



Hunt Institute for Botanical Documentation
5th Floor, Hunt Library
Carnegie Mellon University
4909 Frew Street
Pittsburgh, PA 15213-3890
Telephone: 412-268-2434
Email: huntinst@andrew.cmu.edu
Web site: www.huntbotanical.org

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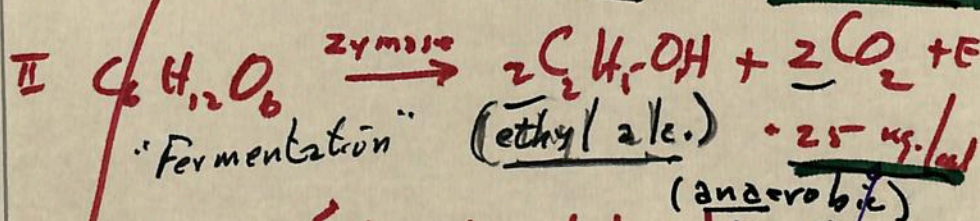
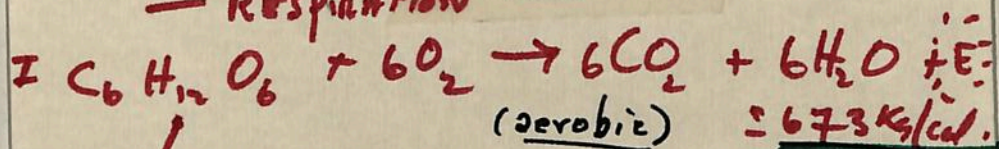
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About the Institute

The Hunt Institute for Botanical Documentation, a research division of Carnegie Mellon University, specializes in the history of botany and all aspects of plant science and serves the international scientific community through research and documentation. To this end, the Institute acquires and maintains authoritative collections of books, plant images, manuscripts, portraits and data files, and provides publications and other modes of information service. The Institute meets the reference needs of botanists, biologists, historians, conservationists, librarians, bibliographers and the public at large, especially those concerned with any aspect of the North American flora.

Hunt Institute was dedicated in 1961 as the Rachel McMasters Miller Hunt Botanical Library, an international center for bibliographical research and service in the interests of botany and horticulture, as well as a center for the study of all aspects of the history of the plant sciences. By 1971 the Library's activities had so diversified that the name was changed to Hunt Institute for Botanical Documentation. Growth in collections and research projects led to the establishment of four programmatic departments: Archives, Art, Bibliography and the Library.

— Respiration —



Glycolysis { Phosphorylation } Yeast
 (Gl-Phosp.) Kilocalorie
 HEAT $94.4^\circ C$

Albert Szent-Györgyi
 ATP muscle physiology

1937 Nobel: Ascorbic acid

$\pm 13 \times 10^{23}$ calories/yr. from SUN
< 1% used in photosynthesis

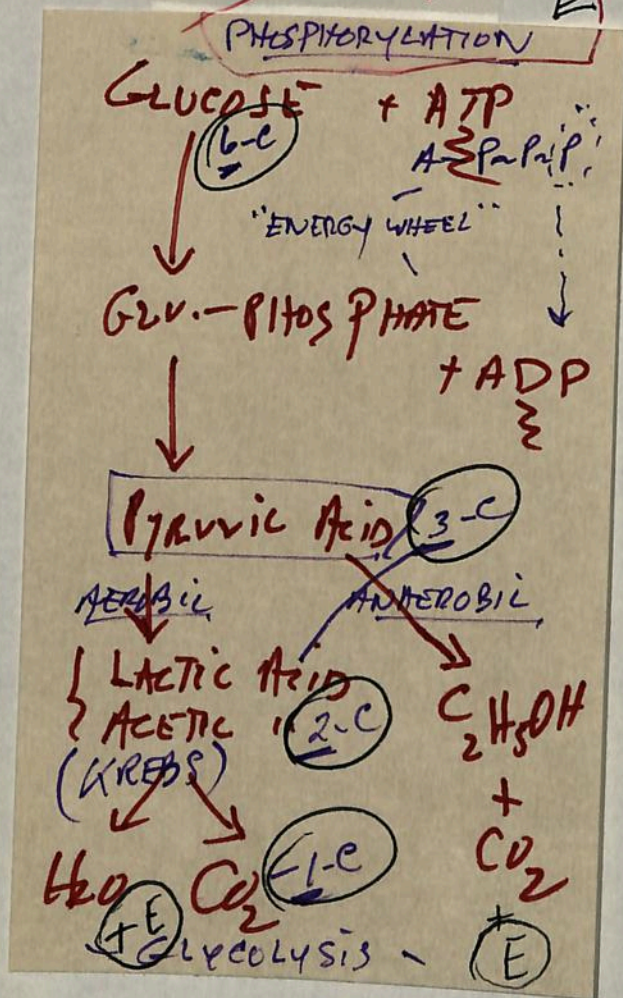
Joe Priestly 1774
 "seltzer" $H_2O \rightarrow H_2O_2$
 soft drinks "dephlogisticated air"

Antoine Lavoisier 1779
 "oxygen" named
 end of "phlogiston" (Scheele)
1794 guillotine

July 14, 1789 - Bastille Day

GLYCOLYSIS

- 6-C 1)
 3-C 3)
 2-C 4)
 1-C 5)



ENZYMATIC

OXIDATIVE PHOSPHORYLATION

ADP → ATP + E⁻

vs. PHOTOPHOSPHORYLATION

ADP → ATP + E⁻

(HANS) KREBS CYCLE

1953 NOBEL

CITRIC ACID
 OXALOACETIC

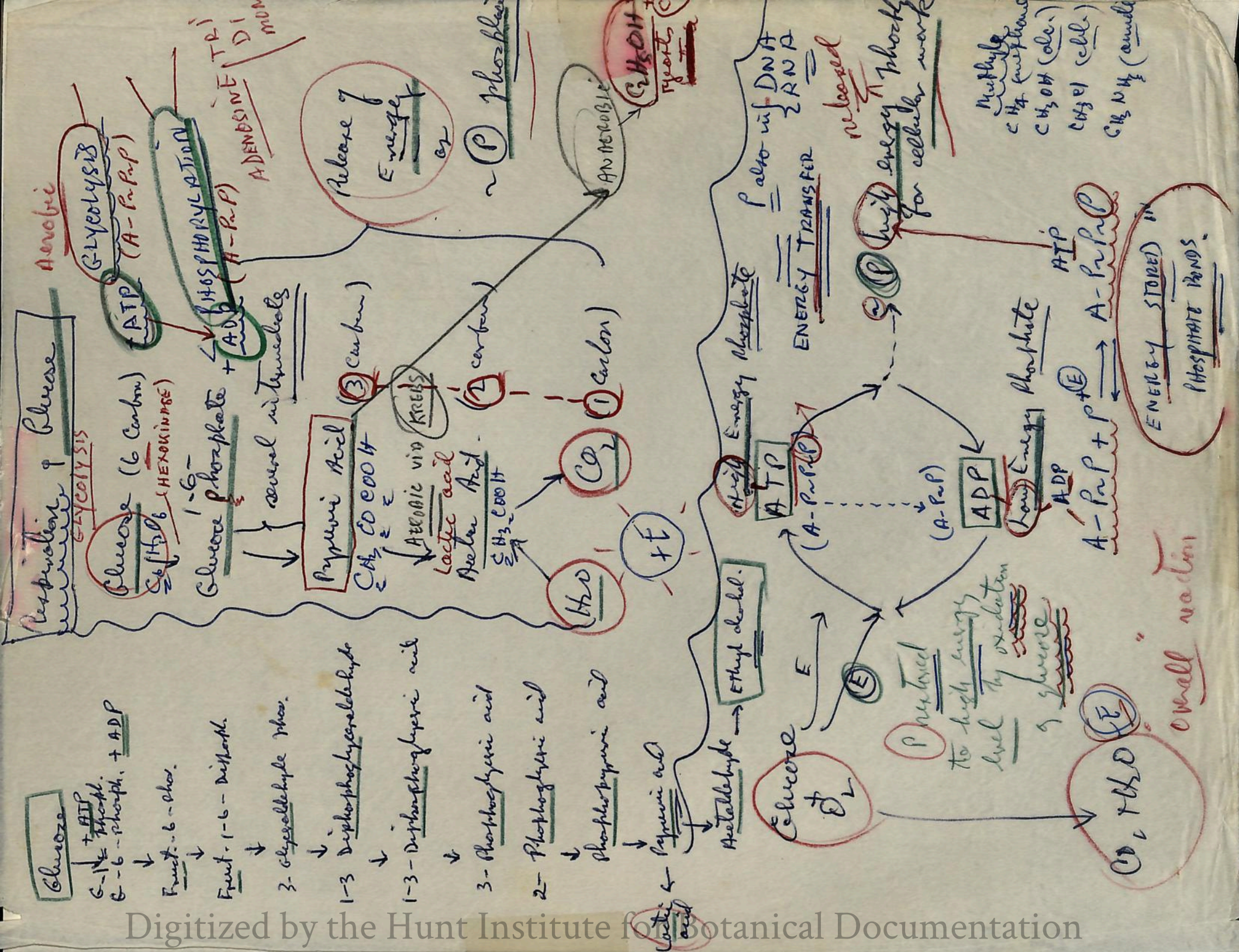
ATP

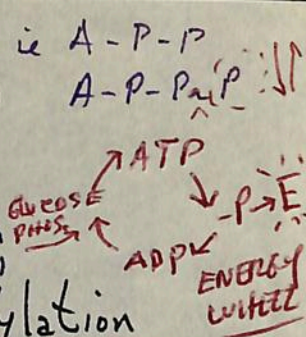
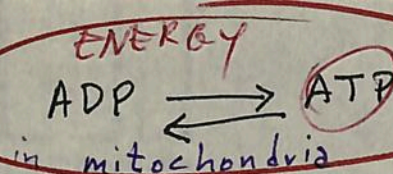
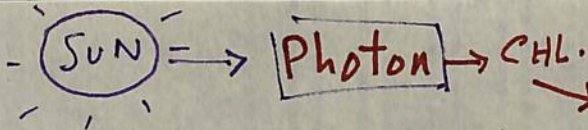
NAD^{RED.}

MITOCHONDRIA

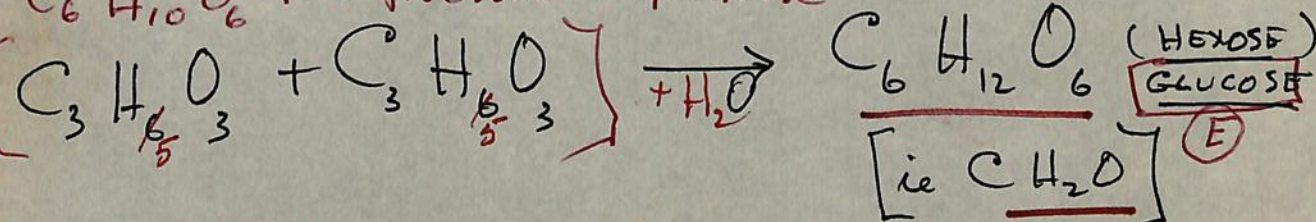
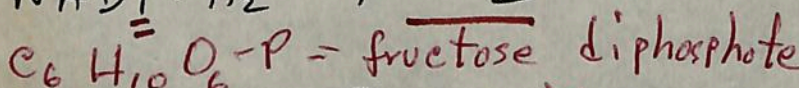
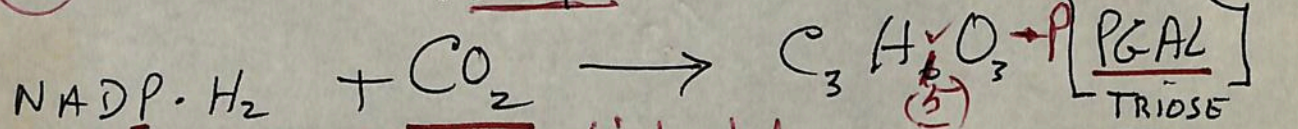
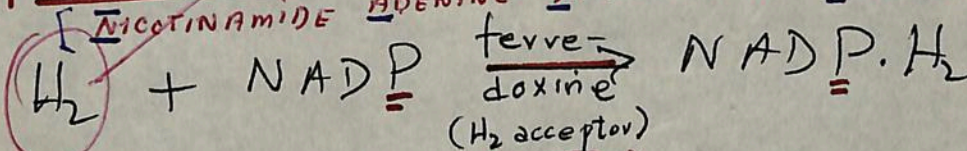
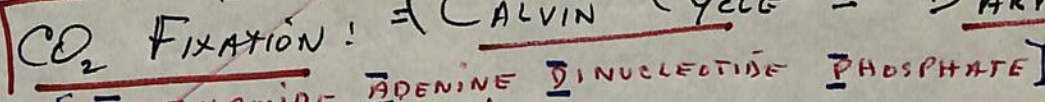
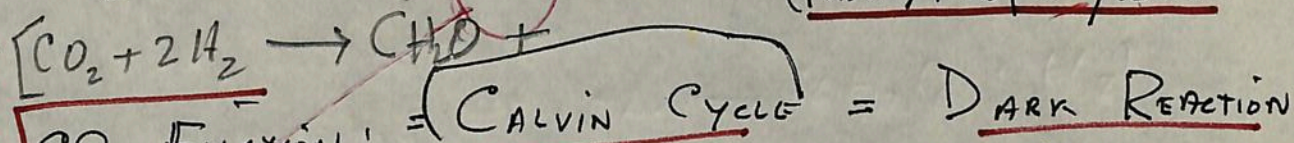
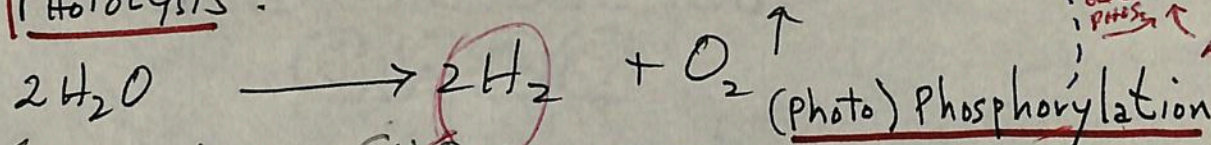
AMP → ADP → ATP

ADENOSINE-P

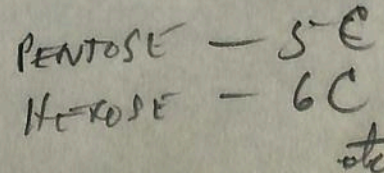
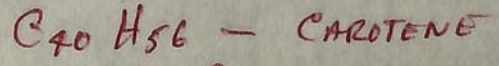
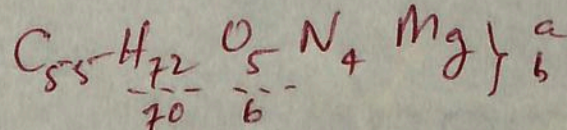
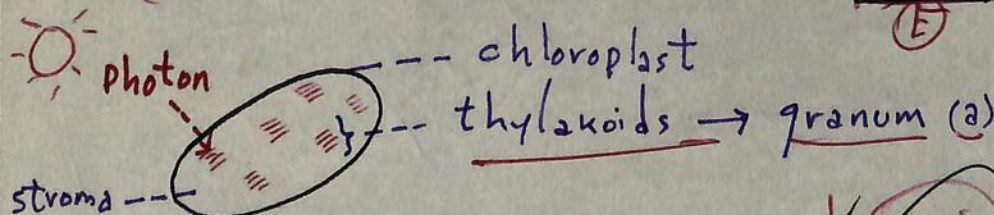
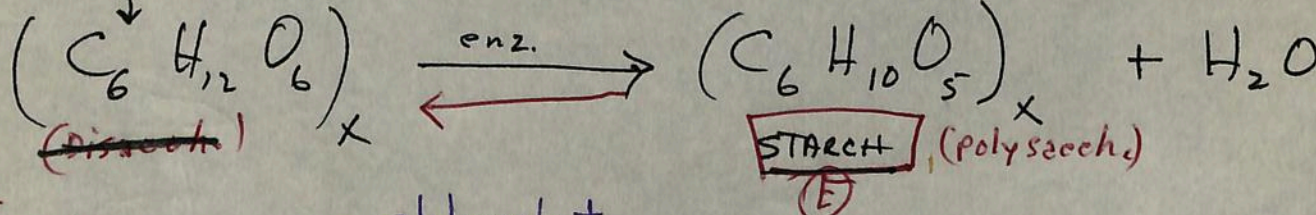
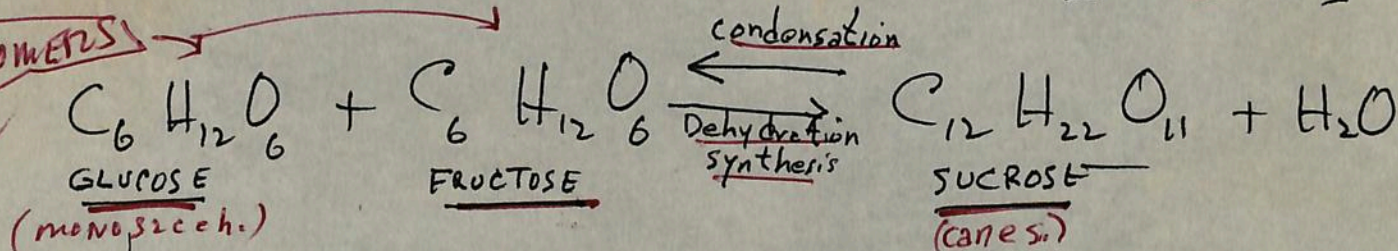




I. PHOTOLYSIS:

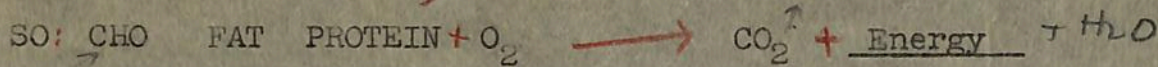


ISOMERS



RESPIRATION

(OXIDATIVE) PROCESS MAKING AVAILABLE STORED ENERGY FOR USE:



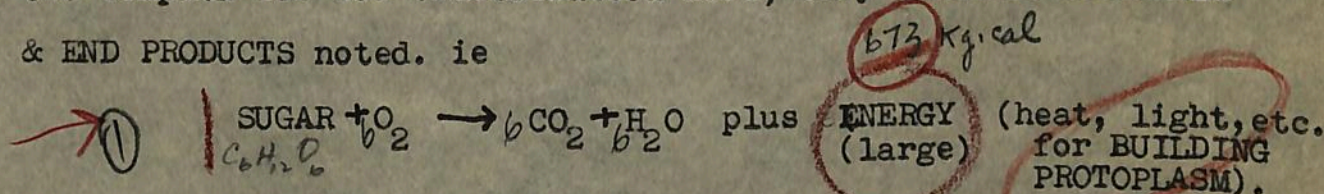
general
respiration
ESSENTIALLY A SIMILAR PROCESS IN ALL LIVING THINGS.

RESPIRATION

Define: Essentially the LIBERATION OF STORED ENERGY derived from photosynthesis. $(6H_2O + 6CO_2 + CHL. + LIGHT \rightarrow C_6H_{12}O_6 + 6O_2 + E.)$

In ALL LIVING CELLS ... PLANT & ANIMAL ALIKE.

INTERMEDIATE ENERGY TRANSFORMATIONS MOST IMPORTANT, but too complex for our consideration here; only INITIAL MATERIALS & END PRODUCTS noted. ie

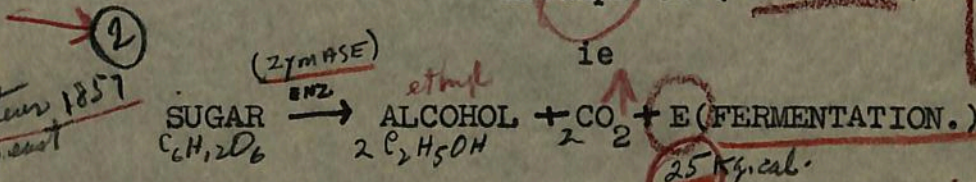


The "REVERSE" of PHOTOSYNTHESIS ... but intermediates not same.

AN OXIDATIVE PROCESS: may be complete (AEROBIC)

OR incomplete (ANAEROBIC) ... YEAST, BACTERIA FUNGI (some)

Compare amt ENERGY
ie 673 cal : 25 cal
± 27:1
Relative efficiency



IMPORTANCE IN : BREAD-MAKING, WINE * ALCOHOLS.

A CONTINUOUS PROCESS IN ALL CELLS, NIGHT & DAY.

** In green plants, in daylight, photosynthesis at a more rapid rate than respiration; at night, reverse.

RESPIRATION (IN ALL LIVING CELLS AT ALL TIMES)

COMPARE:		PHOTOSYNTHESIS	RESPIRATION
EXE COMPARE: →		PRODUCES O_2	USES UP O_2
		USES CO_2	PRODUCES CO_2
		<u>STORES ENERGY</u>	<u>USES ENERGY</u>
		ONLY IN LIGHT	ALL TIMES
		GREEN CELLS ONLY	ALL CELLS
		MAKES SUGAR	USES SUGAR

THALLOPHYTA contd.

FUNGI

assimilative
(Negative) → mycelium
Reproductive → spores

MYCELIUM SPORES NO CHLOROPHYLL SEXUAL & ASEXUAL

GROUPS: MYXOS

PHYCOS

ASCOS (LICHENES)

BASIDIOS

DEUTEROS

(GIVE CHARACTERISTICS)

downy mildew
powdery mildew chestnut blight etc
Truffles
mushrooms
Rusts
chlores

IMPORTANCE TO MAN :

DECOMPOSITION OF ORGANIC MATTER .

DISEASES OF ANIMALS & PLANTS

WOOD ROTTERS

FOOD SPOILAGE

ANTIBIOTICS:

PENICILLIN
etc.

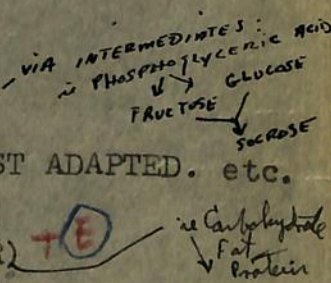
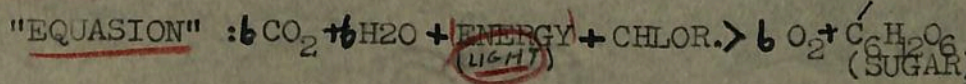
STREPTOMYCIN

AUREOMYCIN

CHLOROMYCETIN

PHOTOSYNTHESIS

IMPORTANCE. ONLY IN GREEN PLANTS ... CHIEFLY LEAVES BEST ADAPTED. etc.



CO₂ in atmosphere (0.03%) or 3 PARTS IN 10,000. SUFFICIENT FOR SUPPORTING ALL EARTHS ANIMALS)

MOST IMP. ENERGY STORING PROCESS IN LIVING WORLD.

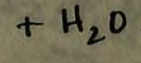
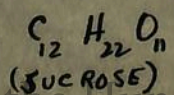
ONLY ABOUT 1% TOTAL AVAILABLE LIGHT ENERGY FROM SUN USED.

REST DISSIPATED AS HEAT, NON*ABSORBED LIGHT.

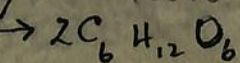
ELECTROMAGNETIC SPECTRUM

COSMIC RAYS GAMMA ULTRA VIOLET VIBGYOR (visible) (3970 - 8000 Å) INFRA RED HERTZIAN

ENZYMES:



SUCRASE



GLUCOSE + FRUCTOSE

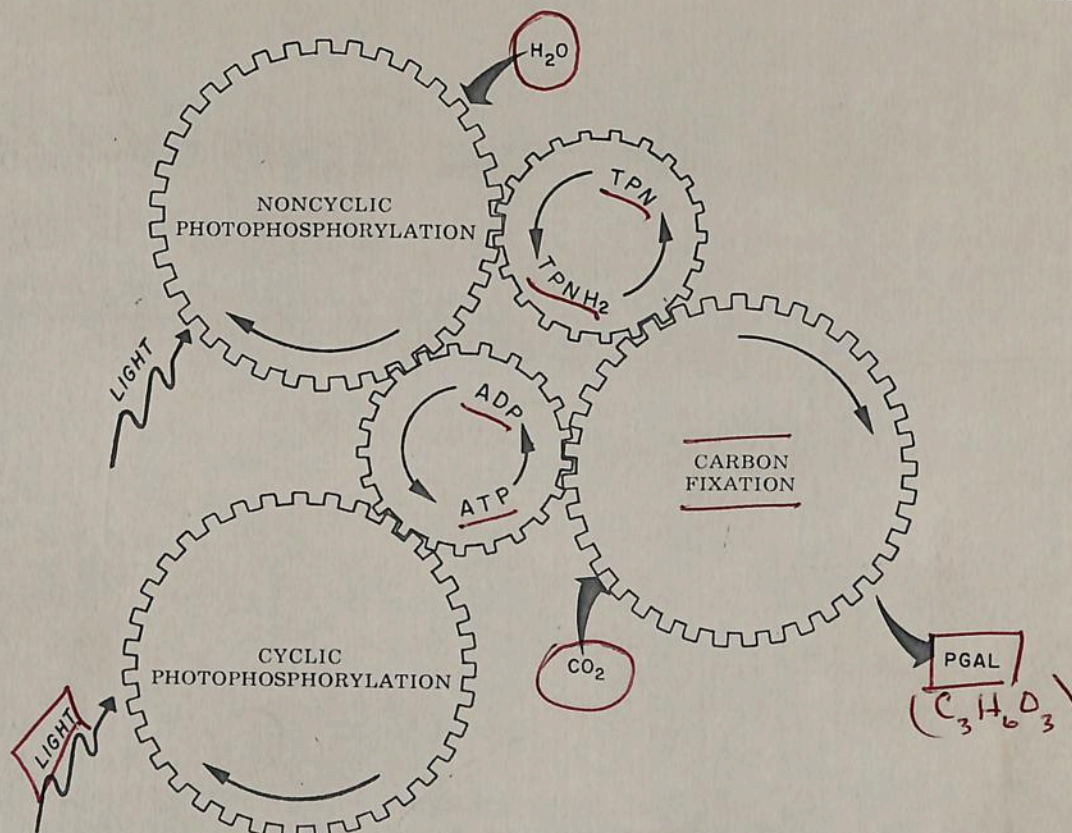


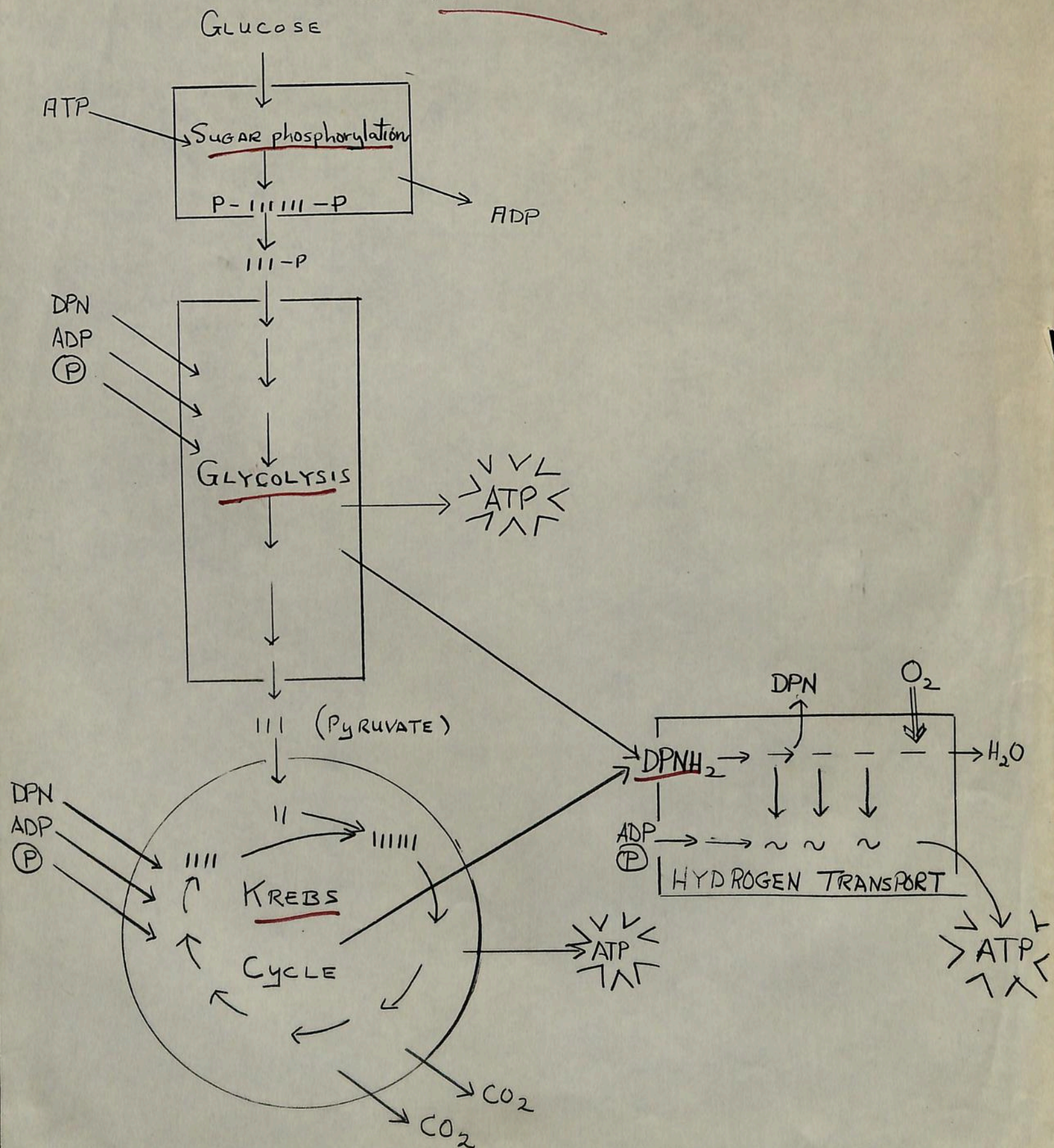
Fig. 4.12. The relationship between photophosphorylation and carbon fixation. The entire photosynthetic process can be visualized as a series of interlocking gears. Energy from light turns the two photophosphorylation gears. The turning of the cyclic-photophosphorylation gear causes the gear of ATP synthesis to turn, and the turning of the noncyclic-photophosphorylation gear causes both the ATP-synthesis and the TPNH₂-synthesis gears to turn. These two gears cause the carbon-fixation gear to turn, with resultant production of carbohydrate (PGAL) from CO₂.

the number of compounds in which C¹⁴ was detected; if the time was very short, the C¹⁴ would reach only the first few compounds in the photosynthetic sequence, while, if the time was longer, the isotope would have moved through more steps in the sequence and would appear in a great variety of compounds. After years of painstaking research, Calvin, who was awarded the Nobel Prize for his critically important work in 1961, worked out a sequence of reactions that we shall outline in very abbreviated form below.

It is not necessary here to discuss in detail

the many reactions now believed to be involved in the reduction of carbon dioxide to glucose. Only the major steps will be mentioned briefly (Fig. 4.13). Under experimental conditions, the CO₂ first combines with a five-carbon compound called *ribulose*. The hypothetical six-carbon compound thus formed is promptly broken into two three-carbon molecules called phosphoglyceric acid, or PGA. Each of these three-carbon molecules of PGA is then phosphorylated by ATP. The new phosphorylated three-carbon compound thus produced is then reduced by the addition of

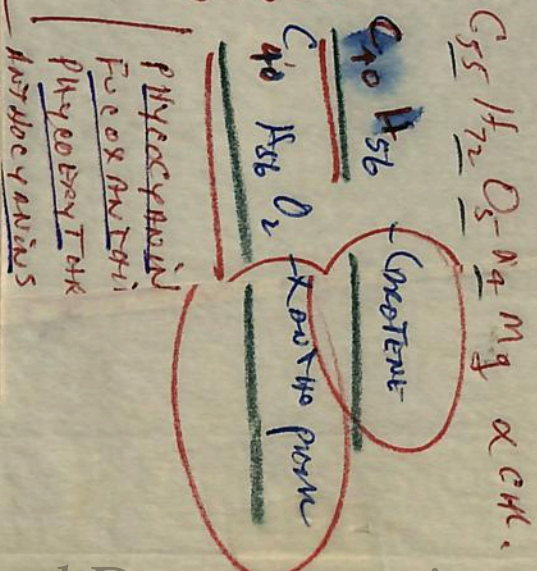
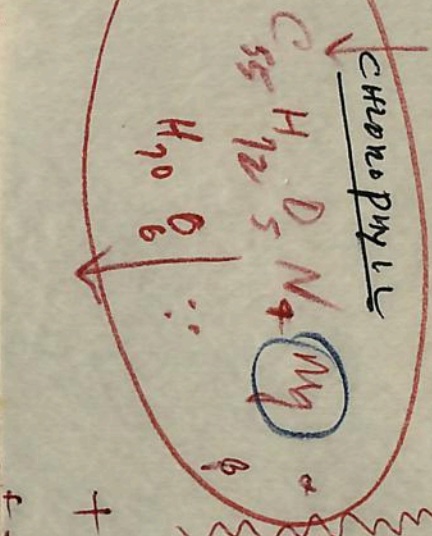
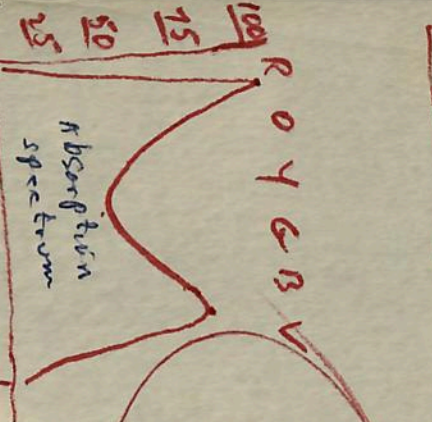
CELL RESPIRATION



Doctur 9 signatures

CO_2 : .03%
 O_2 : 21.7%
 N_2 : 78%

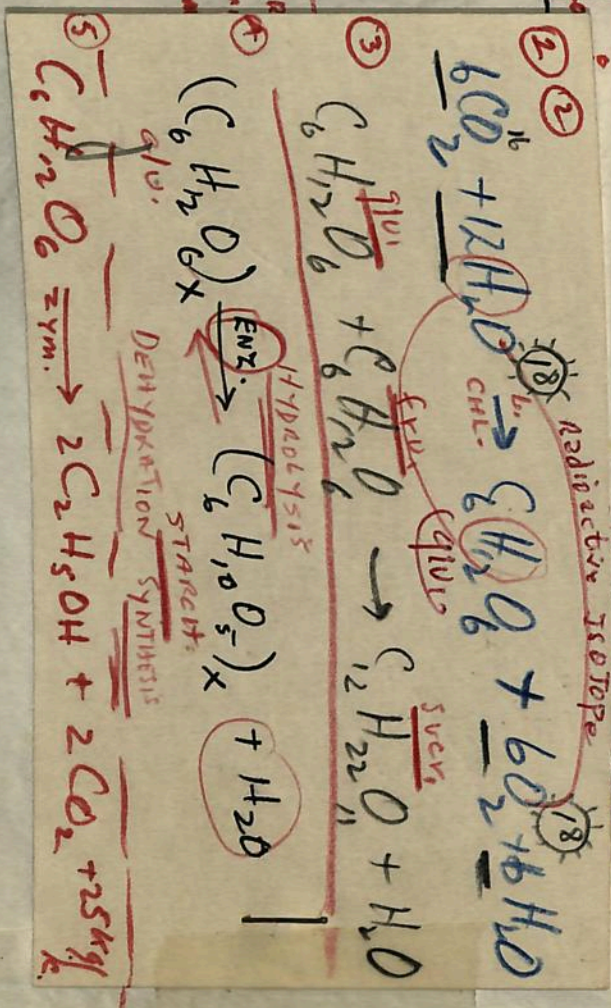
(Plants vs Animals)



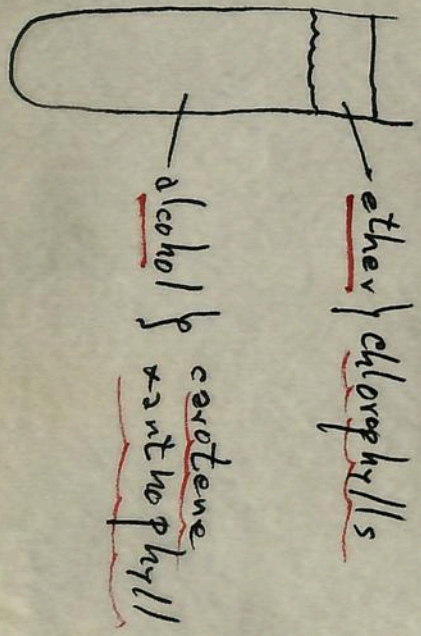
visible spectrum
 38000 Å
 8000 Å

mp = 10^{-10} Torr
 $\lambda = 10^{-8}$ cm
 $\chi_{unit} = 10^{-11}$ cm

RANDOM ETEN
 $= 10^{-3}$



Structure vs Empirical Formulas



1809
 Linde
 Davy
 Thompson
 Faraday

(BENTONITE'S)
 Reducing
 Carbon
 $CO_2 \rightarrow CO$

← X-RAYS ($\pm 1 \text{ \AA}$)

$$N_2 = 78\% \leftarrow$$

$$O_2 = 21\%$$
$$CO_2 = 0.03\%$$

[1789 F.V. REV.]

PRIESTLEY, JOE - 774-0 (Phlogiston)

LAVOISIER, Antoine
d. 1794 (guillotine)

INGENHOUSZ, JAN
1779

showed CO₂ uptake
& O₂ ↑ by green pl.

Von Helmont - Belg.
tiboo

Absent nutrients
from the net
soil!

incorrect but used
sci method -

14 Jul 1789
Bastille

glucose-
phosphate
etc

KREBS CYCLE

ATP Produced

GLYCOLYSIS

λ β_L G_R γ O_R R_{FD} $\rightarrow$ INFRARED $\rightarrow$ RADIO $\rightarrow$ $(\pm 10^{12} \text{ \AA})$
 $3800 \text{ \AA}$ $15000 \text{ \AA}$ $\pm 6000 \text{ \AA}$ $7600 \text{ \AA}$
 $0 - 18 \text{ ISOTYPE}$

[Ångström 1905, 10^{-10} m
Swedish
Physicist
d. 1874]

$$6 \text{CO}_2 + 12 \text{H}_2\text{O} + \text{CHL.} + \text{h.} \rightleftharpoons \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 + 6 \text{H}_2\text{O} + \text{E}$$

— Air composed of 2 gases; only O_2 combustible.

$$-[\text{CH}_2\text{O}] + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$$
$$\text{C}_6\text{H}_{12}\text{O}_6 \rightleftharpoons \text{C}_6\text{H}_{12}\text{O}_5 \xrightarrow{\text{DEHYD.}} \text{C}_{12}\text{H}_{22}\text{O}_{11} + \text{H}_2\text{O}$$

(GLUCOSE) (FRUCTOSE) (SUCROSE)

{ VAN NIEL }
{ HYPOTHESIS }

$C_n H_{2n} O_n$ { CARBO-HYDRATE (FR.)
 [MONO - DI - POLY SACCCHARIDES } $Cu^{++} \rightarrow \underline{Cu_2O}$
 $C_6 H_{12} O_6$ $\rightleftharpoons$ $(C_6 H_{10} O_5)_x$ + H_2O
 (GL.) (STARCH)
STORED FOOD

$$\text{H}_2\text{O} \xrightarrow{\text{not } \text{O}_2} \text{O}_2 \uparrow$$

ISOMERS

29/1/2020 " animal starch " (BENEDICT'S) (FEHLING'S)

$$\left[\begin{array}{c} C_{55} - H_{7,2} O_{,5} N_+ Mg \\ 70 \quad 6 \end{array} \right. \left. \begin{array}{l} \text{chl. a} \\ \text{chl. b} \end{array} \right]$$

RESPIRATION

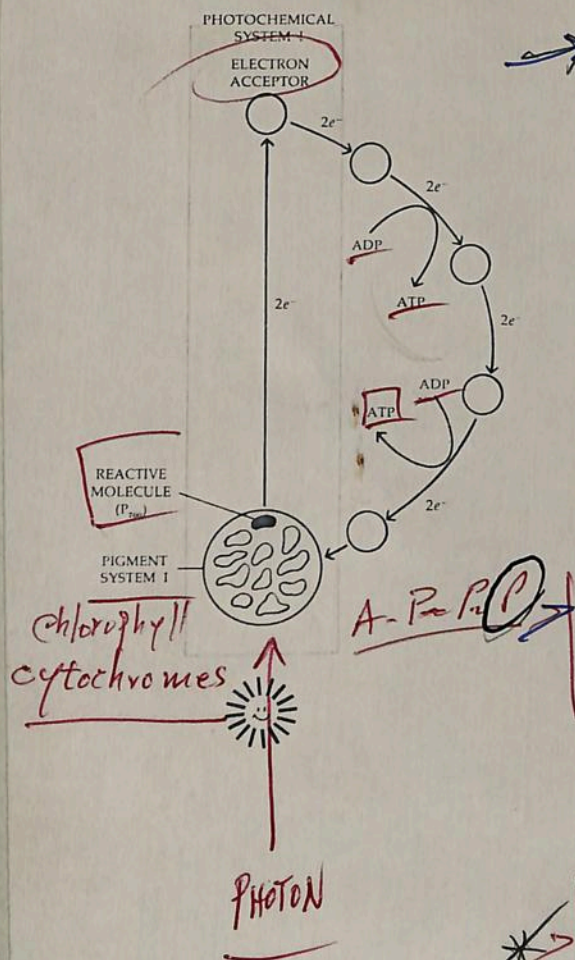
$$\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + 688 \text{ kJ}$$

↑
AEROBIC

2) $C_6H_{12}O_6 \xrightarrow{\text{zymase}}$ $2C_2H_5OH$ + $2CO_2$
(ANEROBIC) (ethyl alc.) + 25 kg/cwt

RESPIRATION - OVER-ALL

9-14 Cyclic electron flow bypasses Photochemical System II and requires only Photochemical System I. ATP is produced from ADP but oxygen is not released and NADP is not reduced.



In Photochemical System I, light energy boosts electrons from P₇₀₀ to an electron carrier from which they are passed downhill to an electron acceptor molecule NADP. NADP closely resembles the related coenzyme NAD, which functions in cellular respiration (it differs only in having an additional phosphate group). The gain from these two steps in photosynthesis is represented by the ATP molecules (the exact number is not certain) and the NADP_{red}. Oxygen is a by-product. The NADP_{red} is the chief source of the reducing power used to reduce carbon to organic compounds.

Why are there two photochemical systems rather than one? The answer seems to lie in the problem of the electron "holes." Suppose for a moment that System I were isolated from System II. There would be no way to fill the "holes" left in the P₇₀₀ molecule in System I. This function is now carried out by the electrons boosted up from System II. And what fills the holes in System II? They are filled by electrons from the water molecules. When the electrons pass from the water molecule to the chlorophyll molecule (which has a greater electron affinity), the water molecule falls apart, releasing oxygen gas.

Thus all the pieces fit together.

As we mentioned previously, there is also some evidence that System I can work independently. When this occurs, no NADP_{red} is formed. In this process, called cyclic electron flow, electrons are boosted from P₇₀₀ to an electron acceptor and from there pass downhill through a series of cytochromes back into the pigment system. ATP is produced in the course of the passage. It is believed that the most primitive photosynthetic mechanisms did, indeed, work in this way. These early photosynthetic mechanisms probably produced ATP; the fact that ATP is an energy carrier in every known kind of living system testifies to its very early appearance in the history of evolution. They did not give off oxygen, however, and it is not known if they reduced carbon to sugar.

Summary of Light Reactions

The reactions that we have just described are the "light reactions" of photosynthesis. In the course of these reactions, as we saw, light energy is converted to electrical energy—the flow of electrons—and the electrical energy is converted to chemical energy stored in the bonds of NADP_{red} and ATP.

In the words of Nobel laureate Albert Szent-Györgyi: "What drives life is . . . a little electric current, kept up by the sunshine."

THE DARK REACTIONS

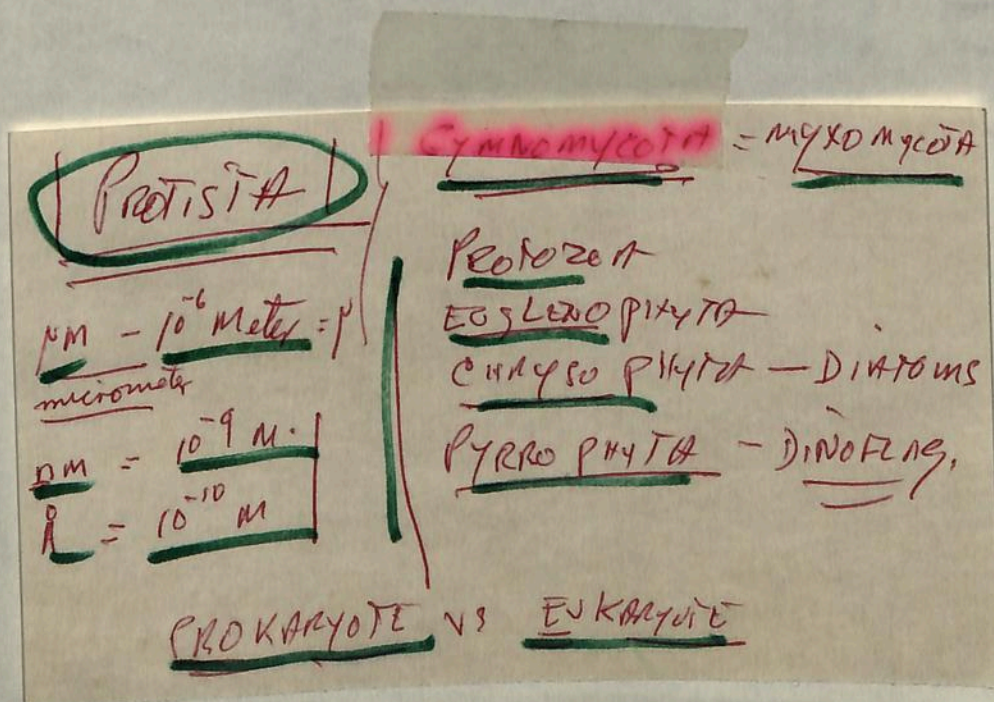
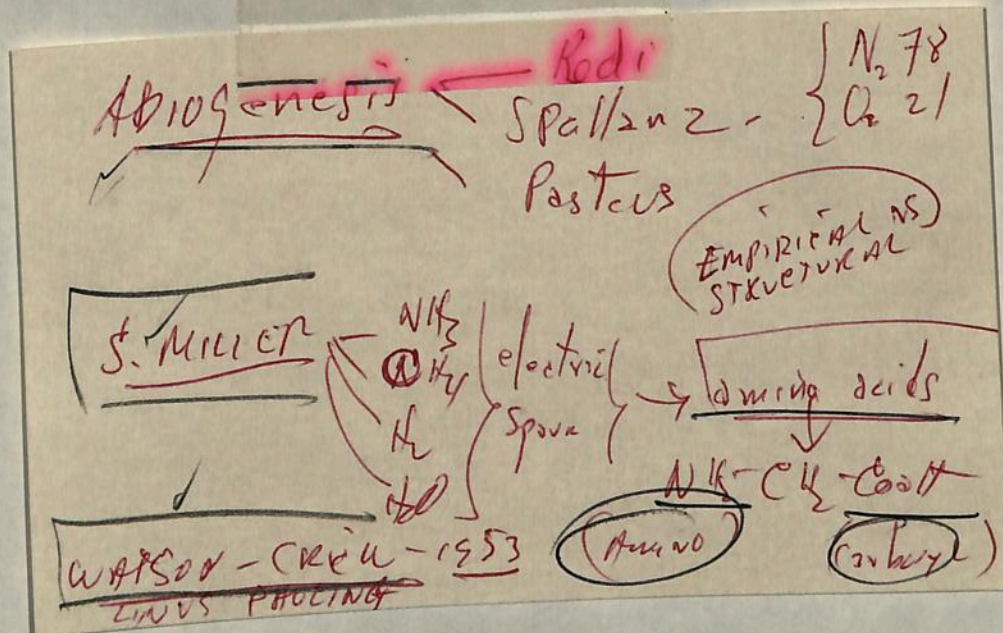
In the second stage of photosynthesis, the energy generated by the light reactions is used to incorporate carbon into organic molecules. These reactions take place in the stroma of the chloroplasts and do not need light, and so they are often referred to as the "dark reactions" (although they can take place equally well in the light). The dark reactions involve a cycle called the Calvin cycle. It is analogous to the Krebs cycle (page 132) in that, in each turn of the cycle, the starting product is again regenerated. The dark reactions convert the chemical energy produced by the light reactions to forms more suitable for storage and transport and also build the basic carbon structures from which all of the other organic molecules of living systems are produced. (This last process is known as the fixation of carbon.)

COVER THESE POINTS

Chlorophyll in Plants
 ✓ AEROBIC / ANAEROBIC RESPN
Hexose SUGARS etc. mono di poly
PHOTOLYSIS → STARCH
 $CO_2 + H_2O \xrightarrow{\text{receptor}} [C_6H_{12}O_6]$
GLYCOLYSIS → $CO_2 + H_2O$
PHYLAKOIDS
RESPIRATION in ALL LIVING CELLS
ANIMALS - Plants - Fungi
Ingestion + Proto - Resorption
AUTOTROPHIC vs HETEROTROPHIC
 ± 1% radiant energy in plants with

Hexose sugar (*)
 ✓ Aerobic vs Anaerobic
 ✓ Resps.
Fermentation ←
Glycolysis ←
Respiration in all cells ←
Ingestion ←
Absorption ←
Autotrophic vs Heterotrophic

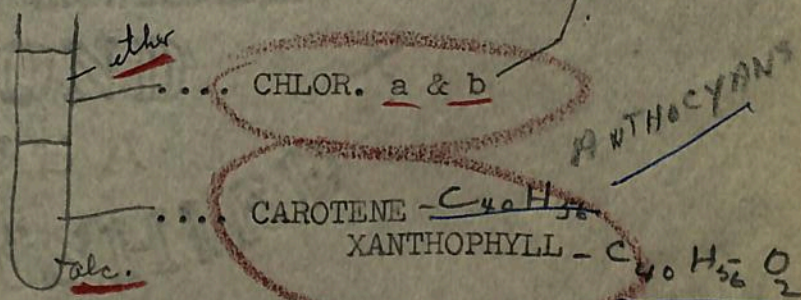
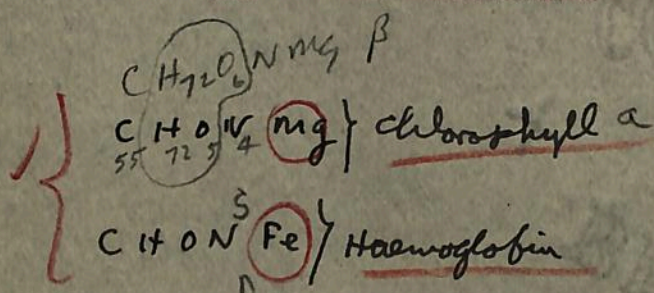
626 vs 25
CARBONIC / KIDNEY
1cm H₂O → 1°C
1k. H₂O → 1°C



VISIBLE SPECTRUM WITH PRISM.

IF CHLOROPHYLL INTERCEPTS PRISM CERTAIN COLORS PASS
THRU OTHERS ABSORBED.

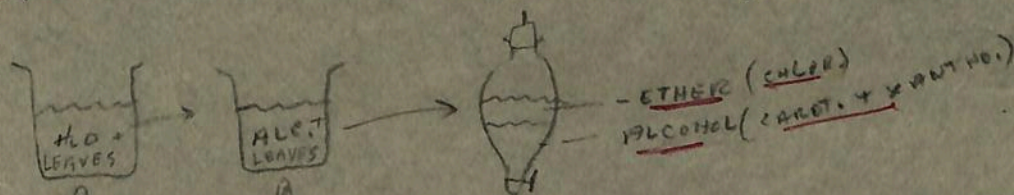
- Spectroscope*
- ** MOST ABSORPTION IN RED. SOME ALSO IN BLUE-VIOLET.
 - ** GREEN NOT ABSORBED APPRECIABLY, GIVING CHARACTERISTIC COLOR TO CHLOROPHYLL.

CHLOROPHYLL SEPARATION. (ALCOHOL PLUS $\frac{1}{2}$ VOL. PETROL. ETHER)

NOW CONSIDER LEAF STRUCTURE RELATED TO PHOTOSYNTHESIS:

(WHAT IS EXCHANGED ? WHERE ? HOW ?)

Leaf thin, > area; is CO_2 diffuses in easily.



CHO. MADE AT RATE OF 1 GRAM per SQ. METER LEAF SURFACE per HOUR.

EX. SUGAR CANE :

SUGAR BEET:

RATE OF PHOTOSYNTHESIS AFFECTED BY: TEMP. (30-35°C opt.)

(NO SYNTHESIS IN VITRO)

CO_2
 KIND OF LIGHT
 H_2O (roots)
 CHLOR.

IF PHOTOSYNTHESIS IN ALL PLANTS CASES, ALL FREE O_2 of ATMOSPHERE

was used up in about 2000 yrs. [Ann. N.Y. Acad. Sci. 69: 296. 1954.]

posed by Arnon, which may not be correct in all details. This process, like that of cyclic photophosphorylation, already described, begins when photons of light strike molecules of chlorophyll and raise electrons to an excited state (Fig. 4.11). But here the first few electron-acceptor molecules that lead the excited electrons away from the chlorophyll are not the same as those involved in the previous process. According to Arnon, one of these acceptor molecules, probably the first, is an iron-containing compound called ferredoxine, which has a very high affinity for electrons. The ferredoxine passes the electrons to an extremely important compound called triphosphopyridine nucleotide, or TPN as it is usually abbreviated (it is also frequently called nicotinamide adenine dinucleotide phosphate).

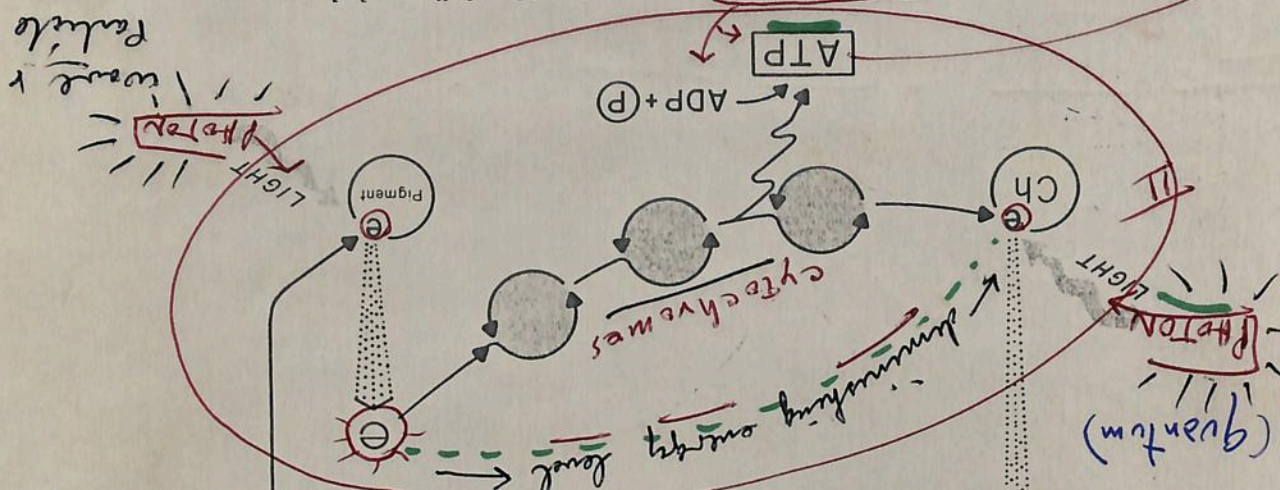
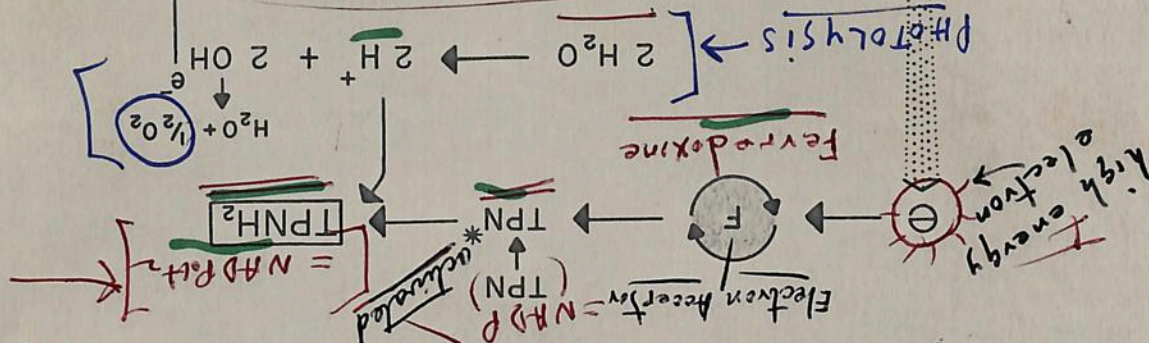


Fig. 4.11. Noncyclic photophosphorylation. Light strikes chlorophyll a , and electrons are raised to a high energy level (left). The electrons are picked up by ferredoxine (F), a very strong electron acceptor and passed to TPN, which thus becomes activated (activation is symbolized by an asterisk). The activated TPN pulls hydrogen ions (H^+) away from water and forms TPNH₂. A second light event raises electrons from a different pigment to a higher energy level (lower right). These electrons are passed along a series of acceptor compounds (dark circles) down an energy gradient until they reach chlorophyll a , where they replace the electrons lost from the chlorophyll as a result of the first light event; energy released from these electrons as they move down the energy gradient is used in synthesis of ATP from ADP and inorganic phosphate. Electrons to replace those lost from the second pigment come from the hydroxyl ions (OH^-) from water. The (OH^-) radicals that remain combine to form new water and O_2 (four (OH^-) radicals are needed for one complete O_2 molecule to be formed). The two important products of noncyclic photophosphorylation, ATP and TPNH₂, make possible the synthesis of carbohydrate from CO_2 .

ADENOSINE
TRIPHOSPHATE

PHOTON
quantum

PHOTOLYSIS

PHOTON

PHOTON

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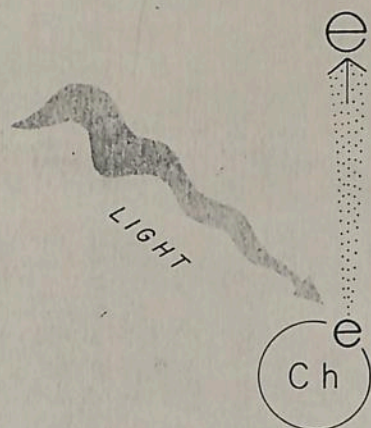


Fig. 4.7. Effect of light on chlorophyll. Light striking a chlorophyll molecule (Ch) causes an electron (e) of the chlorophyll to be raised to a higher energy level.

verting light energy into chemical-bond energy. Once light energy has raised a chlorophyll electron to a high-energy state, other cellular components must come into play if the energy is to be captured and utilized.

Cyclic Photophosphorylation

In the living photosynthesizing cell, the excited chlorophyll electron does not simply fall back to its normal lower energy level, losing its extra energy all at once. Instead, another molecule with a high affinity for electrons leads the high-energy electron away from the chlorophyll. One possible first electron-acceptor molecule passes the electron to another acceptor molecule, an iron-containing pigment called cytochrome, which in turn passes it to still another cytochrome acceptor molecule, and so forth (Fig. 4.8). After being passed from molecule to molecule in a chain of reactions, each catalyzed by an enzyme, the electron finally arrives back in the chlorophyll molecule whence it began. But when the electron leaves the chlorophyll it is energy-rich, and when it finally returns it is energy-poor. Obviously something happens to its extra energy while it is being passed along the circular chain of "electron carrier" molecules. What in fact happens is

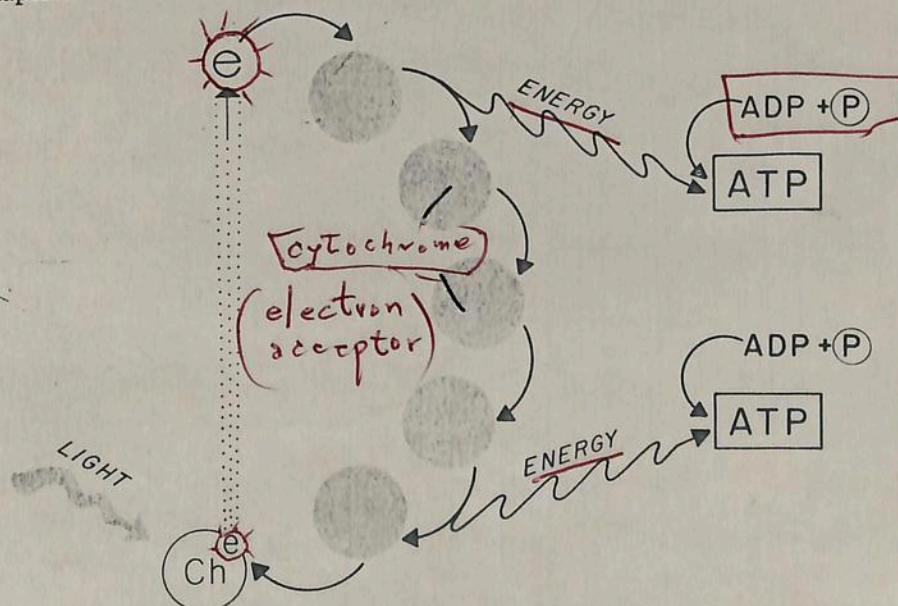


Fig. 4.8. Cyclic photophosphorylation. Light striking a molecule of chlorophyll causes an electron to be raised to a high energy level. The electron is picked up by an electron-acceptor molecule (dark circle), which passes it to a second acceptor molecule at a slightly lower energy level, which passes it to a third at a still lower energy level, etc. Some of the energy released as the electron is eased step by step down the energy gradient is used in the synthesis of ATP from ADP and inorganic phosphate.

Historical - Priestly & C_2
 1771 - Green plants
 1794 - restored air.

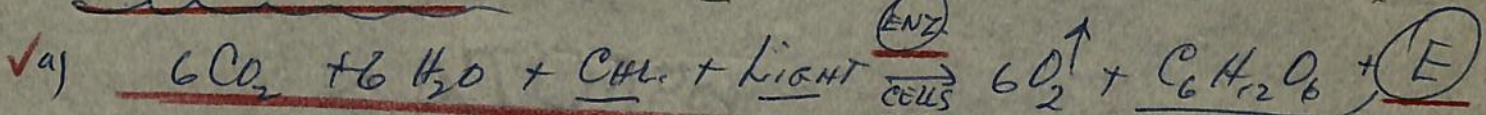
Photosynthesis
 Aristotle (384-322 BC)
 Van Helmont d. 1644

Autotrophs = self-nutrition
 J. Ingen Housz 1772 - O_2 produced in put enphorized "foul" air at night.
 Idea still persistent. (ie flowers removed from hospital rooms at night)
 to 19th century soil most important in growth. then hydroponics.

I Importance

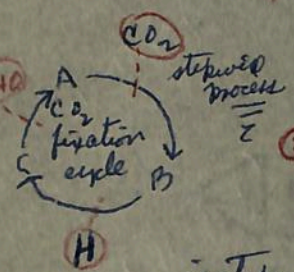
- (a) Dependence of all animals on product for (E) .
 10" tons organic C per yr.
- (b) Only in green plants & chlorosynthetic bacteria. (bacteriochlorophyll)
- (c) Most photosynthesis carried out by marine algae.

General Reaction



b) Intermediate steps not suggested here - only initial ingredients and final products. [ie Phosphoglyceraldehyde $\rightarrow$ Fructose phosphate (PGAL) $\rightarrow$ Glucose phosphate $\rightarrow$ Fructose $\rightarrow$ Glucose]

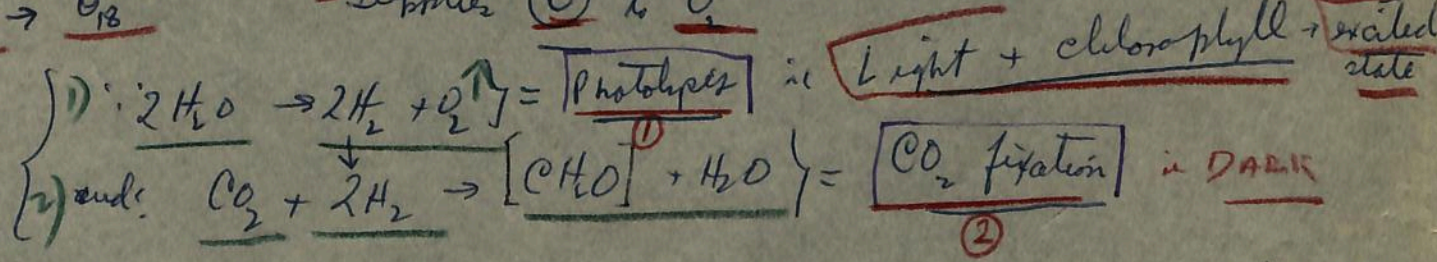
Factors: CO_2 - 0.03% in atmosphere



gas enters thru stomates, diffuses into cells. (details in stomata etc.)
 efficiency increased to $\pm 5\%$
 2) H_2O - thru roots via conducting cells to leaves, stems

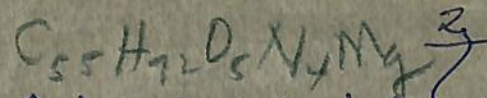
isotope of O_2 Supplies (H) to $C_6(H_{12})O_6$; not O

$O_{16} \rightarrow O_{18}$ Supplies (O) to O_2



is crushed green leaves (chloroplasts isolated) + H_2O + LIGHT $\rightarrow O_2 \uparrow$
chloroplast reaction in VITRO

3) Chlorophyll - $C_{55}H_{72}O_{12}N_4Mg$ related to haemoglobin ($C_4H_4N_4O_2S_2Fe$)
 in chloroplasts and grana, a laminated structure. (10-80/cell)
 leucoplasts - no pigments - starch storage



Carotene - $C_{40}H_{56}$

Xanthophyll - $C_{40}H_{56}O_2$

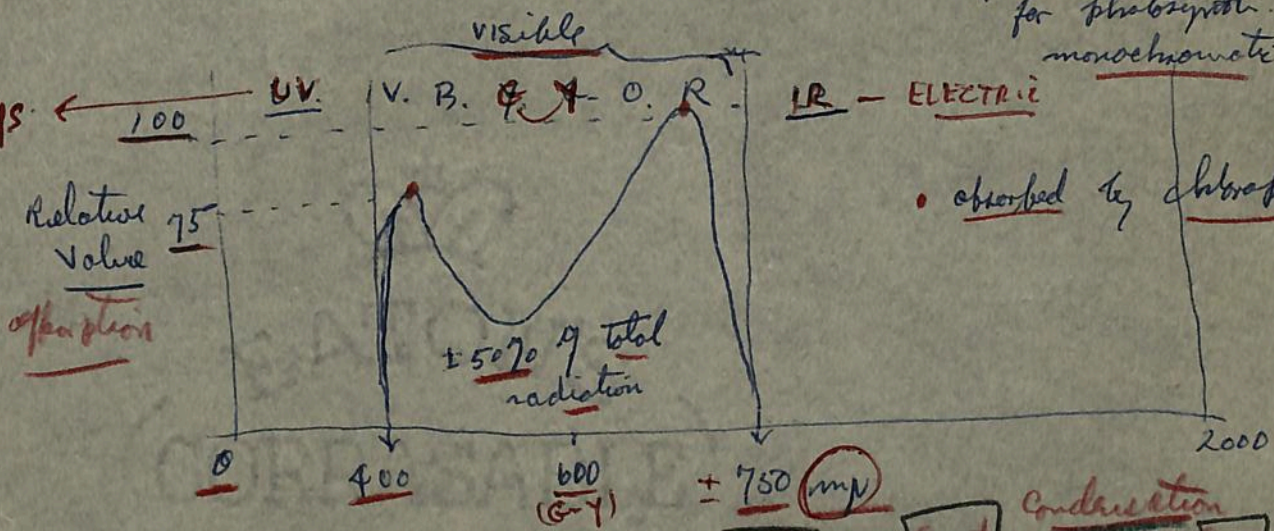
See: HILL, R. & C.P. WITTINGHAM. 1957.
PHOTOSYNTHESIS, JOHN WILEY & Sons Inc
1958.

$\lambda = 10^{-10} m$ $N = 10^{-6} m$
(λ)

④ Light - the solar spectrum

Testing most effective light for photosynth. by monochromatic source

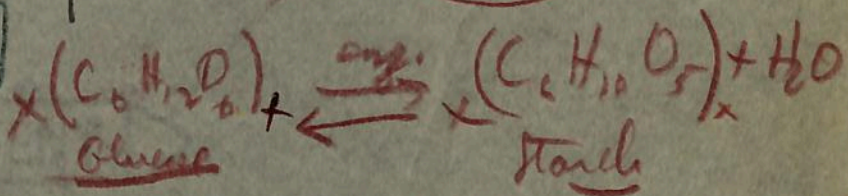
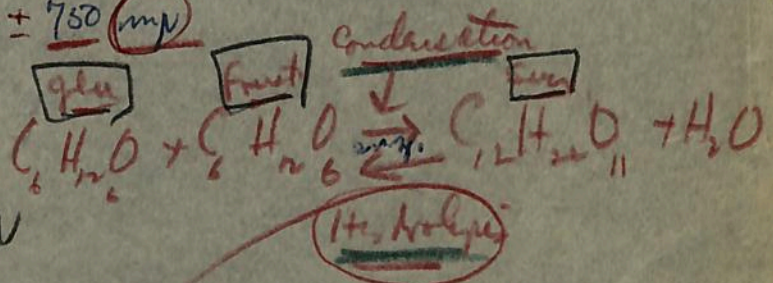
Cosmic Rays



• absorbed by chlorophylls

$\lambda = 10^{-3} m$

$\checkmark \mu = 10^{-4} m = \mu$
 $A = 10^{-7} m$



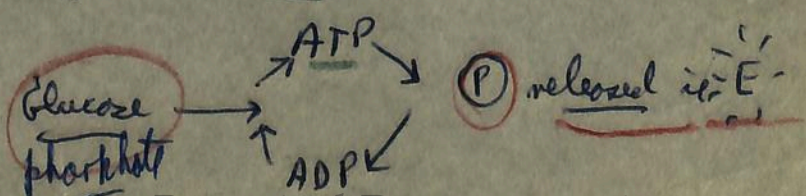
(dehydration synthesis)
= condensation

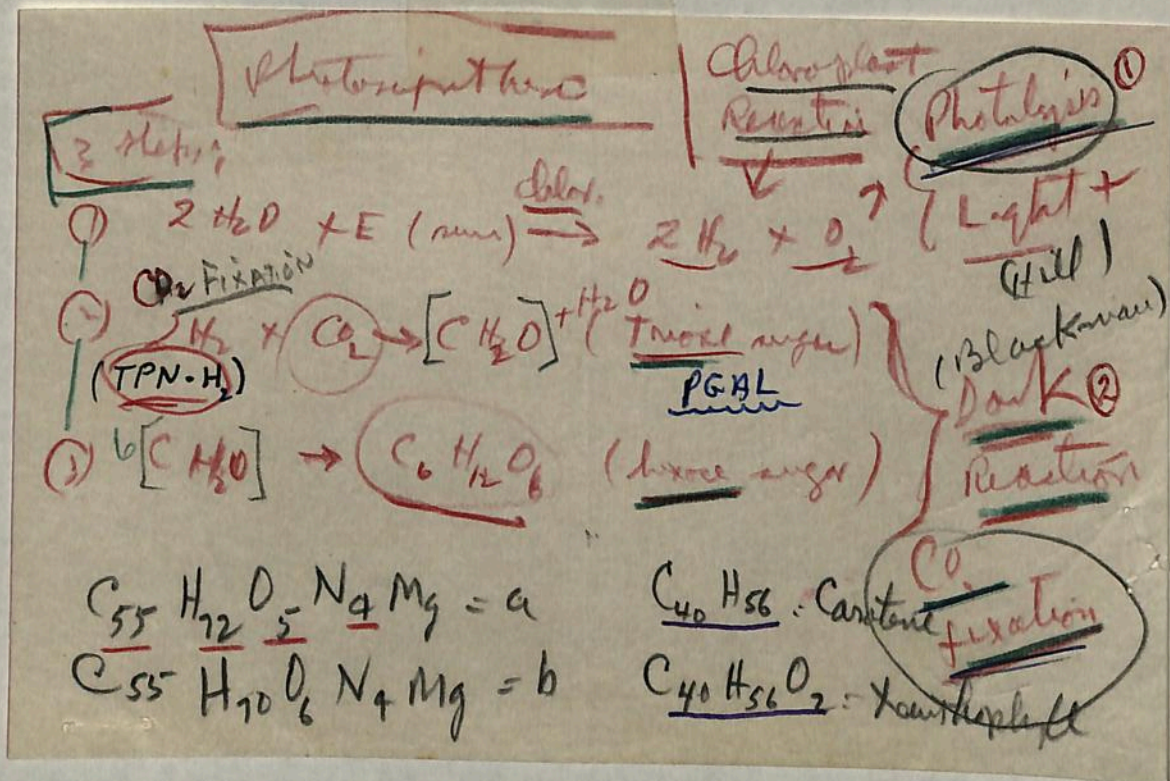
Respiration is Energy release via ATP Adenosine triphosph.
ie A - P ~ P ~ P

Oxidation of glucose is stepwise process, releasing
"small packets" of energy, enough to regenerate

energy incl. phosphate

ATP from ADP





MONERA

BACTERIA

BLUE-GR. ALGAE

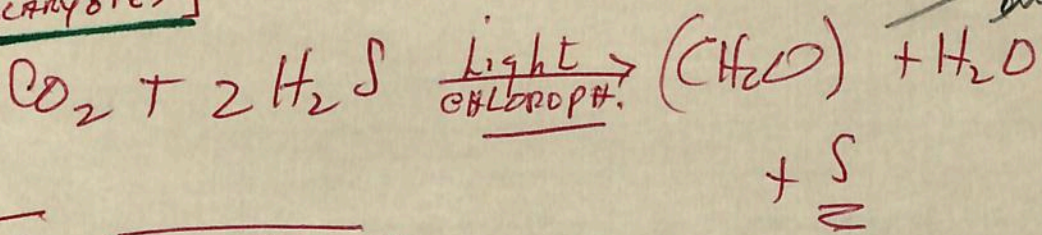
[PROKARYOTES]

BACTERIA

PHOTOSYNTHETIC

SULFUR

PURPLE
etc



MOST: Heterotrophs

ie Parasites / Saprobies

MORPHOLOGY - LEEUWENHOEK

PATHOLOGY

GRAM STAIN

mycobact. tbc

TREPONEMA sp. - V.D.

Vibrio cholera

staph. / strep.

- Leprosy

Pasteurella pestis

→ Lipopolysaccharide combines with gentian violet → Gram +

iodine

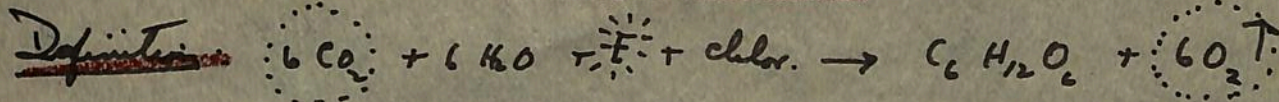
Safranin

[Gram]

Sterile technique

Photosynthesis

12/20



Van Helmont's Experiment: with willow:

Humus Theory

is source of food for plant in H_2O , not soil.

dark in dark:

$\text{CO}_2 \uparrow, \text{O}_2 \downarrow$

in light: $\text{CO}_2 \downarrow, \text{O}_2 \uparrow$

.03% CO_2 in atmosphere. is 3 parts in 10,000.

Where?

Leaf structure best adapted: thin, large area.

large, large thin $\therefore \text{CO}_2 + \text{H}_2\text{O}$ diffuses in.

Conditions:

Light:

Spectrum: IR

(R)

O

Y

G

(B)

V

UV

X

Number of chloroplasts:

250 million / sq. inch. in elm.

each chloroplast $\pm 5\mu$ diam.

large elm may have 71 million leaves.

$= \pm 1$ acre leaf surface

± 16 acres chloroplast surface

1 acre corn = 2 acre leaf surface.
= 10 tons sugar per acre
= $\pm 2\text{ lb. / plant}$

$\left\{ \begin{array}{l} \text{C H O N Mg} = \text{chlorophyll a \& b} \\ \text{C H O N S Fe} = \text{hemoglobin} \end{array} \right.$

Use of Food (Plants)

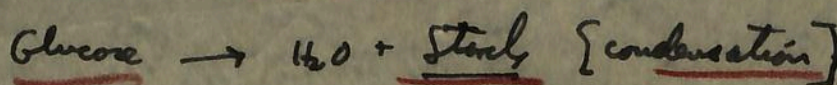
1) Converted to protoplasm

2) Stored

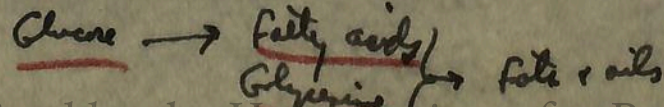
3) $\text{F} +$ for all activities

Syntheses

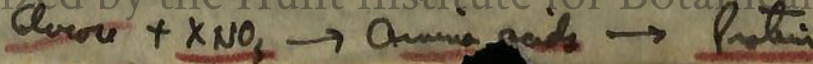
1) Starch:



2) Fats:



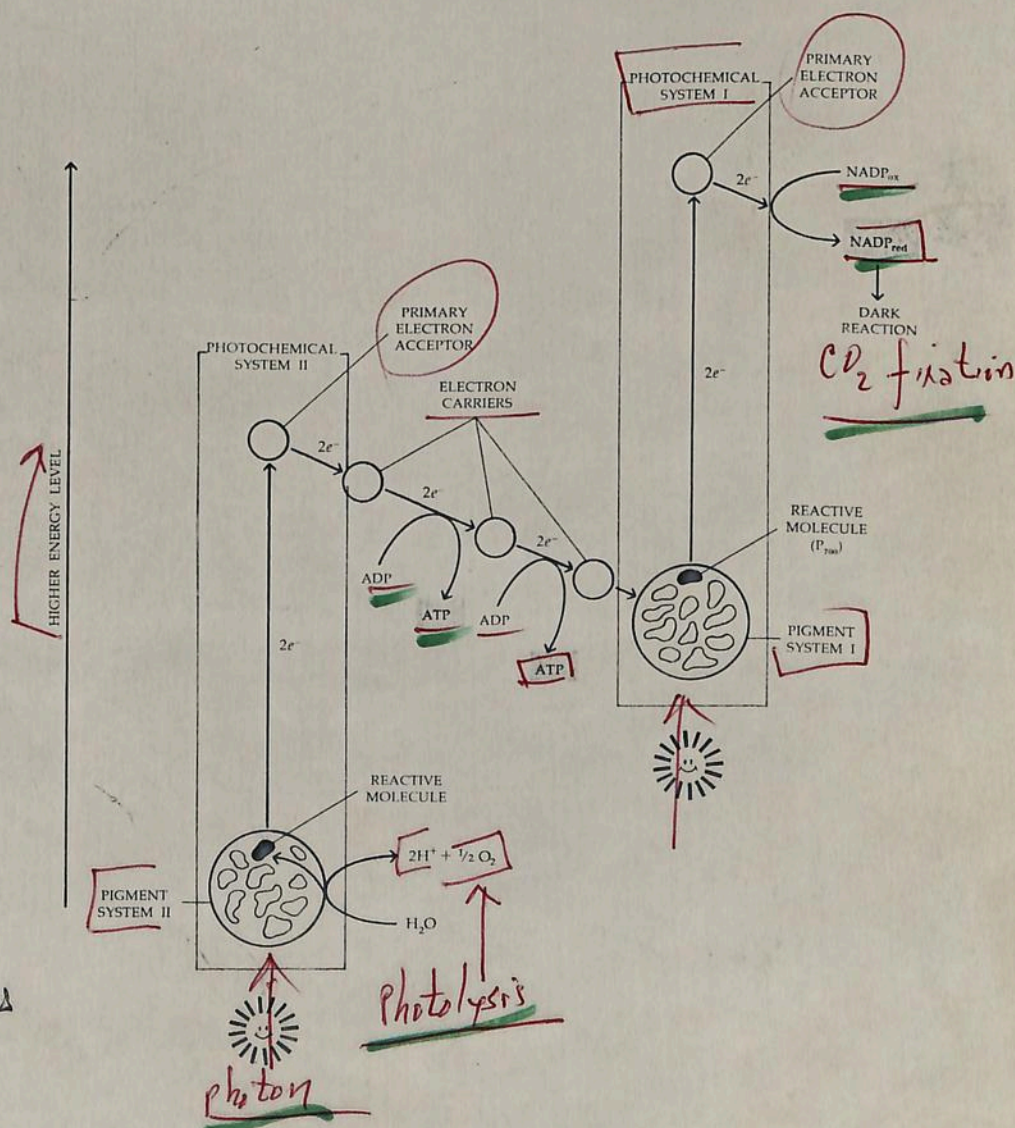
3) Proteins:



MODEL OF LIGHT REACTIONS

Figure 9-13 shows the present model of how the two photochemical systems work together in photosynthesis. Light energy first enters Pigment System II where it is responsible for two important events: (1) electrons are boosted uphill from a reactive molecule, and (2) water is split into protons, electrons, and oxygen gas. As the electrons are removed, they are passed uphill at increasingly higher energy levels to a primary electron acceptor. (The electron acceptors in these reactions, some of which are cytochromes, some of which are other electron-transfer molecules whose identities are known, and some of which are unidentified, are all indicated by circles.) The electrons then pass downhill along an electron transport chain similar to the electron transport chain in the mitochondria. In the course of this passage, ATP is formed from ADP. This process is known as photophosphorylation and is comparable to the oxidative phosphorylation process in cellular respiration. These systems probably evolved separately (with Photochemical System I coming first), and Photochemical System I, as we shall see, can probably operate separately. In general, however, they work together.

Light energy trapped in the reactive molecule of Pigment System II boosts electrons uphill from chlorophyll to a primary electron acceptor. These electrons are replaced by electrons pulled away from water molecules, which then split apart, producing protons and oxygen. The electrons are passed from the primary electron acceptor along an electron transport chain to a lower energy level, the reaction center of Pigment System I. They pass along the electron transport chain, some of their energy is captured in the form of ATP. Light energy absorbed by Pigment System I boosts the electrons to another primary electron acceptor. From this acceptor, they are passed via other electron carriers, ADP_{ox} to form NADP_{red}. The electrons removed from Pigment System II are replaced by those from Pigment System I. ATP and NADP_{red} represent the net gain from the light reactions.



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GLADSTONE, OREGON 97027

PHOTOSYNTHESIS

C. P. WHITTINGHAM

Head of the Botany Department,

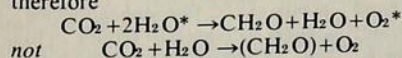
Rothamsted Experimental Station, Harpenden, England

Editor's Note: This article is based on some of the material contained in Oxford Biology Reader CBSCO 45-9609 *Photosynthesis*.

Photosynthesis is the indirect source of most of the organic matter on earth, is the primary source of the energy of all living things, and is the source of free oxygen which makes aerobic respiration possible.

The overall effect of photosynthesis is the reduction of carbon dioxide with a corresponding oxidation of water by removal of hydrogen, resulting in the evolution of oxygen. The energy required is provided ultimately from the light energy absorbed by the plant pigments.

Studies with isotopically-labeled water show that the oxygen evolved comes wholly from the water, and the empirical equation is therefore



In 1905 F. F. Blackman postulated two processes in photosynthesis: (1) a dark thermochemical process involving the uptake of CO_2 , and (2) a separate light reaction whose products drive the dark reaction. To these must be added (3) the reactions concerned with the evolution of oxygen from water. A considerable amount is known today about processes (1) and (2), but very little about (3).

THERMAL REACTIONS INVOLVING CARBON

The most significant advances in studying process (1) came after 1945 when the isotope ^{14}C had become available. Calvin, working with the unicellular alga *Chlorella*, found that after only 5 seconds of photosynthesis in the presence of air enriched with 5 percent $^{14}\text{CO}_2$, five different organic compounds became radioactive. Attempts to find which of these was the first compound into which the radioactive isotope entered by shortening the experimental time proved to be impossible.

However, Calvin noted that in a reaction sequence of the type $a + \text{CO}_2 \rightarrow b \rightarrow c \rightarrow d$ in the very first second of adding the radioactivity it will all pass into b , but not beyond. Hence b has 100 percent of the radioactivity at zero

time. Conversely, c starts with nothing, because when b has 100 percent, c must have zero. The percent in c begins to rise as the percent in b falls. If the final products are represented by d , then ultimately all the radio-

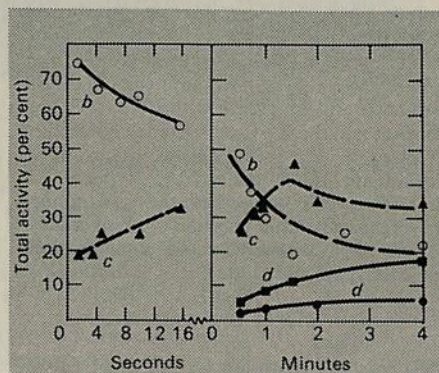
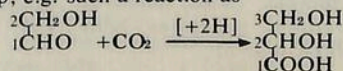


FIGURE 1 The percentage radioactivity incorporated in different compounds plotted against time during photosynthesis in the alga *Scenedesmus* in the presence of $^{14}\text{CO}_2$. $\circ$, phosphoglyceric acid; Δ , sugar phosphates; $\blacksquare$, malic and aspartic acids; $\bullet$, alanine. b , c , and d are the products of the reaction: $a + \text{CO}_2 \rightarrow b \rightarrow c \rightarrow d$.

activity will flow through and end up in d , and the percent in d will rise to 100. The experimental data are shown in Figure 1, from which b is identified as phosphoglyceric acid (PGA), c as the sugar phosphates, and d as the amino acid alanine, malic acid, and sucrose (not shown).

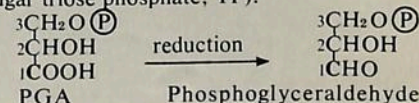
A second experimental approach was to discover which atoms in each molecule become radioactive. Between 1 and 5 seconds all the radioactivity was found in the C atom of the carboxyl group C-1 of PGA. This would be consistent with the formation of PGA by carboxylation of a two-carbon precursor group, e.g. such a reaction as



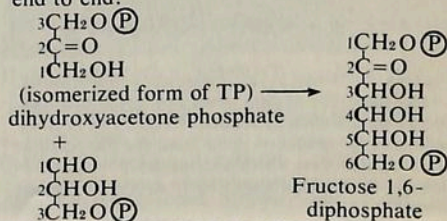
Calvin and his colleagues spent five years looking for such a precursor without success.

The overall process of photosynthesis is the formation of a sugar containing an aldehyde

(-CHO) group rather than an acid containing a carboxyl group. Therefore, there must be a reduction reaction to produce the corresponding aldehyde, phosphoglyceraldehyde (the sugar triose phosphate, TP):



If the phosphoglyceraldehyde is derived by direct reduction, it follows that the aldehyde group should contain all the radioactivity of the molecule which was previously confined to the carboxyl group. By reversing some of the known reactions of the Embden-Meyerhof-Parnas pathway of respiration, two molecules of triose phosphate can form one molecule of fructose 1,6-diphosphate by joining end to end:



Phosphoglyceraldehyde, TP

The carboxyl C atom of PGA becomes eventually both the C-3 and C-4 atoms of the hexose sugar fructose diphosphate, and initially radioactivity should be totally confined to these atoms. When the fructose sugar formed in a short 5 second period of photosynthesis is degraded, it is indeed found that all the label is in the C-3 and C-4 atoms.

If the reaction is continued for up to 30 seconds or 1 minute, the pattern begins to change. Radioactivity now appears in the other carbon atoms of the phosphoglyceric acid and also in the C-1 and C-6 and the C-2 and the C-5 atoms of the fructose. This must mean that if PGA is formed by carboxylating a precursor, the precursor also becomes radioactive after 30 seconds. Therefore, there must be some feedback from the products to form more precursor molecules.

It was realized that the acceptor for CO_2 need not contain only two carbon atoms; it could just as well contain five and be regarded

HOW CELLS TRANSFORM ENERGY

PART I --- PHOTOSYNTHESIS

IN THE CHLOROPLASTS OF PLANT CELLS THE ENERGY OF SUNLIGHT IS TRANSFORMED INTO CHEMICAL FUELS. IN THE MITOCHONDRIA OF PLANT AND ANIMAL CELLS THESE FUELS ARE OXIDIZED TO RUN THE CELLULAR MACHINERY.

A living cell is inherently an unstable and improbable organization; it maintains the beautifully complex and specific orderliness of its fragile structure only by the constant use of energy. When the supply of energy is cut off, the complex structure of the cell tends to degrade to a random and disorganized state. In addition to the chemical work required to preserve the integrity of their organization, different kinds of cells transform energy to do the varieties of mechanical, electrical, chemical and osmotic work that constitute the life processes of organisms.

As man has learned in recent times to use energy from inanimate sources to do his work, he has begun to comprehend the virtuosity and efficiency with which the cell manages the transformation of energy. The same laws of thermodynamics that govern the behavior of inanimate substances also govern the energy transactions of the living cell. The first law of thermodynamics says that the sum of the mass and energy in any physical change always remains constant. The second law states that there are two forms of energy: "free", or useful, energy; and entropy, or useless or degraded energy. It states furthermore that in any physical change the tendency is for the free energy to decline and the entropy to increase. Living cells must have a supply of free energy.

The engineer gets most of the energy he employs from the chemical bonds in fuels. By burning the fuel he degrades the energy locked in these bonds to heat; he can then use the heat to make steam and drive a turbogenerator to produce electricity. Cells also extract free energy from the chemical bonds in fuels. The energy is stored in these bonds by the cells that manufacture foodstuffs that serve as fuel. The cell makes use of this energy, however, in a very special way. Since the living cell functions at an essentially constant temperature, it cannot use heat energy to do work. Heat energy can do work only when it passes from one body to another body that has a lower temperature. The cell obviously cannot burn its fuel at the 900-degree-centigrade combustion temperature of coal, nor can it tolerate superheated steam or high voltage. It must therefore obtain energy and use it at a fairly constant and low temperature, in a dilute and aqueous environment and within a narrow range of concentration of hydrogen ions. To secure its primary energy the cell has during the eons of organic evolution perfected extraordinary molecular mechanisms that work with great efficiency under these mild conditions.

The energy-extracting mechanisms of living cells are of two kinds, and they separate all cells into two great classes. The first type of cell, called heterotrophic, includes the cells of the human body and of higher animals in general. This type of cell requires a supply of preformed, ready-made fuel of considerable complexity, such as carbohydrate, protein, and fats, which are themselves constituents of cells and tissues. Heterotrophic cells obtain their energy by burning or oxidizing these complex fuels, which are made by other cells, in the process called respiration, using molecular oxygen from the atmosphere. They employ

the energy so obtained to carry out their biological work, and give up carbon dioxide to the atmosphere as the end product.

Cells in the other class get their energy from sunlight. Such cells are called autotrophic, or self-reliant. Principal among them are the cells of green plants. By the process of photosynthesis they harness the energy of sunlight for their living needs. They also use solar energy to incorporate carbon from atmospheric carbon dioxide in the elementary organic molecule of glucose. From glucose the cells of green plants and of other organisms build up the more complex molecules of which cells are made. In order to supply energy for this chemical work the cells burn some of the raw material by the mechanism of respiration. From this description of the cellular energy cycle it is clear that living things ultimately derive their energy from sunlight --- plant cells directly and animal cells indirectly.

Investigations of the central questions posed here are converging on a complete description of the primary energy-extracting mechanisms of the cell. Most of the steps in the intricate cycles of respiration and photosynthesis have been worked out. Each process has been localized in a specific organelle of the cell. Respiration is carried on by mitochondria, large numbers of which are found in almost all cells; photosynthesis is conducted by chloroplasts, the cytoplasmic structures that distinguish the cells of green plants. The molecular devices that make up these structures and perform their functions present the next great frontier to cell research.

From the centers of respiration and photosynthesis the same well-defined molecule --- adenosine triphosphate (ATP) --- carries the free energy extracted from foodstuffs or from sunlight to all the energy-expending processes of the cell. ATP, which was first isolated from muscle by K. Lohman of the University of Heidelberg some thirty years ago, contains three phosphate groups linked together. In the test tube the terminal group can be detached from the molecule by the drastic, one-step reaction of hydrolysis to yield adenosine diphosphate (ADP) and simple phosphate. As this reaction proceeds, the free energy of the ATP molecule appears as heat and entropy, in accordance with the second law of thermodynamics. In the cell, however, the terminal phosphate group is not merely detached by hydrolysis but is transferred to a specific acceptor molecule. The free energy of the ATP molecule is largely conserved by "phosphorylation" of the acceptor molecule, the energy content of which is now raised so that it can participate in an energy-requiring process such as biosynthesis or muscle contraction. Left over from this "coupled reaction" is ADP. In the thermodynamics of the cell ATP may be considered as the energy-rich, or "charged", form of the energy carrier and ADP as the energy-poor, or "discharged" form.

It is, of course, one or the other of the two energy-extracting mechanisms that "recharges" the carrier. In respiration in animal cells the energy of foodstuffs is released by oxidation and harnessed to regenerate ATP from ADP and phosphate. In photosynthesis in plant cells the energy of sunlight is trapped as chemical energy and harnessed to drive the recharging of ATP. Experiments employing the radioactive isotope phosphorus 32 have shown that the inorganic phosphate passes into terminal phosphate group of ATP and out again with great rapidity. In a kidney cell the terminal phosphate group turns over so rapidly that its half life is less than a minute, in consonance with the massive and dynamic flux of energy in the cells of this organ. It should be added that there is really no black magic associated with the action of ATP in the cell.

Chemists are familiar with many similar reactions that permit the transfer of chemical energy in inanimate systems. The relatively complex structure of ATP has apparently evolved uniquely in the cell to produce maximum control and organization of energy-transferring chemical reactions.

The role of ATP in photosynthesis has only recently been elucidated. This discovery supplies a major part of the explanation of how photosynthetic cells harness the ultimate energy source of all living things, solar energy, in the synthesis of carbohydrates.

The energy of sunlight comes in packets called photons, or quanta; light of different colors or wavelengths is characterized by different energy content. When the light strikes and is absorbed by certain metallic surfaces, the energy of the impinging photons is transferred to electrons of the metal. This "photoelectric" effect can be measured by the resulting flow of electric current. In the green-plant cell, solar energy of a particular range of wavelengths is absorbed by the green pigment chlorophyll. The absorbed energy raises an electron from its normal energy level to a higher level in the bond structure in this complex molecule. Such "excited" electrons tend to fall back to their normal and stable level, and when they do they give up the energy they have absorbed. In a pure preparation of chlorophyll, isolated from the cell, the absorbed energy is re-emitted in the form of visible light, as it is from other phosphorescent or fluorescent and inorganic compounds.

Thus chlorophyll itself in the test tube cannot store or usefully harness the energy of light; the energy escapes quickly, as though by short circuits. In the cell, however, chlorophyll is so connected spatially with other specific molecules that when it is excited by the absorption of light, the "hot" or energy-rich electrons do not simply fall back to their normal positions. Instead these electrons are led away from the chlorophyll molecule by associated "electron carrier" molecules and handed from one to the other around a circular chain of reactions. As they traverse this external path the excited electrons give up their energy bit by bit and return to their original positions in the chlorophyll, which is now ready to absorb another photon. This energy given up by the electrons has meanwhile gone into the formation of ATP from ADP and phosphate; that is, into recharging the ATP system of the photosynthetic cell.

The electron carriers that mediate this process of "photosynthetic phosphorylation" have not yet been fully identified. One of these molecules is believed to contain riboflavin (vitamin B₂) and vitamin K. Others are tentatively identified as cytochromes: proteins containing iron atoms surrounded by porphyrin groups similar in arrangement and structure to the porphyrin of chlorophyll itself. At least two of these electron carriers are able to cause some of the energy they carry to be captured in order to regenerate ATP from ADP. This appears to be the basic scheme of the conversion of light into the phosphate-bond energy of ATP, as it has been developed by Daniel I. Arnon and his associates at the University of California and by other workers.

The complete photosynthetic process, however, involves the synthesis of carbohydrate as well as the harnessing of solar energy. It is now believed that some of the "hot" electrons from the excited chlorophyll, along with hydrogen ions derived from water, cause the reduction (that is, the addition of electrons or hydrogen atoms) of one of the electron

carriers, triphosphopyridine nucleotide (TPN), which in its reduced form becomes TPNH_2 . In a series of "dark" reactions, so named because they occur in the absence of light, TPNH_2 brings about the reduction of carbon dioxide to carbohydrate. Much of the energy necessary for this series of reactions is supplied by ATP. The pattern of the dark reactions was worked out largely by Melvin Calvin (Nobel Prize Winner) and his associates, also at the University of California. A by-product of the original photoreduction of TPN is the hydroxyl ion (OH^-). Although the evidence not yet complete, it is thought that these ions donate their electrons to a cytochrome in the photosynthetic chain, releasing molecular oxygen in the process. The electrons continue down the carrier chain, contributing to the formation of ATP and finally settling in their energy-depleted state in the chlorophyll.

As the highly organized and sequential nature of the photosynthetic process suggests, the chlorophyll molecules are not randomly situated or merely suspended in the solution inside the chloroplasts. On the contrary, the chlorophyll is arranged in orderly structures within the chloroplasts called grana, and the grana in turn are separated from one another by a network of fibers or membranes. Within the grana the flat chlorophyll molecules are stacked in piles. The chlorophyll molecules can be looked upon as the single plates of a battery, several plates being organized as in an electrical cell, and several cells in a battery, represented by the chloroplast.

The chloroplasts also contain all the specialized electron-carrier molecules that work together with chlorophyll to extract the energy from the hot electrons and use that energy to synthesize carbohydrate. Separated from the rest of the cell, the chloroplasts can carry on the complete photosynthetic process.

The efficiency of these miniature solar power plants is impressive. Though the exact figures are subject to controversy, it can be demonstrated under special laboratory conditions that the photosynthetic process converts as much as 75% of the light that impinges on the chlorophyll molecule into chemical energy. On the other hand, the efficiency of energy recovery of a field of corn, given the random and uneven exposure of the leaves to sunlight and other conditions of nature, it is considerable lower: on the order of only a few per cent.

PART 2 --- RESPIRATION

The molecule of glucose, as the end product of photosynthesis, can therefore be visualized as having a considerable amount of solar energy locked in its molecular configuration. In the process of respiration heterotrophic cells extract this energy by carefully taking apart the glucose molecule step by step, conserving its energy of configuration in the phosphate-bonded energy of ATP.

There are different kinds of heterotrophic cells. Some, such as certain marine organisms, can live without oxygen; some, such as brain cells, absolutely require oxygen; some, such as muscle cells, are more versatile, being able to function either aerobically or anaerobically. Furthermore, although most cells prefer glucose as the major fuel, some can live exclusively on amino acids or fatty acids synthesized from glucose as the basic raw material. The disassembly of the glucose molecule by the liver cell may be taken, however, as typical of the process by which most known aerobic heterotrophs obtain energy.

The total amount of energy available in a molecule of glucose may be quite simply determined. By burning a sample in the laboratory it can be shown that the oxidation of the glucose yields six molecules of water and six molecules of carbon dioxide, with the evolution of some 690,000 calories of energy per gram molecular weight (that is, per 180 grams of glucose) in the form of heat. Energy in the form of heat is, of course, useless to the cell, which functions under essentially constant temperature conditions. The step-by-step oxidation of glucose achieved by the mechanism of respiration occurs in such a way, however, that much of the free energy of the glucose molecule is conserved in a form that is useful to the cell. In the end more than 50% of the available energy is recovered in the form of phosphate-bound energy. This recovery compares most favorably with the standard of the engineers, who rarely convert more than a third of the heat of combustion into useful mechanical or electrical energy.

The oxidation of glucose in the cell proceeds in two major phases. The first, or preparatory, phase, called glycolysis, brings about the splitting of the six-carbon glucose molecule into two three-carbon molecules of lactic acid. This seemingly simple process occurs not in just one step but at least 11 steps, each catalyzed by a specific enzyme. If the complexity of this operation puzzles you, then it must be borne in mind that the function of the reaction is to extract chemical energy from the glucose molecule, not merely to split it in two. Each of the intermediate products contains phosphate groups, and a net of two molecules of ADP and two phosphates are used up in the reaction. Ultimately the splitting of glucose not only yields two molecules of lactic acid but also generates two molecules of ATP.

What does this mean in terms of energy? Thermodynamic equations show that the splitting of a gram molecule of glucose to lactic acid makes a total of 56,000 calories available. Since the charging of each gram molecule of ATP captures about 10,000 calories of energy, the yield at this stage is about 36 per cent, a respectable figure by engineering standards. The conversion of 20,000 calories represents, however, a small fraction -- only 3 per cent --- of the total of 690,000 calories bound in the glucose. Yet many cells, such as anaerobic cells or muscle cells in exercise (which are unable to conduct the process of respiration), must function on this small yield.

With glucose now broken down to lactic acid, aerobic cells proceed to extract a major portion of the remaining energy by a process of respiration, in which the three-carbon lactic acid molecule is broken down into single-carbon molecules of carbon dioxide. The lactic acid, or rather its oxidized form pyruvic acid, undergoes an even more complex series of reactions, each step again being catalyzed by a specific enzyme system. First the three-carbon compound is broken down to an activated form of acetic acid --- acetyl coenzyme A --- and carbon dioxide. The two-carbon acetic acid compound then combines with a four-carbon compound, oxalacetic acid, to make six-carbon citric acid. This is degraded again to oxalacetic acid by a series of reactions, and the three carbon atoms of the pyruvic acid that were fed into this cyclic mechanism at last appear as carbon dioxide. This "mill", which oxidizes not only glucose but also fat and amino acid molecules previously broken down to acetic acid, is known as the Krebs' citric acid cycle. It was first postulated by Sir Hans Krebs in 1937 in one of the great landmarks of modern biochemistry and honored by a Nobel Prize in 1953.

Although the Krebs' cycle accounts for the oxidation of the lactic acid to carbon dioxide, it alone does not explain how the large amount of energy remaining in these molecules is extracted in useful form. The process of energy recovery that accompanies the action of Krebs' cycle has been an intensively active field of investigation in recent years. While the over-all picture can be described with some assurance, there are many details yet to be solved. In the course of the cycle, it appears, electrons are extracted from the intermediates by enzymes and fed into a series of electron-carrier molecules, collectively called the respiratory chain. This chain of enzymes is the final common pathway of all electrons removed from foodstuff molecules during biological oxidation. At the last link in the chain, the electrons combine with oxygen to form water. The breakdown of foodstuffs by respiration therefore in essence reverses the process of photosynthesis in which electrons are removed from water to form oxygen. Moreover, it is striking that the electron carriers in the respiratory chain bear many chemical similarities to those of the corresponding chain in photosynthesis. They contain, for example, riboflavin and cytochrome structures similar to those in chloroplasts.

As in photosynthesis, the energy of the electrons passing along the chain to oxygen is tapped off and used to drive the coupled synthesis of ATP from ADP and phosphate. Actually this respiratory chain phosphorylation, or oxidative phosphorylation, is better understood than the recently discovered photosynthetic phosphorylation. One thing known for certainty is that there are three points along the chain at which ATP is recharged. For each pair of electrons split from lactic acid in the course of its oxidation in the Krebs' cycle, therefore, an average of three molecules of ATP are formed.

From the total yield of ATP molecules it is now possible to calculate the thermodynamic efficiency with which the cell extracts the energy made available by the oxidation of glucose. The preliminary splitting of glucose to two molecules of lactic acid yields two molecules of ATP. Each molecule of lactic acid in turn delivers ultimately six pairs of electrons to the respiratory chain. Since three molecules of ADP are "charged up" to ATP for each pair of electrons traversing the chain, 36 molecules of ATP are formed in the respiratory process proper. On the rough estimate of 10,000 calories each, the 36 molecules incorporate in their phosphate bonds some 360,000 of the 390,000 calories contained in the original gram molecule of glucose. The efficiency of the combined processes of glycolysis and respiration can therefore be

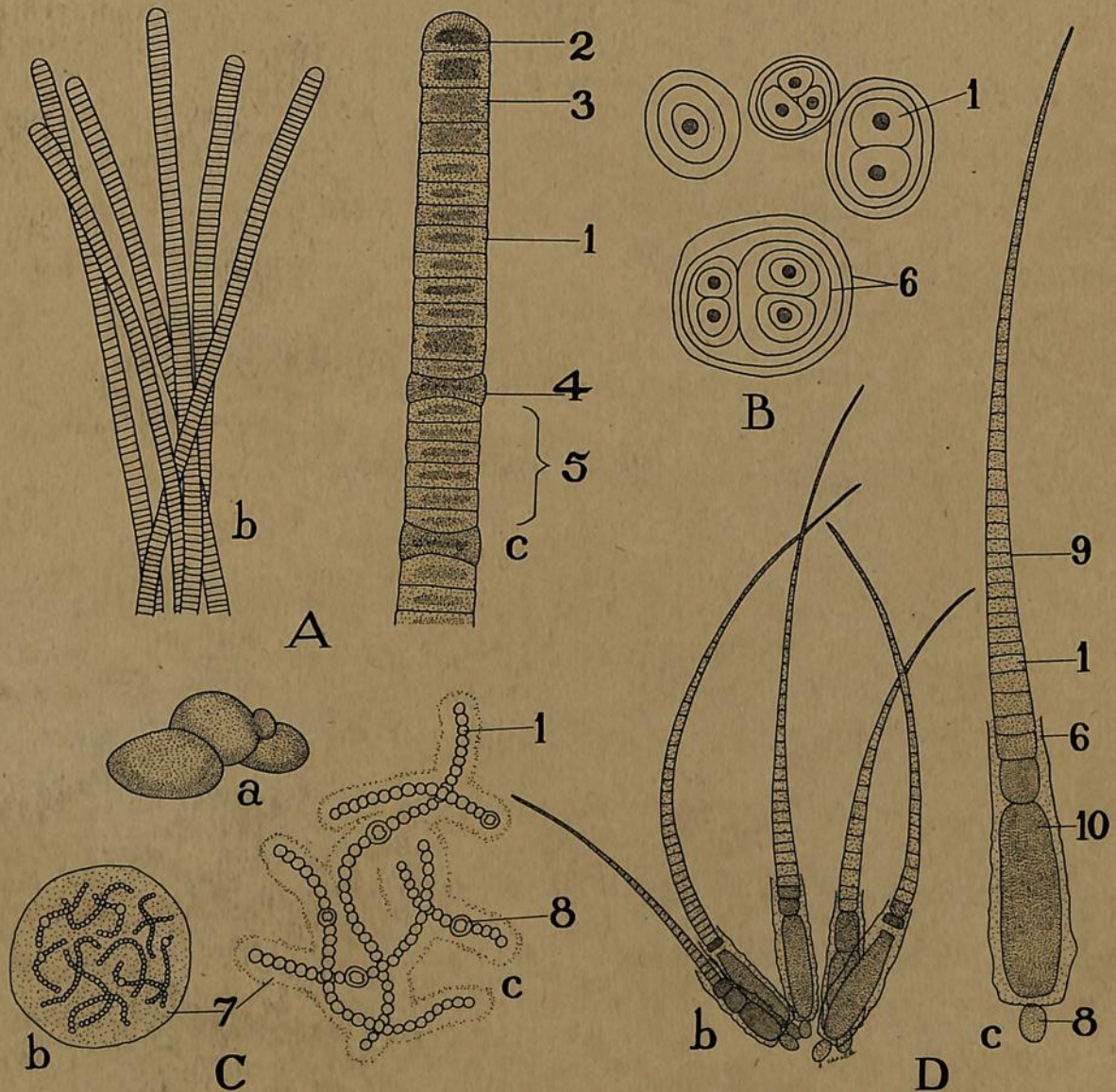
estimated as a minimum of 55 per cent.

The intricacy of the respiratory process in particular suggests again that the enzymatic machinery involved could not do its work if its component parts were randomly mixed together in solution. Just as the molecular devices of photosynthesis appear to be spatially oriented to one another in the chloroplast, so the organelle of respiration in the cell, the mitochondria, presents the same picture of structured order. There may be anywhere from 50 to 5000 mitochondria in a cell, depending on its type and function. A single liver cell of the rat contains about 1000 mitochondria. They are large enough (three to four microns long) to be seen in the cytoplasm with an ordinary light microscope. But their ultrastructure requires the electron microscope to be seen.

In electron micrographs it can be seen that the mitochondrion has two membranes, the inner one occurring in folds in the body of the structure. Recent research on mitochondria isolated from cells of the liver has shown that the Krebs-cycle enzyme molecules are located in the matrix, or soluble portion of the inner contents, but the respiratory chain enzymes, in the form of molecular "assemblies" are located in the membranes. The membranes consist of alternating layers of protein and lipid (fatty) molecules, just as do the membranes of the grana of the chloroplasts. Indeed, there is a remarkable similarity in the structure of these two fundamental power plants of all cellular life, one capable of capturing solar energy in ATP and the other of transforming the energy of foodstuffs to ATP energy.

Modern chemistry and physics have recently been able to specify the three-dimensional structure of certain large molecules, such as those of proteins and of DNA, the molecules that carry genetic information. The next great step in cell research is to find out how the large enzyme molecules, themselves proteins, are arranged together in the mitochondrial membranes, together with the lipids, so that each catalyst molecule is properly oriented and therefore able to react with the next one in the working assembly. The "wiring" diagram of the mitochondrion is already clear!

If the classical engineering science of energy transformation is humbled by what is now known about the power plants of the cell, so are the newer and more glamorous branches of engineering. The technology of electronics has achieved amazing success in packaging and miniaturizing the components of a computer. But these advances still fall short of accomplishing the unbelievable miniturization of complex energy-transducing components that has been perfected by organic evolution in each living cell.



A. Oscillatoria
B. Gleocapsa
C. Nostoc
D. Gleotrichia

a. Colony
b. Group of filaments
c. Detail of filament

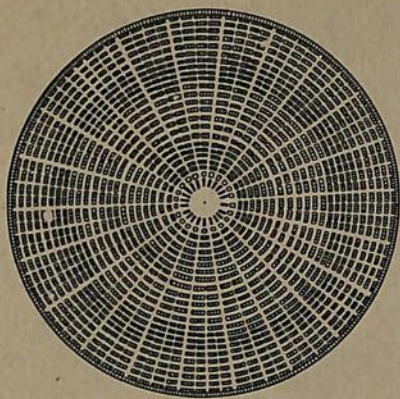
1. Vegetative cell
2. Apical cell
3. Dividing cell
4. Concave cell
5. Horomogonium
6. Gelatinous sheath
7. Gelatinous matrix
8. Heterocyst
9. Trichome
10. Akinete (spore)

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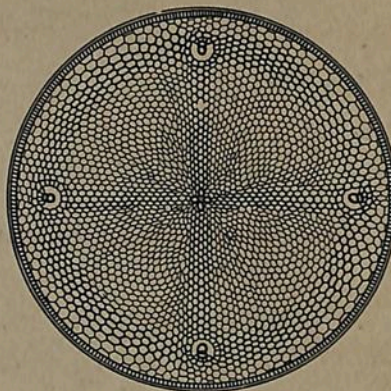
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A



B



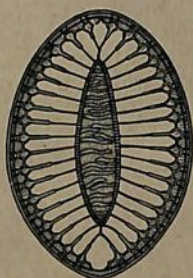
C



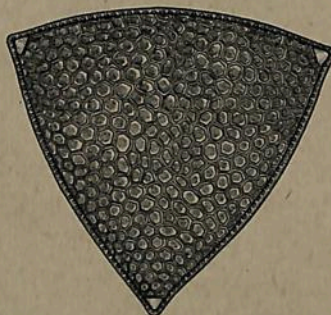
D₁



D₂



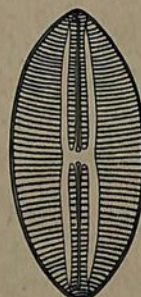
E



F



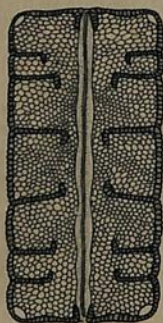
H₂



G



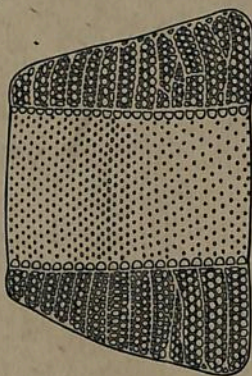
H₁



I₁



I₂



J



K



L₁

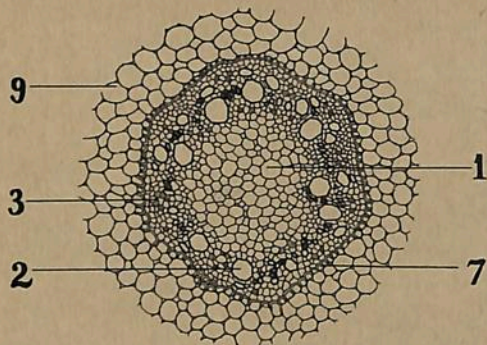


L₂

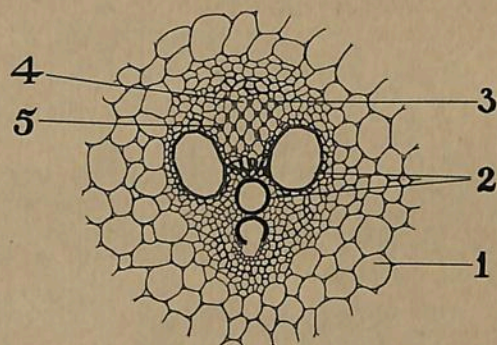
- A. *Arachnoidiscus ehrenbergii*
 B. *Pinnularia nobilis*
 C. *Aulacodiscus janischii*
 D1. *Amphipleura lindheimeri*
 D2. A. *lindheimeri*, enlarged detail of sculpture
 E. *Surirella fastuosa*
 F. *Triceratium fавus*
 G. *Navicula lyra*

- H1. *Pleurosigma angulatum*
 H2. P. *angulatum*, enlarged detail of sculpture
 I1. *Terpsinoe intermedia*
 I2. T. *intermedia*, girdle view
 J. *Isthmia nervosa*
 K. *Climacosira mirifica*
 L1. *Biddulphia rigida*
 L2. *Biddulphia rigida*

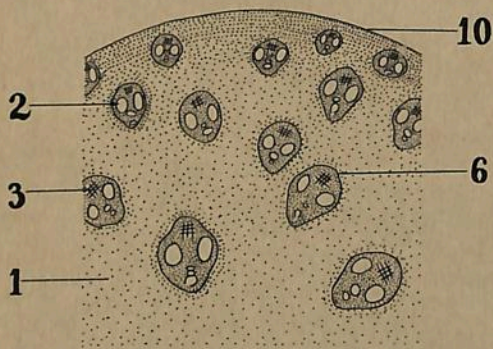
TURTOX KEY CARD
for
Monocot Stem Anatomy



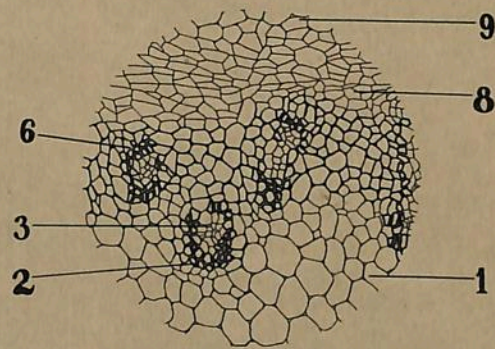
A



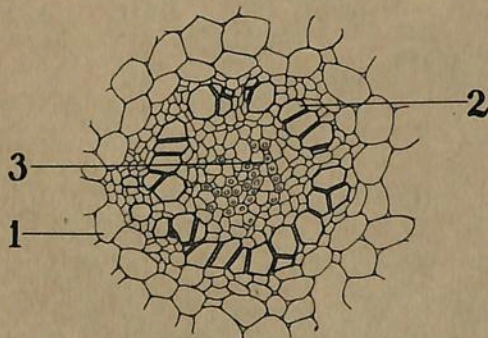
B



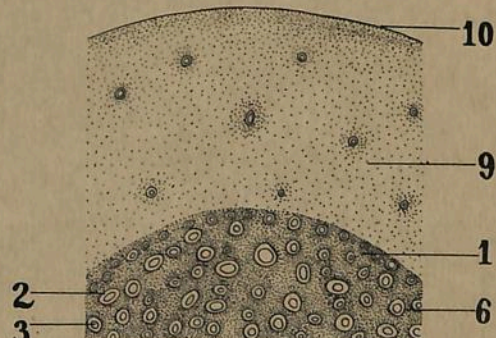
C



D



E



F

- A. Stele of young stem of Corn
B. Bundle from mature stem of Corn
C. Diagram of part of mature stem of Corn showing position of bundles
D. Portion of stem of Aloe showing growth ring
E. Bundle of Acorus
F. Diagram of portion of stem of Acorus showing position of bundles

1. Pith
2. Xylem
3. Phloem
4. Sieve tube
5. Companion cell

6. Bundle
7. Endodermis
8. Growth ring
9. Cortex
10. Epidermis

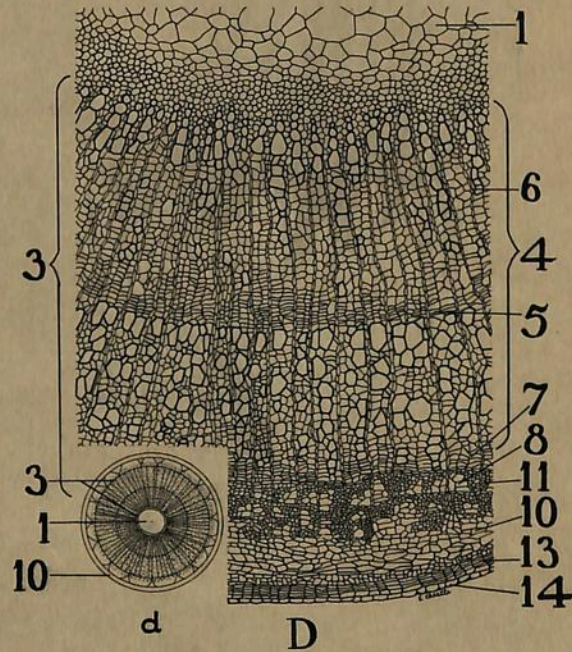
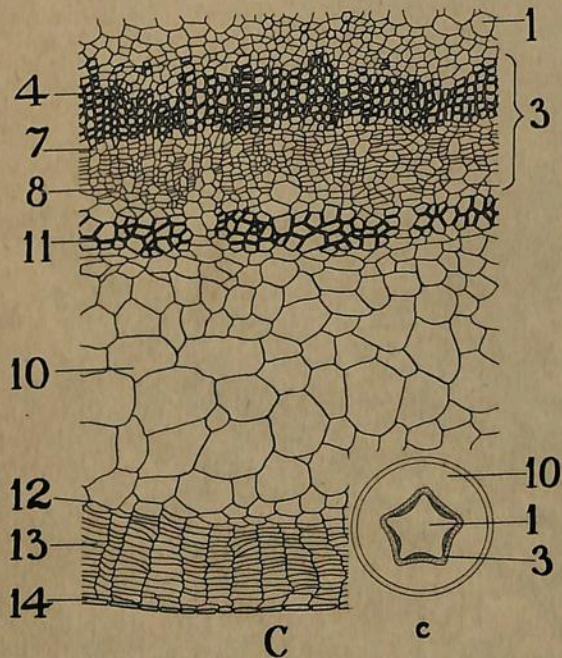
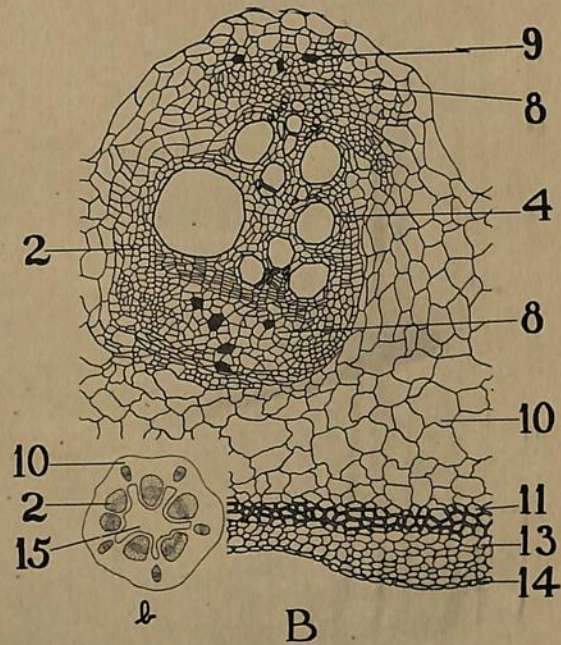
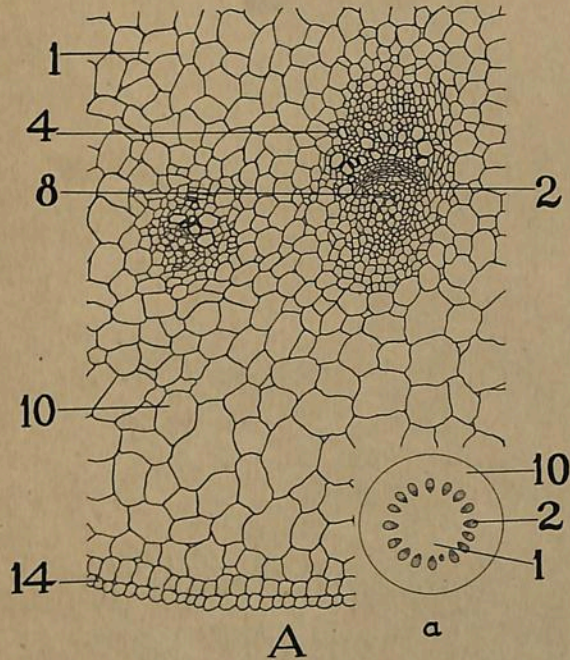


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TURTOX KEY CARD
for
Dicot Stem Anatomy



- A. Ranunculus, detail of portion of stem showing bundle
a. Diagram of complete stem
B. Cucurbita, detail of portion of stem showing bundle
b. Diagram of stem
C. Pelargonium, detail of portion of stem showing part of stele
c. Diagram of stem
D. Tilia, detail of portion of stem showing part of stele
d. Diagram of stem

- | | |
|---------------------------|-----------------------|
| 1. Pith | 9. Sieve plate |
| 2. Fibrovascular bundle | 10. Cortex |
| 3. Fibrovascular cylinder | 11. Mechanical tissue |
| 4. Xylem | 12. Cork cambium |
| 5. Annual ring | 13. Cork |
| 6. Xylem ray | 14. Epidermis |
| 7. Cambium | 15. Cavity |
| 8. Phloem | |



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Subject No. 8K105
24.61

ESTIMATES: SOME THALLI ± UP TO 200 yrs. OLD. 7 up to 4000 yrs
??

SOME FOLILOSE spp. UP TO 3 FT. DIAM.

SOME FOLILOSE spp. " " 6 FT. LENGTH. } Great Smokies, TENN.

SOME CRUSTOSE spp. in Switzerland EST. HUNDREDS OF yrs OLD.

DATED

LICHENS ON TOMBSTONES GIVE ANOTHER APX. READING.

EFFECT OF ATMOSPHERIC CONTAMINANTS:

Trees in large cities HAVE DEPRAPERATE STERILE
FRAGMENTS. GOOD GROWTH AN INDEX OF CLEAN AIR.

1) SULPHUR FUMES FROM COAL

2) CO FROM CAR EXHAUSTS.

3) PREVENTION OF DEW FORMATION BY HEAT CONVECTION.

is Smog - Pollution

PHYSIOLOGY OF LICHEN COMPONENTS

1) ALGA & FUNGUS MAY BE GROWN SEPARATELY.

FUNGUS SPORES ARE DIFFICULT TO GERMINATE, HOWEVER -

15-18°C. PERHAPS BEST, BUT SOME PREFER HIGHER TEMP.

2b. Graphis scripta GROWS BETTER AT 25°C. THAN AT 20°

2) pH REQUIREMENTS DIFFER WITH spp. I pH 2-6.9

3) N₂, C, VITAMINS SOURCES, MINERALS NOT SUFFICIENTLY STUDIED.

4 ORDERS of Ascolichens recognized:

Calicales: Most closely related to Eurotales; esp.

cleistothecia →

Onygenaceae, ie Asci disintegrate early, forming a maezidium (mass of ascospores together with sterile elements, surrounded by a peridium).

PYRENOLICHENS }

Pyrenulales: Asci in perithecia. as in Sphaerales & Hypocreales.
zb. Verrucariaceae & Dermatocarpaceae.

Graphidiales: Hysteriales typical; zb. Graphidiaceae; Graphis sp. well developed proper exciple.

DISCOLICHENS }

Lecanorales: about 75% of lichens. Apothecia produced as in discs. ← Halotiales Pezizales Phycia, Tolouhites, Uncia

Basidiolichens a small group (4 genera); most closely related to Thelephoraceae. zb. Cora, Dictyonema, CONELLA

Lichens with Fungi Imperfecti

✓ Reproduction

Vegetative:

- 1) Fragmentation
- 2) Soredia - masses of algal cells + hyphae
- 3) Isidia - small wool-like outgrowths of thallus

Sexual:

Perithecia / Apothecia.

Ascogonium, trileptogone & non-motile spermatia.

Additional special structures:

Breathing Pores: Consist of branched pores forming intracellular canals. Can be closed when thallus is dry, opened when wet; especially in lower cortex, containing many algal cells; in thin spots of thallus.

STRUCTURE OF THE ASCOCARP:

Consists of the following:

- ✓ a) Epithecium: In mature fruiting bodies, a rudimentary structure usually not distinguishable, covering the surface of the ascocarp. When present, it has the same color as the hymenium.
- ✓ b) Hymenium: Lies below the epithecium & contains asci and paraphyses, oriented perpendicular to the surface.
- ✓ c) Thalloid Exciple: Most common in lichens with well developed thallus; ie esp. in foliose forms; most evident in pedicillate (Cladonia) thalli or in sessile ones; Outer layer of the exciple continuous with upper layer of thallus.
- ✓ d) Proper exciple: Originates in the hypothecium (just below the hymenium); (thalloid exciple originates in thallus); Serves as a protective covering around around hymenium;
- ✓ e) Hypothecium: Lies immediately below hymenium, variable in thickness & color;

- ✓ e) Amphithecium: Proper exciple sometimes extends into perithecial wall, a somewhat hyaline layer may separate it ~~for~~ from the hymenium; this is amphithecium
- ✓ f) Paraphyses: Usually cylindrical. transversely septate, branched, longer than asci;
- ✓ g) Spores: Usually 8 per ascus; variously septate or asexual spores;
DICTYOSPORE — MURIFORM
1) SIMPLE
2) SEPTATE
3) POLARILLOCULAR
- ✓ Thecial Algae: Algal cells found in hymenium of some sp.;
Usually associated with immature thalli, and smaller in size than cells of normal thallus; function may be to nourish tissue of ascocarp (Fink).

UNICAT 20R

VERY THICK MEDIAN
WATER. ! APPEAR

2 - covered



Specialized structures found in some thalli:

- ✓ Rhizoids: ventral surface of some foliose thalli; as holdfasts;
RAIZINES colors from white to black.
- ✓ Cilia: Confined to upper surface of thallus; "retain drops of water and gradually absorb them;
- ✓ Umbilicus: attaching organs on ventral side of thalli of species of Gyrophora, Umbilicaria & some Dermatocarpon.
- ✓ Cephalodia: Wartlike bodies on upper surface of thallus; (Peltigera an abnormality containing with alga of diff. apthosa) species FUNCTION? (BLUE-GREEN)
- ✓ Cyphellae: (Pits) in lower surface of some foliose sp. (Sticta sp.) May admit air into thallus; (?) cup-shaped area lined

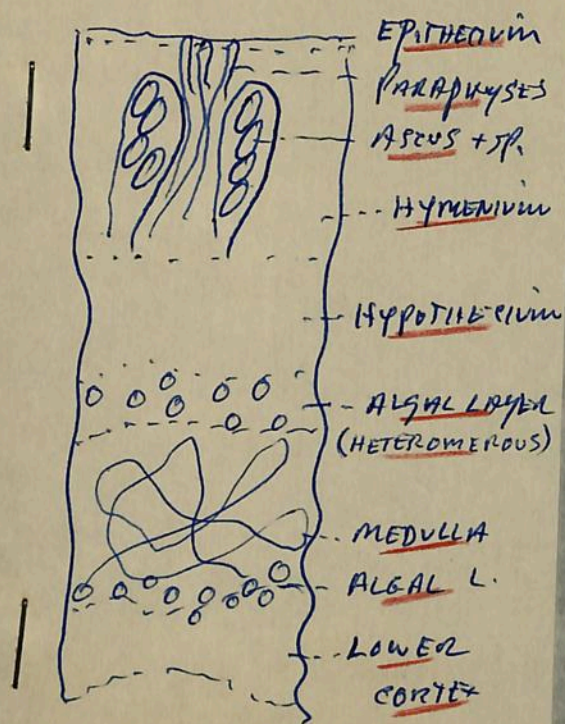
- POWDERY CLUSTERS
TAXONOMIC USEFUL } SORALIA ← with hyphal elements.
 1 } Soredium. Mass of GELATINIZED hyphal filaments and algal cells which break thru ORIGINATE IN ALGAL LAYER.
 2 } (AL-SORALIA) INCLUDE MEDULLA upper cortex; become detached from thallus and form new plant.
- SOREDIA → MEGRO
SORALIA → MACROSCOPIA
Spermatogonia: Spherical bodies sunken in thallus surface, bearing spermatia within them on "sterigmata". Spermatia are non-motile sperm which enters the trichogyne of an ascogonium in sexual reproduction.
- ✓ Isidium: Small coral-like outgrowths from CORTEX OF + MEDULLA thallus, containing algae; asexual reproduction. COVERED BY CORTEX IN 15%. FOLIOSE spp.

Sexual reproduction as in Ascomycetes .. perithecia or apothecia.

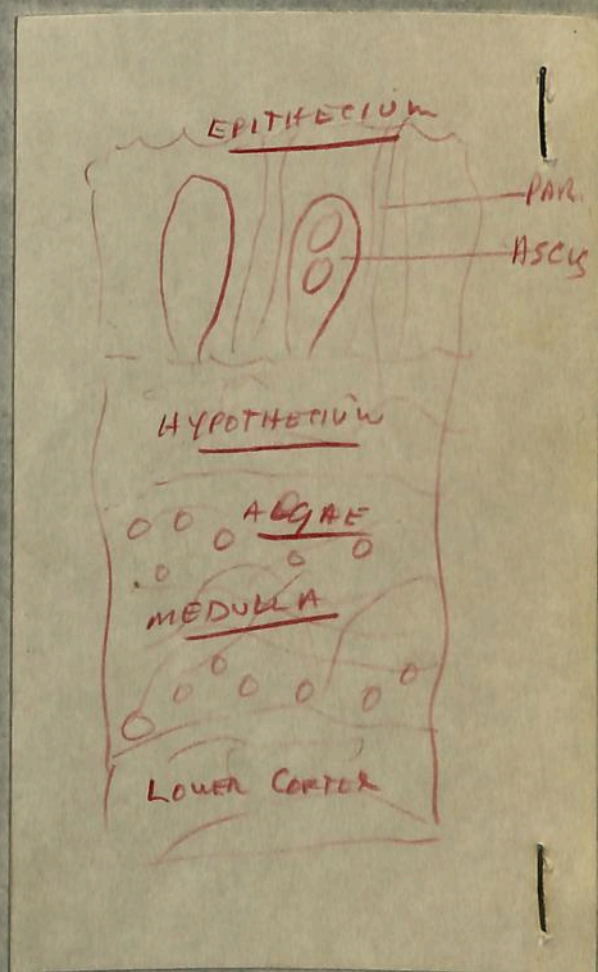
- { Apothecia of two types: genus Biatra
 - ✓ 1.) Biatorine: composed of fungus only and soft & brightly colored. no proper exciple only.
 - (Lecideoid) → 2.) Lecideine (Lecanora): both thalline & proper exciple present. DARK CARAMEL COLORED.
genus Lecidea
- (Asexual reproduction common by fragmentation).

STIPE: ERECT SUPPORTING STRUCTURE WITHOUT ALGAL CELLS.

PODETIUM: WITH ALGAL LAYER
 Podetiumized by the Hunt Institute for Botanical Documentation



Parmelia sp
X. SECT. Apothecium



LICHENS

by I. MACKENZIE LAMB

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