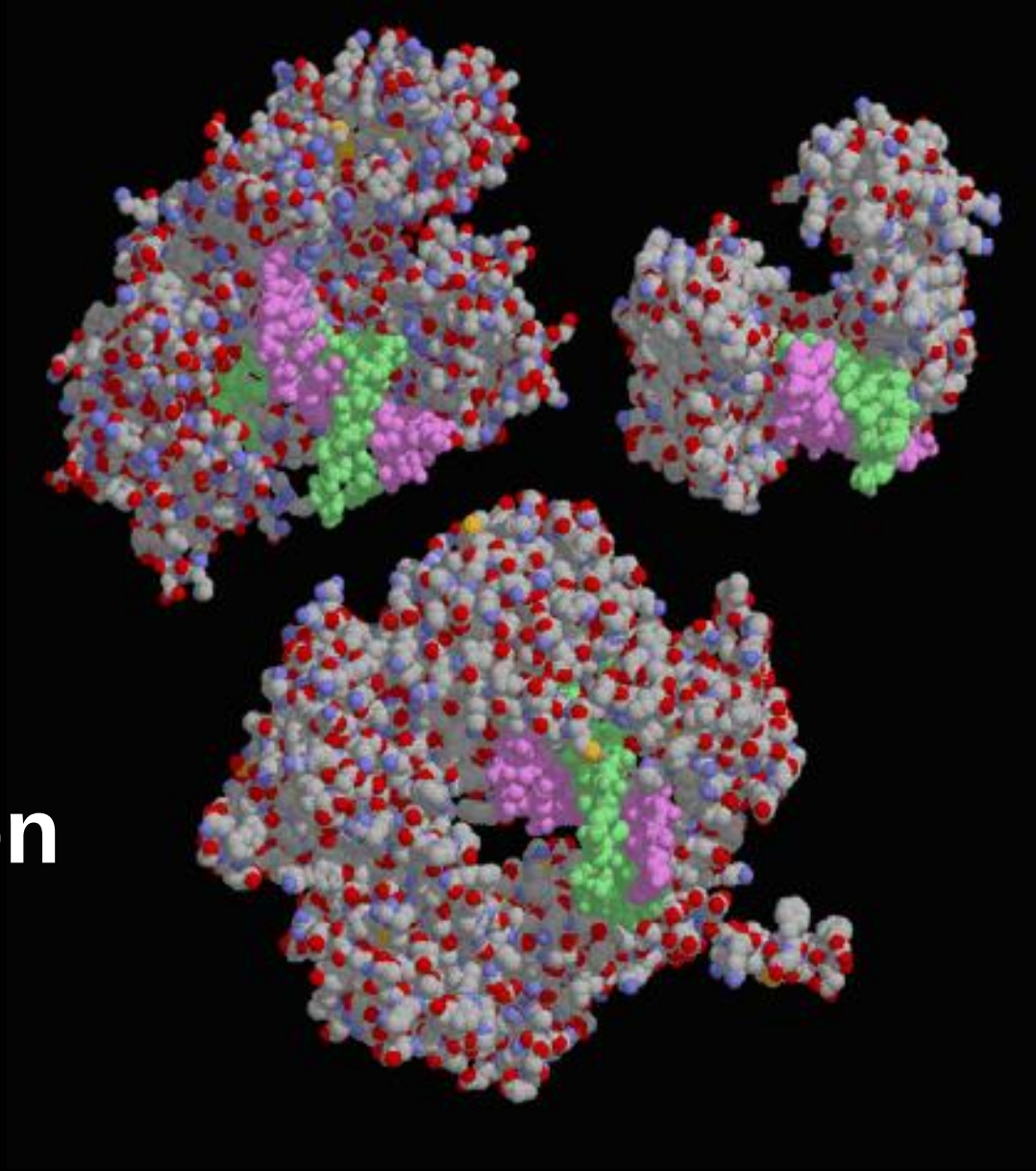
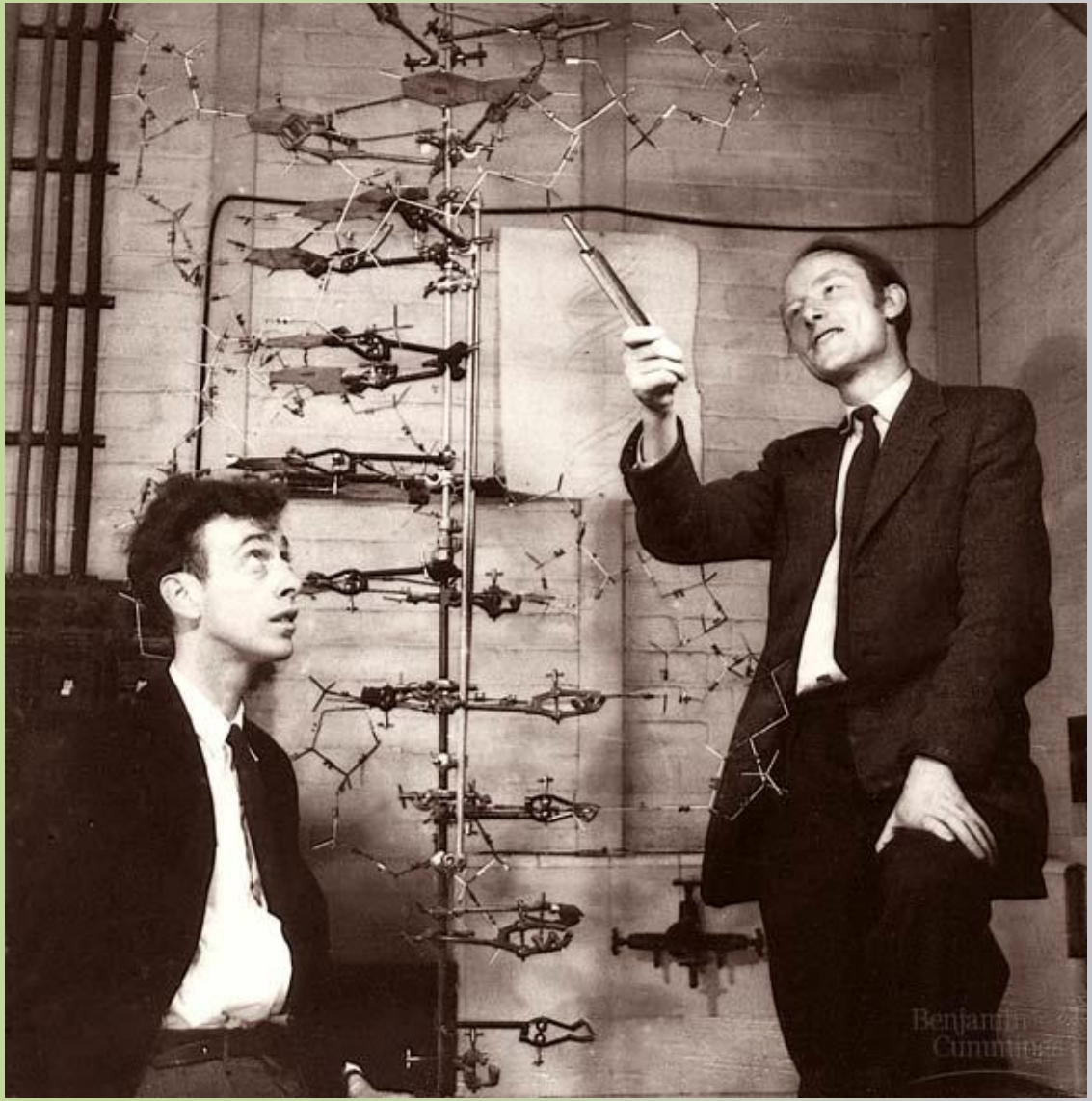
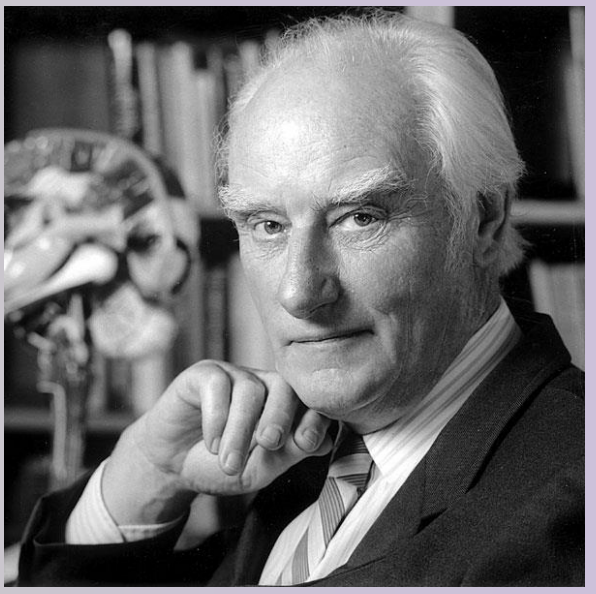
DNA Replication
Ch. 12



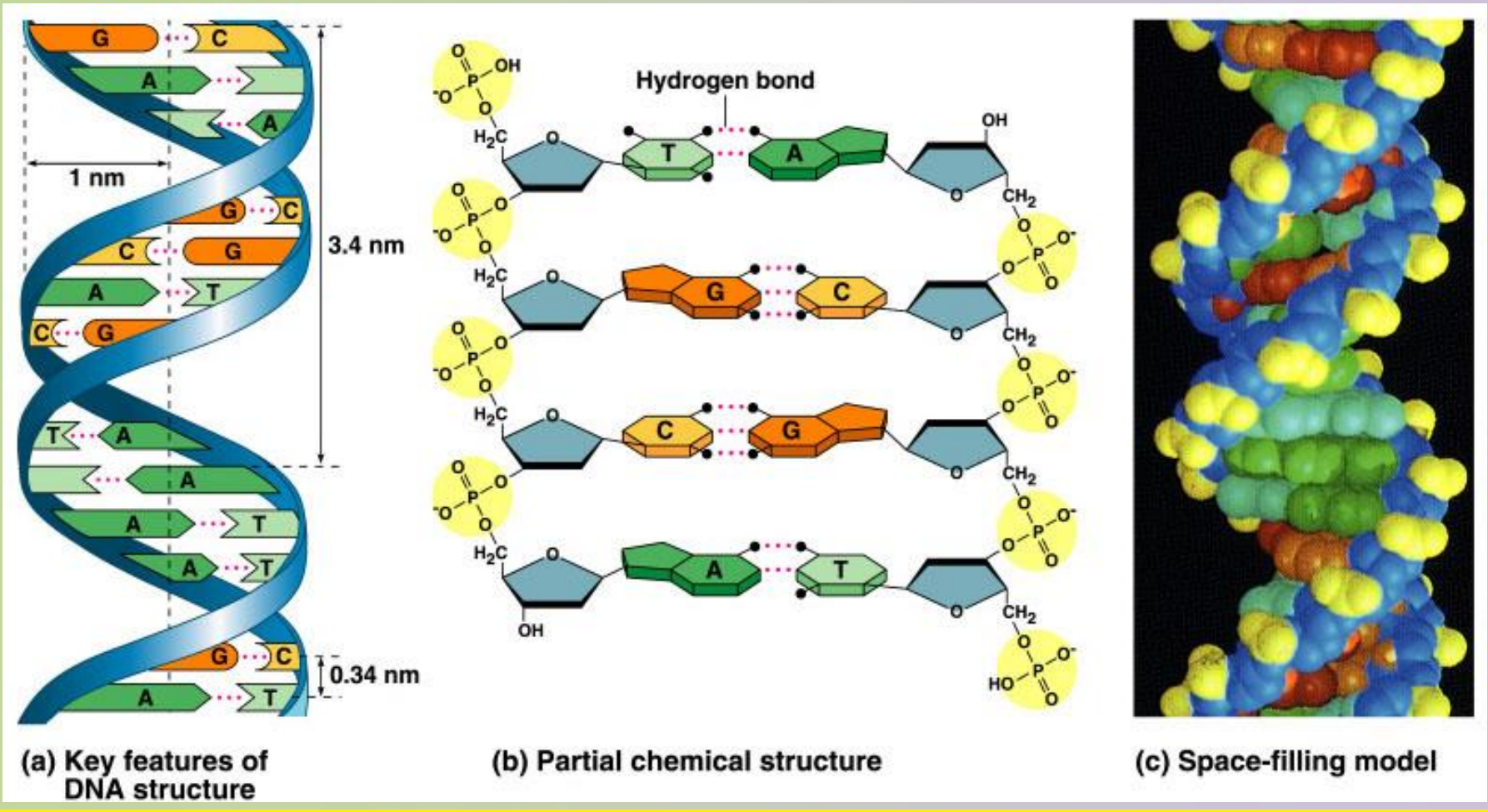
Watson and Crick

1953 article in Nature





Double helix structure of DNA

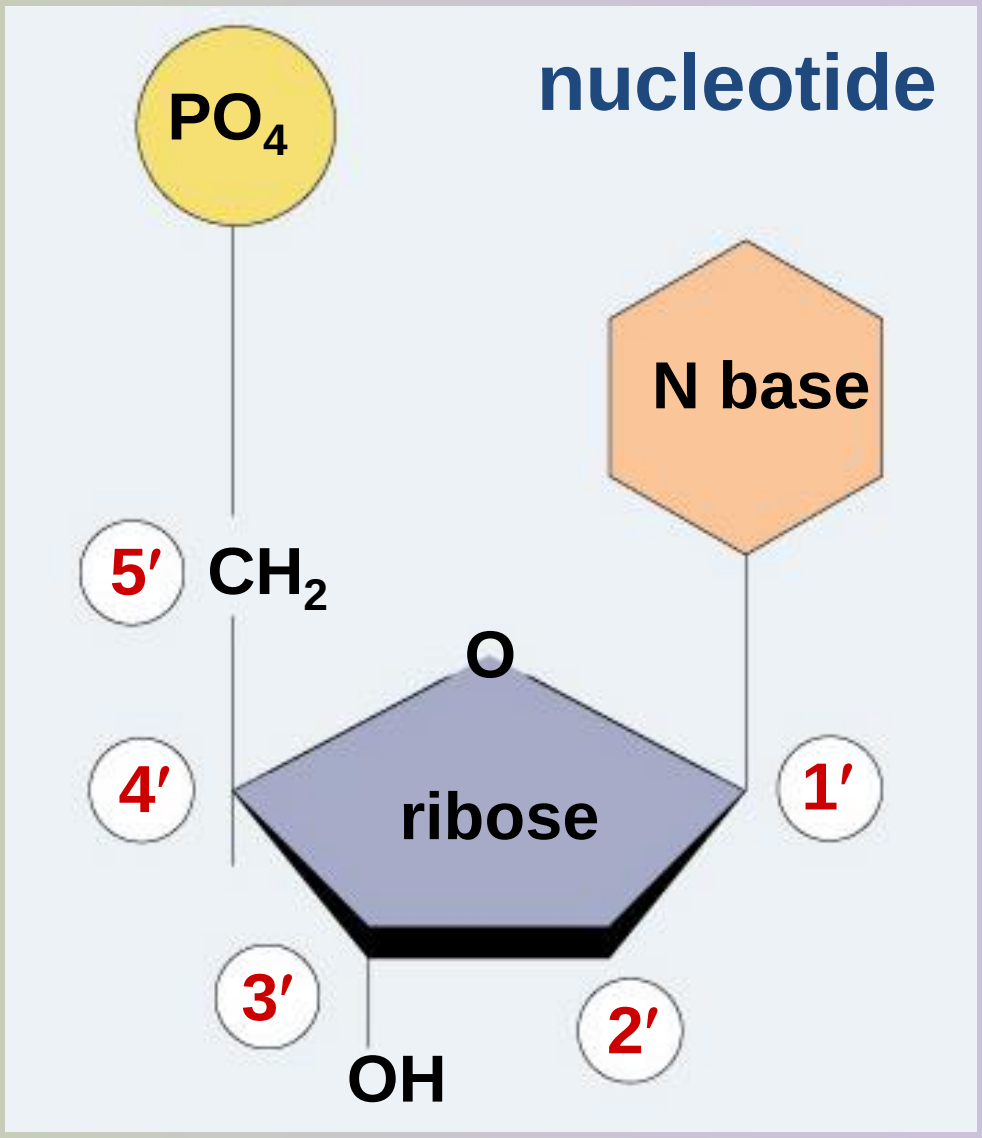


"It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material."

Watson & Crick

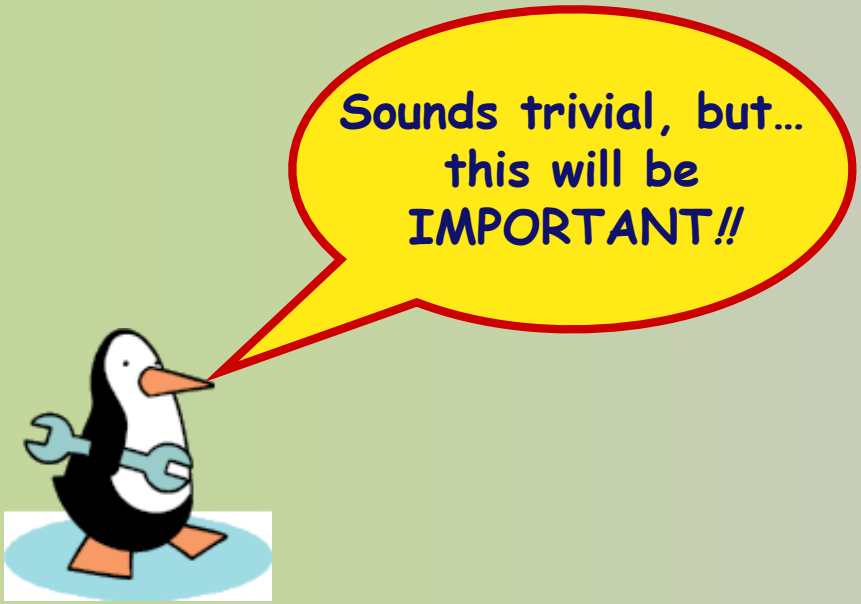
Directionality of DNA

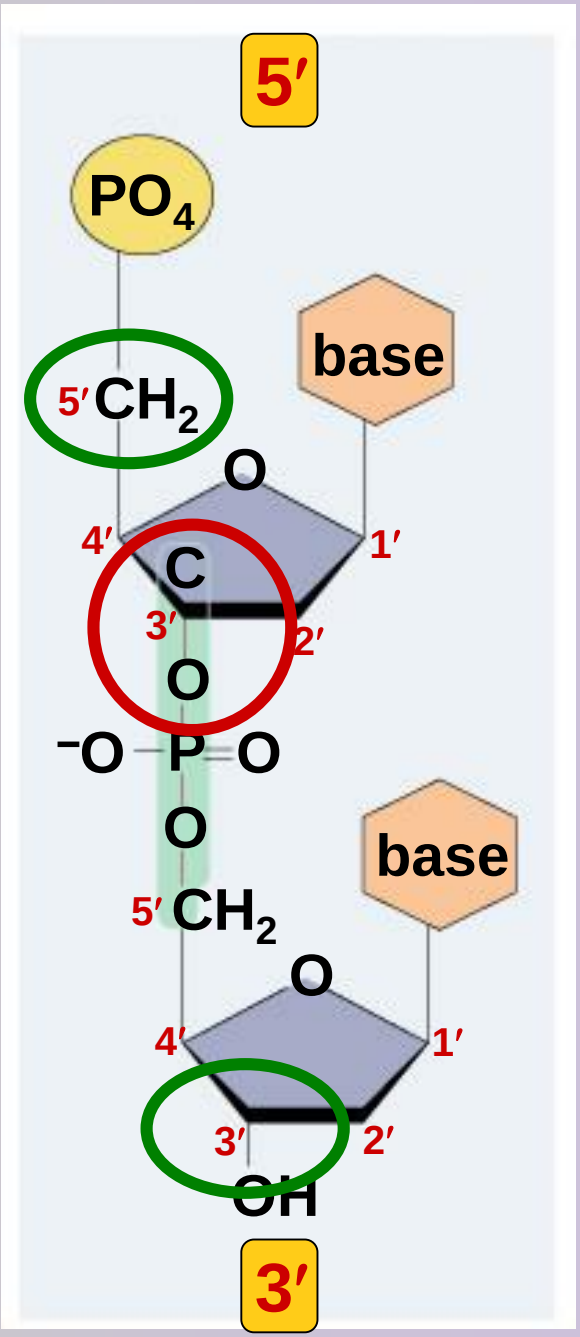
- You need to number the carbons!
  - it matters!



The DNA backbone

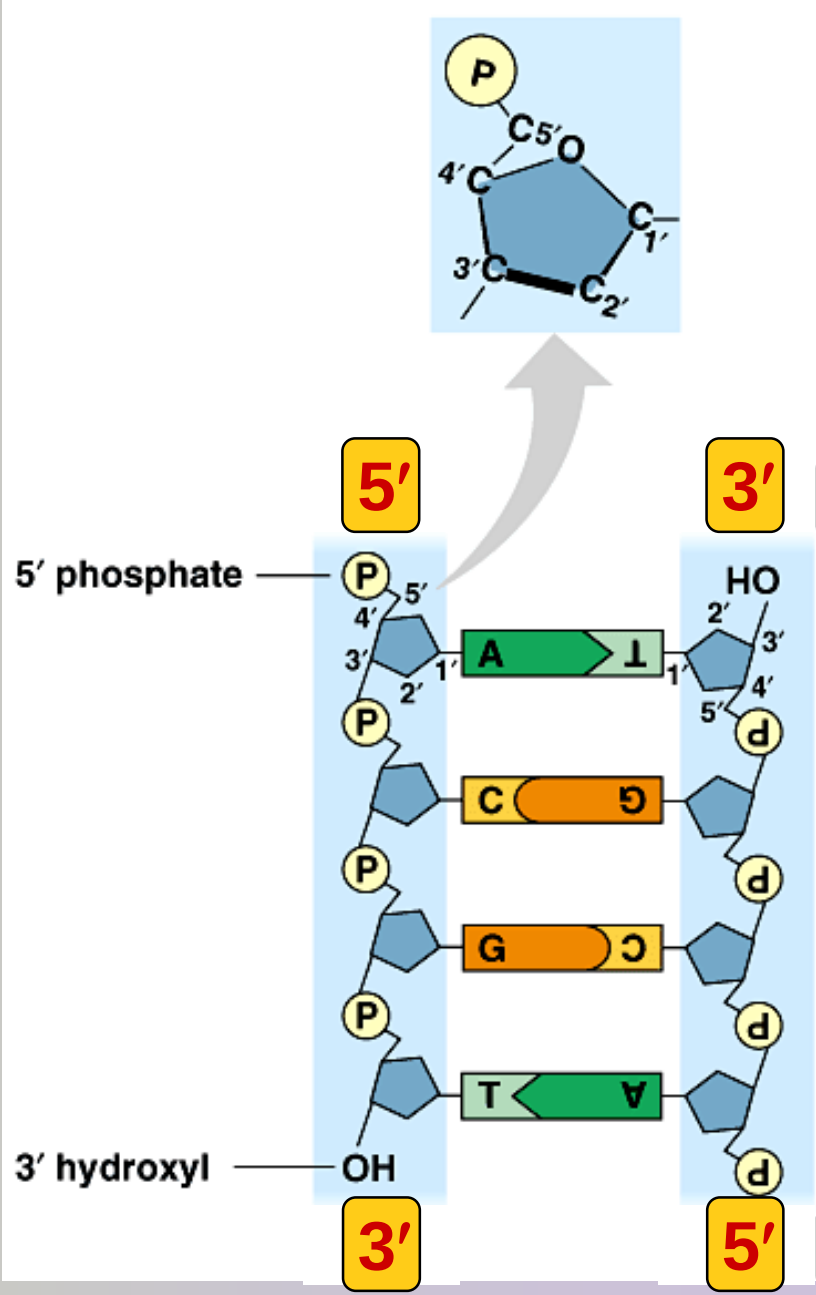
- Putting the DNA backbone together
  - refer to the 3′ and 5′ ends of the DNA
    - the last trailing carbon



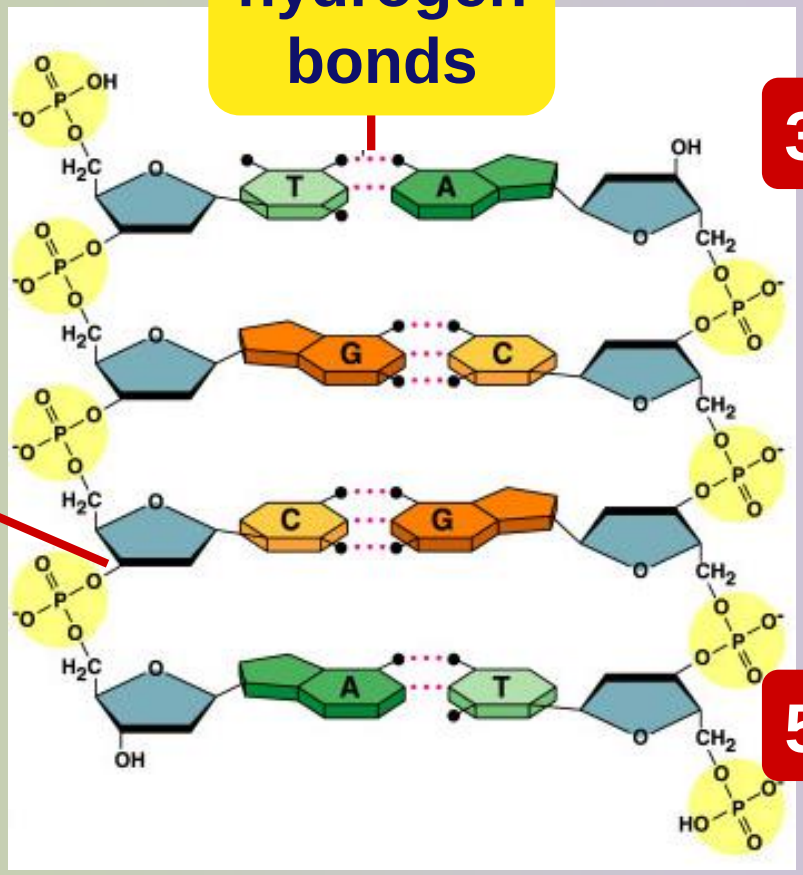


Anti-parallel strands

- Nucleotides in DNA backbone are bonded from phosphate to sugar between 3′ & 5′ carbons
  - DNA molecule has “direction”
  - complementary strand runs in opposite direction



Bonding in DNA

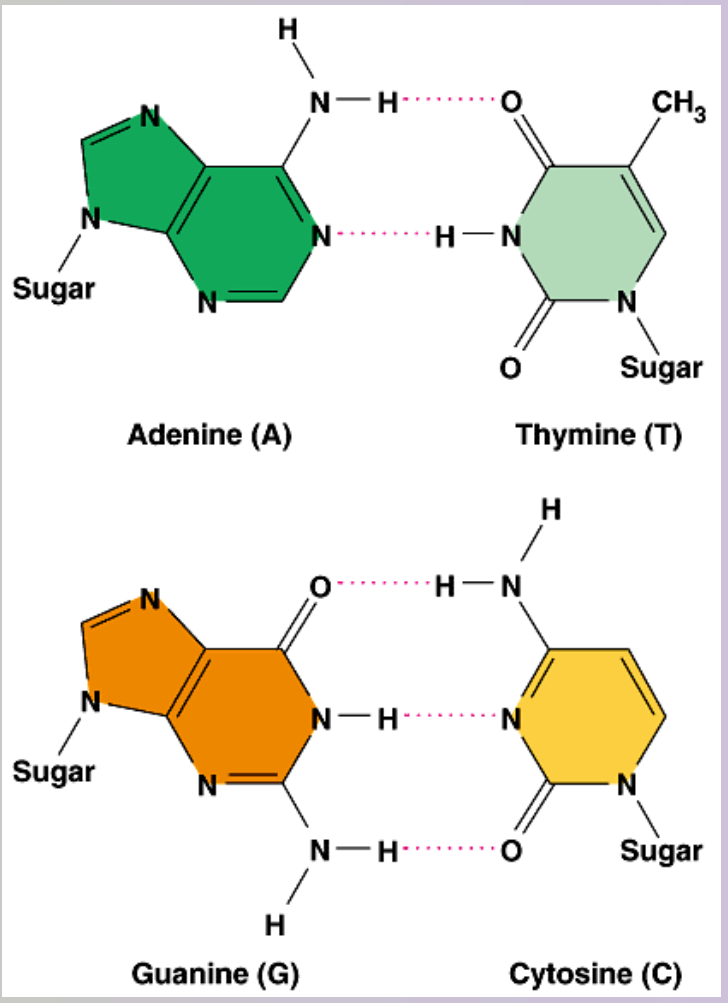


….strong or weak bonds?

How do the bonds fit the mechanism for copying DNA?

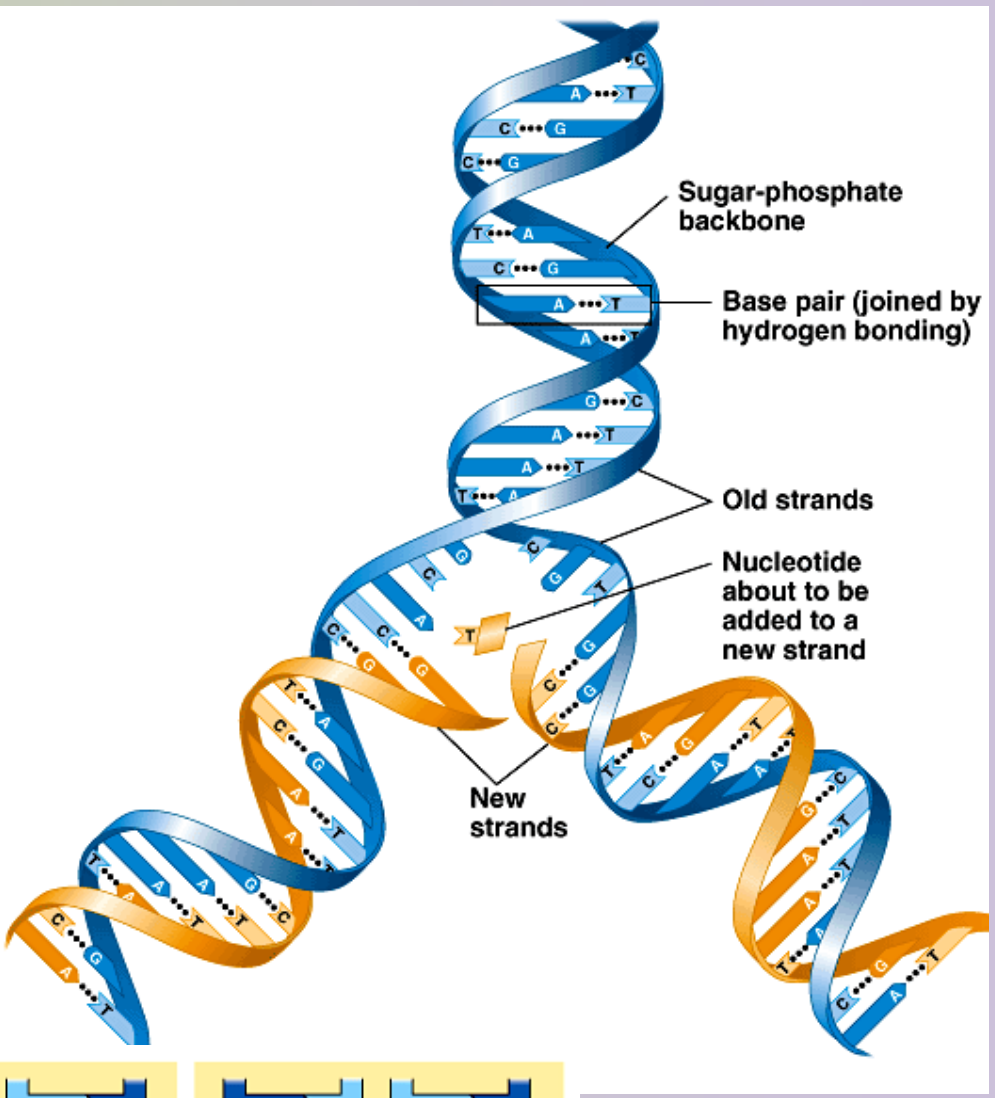
Base pairing in DNA

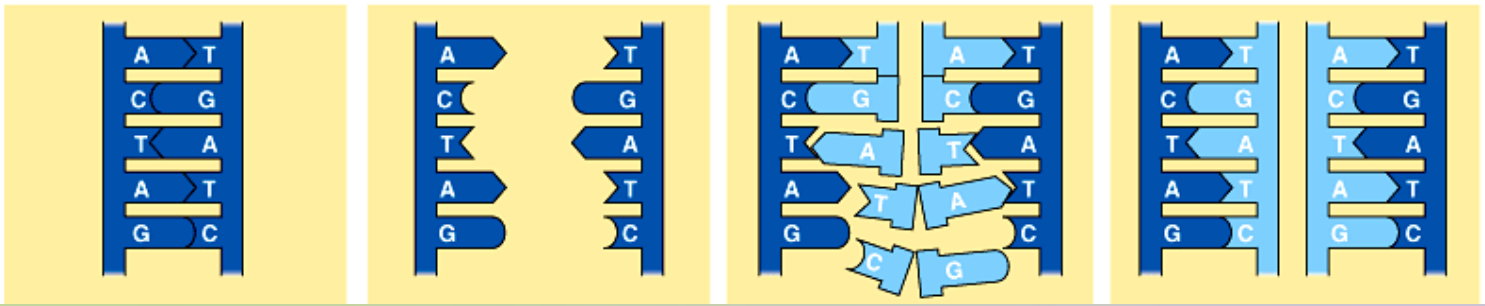
- Purines
  - adenine (A)
  - guanine (G)
- Pyrimidines
  - thymine (T)
  - cytosine (C)
- Pairing
  - A : T
    - 2 bonds
  - C : G
    - 3 bonds



Copying DNA

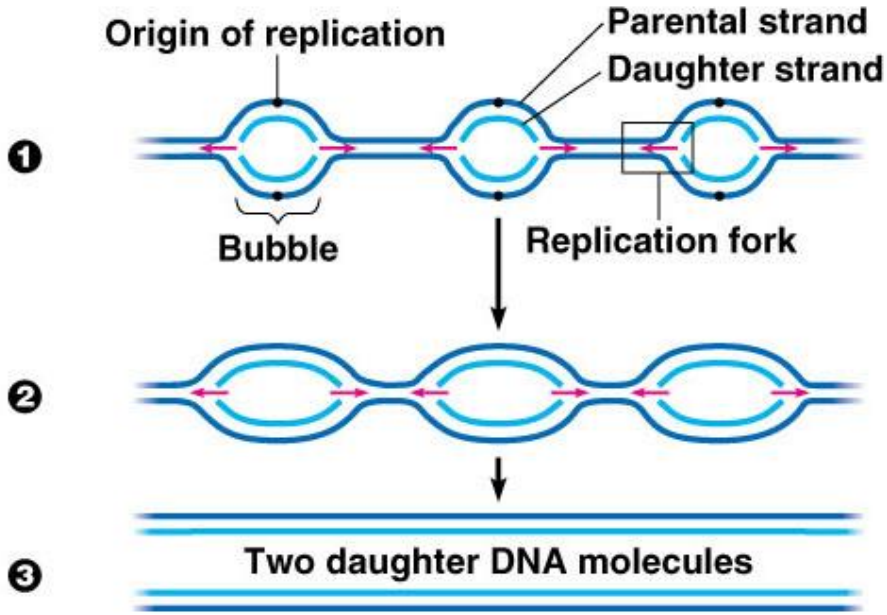
- Replication of DNA
  - base pairing allows each strand to serve as a template for a new strand
  - new strand is 1/2 parent template & 1/2 new DNA
    - semi-conservative copy process



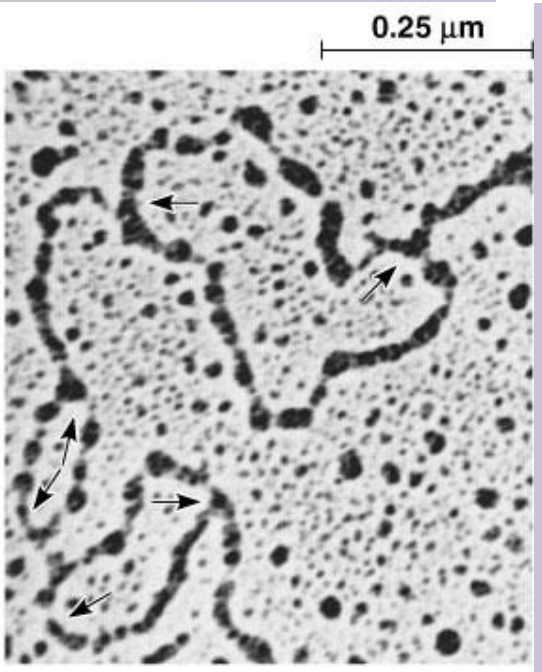


DNA Replication

- Large team of enzymes coordinates replication



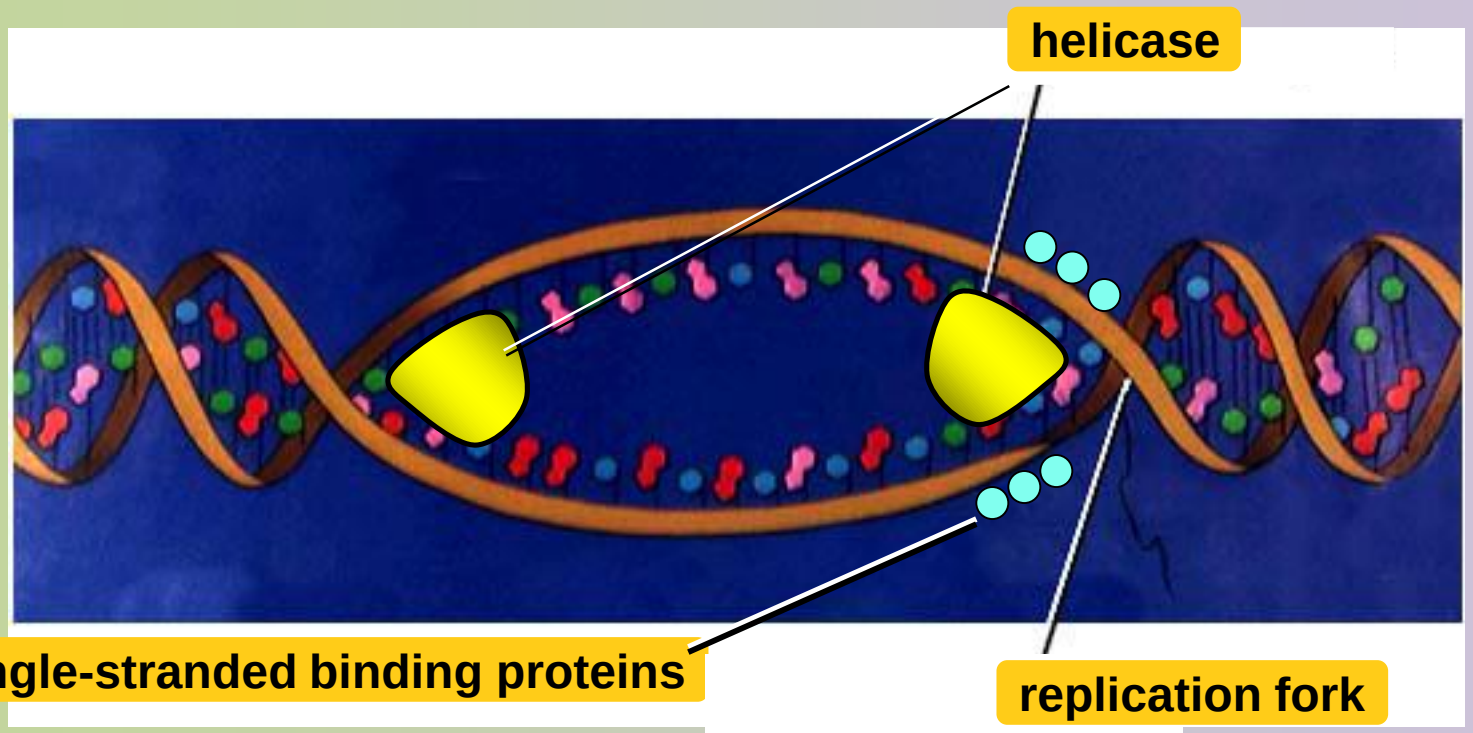
(a) In eukaryotes, DNA replication begins at many sites along the giant DNA molecule of each chromosome.



(b) In this micrograph, three replication bubbles are visible along the DNA of cultured Chinese hamster cells. The arrows indicate the direction of DNA replication at the two ends of each bubble (TEM).

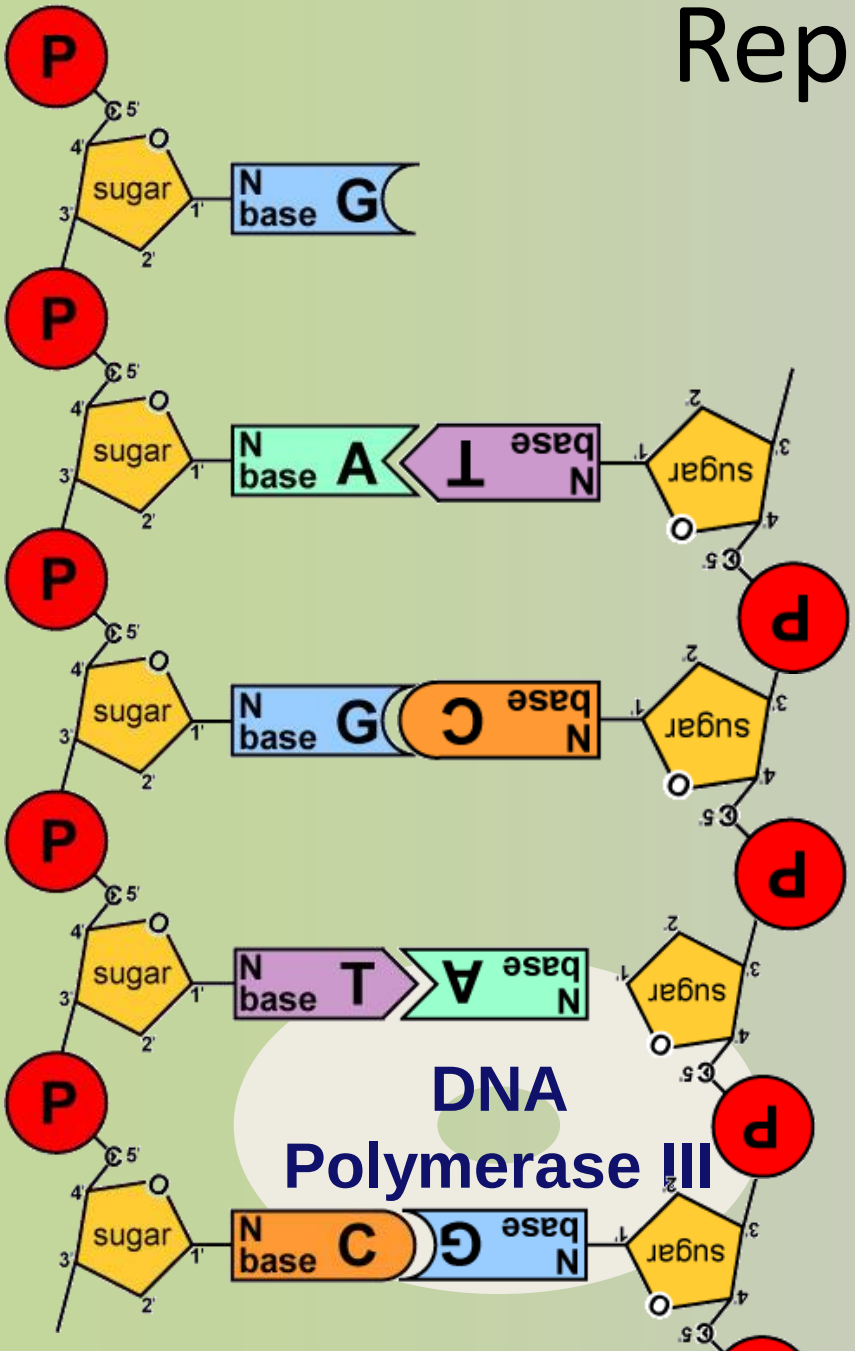
Replication: 1st step

- Unwind DNA
  - helicase enzyme
    - unwinds part of DNA helix
    - stabilized by single-stranded binding proteins



Replication: 2nd step

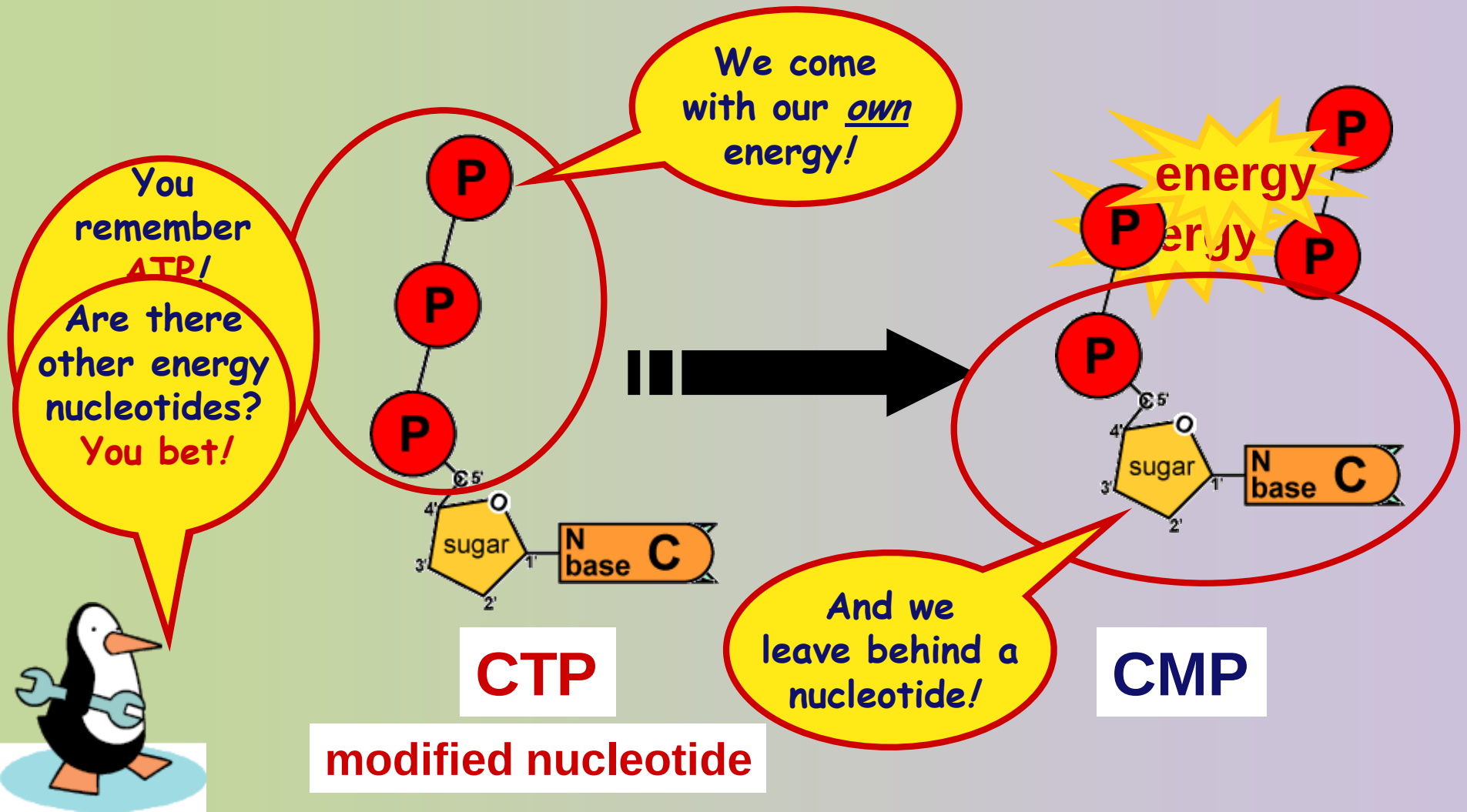
- **Build daughter DNA strand**
  - **add new complementary bases**
  - **DNA polymerase III**



Where's the *ENERGY* for the bonding!

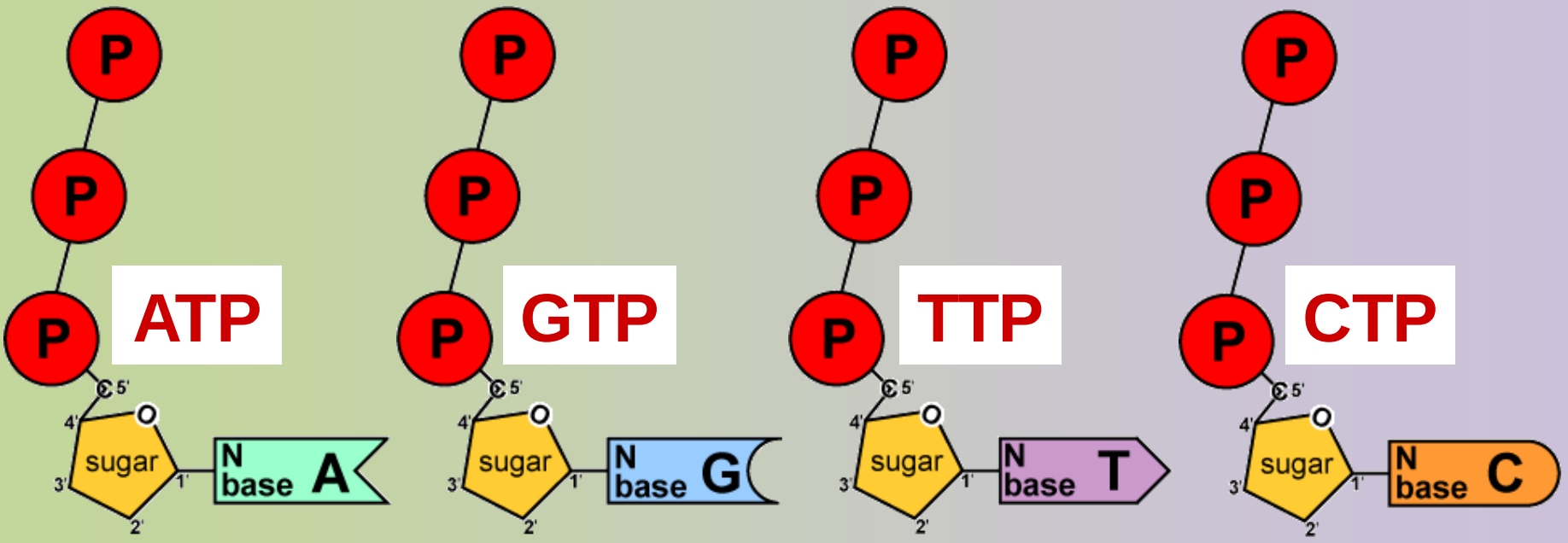
Energy of Replication

Where does energy for bonding *usually* come from?



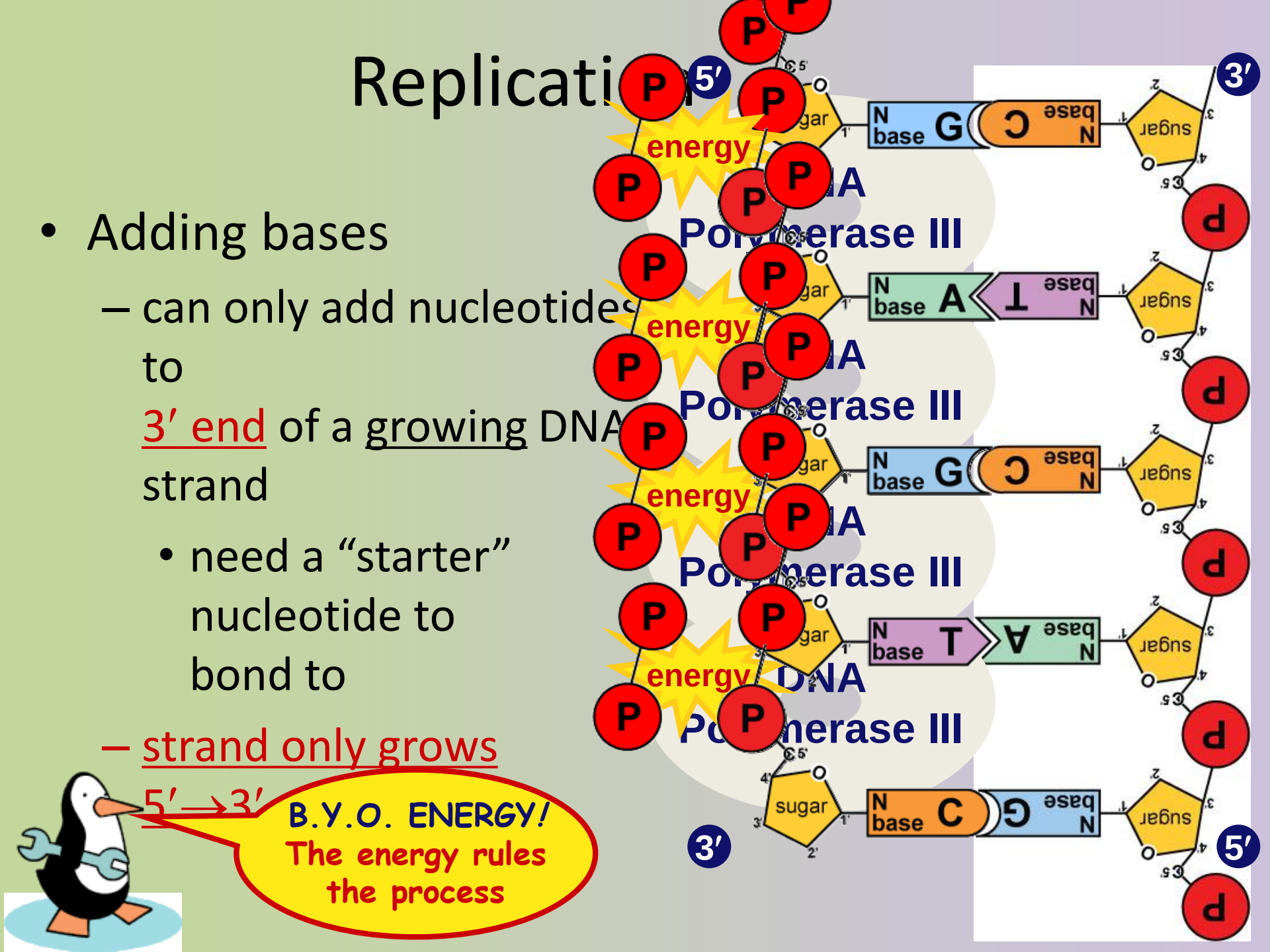
Energy of Replication

- The nucleotides arrive as nucleosides
  - DNA bases with P–P–P
    - P-P-P = energy for bonding
  - DNA bases arrive with their own energy source for bonding
  - bonded by enzyme: DNA polymerase III



Replicati

- Adding bases
  - can only add nucleotides to 3′ end of a growing DNA strand
    - need a “starter” nucleotide to bond to
  - strand only grows 5′→3′



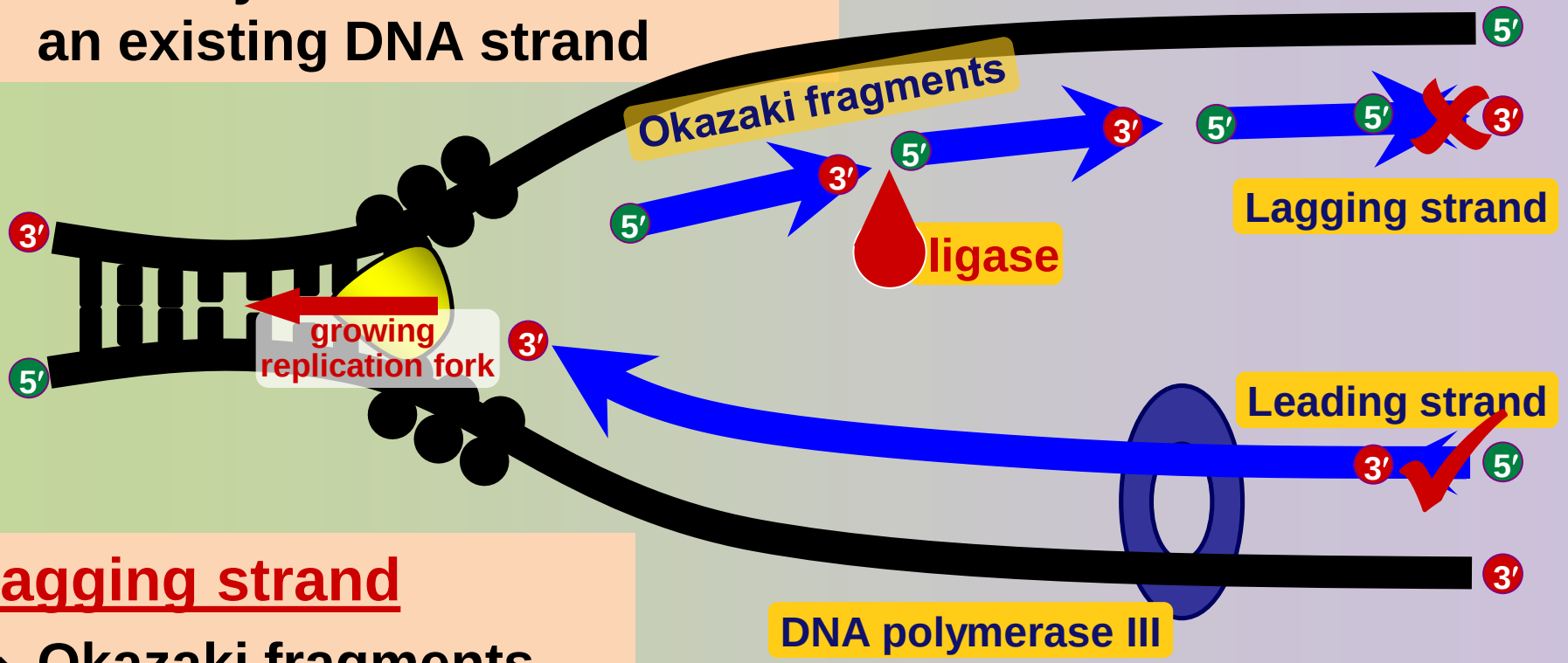
B.Y.O. ENERGY!
The energy rules the process

Okazaki

Leading & Lagging strands

Limits of DNA polymerase III

- can only build onto 3′ end of an existing DNA strand



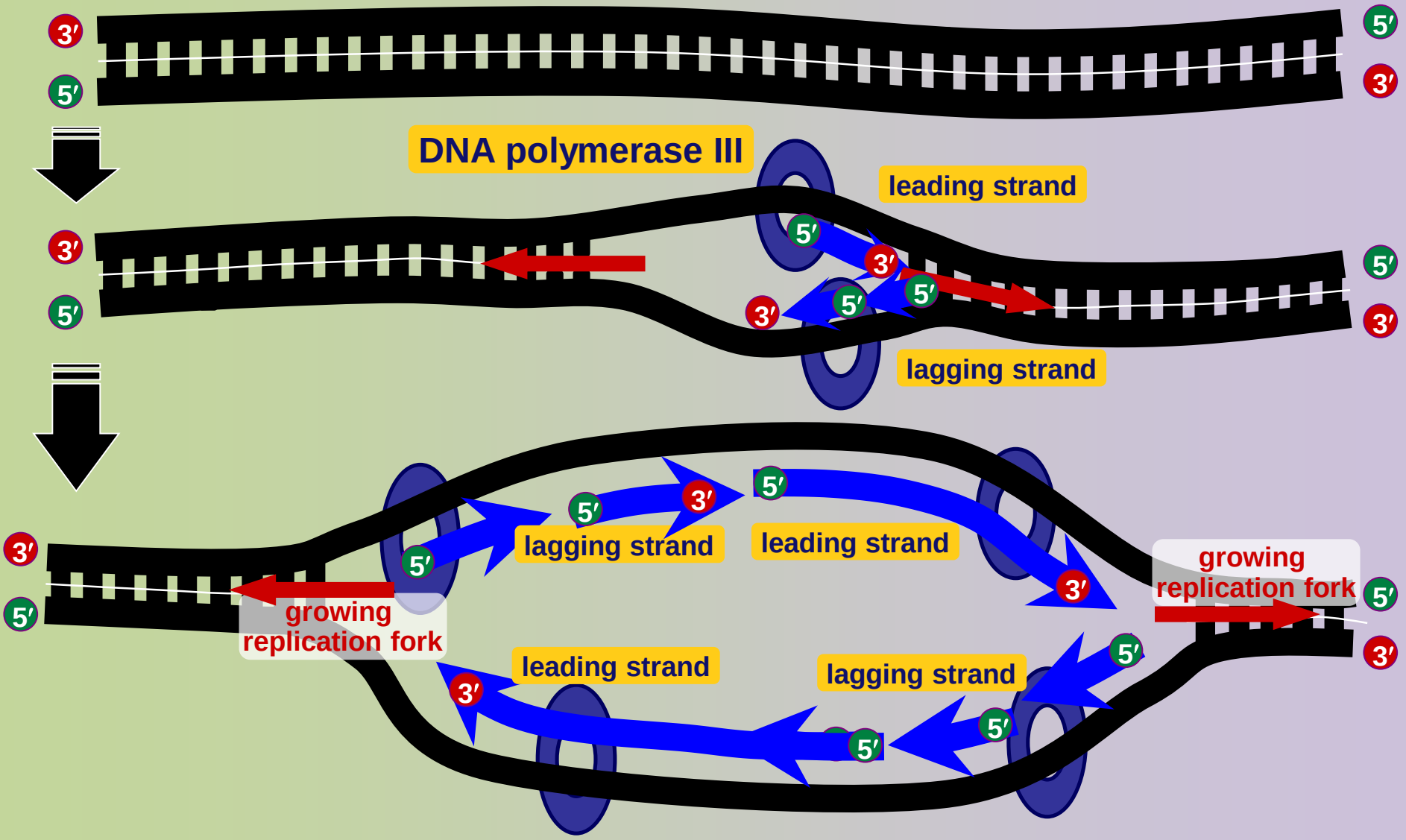
Lagging strand

- Okazaki fragments
- joined by ligase
  - "spot welder" enzyme

Leading strand

- continuous synthesis

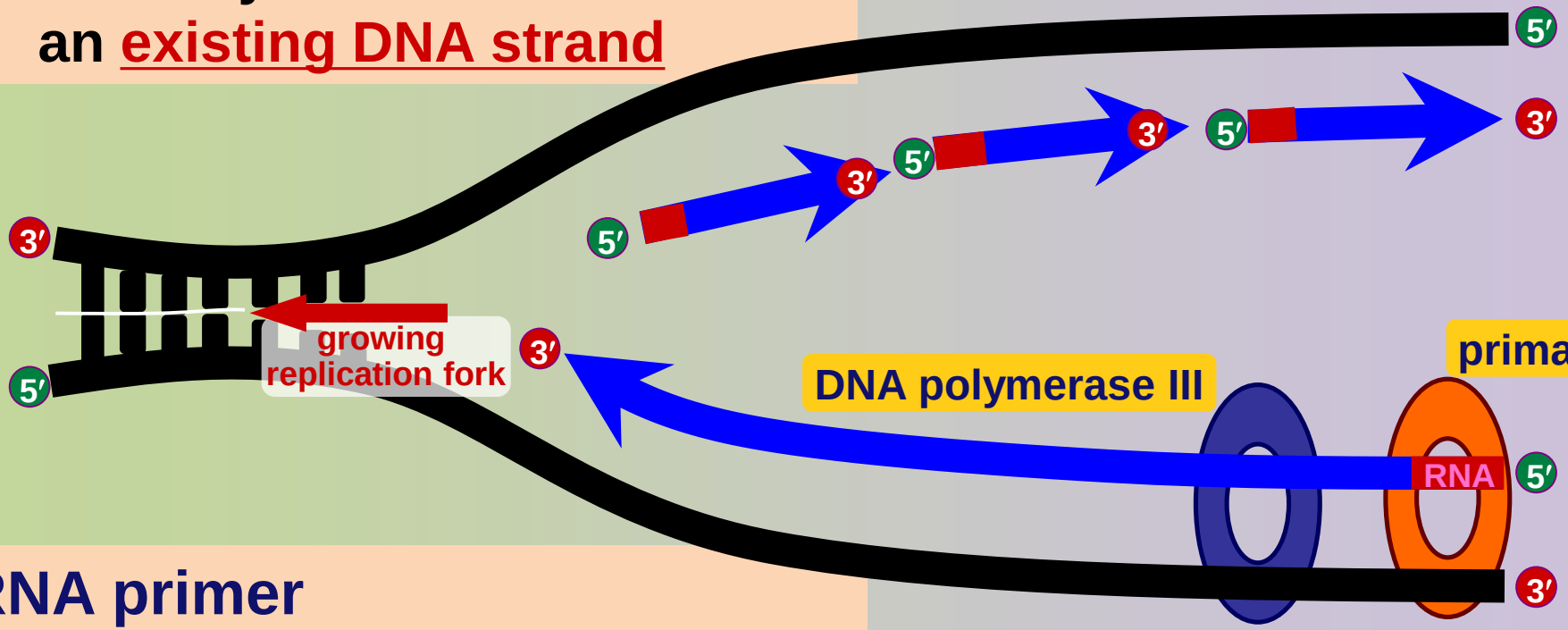
Replication fork / Replication bubble



Starting DNA synthesis: RNA primers

Limits of DNA polymerase III

- can only build onto 3′ end of an existing DNA strand



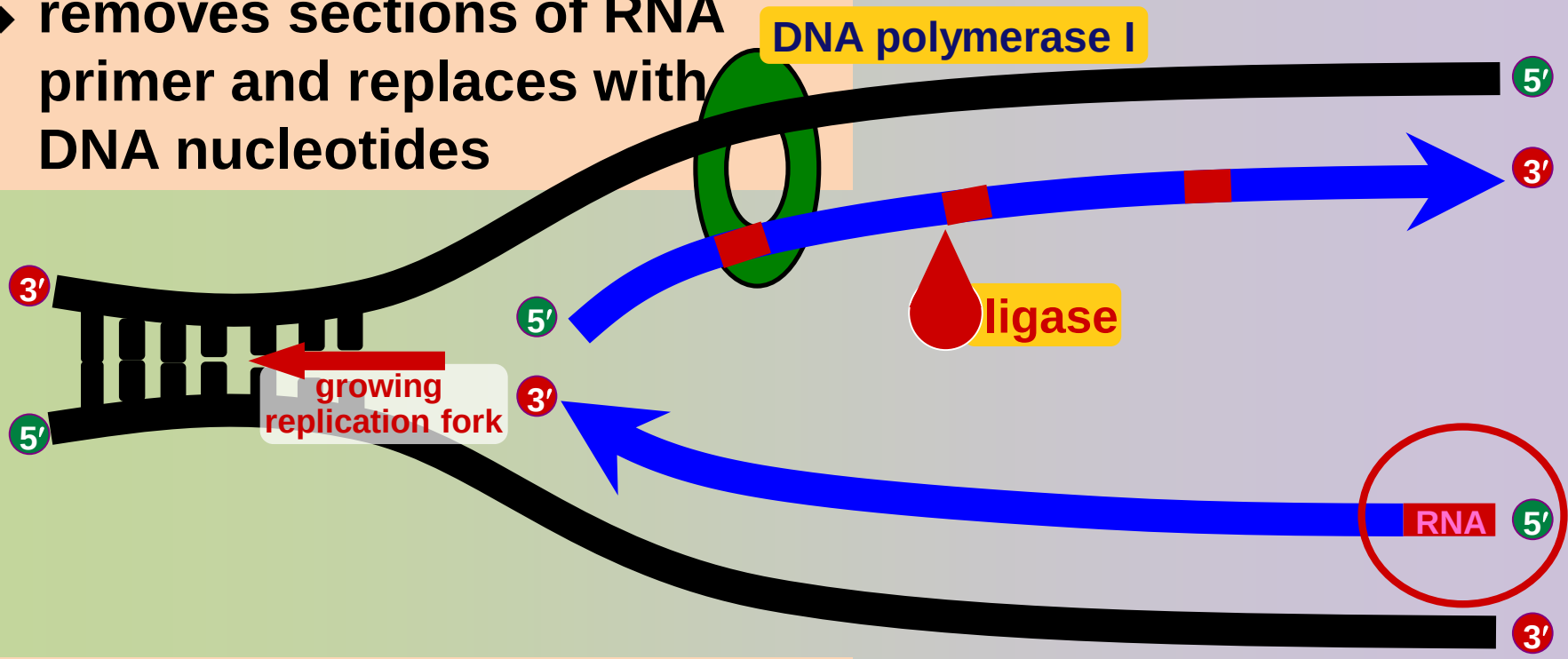
RNA primer

- built by primase
- serves as starter sequence for DNA polymerase III

Replacing RNA primers with DNA

DNA polymerase I

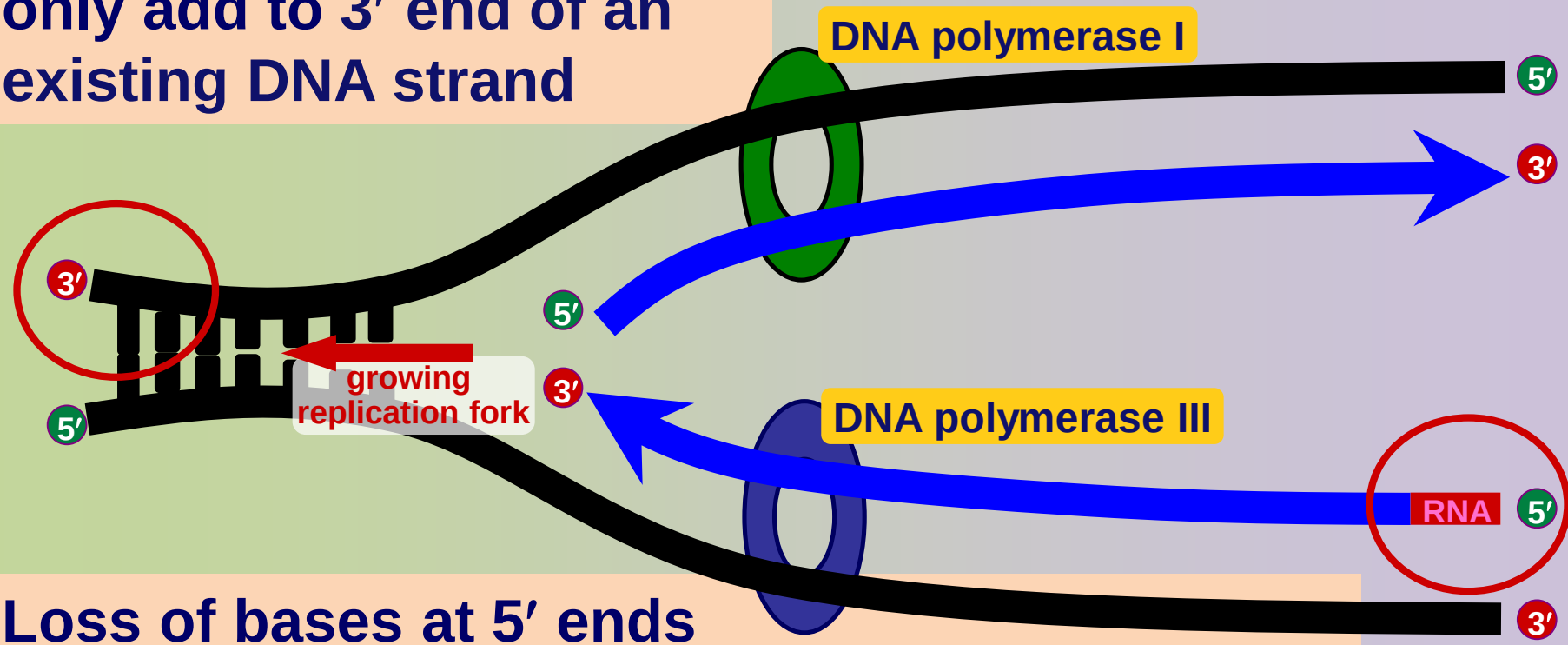
- **removes sections of RNA primer and replaces with DNA nucleotides**



But DNA polymerase I still can only build onto 3′ end of an existing DNA strand

Chromosome erosion

All DNA polymerases can only add to 3′ end of an existing DNA strand



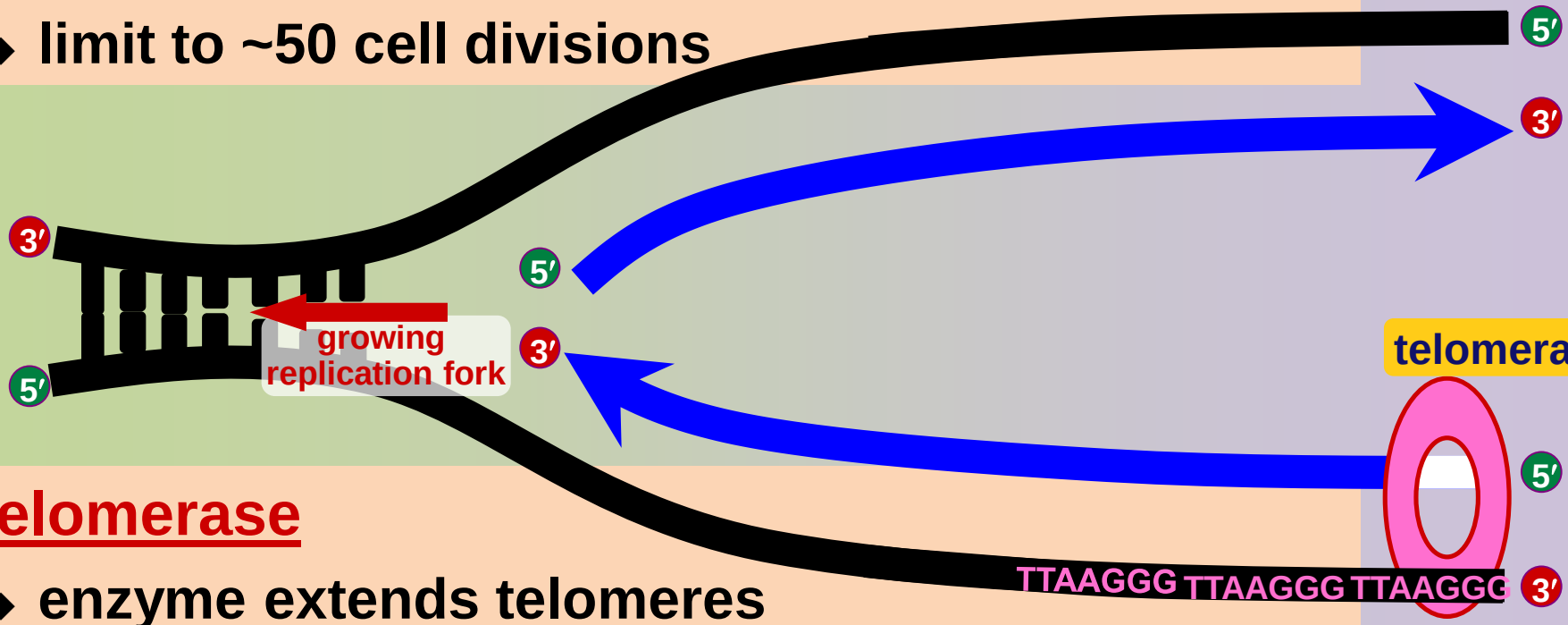
Loss of bases at 5′ ends in every replication

- **chromosomes get shorter with each replication**
- **limit to number of cell divisions?**

Telomeres

Repeating, non-coding sequences at the end of chromosomes = protective cap

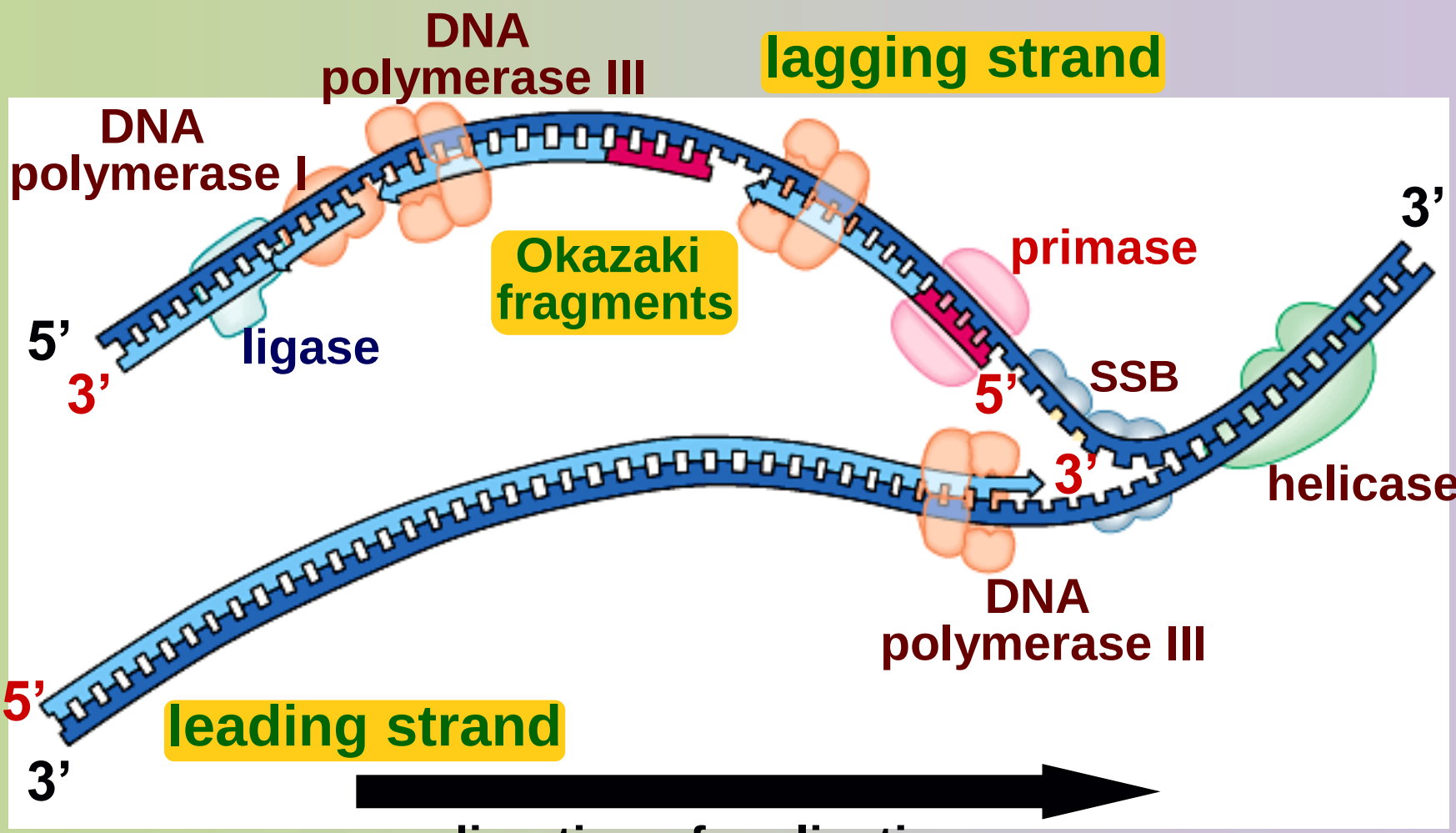
- **limit to ~50 cell divisions**



Telomerase

- **enzyme extends telomeres**
- **can add DNA bases at 5′ end**
- **different level of activity in different cells**
  - **high in stem cells & cancers -- Why?**

Replication fork



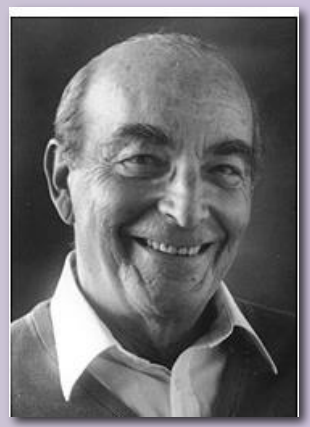
SSB = single-stranded binding proteins

DNA polymerases

- DNA polymerase III
  - 1000 bases/second*!*
  - main DNA builder
- DNA polymerase I
  - 20 bases/second
  - editing, repair & primer removal

Thomas Kornberg

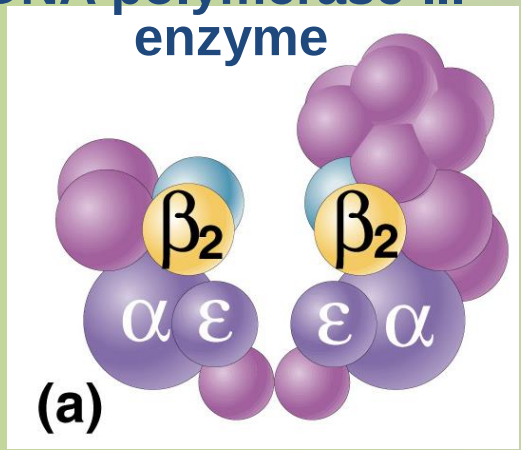
??

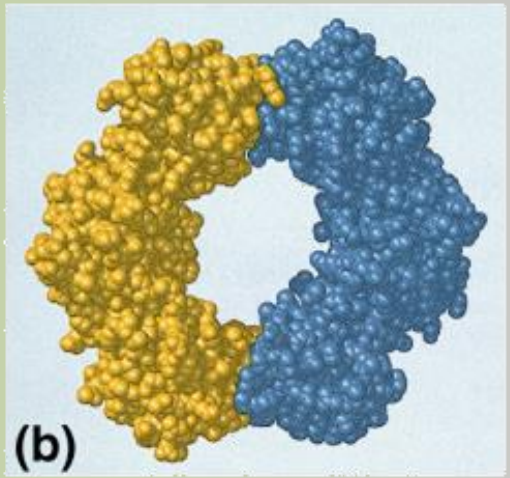


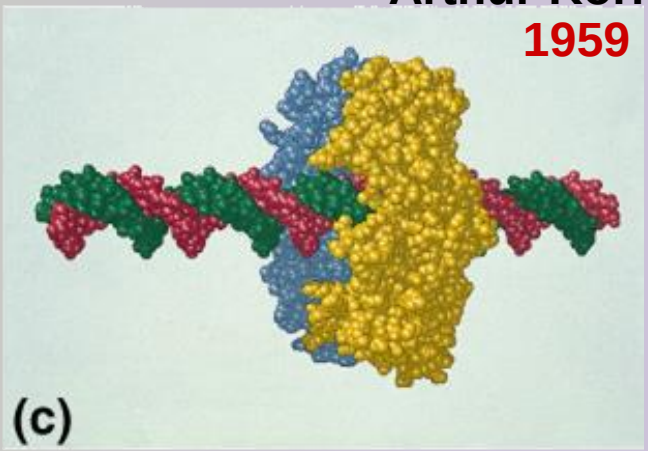
Arthur Kornberg

1959

DNA polymerase III enzyme

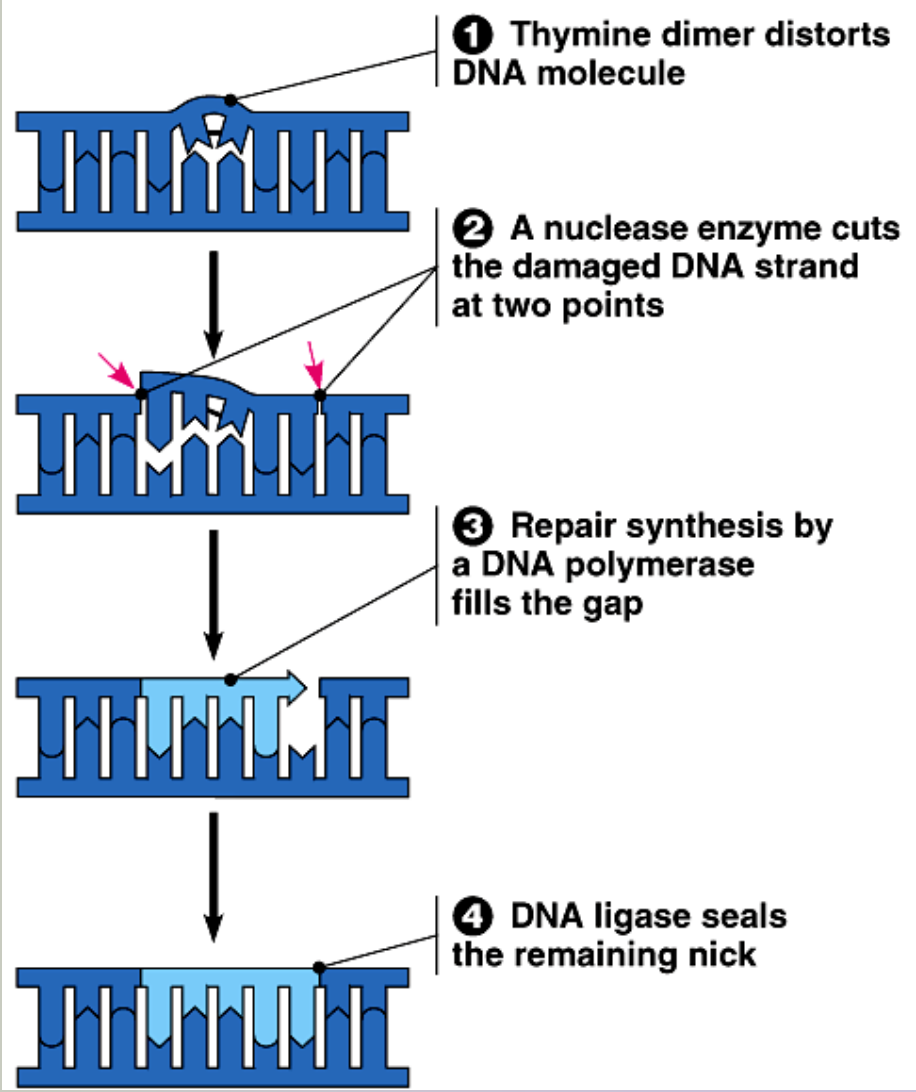






Editing & proofreading DNA

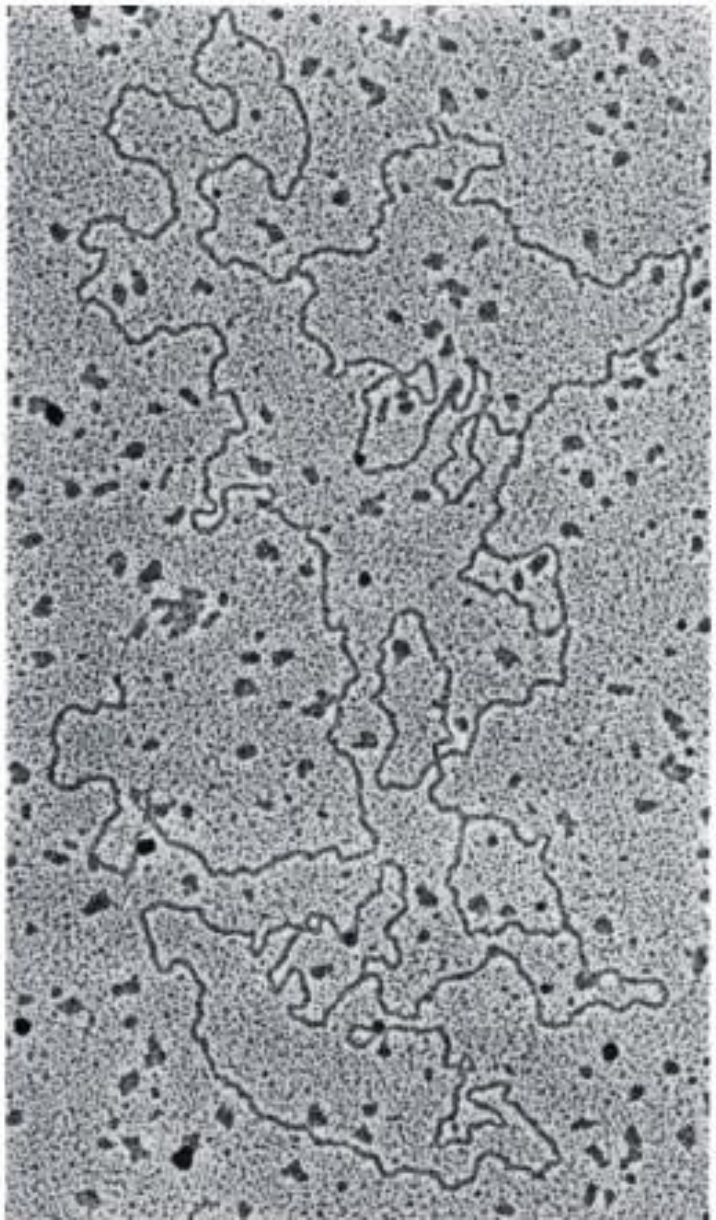
- 1000 bases/second = lots of typos!
- DNA polymerase I
  - proofreads & corrects typos
  - repairs mismatched bases
  - removes abnormal bases
    - repairs damage throughout life
  - reduces error rate from 1 in 10,000 to 1 in 100 million bases



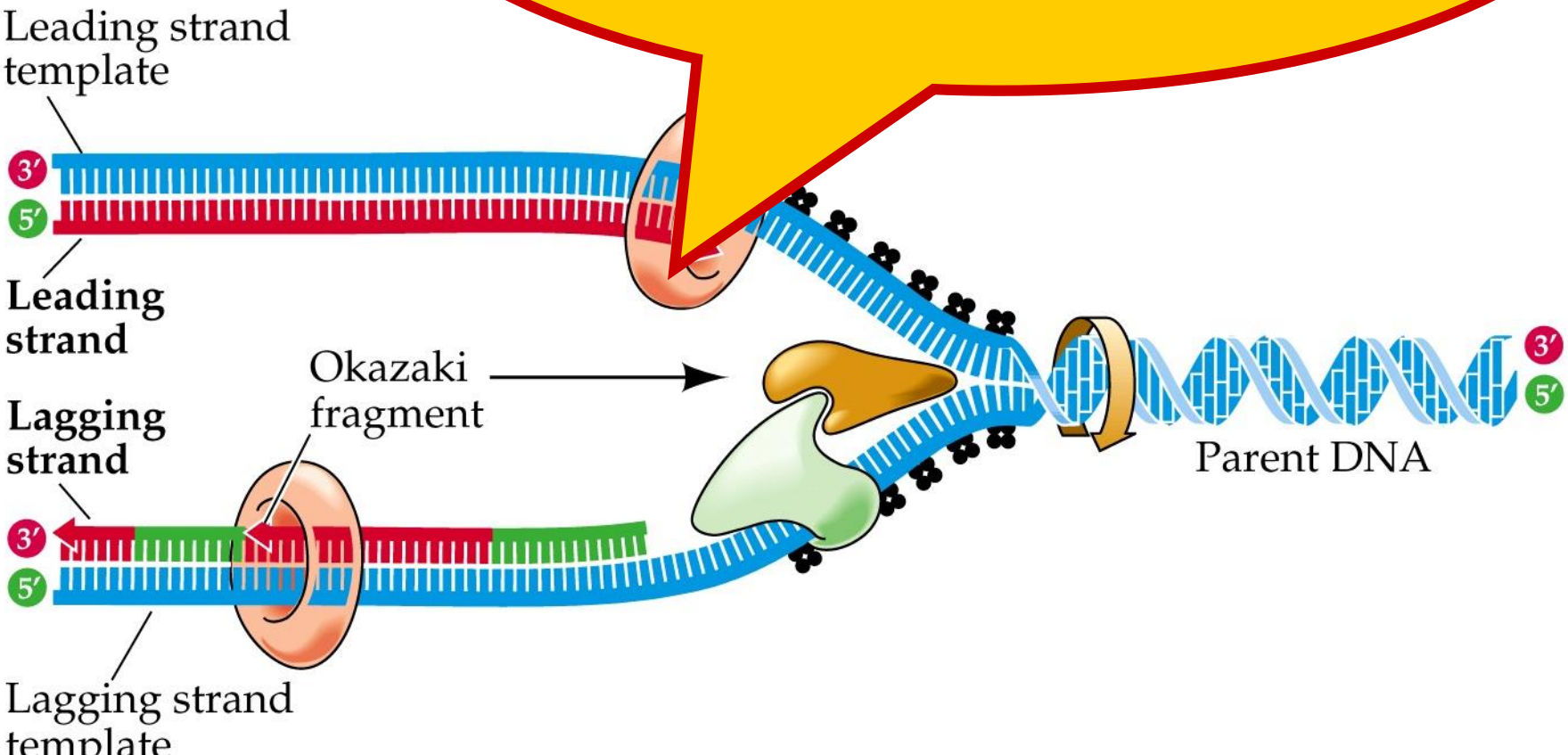
Fast & accurate!

- It takes *E. coli* <1 hour to copy
  5 million base pairs in its single chromosome
  - divide to form 2 identical daughter cells
- Human cell copies 6 billion bases & divide into daughter cells in only few hours
  - remarkably accurate
  - only ~1 error per 100 million bases
  - ~30 errors per cell cycle

What does it really look like?



Any Questions??



Review Questions

Base your answers to the following questions on the choices below:

A. Helicase
B. Polymerase
C. Ligase
D. Primase

1. Brings together the Okazaki fragments.
2. Adds nucleotides to the leading strand.
3. Recognizes the origin of replication in the DNA.

4. In DNA synthesis, DNA is
   A. Read 3’ to 5’ and made 5’ to 3’
   B. Read 3’ to 5’ and made 3’ to 5’
   C. Read 5’ to 3’ and made 3’ to 5’
   D. Read 5’ to 3’ and made 5’ to 3;