1. **Pick up** Name Folder

- Pick up your name folder and set it up in front of you at your seat.

2. **Clicker** Attendance

- Launch your Top Hat and get ready for a Pop Quiz! on the reading.

3. Laptops closed (unless TopHat)

- (open if need 4 TopHat, don’t distract others)

Announcements

1. **Advice: Remember Course pack for admission to lab today.** On Monday, show us your best work for the formal Proposal Talks (LIVE & recorded video).
2. **145 Contract:** signed and submitted by Friday 5pm
3. **Office Hours**- M/W 2-3pm, if there's a line, 10-minute limit.
4. **TopHat questions** gain points if answered correctly (but only need to get 70%, to earn 4.0 for TopHat)
5. **We will use a *University-level Grading System* this semester and scores will be grade levels, 4.0, 3.5, 3.0, 2.5, etc for human-graded assignments. Everyone who earns same grade level on an assignment gets the exact same percentage score for it, e.g. all "3.5" grades ultimately become a 87.5% for everyone, all "4.0" grades become a 95% for everyone.**

What is a 4.0?

In the university grading system

Quantity

PERCENTAGE of mastery = PERCENTAGE grade

What is a 4.0?

In the university grading system

Quality

Quality of work = Level of grade

What is a 4.0?

In the university grading system

If a student does mostly what was asked of them on an assignment and does a pretty good job, what's the grade supposed to be?

a. 4.0
b. 3.5
c. 3.0
d. 2.5
e. other

What is a 4.0?

In the university grading system

- The **“4.0” is Outstanding** is the student blew you away with how much and how well they did the work. They taught you something you didn’t know.

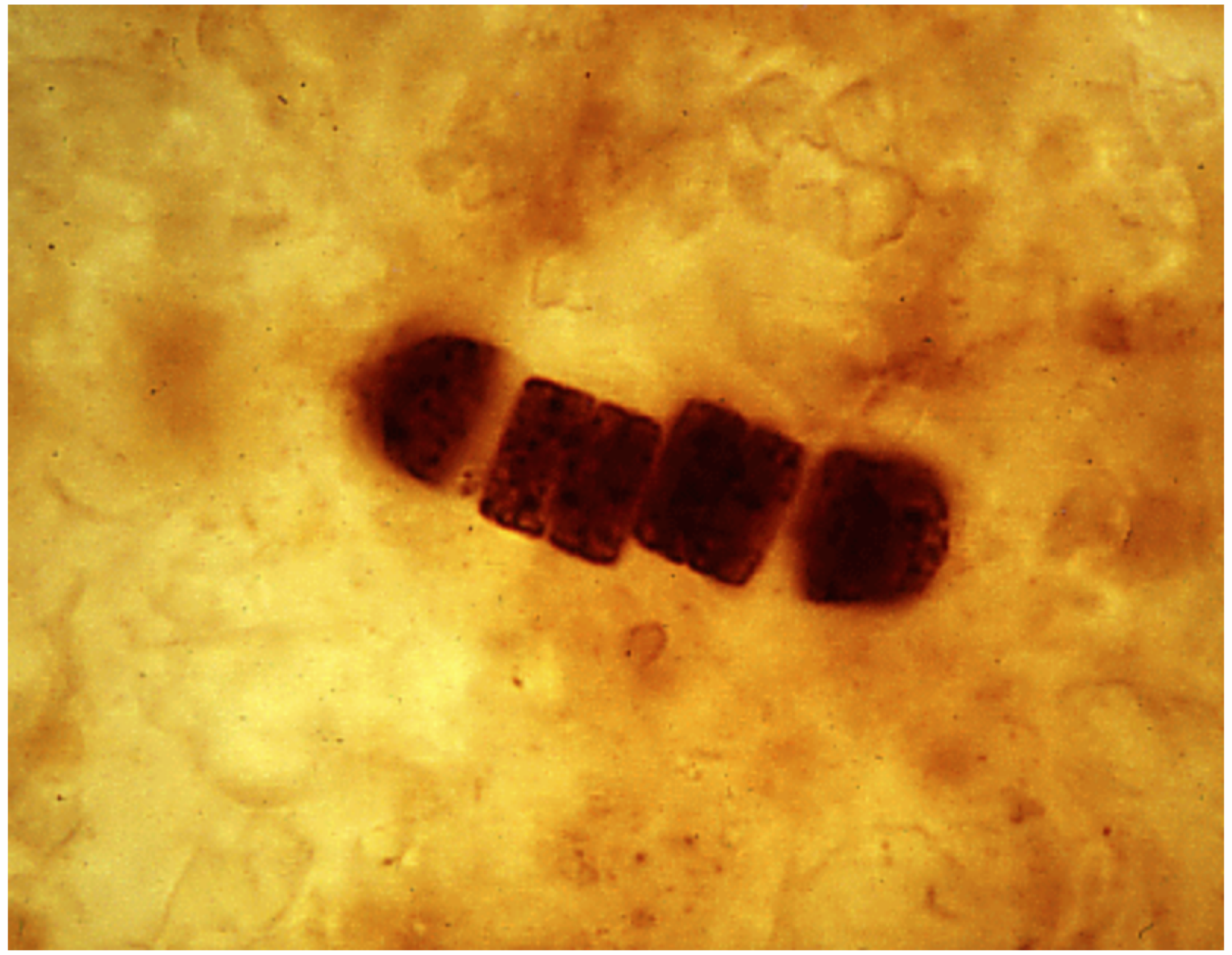
- A “**3.5” is Most Excellent** every detail of their work was done extremely well and they found additional papers and evidence beyond what they were told/expected to do, to complete their work.

- A **“3.0” is Excellent** is impressive work, top of the class, and their work was done extremely well but nothing beyond what was expected.

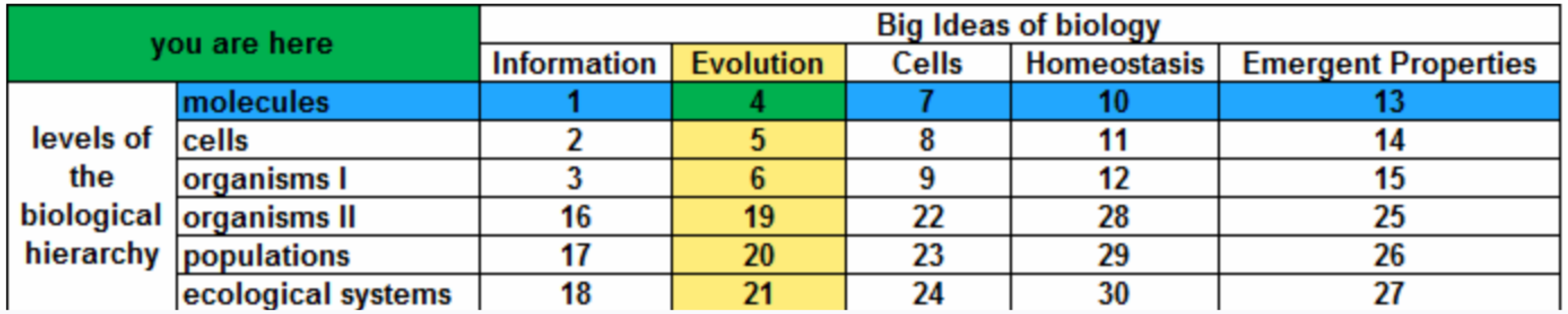
- 2.0-2.5 "Pretty Good" the student mostly did the work required and a pretty good job, the average in the class.

Chapter 4: Evolution and Origin of Cells

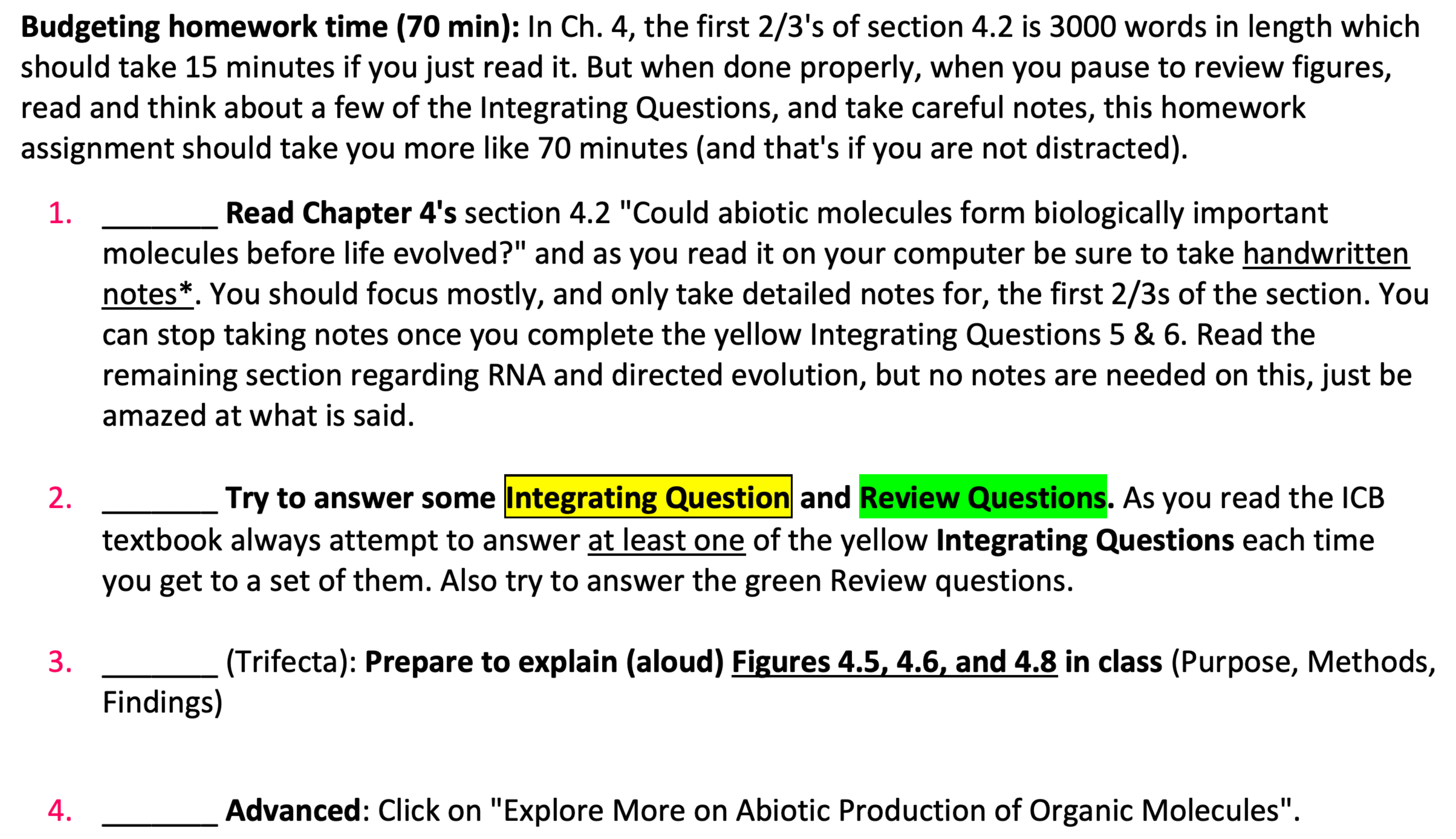
A vexing problem in biology is trying to use evidence to understand how life first began. Today, all organisms come from preexisting organisms so it is difficult to imagine how the first living cells came into existence. How could **abiotic** (non-living) molecules coalesce to form a living (**biotic**) cell? Just because it is hard to imagine, however, does not mean this problem is beyond scientific investigation. A growing number of scientists (biologists, chemists, biochemists, and biophysicists) have designed very clever experiments to improve our understanding about the origin of life. Chapter 4 focuses on the molecular aspects of evolution with special attention to the formation of complex living cells from simpler abiotic components. After clearly defining evolution, you will examine data that reveal how non-living chemicals can exhibit traits resembling simple cells. In Chapter 4, you will analyze data that illuminate the origin of eukaryotic cells from prokaryotic ancestors as well as the origins of chloroplasts and mitochondria which are DNA-containing organelles. The four Sections of Chapter 4 focus on evolution at the molecular level.



Micrograph of one billion year old fossilized microbe. Photo courtesy of William Schopf, UCLA



you are here		Big Ideas of biology				
		Information	Evolution	Cells	Homeostasis	Emergent Properties
levels of the biological hierarchy	molecules	1	4	7	10	13
	cells	2	5	8	11	14
	organisms I	3	6	9	12	15
	organisms II	16	19	22	28	25
	populations	17	20	23	29	26
	ecological systems	18	21	24	30	27



Budgeting homework time (70 min): In Ch. 4, the first 2/3's of section 4.2 is 3000 words in length which should take 15 minutes if you just read it. But when done properly, when you pause to review figures, read and think about a few of the Integrating Questions, and take careful notes, this homework assignment should take you more like 70 minutes (and that's if you are not distracted).

1. _______ **Read Chapter 4's** section 4.2 "Could abiotic molecules form biologically important molecules before life evolved?" and as you read it on your computer be sure to take handwritten notes*. You should focus mostly, and only take detailed notes for, the first 2/3s of the section. You can stop taking notes once you complete the yellow Integrating Questions 5 & 6. Read the remaining section regarding RNA and directed evolution, but no notes are needed on this, just be amazed at what is said.

2. _______ **Try to answer some Integrating Question and Review Questions.** As you read the ICB textbook always attempt to answer at least one of the yellow **Integrating Questions** each time you get to a set of them. Also try to answer the green Review questions.

3. _______ (Trifecta): **Prepare to explain (aloud) Figures 4.5, 4.6, and 4.8 in class** (Purpose, Methods, Findings)

4. _______ **Advanced**: Click on "Explore More on Abiotic Production of Organic Molecules".

[redacted] Evolution + Origin of cells

- Pink sheets
- need Cpock

Section 4.2 Could abiotic molecules ... form life?

L.O.s
- Use evidence to support life came from abiotic ...
- Define four properties of life
- Describe how RNA molecules can be enzymes

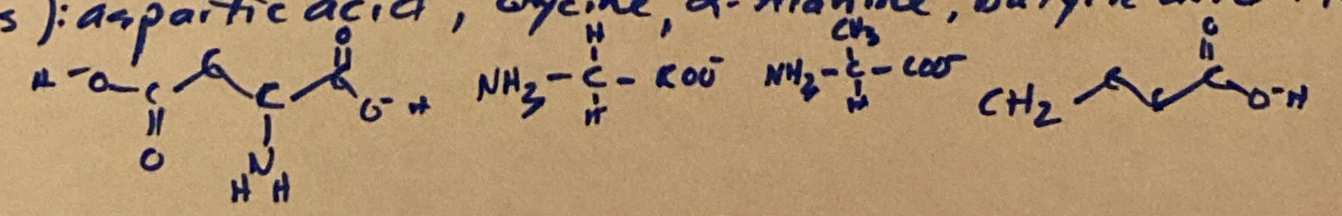
Origin of life
-> long been a religious question, ELSI 4.1 clarified no fight between religion + science
-> could life come from non-life?
-> life made up up four molecules Nucleic Acids, CHOs, Lipids, Proteins "organic molecules"
  ↳ intro to Lipids + photpho lipids -> vesicles + micelle structures
-> Generally, atoms do not typically self-assemble spontaneously if mixed in tube
-> chicken vs. egg. all theory vs how first cell formed?

IQs: 1. molecule structure + hydrophilic/phobic NOPS 2. Look at structures, fatty acid amino acids

1953 -> Univ. of Chicago Stanley Miller
-> tried to replicate primitive earth conditions, see if can make complex molecules

Figure 4.5

Purpose -> test if abiotic -> biotic in early earth conditions
Methods -> glassware, heat, spark, coolant, vacuum, H_2, CH_4, NH_3 gas
ran for entire week Student WOB illustrate + explain? used spray stain to visualize
Findings - observed water -> pink -> red (cloudy), pulled out, liquid dried to concentrate
used 2D TLC to separate + visualize molecules to ID ~~them~~
ID'ed: (aa's): aspartic acid, glycine, α-Alanine, butyric acid (fat)



-> Since 1953 others have found more lipids + nucleic acids
-> NASA also found lipids in Murchison meteorite (landed in Australia 1969) then 2001
-> NASA chemists replicated outer space synthesis of lipids via UV light on inorganic
-> Interstellar ice has some four gases as in NASA experiment + UV is abundant too
these lipids form vesicles 3D + can carry cargo.

Fig 4.6 - lipids + vesicles + structure illustration of vesicles

IQ 3. Outcome of Miller's experiment? New Qs? Meteorite? 4. 2008 PubMed paper

(section 4.2 cont.)

2008 Science paper by Johnson et al - re examined Miller's his samples
discussed his volcanic apparatus vs classic one.
→ Found aa's, lipids ∴ proteins, fats, nucleic acids

*So, if found complex organic materials can be generated from abiotic they turned to question, could one create a cell?

Life's properties: Change, Replication, energy + existence as 3D + cargo
↳ who can copy themselves?

Self-organizing + replicating molecules

Membranes... RNA molecules ... not alive, life emerges...
ribosomes are self-organizing, (lipids are too.)

1985 → RNA-world hypothesis - earliest genomes were RNA
- result of discovery of ribozymes = Nobel Prize (+ enzymes)
-> bizarre little organism Tetrahymena RNA could self-splice it's intron cut + ligate! 188nts
glue like taq DNA polymerase

Ribozyme can do this (Chemistry) CpU + GpN + ribozyme
→ CpUpN + G + ribozyme

Figure 4.8 Been + Cech 1988 Science

"Net Elongation of an RNA Primer catalyzed by the Tetrahymena Ribozyme"
- PCR knowledge help you translate title to human language?

Purpose: test RNA world hypothesis or - test if ribozyme can elongate primer

Methods: Controls → negative → absence of of free nucleotides (dinucleotides specifically)
"Starter RNA" pCs is 5-base long Primer of just $C\overset{*}{\underset{p}{-}}C\overset{*}{\underset{p}{-}}C\overset{*}{\underset{p}{-}}C\overset{*}{\underset{p}{-}}C$
In four separate tubes had different free nucleotides (A, G, C, U)
GpA, GpG, GpC, GpU
Analysis by gel electrophoresis, gel separates, radioactivity visualizes ^{32}P ← radioactive
Xray film exposed to radioactivity turned black.
MW ladders included 3 to 11 bases in length + radioactive

IQs: 5. Which base worked best? (why?, what evidence) 6. Significance of experiment?
that ribozcould not add "G"!? replication is possible

STAND UP

Remain standing if:

1. **You have attended all classes**
2. **you have completed all the readings this semester**
3. **Taken notes on those readings (handwritten)**
4. **Prepared for today’s class in case there’s a quiz**

“Pop Quiz”: **Reward** for those who remember or wrote in notebook.
(clicker questions, 60 seconds each, handwritten notes can be used)

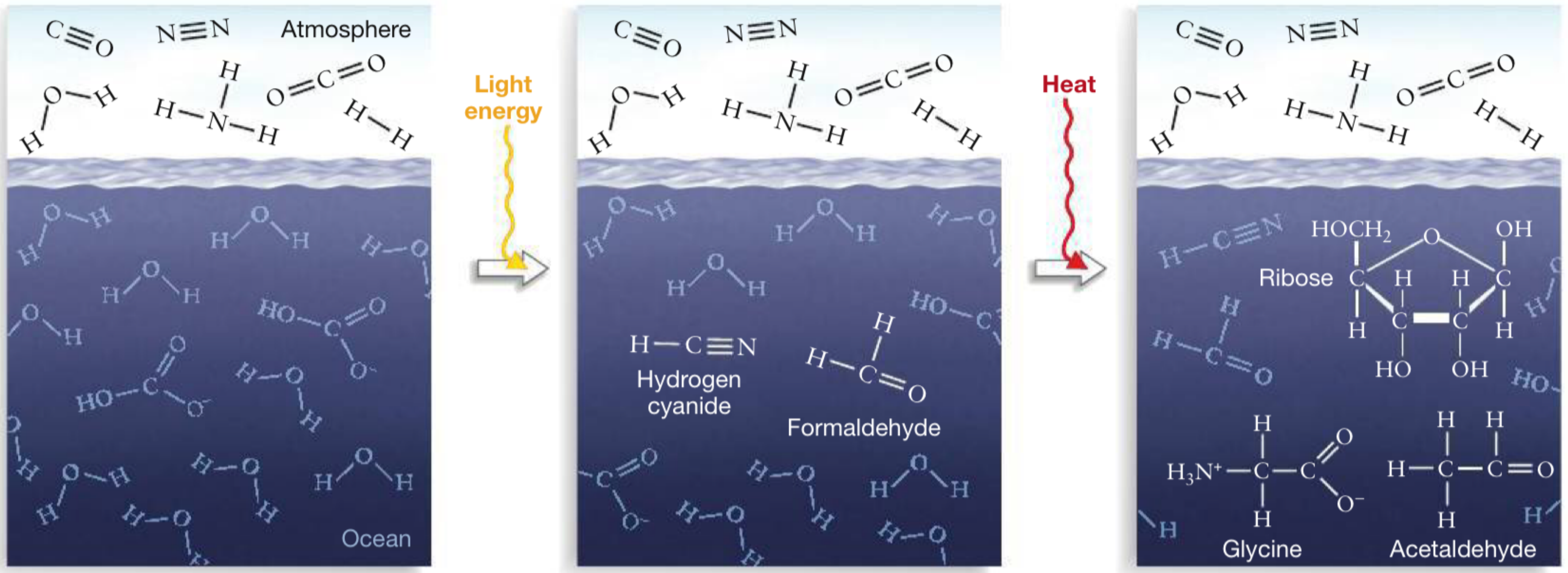
4.2 Could abiotic molecules form biologically important molecules before life evolved?

Biology Learning Objectives

- Use evidence to support the scientific hypothesis that life evolved from abiotic forces and phenomenon.
- Define the fundamental properties of living systems.
- Describe how RNA molecules can function as enzymes.


iPad
9:40 AM
99%
Done
1:24
-7:10
PROF. COLIN W. DEVEY
Marine Geologist, University of Kiel

(a) PROCESS: PREBIOTIC SOUP MODEL OF CHEMICAL EVOLUTION

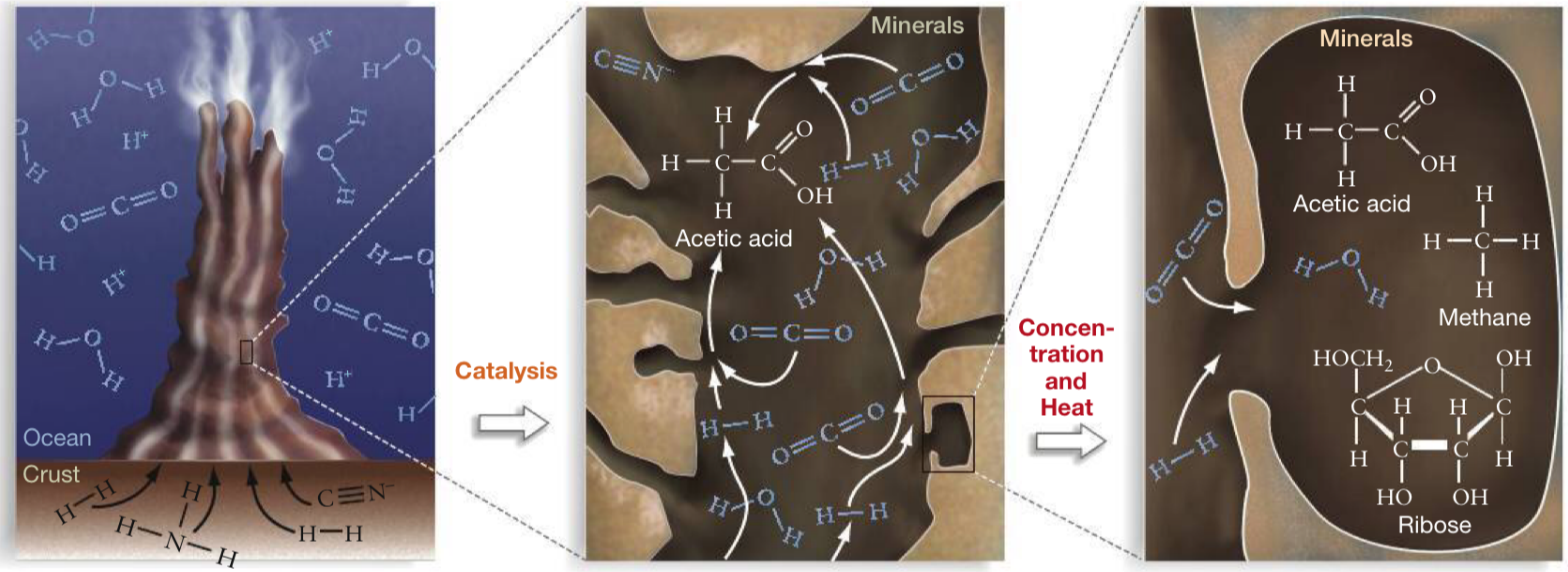


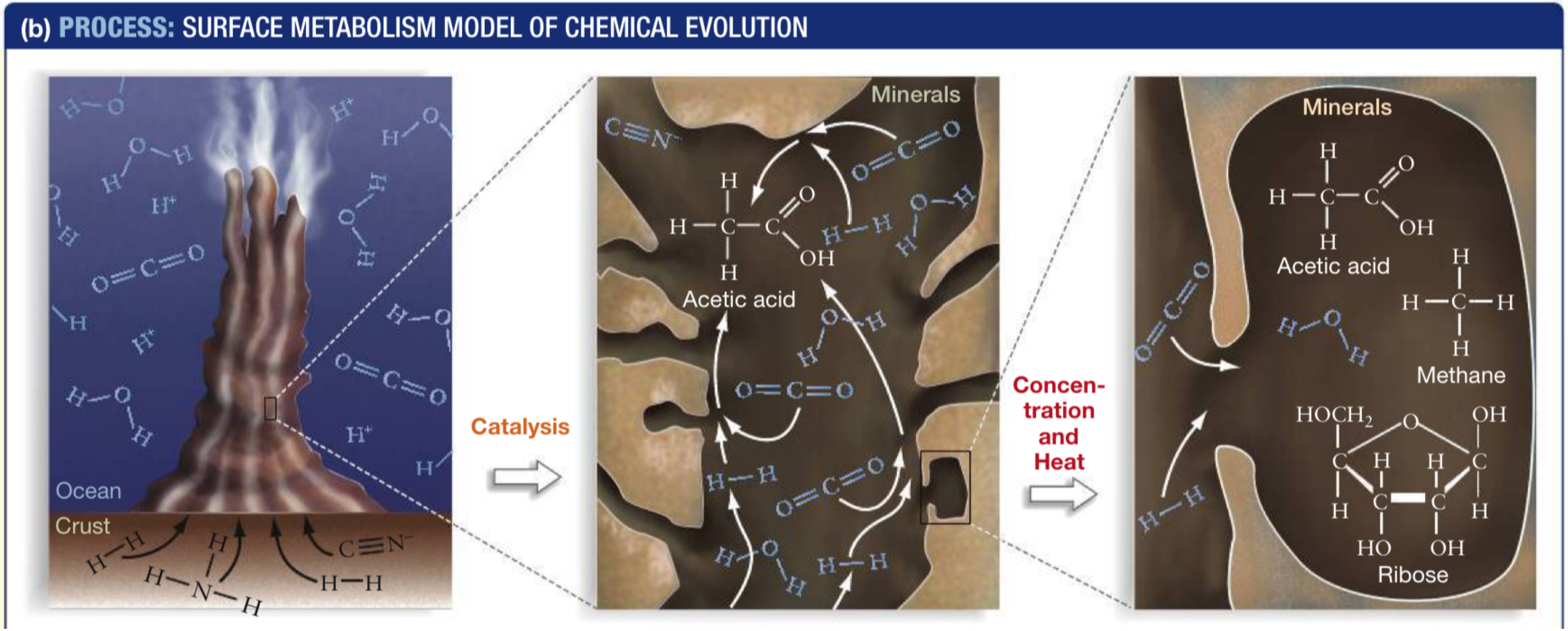
1. Simple molecules were present in the atmosphere of ancient Earth.

2. Energy in sunlight drove reactions among the simple molecules.

3. Stimulated by heat, the products formed more complex molecules.

(b) PROCESS: SURFACE METABOLISM MODEL OF CHEMICAL EVOLUTION





(b) PROCESS: SURFACE METABOLISM MODEL OF CHEMICAL EVOLUTION

(Trifecta)

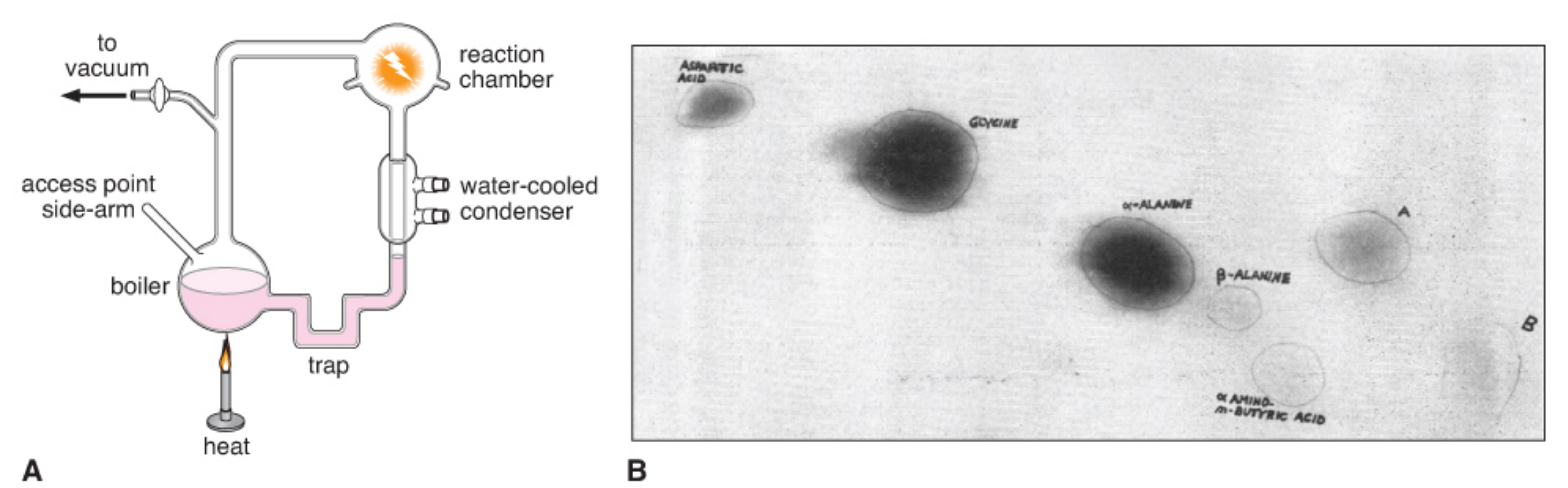


Figure 4.5 Miller's experiment to simulate primitive Earth. **A,** Modified drawing from Miller showing the parts of his ancient world device. **B,** Thin layer chromatography results after running the primitive earth experiment for 1 week. (Hand-written labels and circles by Miller.) From Stanley L. Miller. 1953. Figure 1. Stanley L. Miller. 1953. A Production of amino acids under possible primitive earth conditions. Science. 117: 528 – 529. Reprinted with permission from AAAS.

Stanley Miller's
abiotic gases -> amino acids and lipids

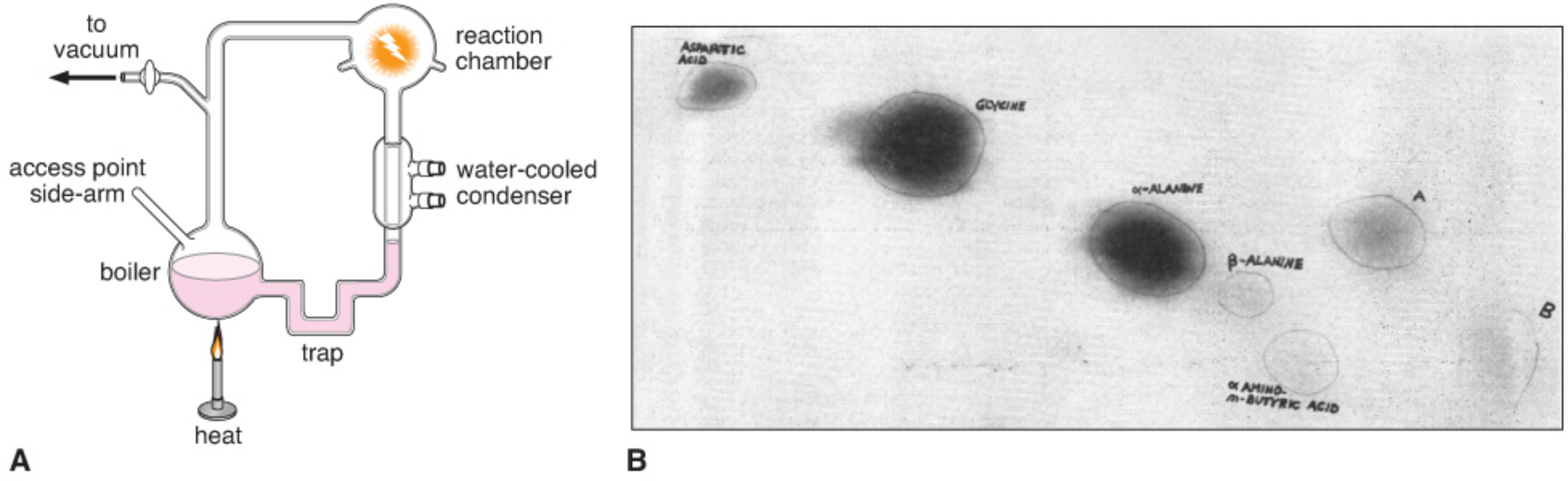


Figure 4.5 Miller's experiment to simulate primitive Earth. **A,** Modified drawing from Miller showing the parts of his ancient world device. **B,** Thin layer chromatography results after running the primitive earth experiment for 1 week. (Hand-written labels and circles by Miller.) From Stanley L. Miller. 1953. Figure 1. Stanley L. Miller. 1953. A Production of amino acids under possible primitive earth conditions. Science. 117: 528 – 529. Reprinted with permission from AAAS.

Miller Separated Products by TLC

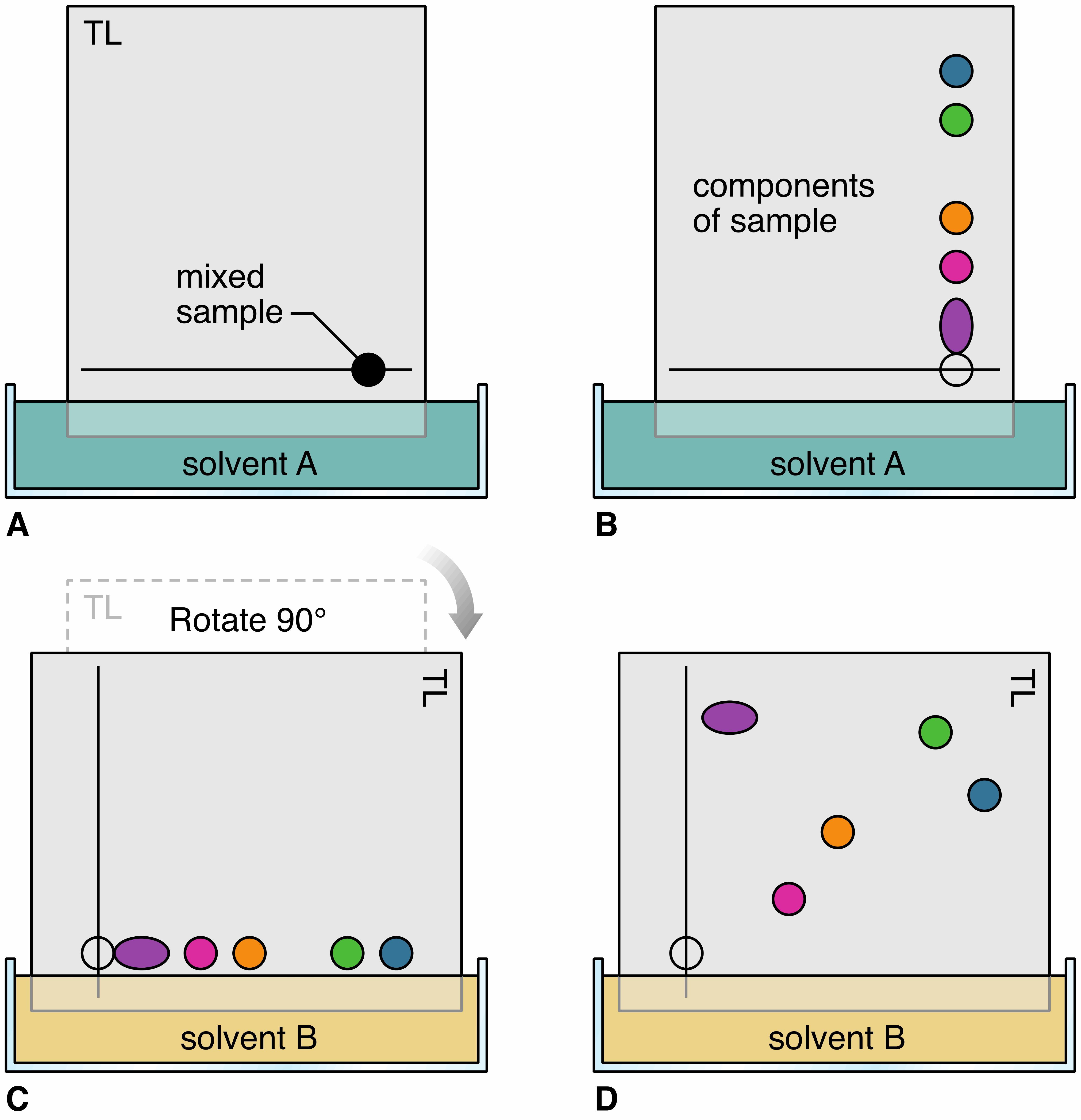
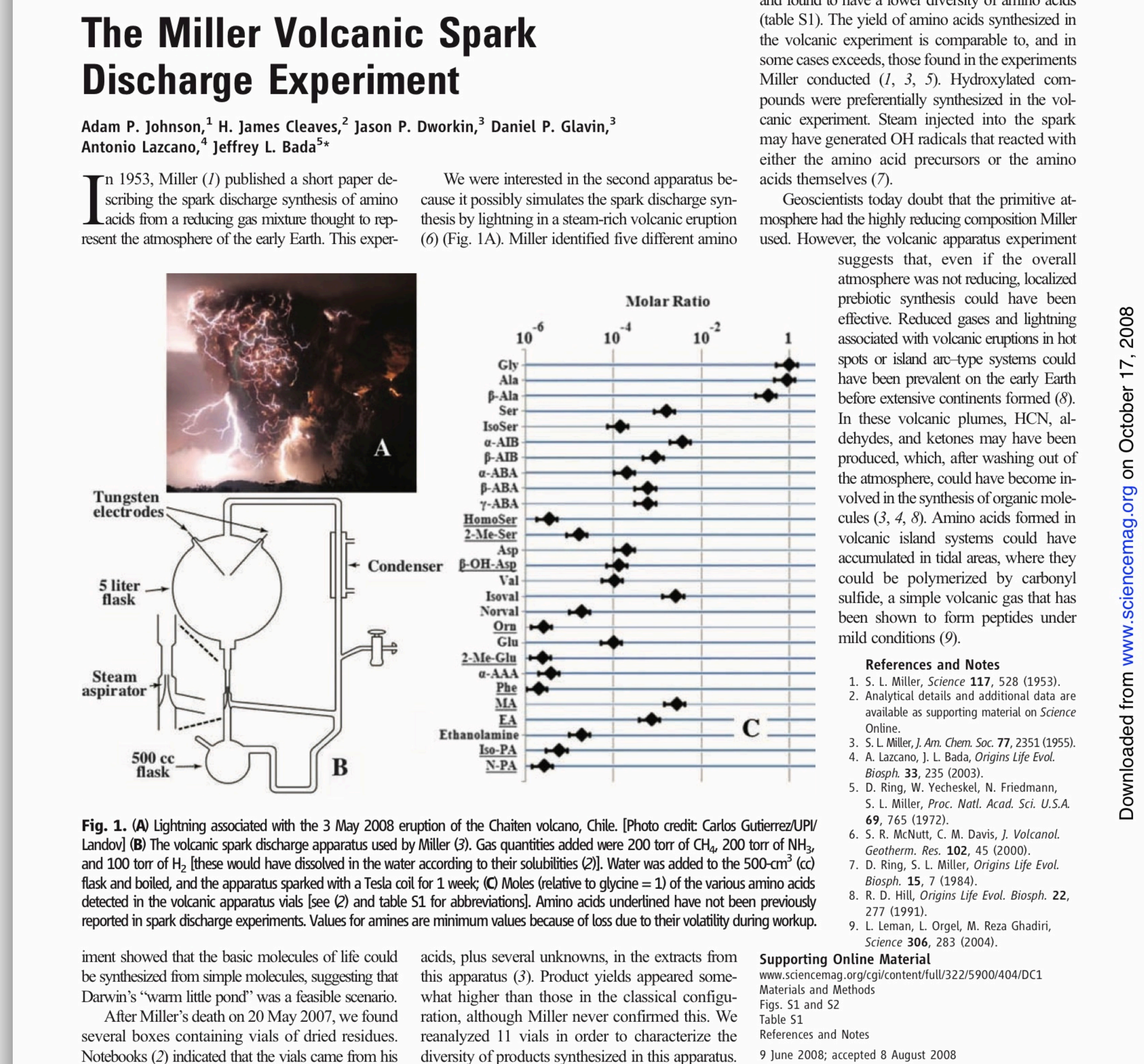


Fig. 1.19



The Miller Volcanic Spark Discharge Experiment

Adam P. Johnson,[1] H. James Cleaves,[2] Jason P. Dworkin,[3] Daniel P. Glavin,[3] Antonio Lazcano,[4] Jeffrey L. Bada[5]*

In 1953, Miller (*1*) published a short paper describing the spark discharge synthesis of amino acids from a reducing gas mixture thought to represent the atmosphere of the early Earth. This experiment showed that the basic molecules of life could be synthesized from simple molecules, suggesting that Darwin's "warm little pond" was a feasible scenario.

After Miller's death on 20 May 2007, we found several boxes containing vials of dried residues. Notebooks (*2*) indicated that the vials came from his

We were interested in the second apparatus because it possibly simulates the spark discharge synthesis by lightning in a steam-rich volcanic eruption (*6*) (Fig. 1A). Miller identified five different amino acids, plus several unknowns, in the extracts from this apparatus (*3*). Product yields appeared somewhat higher than those in the classical configuration, although Miller never confirmed this. We reanalyzed 11 vials in order to characterize the diversity of products synthesized in this apparatus.

and found to have a lower diversity of amino acids (table S1). The yield of amino acids synthesized in the volcanic experiment is comparable to, and in some cases exceeds, those found in the experiments Miller conducted (*1*, *3*, *5*). Hydroxylated compounds were preferentially synthesized in the volcanic experiment. Steam injected into the spark may have generated OH radicals that reacted with either the amino acid precursors or the amino acids themselves (*7*).

Geoscientists today doubt that the primitive atmosphere had the highly reducing composition Miller used. However, the volcanic apparatus experiment suggests that, even if the overall atmosphere was not reducing, localized prebiotic synthesis could have been effective. Reduced gases and lightning associated with volcanic eruptions in hot spots or island arc–type systems could have been prevalent on the early Earth before extensive continents formed (*8*). In these volcanic plumes, HCN, aldehydes, and ketones may have been produced, which, after washing out of the atmosphere, could have become involved in the synthesis of organic molecules (*3*, *4*, *8*). Amino acids formed in volcanic island systems could have accumulated in tidal areas, where they could be polymerized by carbonyl sulfide, a simple volcanic gas that has been shown to form peptides under mild conditions (*9*).

Fig. 1. (**A**) Lightning associated with the 3 May 2008 eruption of the Chaiten volcano, Chile. [Photo credit: Carlos Gutierrez/UPI/Landov] (**B**) The volcanic spark discharge apparatus used by Miller (*3*). Gas quantities added were 200 torr of CH$_4$, 200 torr of NH$_3$, and 100 torr of H$_2$ [these would have dissolved in the water according to their solubilities (*2*)]. Water was added to the 500-cm^3 (cc) flask and boiled, and the apparatus sparked with a Tesla coil for 1 week; (**C**) Moles (relative to glycine = 1) of the various amino acids detected in the volcanic apparatus vials [see (*2*) and table S1 for abbreviations]. Amino acids underlined have not been previously reported in spark discharge experiments. Values for amines are minimum values because of loss due to their volatility during workup.

References and Notes

1. S. L. Miller, *Science* **117**, 528 (1953).
2. Analytical details and additional data are available as supporting material on *Science* Online.
3. S. L. Miller, *J. Am. Chem. Soc.* **77**, 2351 (1955).
4. A. Lazcano, J. L. Bada, *Origins Life Evol. Biosph.* **33**, 235 (2003).
5. D. Ring, W. Yecheskel, N. Friedmann, S. L. Miller, *Proc. Natl. Acad. Sci. U.S.A.* **69**, 765 (1972).
6. S. R. McNutt, C. M. Davis, *J. Volcanol. Geotherm. Res.* **102**, 45 (2000).
7. D. Ring, S. L. Miller, *Origins Life Evol. Biosph.* **15**, 7 (1984).
8. R. D. Hill, *Origins Life Evol. Biosph.* **22**, 277 (1991).
9. L. Leman, L. Orgel, M. Reza Ghadiri, *Science* **306**, 283 (2004).

Supporting Online Material

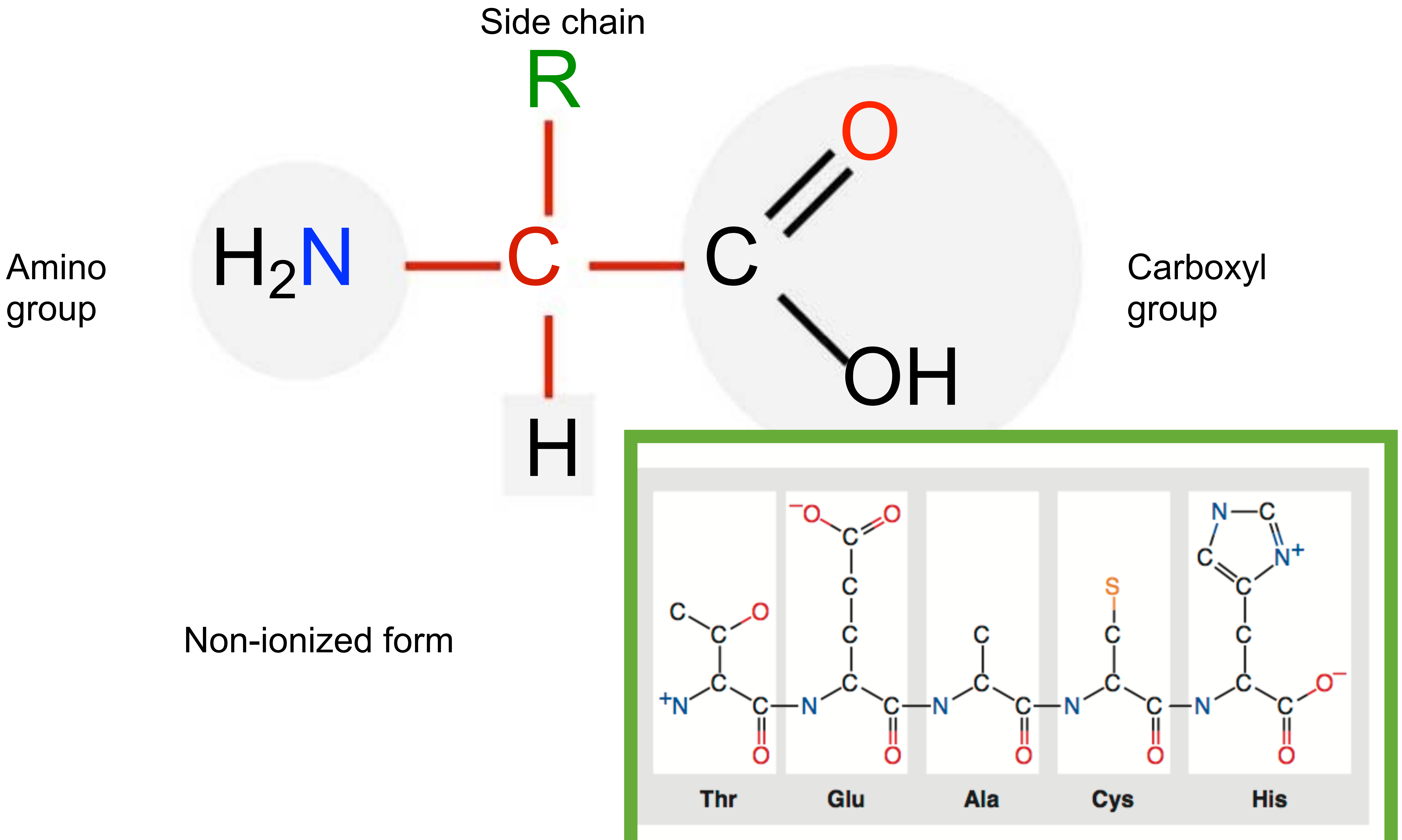
www.sciencemag.org/cgi/content/full/322/5900/404/DC1
Materials and Methods
Figs. S1 and S2
Table S1
References and Notes

9 June 2008; accepted 8 August 2008

Molecules of the Prebiotic Soup

- Amino acids are the monomers that are the building blocks of proteins.
  - **Carbon** bonded to four functional groups, including a variable R-group.
  - Readily form in **Stanley Miller experiment** and have been found on meteorites striking earth.

All **amino acids** have the same general structure.



Non-ionized form

Miller's Primitive Earth Experiment

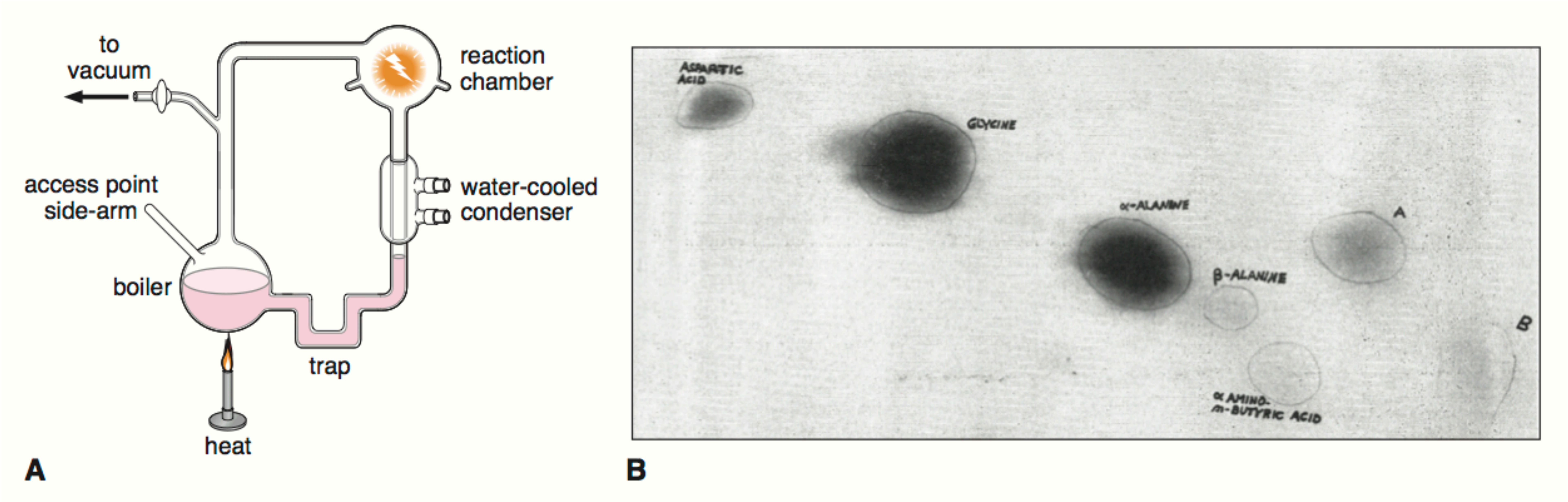


Fig. 4.5

modified from Stanley L. Miller. 1953

Miller's Primitive Earth Apparatus

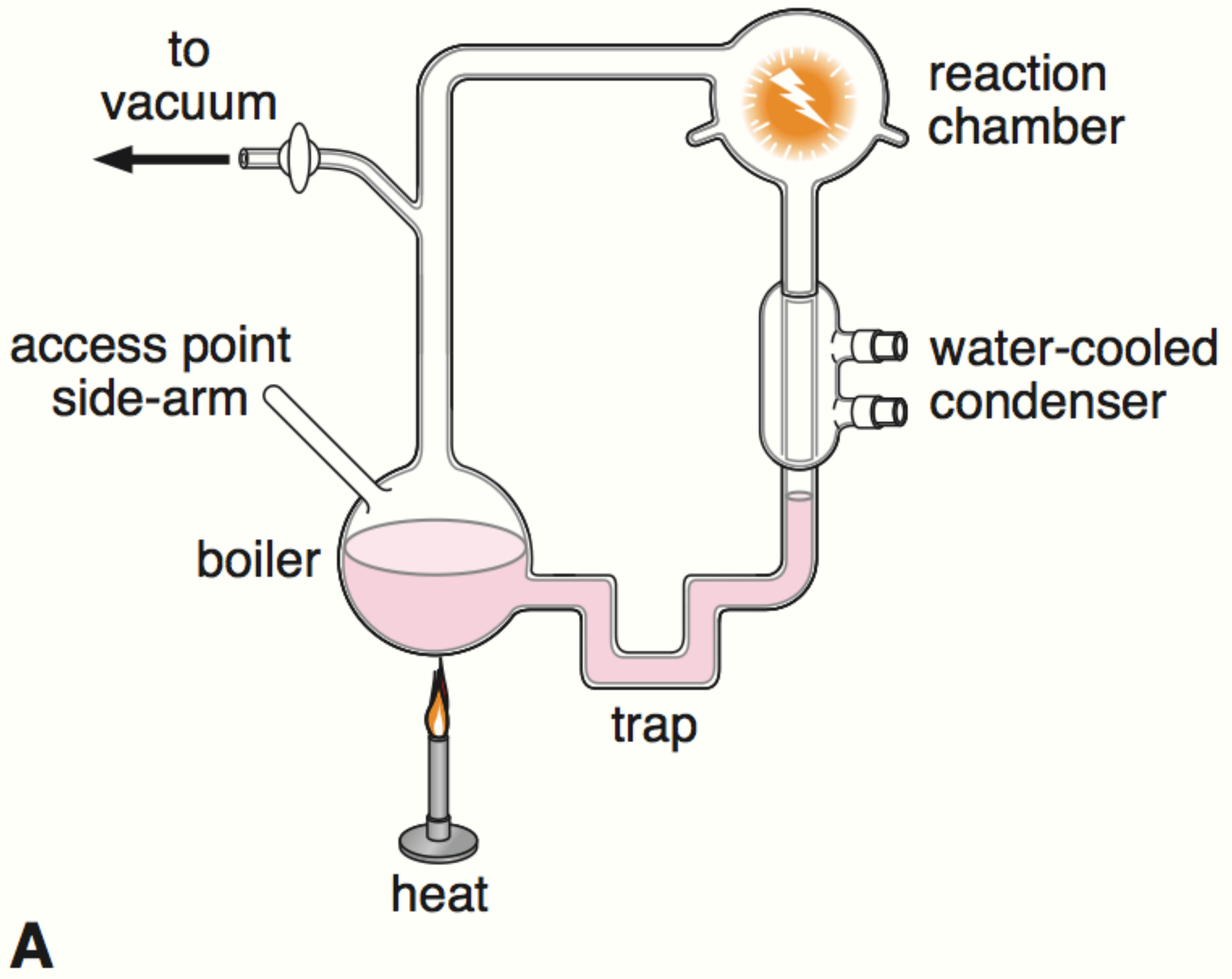


Fig. 4.5

modified from Stanley L. Miller. 1953

Miller's Primitive Earth Apparatus

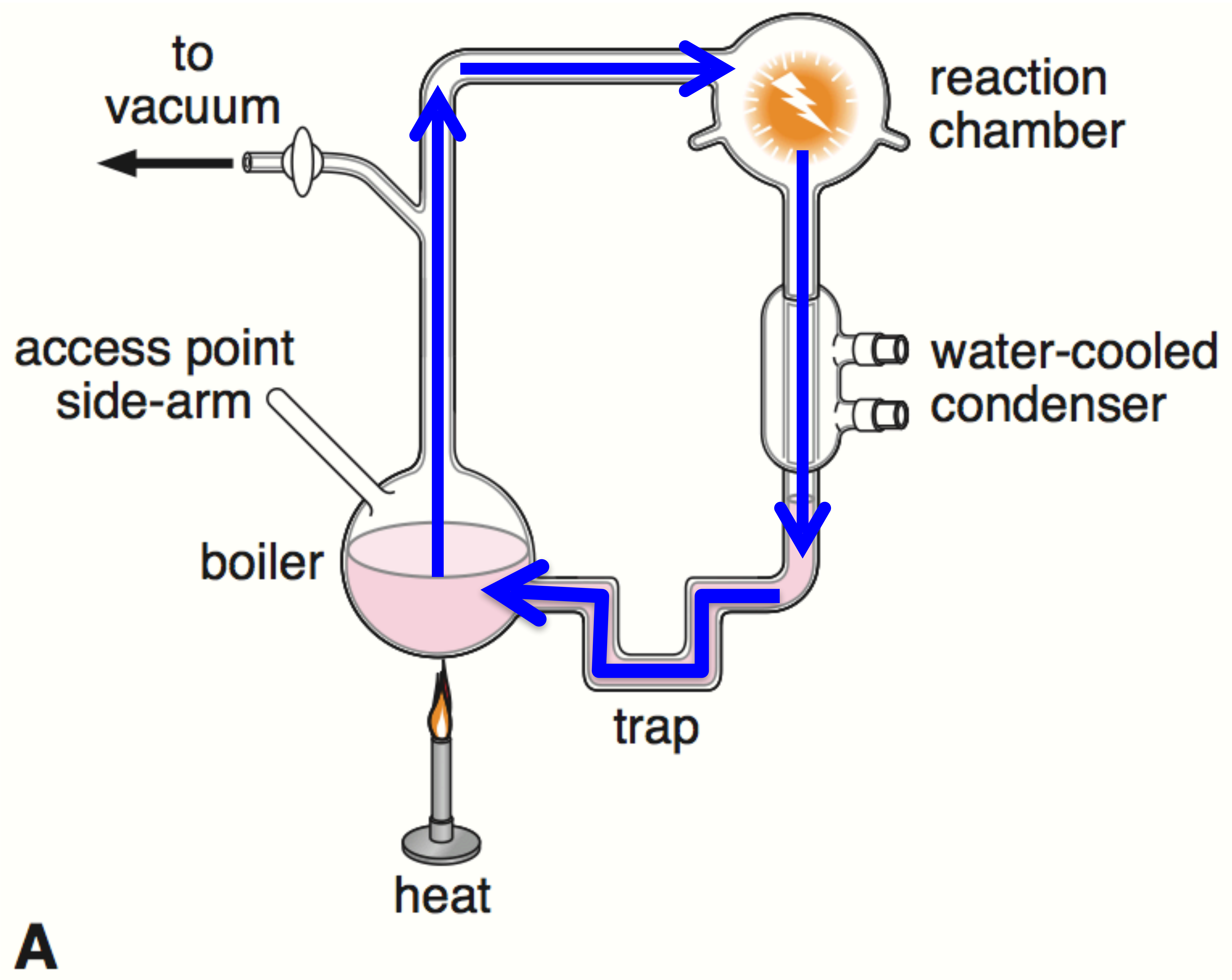


Fig. 4.5

modified from Stanley L. Miller. 1953

Products from Miller's Experiment

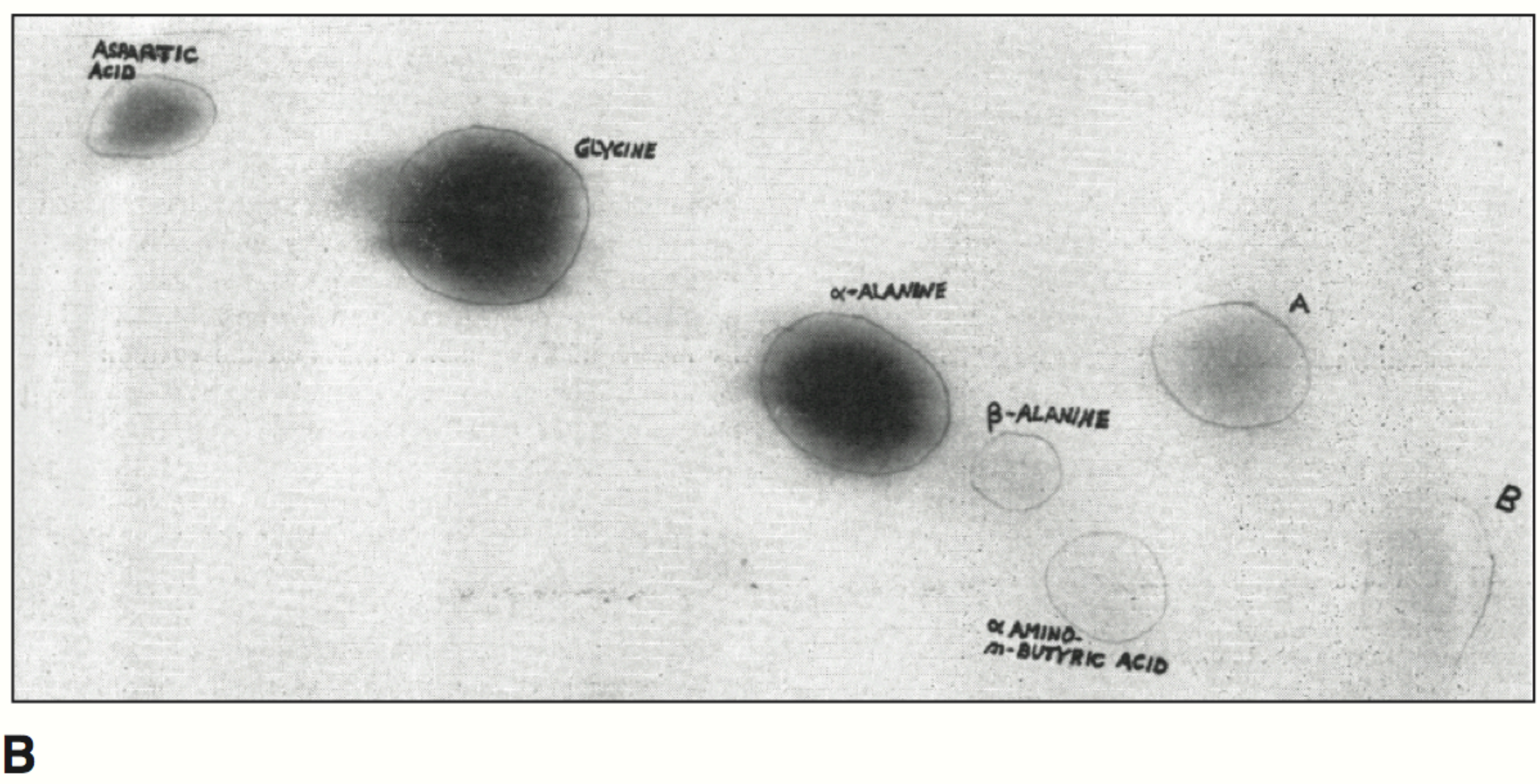
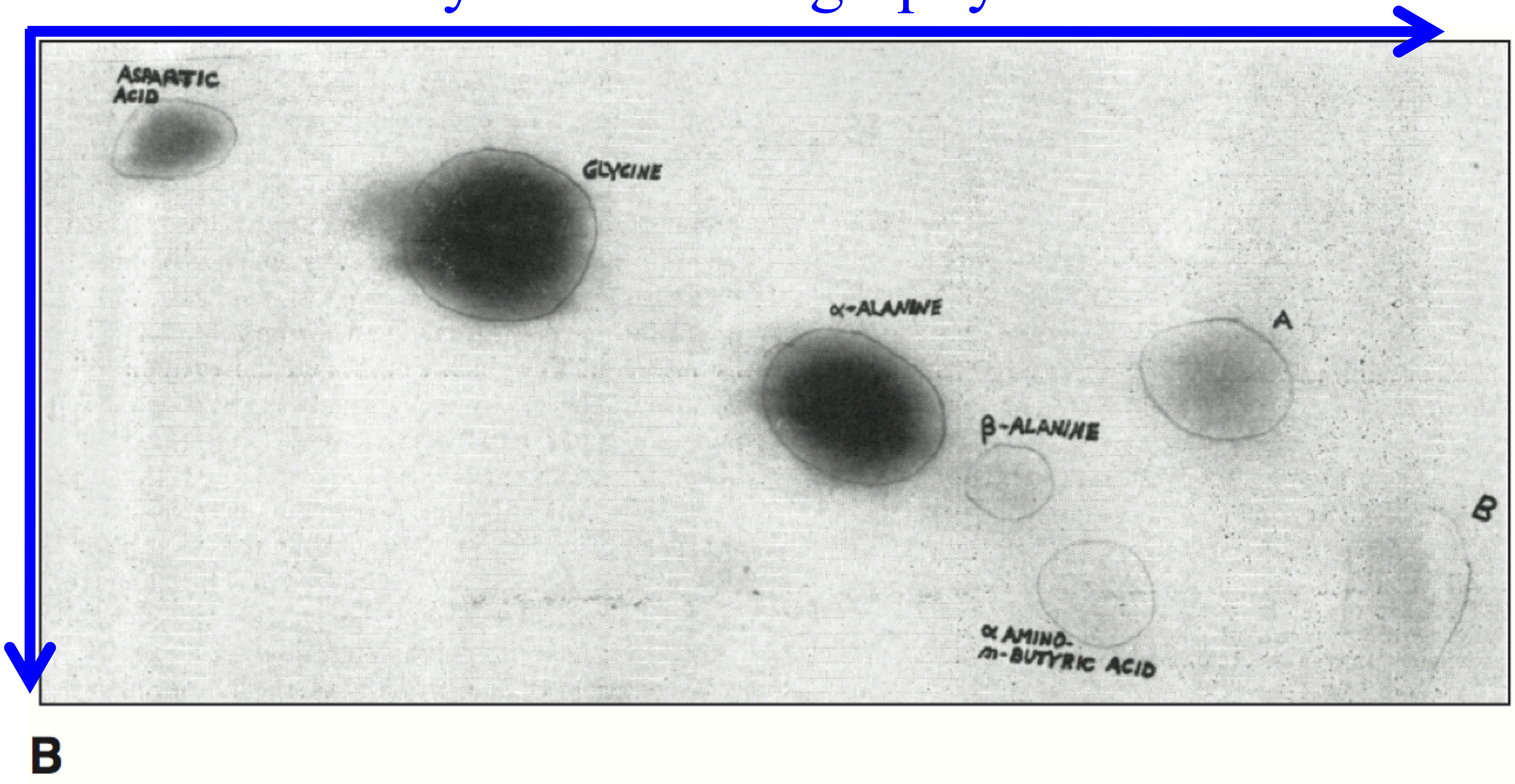


Fig. 4.5

modified from Stanley L. Miller. 1953

Separated by 2D TLC



modified from Stanley L. Miller. 1953

Fig. 4.5

Separated by 2D TLC

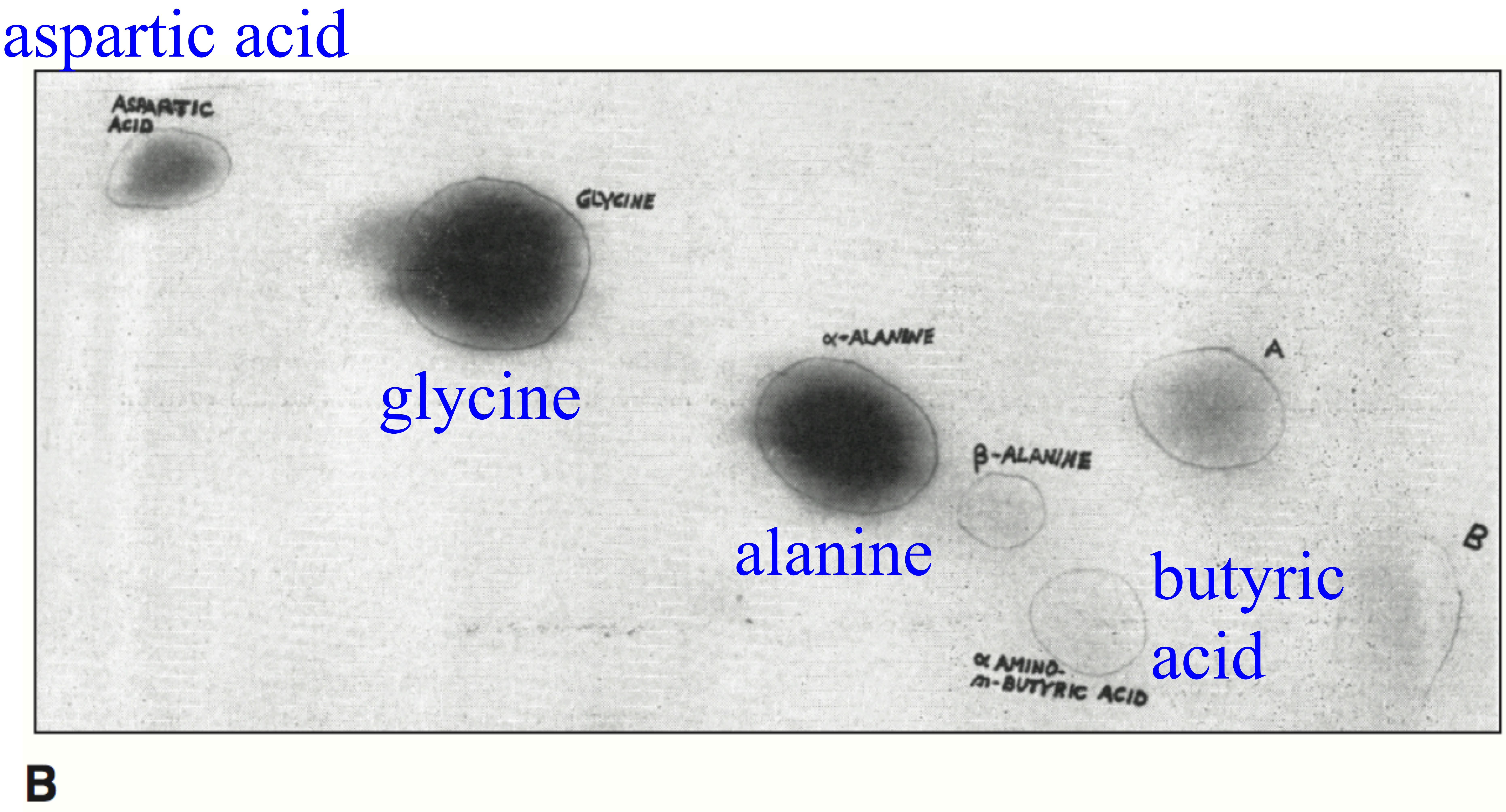
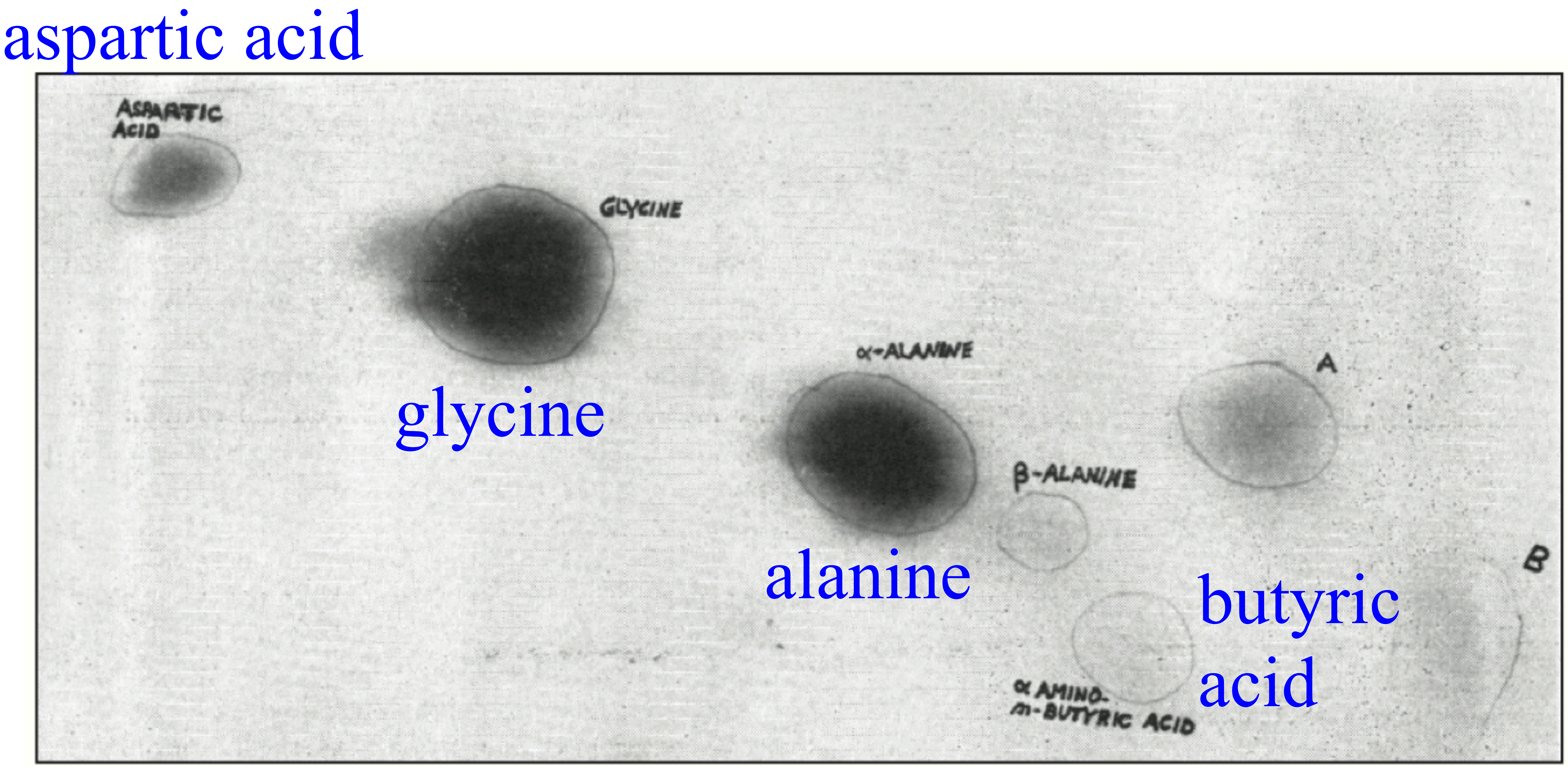


Fig. 4.5

modified from Stanley L. Miller. 1953

Separated by 2D TLC



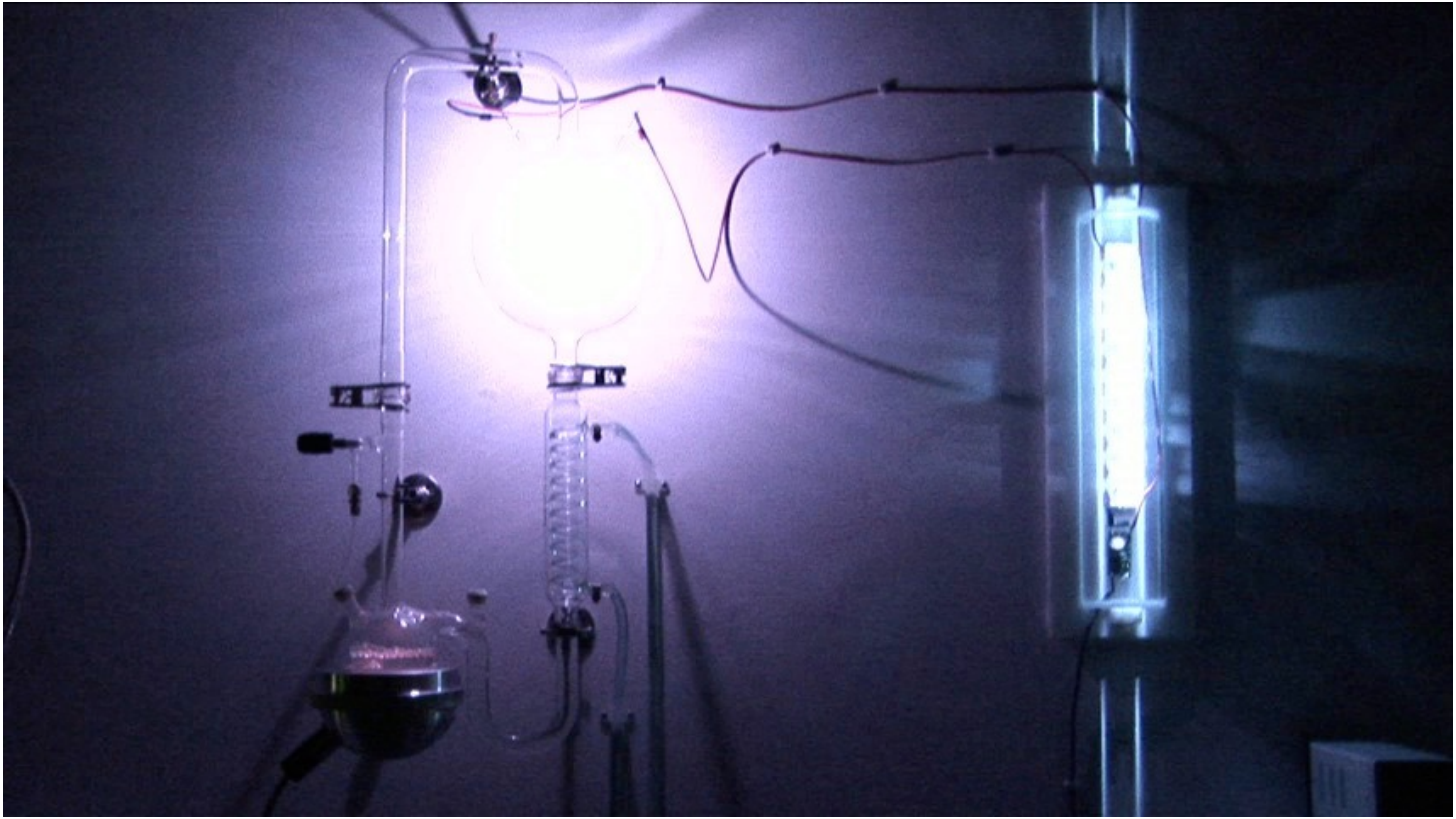
B amino acids and fatty acids produced abiotically

Fig. 4.5

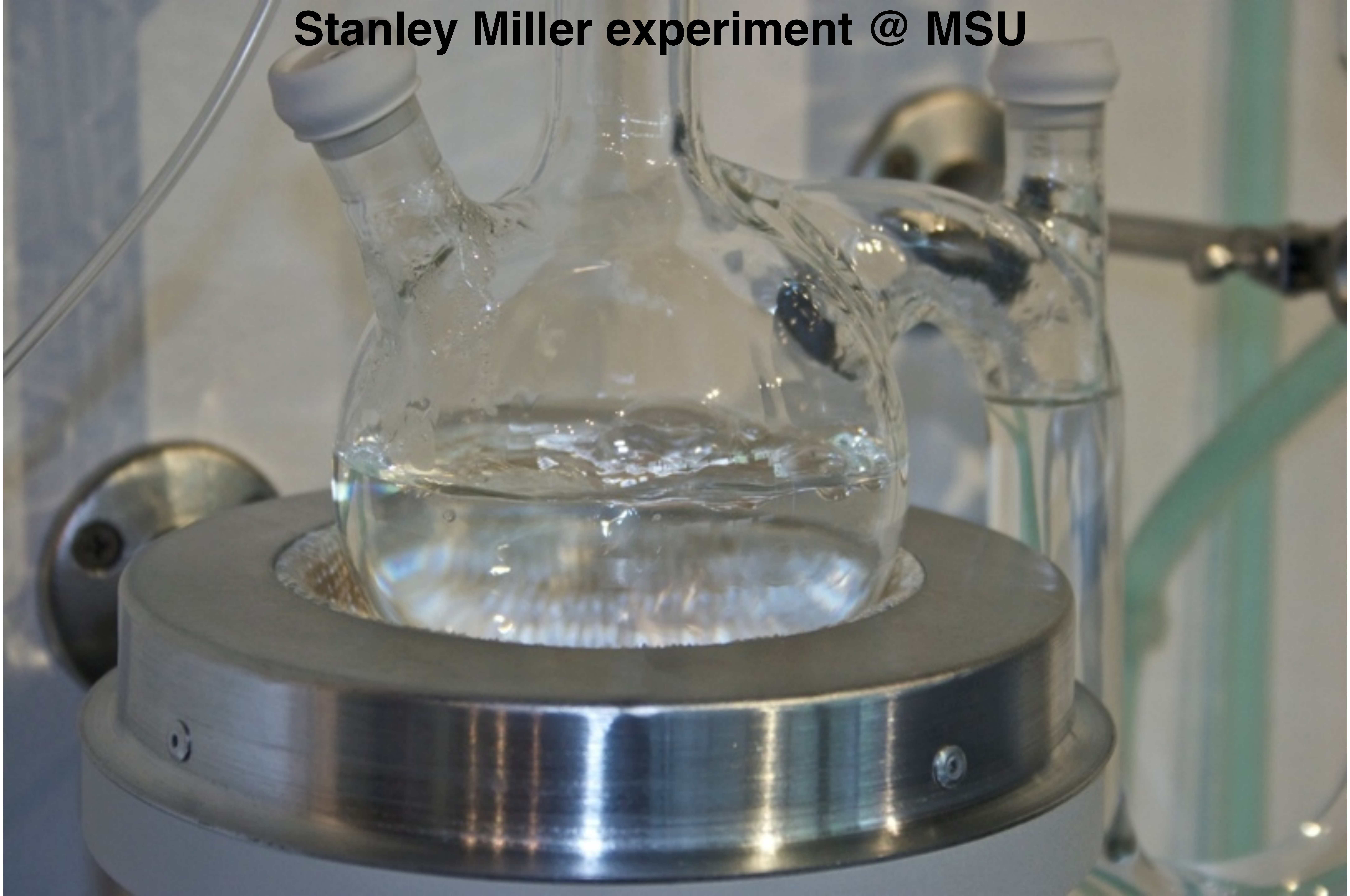
modified from Stanley L. Miller. 1953

Stanley Miller experiment @ MSU

Stanley Miller experiment @ MSU



Stanley Miller experiment @ MSU



Origins of Life: Experiment #1.x

from **Adam W. Brown** 2 years ago NOT YET RATED

http://vimeo.com/32106116

(Trifecta)

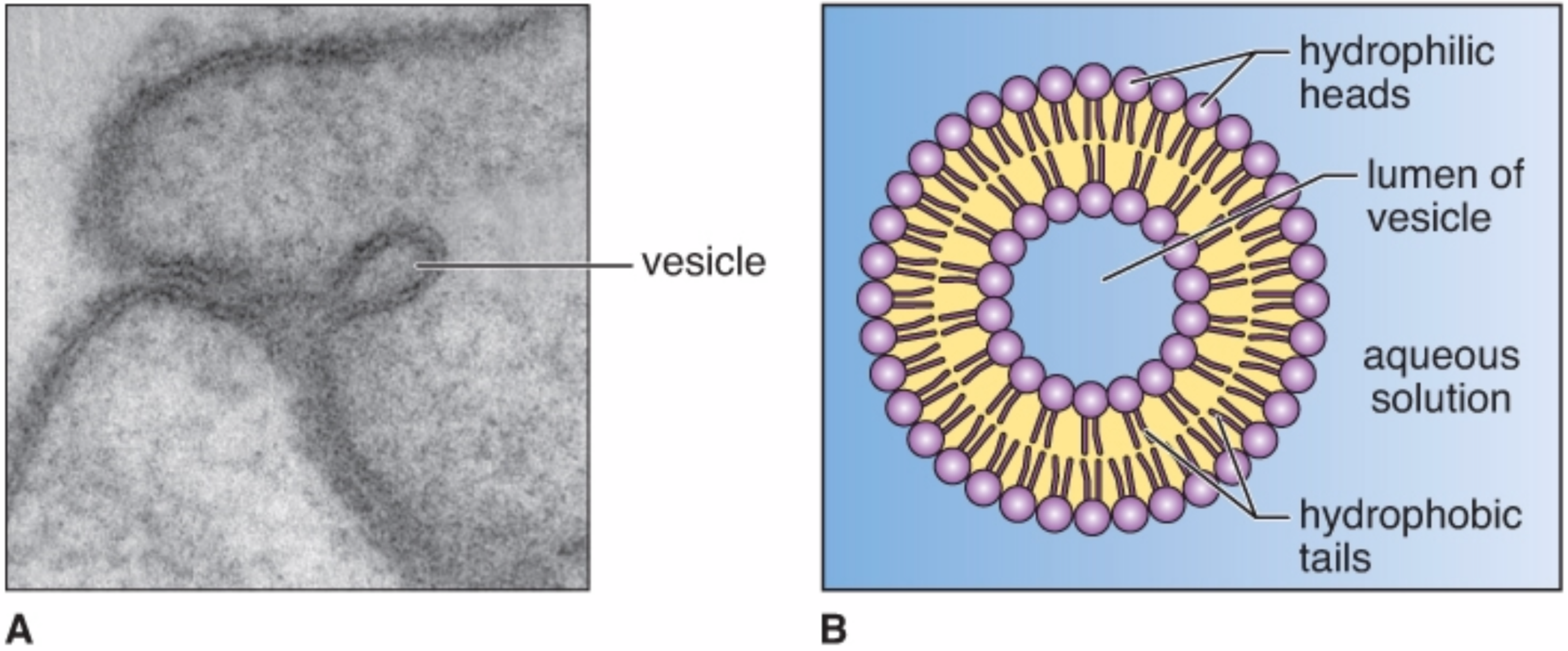


Figure 4.6 Vesicles made of lipids similar to those formed in NASA's experiments. Electron micrograph **(A)** and line drawing **(B)** of vesicles. Vesicles are spheres made of two lipid layers or a bilayer. The center cavity of a vesicle is called its lumen. A.http://www.zonapse.net/sitebuildercontent/sitebuilderpictures/vesicle.jpg B. Original art.

NASA:
UV light helps form lipids and vesicles

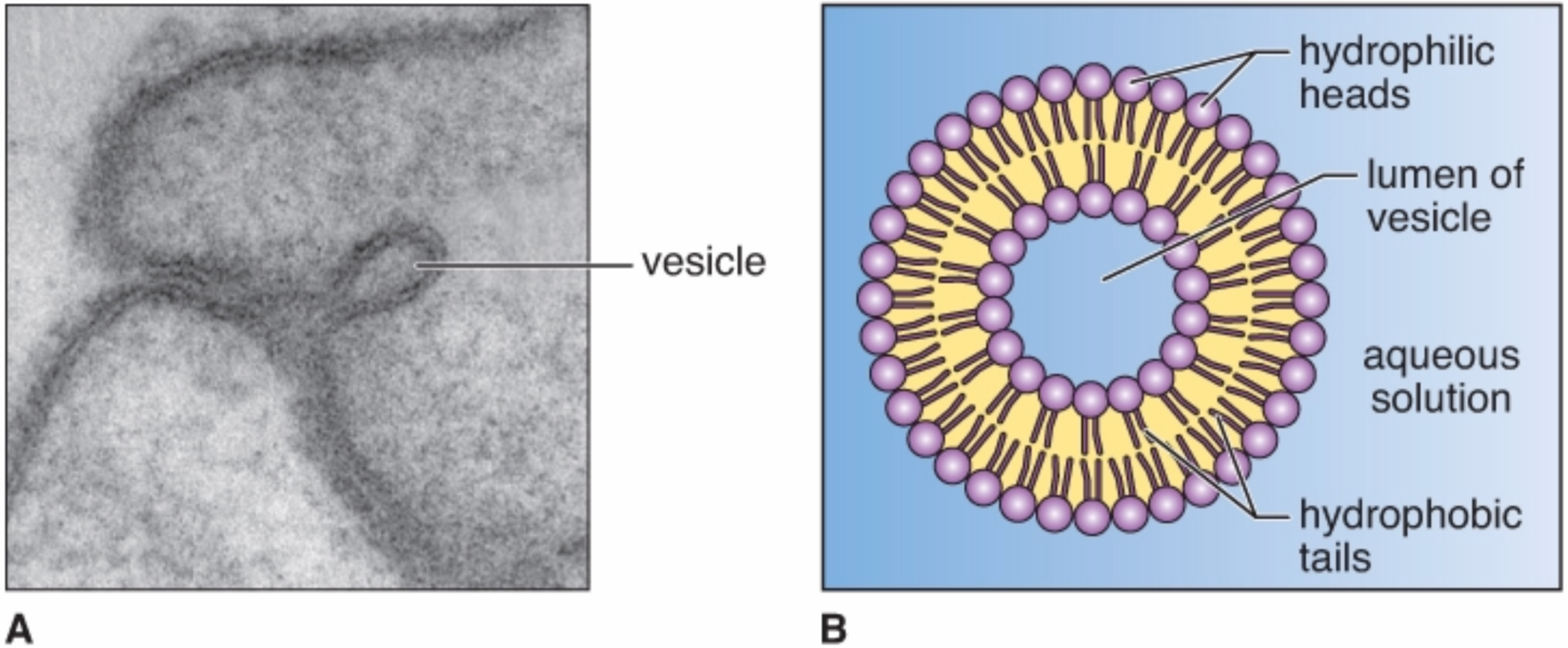


Figure 4.6 Vesicles made of lipids similar to those formed in NASA's experiments. Electron micrograph **(A)** and line drawing **(B)** of vesicles. Vesicles are spheres made of two lipid layers or a bilayer. The center cavity of a vesicle is called its lumen. A.http://www.zonapse.net/sitebuildercontent/sitebuilderpictures/vesicle.jpg B. Original art.

What Constitutes Life?

(Take notes)

- First living entity was likely a self-replicating macromolecule that could:
  - Act as a template.
  - Catalyze reactions.
- First "living organism" was a type of enclosed environment, assisting replication.

Unicellular Tetrahymena

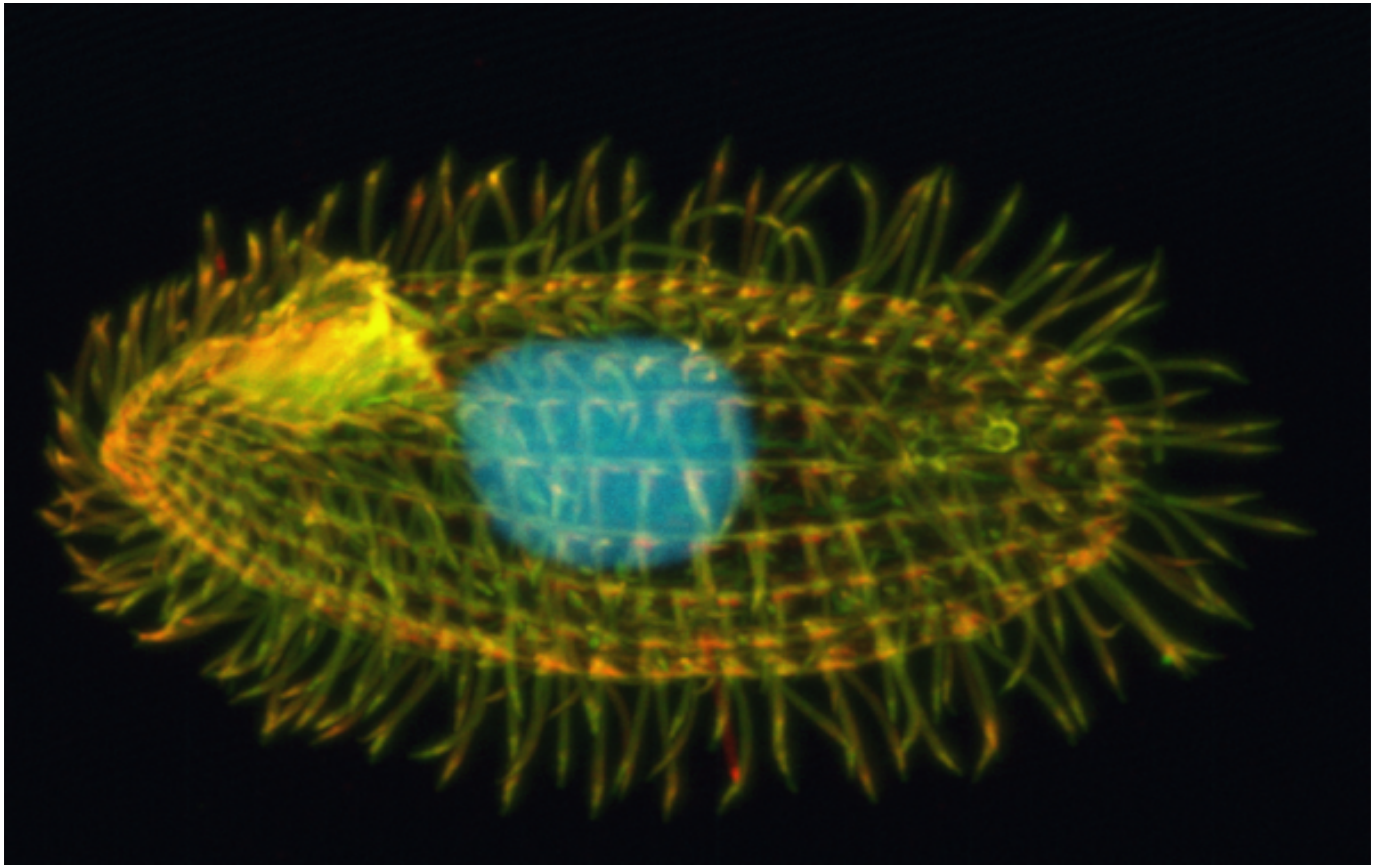
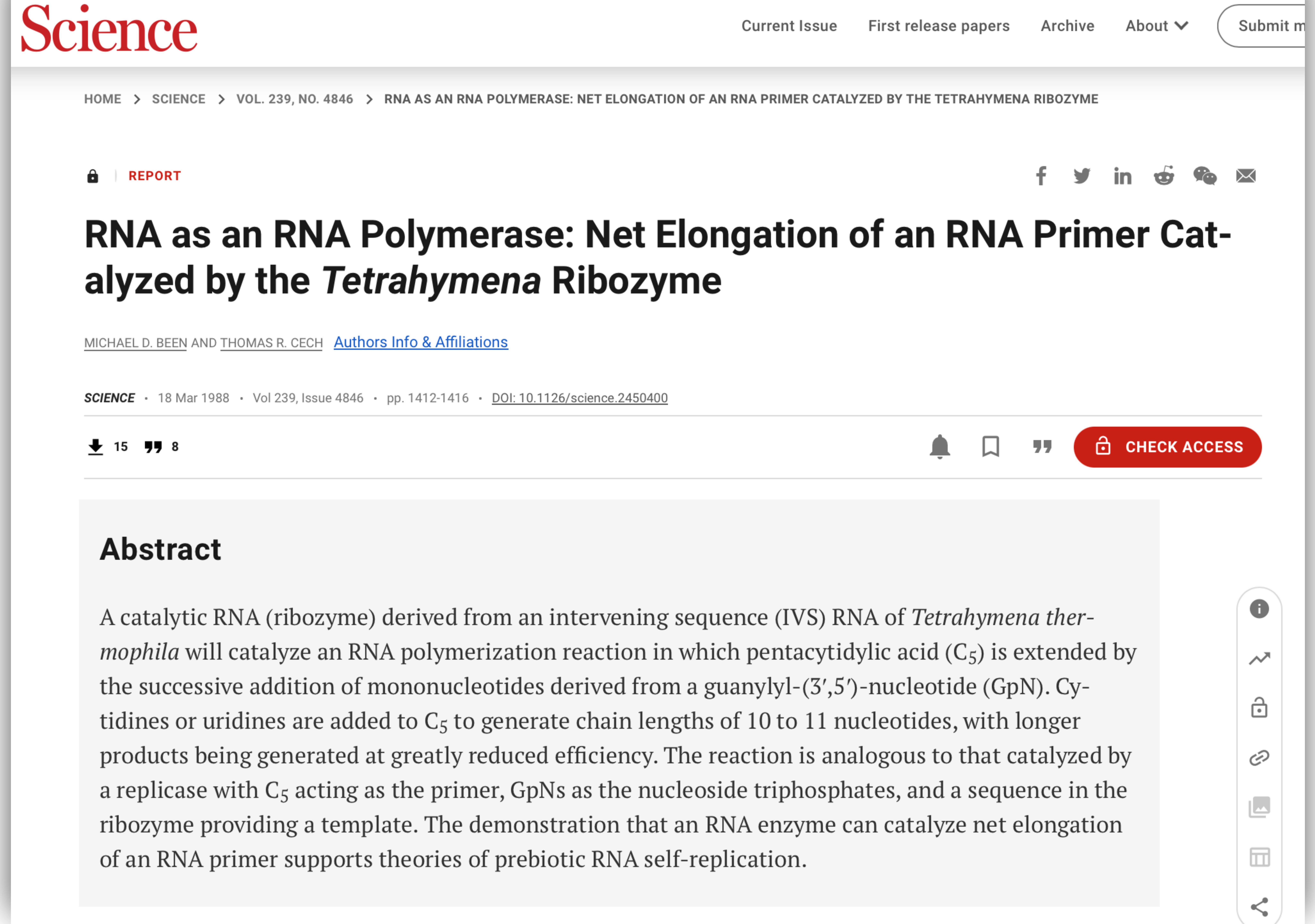


Fig. 6.7

A: courtesy Esther Zhuang and Kalju Kahn; B public domain



RNA as an RNA Polymerase: Net Elongation of an RNA Primer Catalyzed by the *Tetrahymena* Ribozyme

MICHAEL D. BEEN AND THOMAS R. CECH Authors Info & Affiliations

SCIENCE • 18 Mar 1988 • Vol 239, Issue 4846 • pp. 1412-1416 • DOI: 10.1126/science.2450400

Abstract

A catalytic RNA (ribozyme) derived from an intervening sequence (IVS) RNA of *Tetrahymena thermophila* will catalyze an RNA polymerization reaction in which pentacytidylic acid (C_5) is extended by the successive addition of mononucleotides derived from a guanylyl-(3′,5′)-nucleotide (GpN). Cytidines or uridines are added to C_5 to generate chain lengths of 10 to 11 nucleotides, with longer products being generated at greatly reduced efficiency. The reaction is analogous to that catalyzed by a replicase with C_5 acting as the primer, GpNs as the nucleoside triphosphates, and a sequence in the ribozyme providing a template. The demonstration that an RNA enzyme can catalyze net elongation of an RNA primer supports theories of prebiotic RNA self-replication.

(Trifecta)

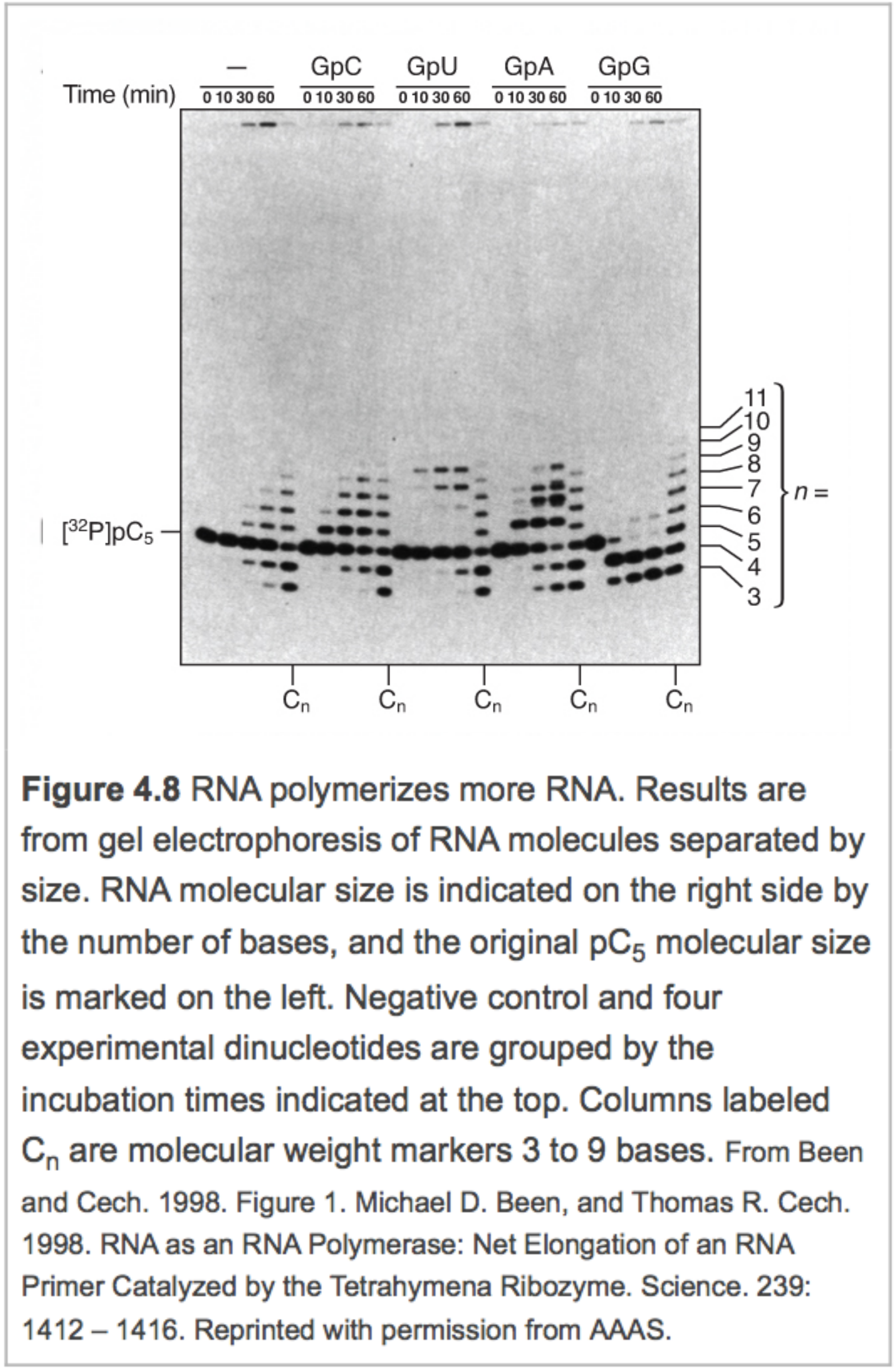


Figure 4.8 RNA polymerizes more RNA. Results are from gel electrophoresis of RNA molecules separated by size. RNA molecular size is indicated on the right side by the number of bases, and the original pC_5 molecular size is marked on the left. Negative control and four experimental dinucleotides are grouped by the incubation times indicated at the top. Columns labeled C_n are molecular weight markers 3 to 9 bases. From Been and Cech. 1998. Figure 1. Michael D. Been, and Thomas R. Cech. 1998. RNA as an RNA Polymerase: Net Elongation of an RNA Primer Catalyzed by the Tetrahymena Ribozyme. Science. 239: 1412 – 1416. Reprinted with permission from AAAS.

1. How do they visualize the molecules of interest?
2. How do they separate them in an orderly fashion?

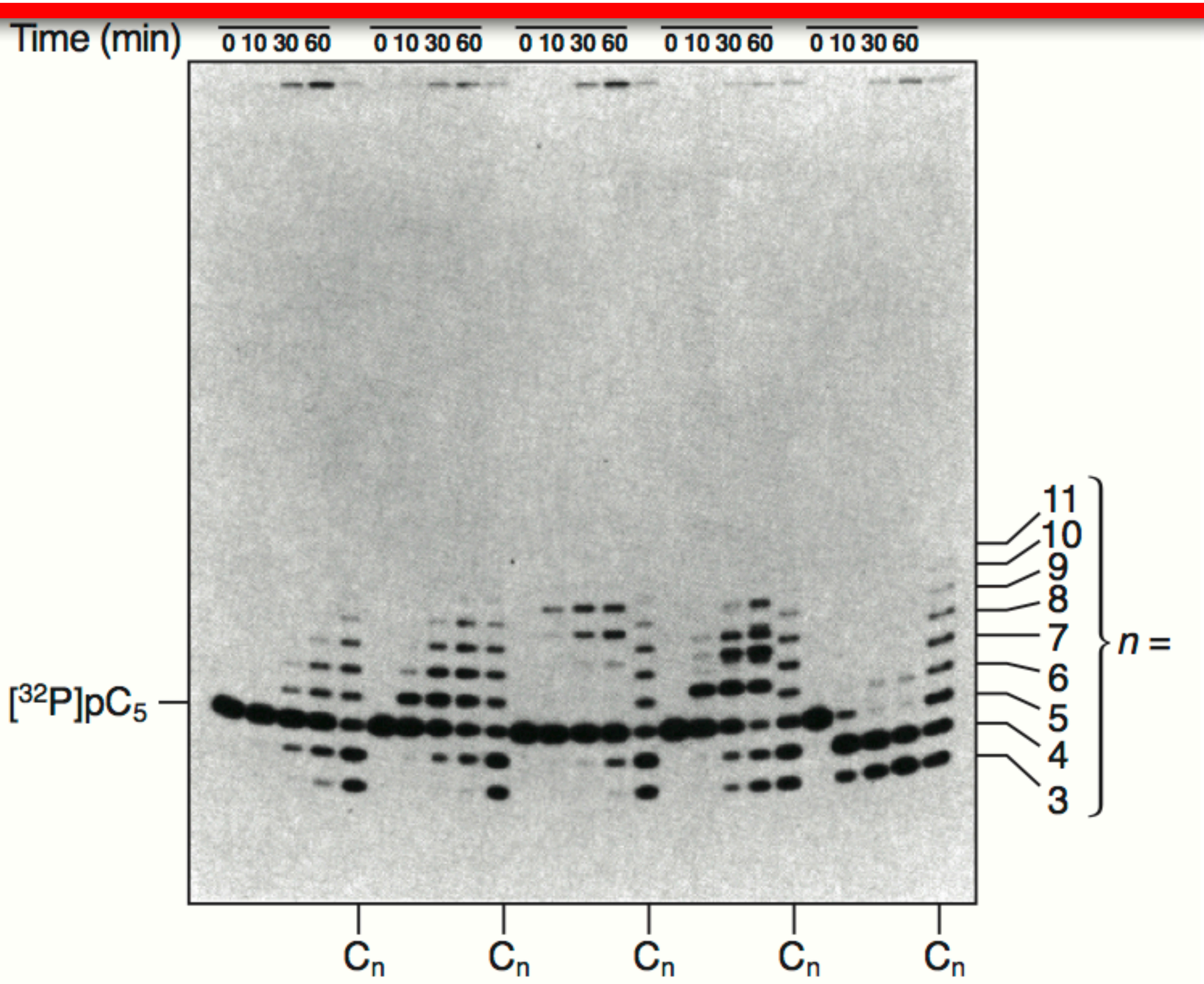


Figure 4.8 RNA polymerizes more RNA. Results are from gel electrophoresis of RNA molecules separated by size. RNA molecular size is indicated on the right side by

Modified from Been and Cech. 1998

Fig. 4.8

RNA World: RNA (ribozyme) can polymerize nucleotides

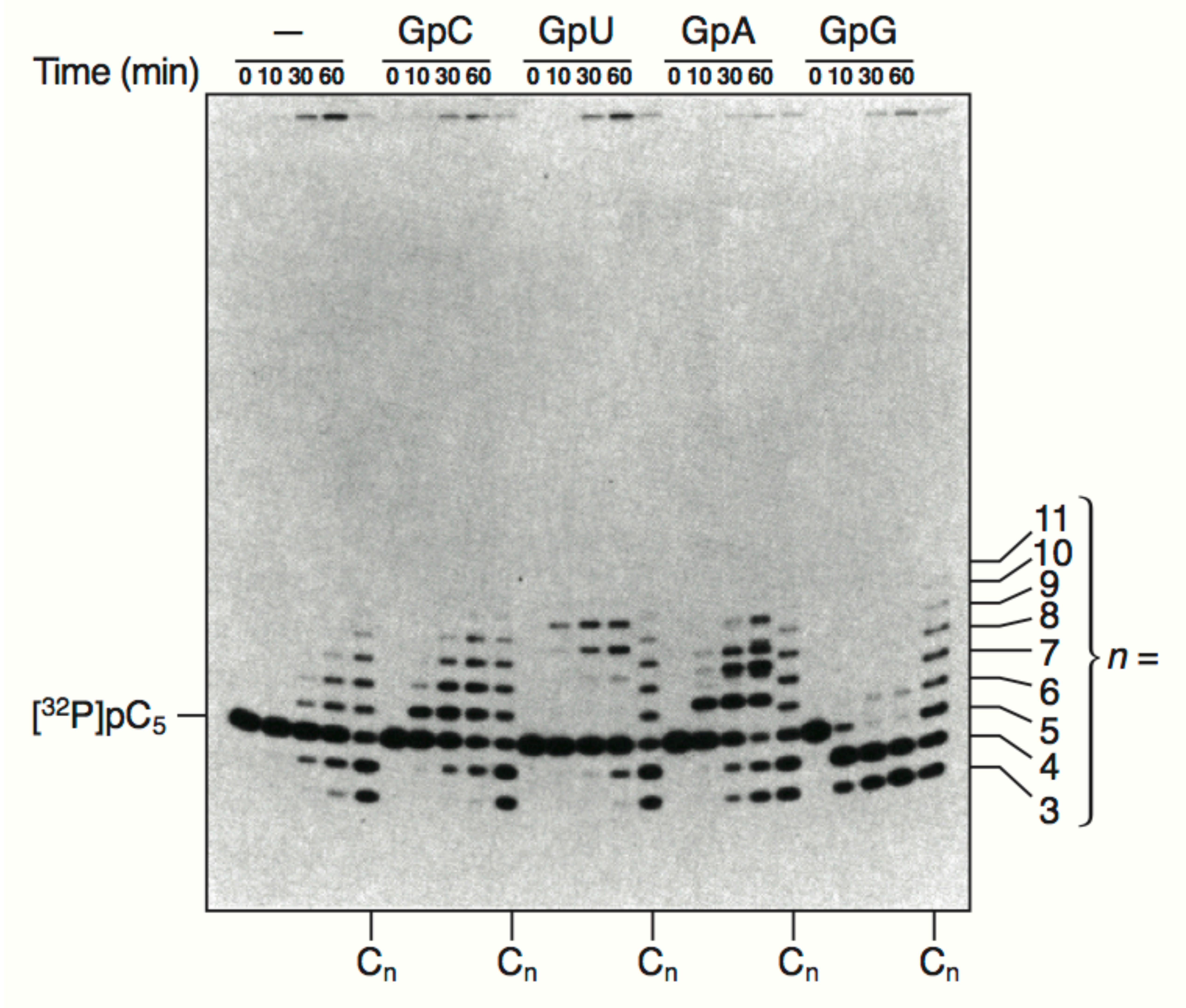


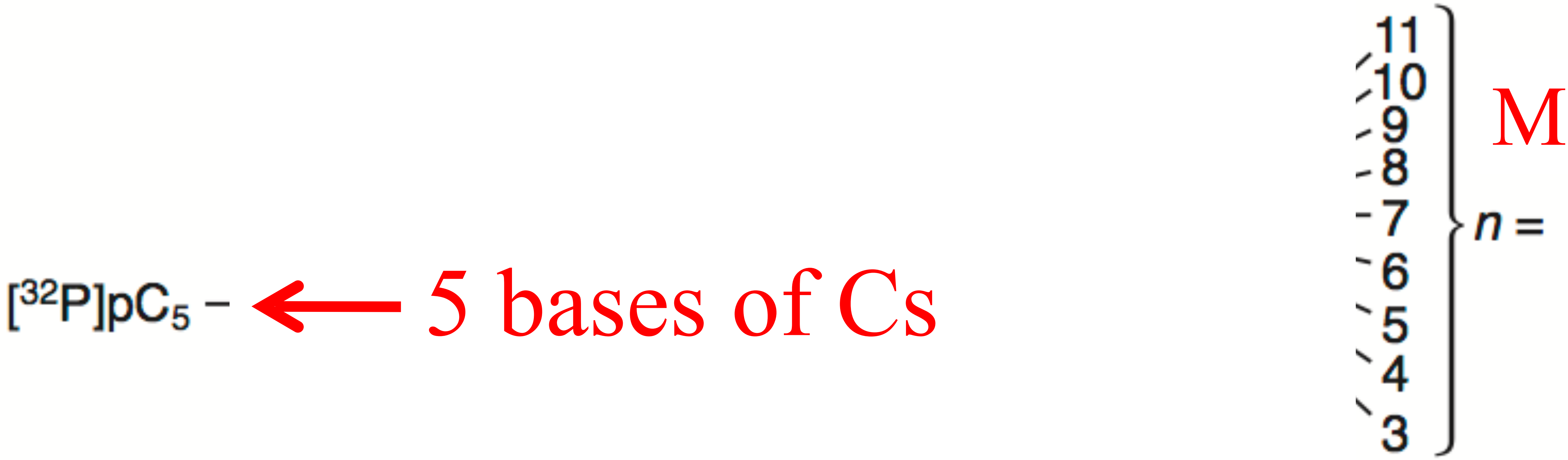
Fig. 4.8

Figure 4.8 RNA polymerizes more RNA. Results are

modified from Been and Cech. 1998

Functional Ribozyme

CpU + GpN + ribozyme → CpUpN + G + ribozyme.



5 bases of Cs

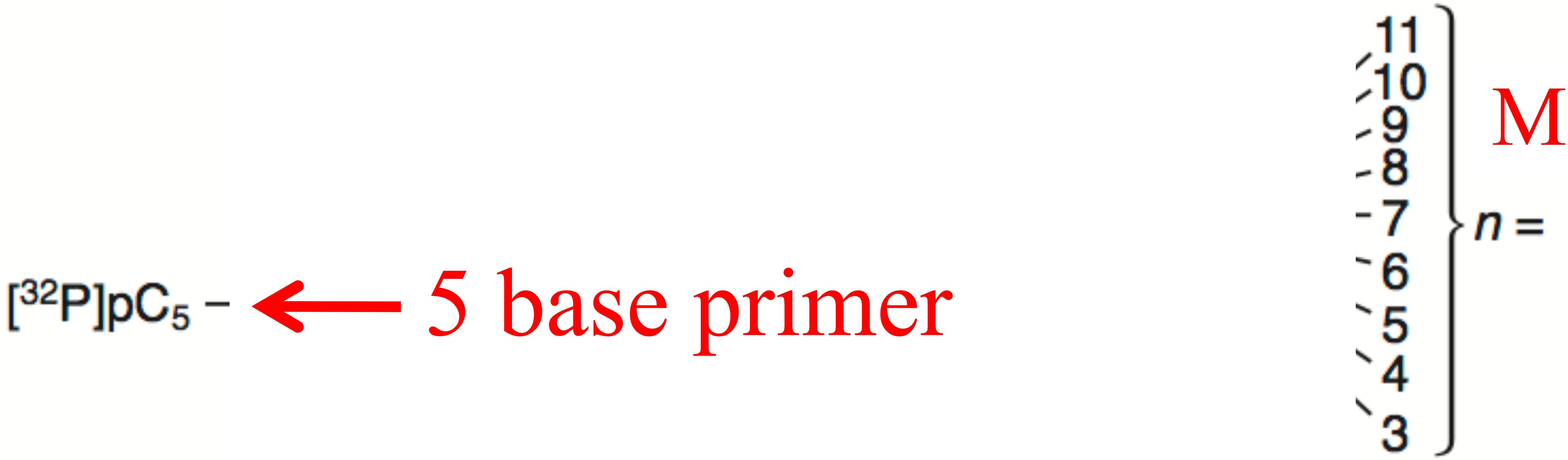
MW

modified from Been and Cech. 1998

Functional Ribozyme

GpC GpU GpA GpG

add different dinucleotides
as substrate for polymerization

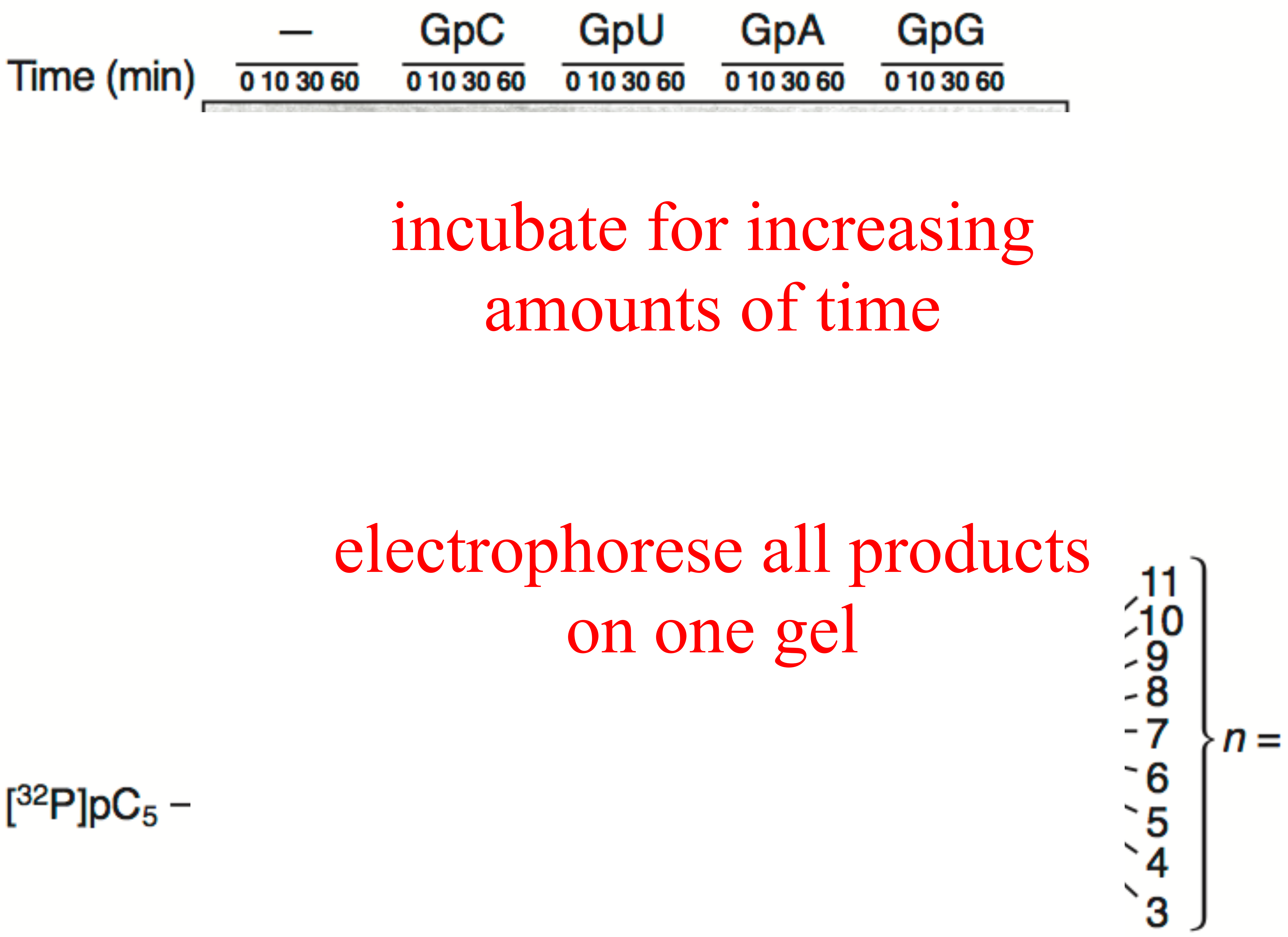


5 base primer

MW

modified from Been and Cech. 1998

Functional Ribozyme

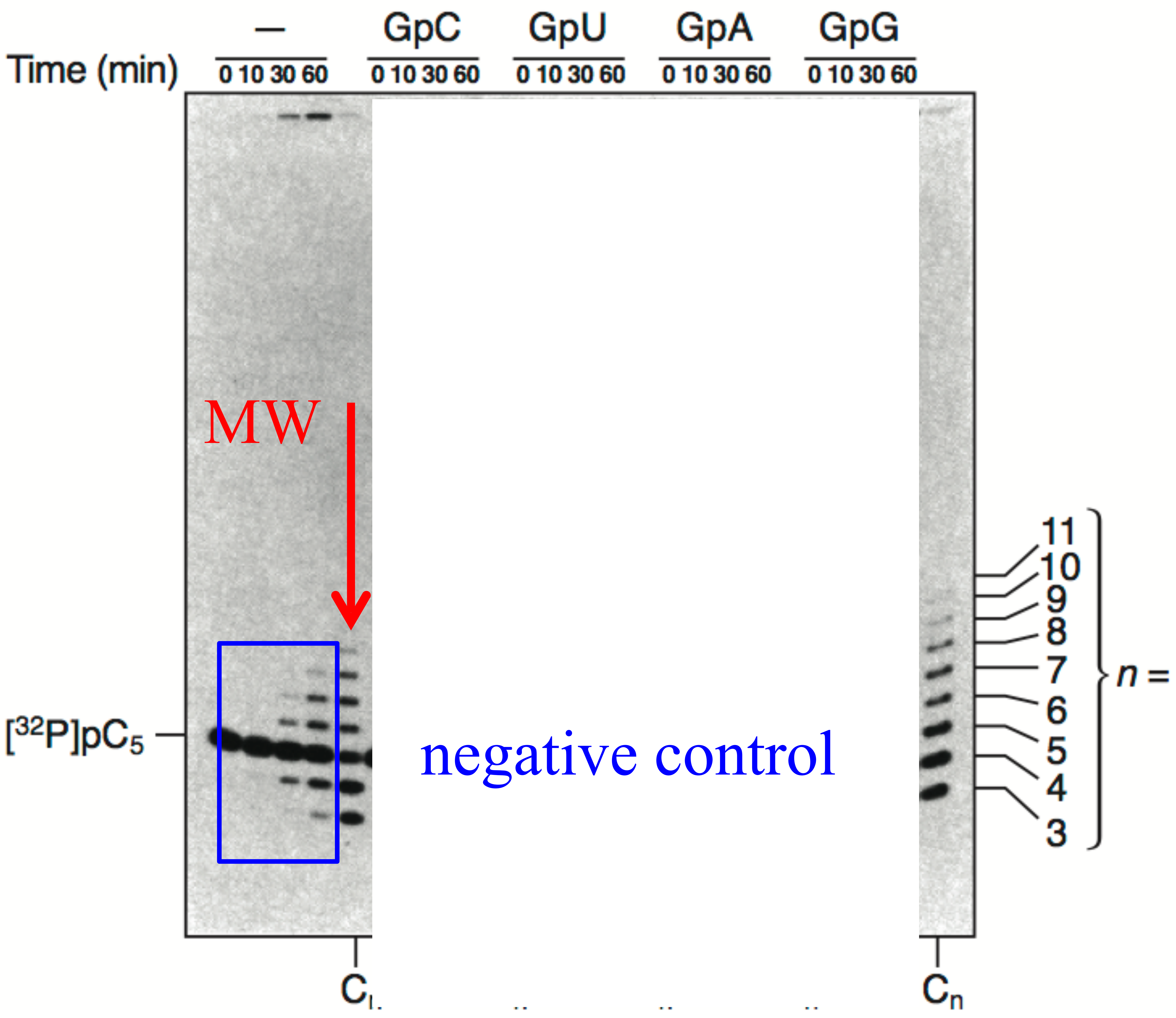


incubate for increasing amounts of time

electrophorese all products on one gel

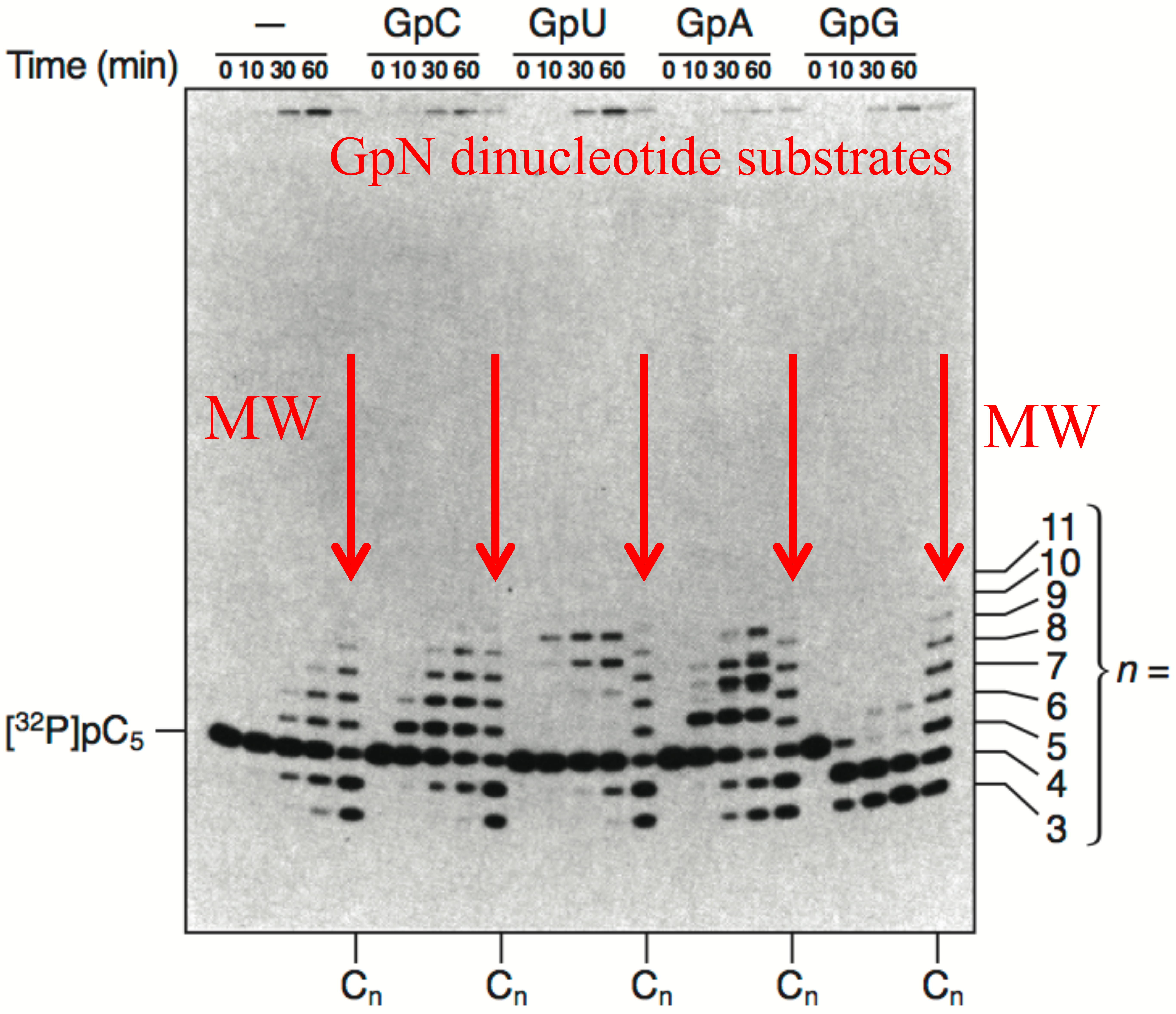
modified from Been and Cech. 1998

Functional Ribozyme



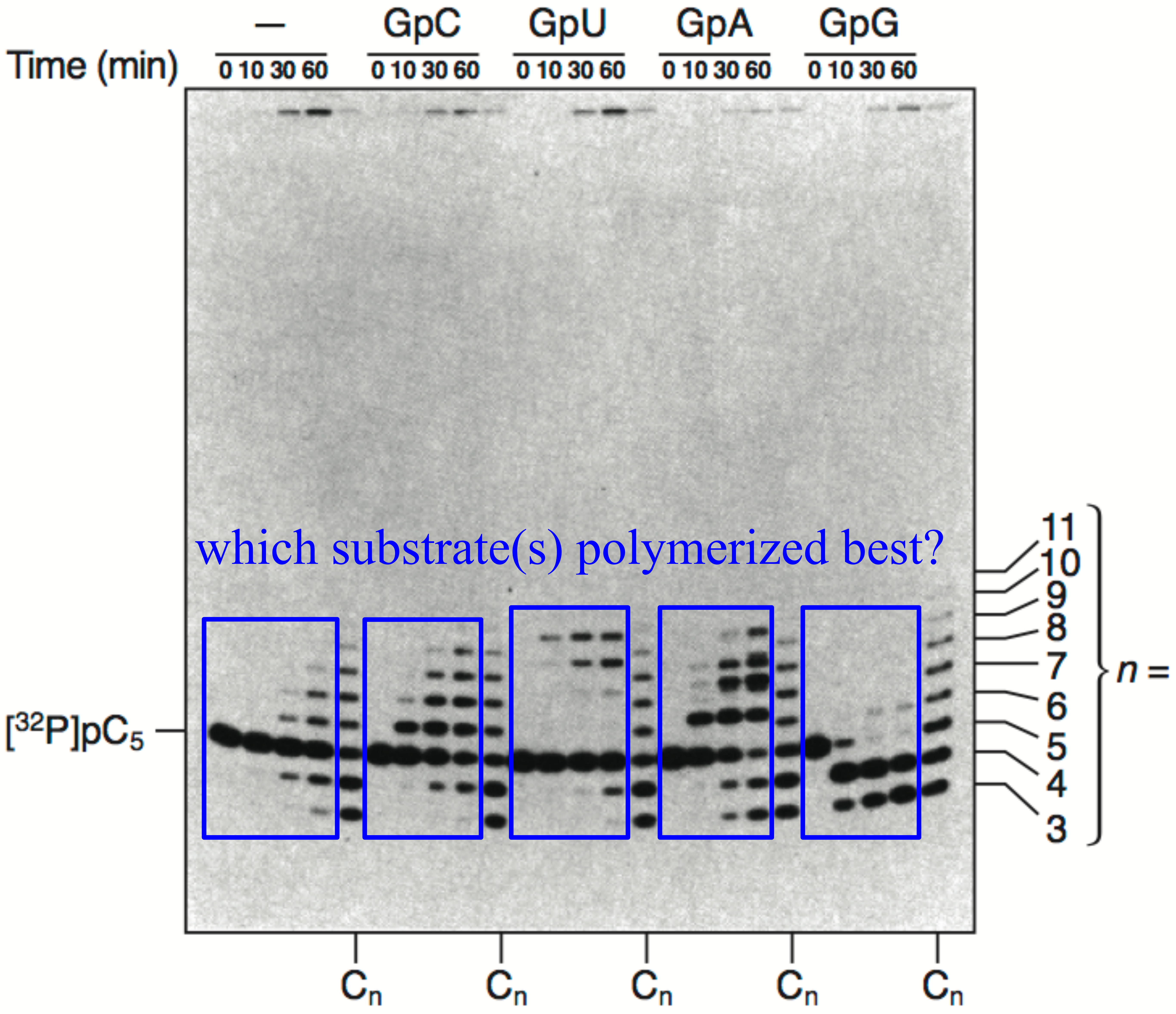
modified from Been and Cech. 1998

Functional Ribozyme



modified from Been and Cech. 1998

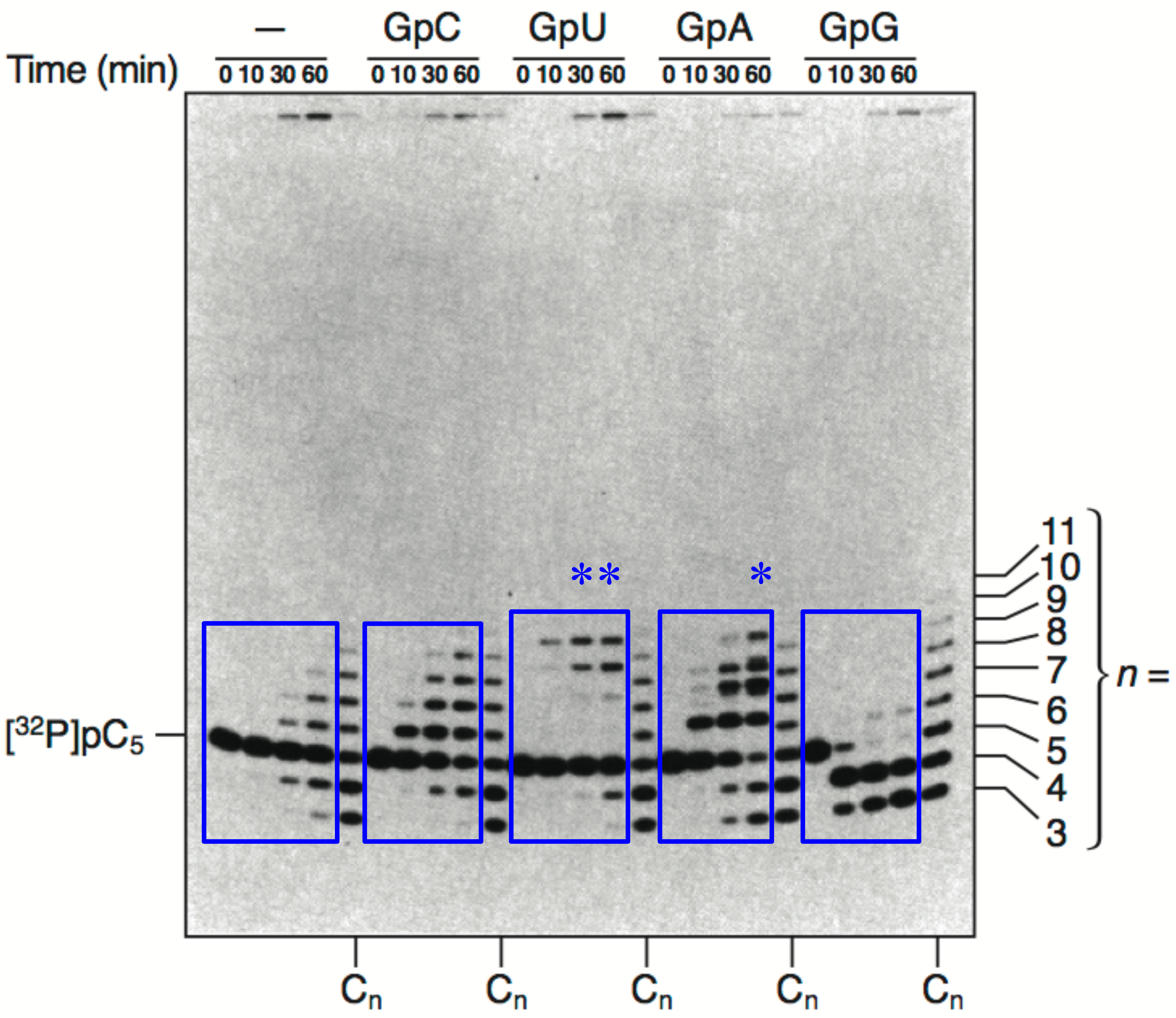
Functional Ribozyme



which substrate(s) polymerized best?

modified from Been and Cech. 1998

Functional Ribozyme



modified from Been and Cech. 1998

Molecules of the Prebiotic Soup

- Sugar monomers together make nucleotides.
  - hexoses and pentoses form readily in **Miller exp.**
  - **Ribose Question**: did ribose dominate, i.e., RNA?
- Nucleotide monomers together make nucleic acids.
  - Only **purines** have been synthesized in experiments simulating early earth conditions, not pyrimidines.