1. **Pick up** Name Folder

- Pick up name folder and set it up at seat.

2. **Sit** with your lab group.

- laptops almost closed (avoid distracting)

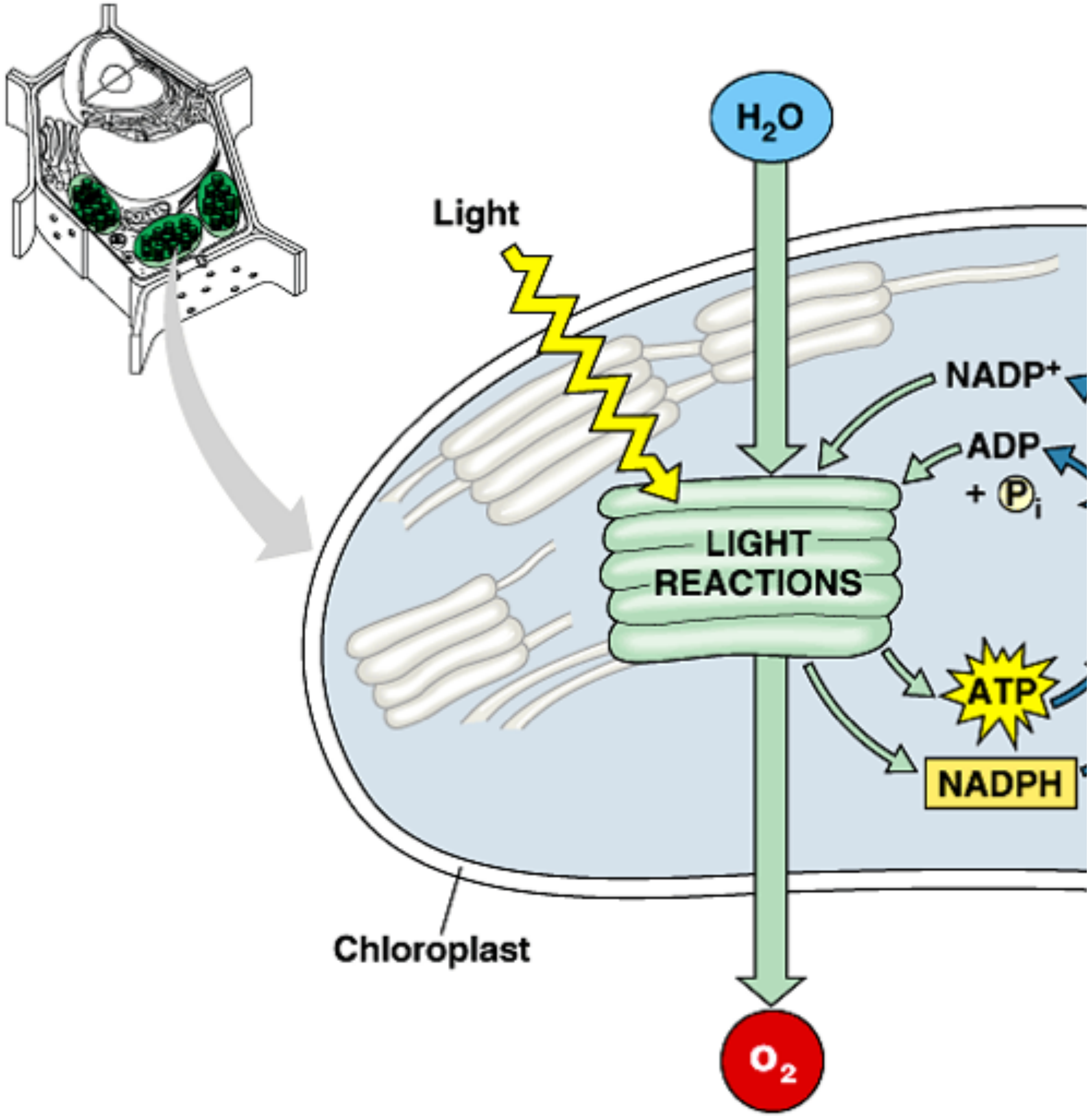
3. **Clicker** Attendance

- Launch your Top Hat, and get ready to click.

incoming photon
Stroma (pH8)
incoming photon
NADP$_{ox}$
2H$^+$
ATP
OH$^-$
NAD$_{re}$
Q
PQ
P700
CF
P680
2e$^-$
Fd
Cyt f
PC
FAD
FeS
Z
PQ
2H$^+$
H$^+$
PHOTOSYSTEM II
PHOTOSYSTEM I
H$_2$O
$\frac{1}{2}$O$_2$
Thylakoid interior (pH4)

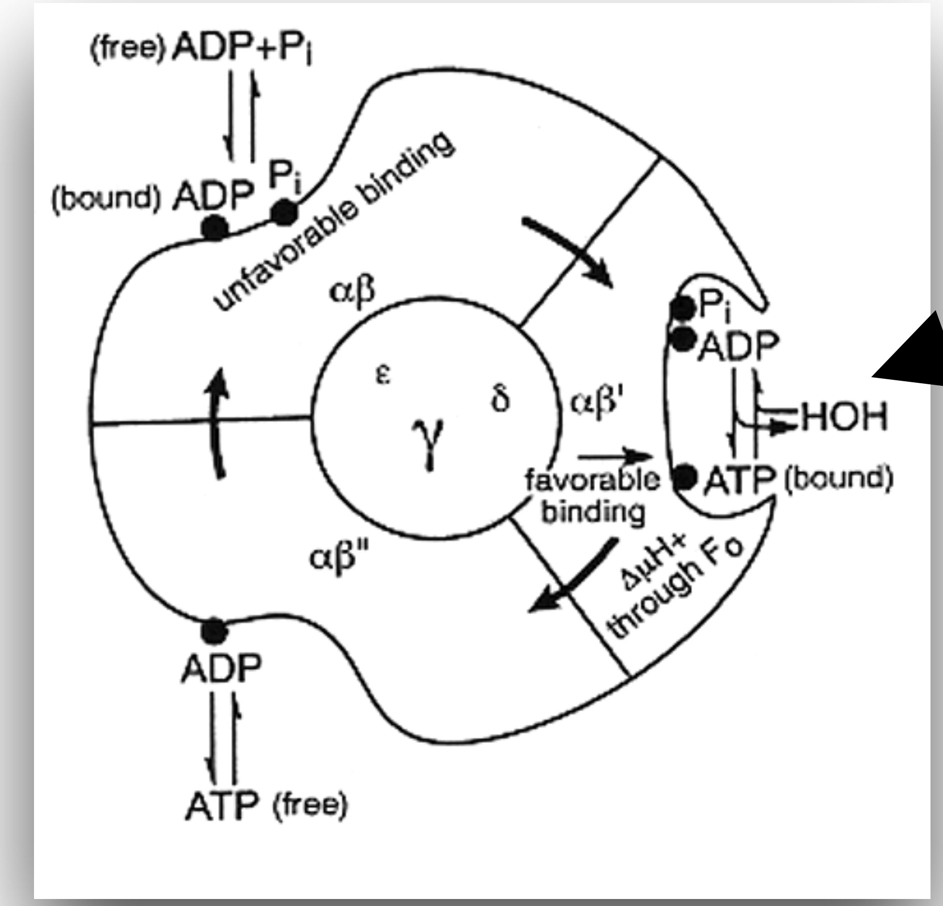
“4-minute Pop Quiz”: **Reward** for those who prepared.
(4 questions, 60 seconds each)

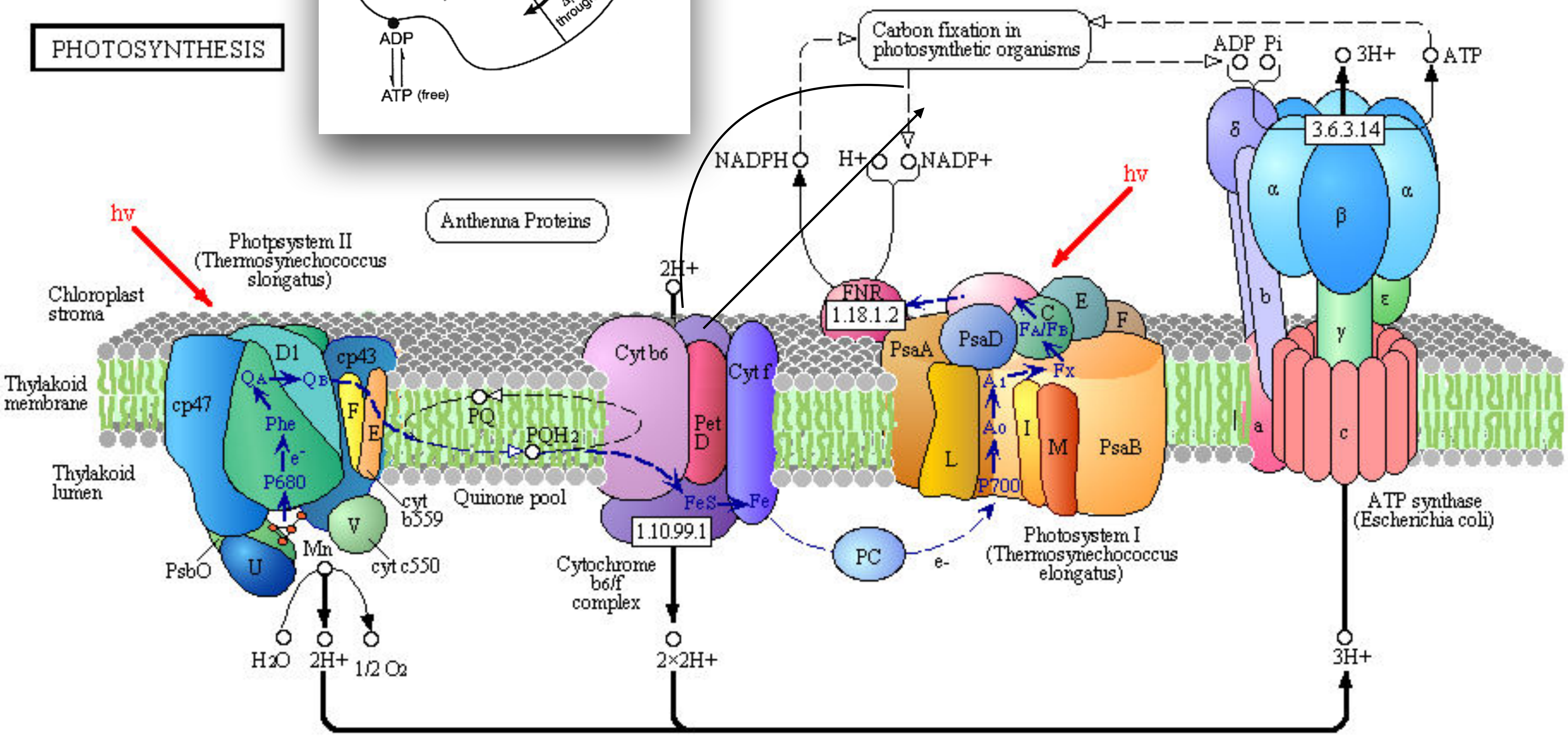

Laptops closed



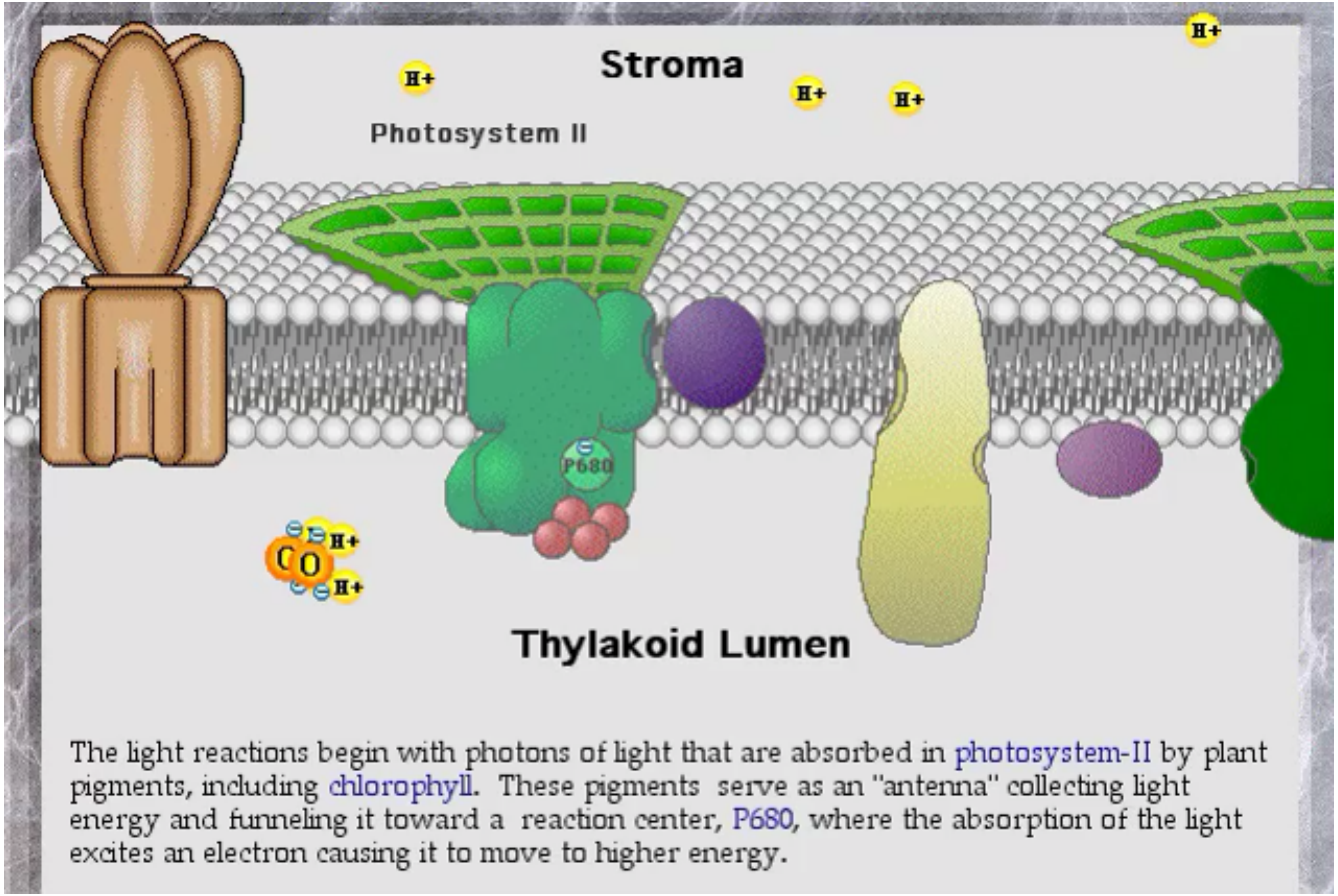
Light
H_2O
NADP+
ADP
+ Pi
LIGHT REACTIONS
ATP
NADPH
Chloroplast
O_2

Images of "Xmas future"

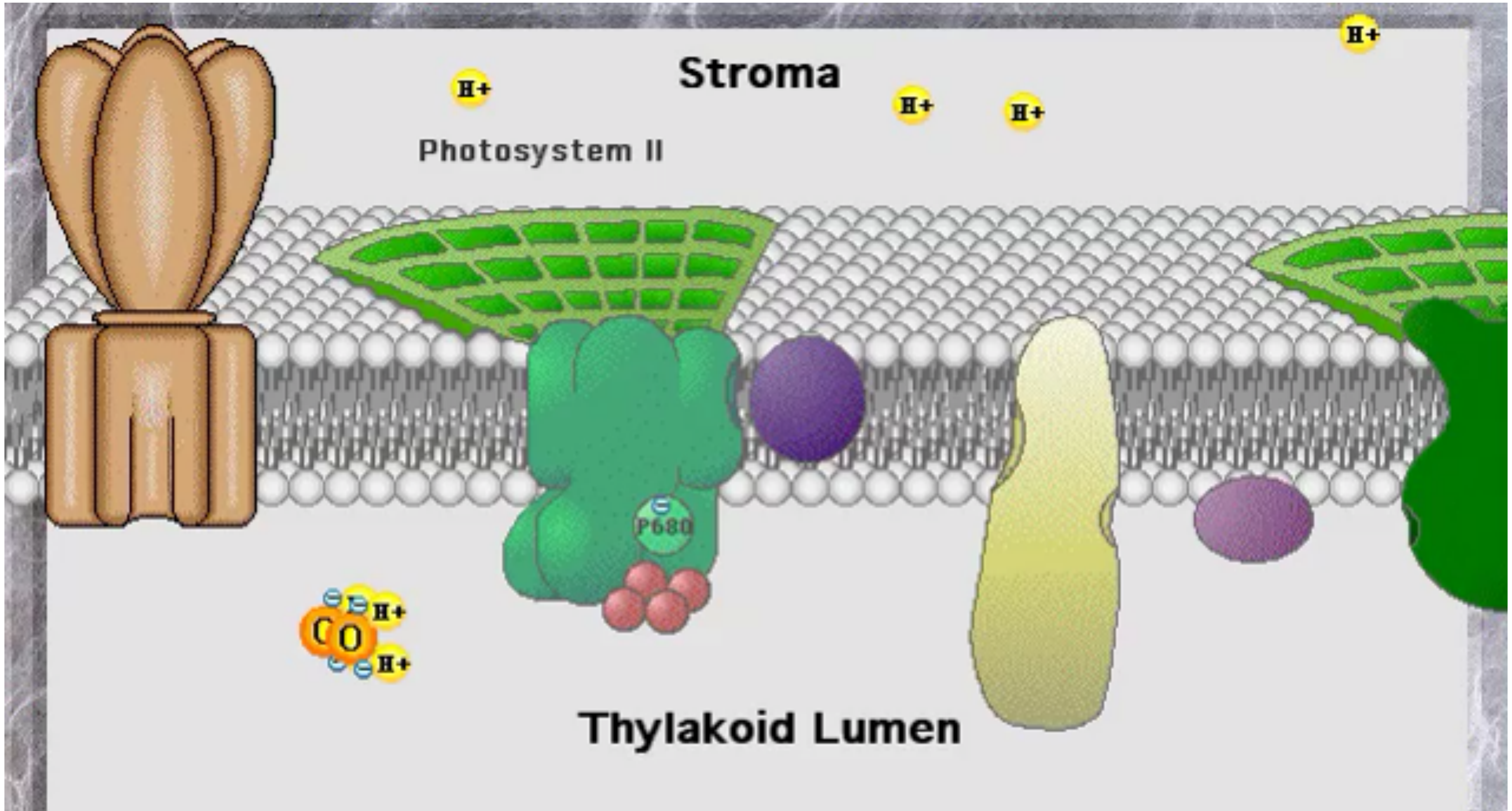




You get a chance to narrate (1.0)

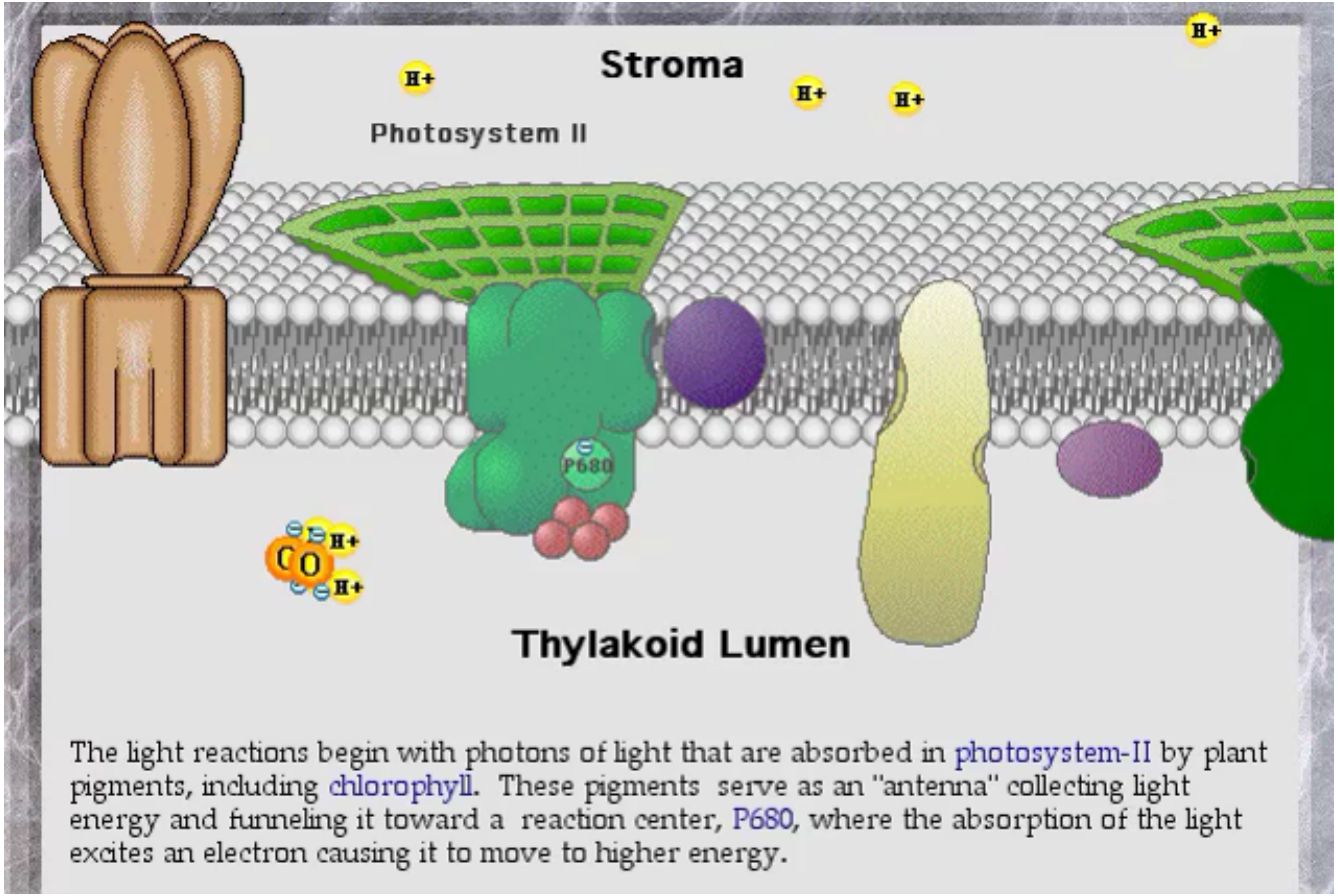


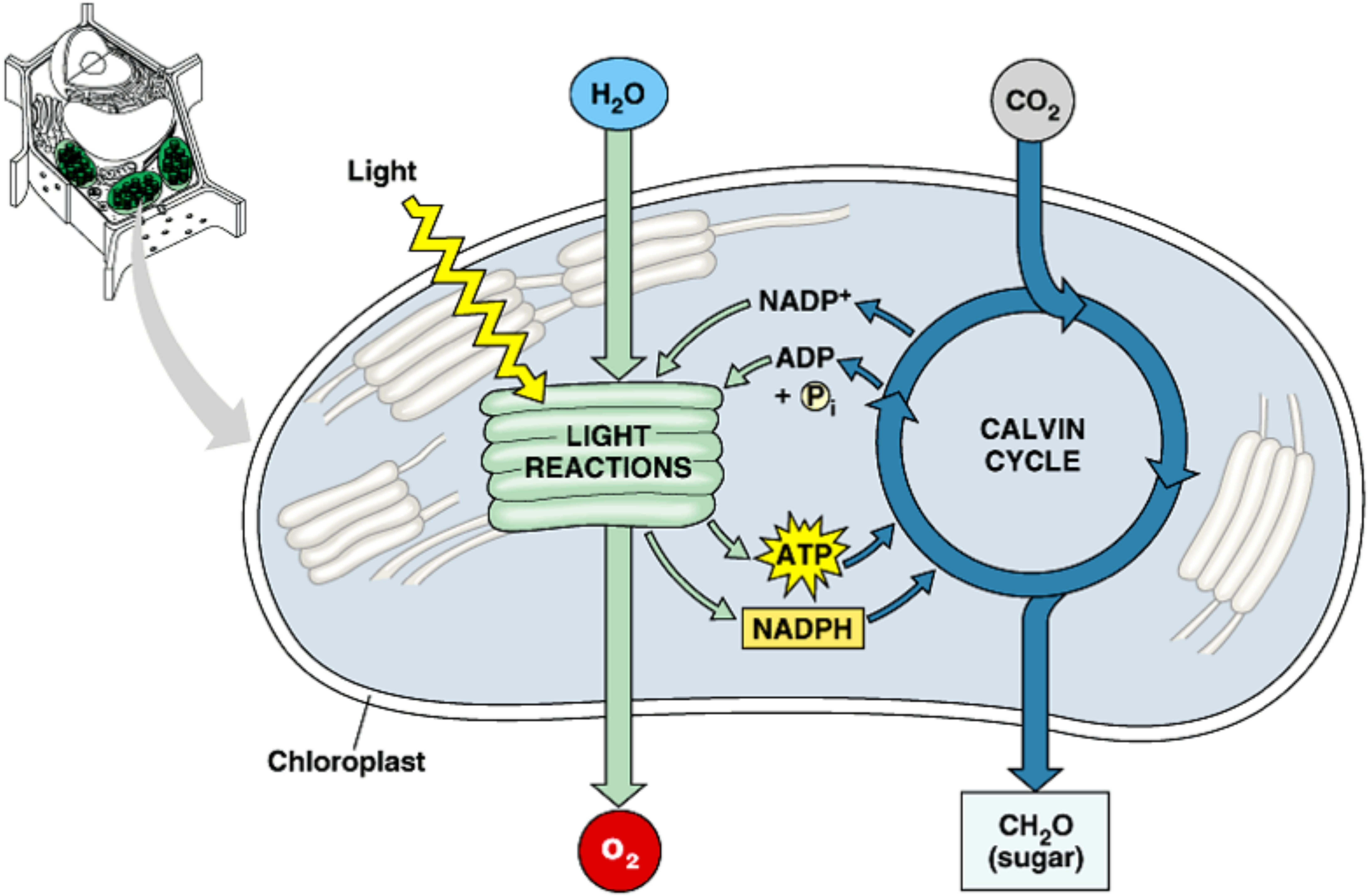
You get a chance to narrate (2.0)



The light reactions begin with photons of light that are absorbed in photosystem-II by plant pigments, including chlorophyll. These pigments serve as an "antenna" collecting light energy and funneling it toward a reaction center, P680, where the absorption of the light excites an electron causing it to move to higher energy.

You get a chance to narrate (3.0)





H_2O
CO_2
Light
$NADP^+$
ADP
+ P_i
LIGHT REACTIONS
CALVIN CYCLE
ATP
NADPH
Chloroplast
O_2
CH_2O (sugar)

Where do plants get their ‘food’...

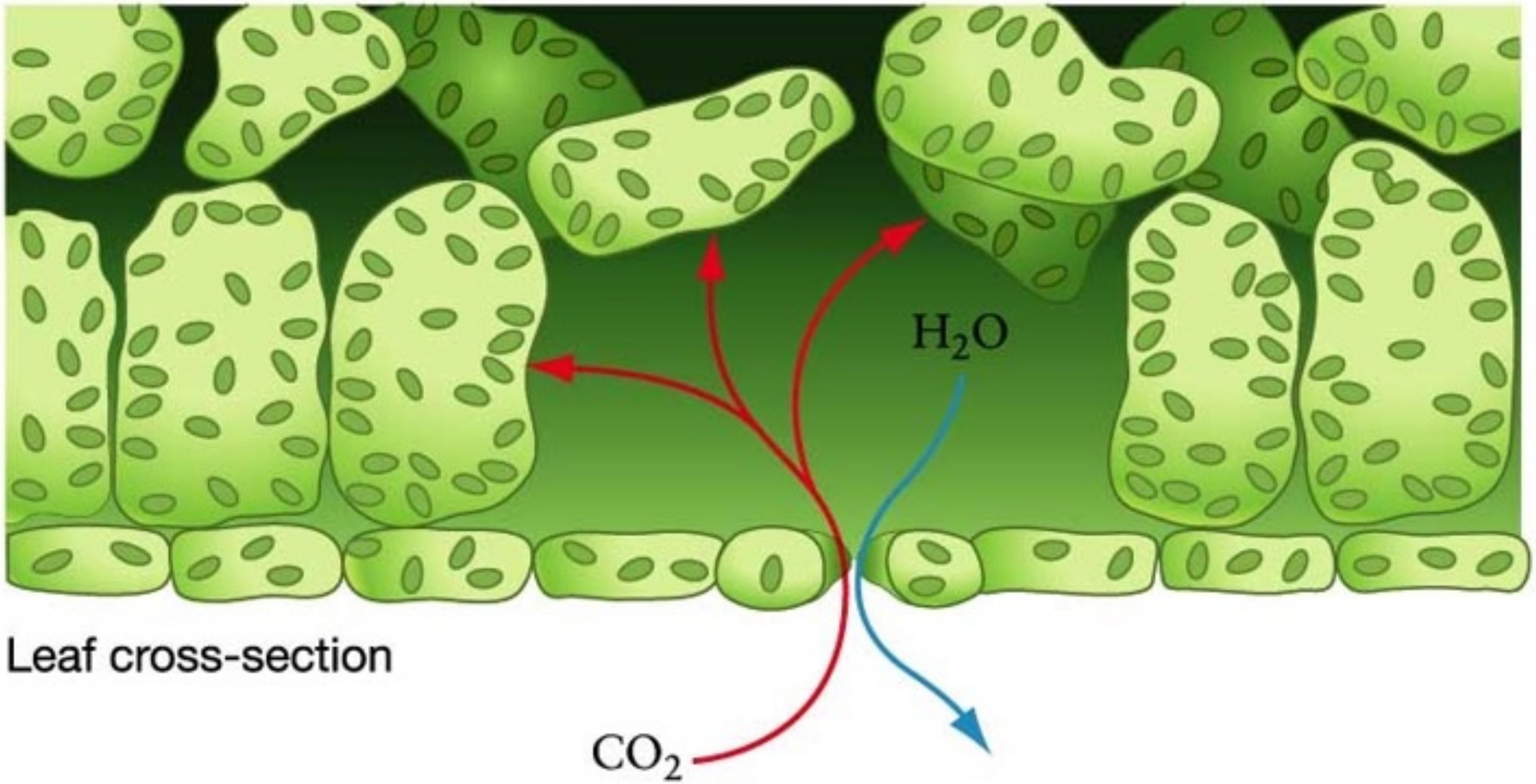
Where do plants get their ‘food’…

CO2

CO2

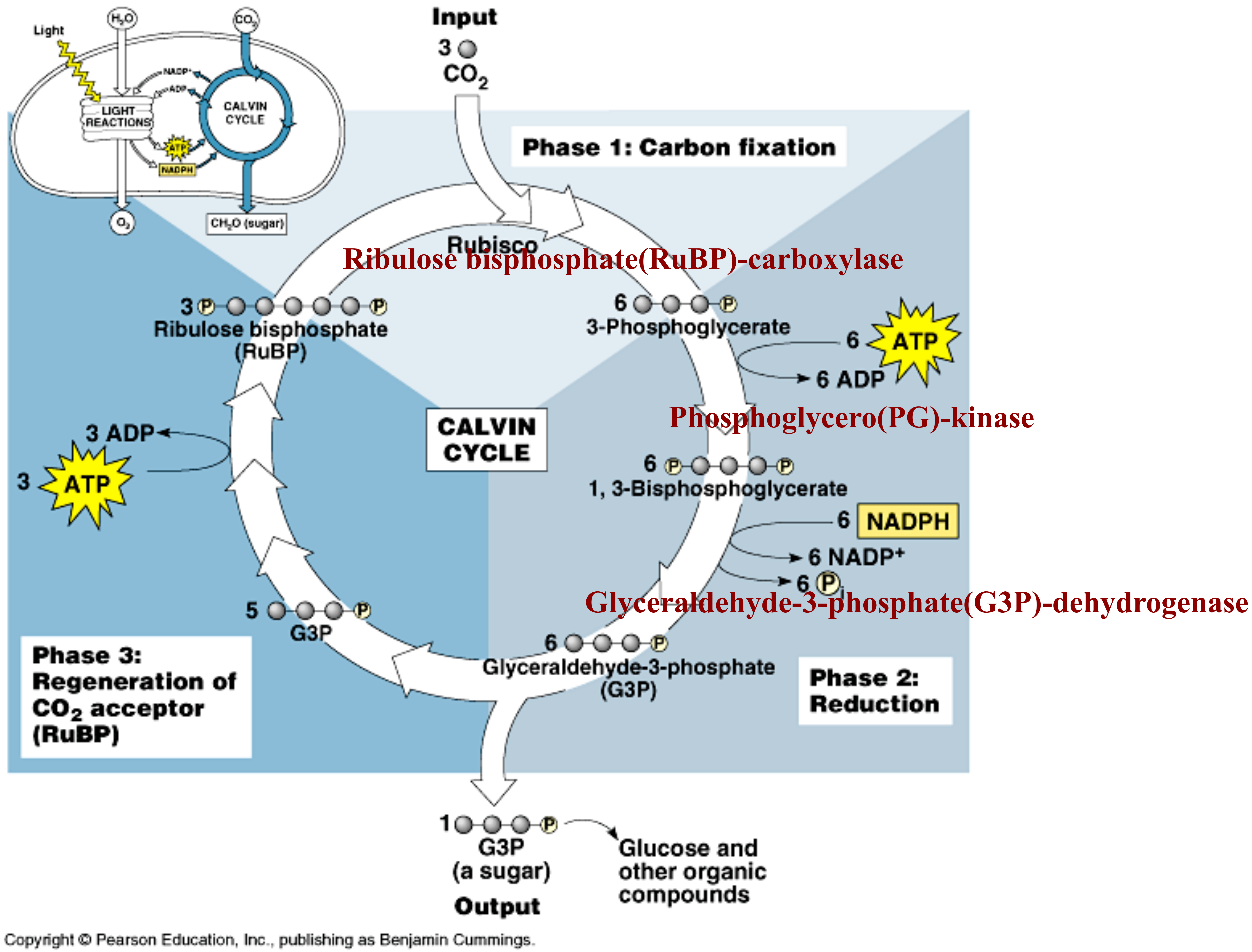
CO2

Thin Air…



Leaf cross-section

Ok, but what do I need to know for the test?



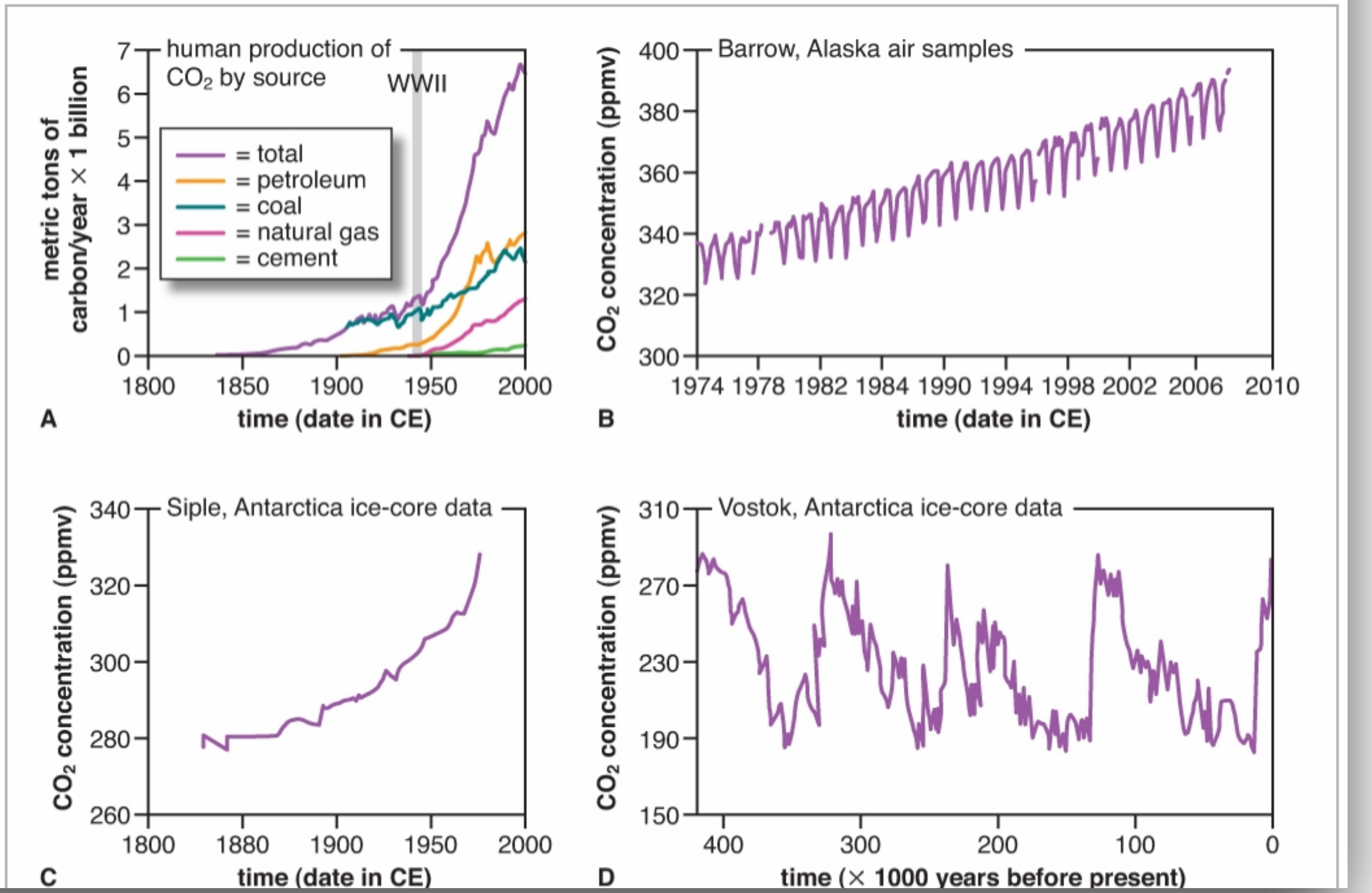
11.2 How does Brazil's rainforest affect Greenland's glaciers?

- Context: Plants produce O_2 and consume CO_2 to produce sugars as precursors to amino acids, carbohydrates, and lipids.
- Major themes: Biological systems use feedback mechanisms to regulate and maintain optimal conditions; time-dependent processes regulate biological systems; life requires organization, which is energy dependent; and a biological system's size and environment influences how it addresses physical and chemical challenges.
- Bottom line: Plants convert the energy stored in ATP and NADPH to reduce CO_2 and produce multicarbon molecules required for plant and animal life.

Biology Learning Objectives

- Explain the relationship between photosynthesis and global climate change.
- Discuss how carbon fixation is regulated by homeostasis of metabolic reactions.

Almost every week, you hear news about global climate change and atmospheric CO_2 levels. The amount of CO_2 released into the atmosphere as a direct consequence of human activity has increased dramatically over the last 150 years (Figure 11.11A). Consumption of petroleum, coal, and natural gas are the three leading sources of new CO_2 in the atmosphere. These three sources of CO_2 are called fossil fuels because like real fossils, these fuels were once organisms that died millions of years ago. Through pressure and chemical reactions, their bodies have produced a variety of hydrocarbons rich in covalent bonds. As human consumption of fossil fuels has increased, so has atmospheric concentration of CO_2 in parts per million (ppm; see Figure 11.11B and C). *{Connections: You learned how the concentration of gases is often measured in ppm in Bio-Math Exploration 10.1.}* The current level of atmospheric CO_2 has surpassed 403 ppm, which is nearly 50% higher than it was when America became a new country. Over the last 400,000 years, the level of CO_2 has fluctuated between 290 and 190 ppm (Figure 11.11D). CO_2 levels had not exceeded 400 ppm since 15 million years



11.2 How does Brazil's rainforest affect Greenland's glaciers?

Biology Learning Objectives

- Explain the relationship between photosynthesis and global climate change.
- Discuss how carbon fixation is regulated by homeostasis of metabolic reactions.

“Training like an athlete”

(Preparing for) **Thursday's lecture:**

Budgeting homework time (70 min): Chapter 11 section 11.2 is 3593 words in length with several data figures that require thinking and notetaking for the Trifecta. Reading at 200 words per minute would mean the section might take 18 minutes to read. Of course, when done properly, when you pause to review figures, try Integrating Questions, and take notes, this assignment will take you more like 70 minutes. It could be shorter if you have been doing homework regularly, ie. training like an athlete, and getting much better at this now that it is week 5.

1. _______ **For Thursday's lecture,** read **Chapter 11: Photosynthesis**, section 11.2 "How does Brazil’s rainforest affect Greenland’s glaciers?" (3593 words), and take handwritten notes in your lecture notebook.

2. _______ **Try to answer some Integrating Questions and Review Questions.** As you read the ICB textbook always attempt to test yourself a little, answer at least one of each set.

3. _______ (Trifecta): **Prepare to explain (aloud) Figures 11.11** (just pick one graph), **11.12, 11.13, and 11.15** (Purpose, Methods, Findings).

Trifecta **BATTLE**

East side versus West

(keep score)

Good answer = 1 point

Full *Trifecta* = 3 points

(purpose, methods and findings)

Trifecta

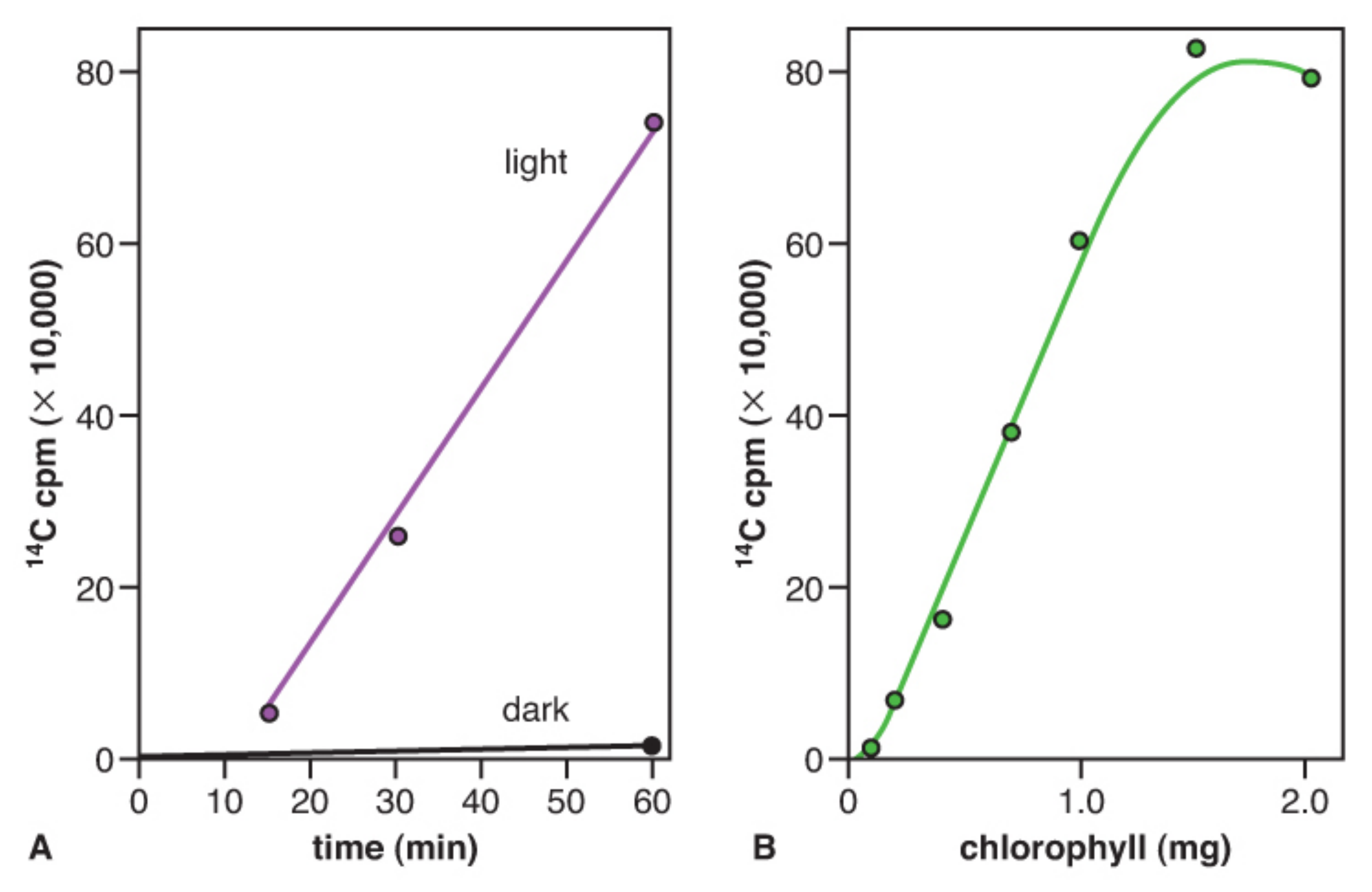


Figure 11.12 Carbon fixation capacity. **A,** When exposed to light

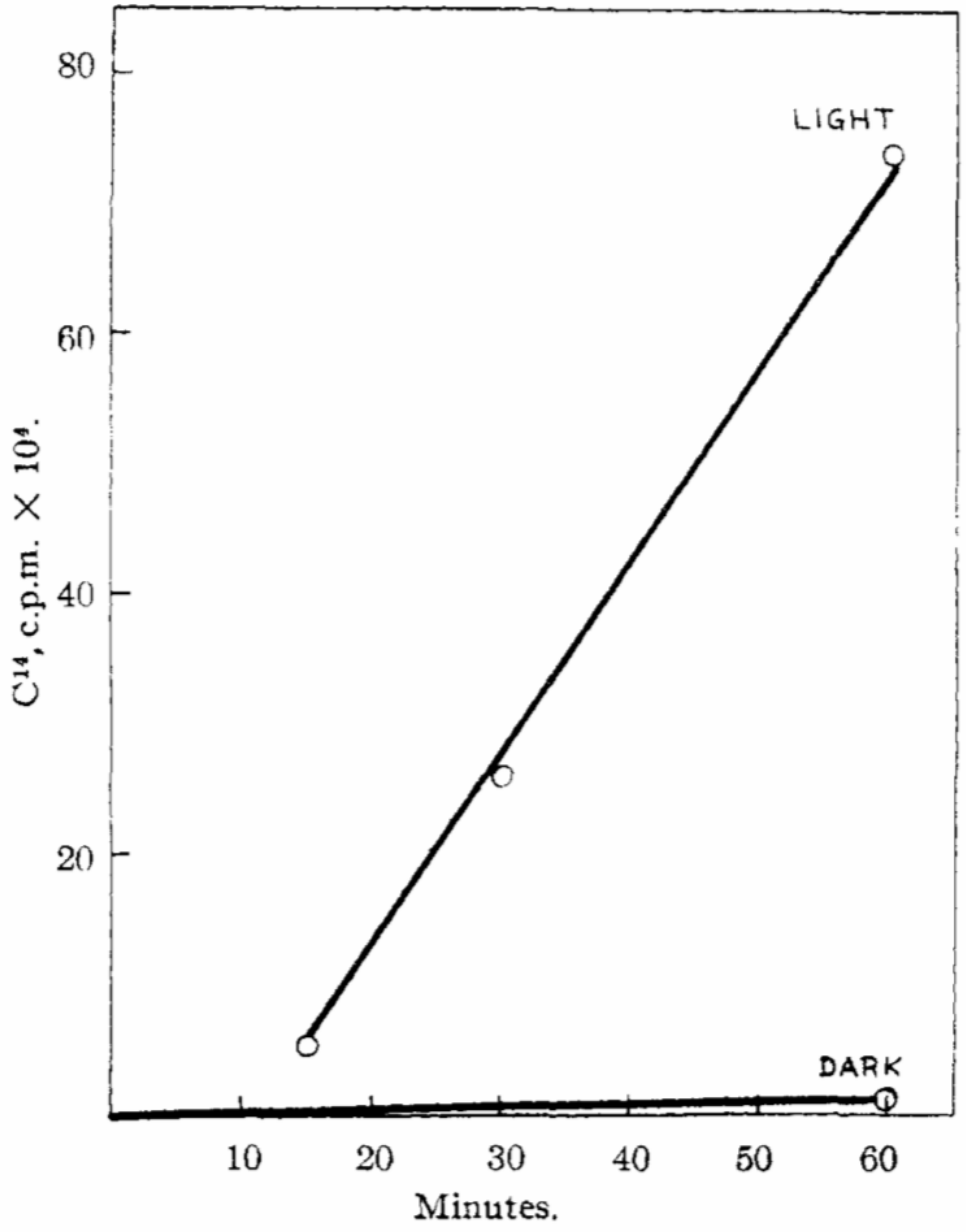


Fig. 1.—Time course of CO_2 fixation by isolated spinach chloroplasts in light and dark. Reaction mixture is described in text. The lag in CO_2 fixation during the first few minutes of illumination is attributed to a time lag in equilibration after the release of $C^{14}O_2$ gas from the sidearm

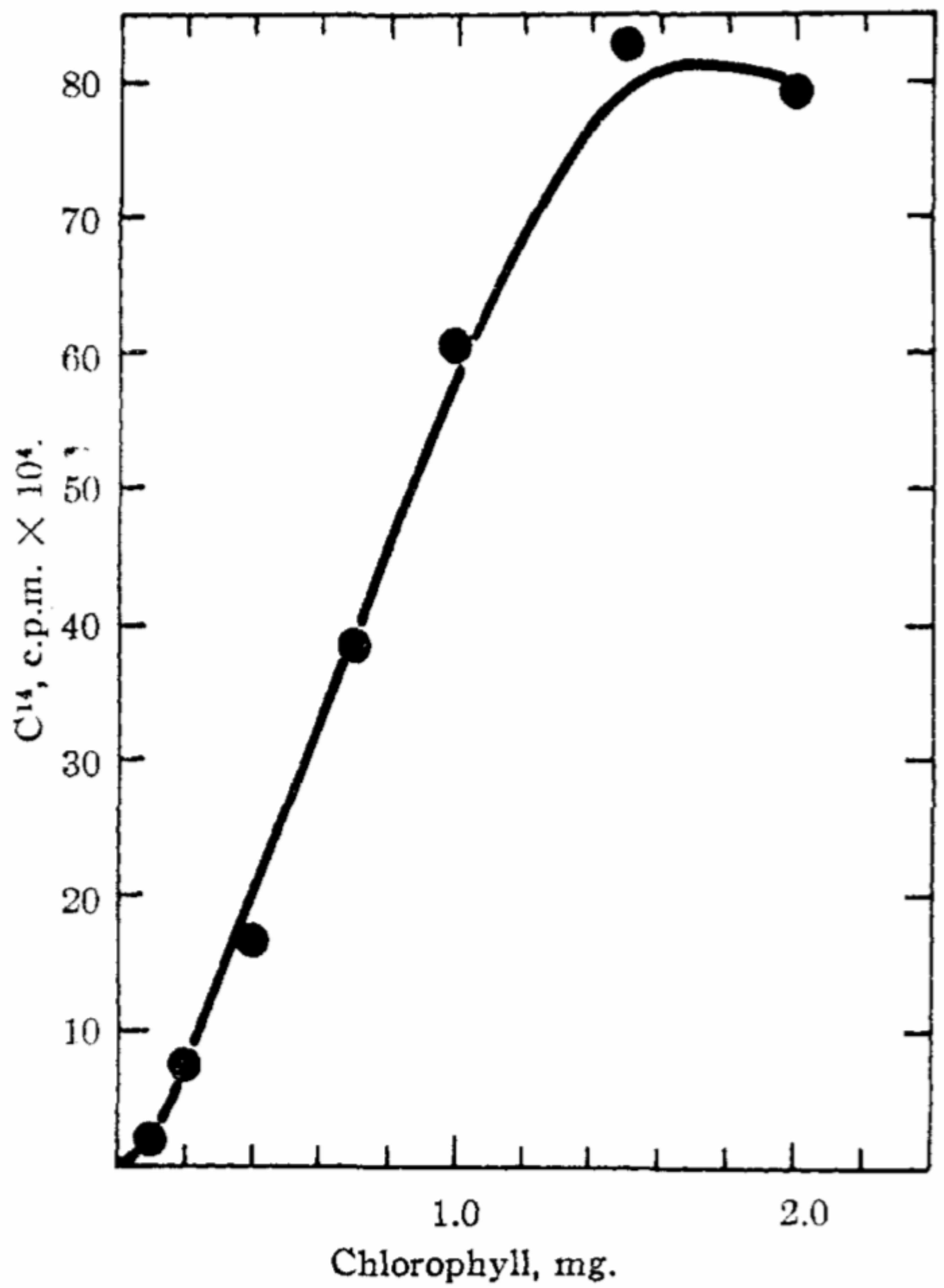


Fig. 2.—Dependence of CO_2 fixation upon amount of chloroplast suspension added. Reaction mixture is described in text.

with the well-known photosynthetic quotient of

Trifecta

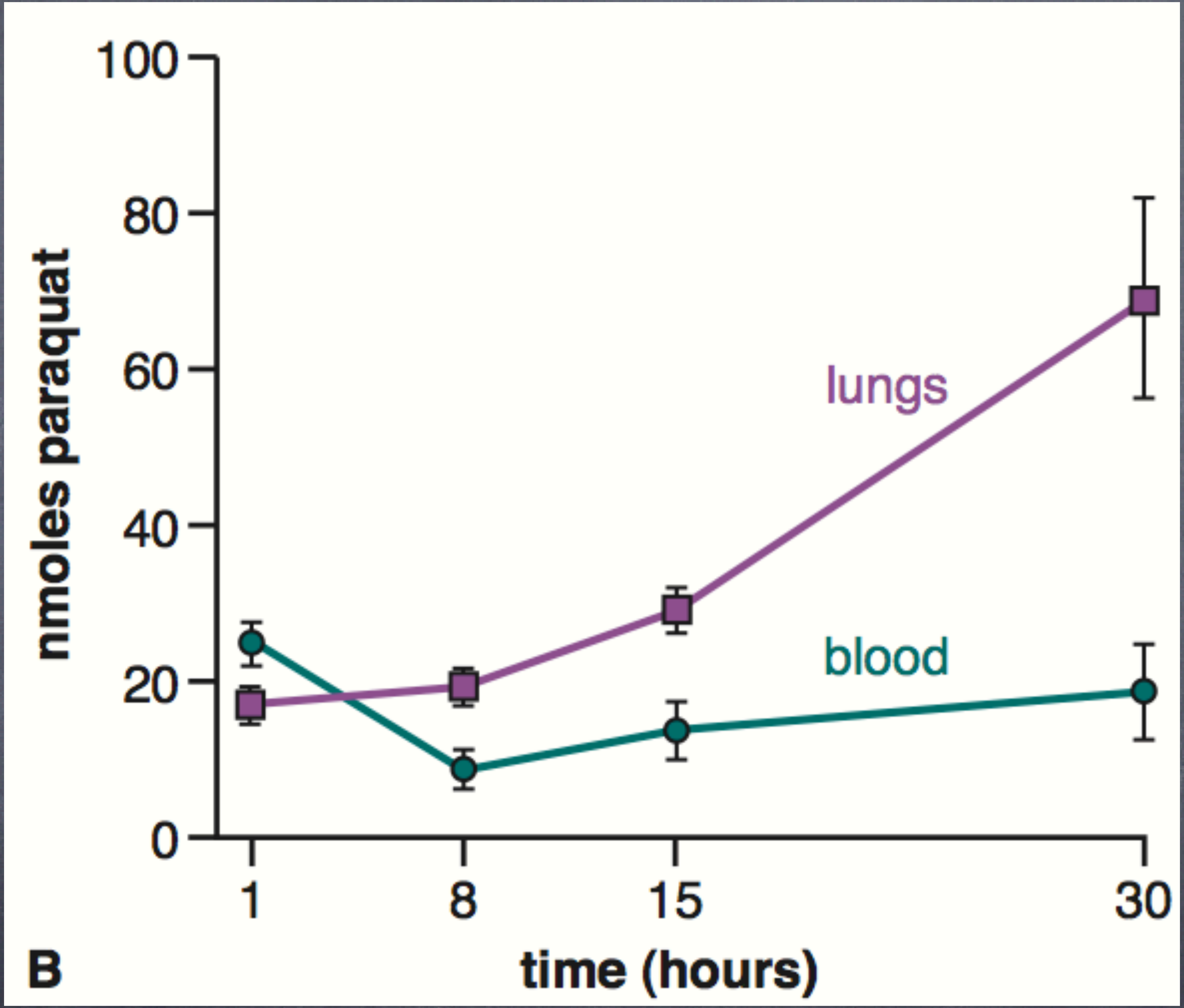
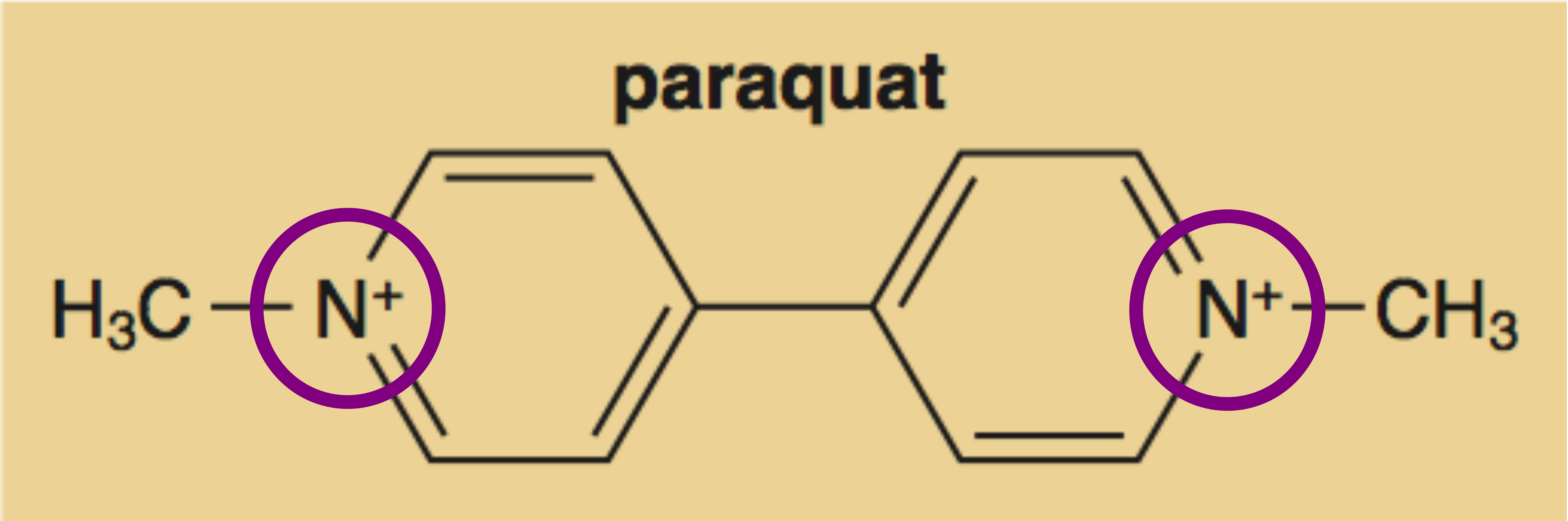


Figure 11.1 Paraquat and its mammalian consequences. **A,**

Legal in US, Illegal in EU – why?



+2 charged molecule

Plastoquinone PQ ->

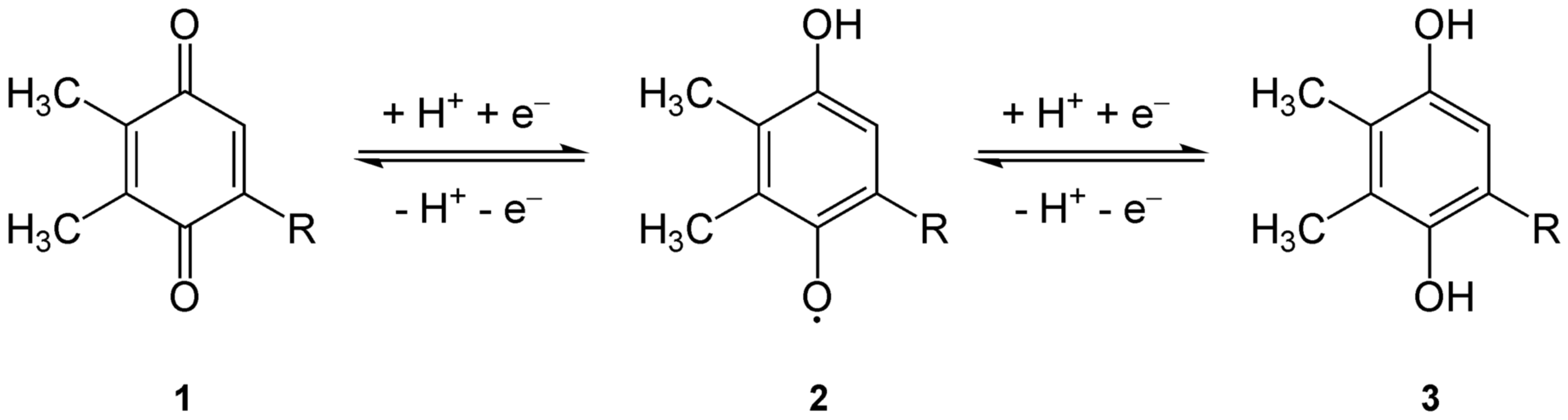


Fig. 11.1

B: modified from LL Smith, 1985

Trifecta

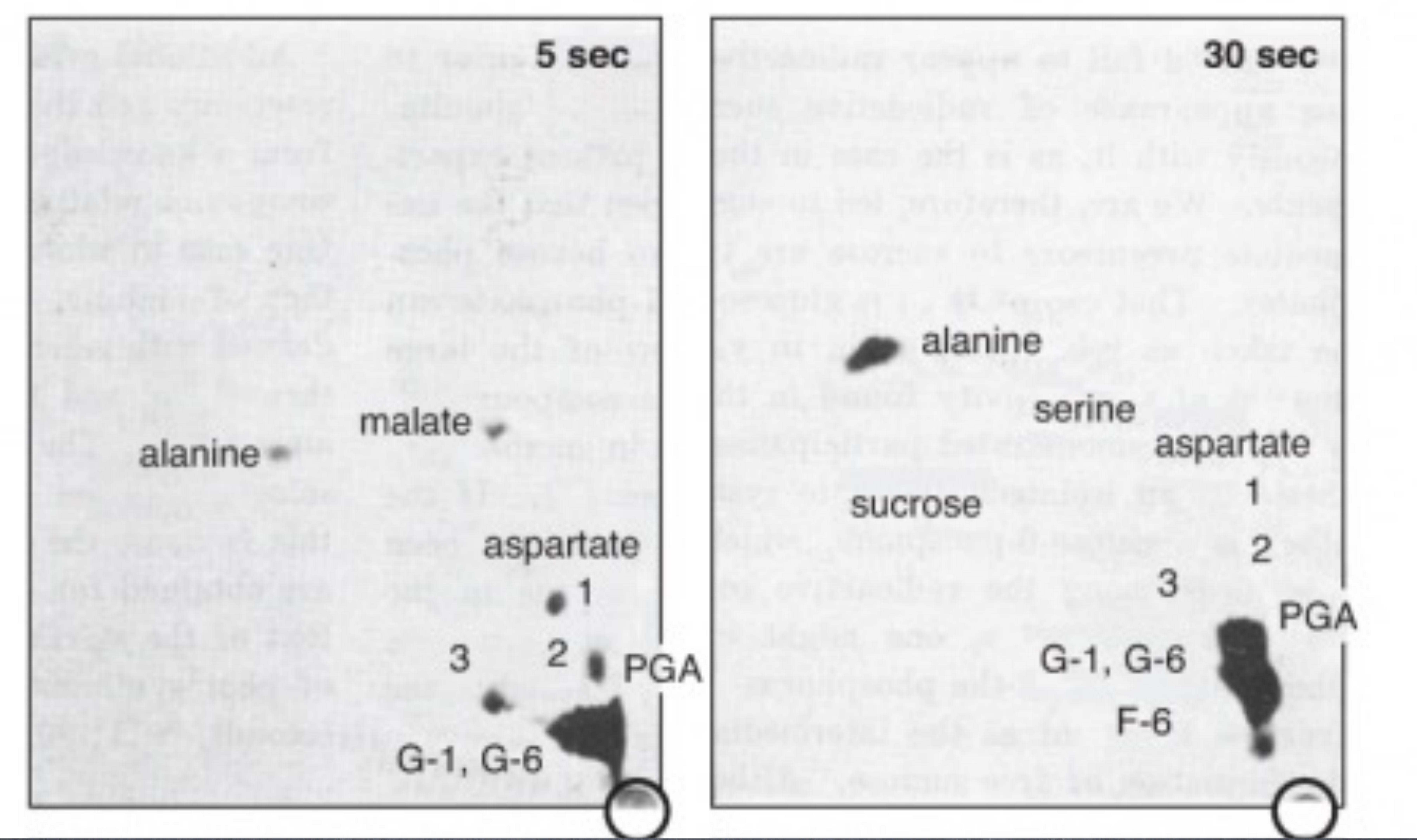


Figure 11.13 Incorporation of radioactive carbon into organic molecules. Algae cells

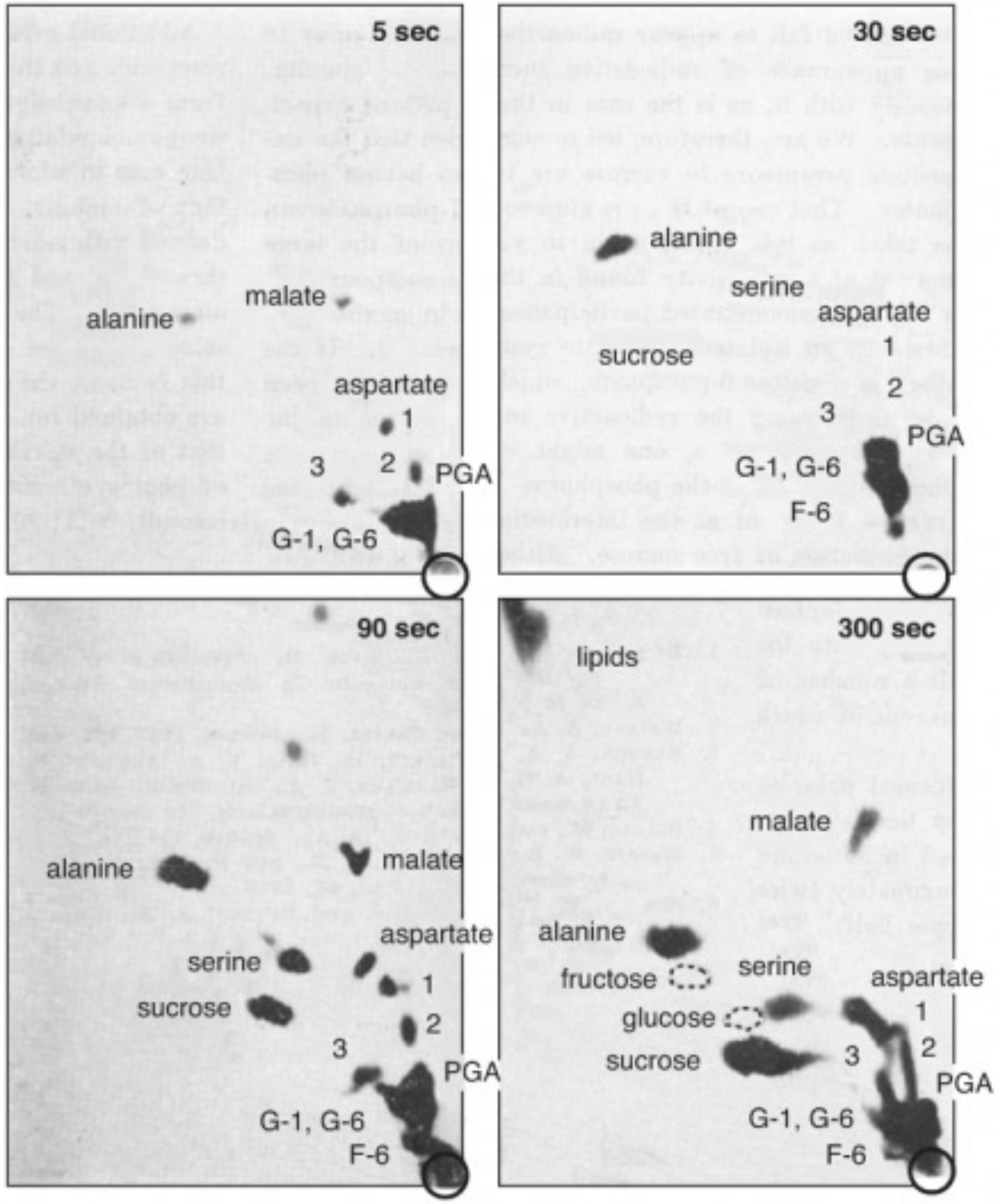
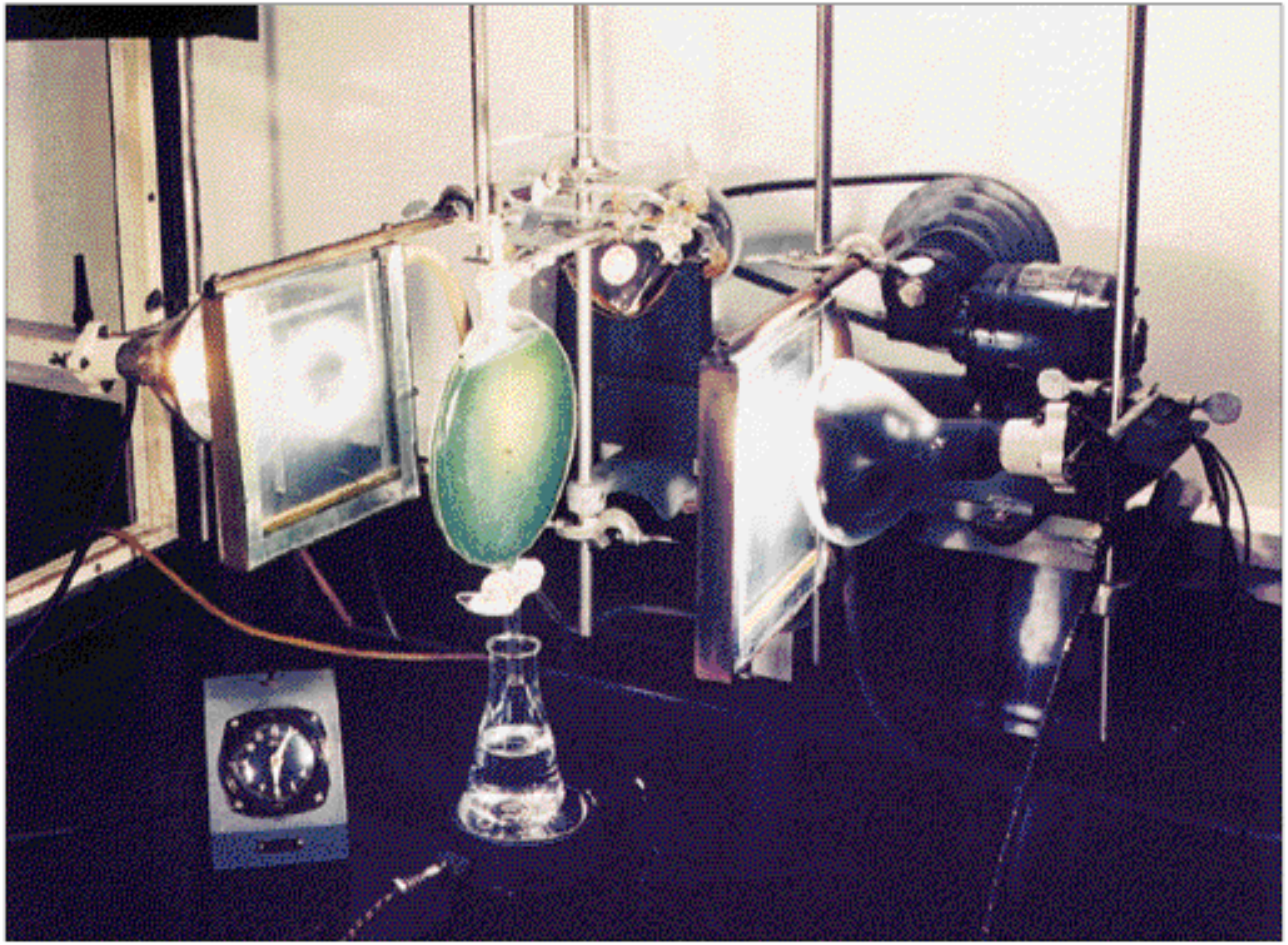
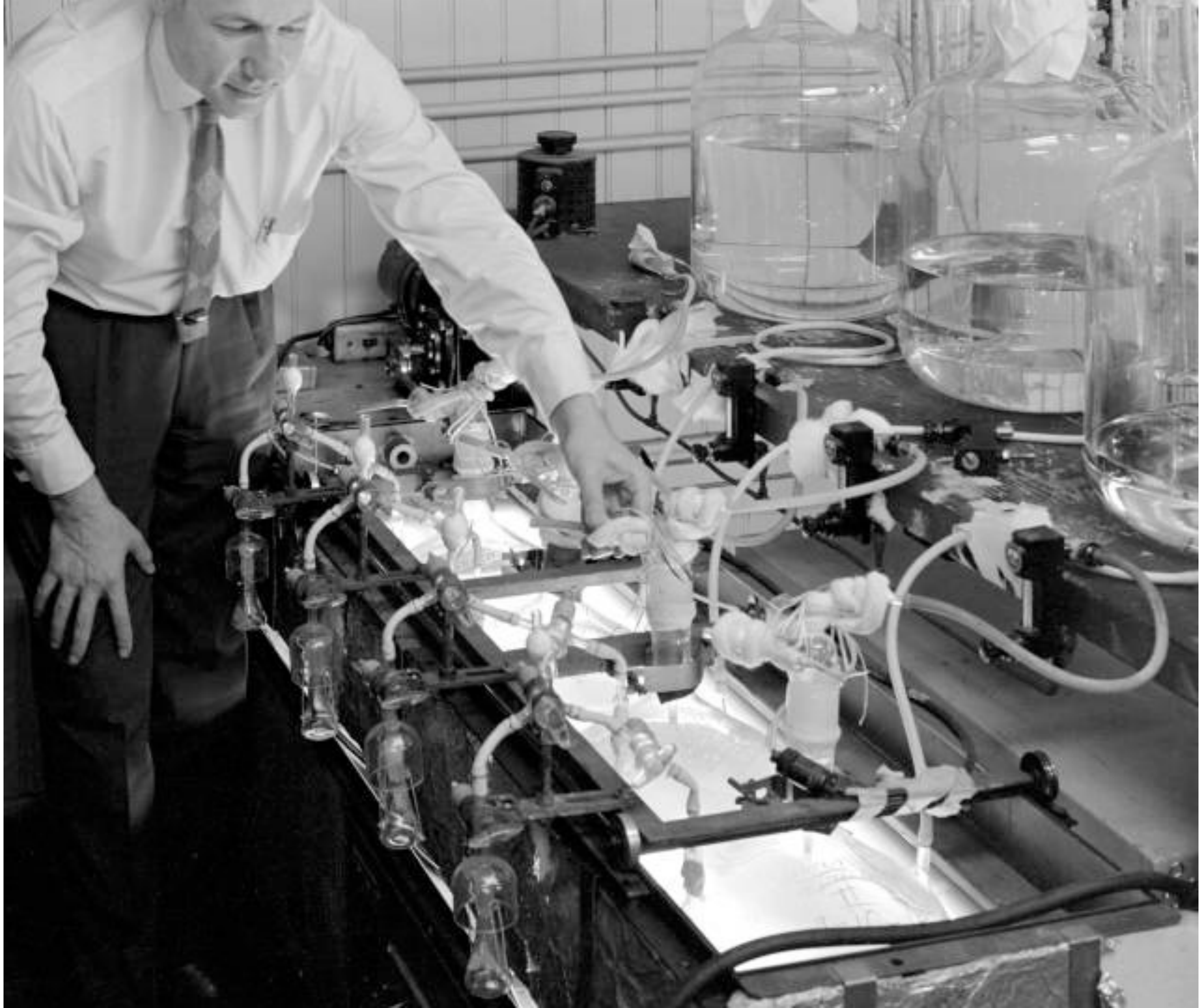


Figure 11.13 Incorporation of radioactive carbon into organic molecules. Algae cells *Chorella pyrenoidosa* cells produce increasingly more complex organic molecules with longer exposure times to light and CO_2. Black circles in the bottom right corner indicate the location of the spotted materials placed on the TLC surface. Dashed lines denote the position of sugars that are not radioactive. G-1, Glucose-1-phosphate; G-6, glucose-6-phosphate; PGA, phosphoglyceric acid; 1, 2, and 3 are additional sugars. Modified from Calvin and Benson, 1949; panels b – e of their only figure.





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

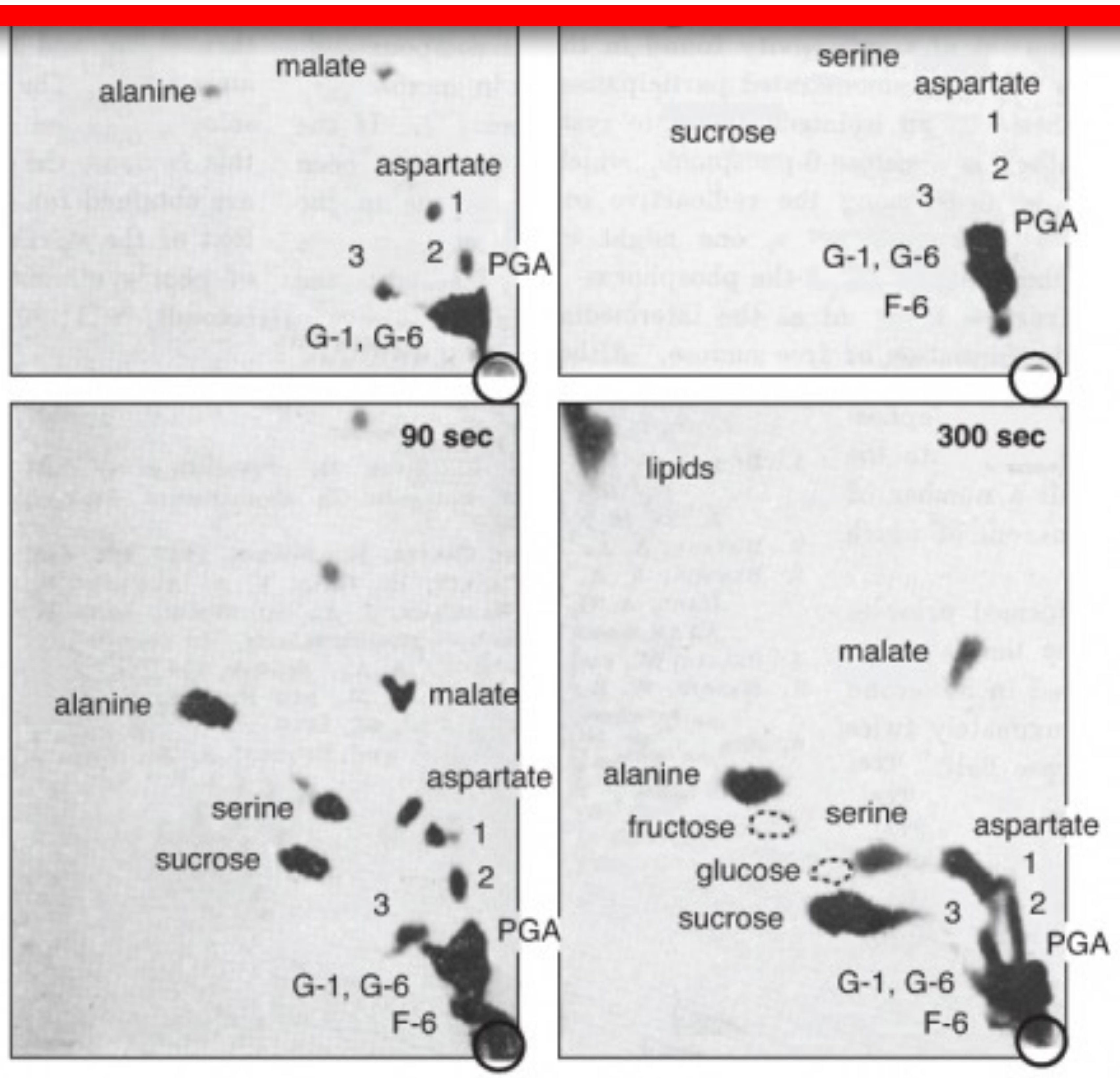


Figure 11.13 Incorporation of radioactive carbon into organic molecules. Algae cells *Chorella pyrenoidosa* cells produce increasingly more complex organic molecules with longer exposure times to light and CO_2. Black circles in the bottom right corner indicate the location of the spotted materials placed on the TLC surface. Dashed lines denote the position of sugars that are not radioactive. G-1, Glucose-1-phosphate; G-6, glucose-6-phosphate; PGA, phosphoglyceric acid; 1, 2, and 3 are additional sugars. Modified from Calvin and Benson, 1949; panels b – e of their only figure.

Who else separated by TLC?

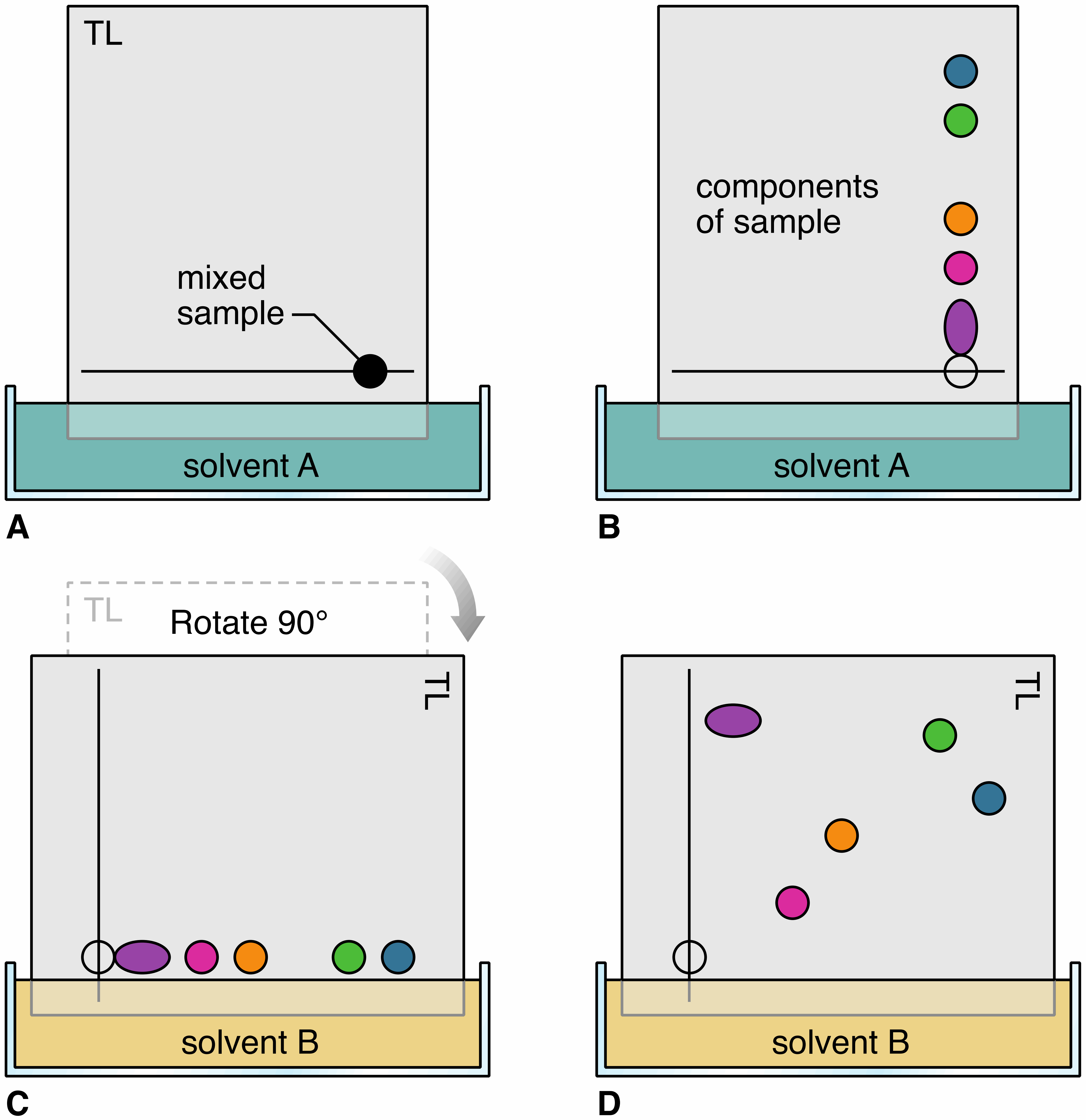
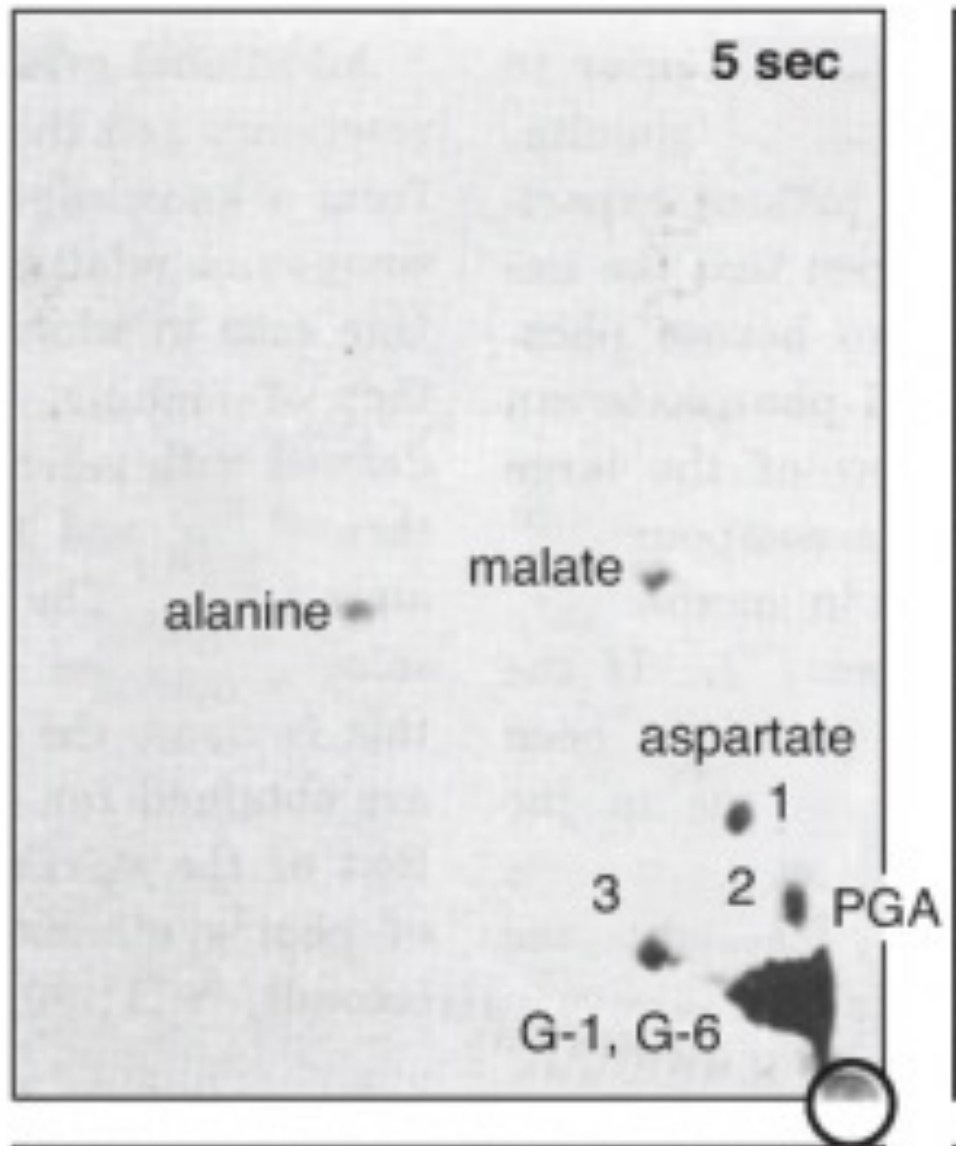


Fig. 1.19

1. First **stable** product of Calvin Cycle

***C-C-C-P**

3-Phosphoglycerate (3-PGA)



Initial Sugar Production by Plants

5 sec of fixation

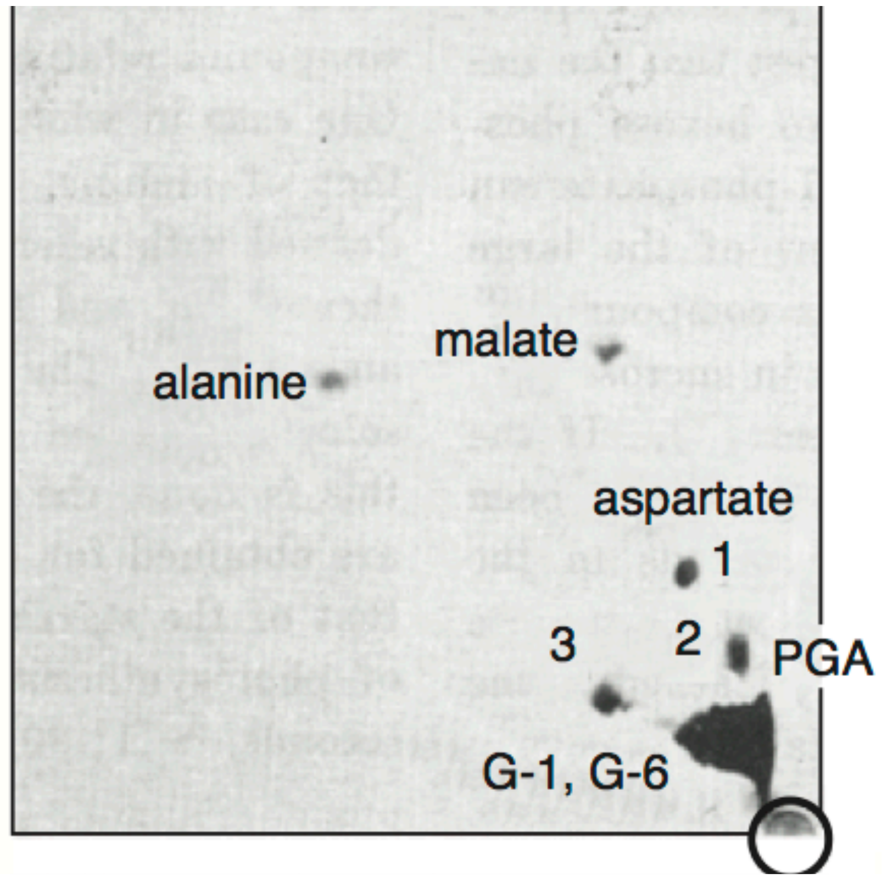
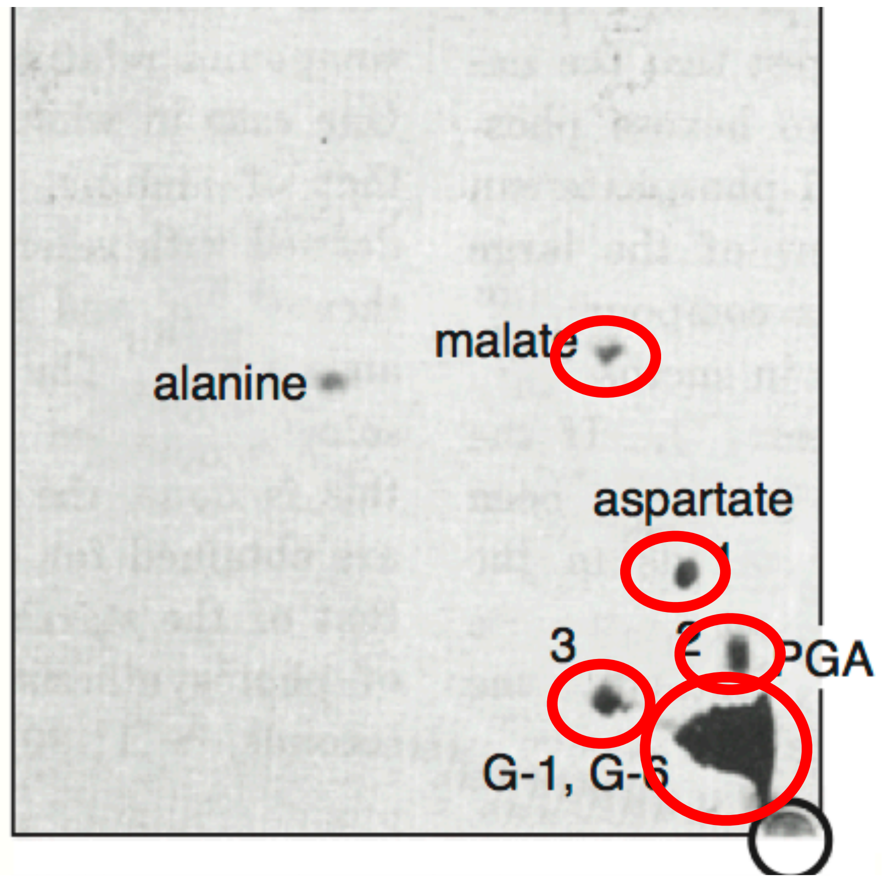


Fig. 11.13

modified from Calvin and Benson, 1949

Initial Sugar Production by Plants

5 sec of fixation



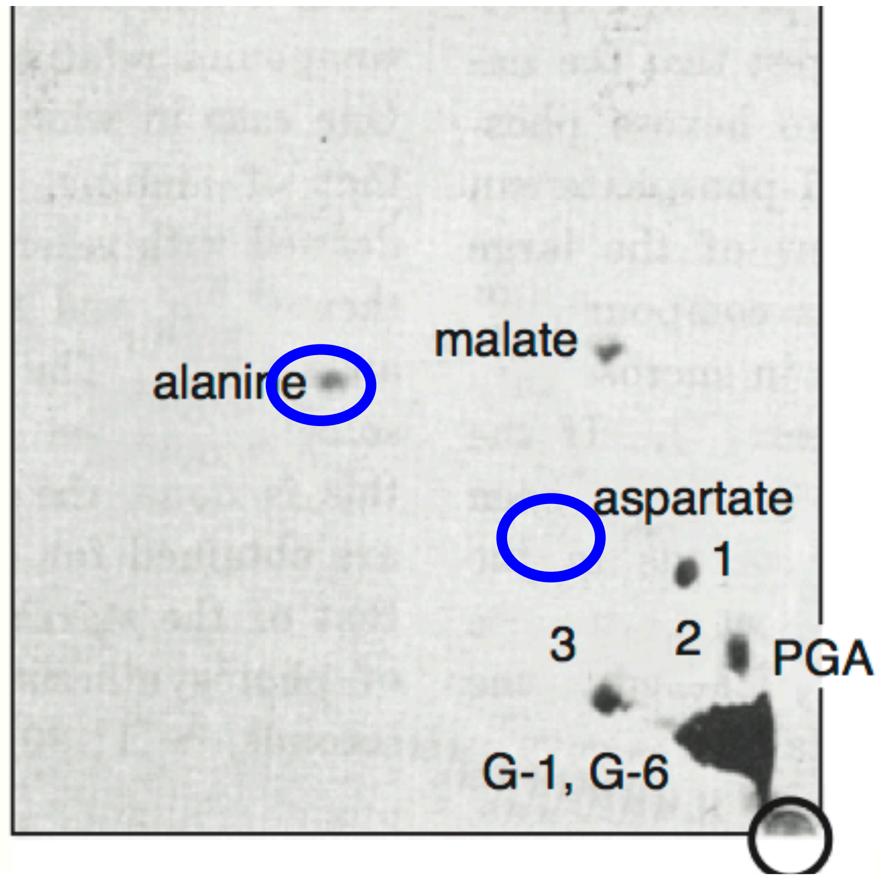
sugars

Fig. 11.13

modified from Calvin and Benson, 1949

Amino Acids from Plants

5 sec of fixation



amino acids

Fig. 11.13

modified from Calvin and Benson, 1949

Incorporation of Carbon

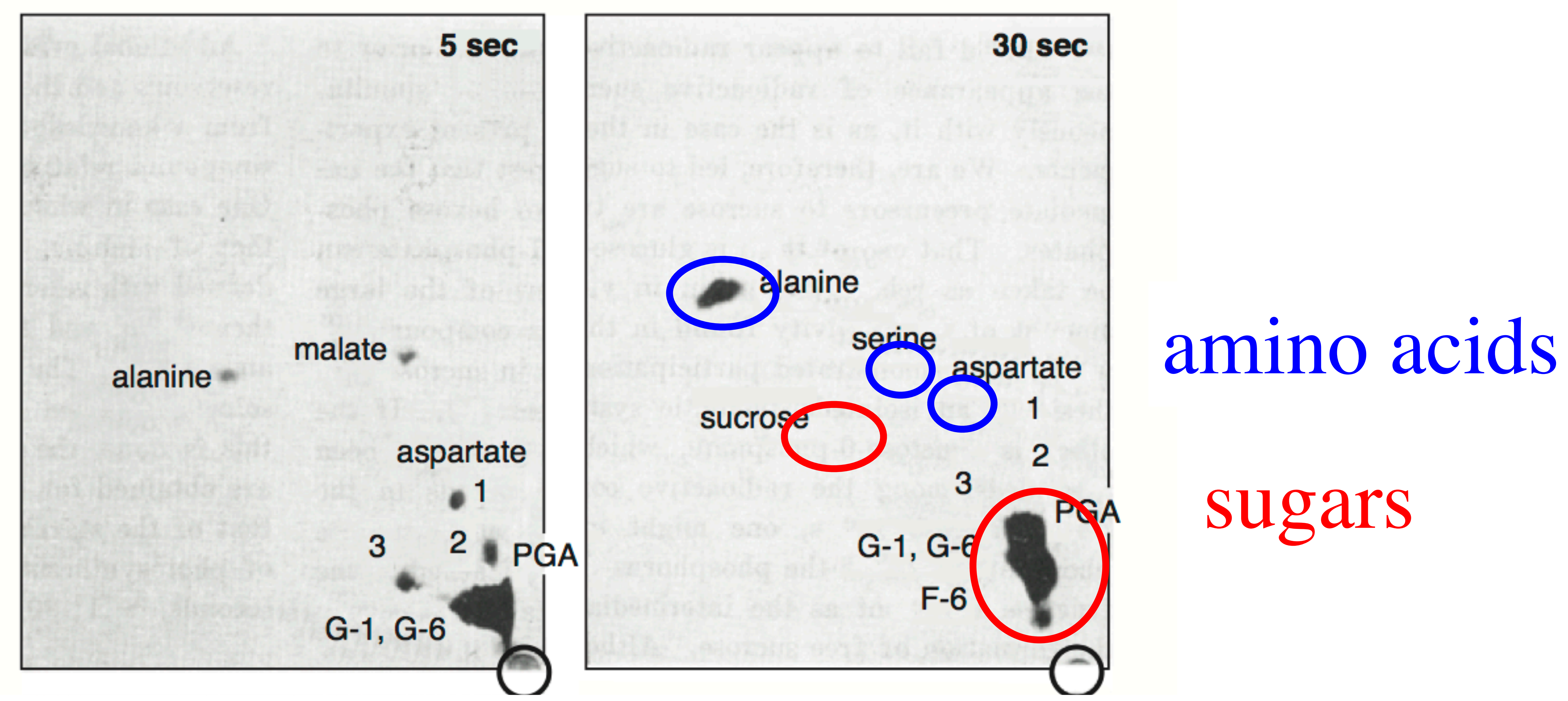
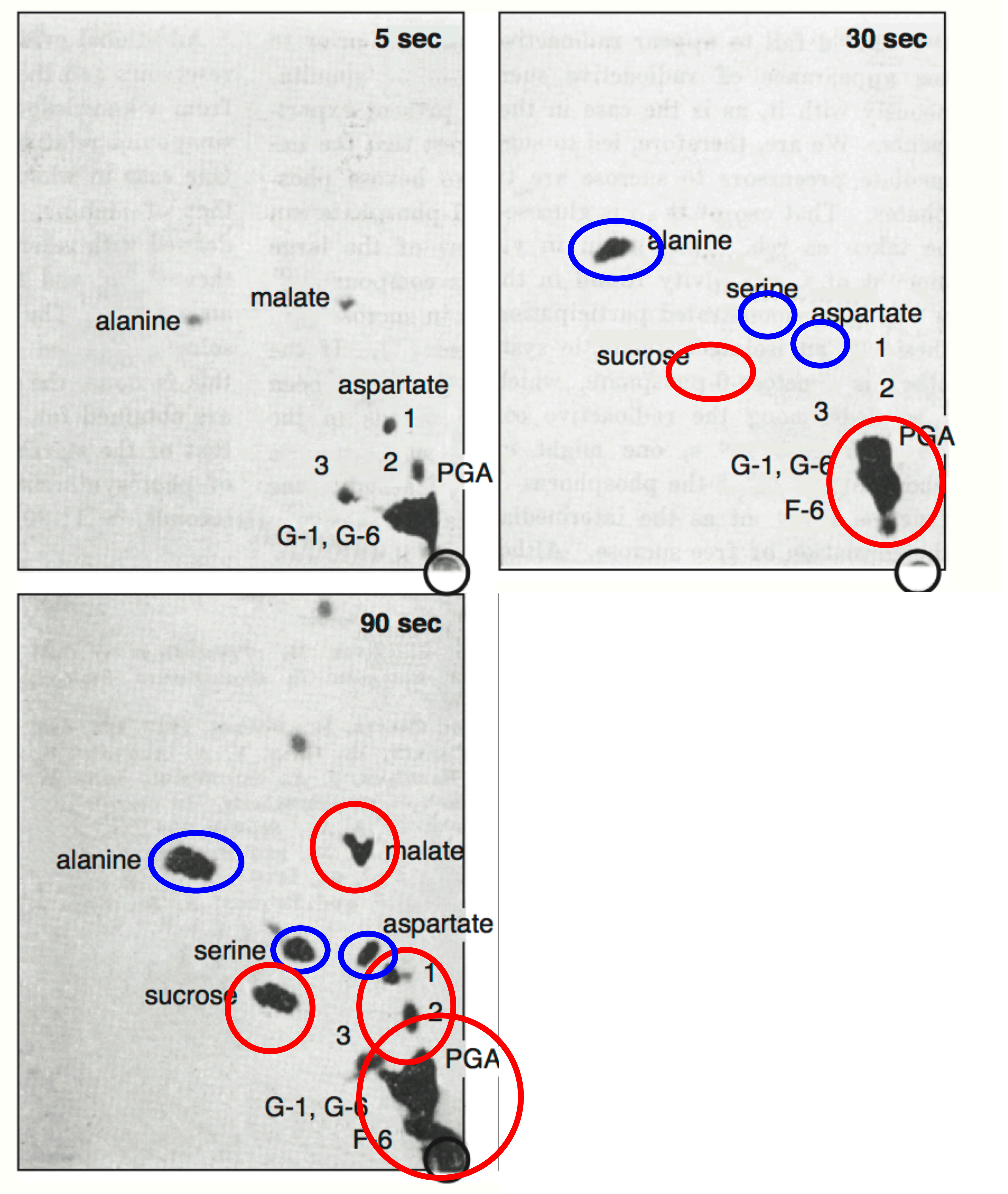


Fig. 11.13

modified from Calvin and Benson, 1949

Incorporation of Carbon



amino acids

sugars

Fig. 11.13

modified from Calvin and Benson, 1949

Incorporation of Carbon

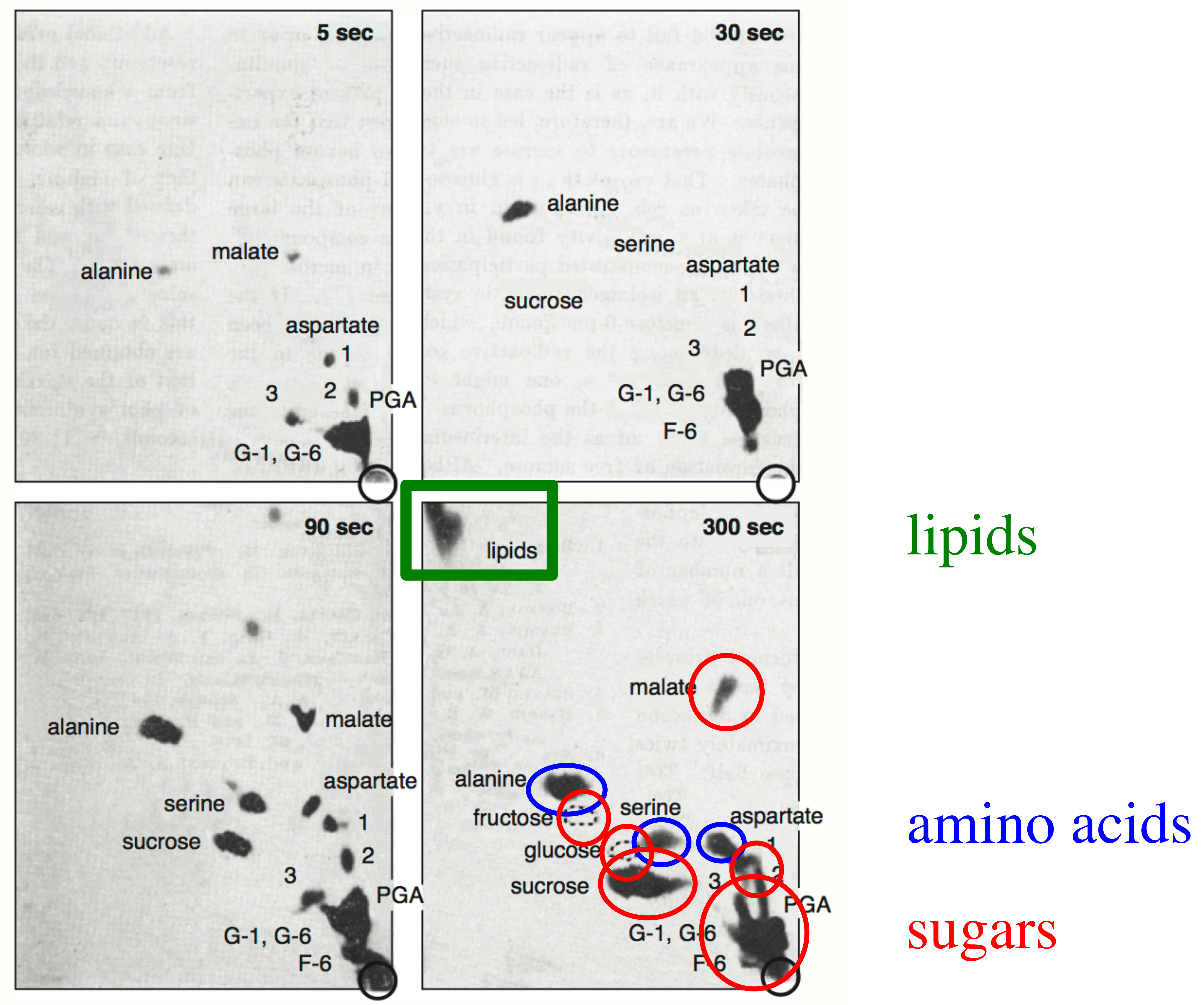


Fig. 11.13

modified from Calvin and Benson, 1949

Why this order of production?

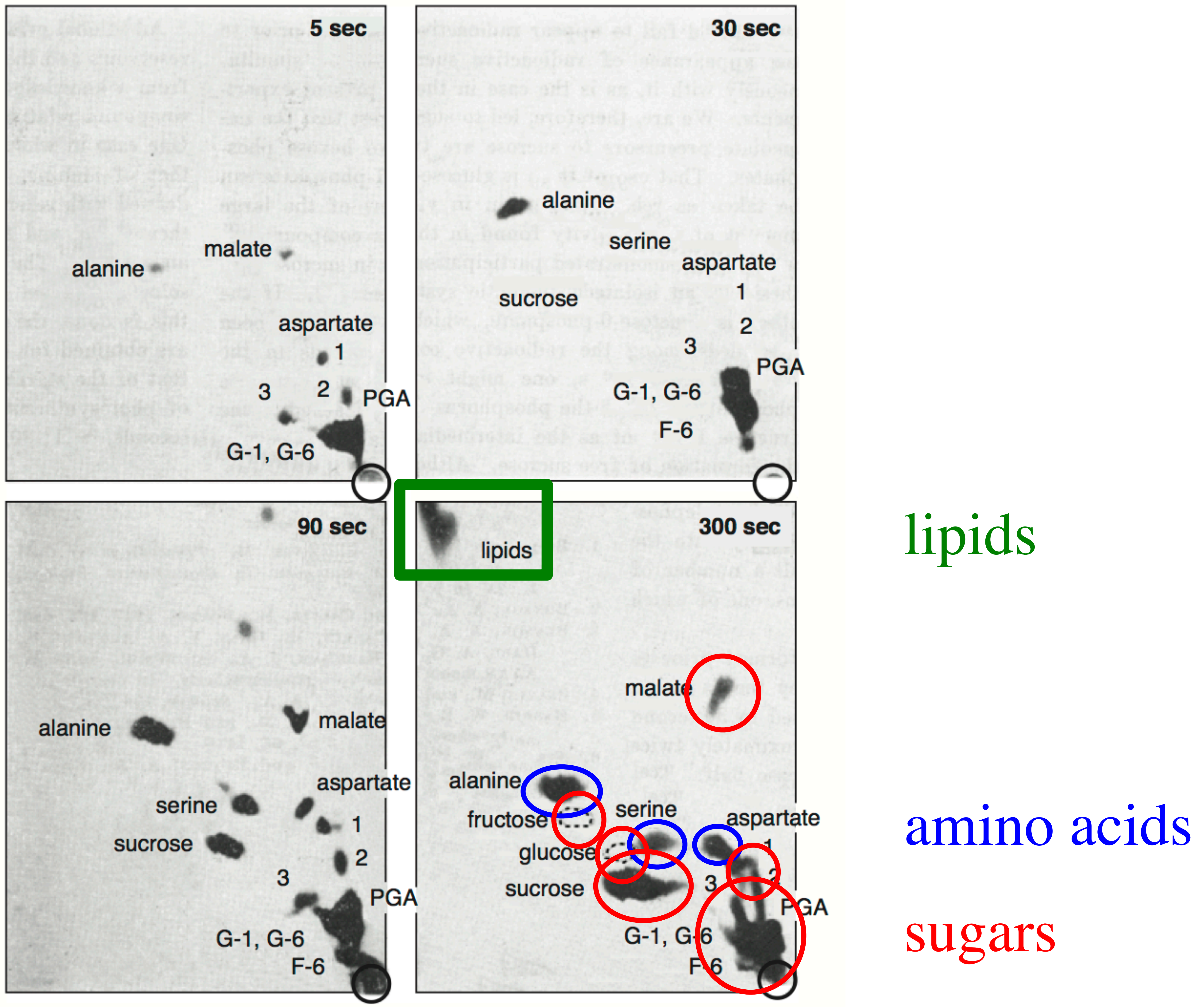
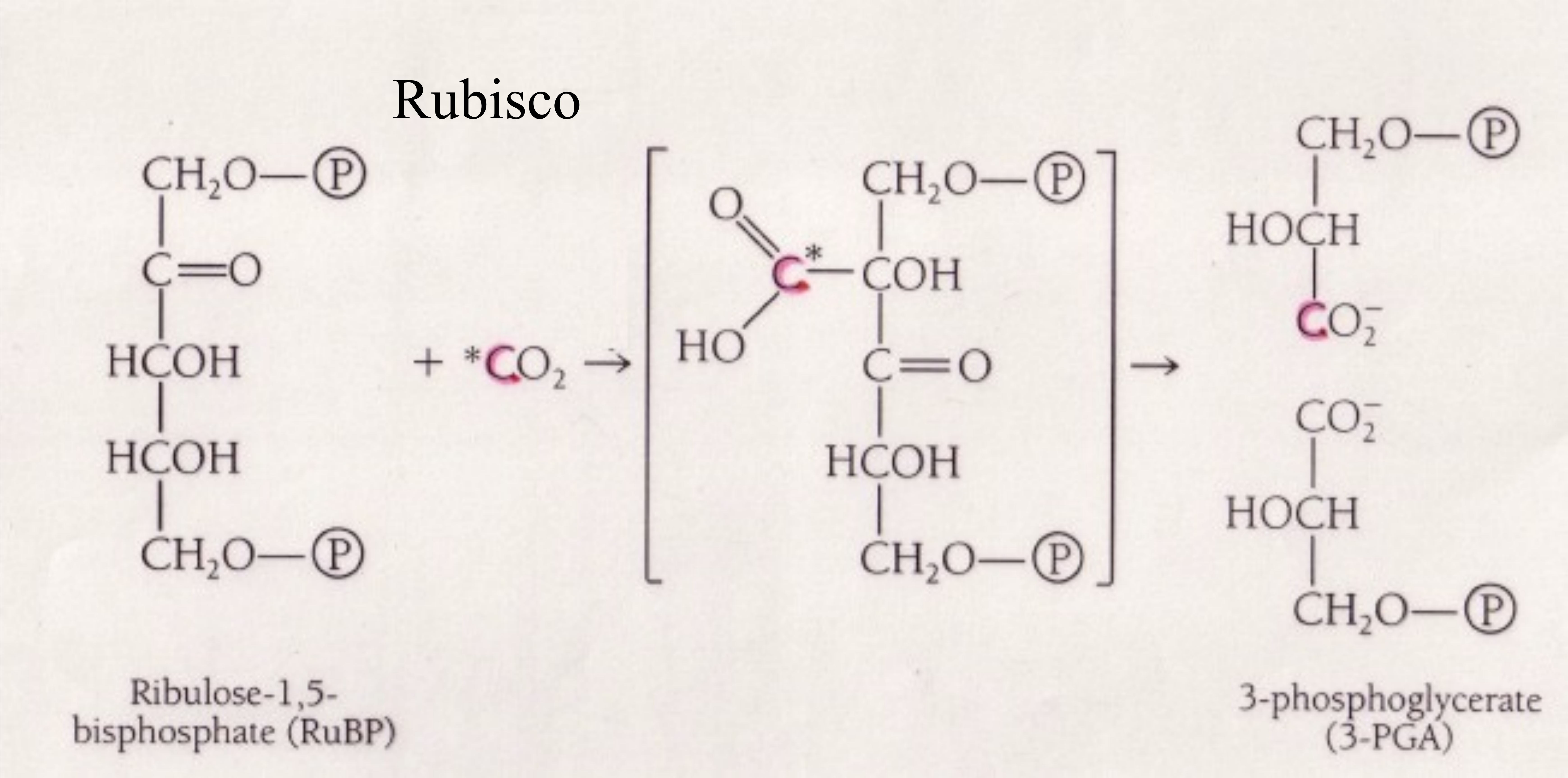


Fig. 11.13

modified from Calvin and Benson, 1949


Rubisco
CH2O—P
C=O
HCOH
HCOH
CH2O—P
+ *CO2 →
O
C*
HO
CH2O—P
COH
C=O
HCOH
CH2O—P
→
CH2O—P
HOCH
CO2−
CO2−
HOCH
CH2O—P
Ribulose-1,5-
bisphosphate (RuBP)
3-phosphoglycerate
(3-PGA)

1. Fixation

Trifecta

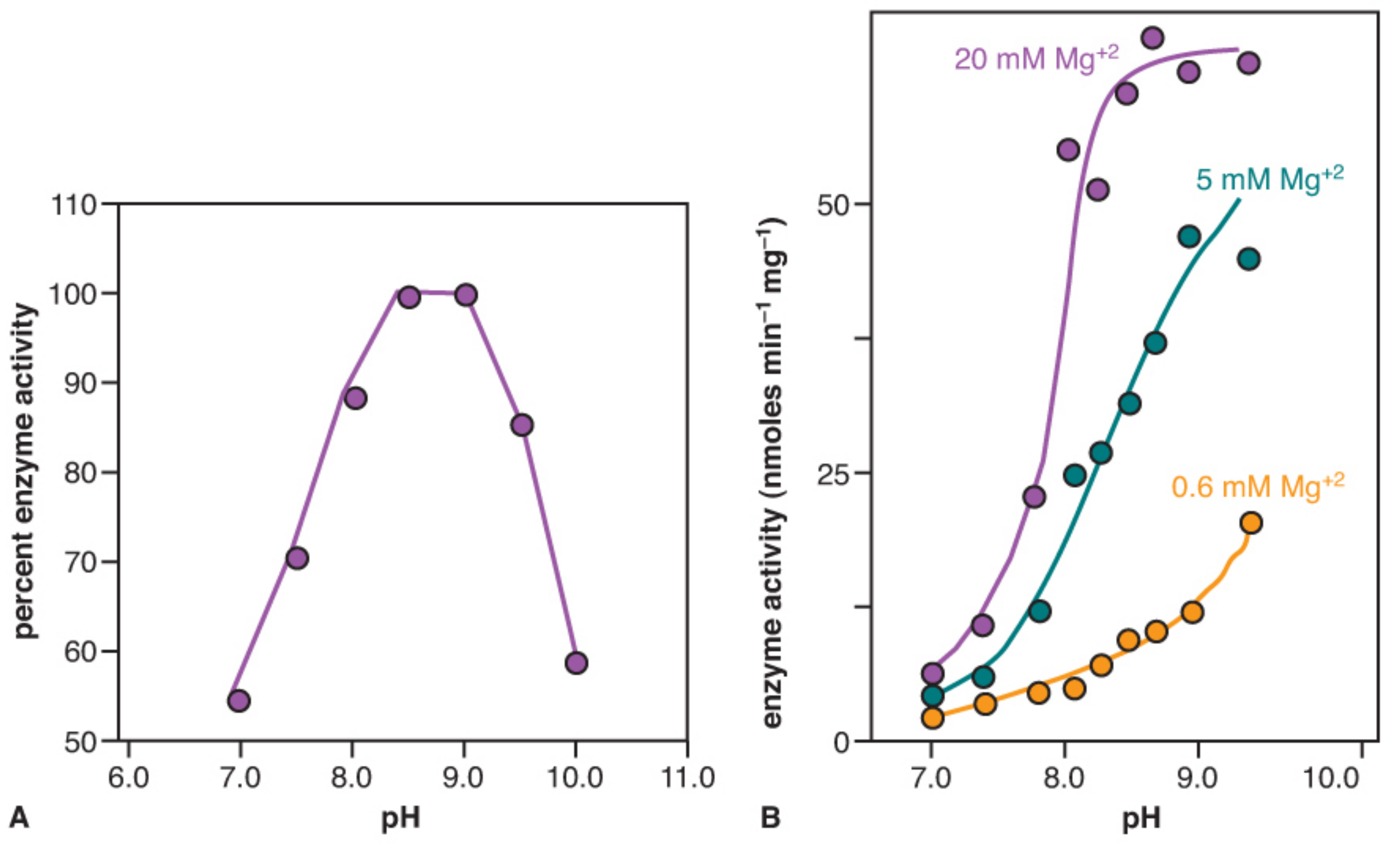
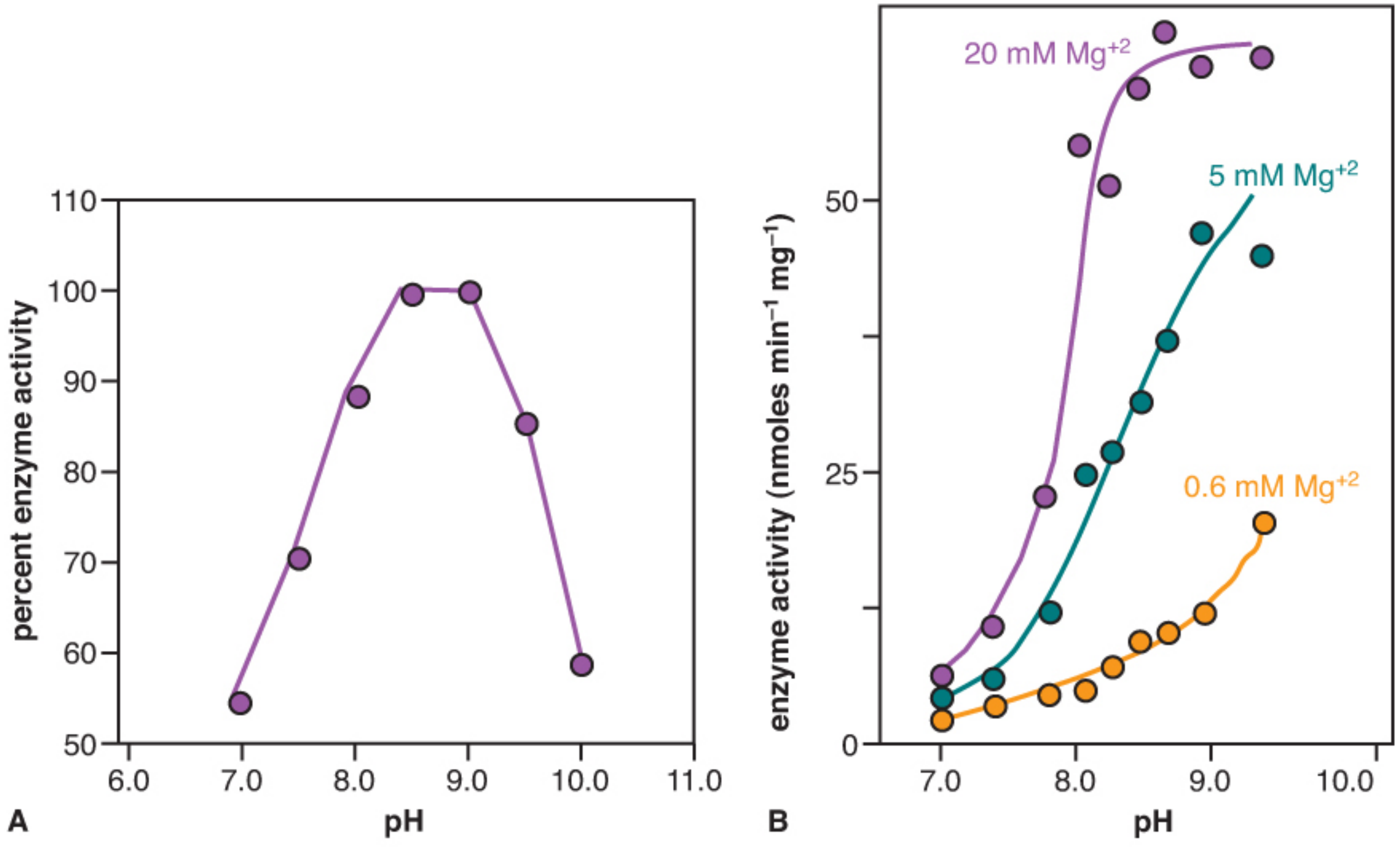
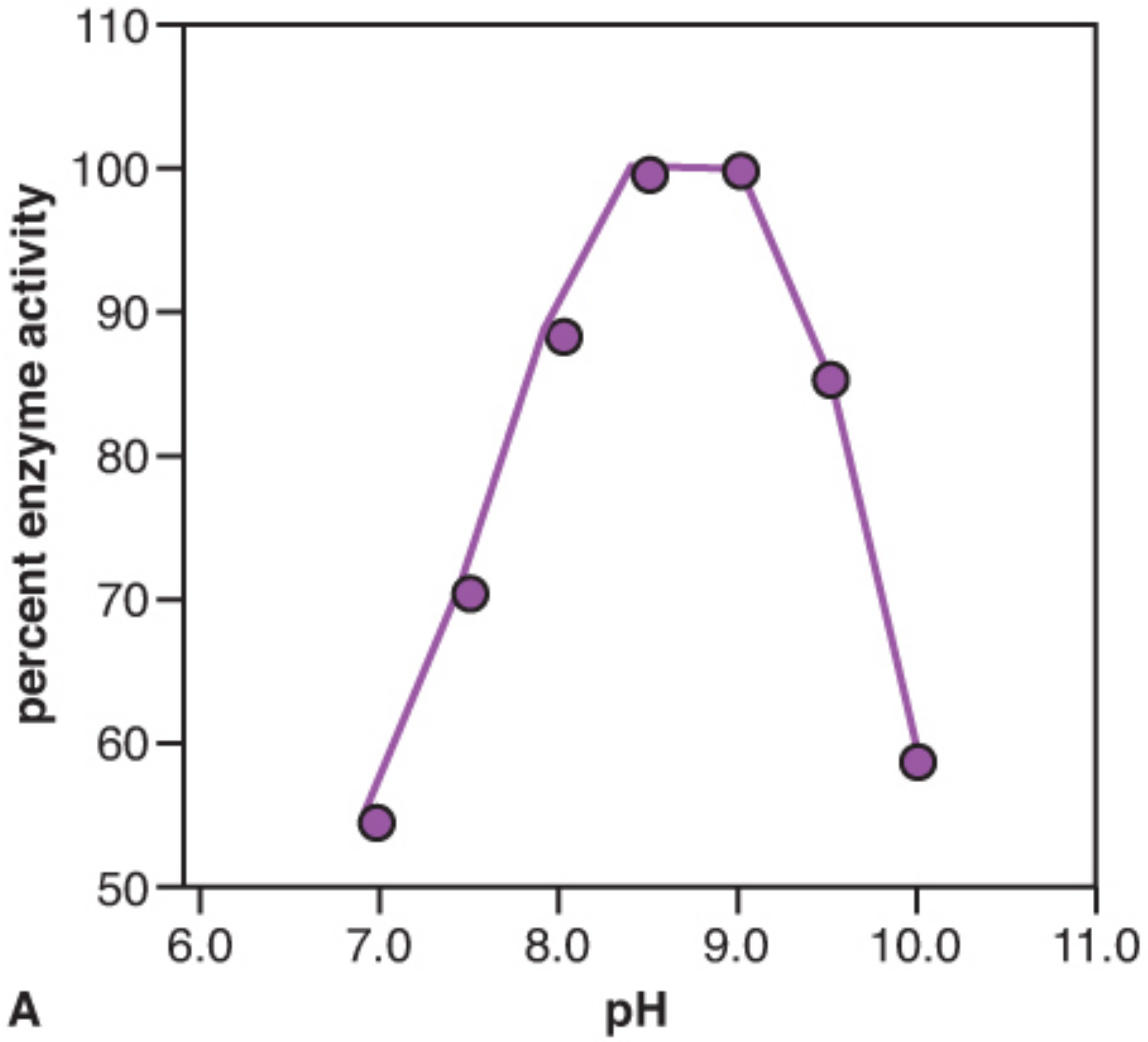


Figure 11.15 Physiological regulation of rubisco. **A,** Rubisco activity is sensitive to pH. **B,** Rubisco activity is sensitive to Mg^{+2} concentration and pH. Panel A modified from Chakrabarti et al., 2003, figure 2. Panel B modified from Lorimer et al., 1976, their figure 5Reprinted (adapted) with permission from Lorimer, George H., Murray R. Badger and T. John Andrews. 1976. The Activation of Ribulose- 1,5-bisphosphate Carboxylase by Carbon Dioxide and Magnesium Ions. Equilibria, Kinetics, a



Taq needs Mg also

Figure 11.15 Physiological regulation of rubisco. **A,** Rubisco activity is sensitive to pH. **B,** Rubisco activity is sensitive to Mg^{+2} concentration and pH. Panel A modified from Chakrabarti et al., 2003, figure 2. Panel B modified from Lorimer et al., 1976, their figure 5Reprinted (adapted) with permission from Lorimer, George H., Murray R. Badger and T. John Andrews. 1976. The Activation of Ribulose- 1,5-bisphosphate Carboxylase by Carbon Dioxide and Magnesium Ions. Equilibria, Kinetics, a Suggested Mechanism, and Physiological Implications. Biochemistry. Vol. 15(3): 529-536. . Copyright 1976 American Chemical Society.


110
100
90
80
70
60
50
percent enzyme activity
6.0
7.0
8.0
9.0
10.0
11.0
pH

A

zyme showed activity plateau between the pH range of 8.0 and 9.0. The decrease in activity to either side of plateau for soluble enzyme was sharper than that observed for immobilized enzyme. The immobilized enzyme pH–activity profile showed a shift to the right as compared to the soluble enzyme (Fig. 2).

Figure 1. SDS-PAGE analysis of purified spinach Rubisco. Spinach Rubisco was purified from freshly prepared leaf extract. Lysate (15 µg) and purified protein (5 µg) were loaded on a 12% SDS-PAGE and stained with Coomassie blue.

Temperature–Activity Relationship

The residual activity as a function of time was determined at different temperatures. Figure 3 presents temperature–activity profile of soluble and immobilized Rubisco. To determine the effect of temperature on the rate of deactivation of the enzyme at 20°C and at 55°C, the lowest and highest temperatures at which Rubisco activity has been determined in the present investigation, the residual activity (percent) at these temperatures was determined and the natural log of the ratio of residual activity at specified temperature to that of the initial activity (taken as 100%) was plotted against incubation time. The resulting plots are presented in Fig. 4. As evident from Fig. 4, rates of deactivation at 20°C among enzymes (soluble or immobilized) were extremely low, differences in the rates of deactivation (slope of the graph) were also very low, and slopes were almost identical. However, the rate of deactivation at 55°C is significantly different for soluble and immobilized enzymes.

Table II. Leached protein amounts with respect to number of use cycle for Rubisco immobilized on nylon matrix and on protein A agarose.[a]

No. of residence time	Rubisco immobilized on nylon matrix	Rubisco immobilized on protein A agarose
1	0	0
2	0	0
3	0	0
4	8 ± 2	0
5	10 ± 2	0
6	30 ± 2	5 ± 2

[a]The total initial protein load was taken as 100 percent and leached protein amounts determined using method of Bradford have been expressed as percent.

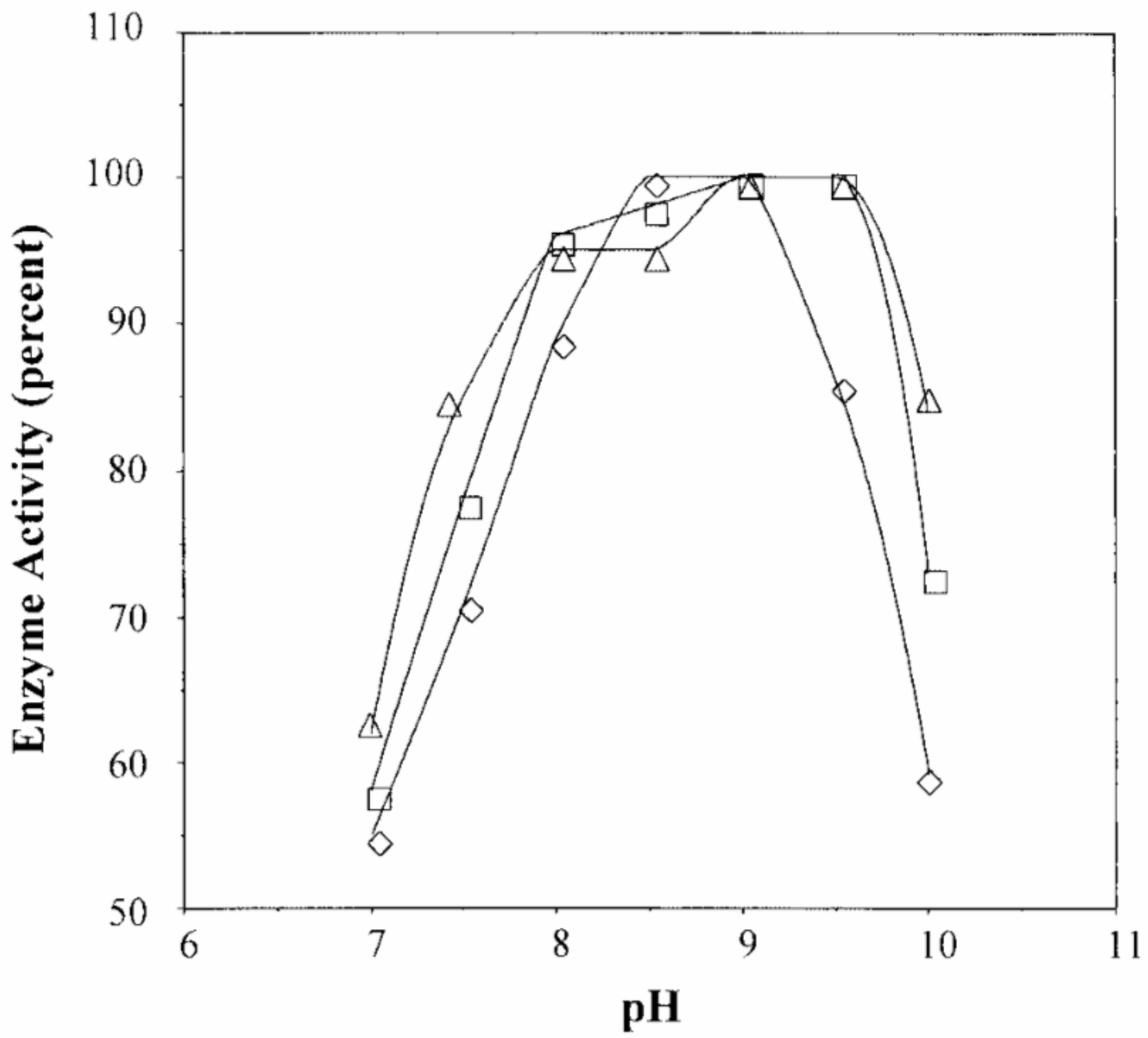
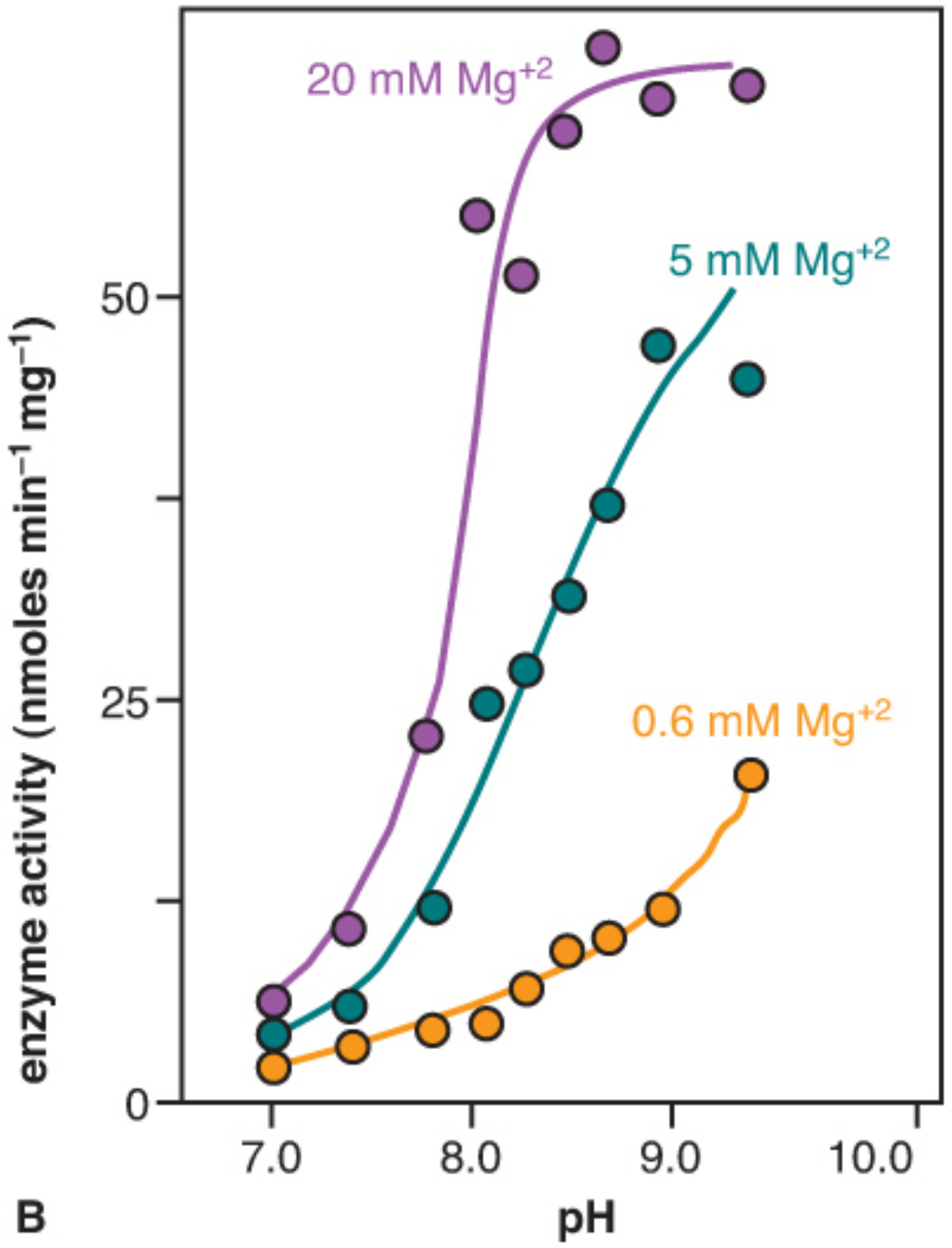
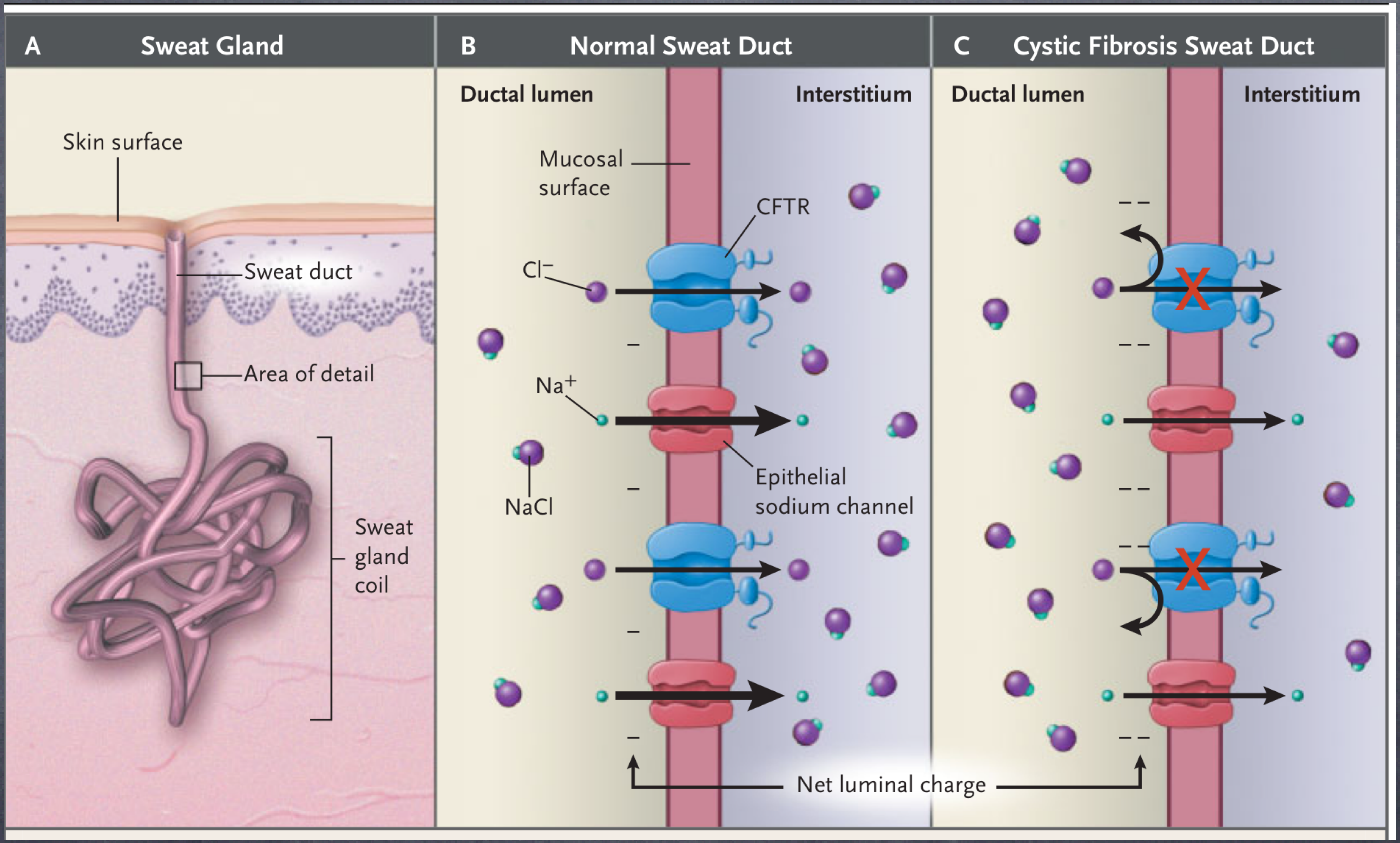


Figure 2. pH–activity profile of the soluble and immobilized Rubisco. The enzymes were subjected to a buffer of pH 7.0–10.0 for determination of activity. Soluble enzyme (◇), Rubisco immobilized using DCC coupling on nylon (□), and Rubisco immobilized using DMP coupling (△).



20 mM Mg+2
5 mM Mg+2
0.6 mM Mg+2
enzyme activity (nmoles min−1 mg−1)
50
25
0
7.0
8.0
9.0
10.0
pH
B

Explain



A Sweat Gland
B Normal Sweat Duct
C Cystic Fibrosis Sweat Duct
Skin surface
Sweat duct
Area of detail
Sweat gland coil
Ductal lumen
Interstitium
Mucosal surface
CFTR
Cl−
Na+
NaCl
Epithelial sodium channel
Ductal lumen
Interstitium
Net luminal charge

Trifecta

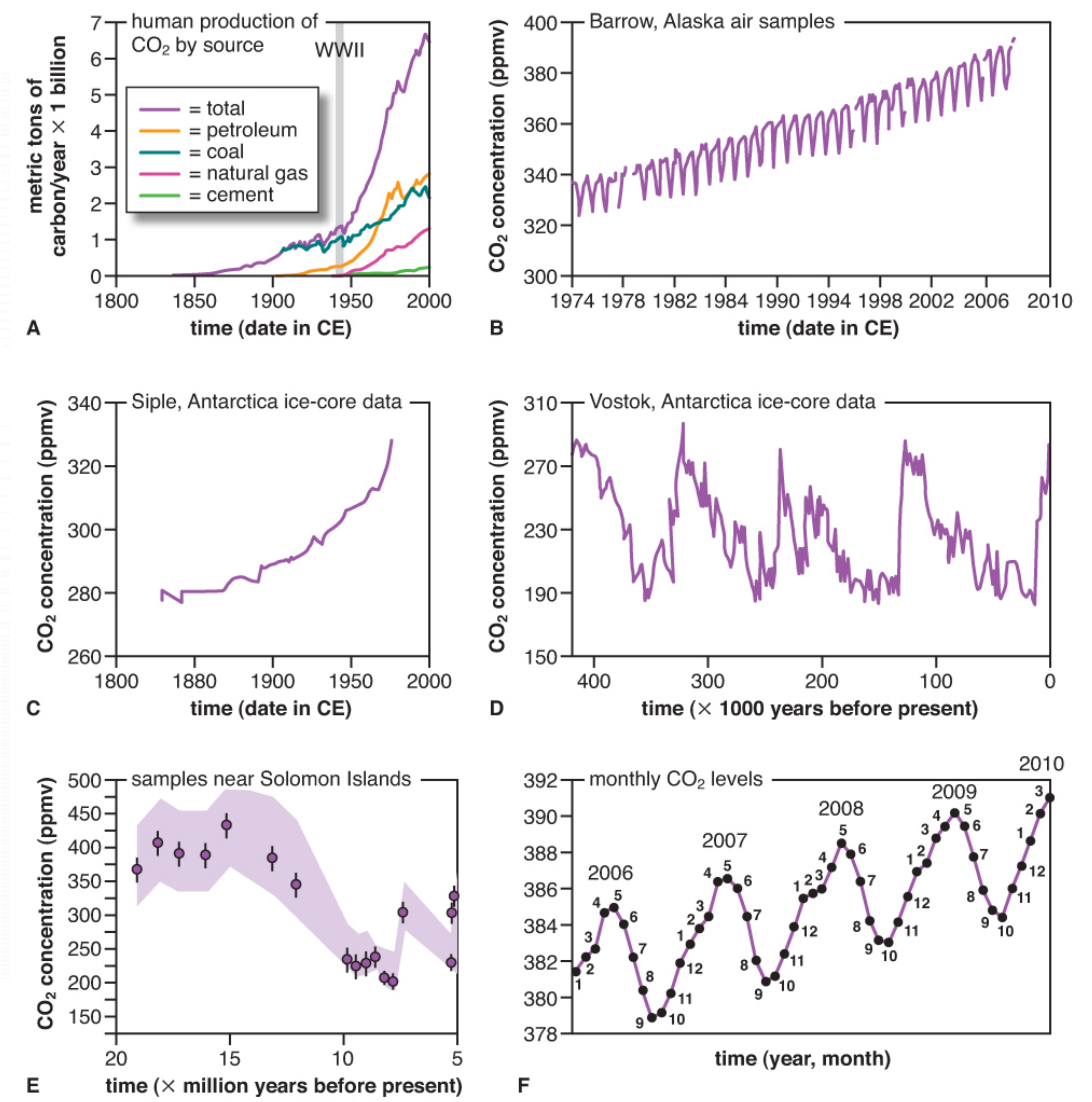


Figure 11.11 Energy consumption and CO_2 levels. **A,** The total production of CO_2 and its sources over the last 200 years. The gray stripe denotes the 5 years of World War II. Manufacturing cement produces CO_2 as well. **B,** The amount of CO_2 measured directly from air in Alaska. **C,** CO_2 levels over the past 200 years measured from ice cores taken in Antarctica. **D,** CO_2 levels over the past 425,000 years measured from ice cores taken Antarctica. **E,** CO_2 levels over the past 20 million years measured from ocean floor sediment in the South Pacific Ocean. Error bars are +/- standard deviation, and the red shaded area

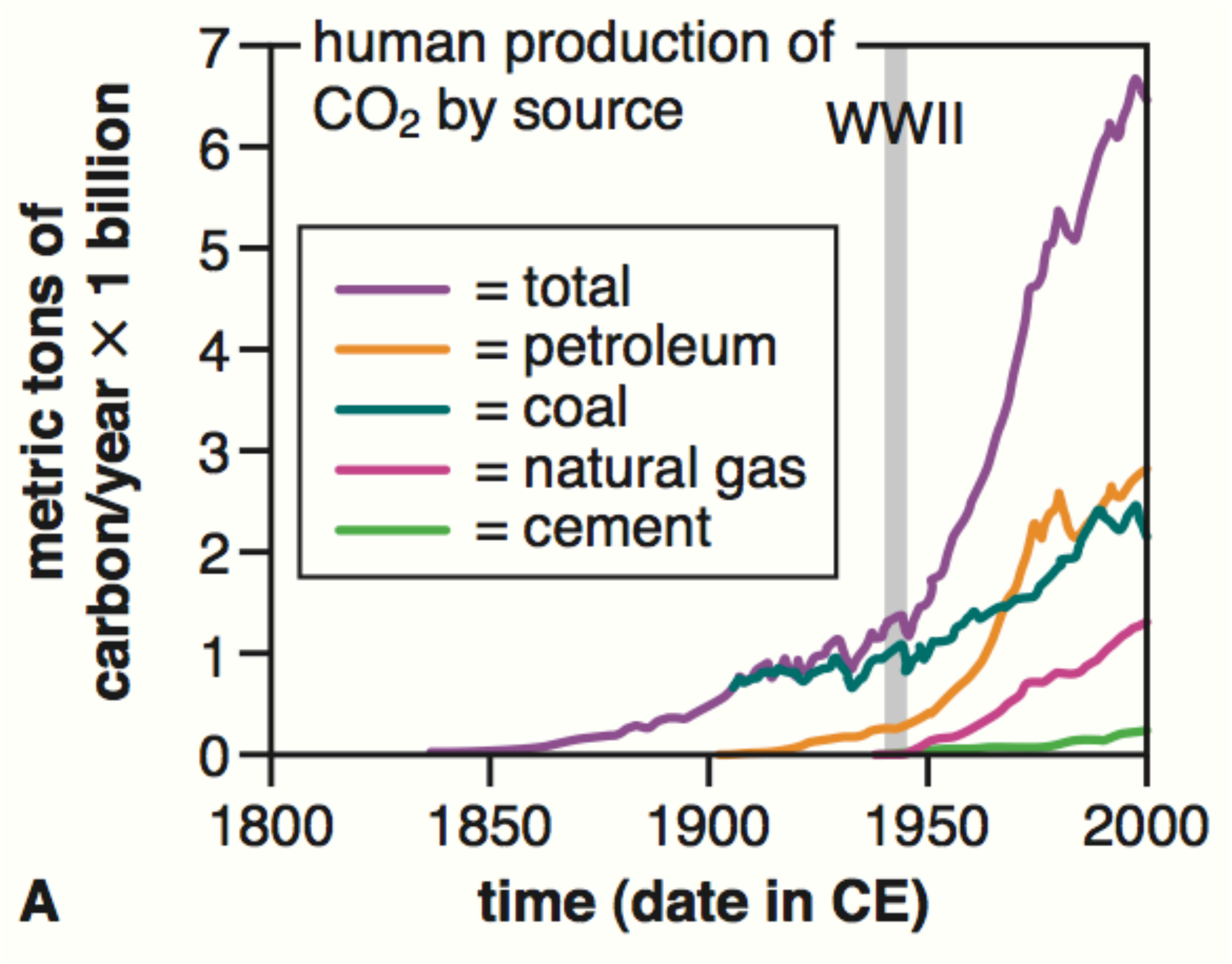
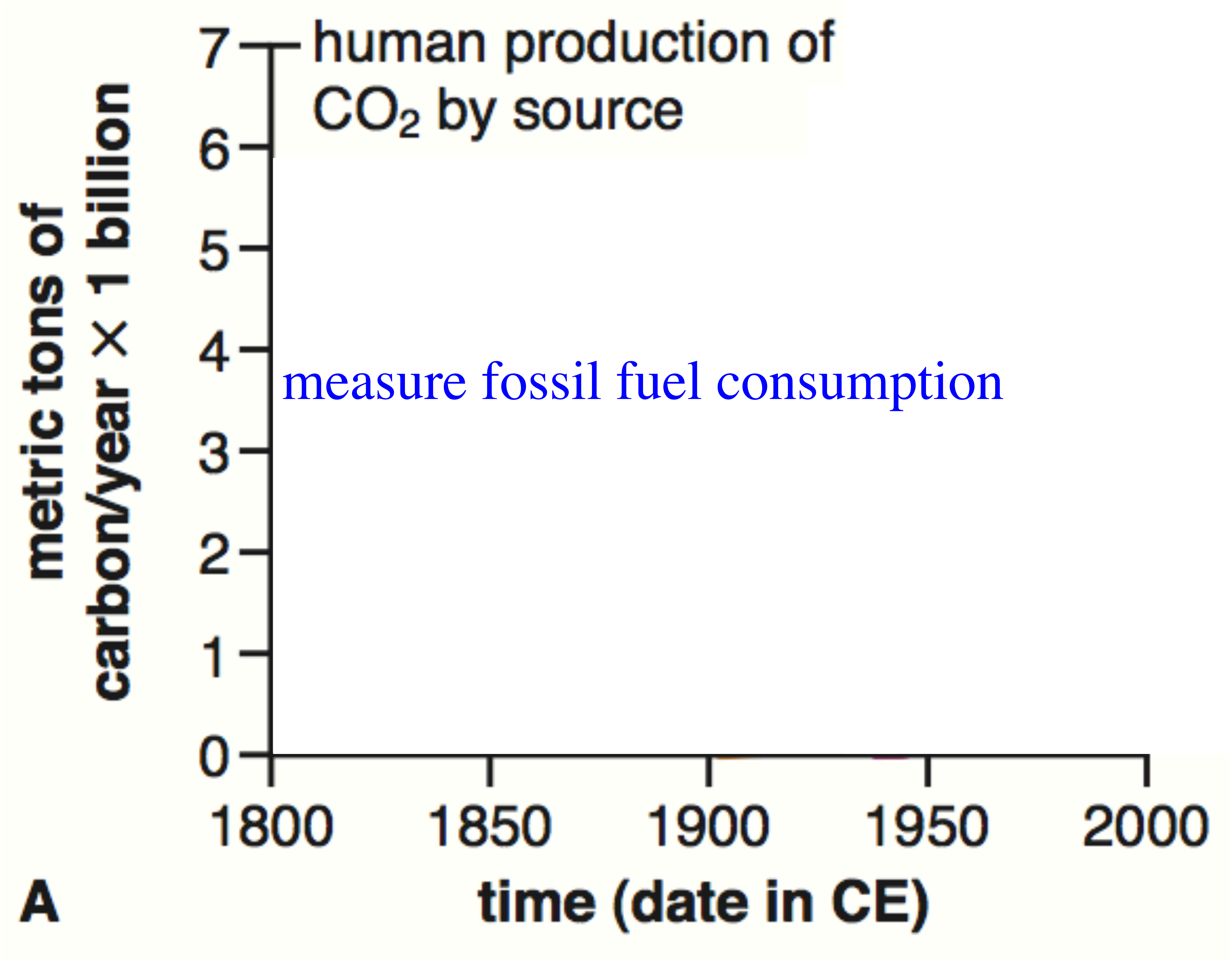


Fig. 11.11

E: modified from Tripati *et al.*, 2009

Historic Atmospheric CO_2 Levels



measure fossil fuel consumption

Fig. 11.11

E: modified from Tripati *et al.*, 2009

Historic Atmospheric CO_2 Levels

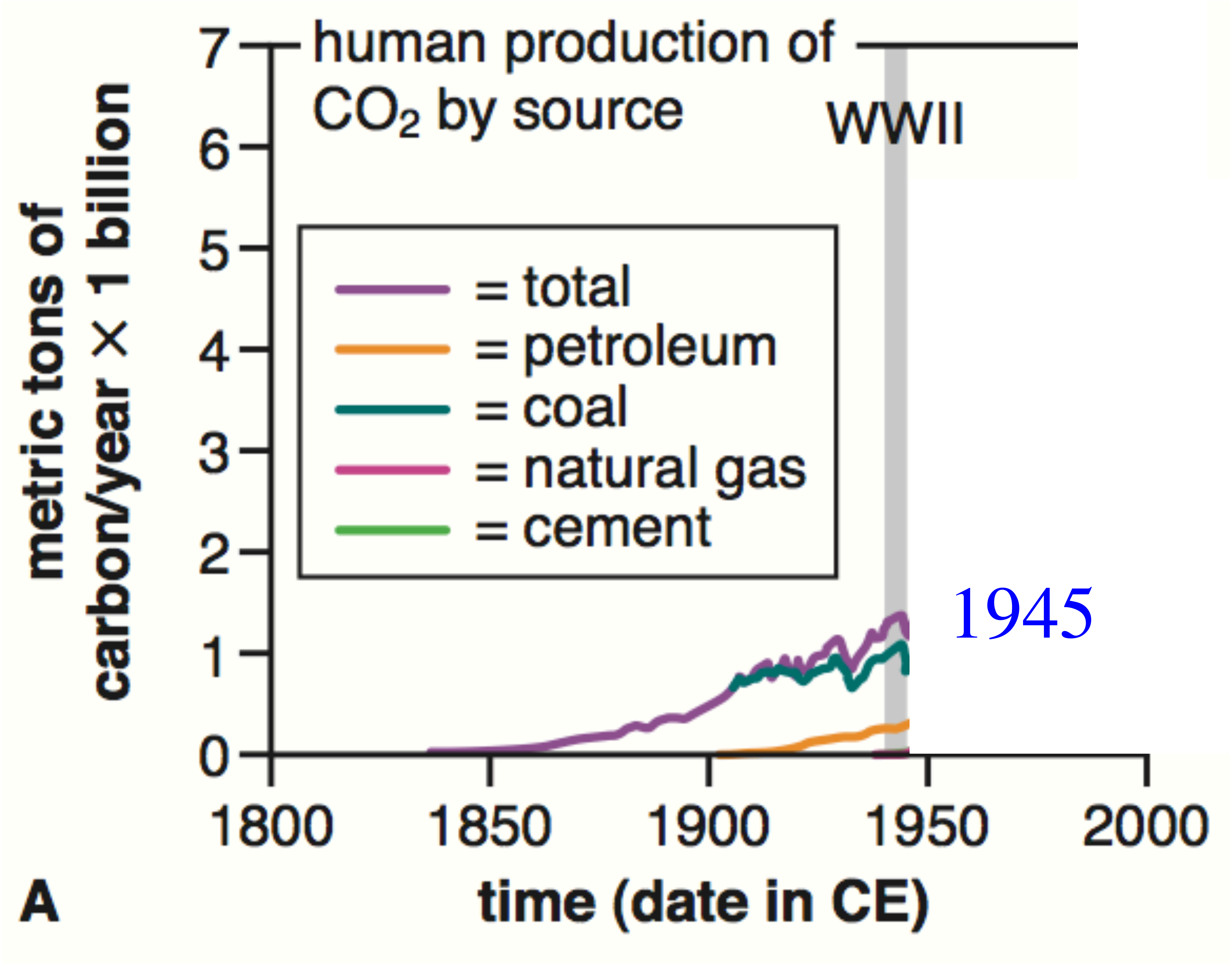
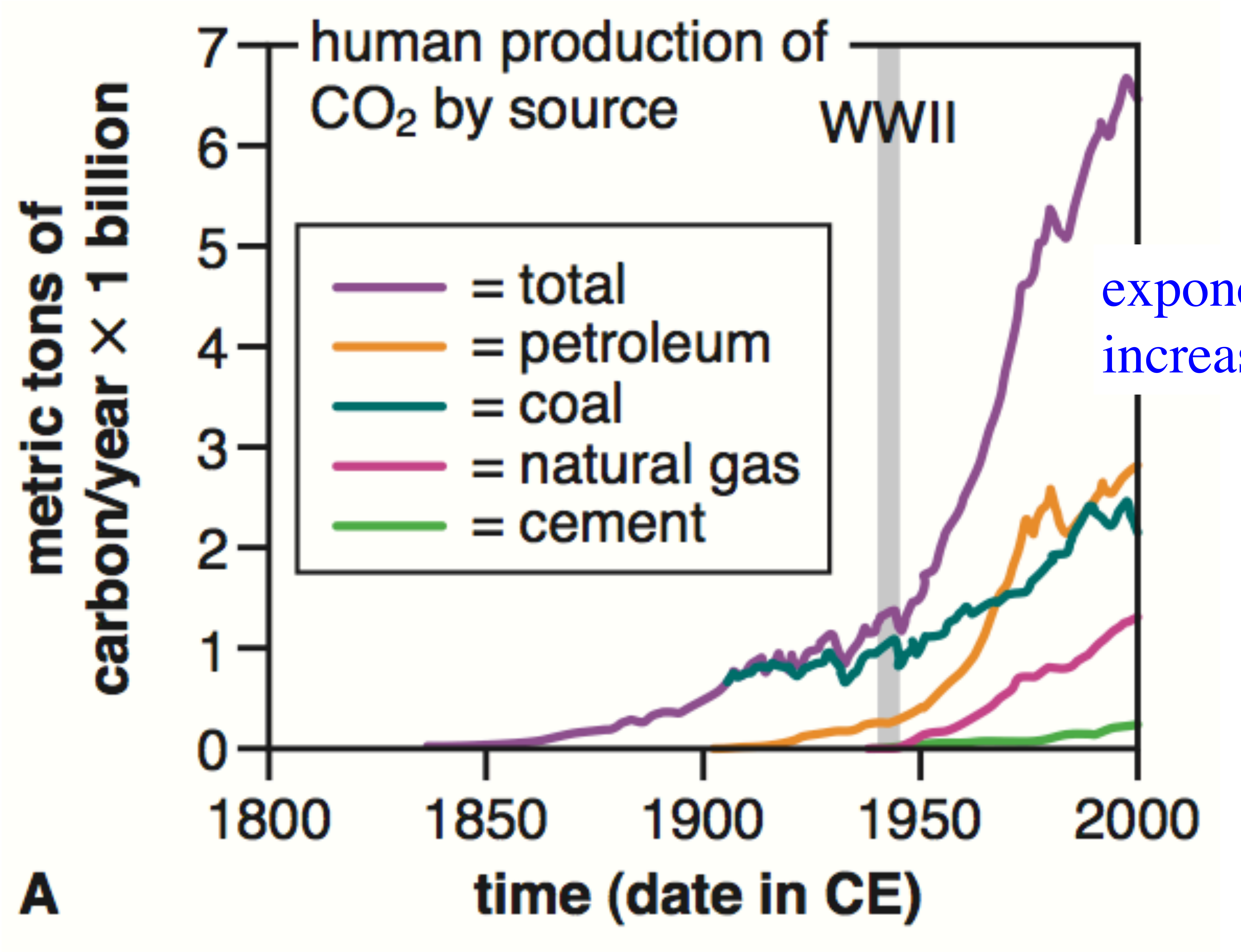


Fig. 11.11

E: modified from Tripati *et al.*, 2009

Historic Atmospheric CO_2 Levels



exponential increase

Fig. 11.11

E: modified from Tripati *et al.*, 2009

Historic Atmospheric CO_2 Levels

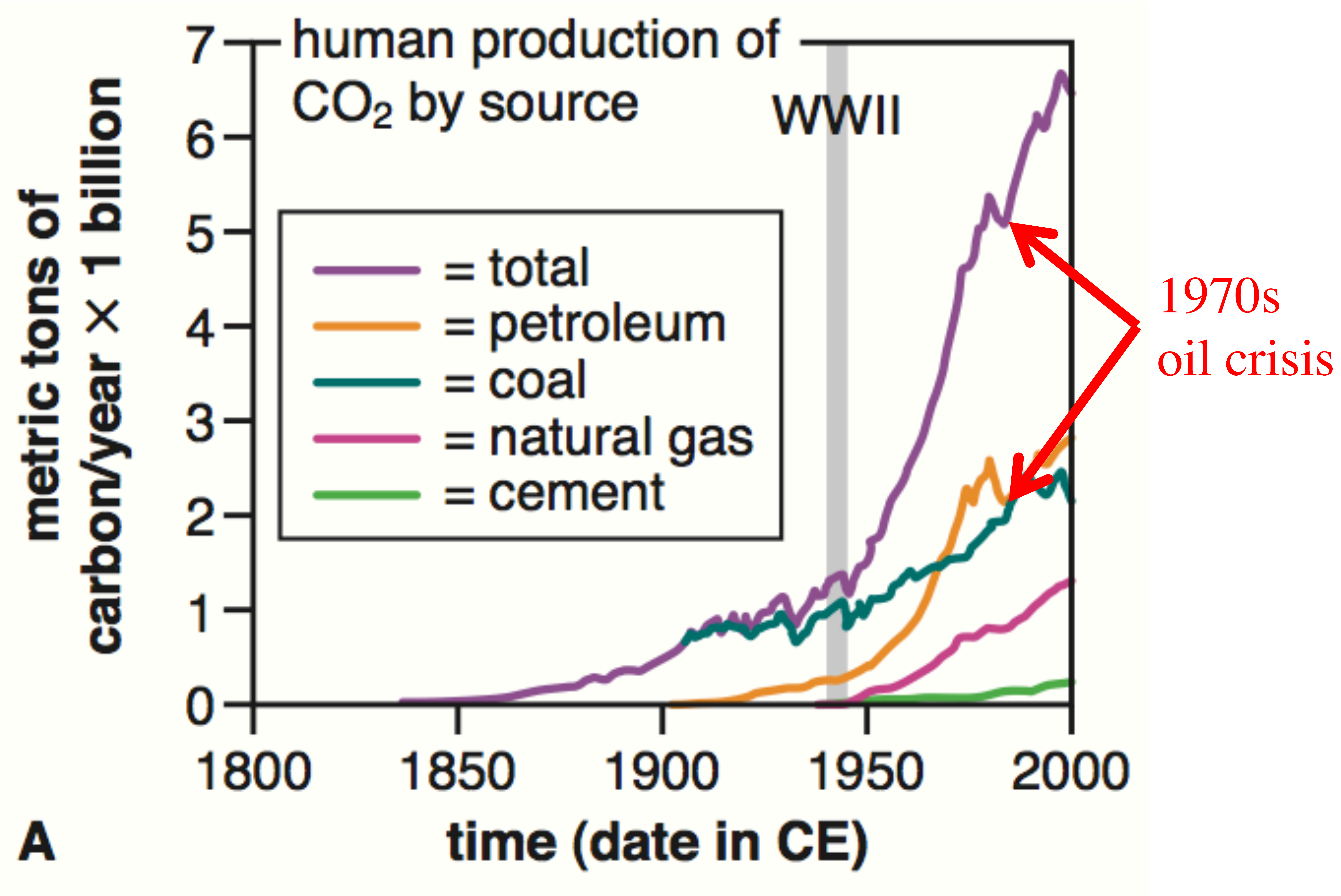


Fig. 11.11

E: modified from Tripati *et al.*, 2009

Trifecta

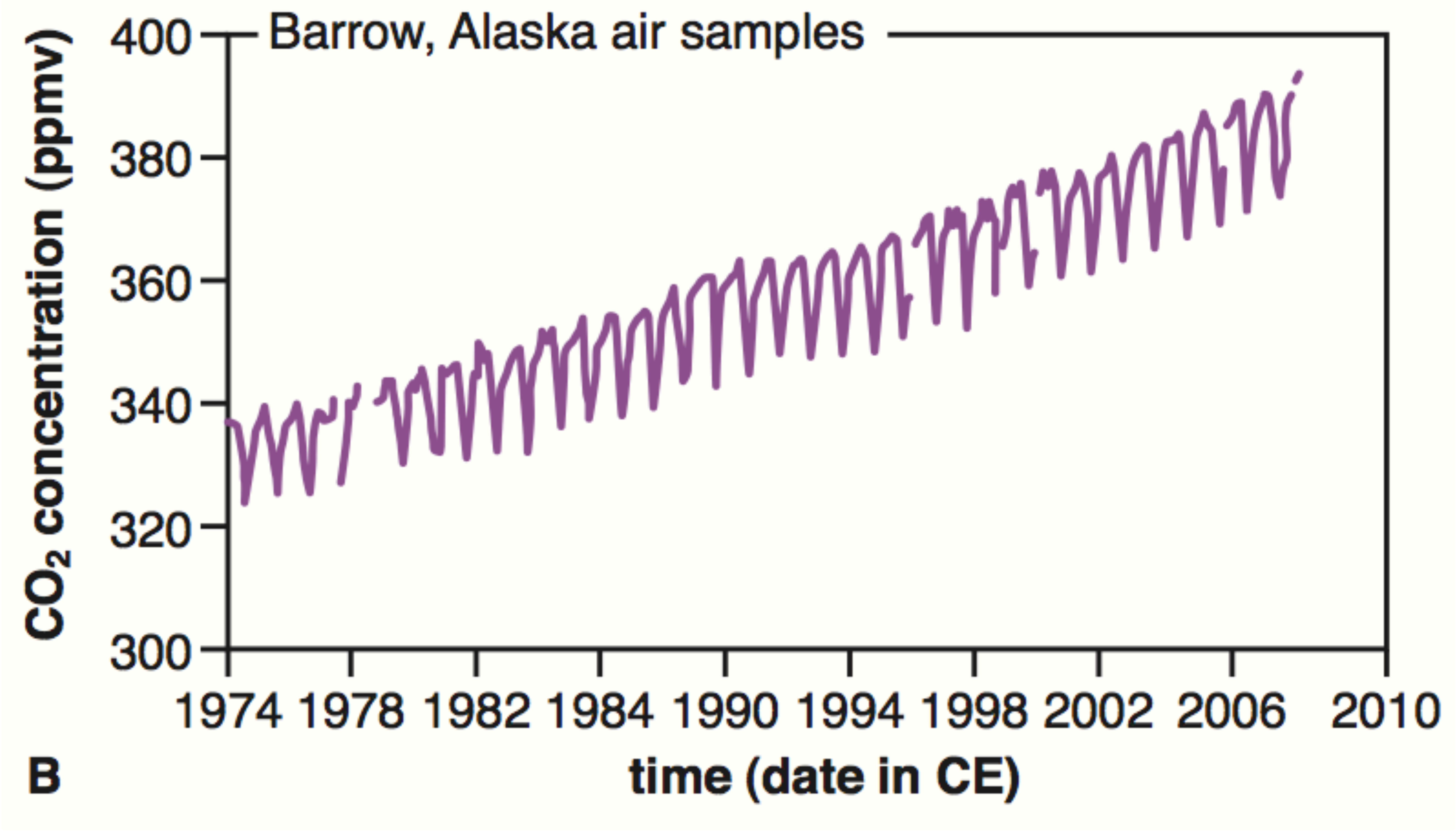


Fig. 11.11

E: modified from Tripati *et al.*, 2009

Historic Atmospheric CO_2 Levels

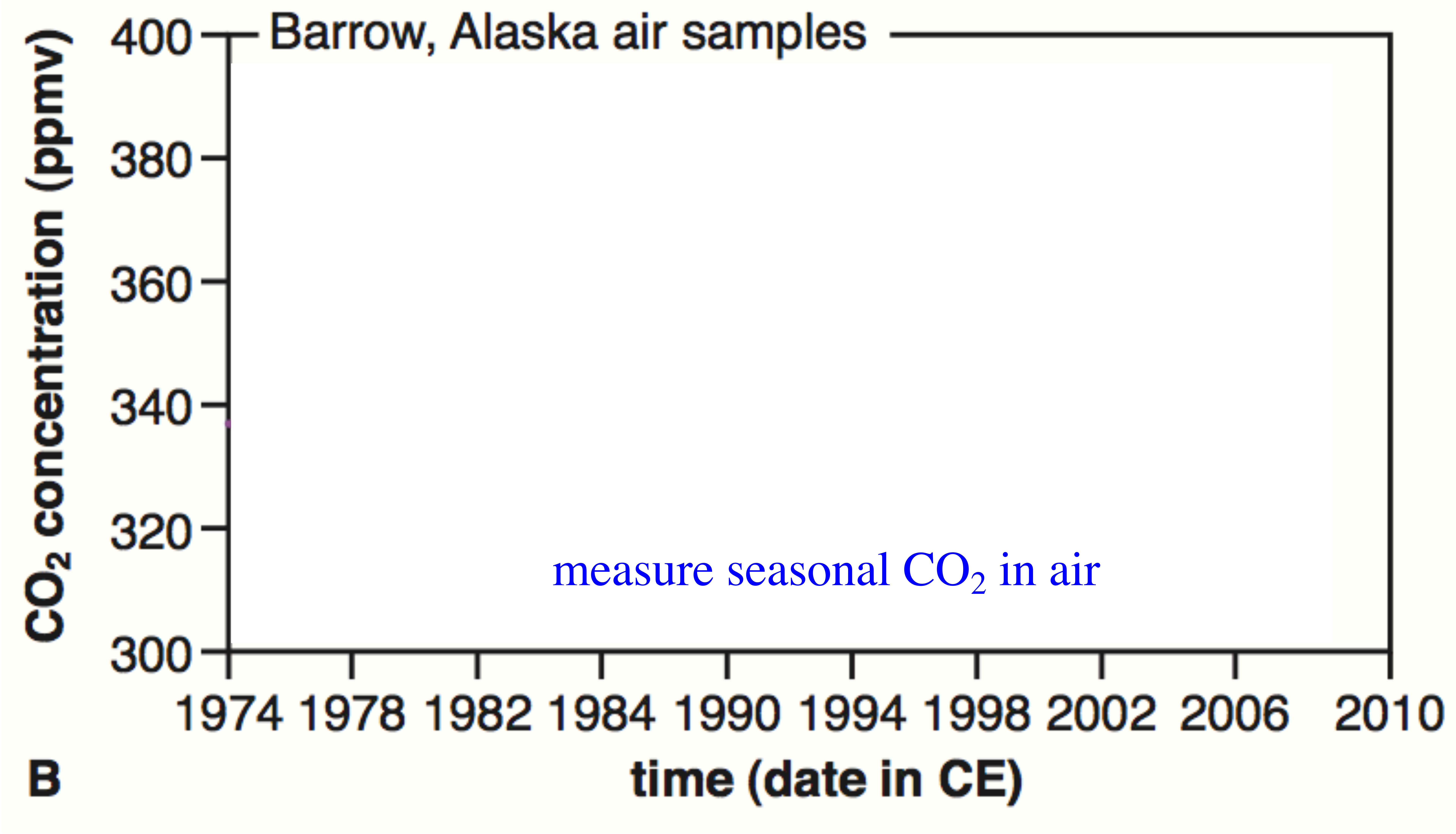


Fig. 11.11

E: modified from Tripati *et al.*, 2009

Historic Atmospheric CO_2 Levels

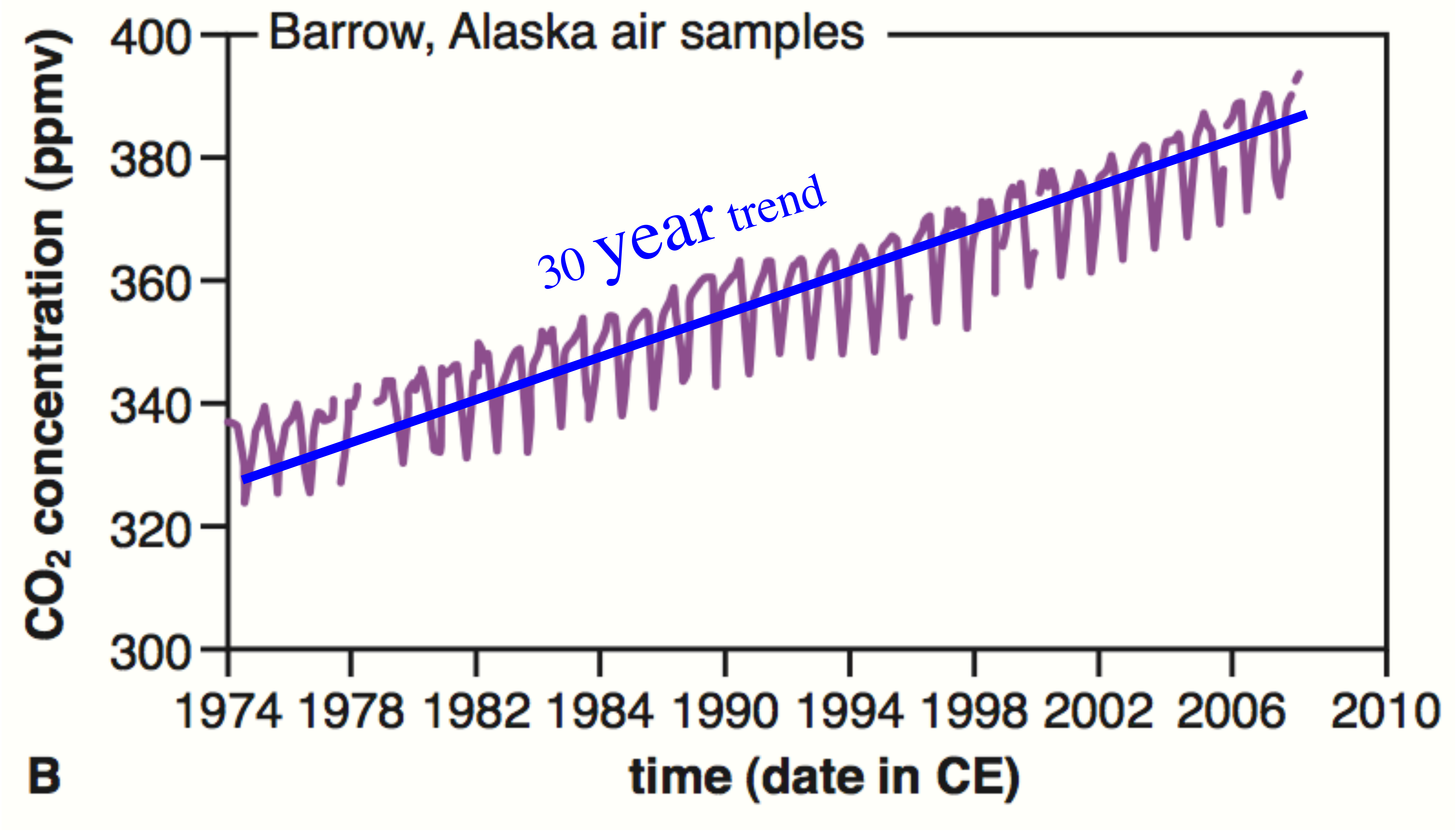


Fig. 11.11

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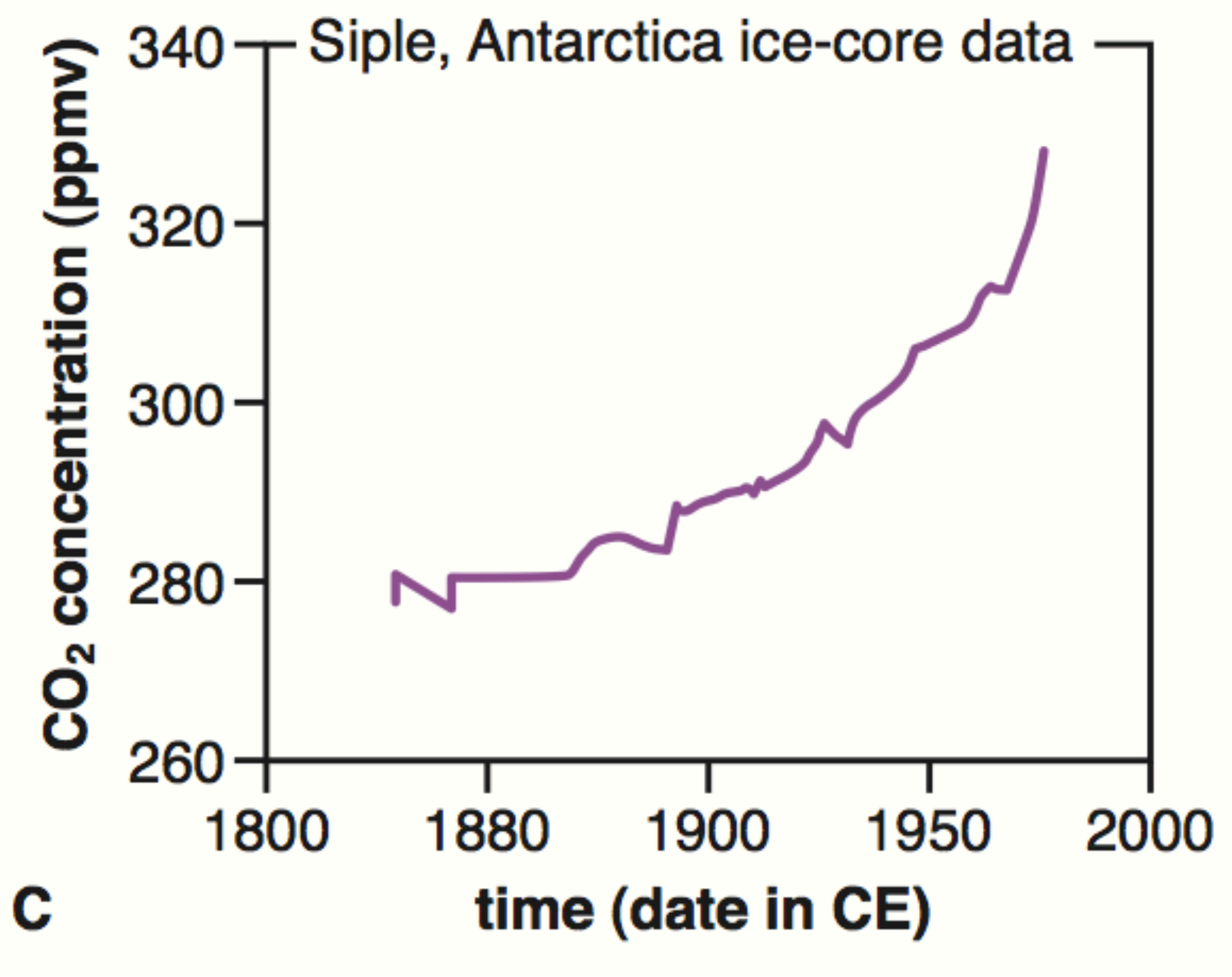

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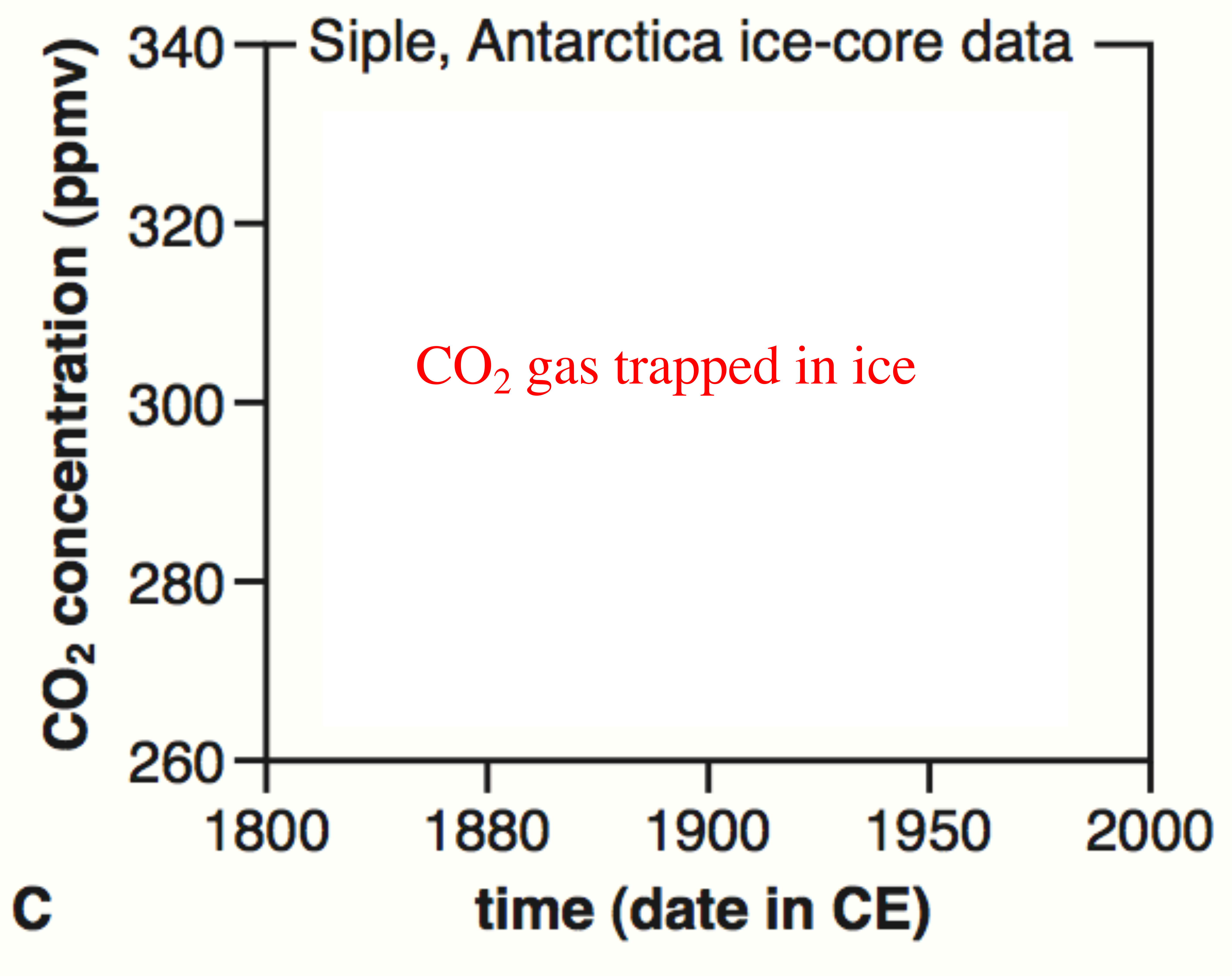
Historic Atmospheric CO_2 Levels



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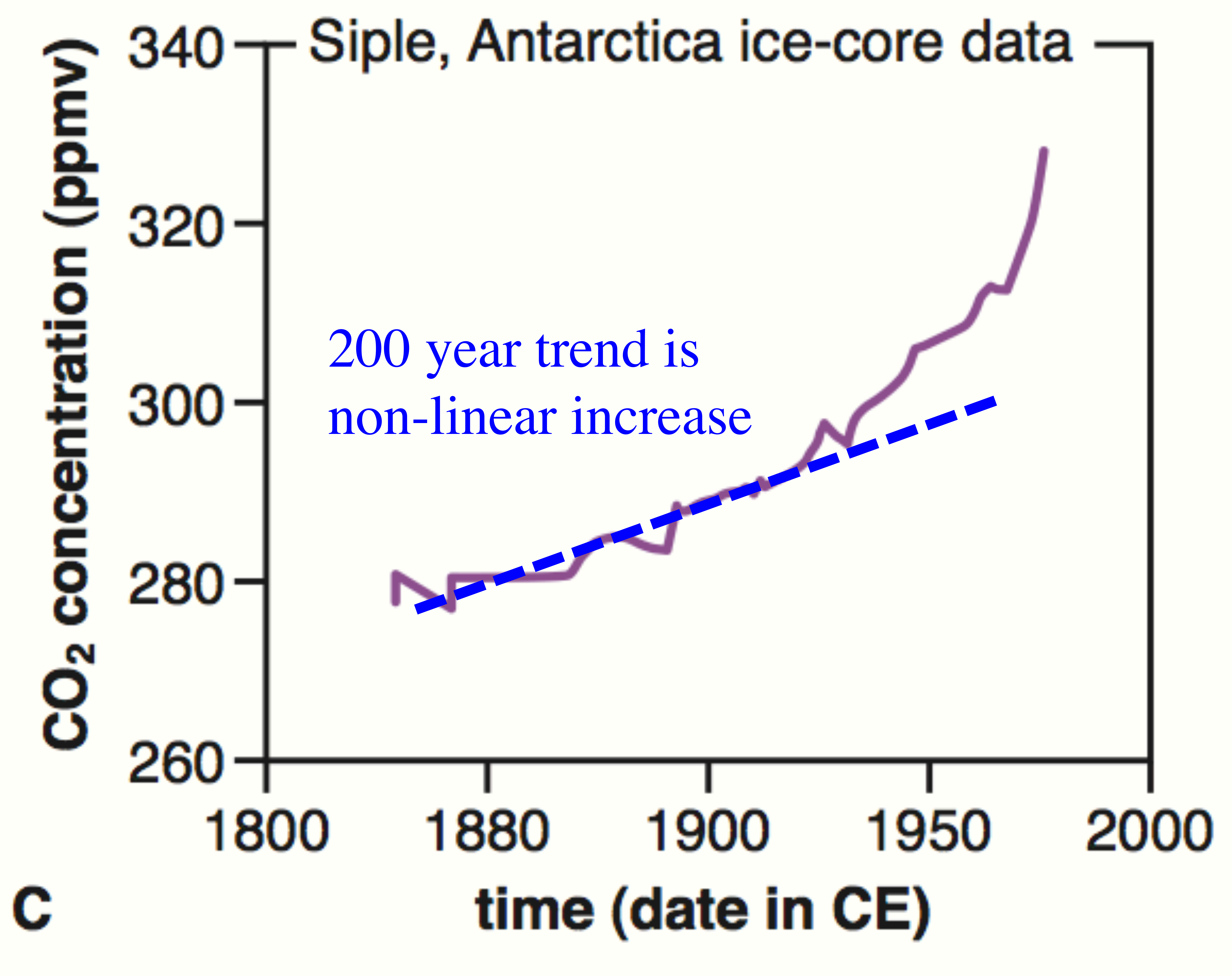
Historic Atmospheric CO_2 Levels



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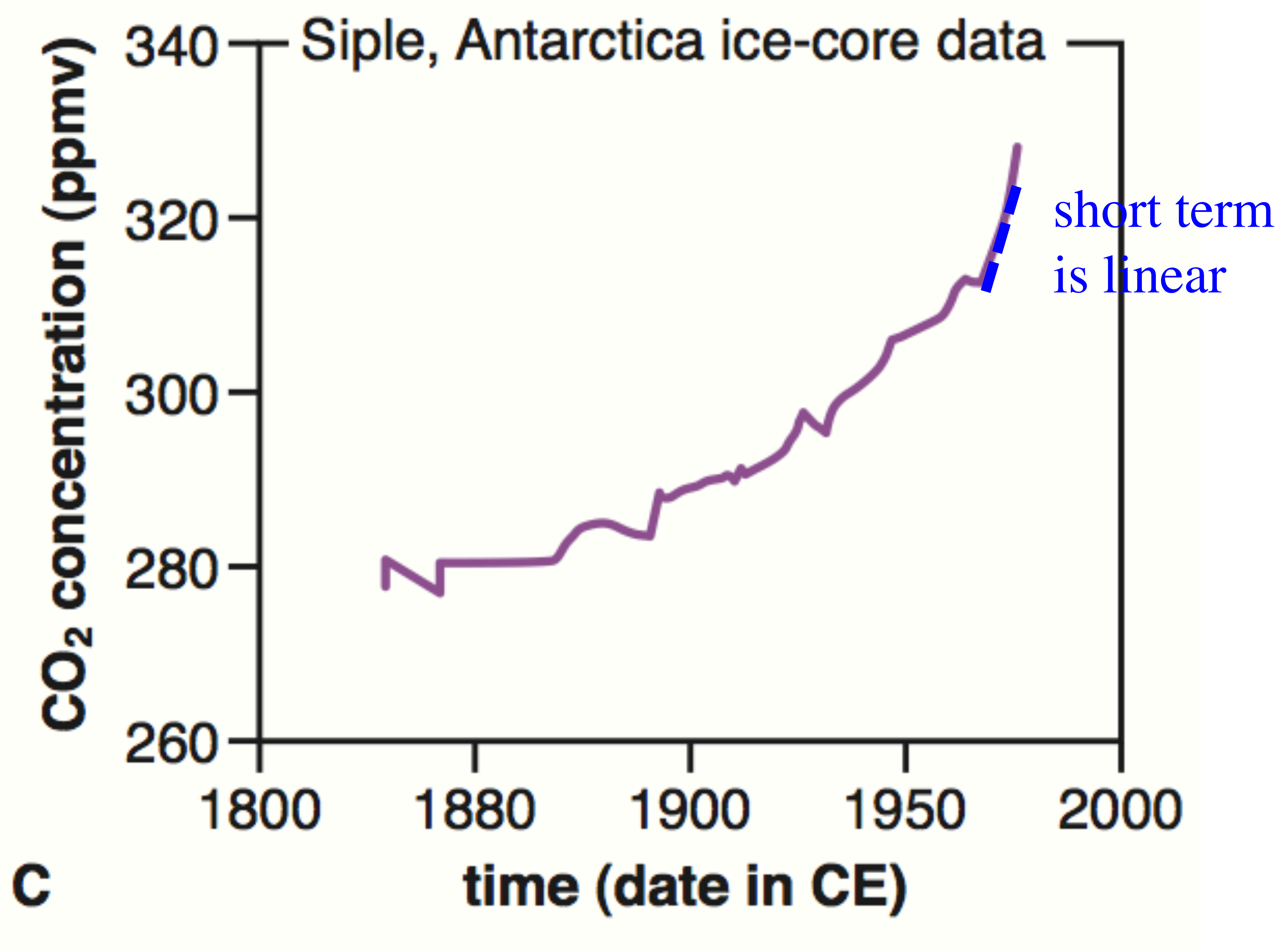

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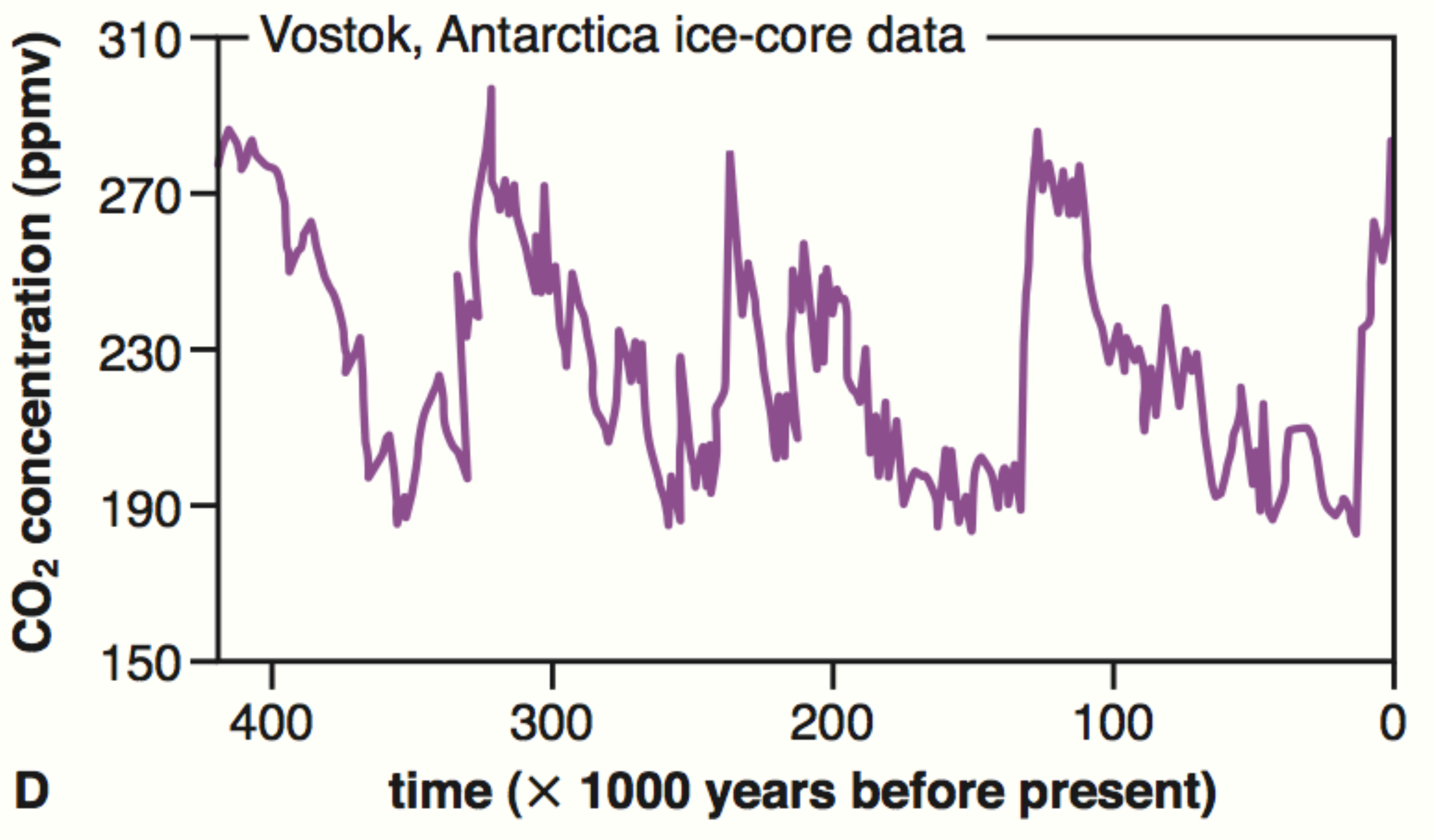

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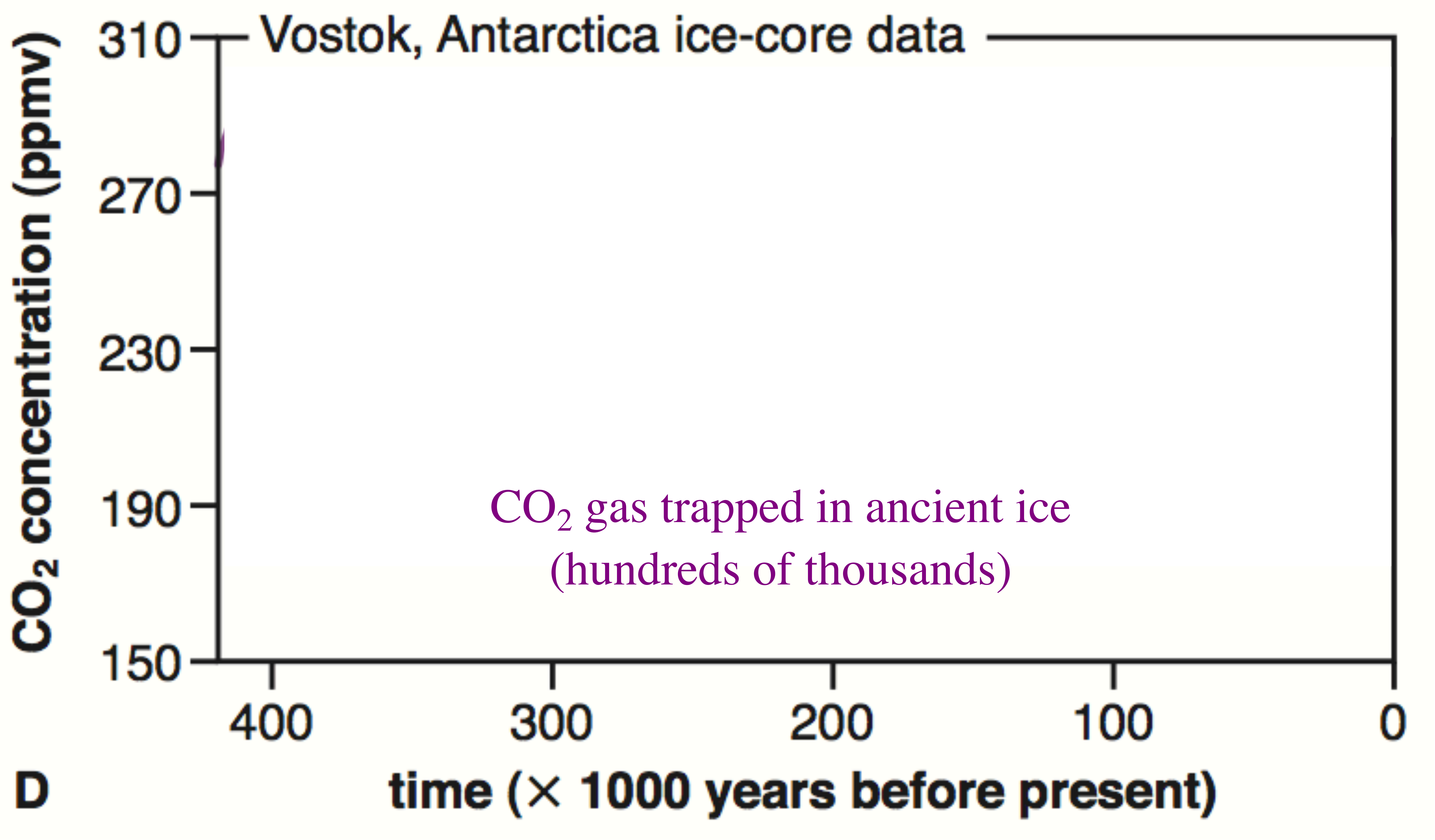
Historic Atmospheric CO_2 Levels



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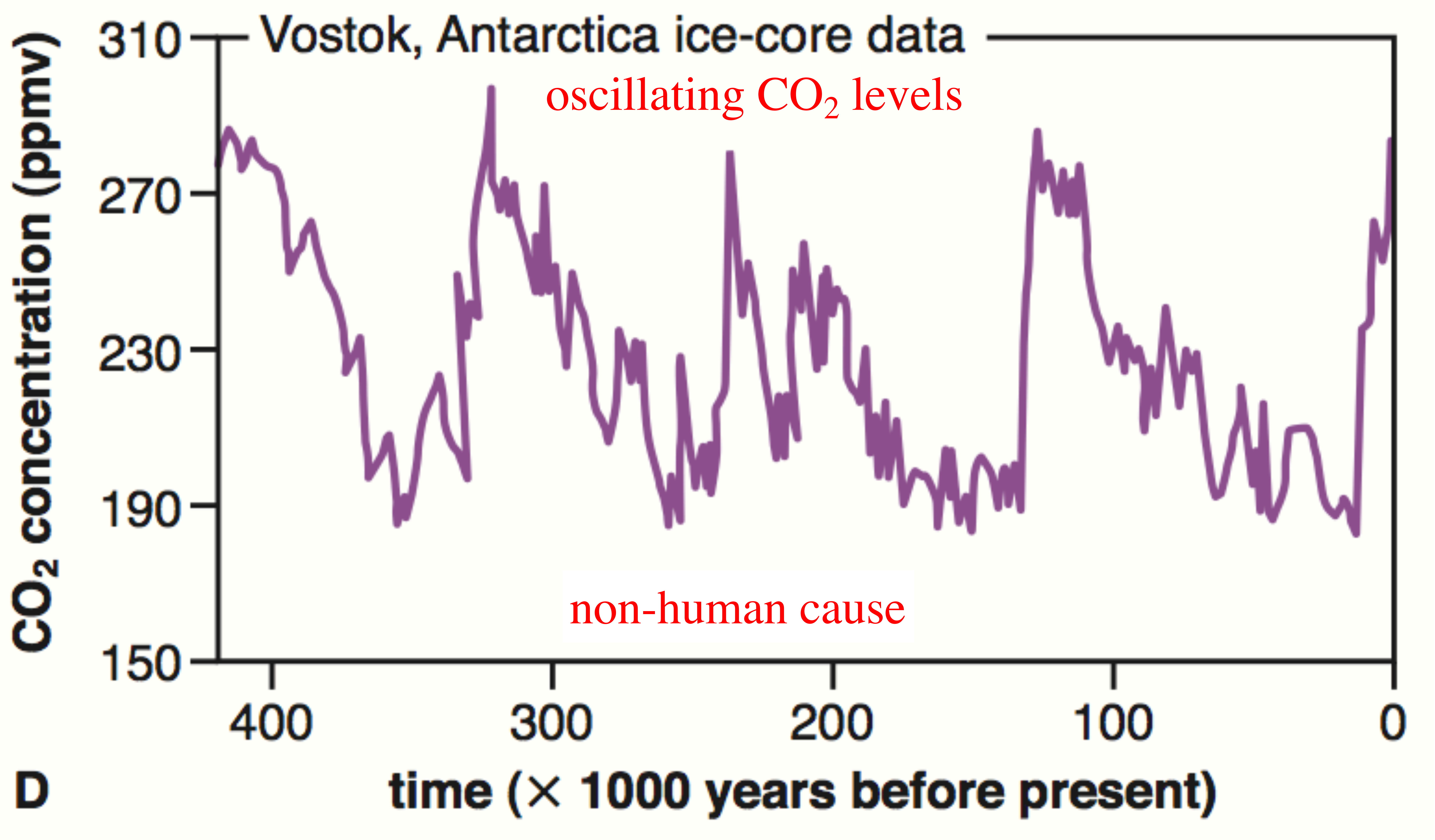

Fig. 11.11

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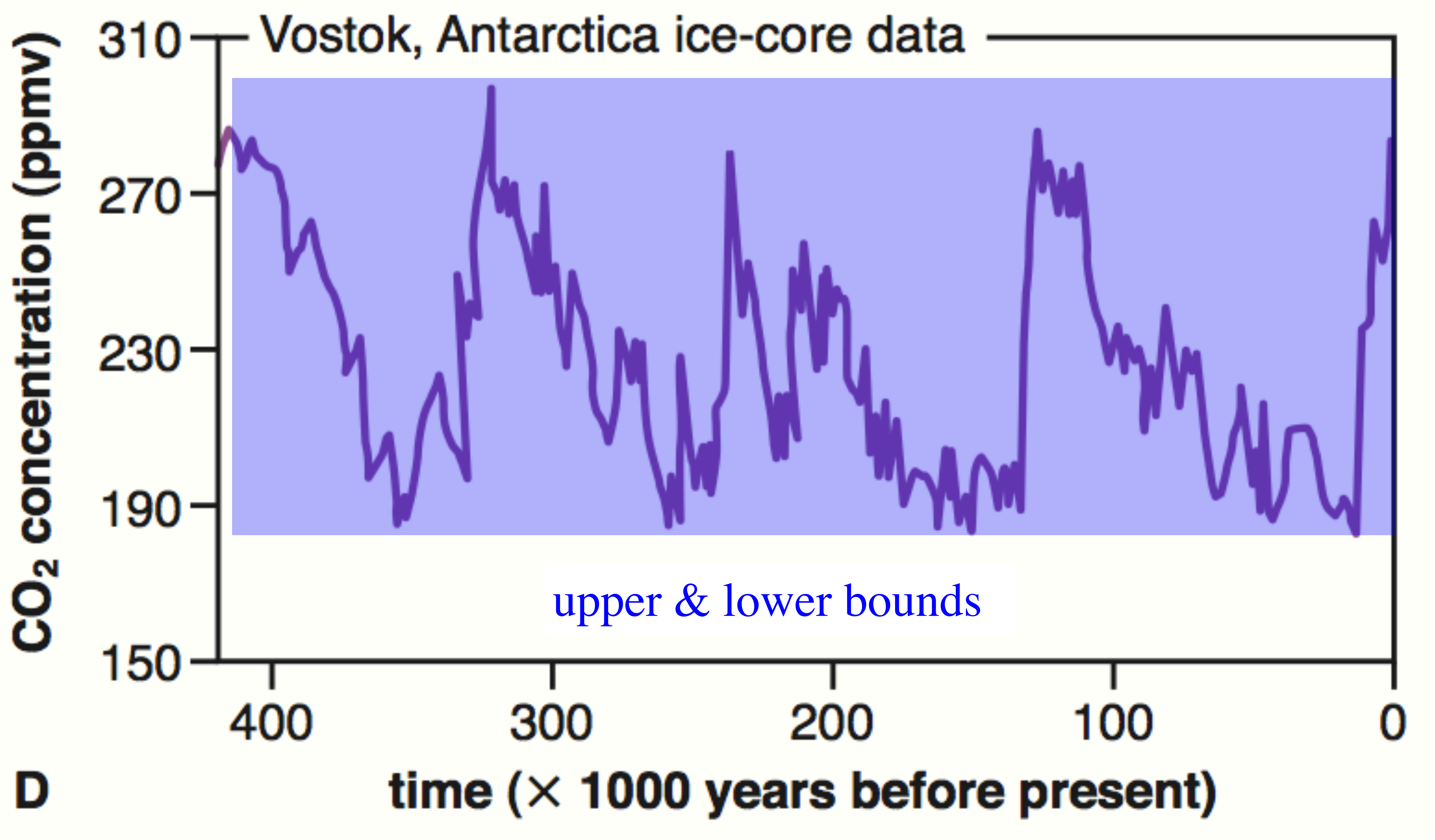

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Historic Atmospheric CO_2 Levels

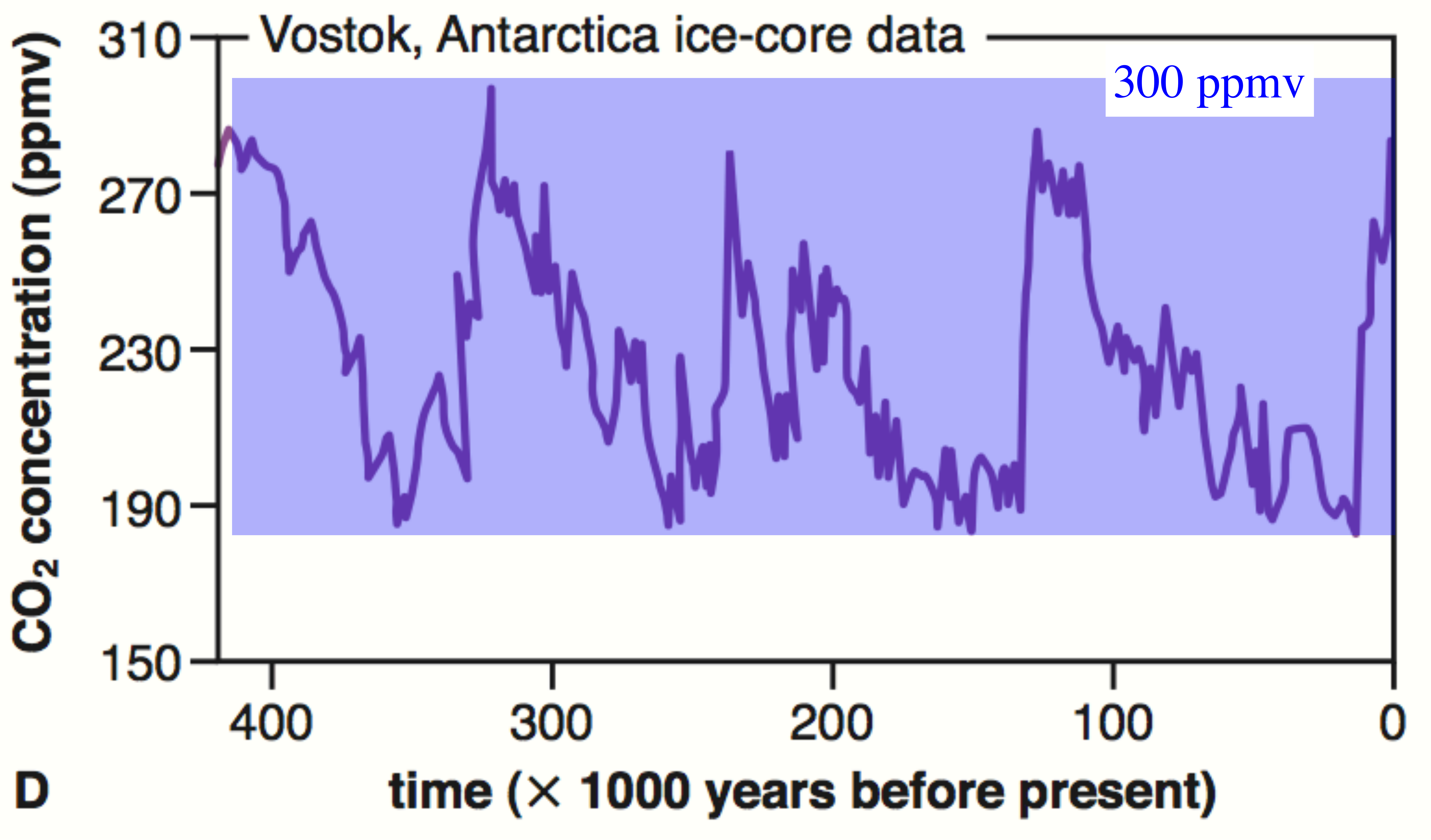

Fig. 11.11

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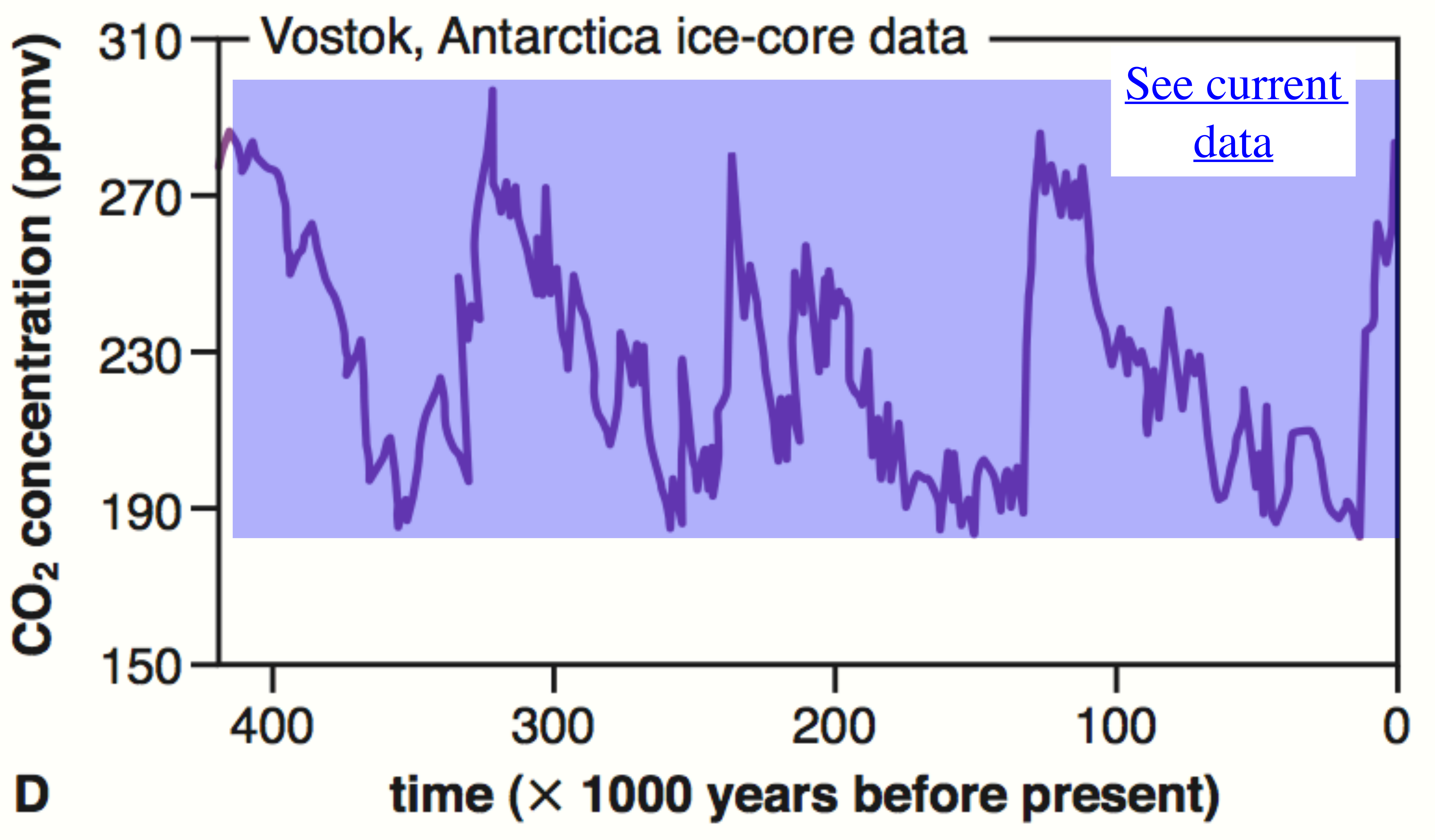
Current Levels Highest in 400K Years



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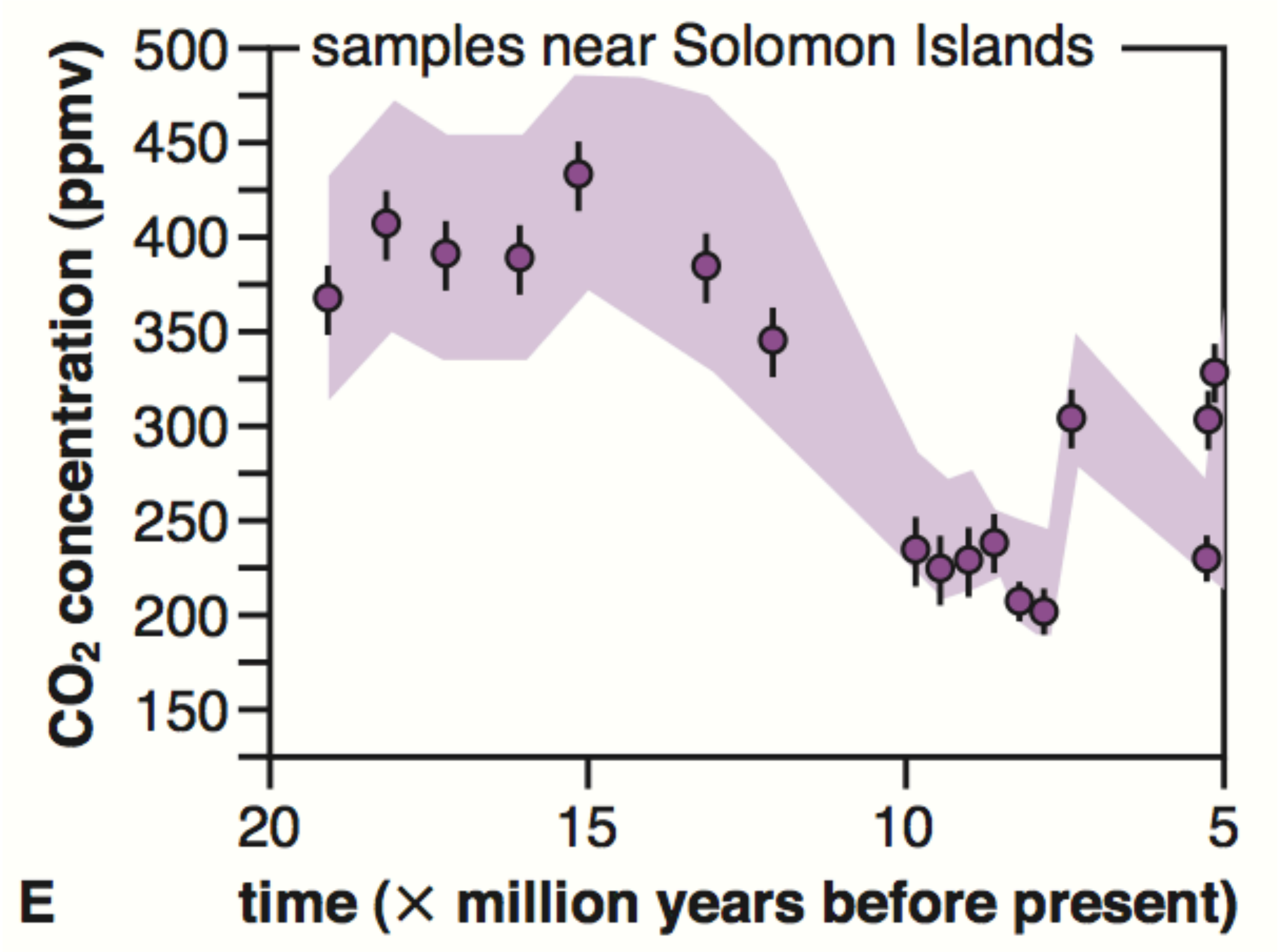

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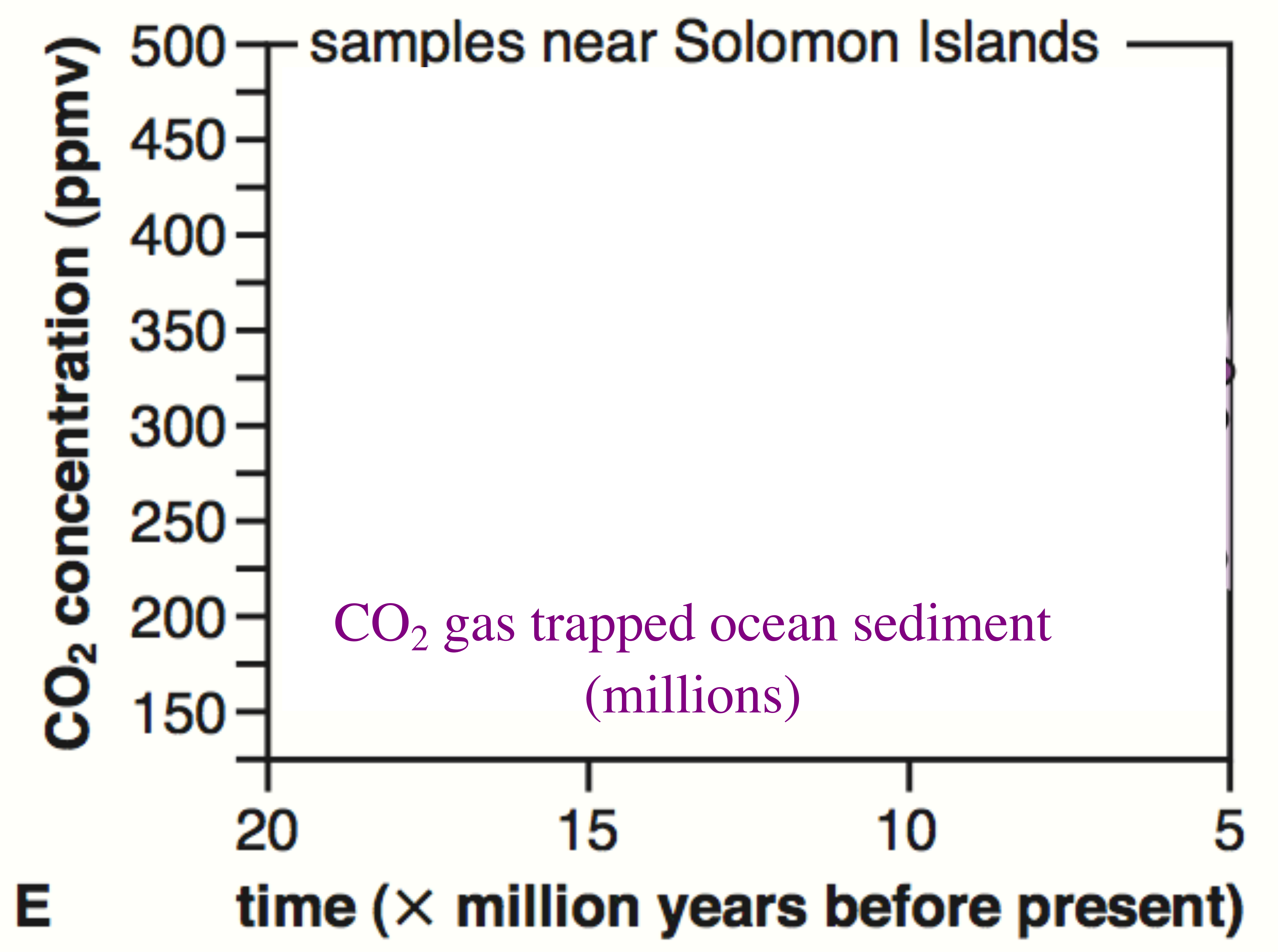

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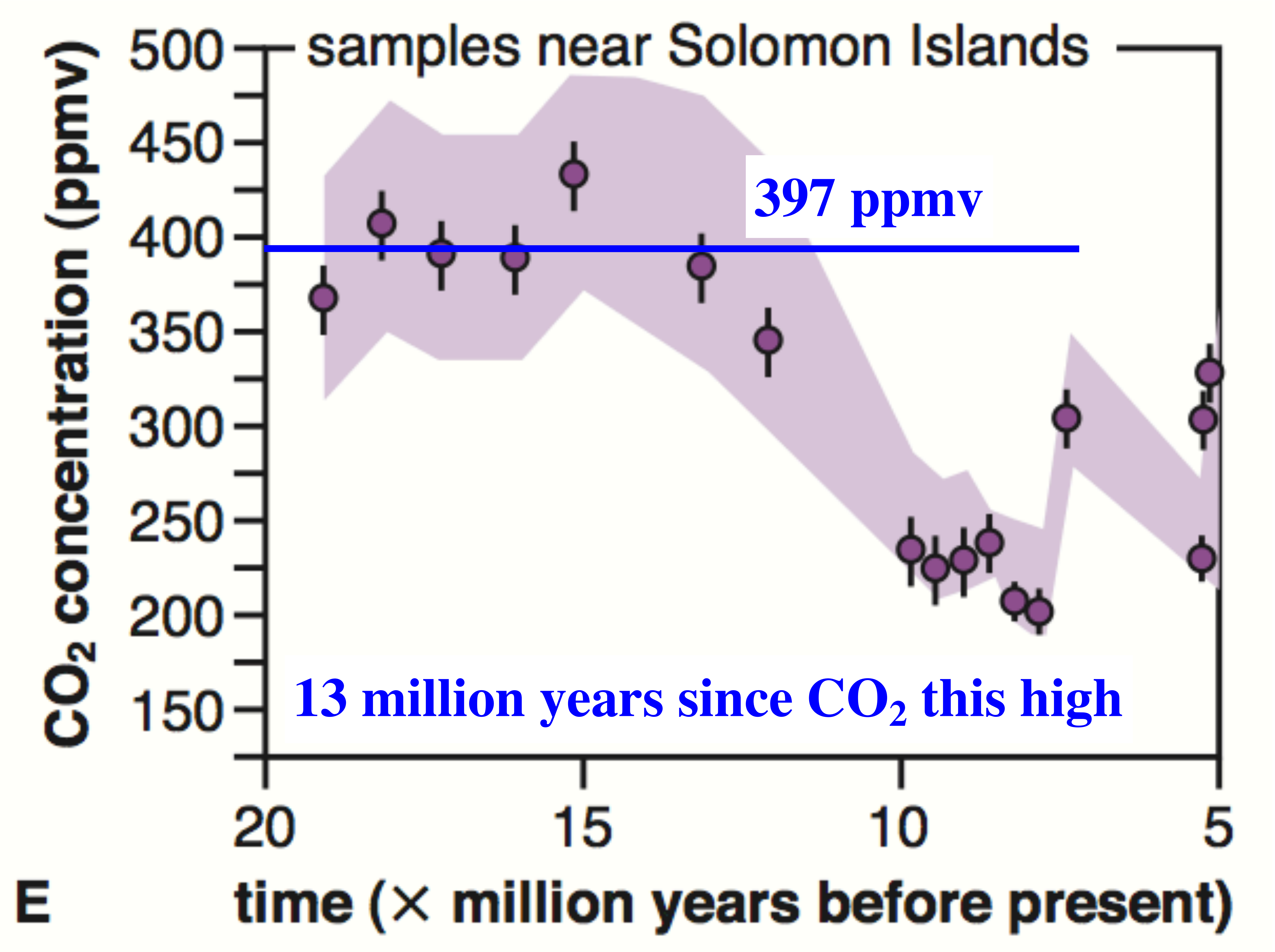

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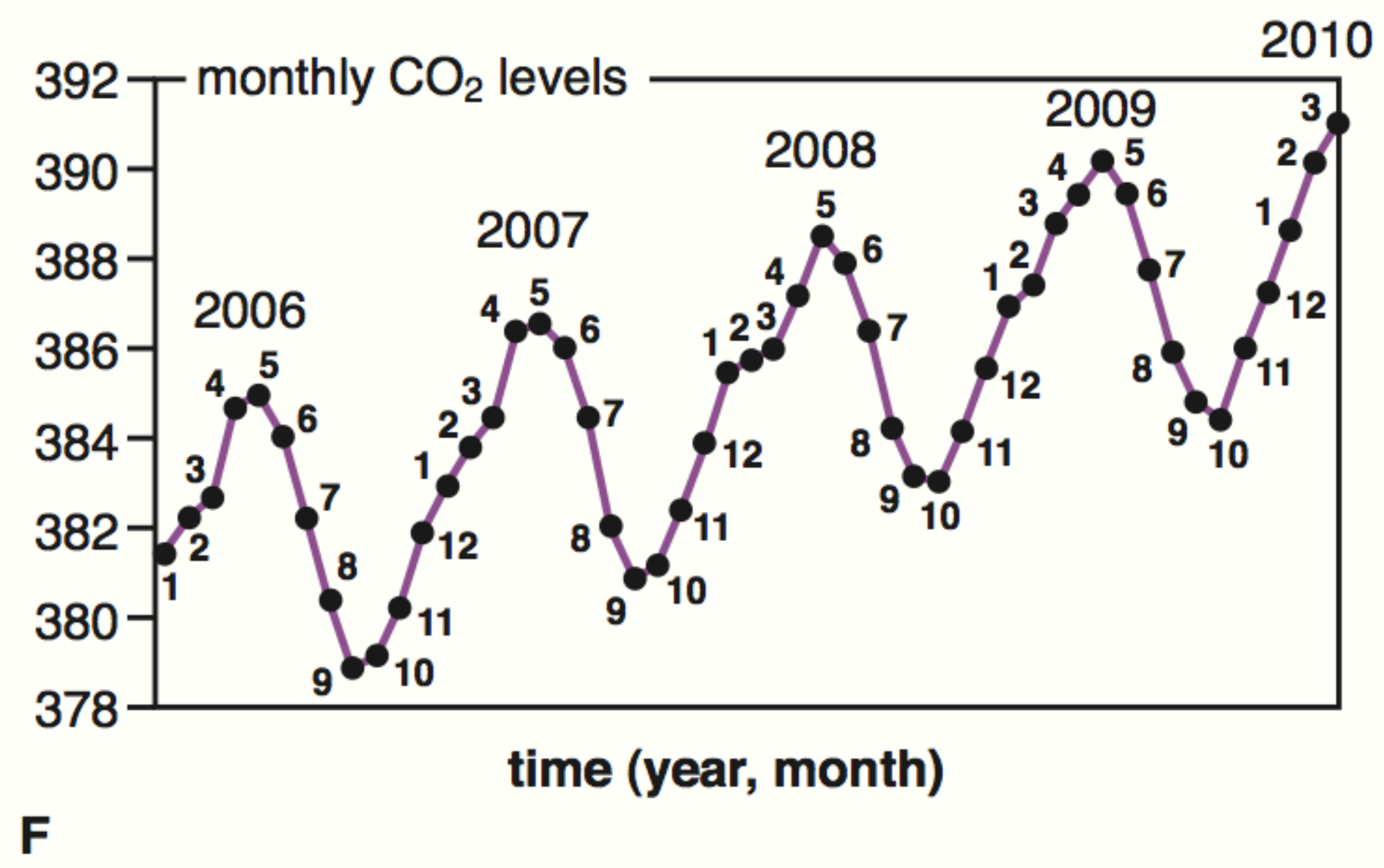

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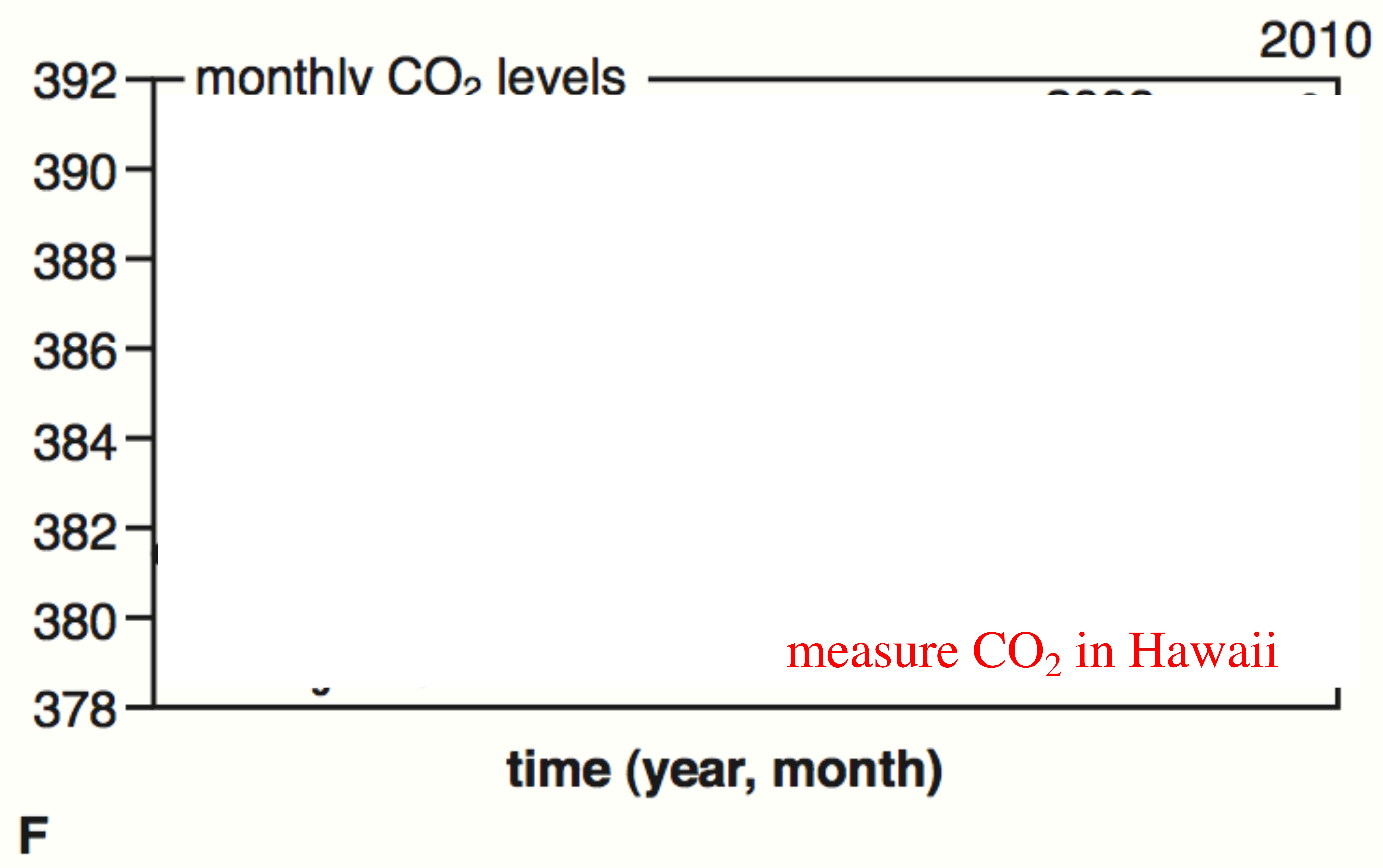
Historic Atmospheric CO_2 Levels



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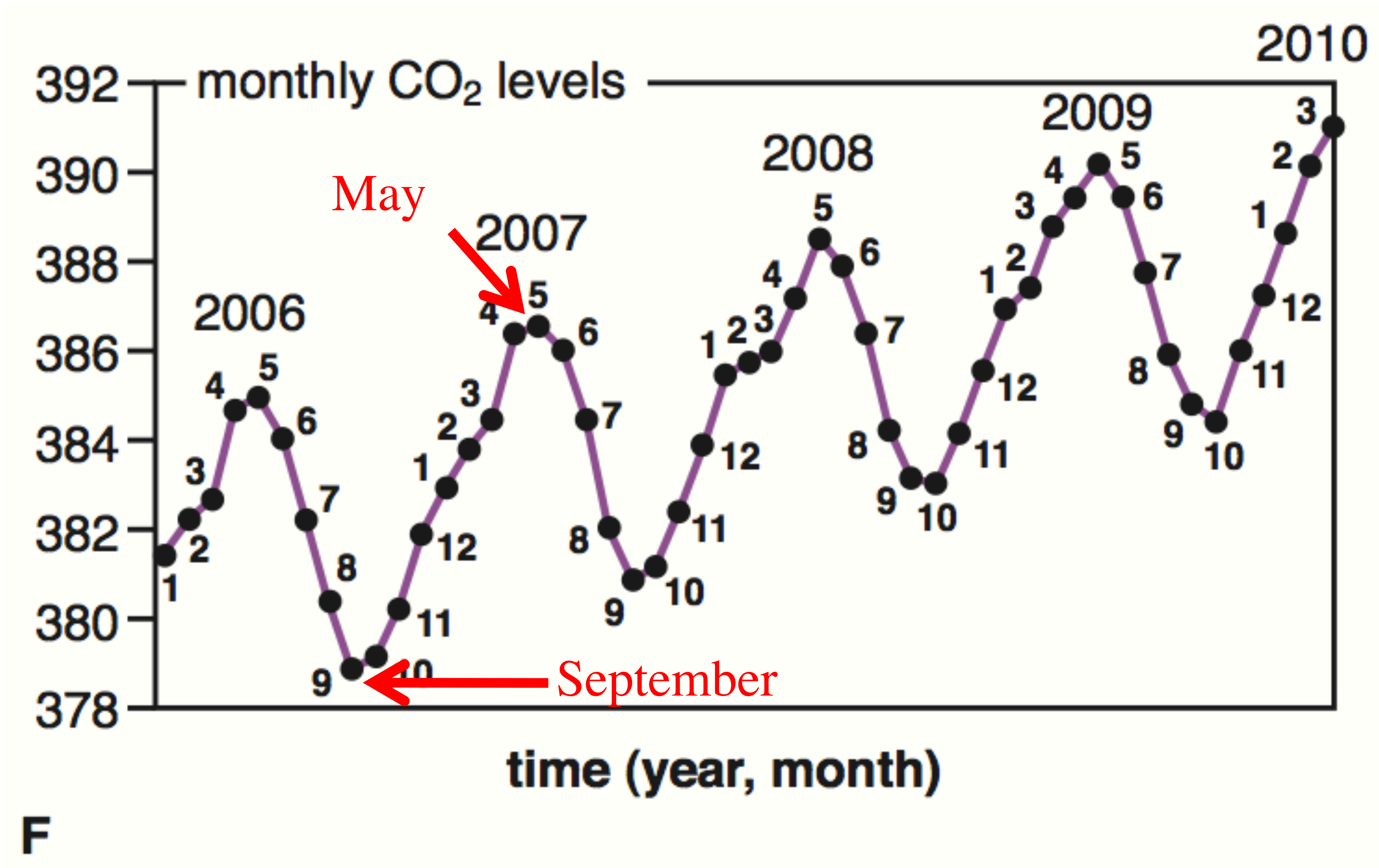
Historic Atmospheric CO_2 Levels



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Historic Atmospheric CO_2 Levels

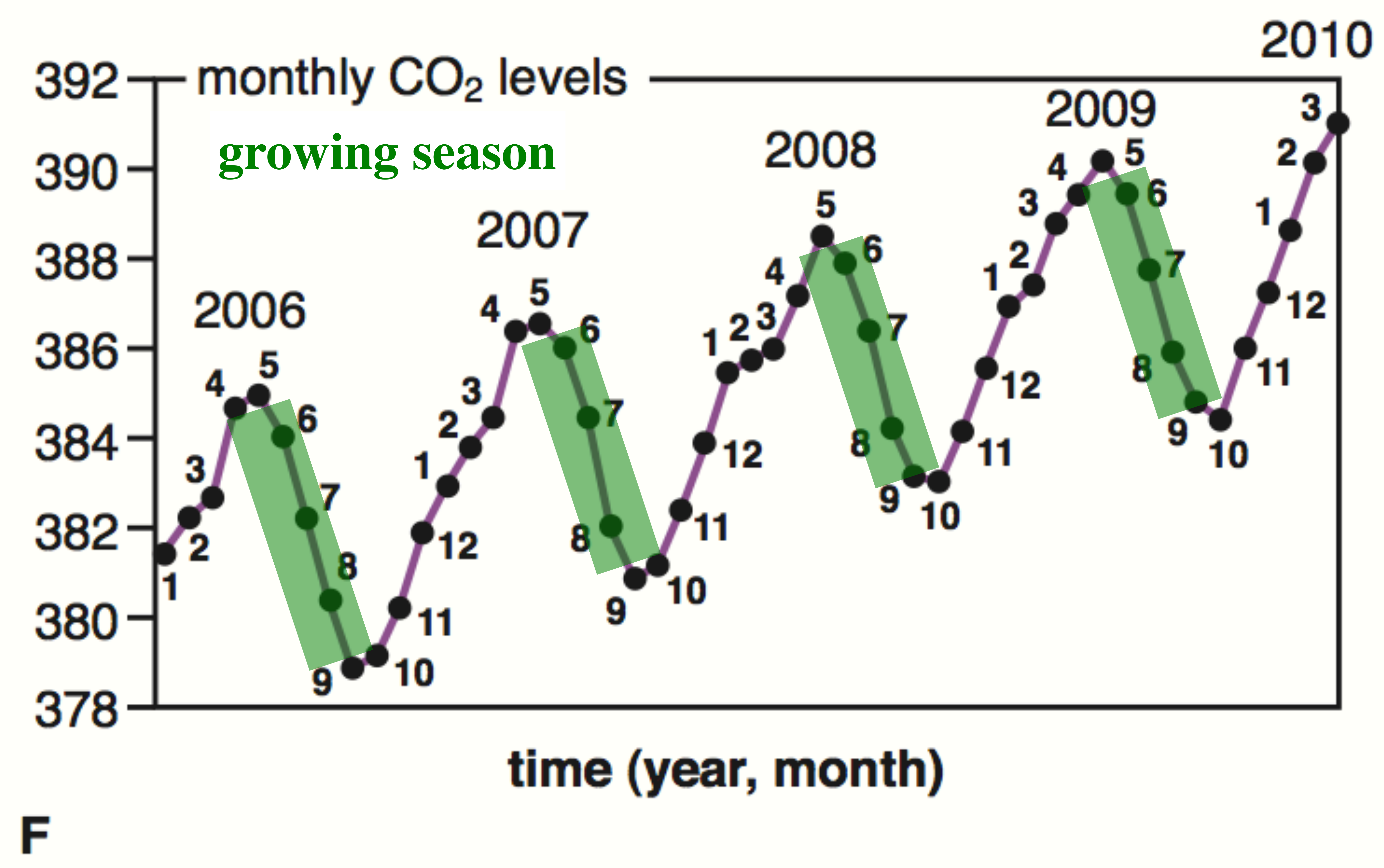

Fig. 11.11

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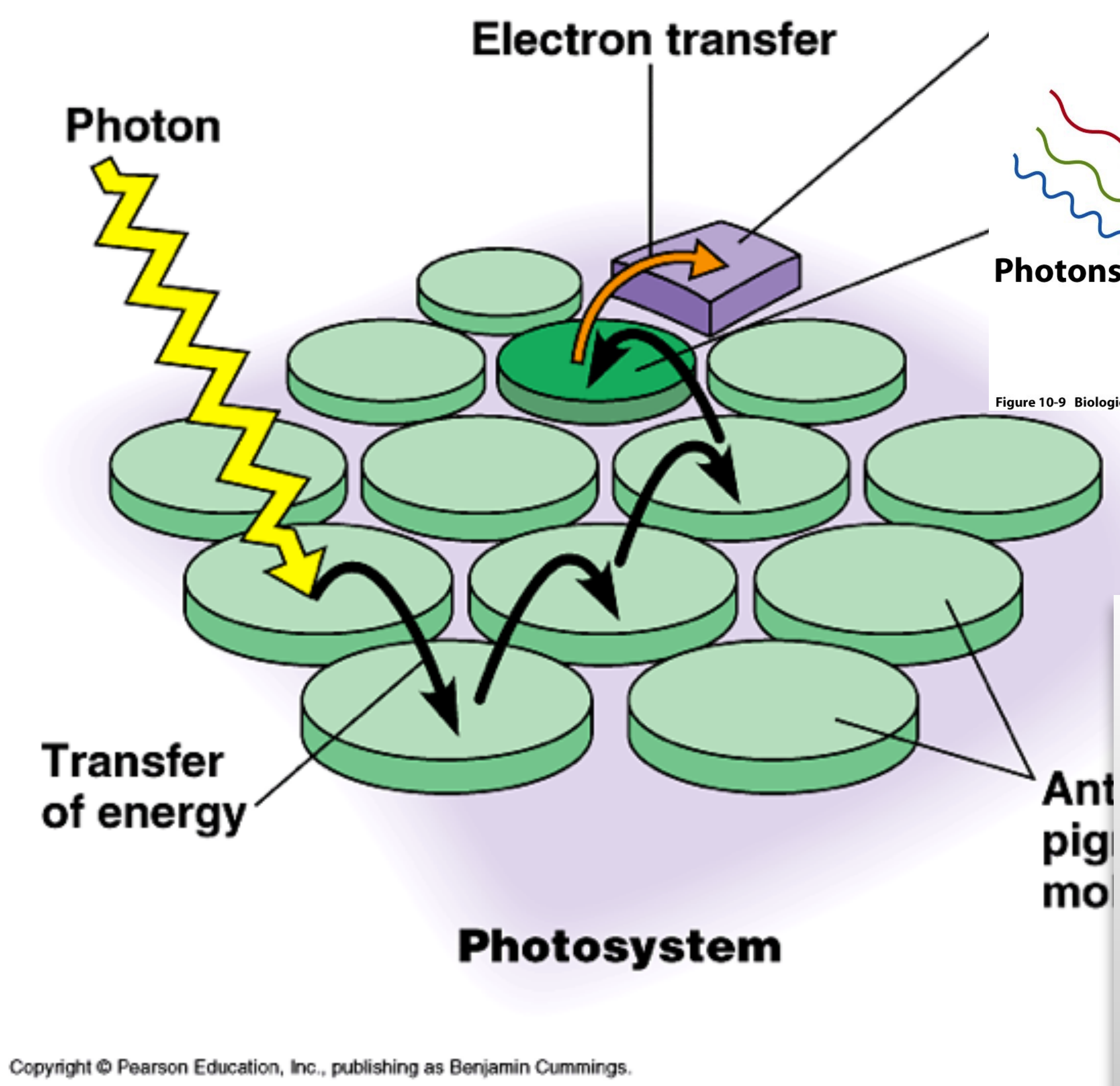
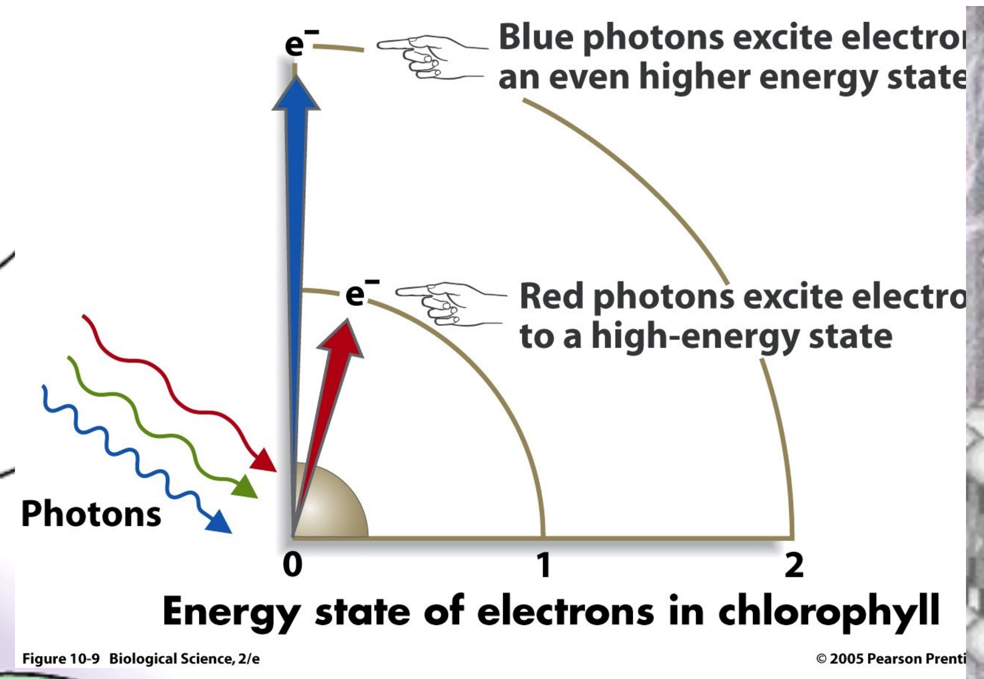
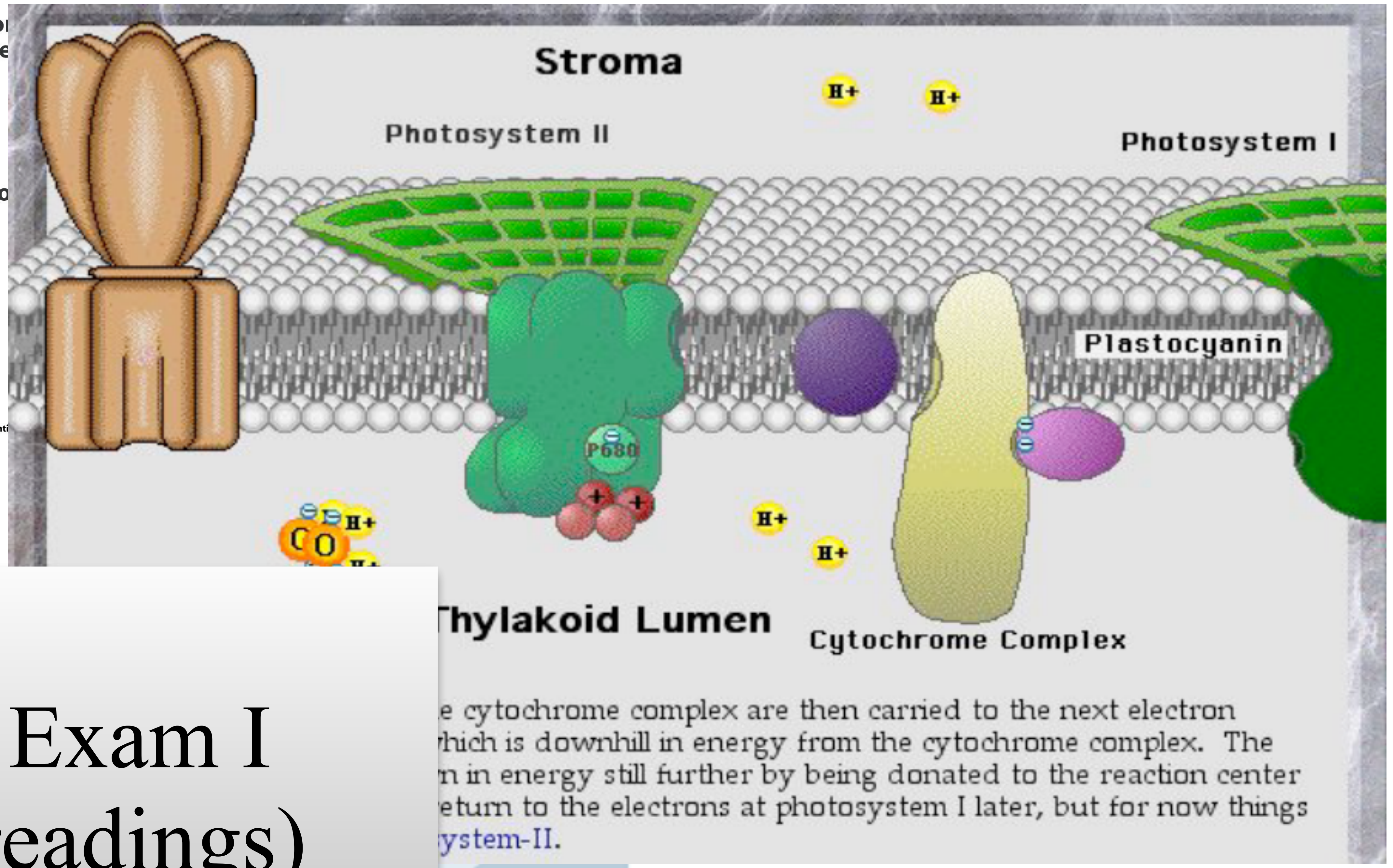
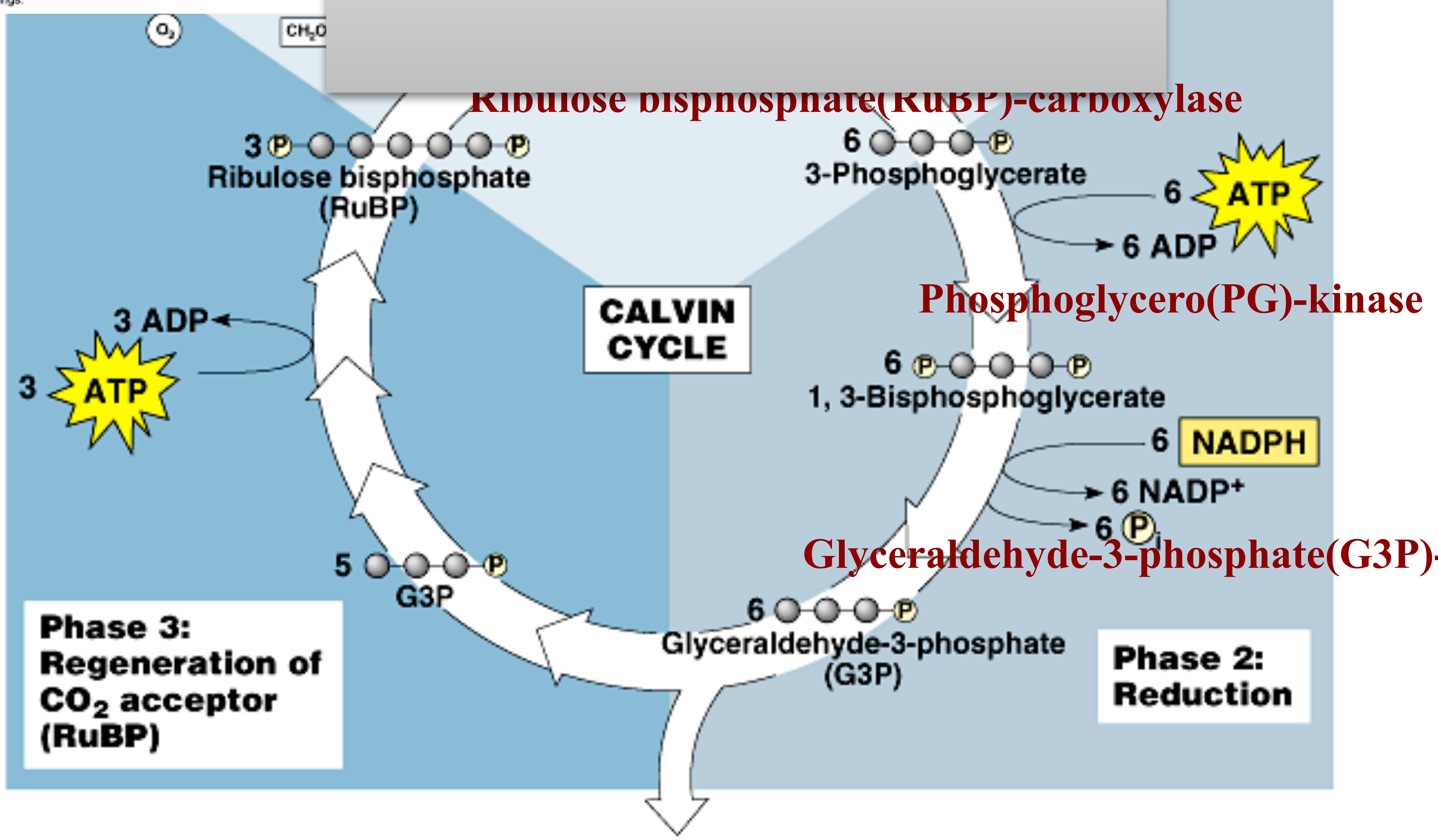




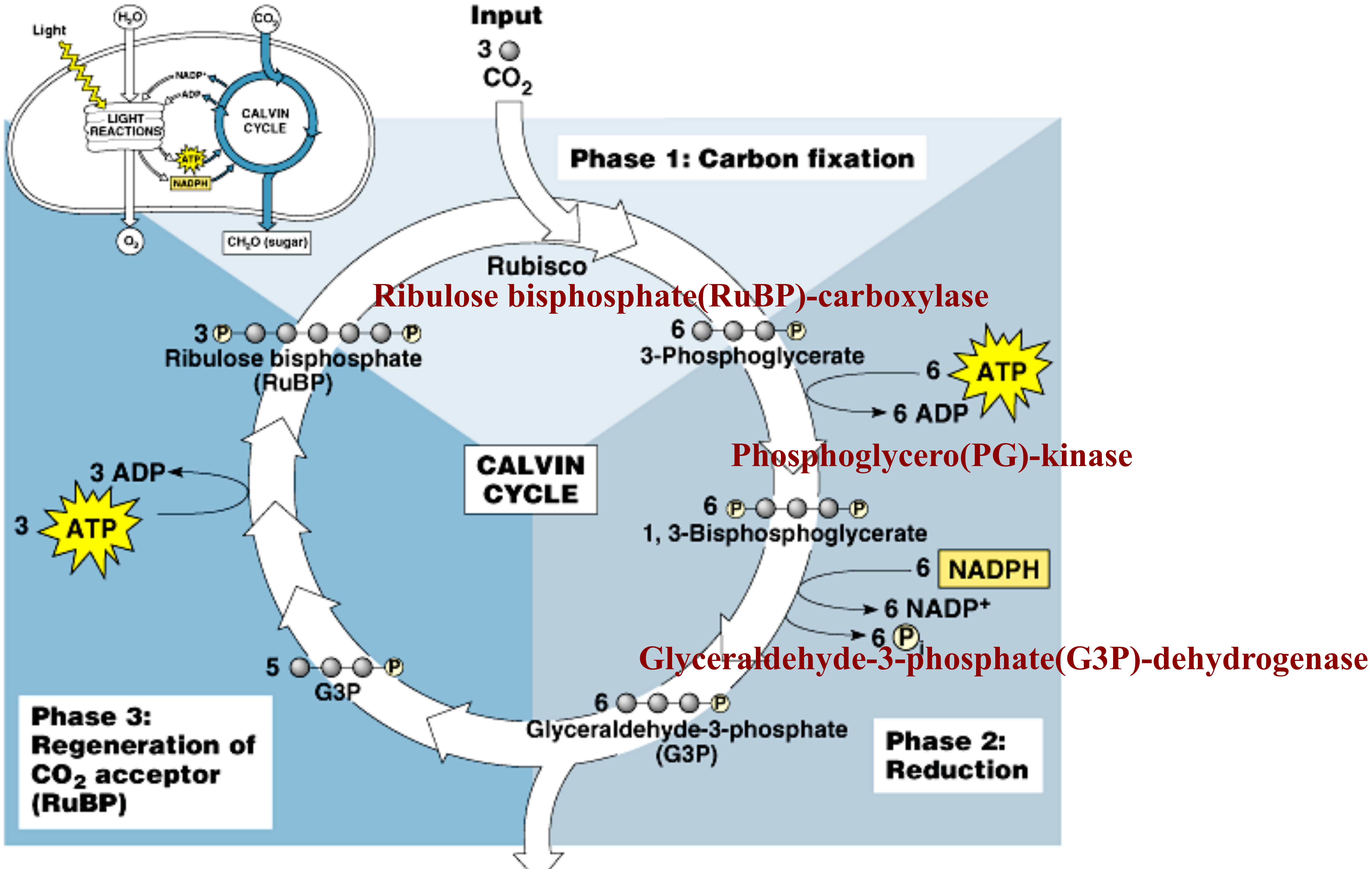


So, about Exam I
(the OSB readings)



Learning Questions for the day (focus)

- **How does Calvin Cycle** work?
  - What are the reactants?
  - When is energy involved?
  - What are the stages called, what happens?



So, about Exam I
(the ICB readings)

Reading 1: Ch1-ICB 1.2
Dr. Fred Griffith
Dr. Oswald Avery
Figure 1.4 Avery
Table 1.1 Avery

Reading 2: Ch.4-ICB 4.1 Charles Darwin
Figure 4.1 Cartoon acorns
ELSI Figure 4.1 Darwin monkey

Reading 3: Ch.4-ICB: 4.2
Dr. Stanley Miller
Figure 4.5 Miller experiment
Figure 4.6 NASA experiment with meteors
Figure 4.8 ribozyme experiment (big gel)

Reading 4: Ch.4-ICB: 4.3(1st half), 4.4
Figure 4.11 Microspheres and clay vesicle formation
Figure 4.12 Microscopy of spontaneous vesicles with cargo (Green & red-stained).
Figure 4.13 vesicle growth and reproduction
Figure 4.17 Vesicle pH after adding micelles

Reading 5: Margulis endosymbiosis

Reading 8: Ch.11-ICB: 11.1
Joseph Priestley (Figure 11.2A sprig of mint)
Theodor Wilhelm Engelmann (Figure 11.2B algae and Zeiss)
Robin Hill (Figure 11.2C Oxygen evolved by isolated chloroplasts)
Daniel Arnon (Figure 11.4 Photosynthesis is a summation of three parts & Figure 11.8 ATP production from light energy)
Hans Heldt (Figure 11.5 Comparison of pH in stroma and thylakoid space)

Reading 9: Ch.11-ICB: 11.2
Figure 11.11 Energy consumption and CO2 levels.
M.B. Allen (Figure 11.12 Carbon fixation capacity)
Melvin Calvin and Andrew Benson (Figure 11.13 Incorporation of radioactive carbon into organic molecules)
Figure 11.15 Physiological regulation of rubisco

15 people/figures to Trifecta on Exam I

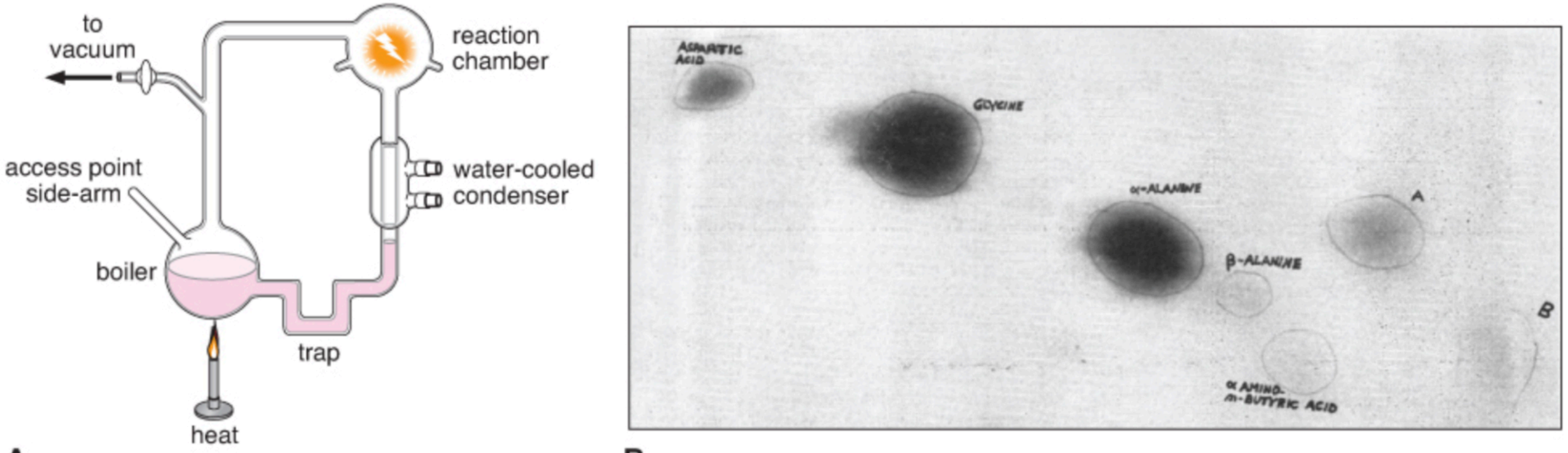
(need textbook & lecture info)

1. Dr. Oswald Avery
2. Dr. Fred Griffith
3. Figure 1.4 Avery
4. Table 1.1 Avery
5. Dr. Stanley Miller (Figure 4.5)
6. Figure 4.6 NASA experiment with meteors
7. Figure 4.8 Ribozyme experiment
8. Figure 4.11 Microspheres and clay vesicle formation
9. Figure 4.17 Vesicle pH after adding micelles
10. Dr. Lynn Margulis
11. Theodor Engelmann (Figure 11.2B)
12. Hans Heldt (Figure 11.5)
13. Figure 11.11 Energy consumption and CO2 levels.
14. Melvin Calvin and Andrew Benson (Figure 11.13)
15. Figure 11.15 Physiological regulation of rubisco

Possible exam question format

Predict how many photons of red light are minimally required to create one glucose molecule in photosynthesis (or two glyceraldehyde-3-phosphate molecules) and explain your reasoning. (i) **Illustrate** the non-cyclic electron transport version of light reactions and the Calvin cycle. (ii) **Explain** in full sentences your prediction and your rationale for it. Explain in detail the sequence of events that occur in the process of photosynthesis and your step-by-step rationale/logic in your calculations [Assume: the Calvin cycle must occur in full cycles, you must only use linear electron transport, 3 H^+ travel through ATP Synthase for it to generate one ATP].

Possible exam question format



A B

6) What was the outcome of this experiment on the origin of life? Structure your answer into: Purpose, Methods, Findings.

Possible exam question format

5) Explain the Purpose, Methods and Findings of Stanley Miller's famous experiment. (50 word limit)

Possible exam question format

What is a multiple True/False/Why question?
(Multiple-choice with partial credit)

Example:

A. What are the official sport team colors of Michigan State University?

1. Maize
2. Blue
3. Green
4. Yellow
5. White

6. **Why?:** Historically, why were those colors chosen?

For full credit you must respond with:
The answer #3 is True
The answer #5 is True
The answer to #6 you accurately explain why those are the colors