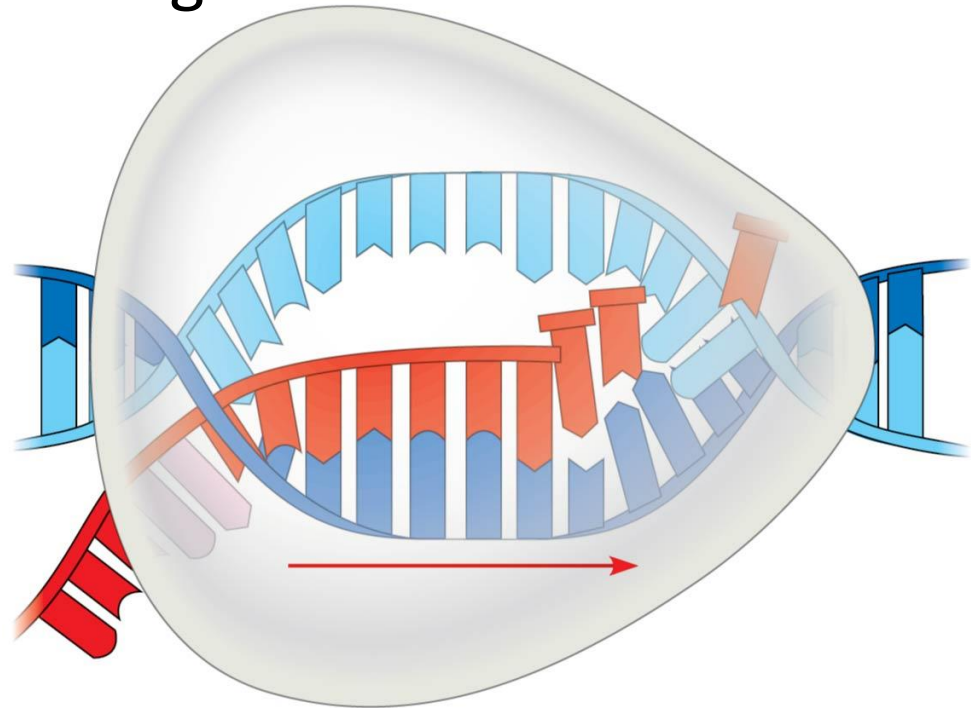


We are going to focus mostly on Eukaryotic cell transcription and translation (but see Box 5.1).



We are going to take this double helix and unwind it a bit....(actually lots of little important molecules do that part).

A gray blob (another molecule) will come along....



# To make a protein you need to first make some mRNA from DNA (Transcription!)

*You need a gray blob (RNA polymerase) to add nucleotides!*

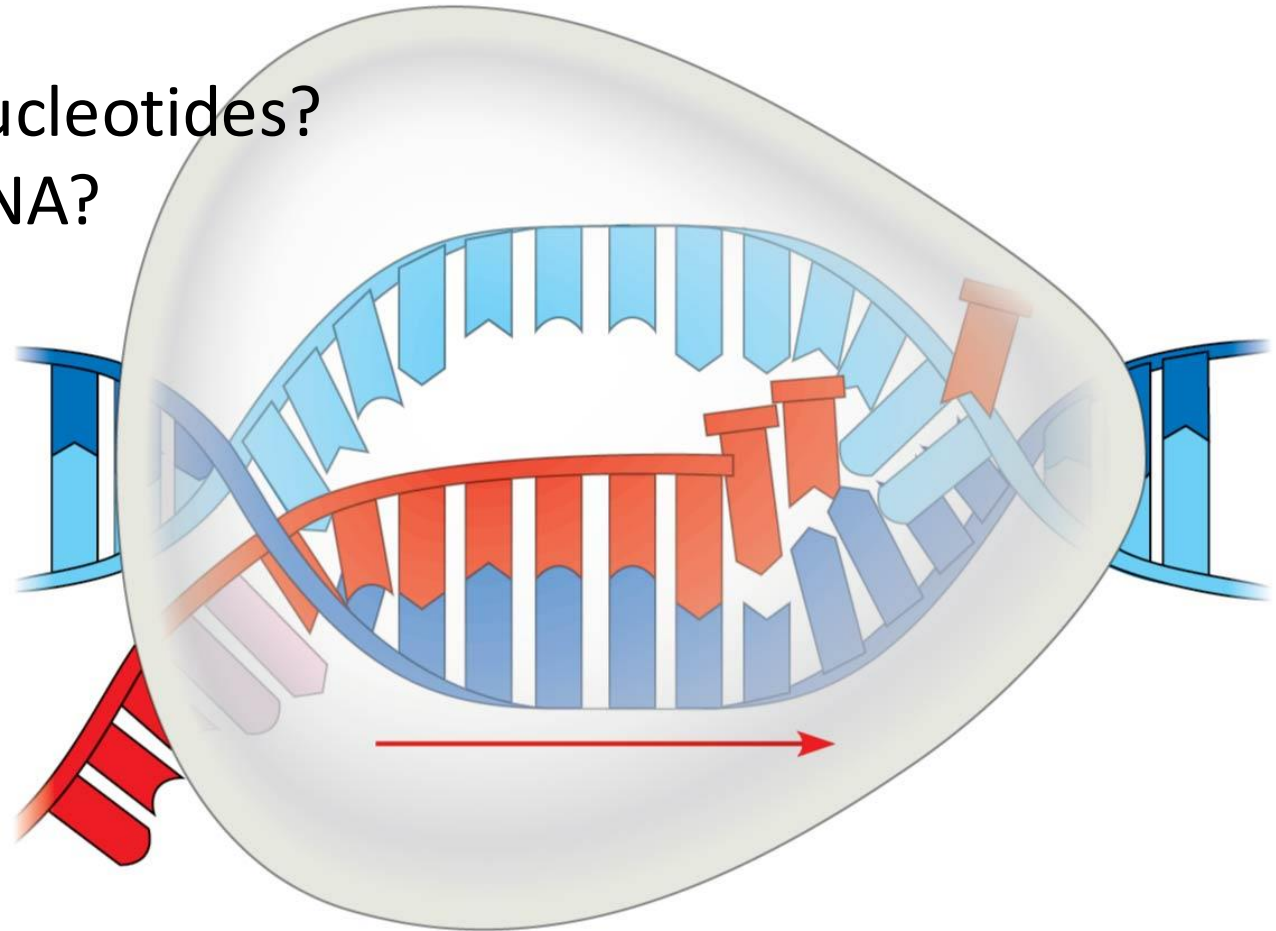
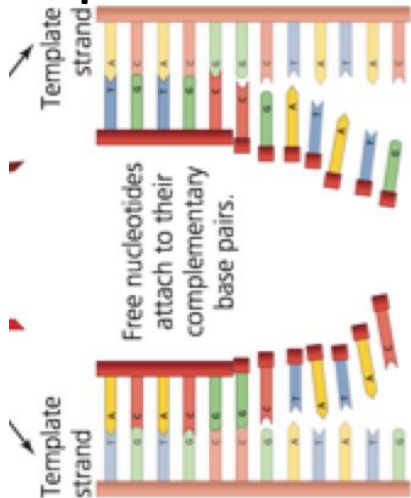
What seems to be happening here?

Where is DNA?

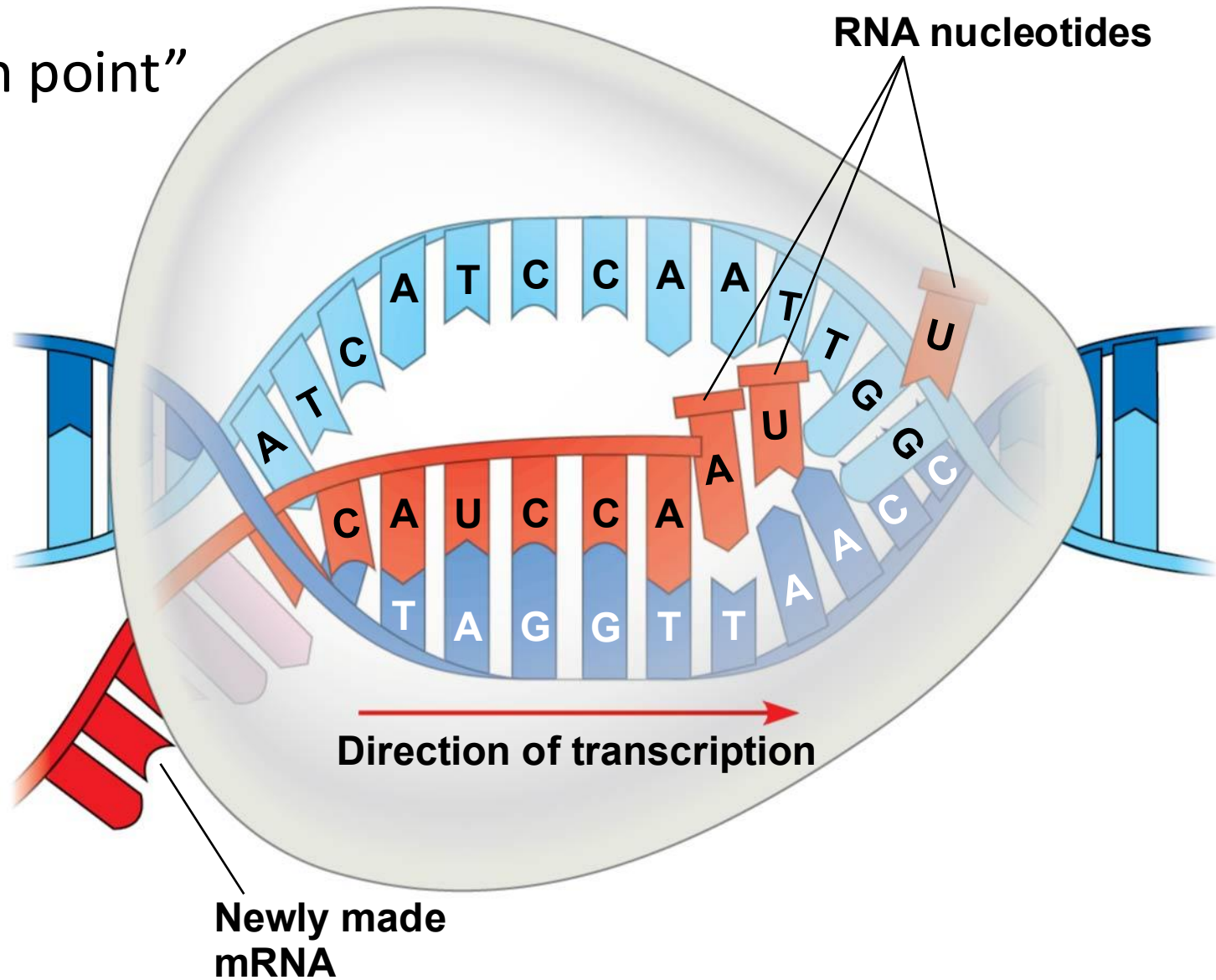
Where are **RNA** nucleotides?

Where is new mRNA?

**Reality Check:**  
Making proteins is not the same as Replication!



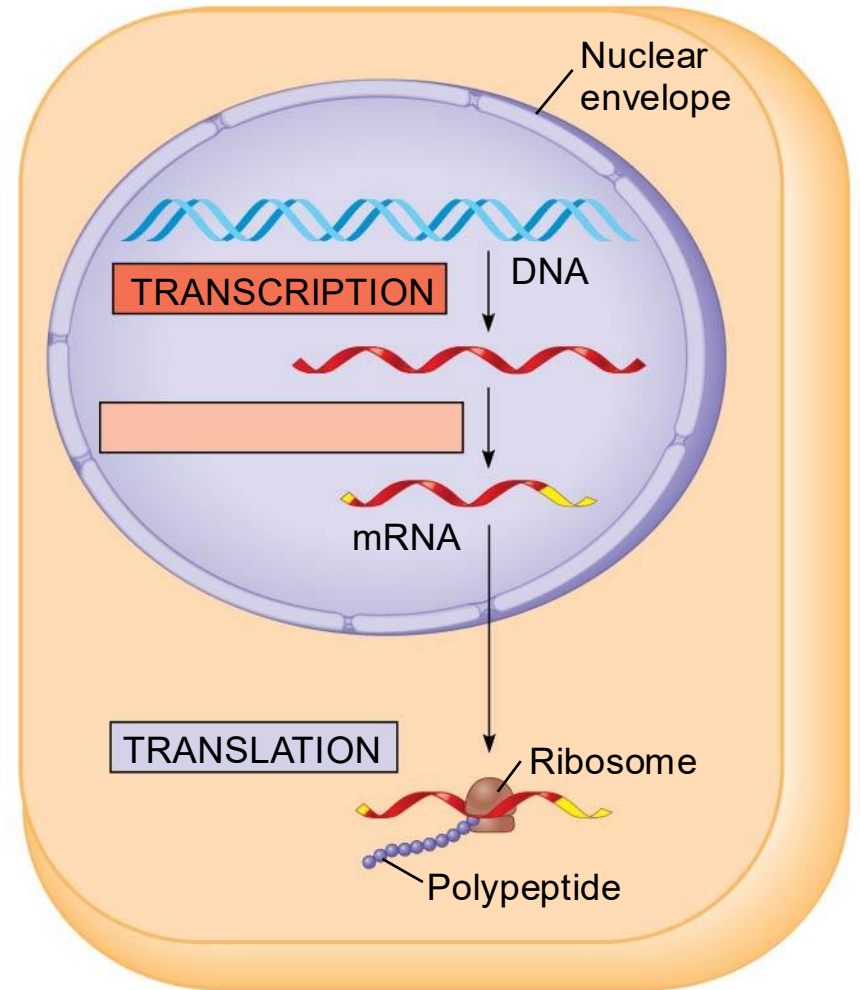
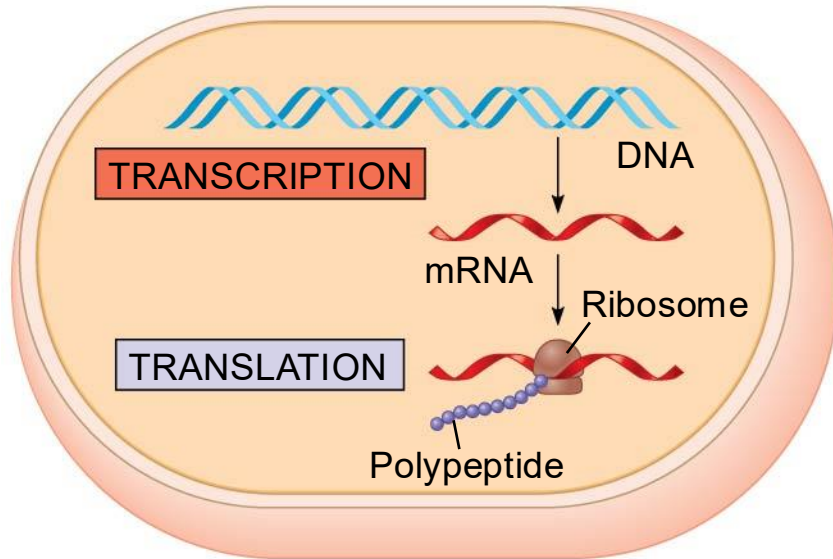
Nucleotides exposed by uncoiling at a "transcription point"



FYI...A single gene (“a region of a chromosome that makes protein”) may have multiple transcription points (places on the DNA molecule where transcription is taking place) and multiple gray blobs (RNA polymerases) working on it like “trucks in a convoy”

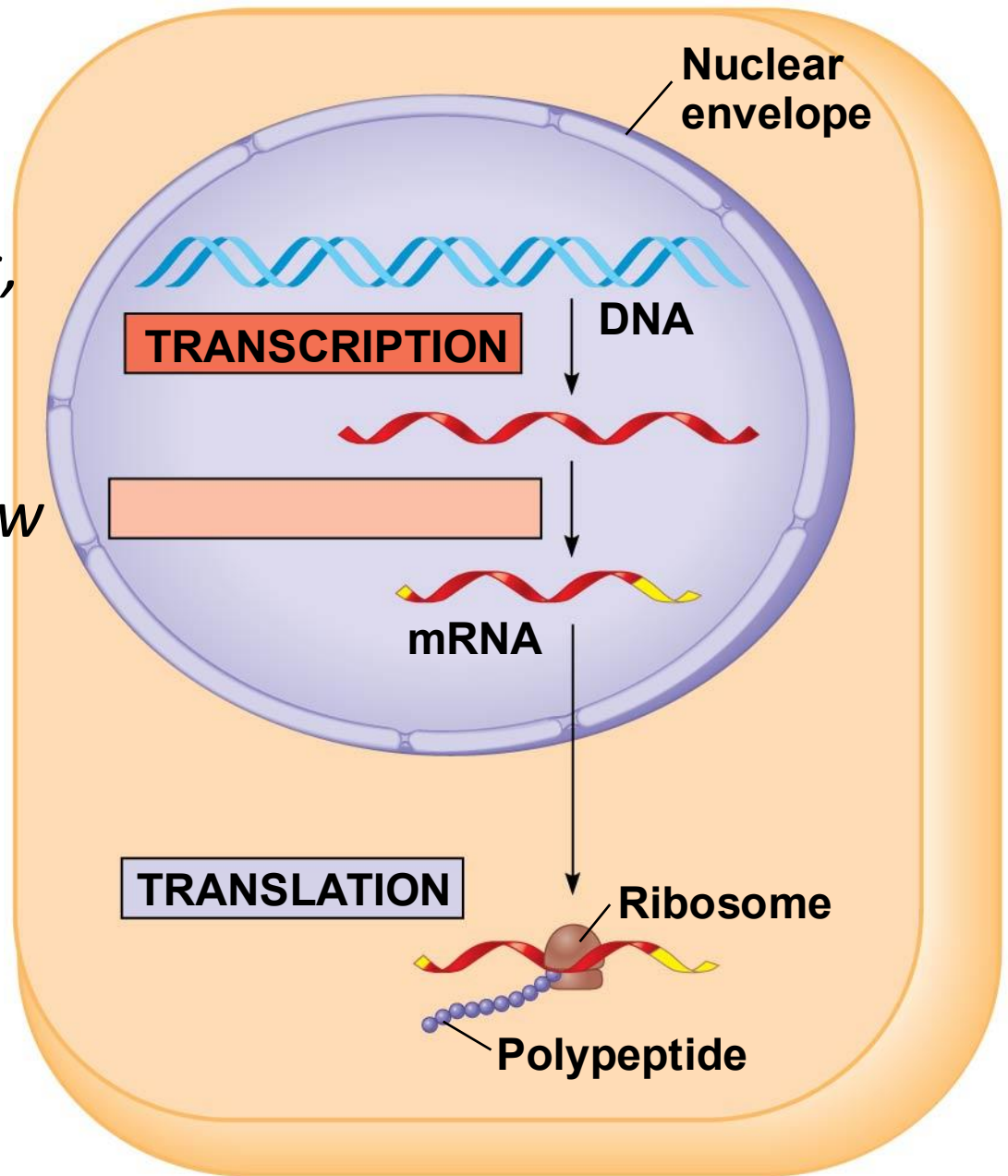
What does that mean for the product or the protein that is being made or encoded by that gene?

# Then mRNA goes somewhere...Where does mRNA go?



*“While DNA stays safe and secure in nucleus, mRNA takes the chances, venturing out into the cell’s cytoplasm and mingles with a whole new crew of construction enzymes and protein-making factories called ribosomes.”*

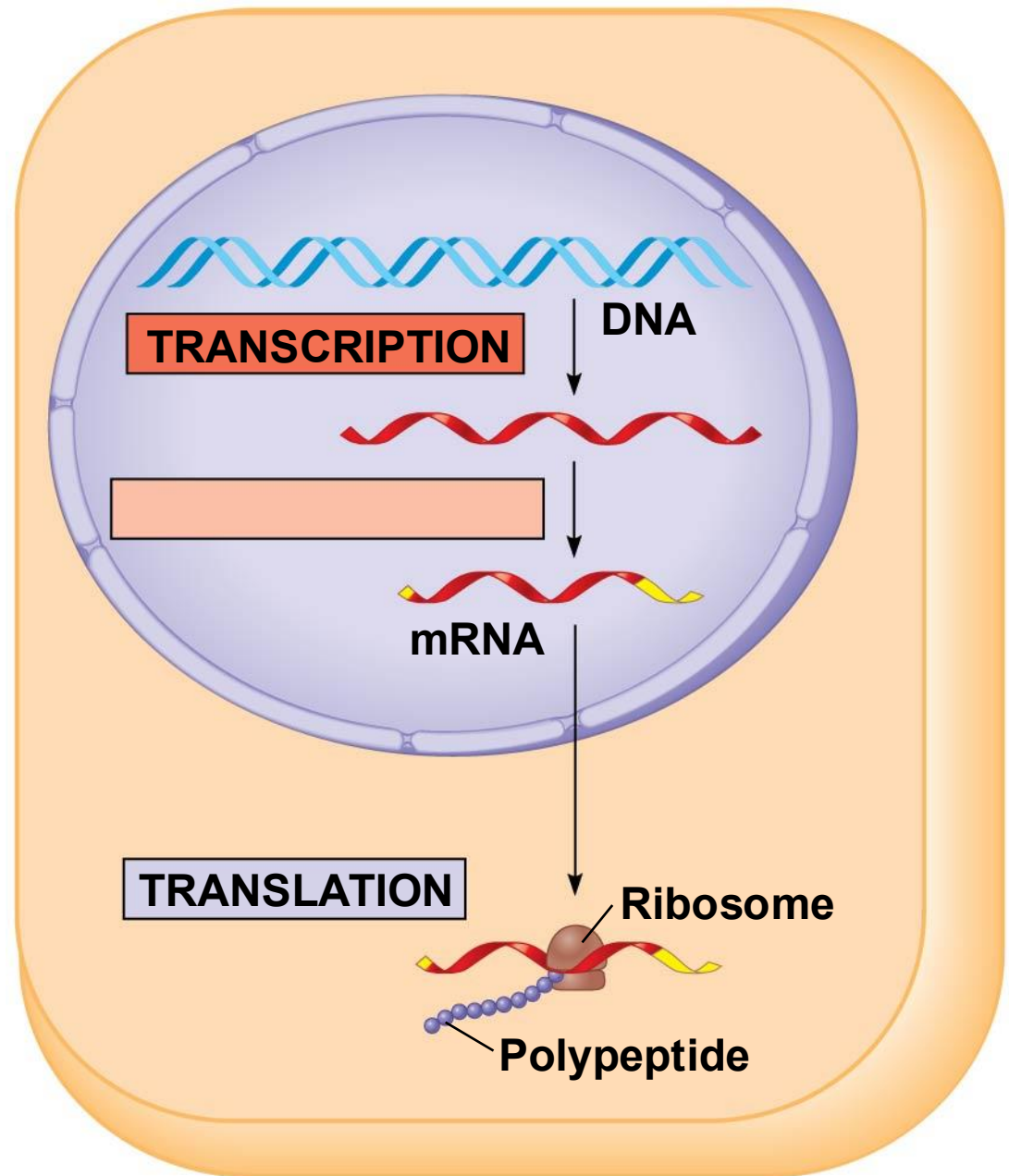
**How do we go from mRNA to a protein or polypeptide?**



**(b) Eukaryotic cell**

# Translation!

mRNA gets “threaded through” the ribosome to make a polypeptide (string of amino acids, i.e. the purple beads)



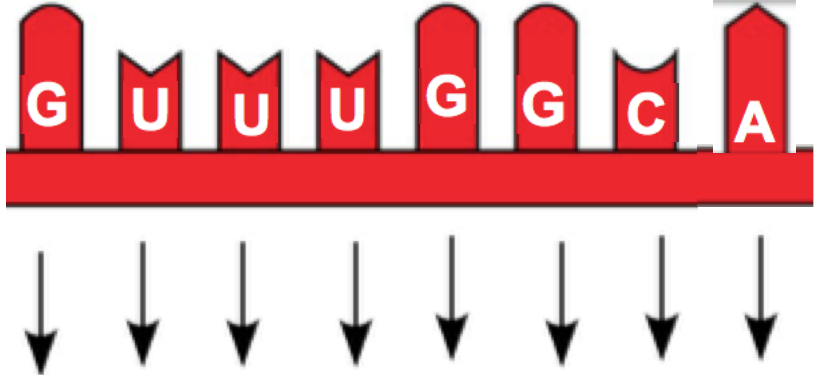
(b) Eukaryotic cell

# Lets look a little more closely at that “red ribbon” of mRNA!



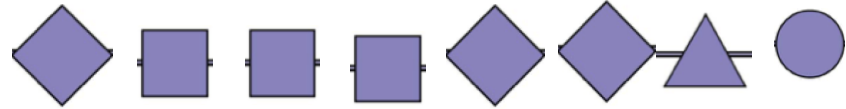
mRNA (bases)

Each purple bead is an amino acid which when strung together make a polypeptide.



Note Uracil in mRNA instead of Thymine!

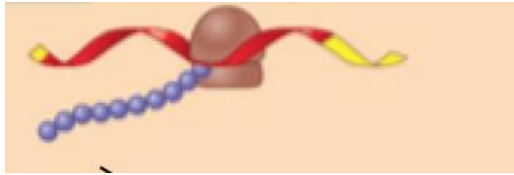
Polypeptide (a.a.)



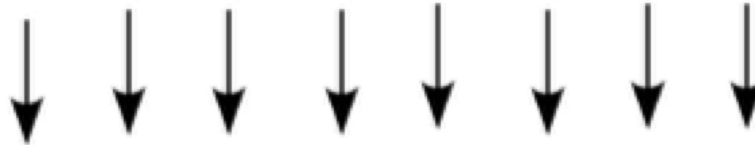
Is this image correct???????

Does each individual base match with a different amino acid?  
If this was the case we could have only 4 amino acids!

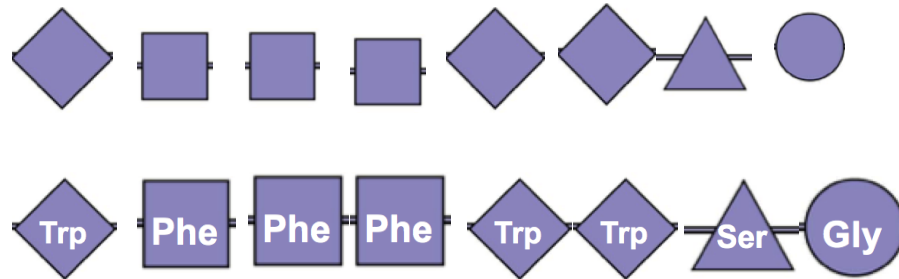
# Lets look a little more closely!



mRNA



polypeptide



4 bases

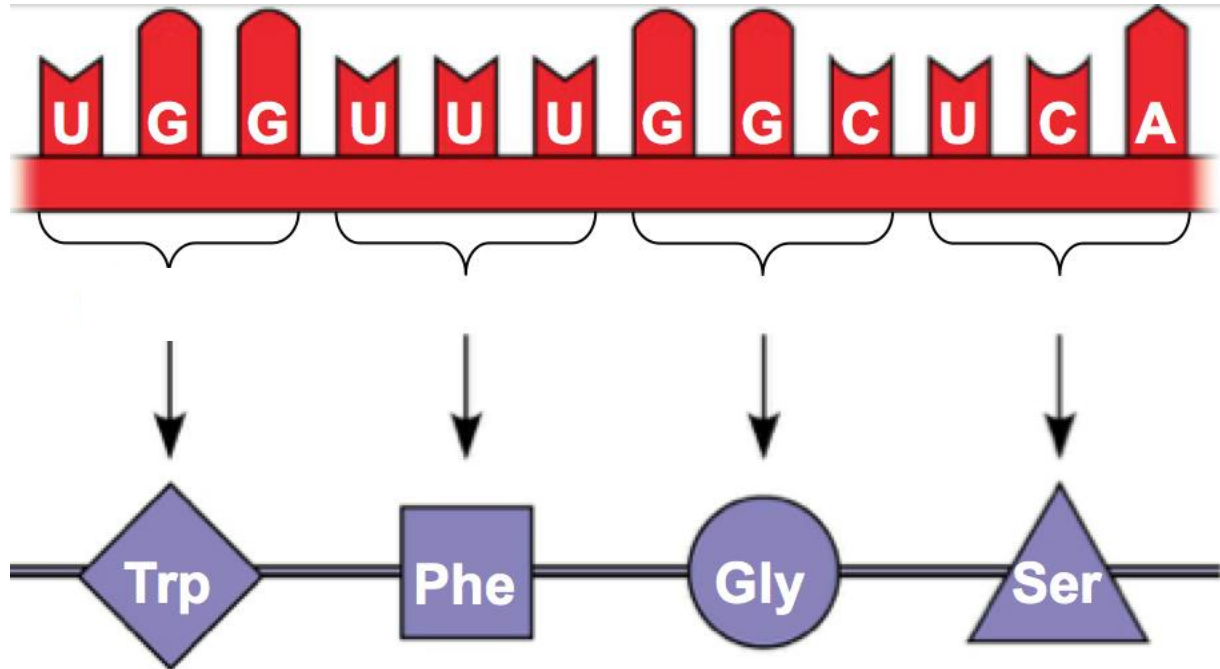


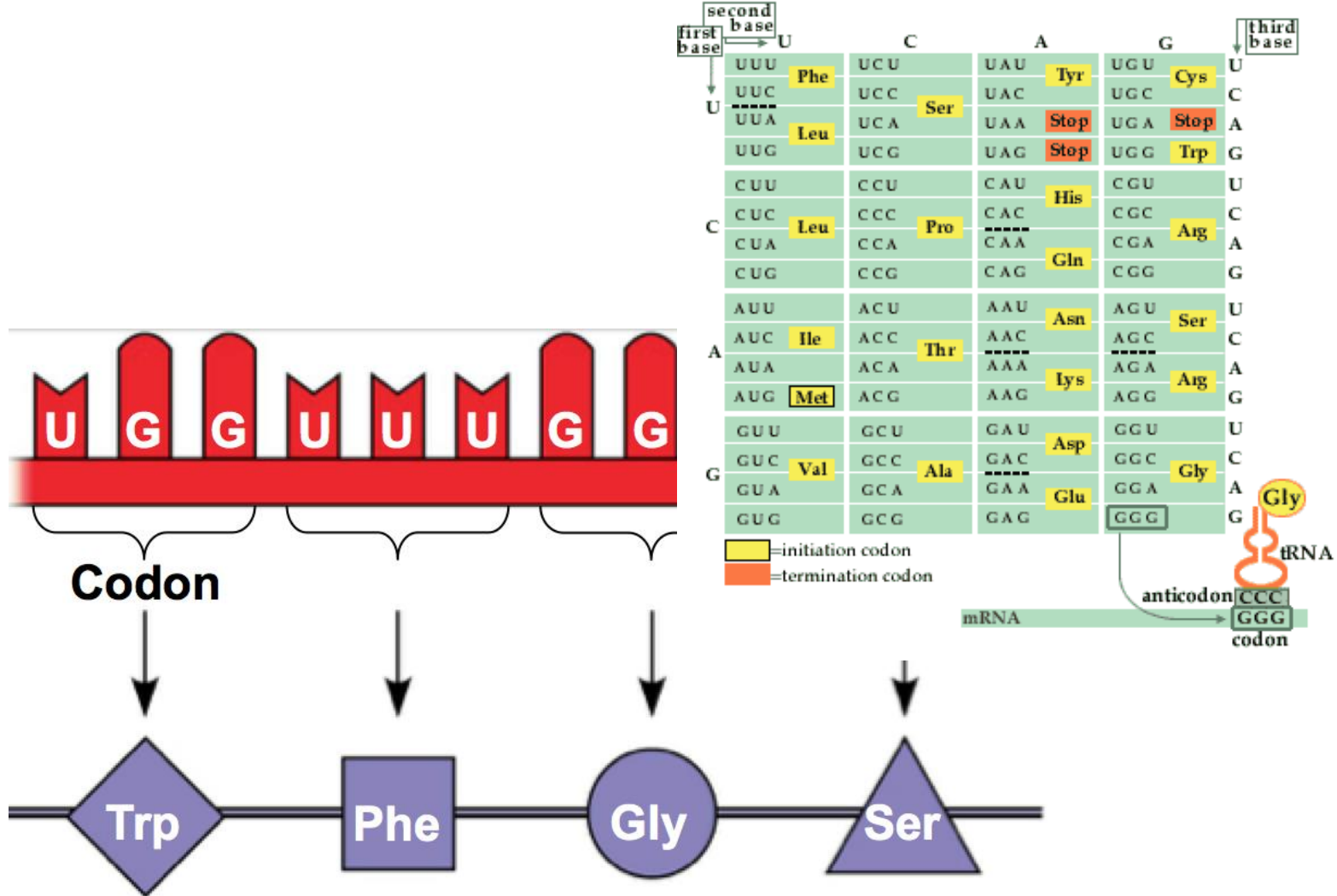
4 amino acids?

**Is this correct?**

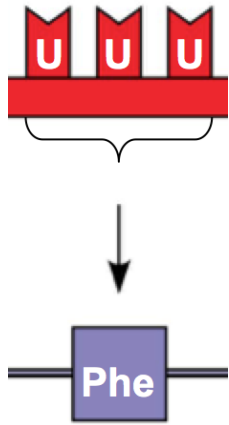
This 1-1 system is **not** what was selected for in our deep evolutionary history. You might consider why?

Instead this is what evolved...

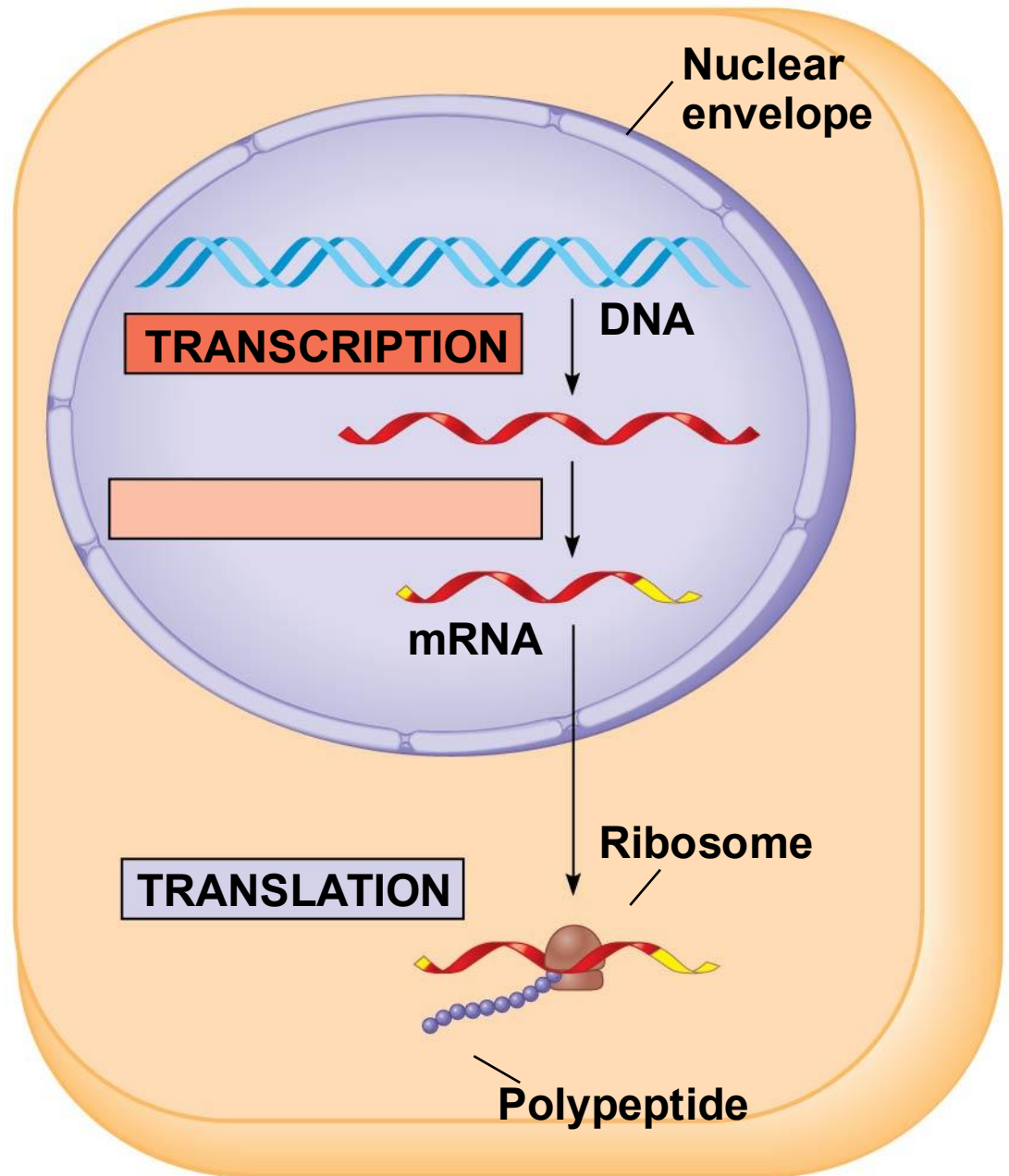




This way you can have many more amino acids-AND thus many more different combinations of amino acids which results in enormous **Protein Diversity (yay)**



At **ribosome** each set of **three** mRNA nucleotides (a codon) is matched to a particular amino acid.



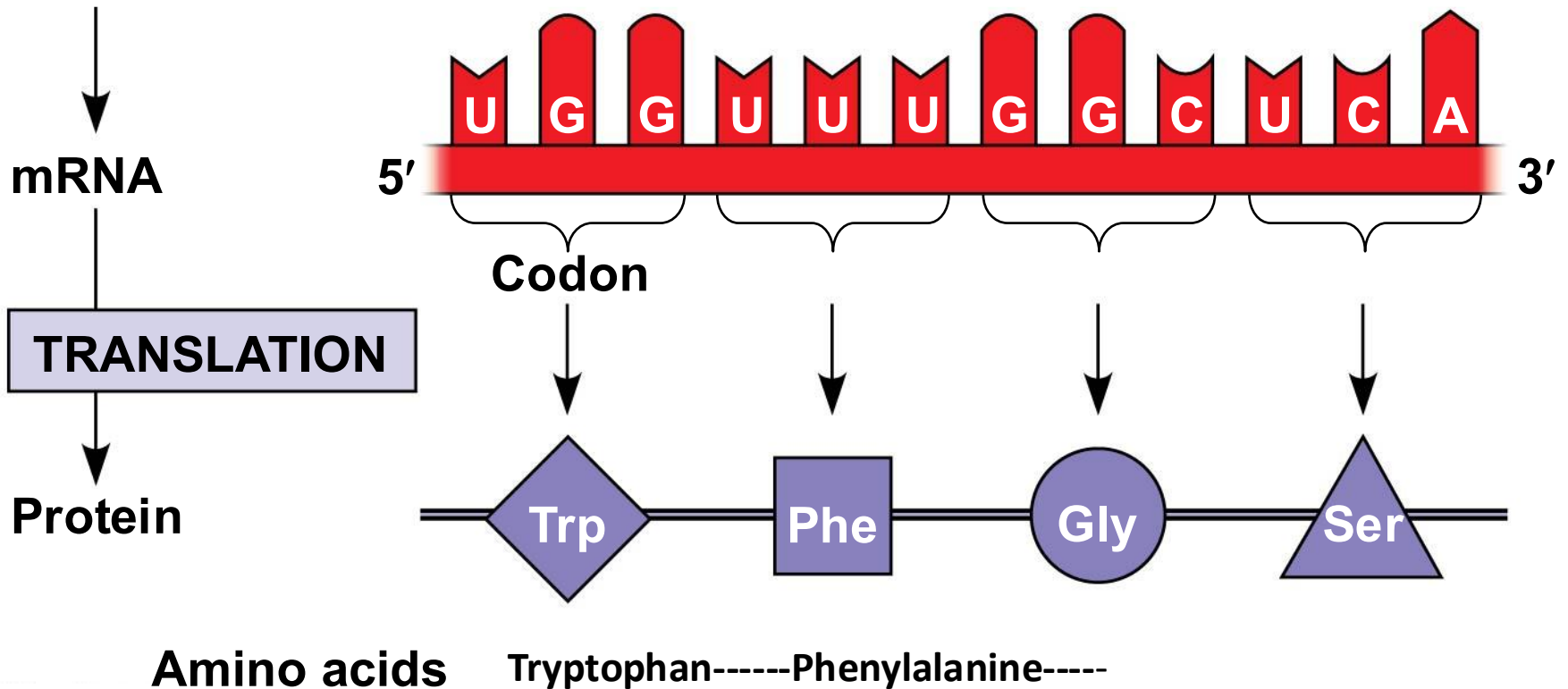
(b) Eukaryotic cell

So for example...

Here is the mRNA we just made out in the cytoplasm.

It will get threaded through the ribosome.

As each codon gets pulled through it is matched with a single amino acid.



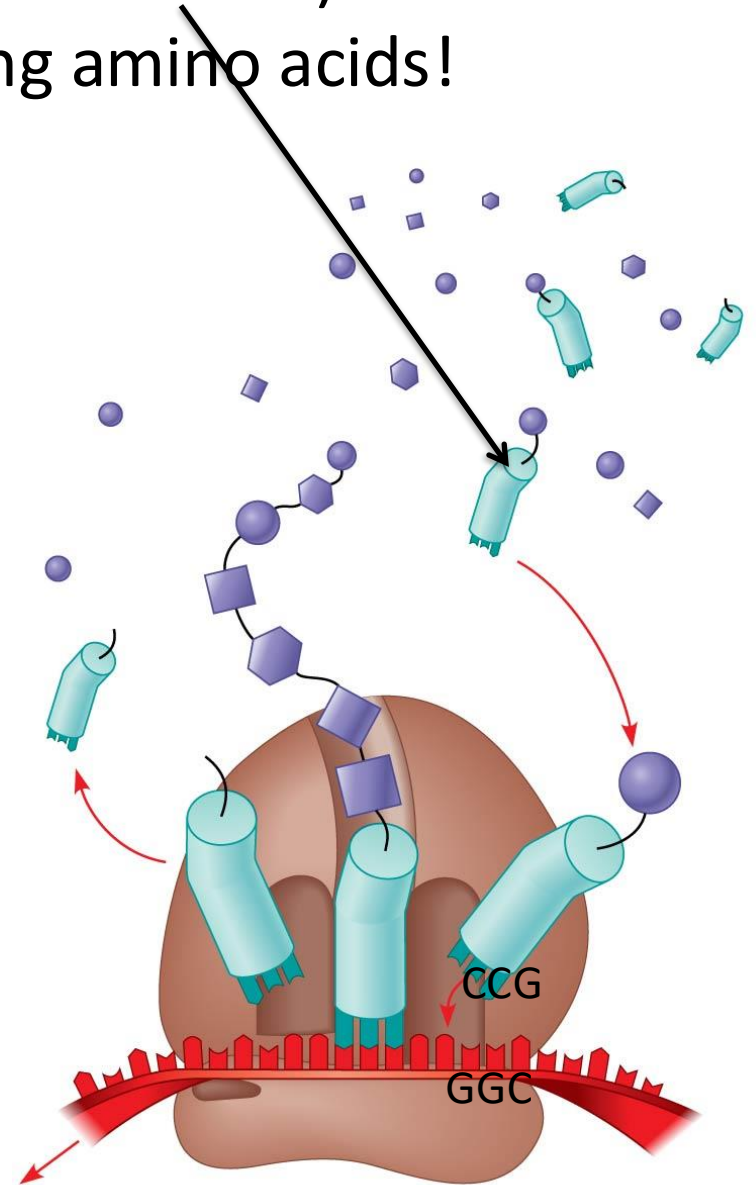
## Now even more closely! How does it work?

Another kind of RNA (transfer RNA or tRNA) is out in cytoplasm hanging around holding amino acids!

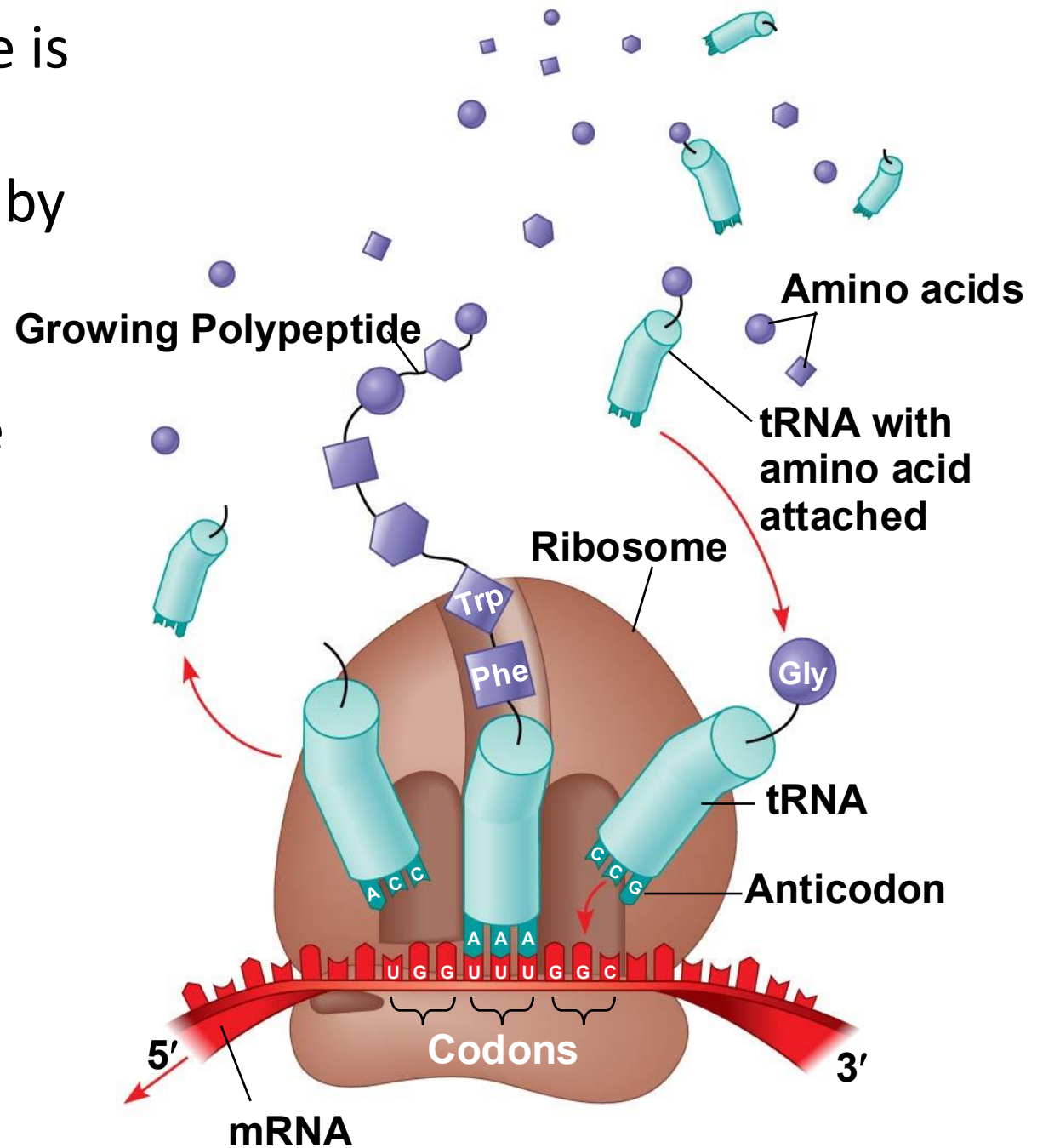
tRNA has dark teal “anticodon” at one end and a specific amino acid at other

if mRNA **codon** is GGC  
**tRNA anticodon** to match will be CCG

and would have grabbed glycine as its amino acid



Growing polypeptide is held by ribosome as tRNAs sweep in one by one attaching their amino acid to the growing polypeptide chain.



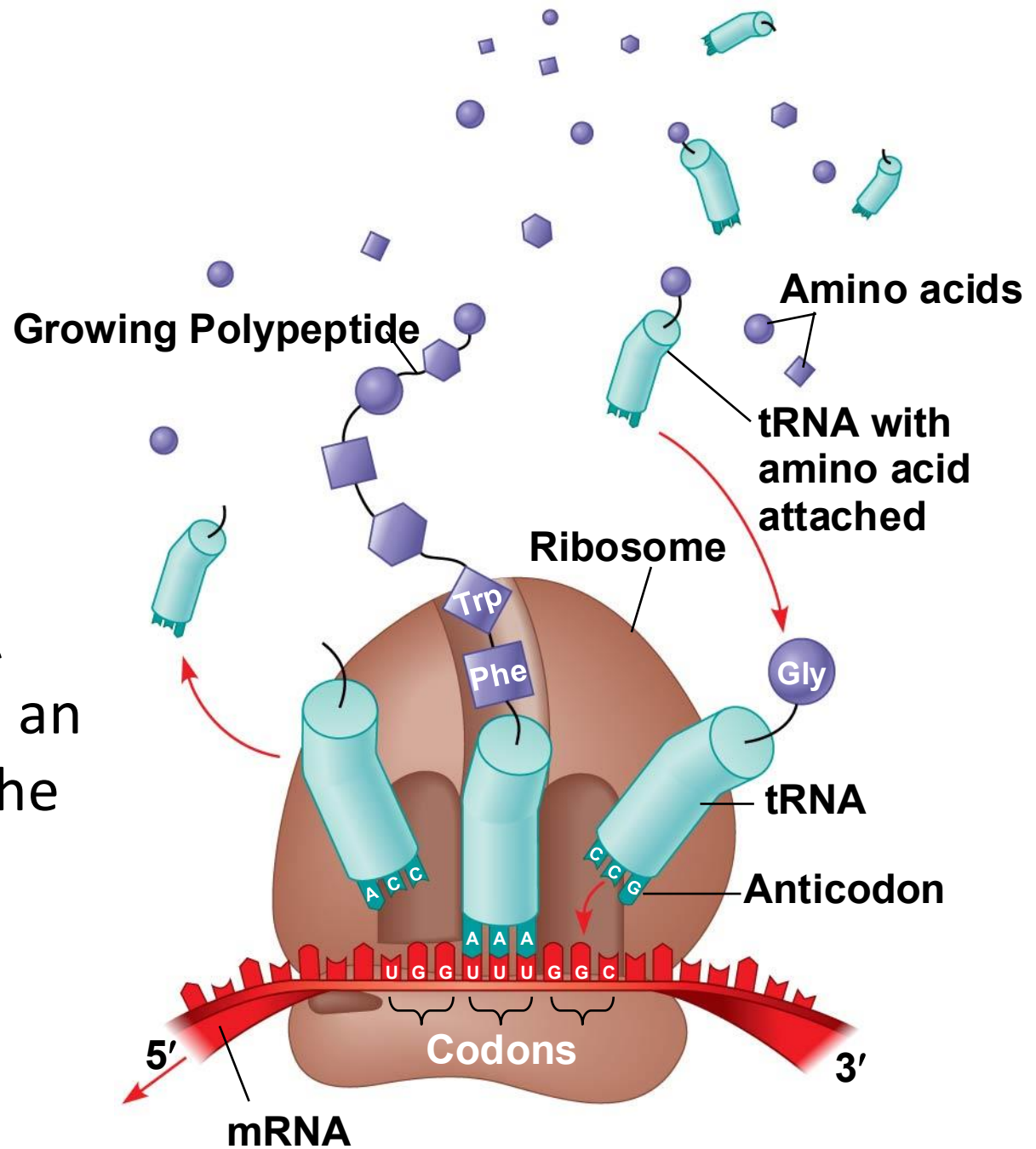
# The entire mRNA strand will not be translated!!!!

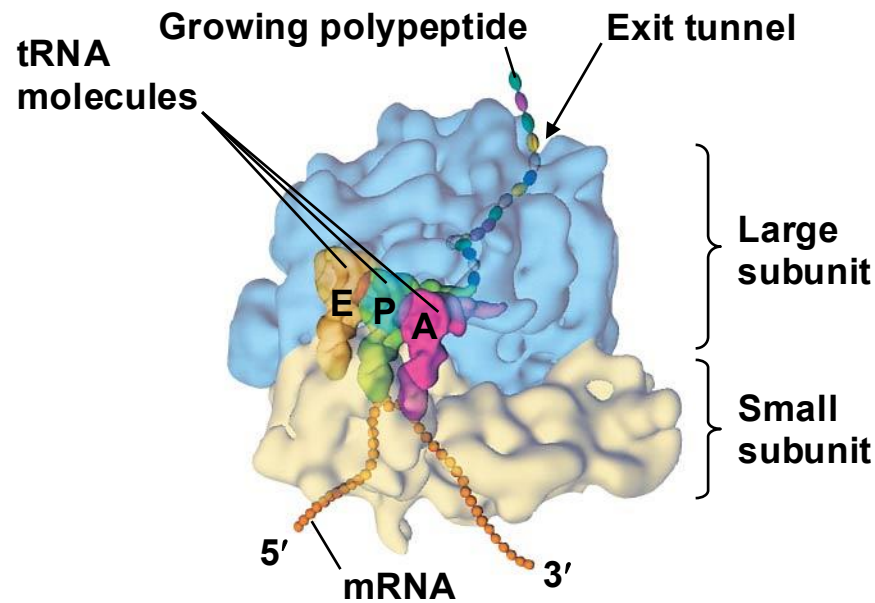
## What happens is...

- mRNA-gets conveyed thru the ribosome until a start codon is encountered (always AUG )
- Start codon establishes **reading frame** (every set of three after that is then defined as a codon)
- Once start codon is encountered, tRNA hauls amino acids to the ribosome

What if there was a mutation in the DNA molecule that added an extra nucleotide to the mRNA (red ribbon)?

Would disrupt the reading frame!





## More about ribosomes...

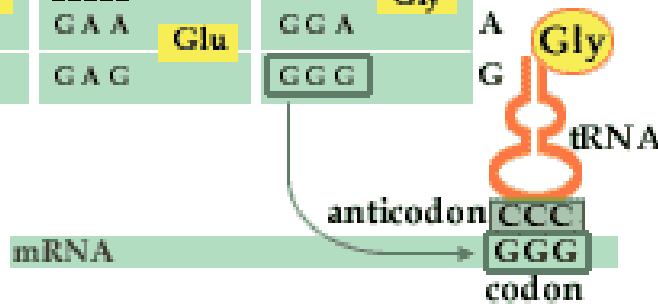
- Are tons of these within the cell
- Made up of yet another kind of RNA (ribosomal RNA)

How many different kinds of RNA are there?  
(mRNA, tRNA, rRNA)

second base	U	C	A	G	third base
U	UUU Phe	UCU	UAU Tyr	UGU Cys	U
	UUC	UCC Ser	UAC	UGC	C
	UUA Leu	UCA	UAA Stop	UGA Stop	A
	UUG	UCG	UAG Stop	UGG Trp	G
C	CUU	CCU	CAU His	CGU	U
	CUC Leu	CCC Pro	CAC	CGC	C
	CUA	CCA	CAA Gln	CGA Arg	A
	CUG	CCG	CAG	CGG	G
A	AUU	ACU	AAU Asn	AGU Ser	U
	AUC Ile	ACC Thr	AAC	AGC	C
	AUA	ACA	AAA Lys	AGA Arg	A
	AUG Met	ACG	AAG	AGG	G
G	GUU	GCU	GAU Asp	GGU	U
	GUC Val	GCC Ala	GAC	GGC Gly	C
	GUA	GCA	GAA Glu	GGA	A
	GUG	GCG	GAG	GGG	G

= initiation codon  
 = termination codon

mRNA Table



# How do we read these codon tables?

## 64 possible codons

[4 possible bases (A, G, C, U) and 3 bases per codon so  $4^3$ ]

- 3 stop codons
- 1 start codon

BUT THERE are not 60 different amino acids because multiple codons match with each a.a.

“wobble” = 3<sup>rd</sup> “slot” is more “flexible”

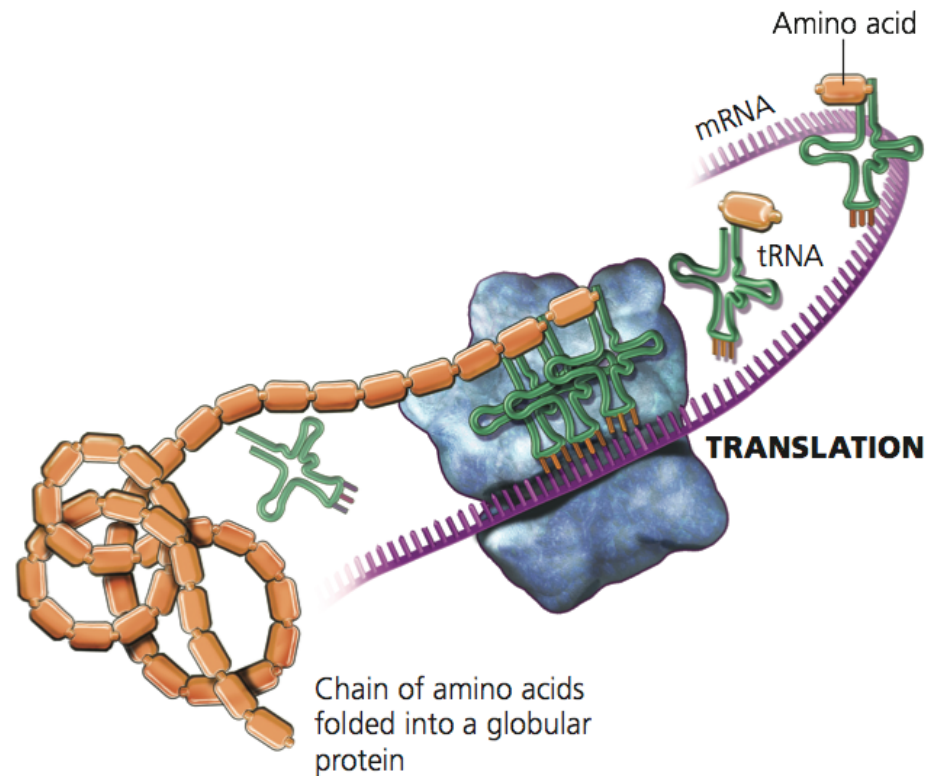
GGU, GGC, GGA and GGG will **all** match to Glycine

AGA, AGG will both code for Arginine

Picture from your text of Ribosomes translating mRNA into protein. (purple ribbon of mRNA instead of red ribbon)

		2nd base in Codon				
		U	C	A	G	
1st base in Codon	U	Phe Phe Leu Leu	Ser Ser Ser Ser	Tyr Tyr <b>STOP</b> <b>STOP</b>	Cys Cys <b>STOP</b> Trp	U C A G
	C	Leu Leu Leu Leu	Pro Pro Pro Pro	His His Gln Gln	Arg Arg Arg Arg	U C A G
	A	Ile Ile Ile Met	Thr Thr Thr Thr	Asn Asn Lys Lys	Ser Ser Arg Arg	U C A G
	G	Val Val Val Val	Ala Ala Ala Ala	Asp Asp Glu Glu	Gly Gly Gly Gly	U C A G
		3rd base in Codon				

Start



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*(and HGT)*
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4. Making proteins!
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- 5. Gene regulation!**
6. Sizing up the Genome
7. Mutations
8. Mitosis and Meiosis (*sexual reproduction*)
9. Mendel and Punnett Squares

**Now we get to the fun stuff!**

**5. Gene regulation!**