


The background of the slide is a light gray gradient with several realistic water droplets of various sizes scattered across it. The droplets have highlights and shadows, giving them a three-dimensional appearance. They are located in the top left, top center, and bottom right areas of the slide.

# MOLECULAR INVENTIONS AND THE TREE OF LIFE

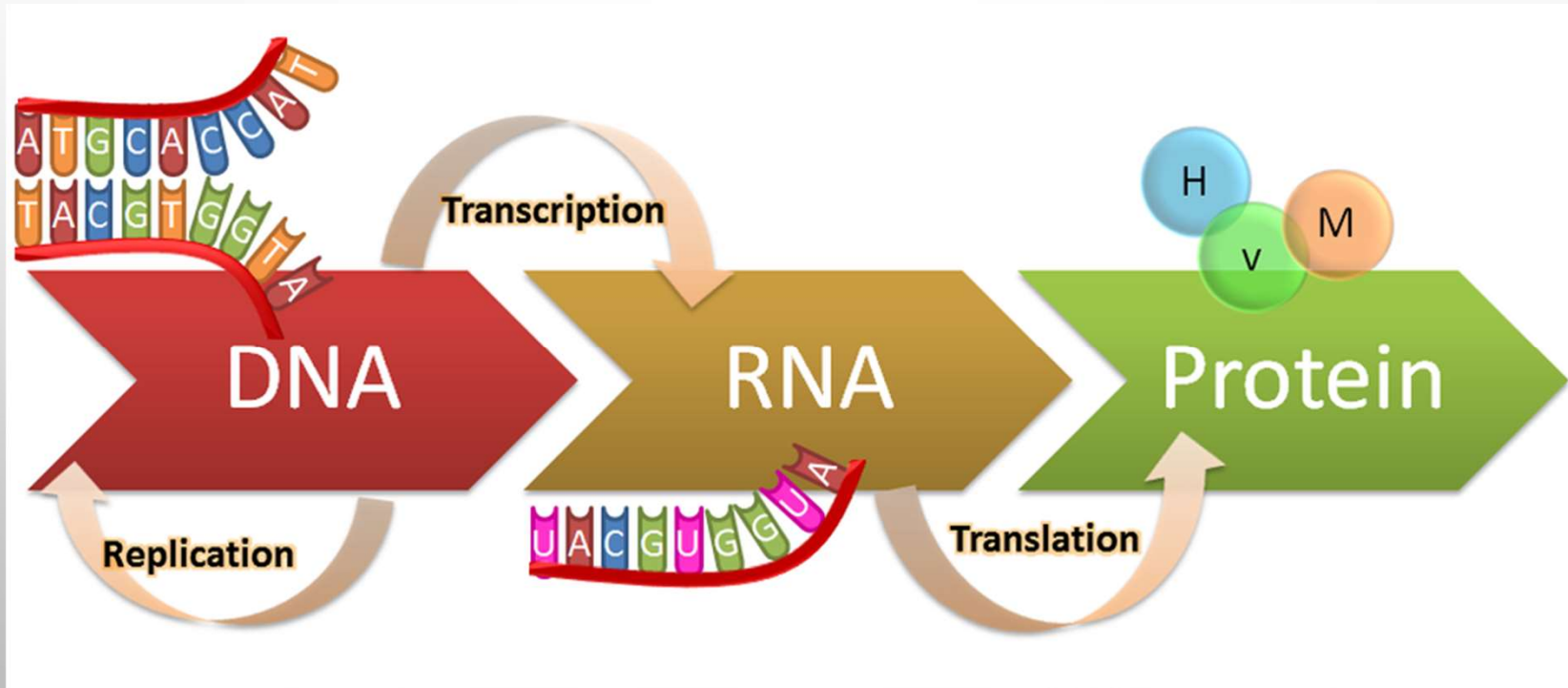
SPRING 2024



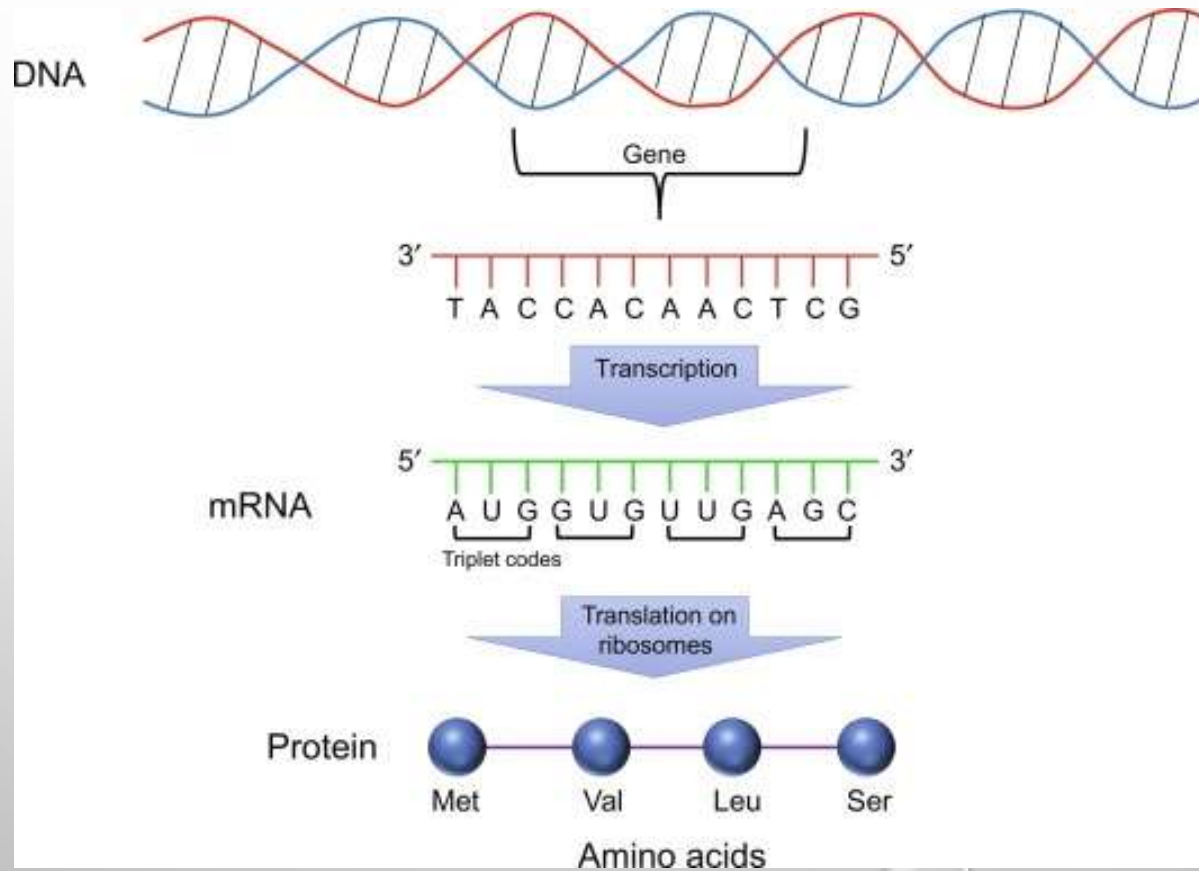
# THE ESSENTIALS OF LIFE

- HIGH LEVELS OF ORGANIZATION
  - A SOURCE OF ENERGY TO COUNTERACT ENTROPY
  - CLEAR BOUNDARIES BETWEEN THE LIVING ENTITY AND THE ENVIRONMENT
  - INFORMATION SYSTEMS
  - REPRODUCTION AND BUILT-IN VARIATION
  - EVOLUTION
- 

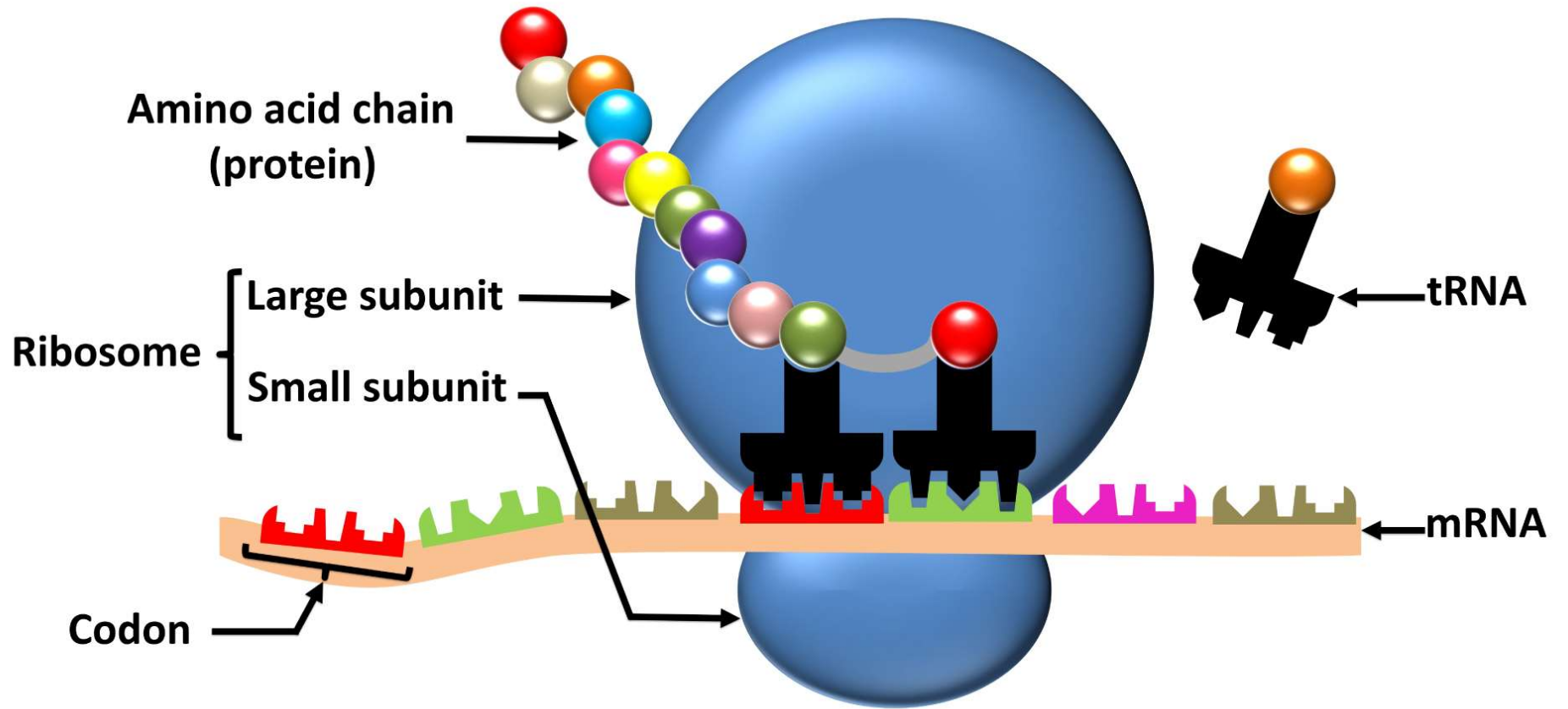
# THE INFORMATION HIGHWAY: FROM CODE TO CELLULAR FUNCTION



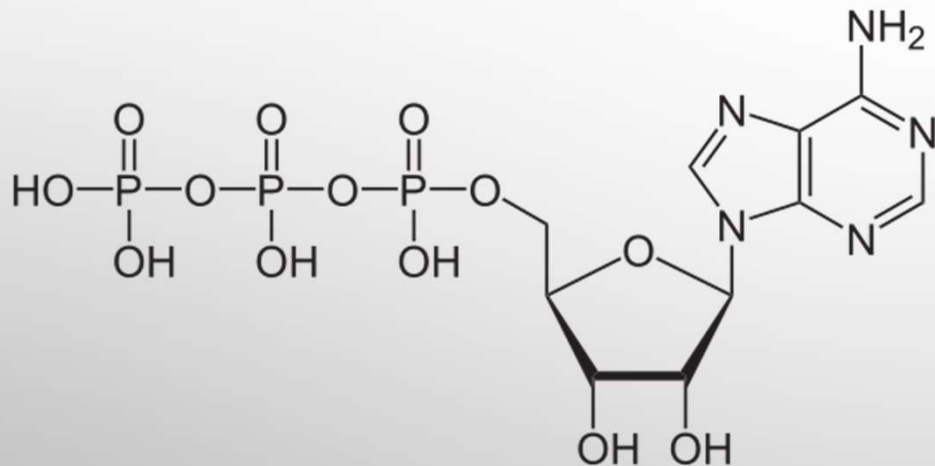
# HOW TO READ THE CODE



# Ribosome



# ATP: THE ENERGY CURRENCY OF LIFE

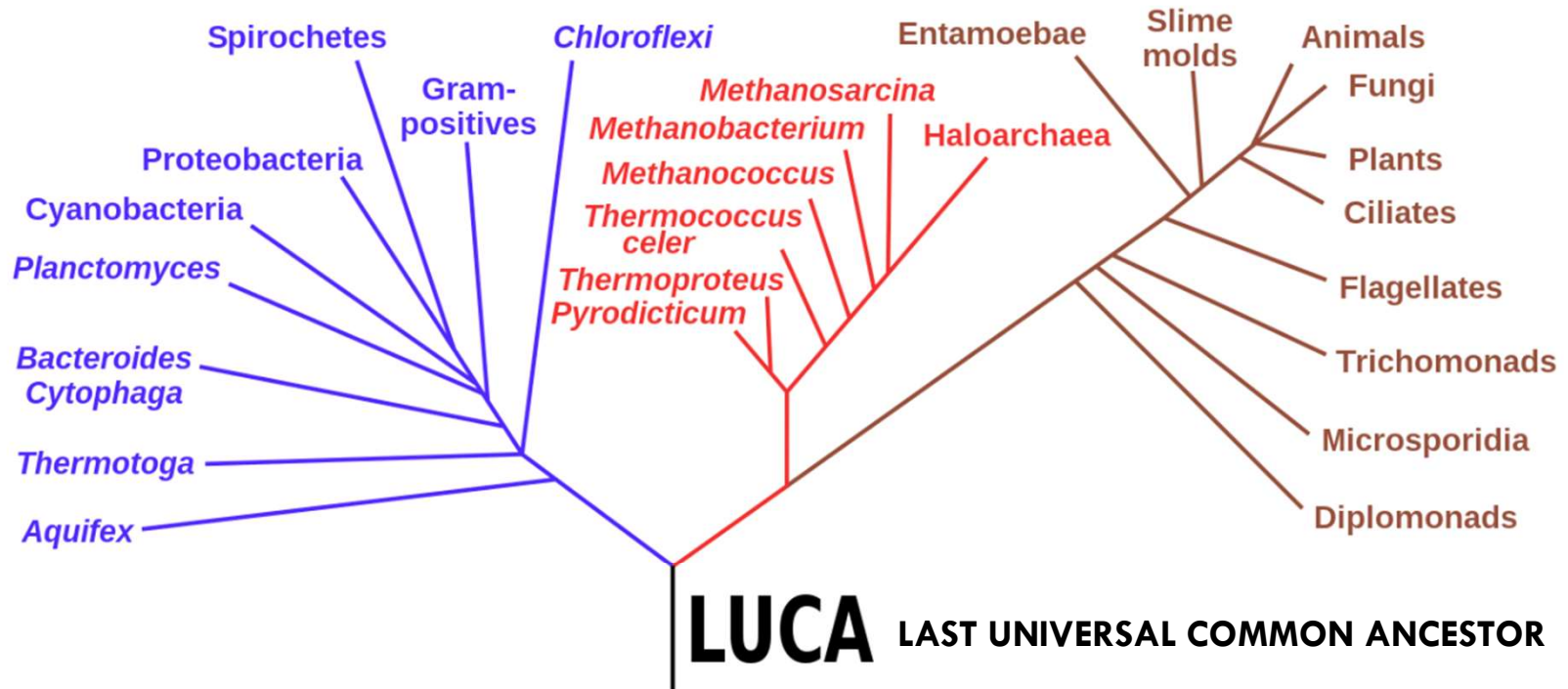


- EVERY REACTION THAT REQUIRES ENERGY IN A LIVING SYSTEM USES ATP AS ITS PRIMARY ENERGY SOURCE
- NEED AN OUTSIDE SOURCE OF ENERGY TO SYNTHESIZE ATP
- FUN FACT: THE HUMAN BODY USES ABOUT ITS WEIGHT IN ATP DAILY (WE DON'T EAT IT, WE TURN IT OVER → SYNTHESIS AND UTILIZATION). IT'S NOT AN ENERGY BANK DEPOSIT; IT'S ENERGY CASH

## Bacteria

## Archaea

## Eukaryota





**Genomes of Bacteria**

**Genomes of Archaea**

**LUCA's  
ancestral  
genes  
?**

A Venn diagram with two overlapping circles. The left circle is blue and labeled 'Genomes of Bacteria'. The right circle is orange and labeled 'Genomes of Archaea'. The intersection of the two circles is shaded grey and contains the text 'LUCA's ancestral genes ?'. The background is black, and the entire diagram is set against a light grey background with decorative water droplets.




# IT SHOULD BE EASY, BUT THERE'S A RUB

- LOOK FOR THE GENES THAT ARE PRESENT IN ALL GENOMES. EASY ENOUGH, BUT THE RESULTS ARE SOBERING. WHAT ONE FINDS IS A COLLECTION OF ABOUT 30 GENES, MOSTLY FOR RIBOSOMAL PROTEINS, TELLING US THAT LUCA HAD A RIBOSOME AND HAD THE GENETIC CODE
- RELAX THE CRITERIA OF UNIVERSAL PRESENCE TO 90% AND ALLOW FOR GENE LOSS IN SOME LINEAGES, ONE FINDS ABOUT 100 PROTEINS THAT ARE NEARLY UNIVERSAL. THE GREAT MAJORITY OF THESE ARE GENES ENCODING PROTEINS INVOLVED IN TRANSLATION AND THE CORE ASPECTS OF TRANSCRIPTION
- LUCA TRANSLATED RNA INTO PROTEIN, AND HAD DNA AS THE REPOSITORY OF INFORMATION
- BUT HOW DID LUCA MAKE A LIVING?
- ALL MAJOR SYSTEMS FOR SYNTHESIZING ATP ARE OPERATIVE IN BOTH LINEAGES
- RELAXING EVEN MORE, ALL GENES PRESENT IN AT LEAST ONE ARCHAEON AND ONE BACTERIUM TRACE TO LUCA, MAKING IT THE MOST VERSATILE ORGANISM THAT EVER EXISTED




# IS THIS AN OMNIPOTENT ANCESTOR???

- SOUNDS TOO MUCH LIKE A MIRACLE FOR COMFORT
  - ALL THESE INVENTIONS HAPPEN IN PARALLEL
  - IT'S A TIME OF RAMPANT INNOVATION
  - THESE INNOVATIONS ARE SHARED
  - THE “OMNIPOTENT ANCESTOR” IS ACTUALLY A **COMMUNITY** OF CELLS FREELY EXCHANGING INFORMATION
  - THIS IS A WEB OF CELLS, PERVADING THE BIOSPHERE, SHARING THE SUCCESS STORIES!
- 




# WHAT MAKES THIS SHARING POSSIBLE

- UNIVERSAL GENETIC CODE
  - NON-ISOLATING, 'PERMEABLE' CELL BOUNDARIES
  - FUSION OF PROTOCELLS
  - PICKING UP EXOGENOUS DNA FROM THE ENVIRONMENT
  
  - THE TANGLED ROOTS OF HORIZONTAL SHARING THROUGH COMMUNAL PROTOCELLS CAN NOW SUPPORT THE GROWTH OF MULTIPLE INTERWOVEN BRANCHES AS THE TREE OF LIFE BEGINS TO FORM
- 



# CROSSING THE DARWINIAN THRESHOLD (OR PICKING FROM THE POOL)

- AS PROTOCELLS BECOME MORE COMPLEX, “COMMUNAL LIVING” BECOMES LESS TENABLE
  - THE TANGLED WEB OF PROTOCELLS TEND TO COALESCE INTO DEFINED BRANCHES
  - EVENTUALLY, INDIVIDUAL CELLS WOULD BECOME SUFFICIENTLY ADVANCED TO SURVIVE AND REPRODUCE FREELY IN SOLUTION, DETACHED FROM THEIR ORIGINAL COMMUNAL COMPLEXES.
  - RAMPANT HORIZONTAL GENE TRANSFER IS RESTRICTED
  - VERTICAL INHERITANCE STARTS TO PREDOMINATE
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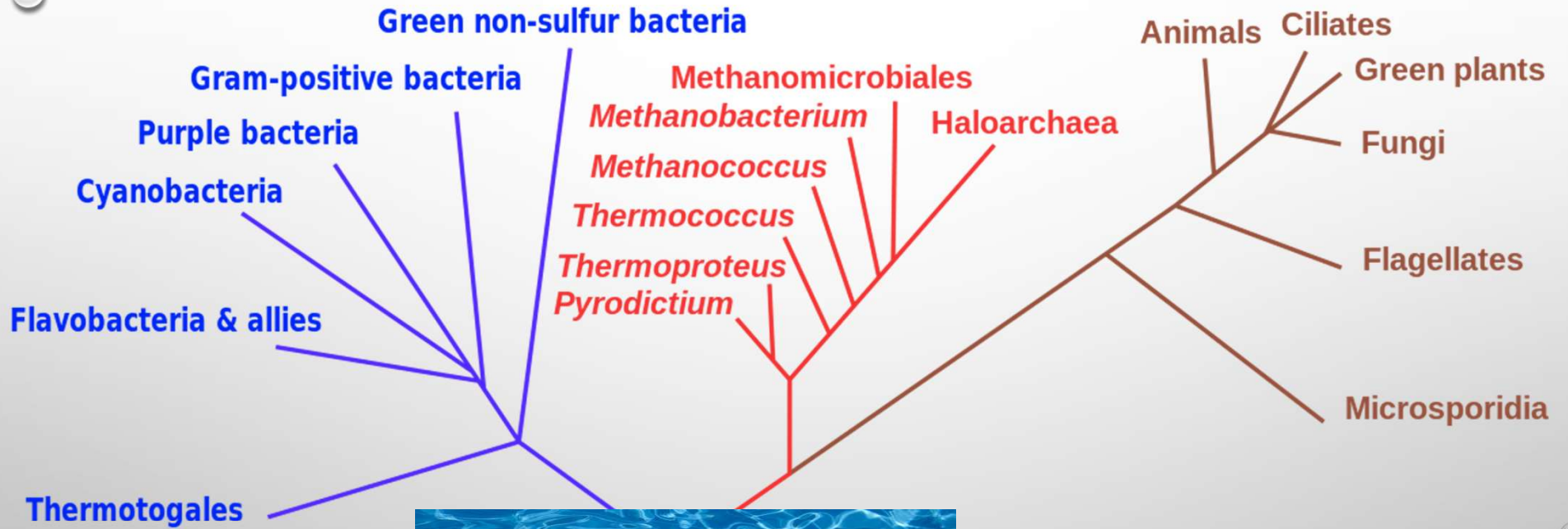
## DARWINIAN THRESHOLD



# Bacteria

# Archaea

# Eukarya



# BECOMING A...

- **BACTERIUM**

- SIMILAR TRANSLATION APPARATUS
- RELATED RNA POLYMERASES BUT DIFFERENT ARCHITECTURE FOR THE START POINTS OF RNA TRANSCRIPTION (I.E. GENES)
- BACTERIAL CELL MEMBRANE


- **ARCHAEON/EUKARYOTE**

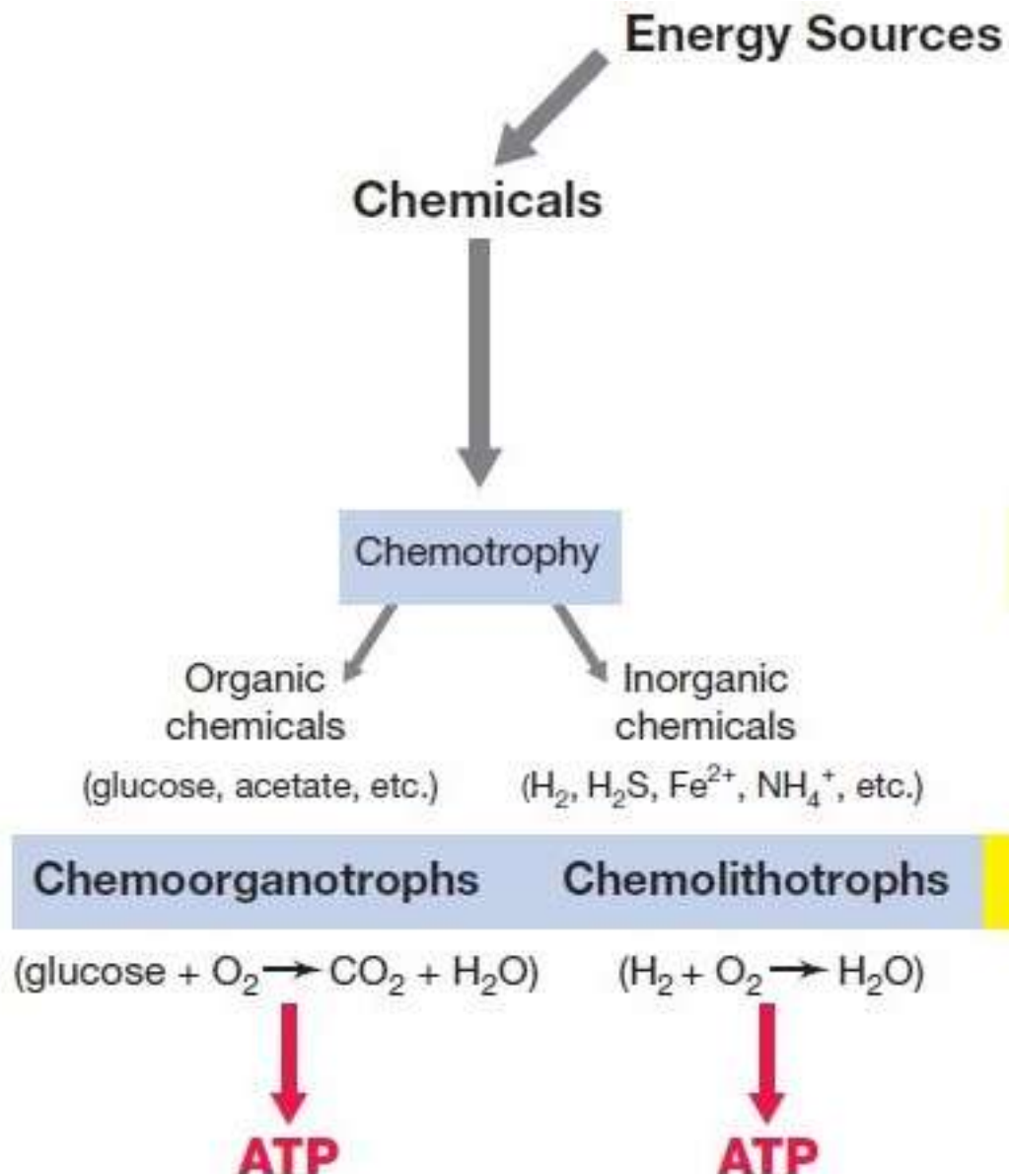
- SIMILAR TRANSLATION APPARATUS
- RELATED RNA POLYMERASES BUT COMPLETELY DIFFERENT TRANSCRIPTION START MACHINERY
- COMPLETELY DIFFERENT MEMBRANE



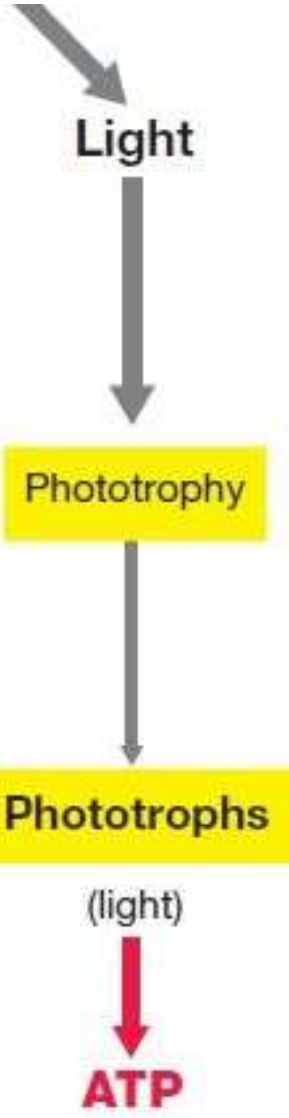


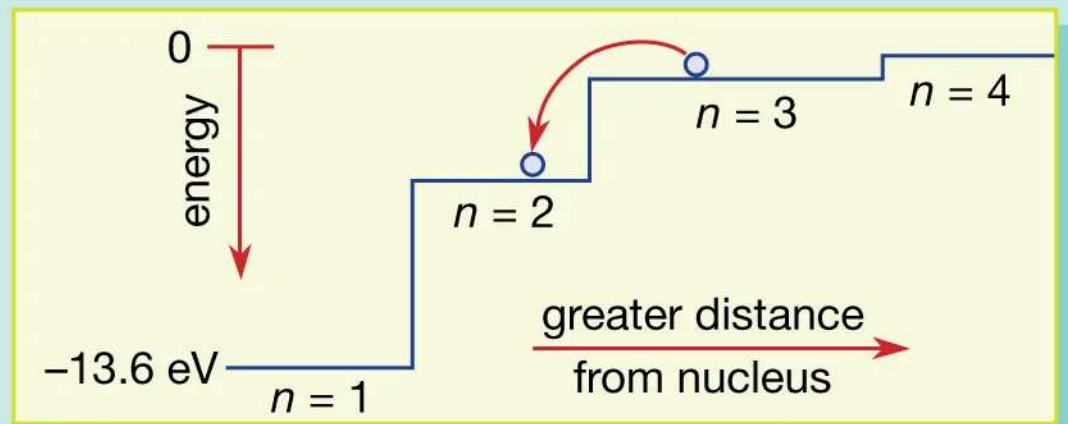
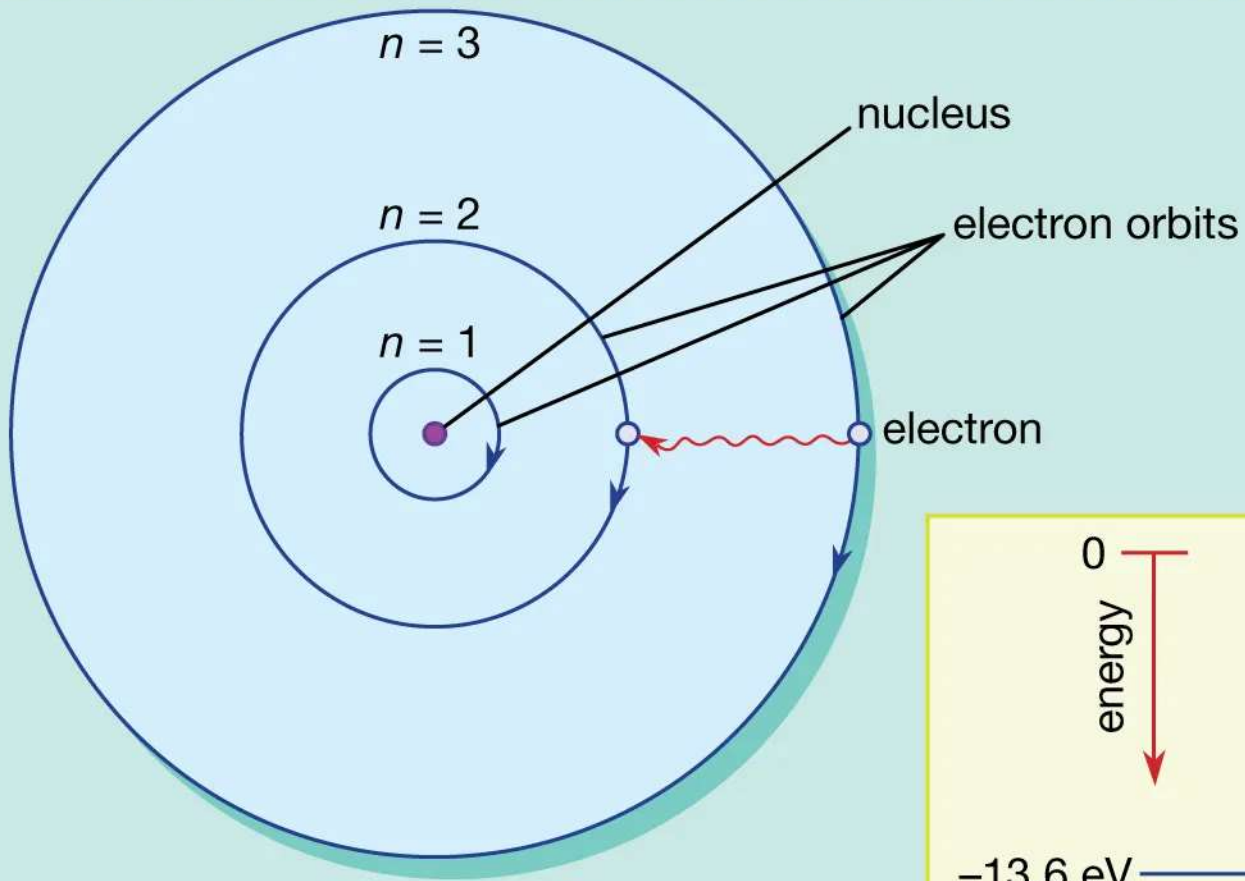
# HARNESSING ENERGY

- IN THIS EARLY ENVIRONMENT, POSSIBLE SOURCES OF ENERGY:
  - CHEMICAL ENERGY IN ORGANIC SUBSTRATES → ESPECIALLY SUGARS (SYNTHESIZED IN ABIOTIC CONDITIONS OR RELEASED FROM PROTOCELLS)
  - CHEMICAL ENERGY IN INORGANIC COMPOUNDS → SULFUR COMPOUNDS, IRON, AMMONIUM
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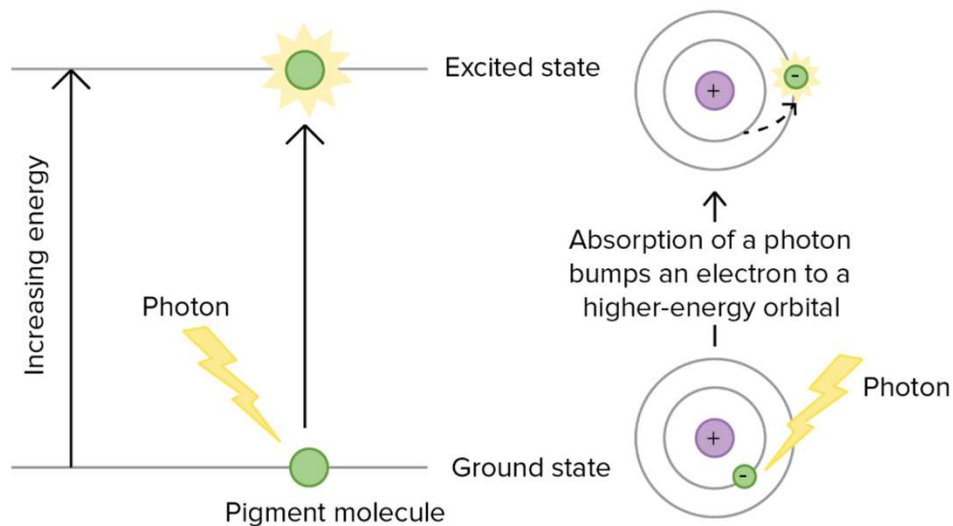


**ENERGY SOURCE**





# CAPTURING THE ENERGY OF THE SUN




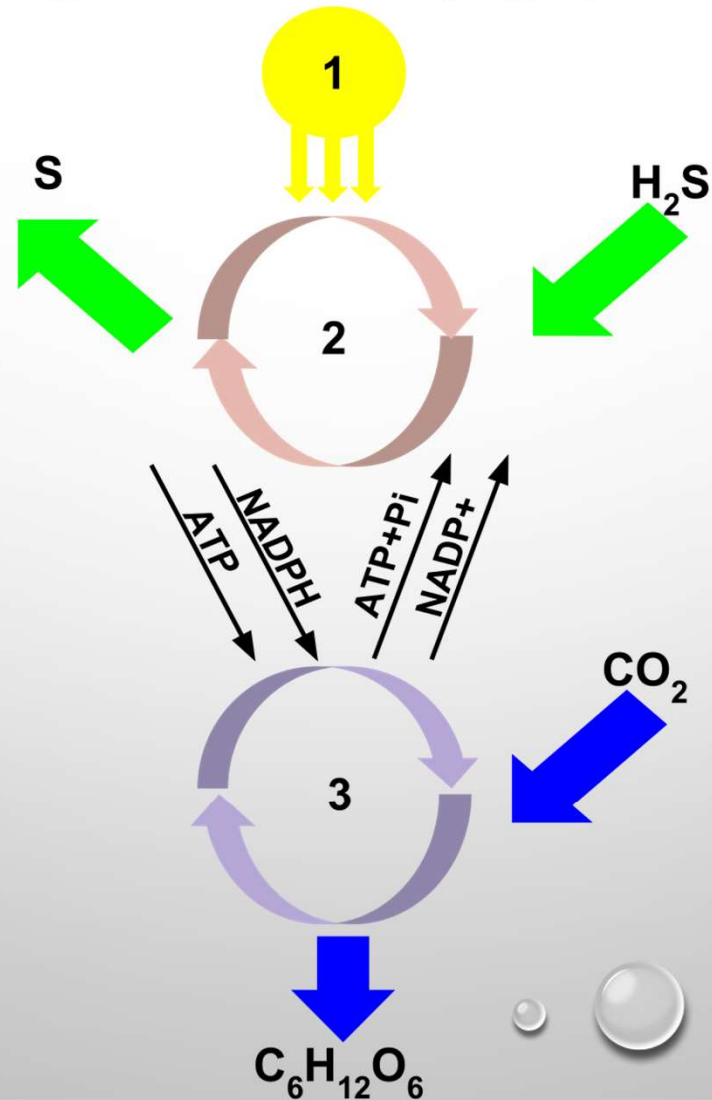
REQUIRES THE EVOLUTION OF PIGMENTS ABLE TO CAPTURE PHOTONS

- THIS LEADS TO AN “EXCITED” STATE
- THE EXCITED ELECTRON IS SHUNTED TO ANOTHER ATOM
- IN THIS NEW ENVIRONMENT, FALLING TO A LOWER ENERGY STATE IS LINKED TO DOING USEFUL WORK → IT IS USED TO SYNTHESIZE ATP
- THE ATP IS USED FOR ALL BIOLOGICAL FUNCTIONS: SYNTHESIZING GLUCOSE FROM  $\text{CO}_2$  AND  $\text{H}_2\text{O}$ , MAKING PROTEINS, DUPLICATING DNA, SYNTHESIZING RNA, AND EVERYTHING ELSE



# DURING THIS PROCESS, NADPH IS GENERATED

- NICOTINAMIDE ADENINE DINUCLEOTIDE PHOSPHATE
  - ESSENTIAL MOLECULE IN ALL ORGANISMS
  - IT IS THE DRIVING FORCE OF MOST BIOSYNTHETIC ENZYMATIC REACTIONS, INCLUDING THOSE RESPONSIBLE FOR THE BIOSYNTHESIS OF ALL MAJOR CELL COMPONENTS, SUCH AS DNA AND LIPIDS
- 





# GRAND PRISMATIC SPRING - YELLOWSTONE





# STROMATOLITES

EARLY MICROBIAL MATS MACROFOSSILS (WESTERN AUSTRALIA)~3.8 GA



Present Day Stromatolites  
Shark Bay, Australia

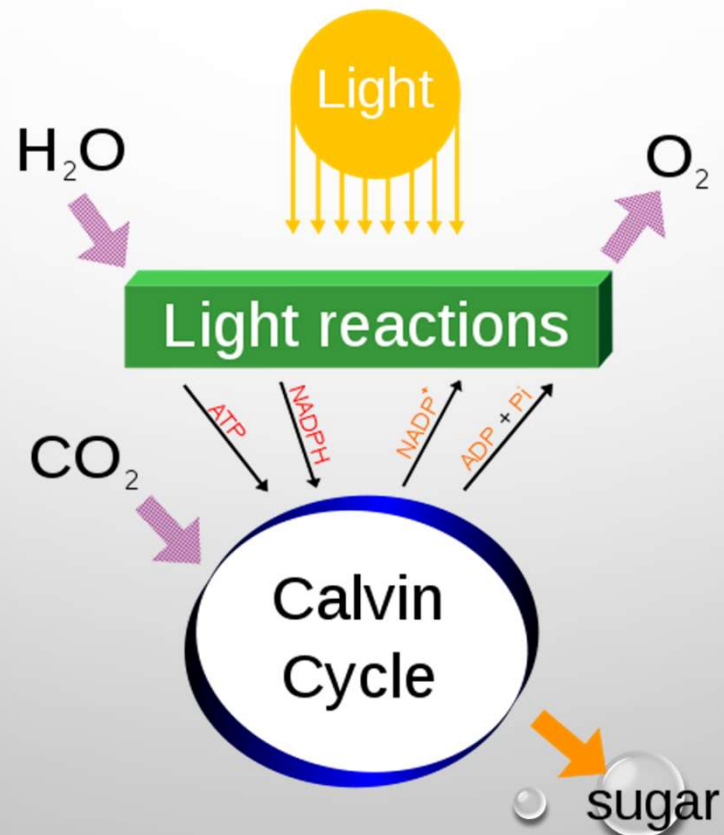


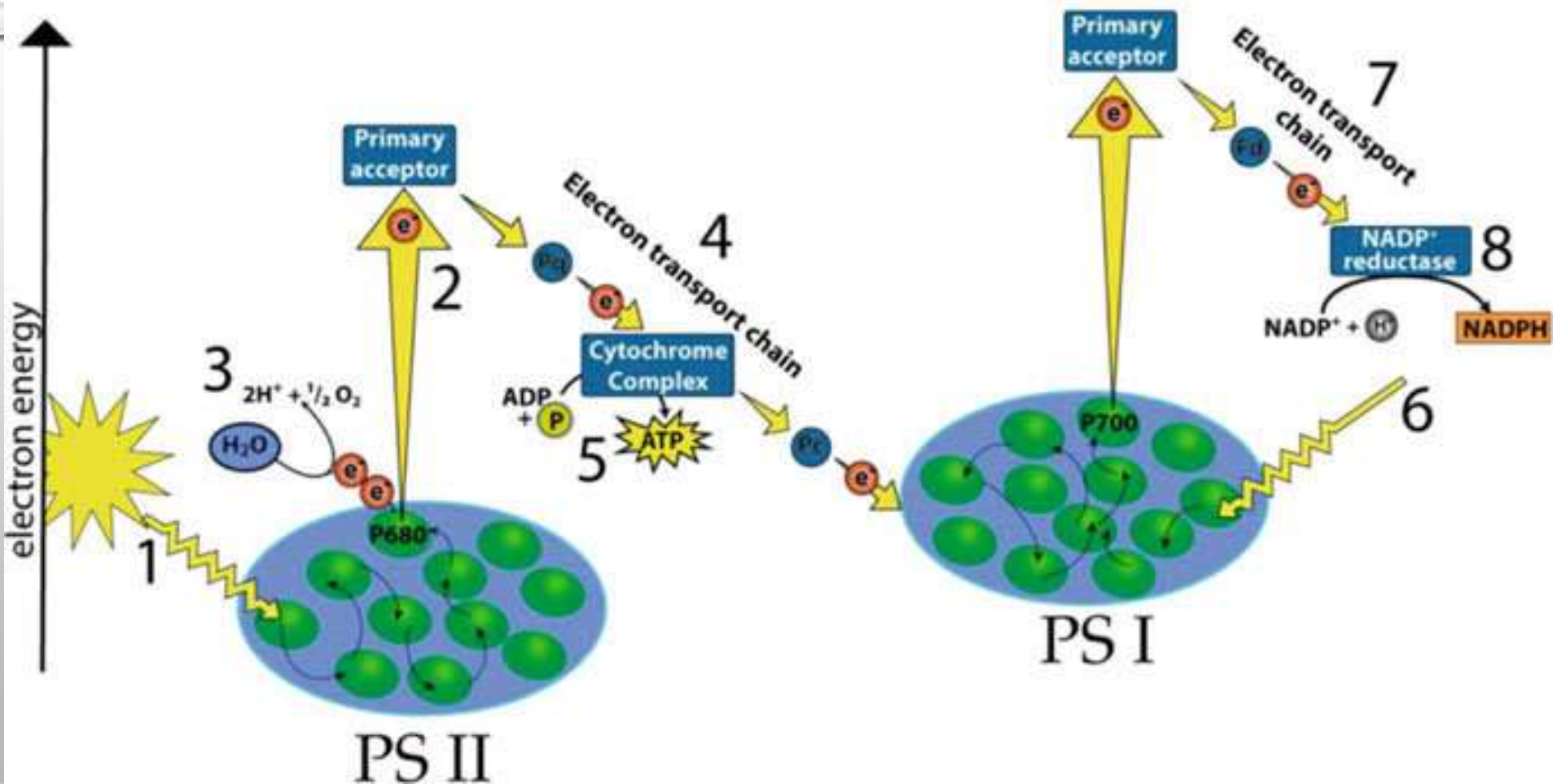
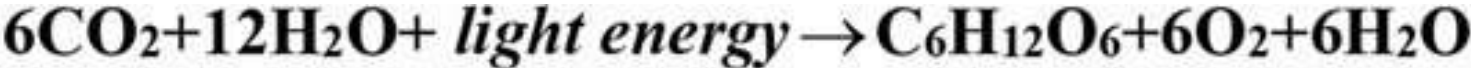
Fossilized stromatolite

# THIS IS ANOXYGENIC PHOTOSYNTHESIS

- HOW FAR CAN YOU GO?
- RELYING ON INORGANIC COMPOUNDS SUCH AS SULFUR, IRON, AMMONIUM COMPOUNDS, ETC. RESTRICTS THE LIFESTYLE TO ENVIRONMENTS THAT ARE RICH IN THEM
- BUT WHAT IS AVAILABLE EVERYWHERE IS **WATER!!!!**
- THE QUESTION IS CAN YOU USE  $H_2O$  INSTEAD OF INORGANIC COMPOUNDS?????

# PHOTOSYNTHESIS AS WE KNOW AND LOVE IT

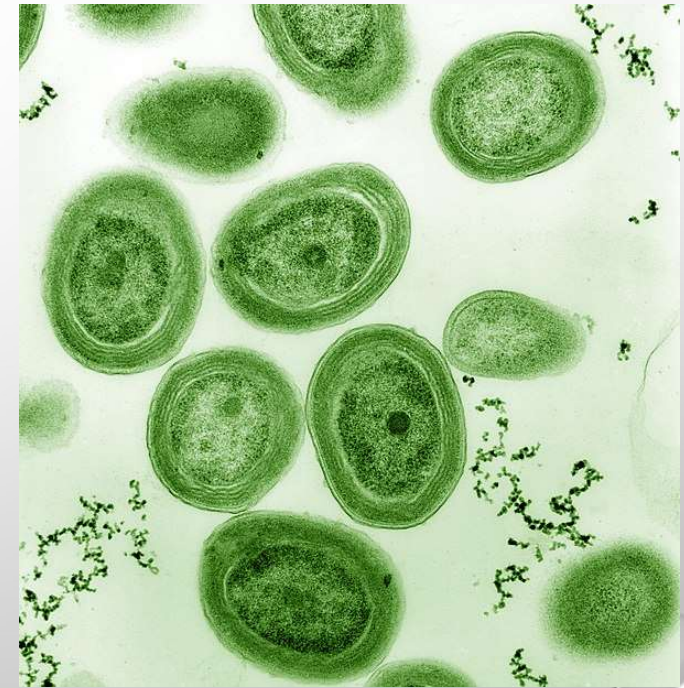






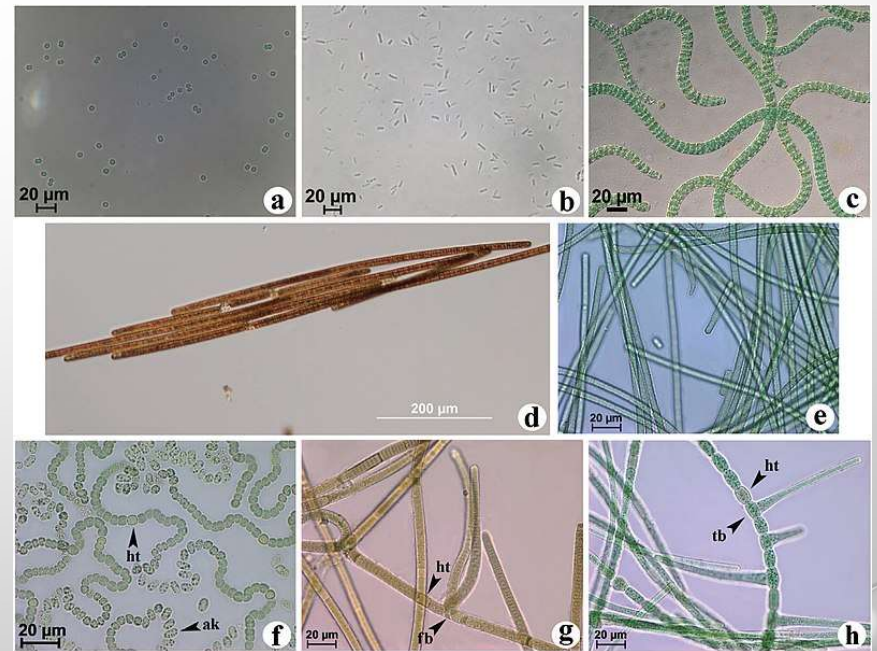
# CYANOBACTERIA

- MOST NUMEROUS AND WIDESPREAD MICROBES
- THE ONLY OXYGEN-RELEASING PHOTOSYNTHETIC BACTERIA
- CONTRIBUTE ALMOST HALF OF THE EARTH'S TOTAL PRIMARY PRODUCTION
- MARINE CYANOBACTERIA INCLUDE THE SMALLEST KNOWN PHOTOSYNTHETIC ORGANISMS. THE SMALLEST OF ALL, *PROCHLOROCOCCUS*
- IT IS POSSIBLY THE MOST PLENTIFUL GENUS ON EARTH: A SINGLE MILLILITER OF SURFACE SEAWATER CAN CONTAIN 100,000 CELLS OF THIS GENUS OR MORE
- THE BACTERIUM ACCOUNTS FOR ABOUT 20% OF THE OXYGEN IN THE EARTH'S ATMOSPHERE.



# ECOLOGY OF CYANOBACTERIA

- CYANOBACTERIA ARE ARGUABLY THE MOST SUCCESSFUL GROUP OF MICROORGANISMS ON EARTH
- THEY ARE THE MOST GENETICALLY DIVERSE
- CAN BE FOUND IN ALMOST EVERY TERRESTRIAL AND AQUATIC HABITAT – OCEANS, FRESH WATER, DAMP SOIL, TEMPORARILY MOISTENED ROCKS IN DESERTS, BARE ROCK AND SOIL, AND EVEN ANTARCTIC ROCKS
- THEY CAN OCCUR AS FREE-SWIMMING CELLS OR FORM MICROBIAL BIOFILMS AND MATS





# SOME CYANOBACTERIA FORM ALGAL BLOOMS

