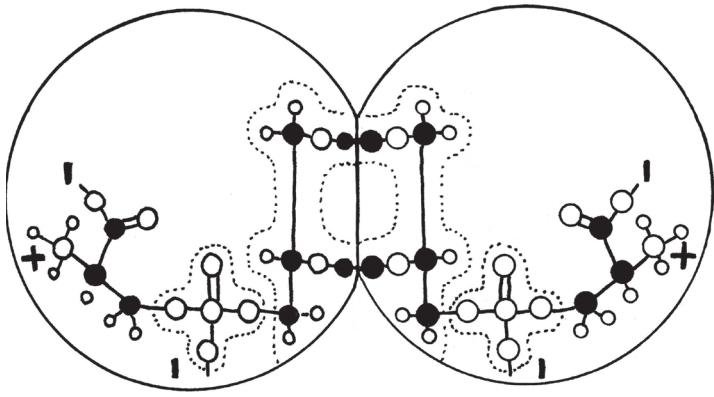
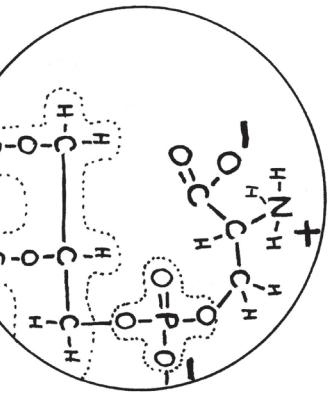
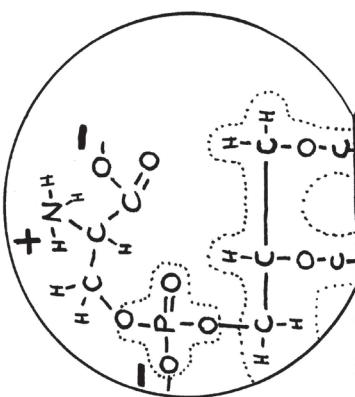
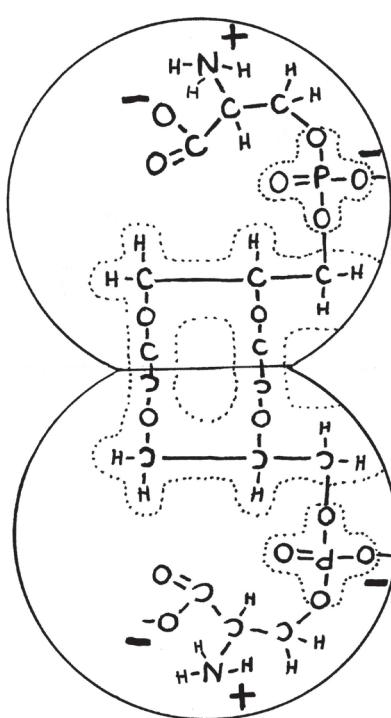
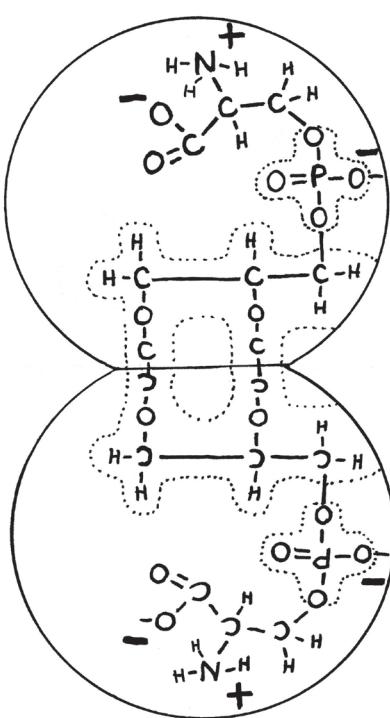
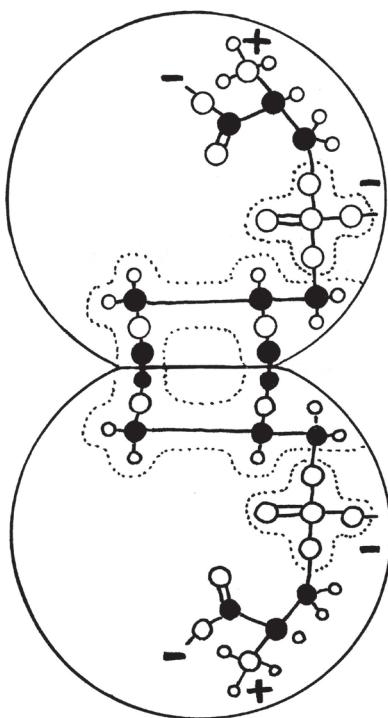
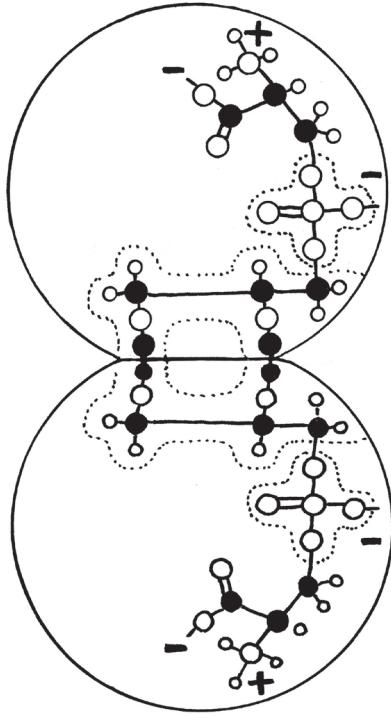
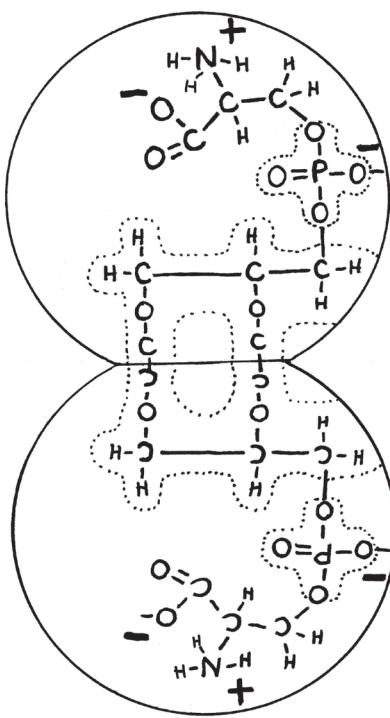
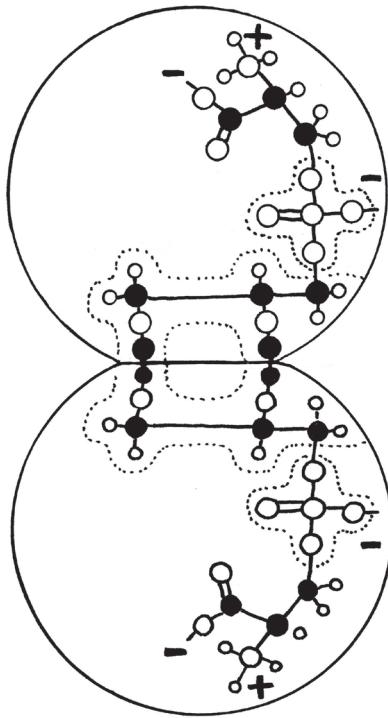
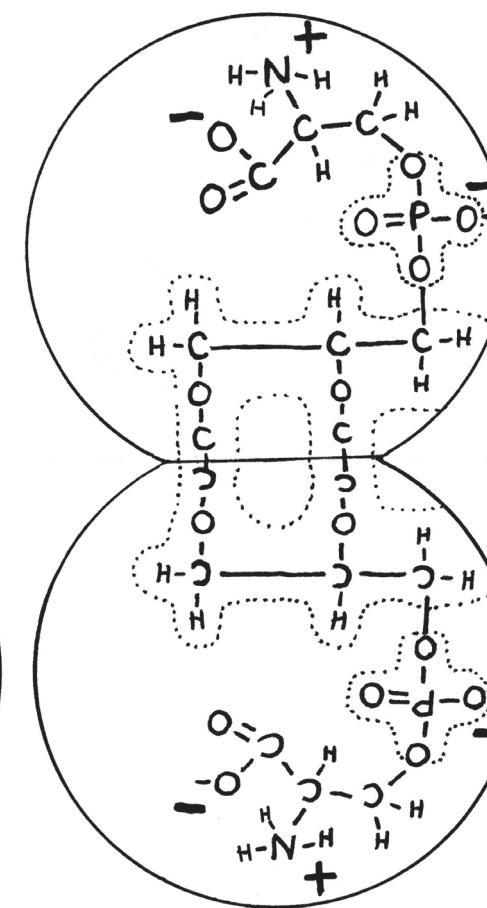
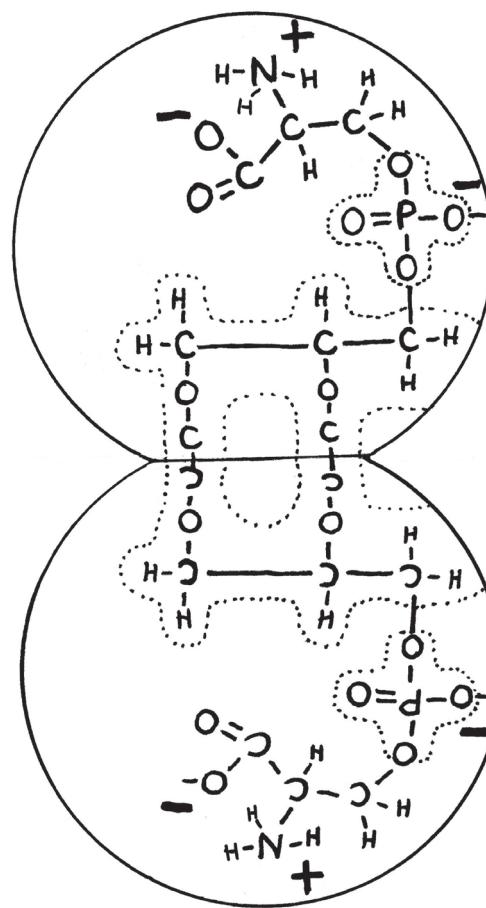
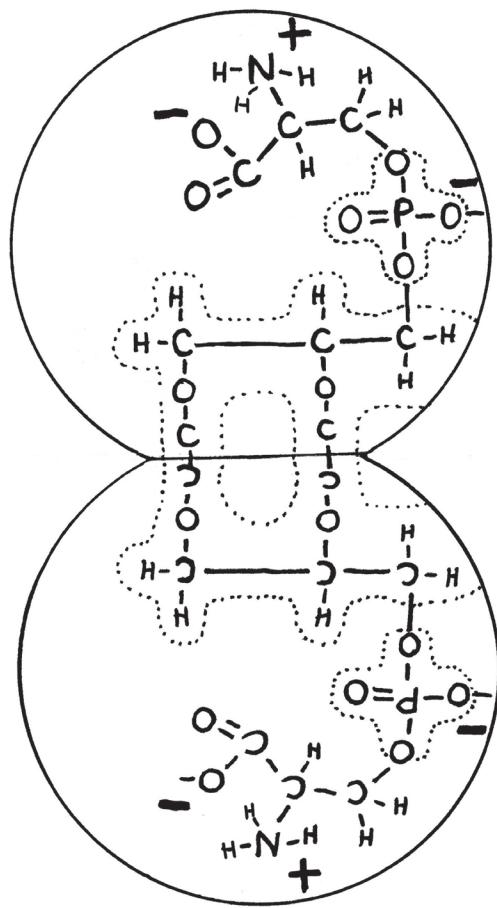
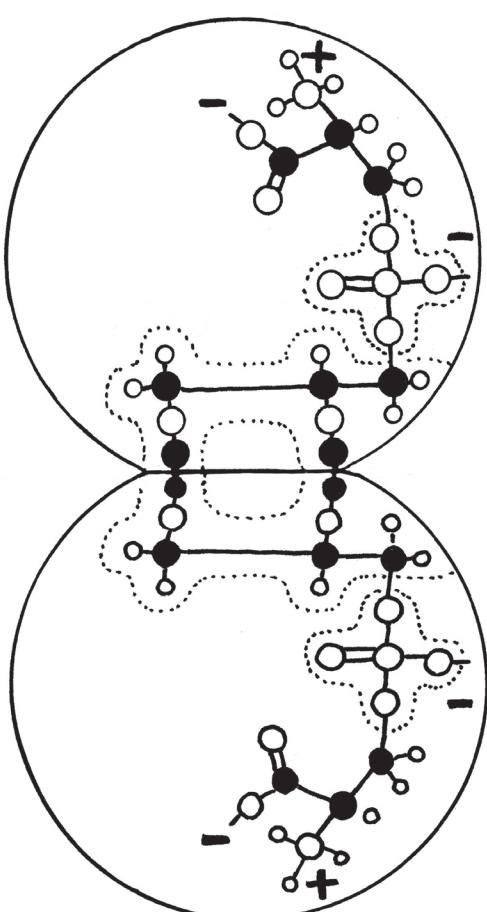
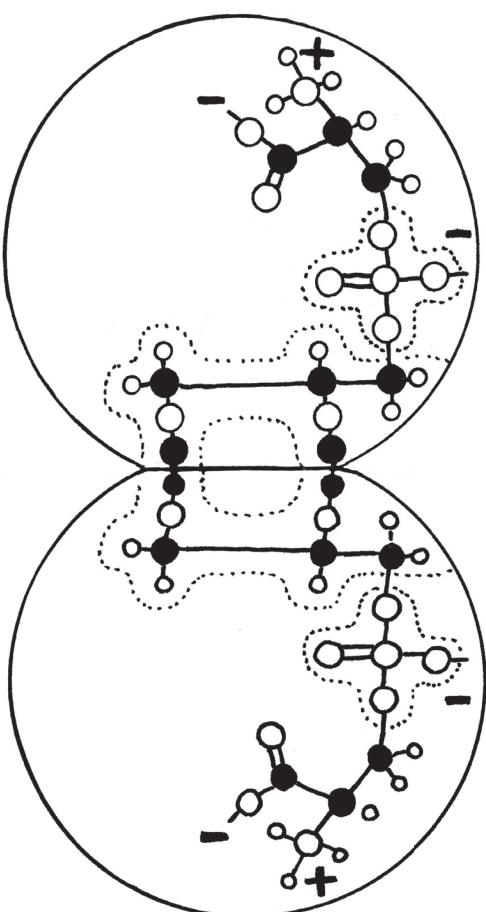
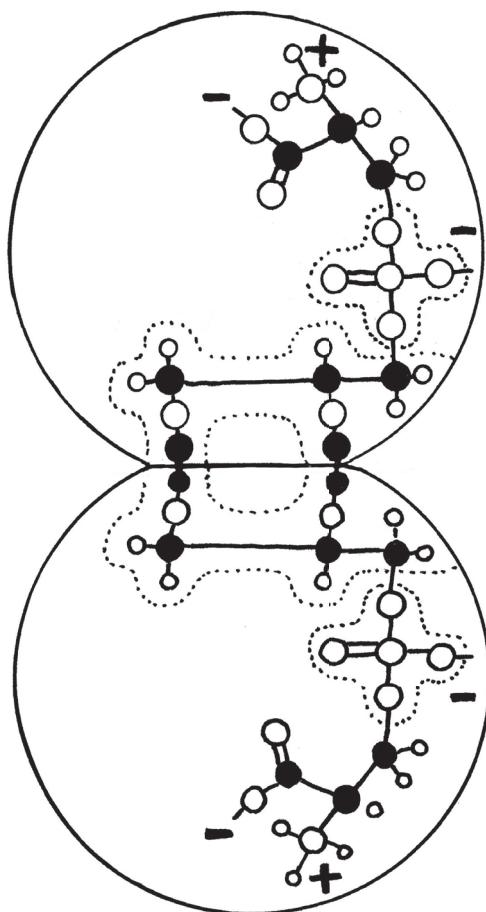


SMALL  
2" dia.

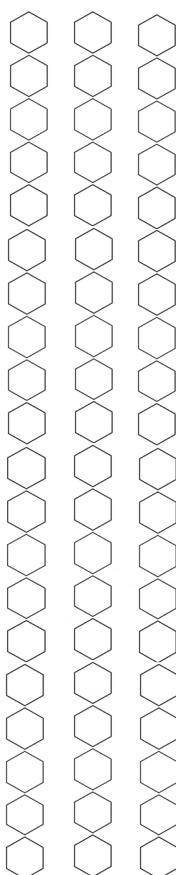
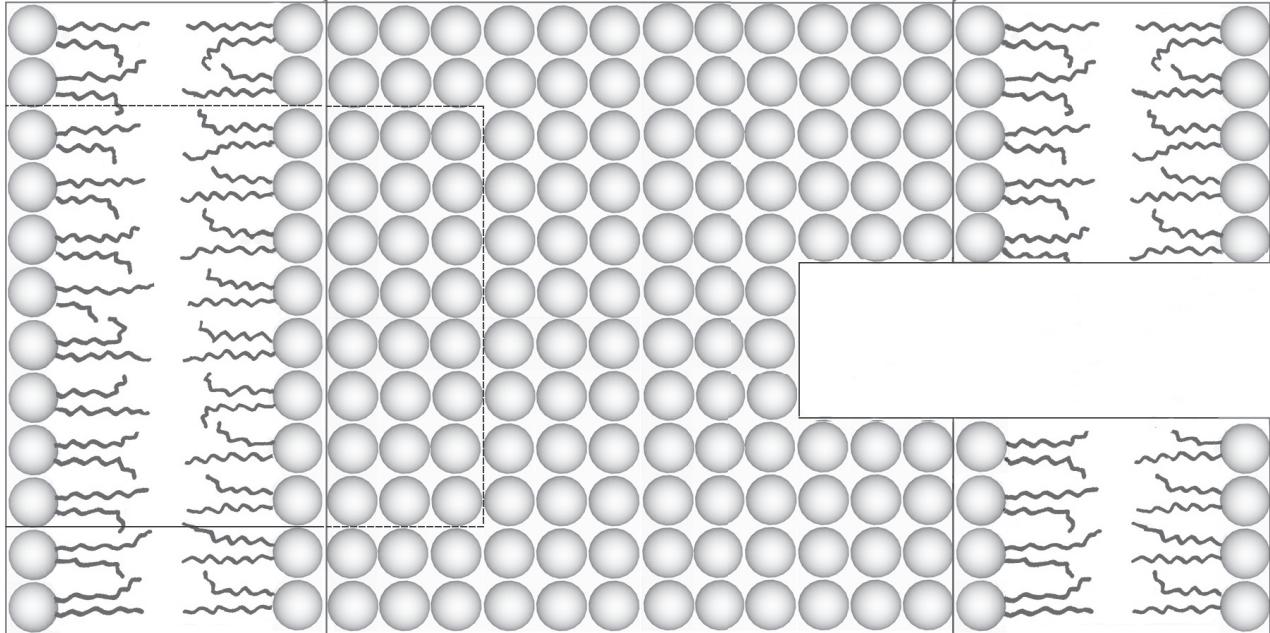
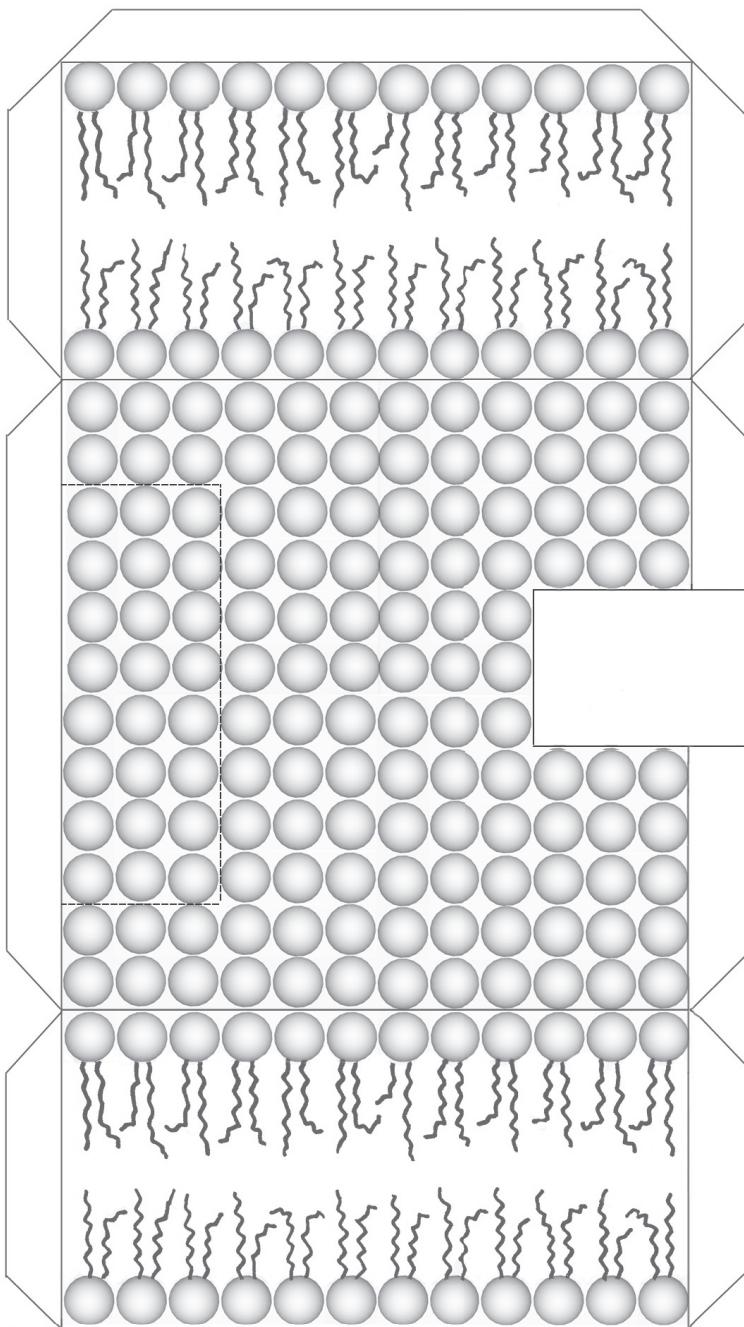


If you need a digital copy of this pattern page, go to [www.ellenjmhchenry.com](http://www.ellenjmhchenry.com), click on FREE DOWNLOADS, then on HUMAN BODY, then scroll down to find "Printable patterns for Cells curriculum."

MEDIUM 2.5" dia.



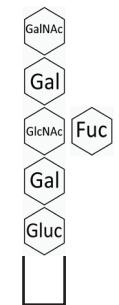
This is a paper stand you can use (as shown in sample photo). You don't have to glue it to the model. The model can simply rest on top of it. Use this corner for the base but use it upside down so the words don't show,



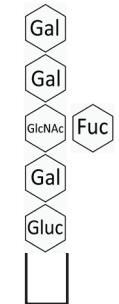
Optional:

ABO  
Blood  
antigens  
(made of  
sugars)

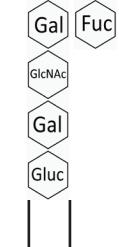
Type A



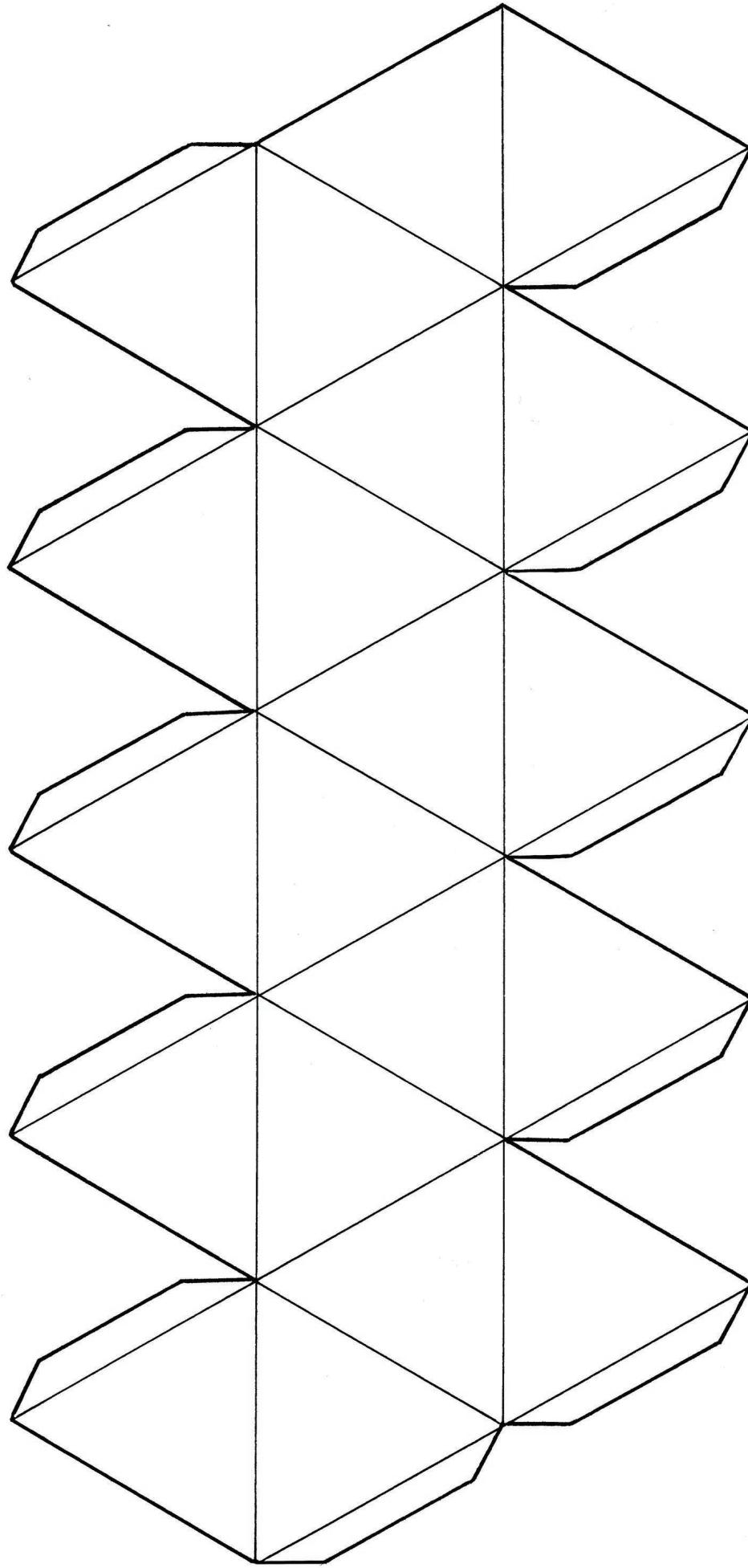
Type B



Type O

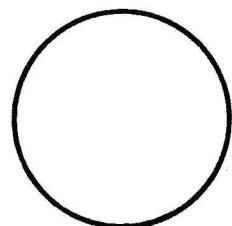
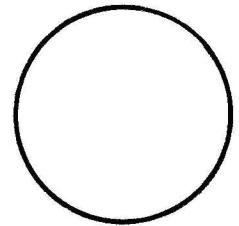


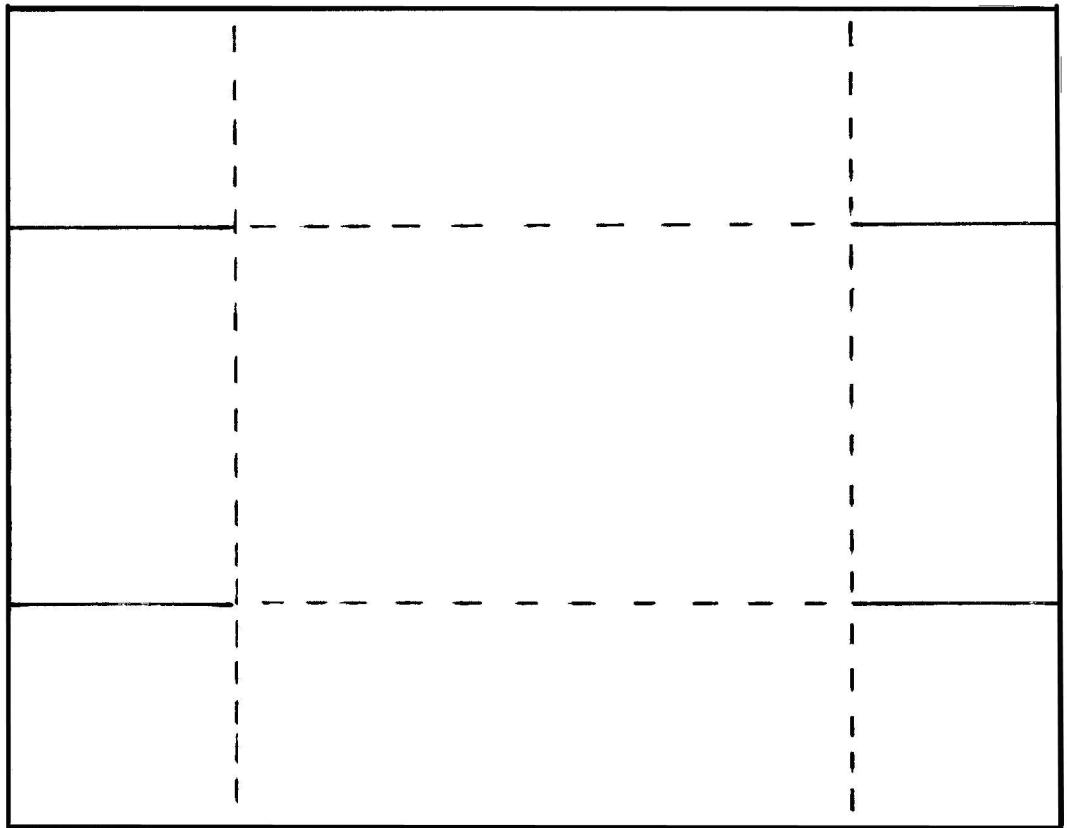
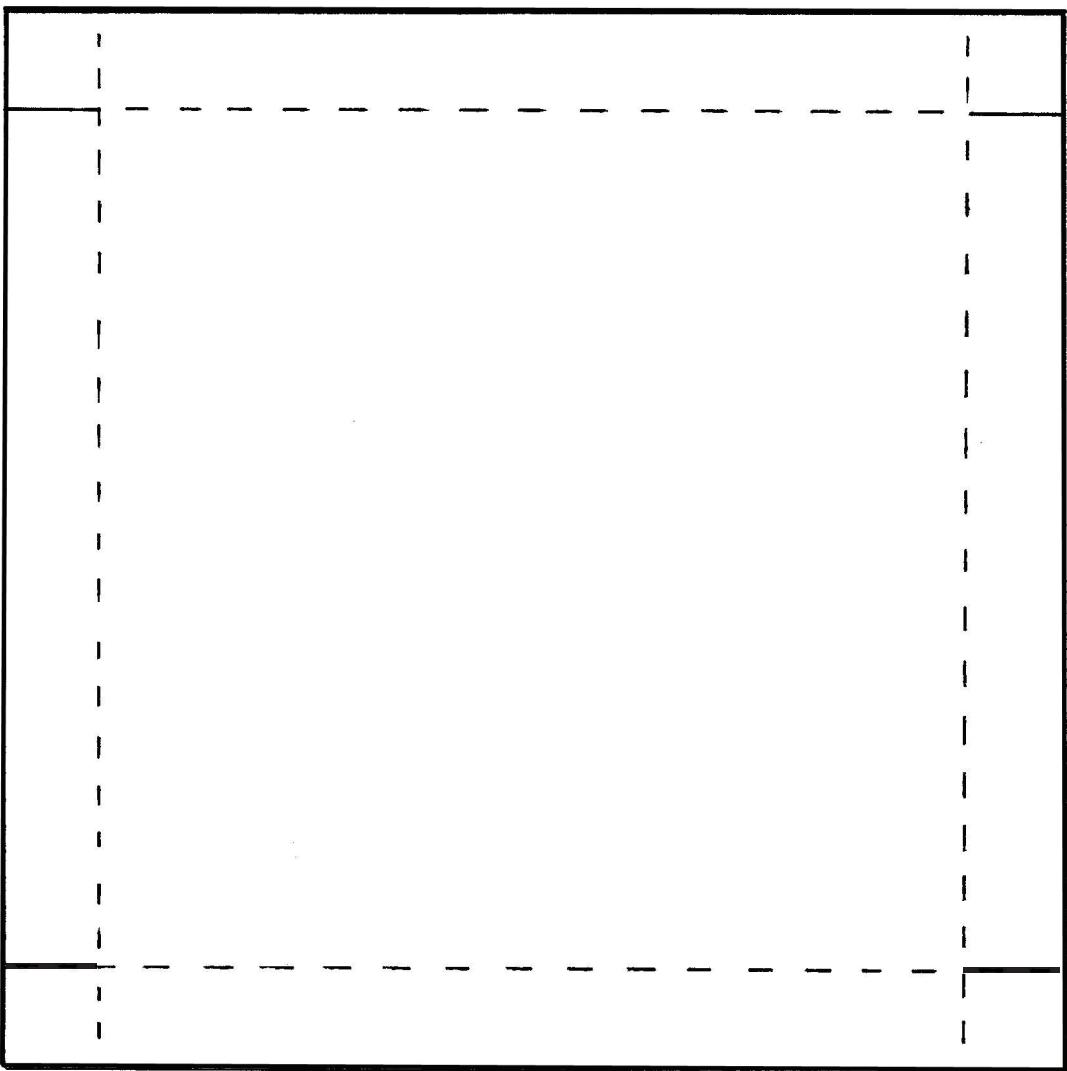
For type AB, use both A and B.



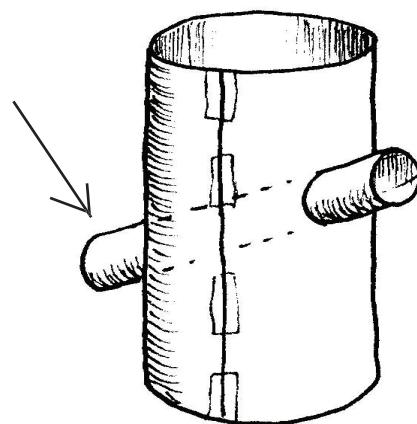
PATTERN for making a paper vesicle  
for motor protein craft if a hollow  
plastic ball is not available.

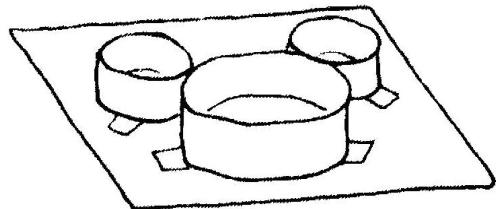
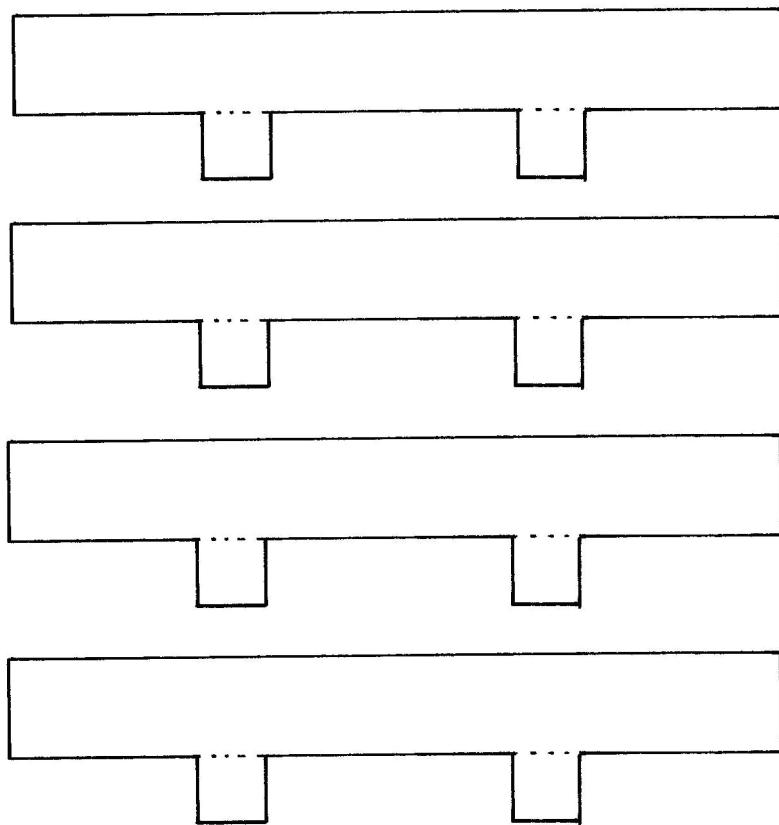
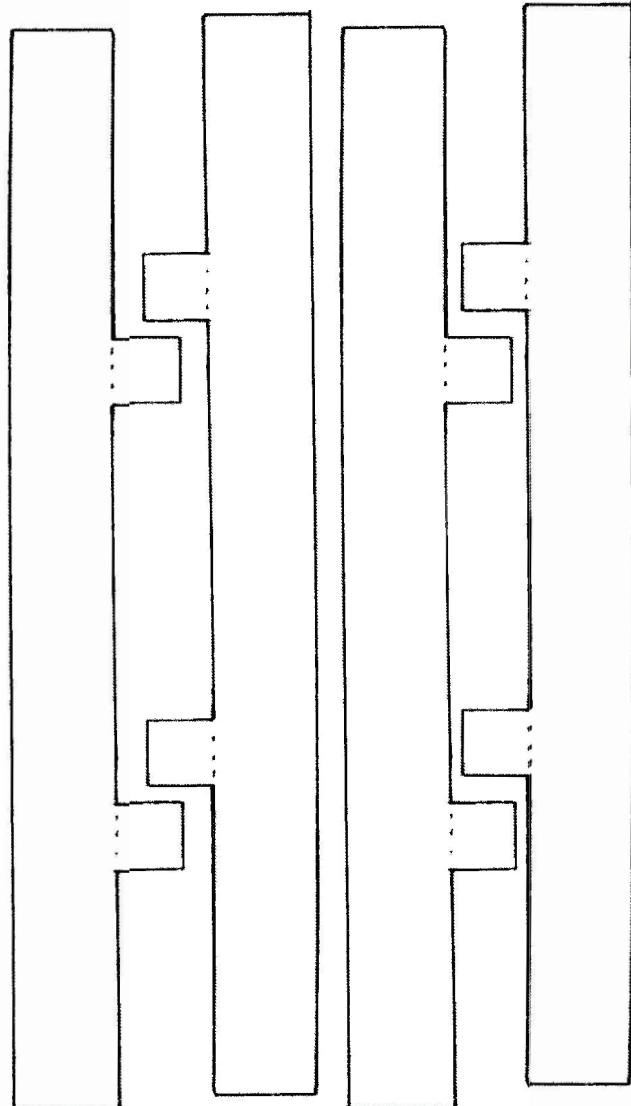
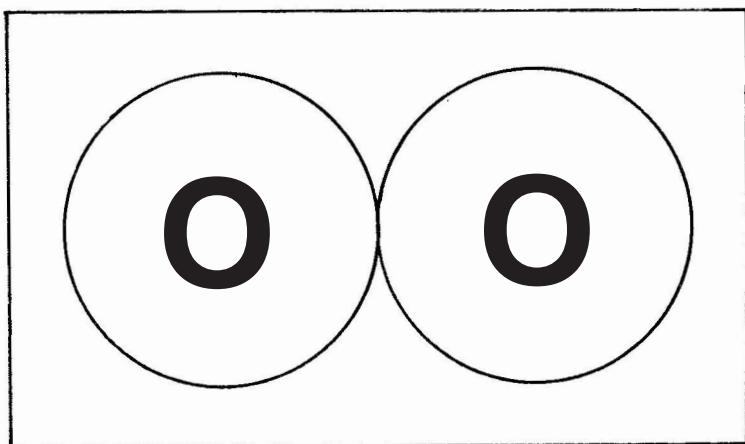
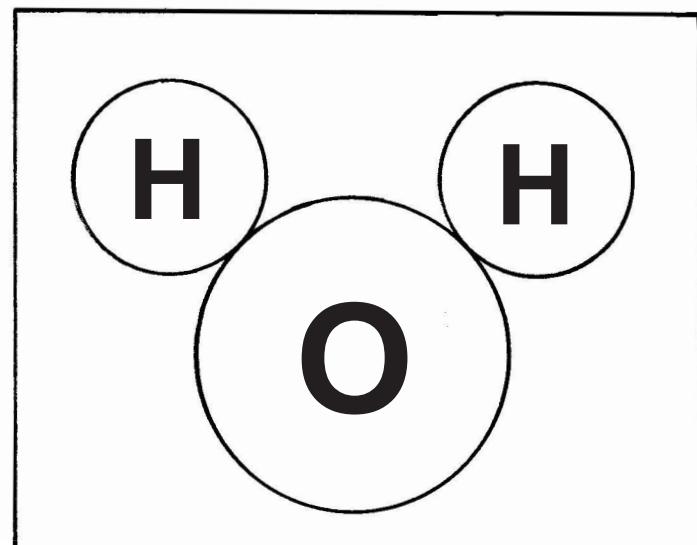
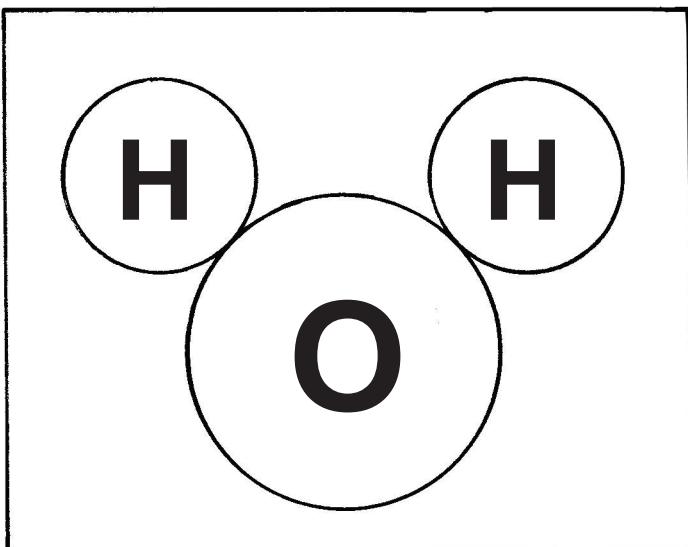
**PRINT ONTO CARD STOCK**





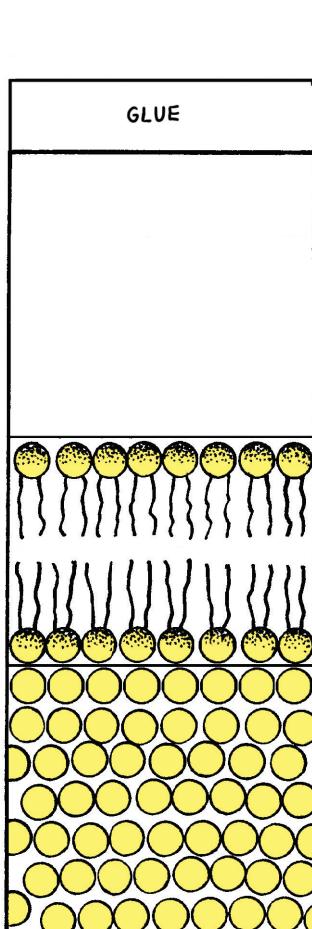
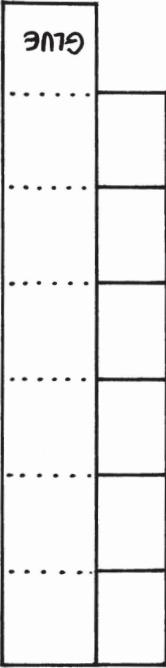
Use these three rectangles for the smaller tubes that insert into the larger tubes. (Roll them lengthwise.)



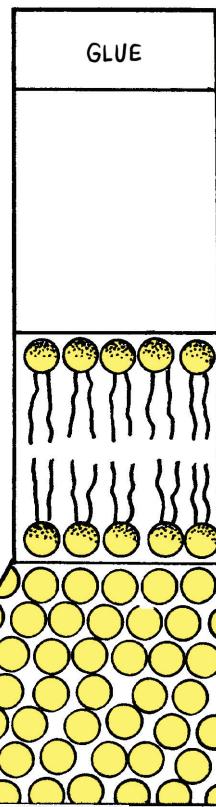


COPY ONTO CARD STOCK

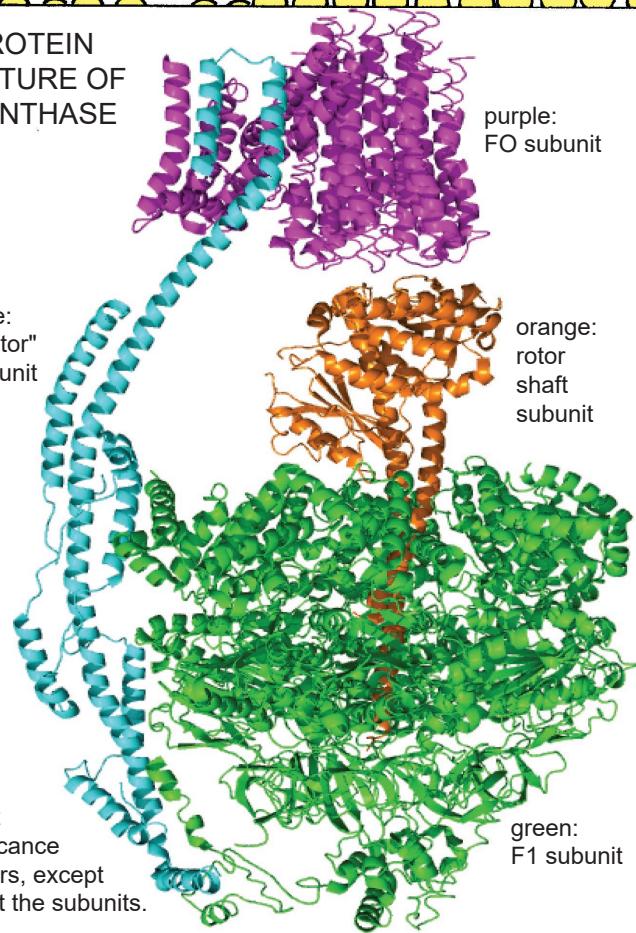
HEXAGON THAT ATTACHES TO FLOOR



BACK WALL AND BILAYER MEMBRANE



THE PROTEIN  
STRUCTURE OF  
ATP SYNTHASE



purple:  
FO subunit

orange:  
rotor shaft  
subunit

green:  
F1 subunit

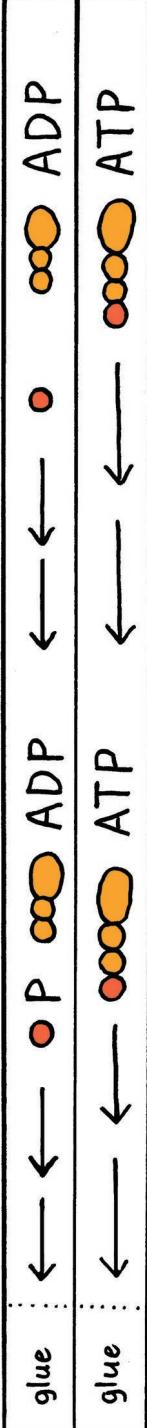
blue:  
"stator"  
subunit

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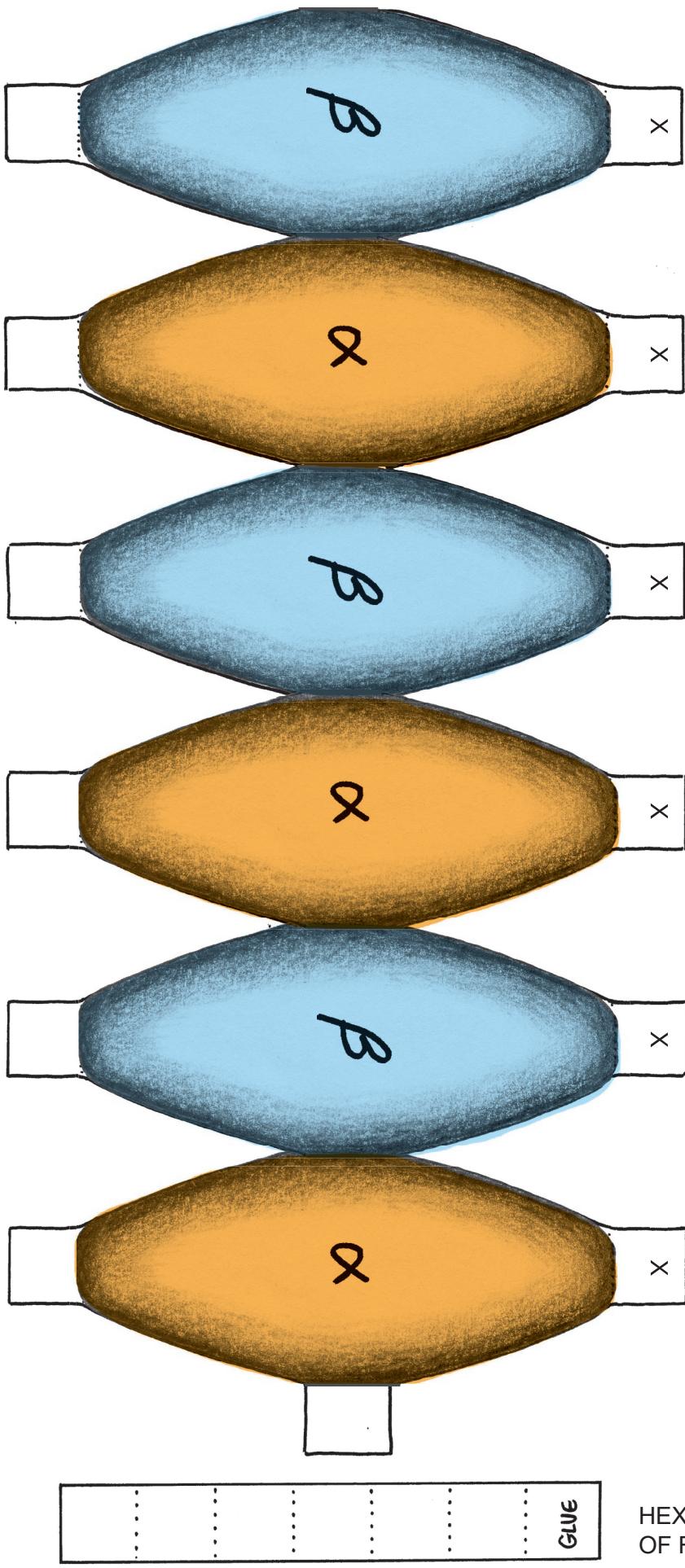
CUT OUT

CUT OUT

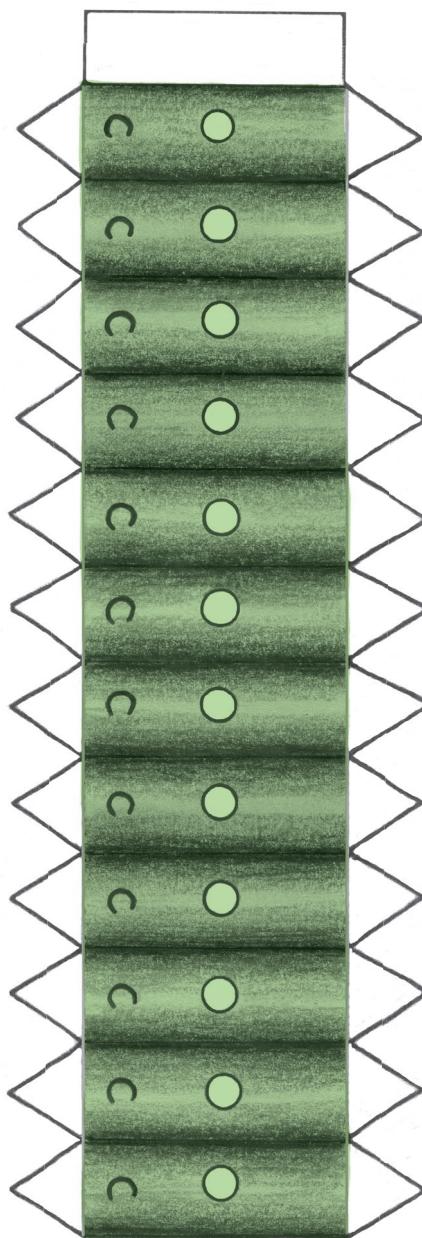
By BioChemEkaterina - Own work, CC BY-SA 4.0, <https://commons.wikimedia.org/w/index.php?curid=59979304>



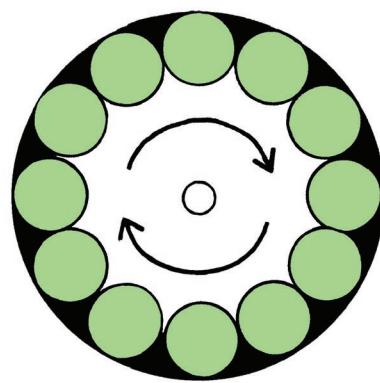
### F1 SPHERICAL SUBUNIT



### COPY ONTO CARD STOCK



CYLINDER PORTION OF F0 SUBUNIT



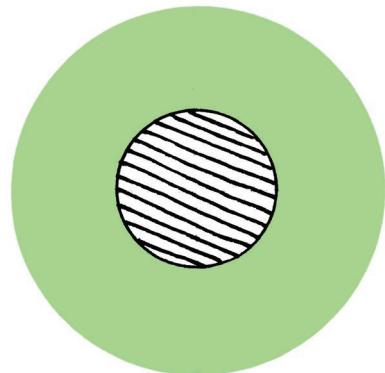
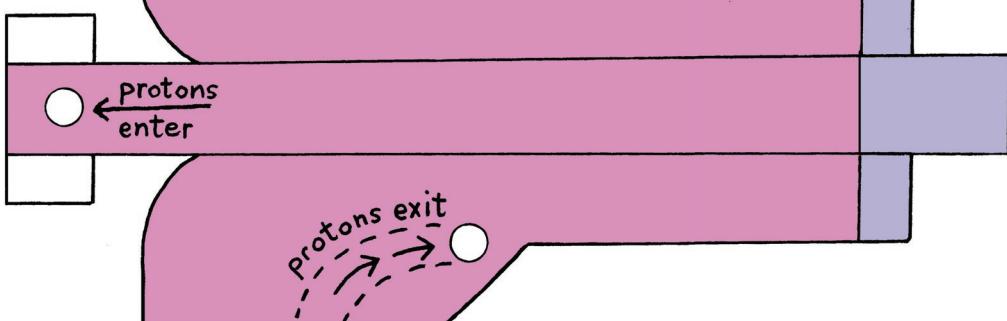
TOP OF F0 SUBUNIT

HEXAGONAL RING FOR TOP  
OF F1 SUBUNIT SPHERE

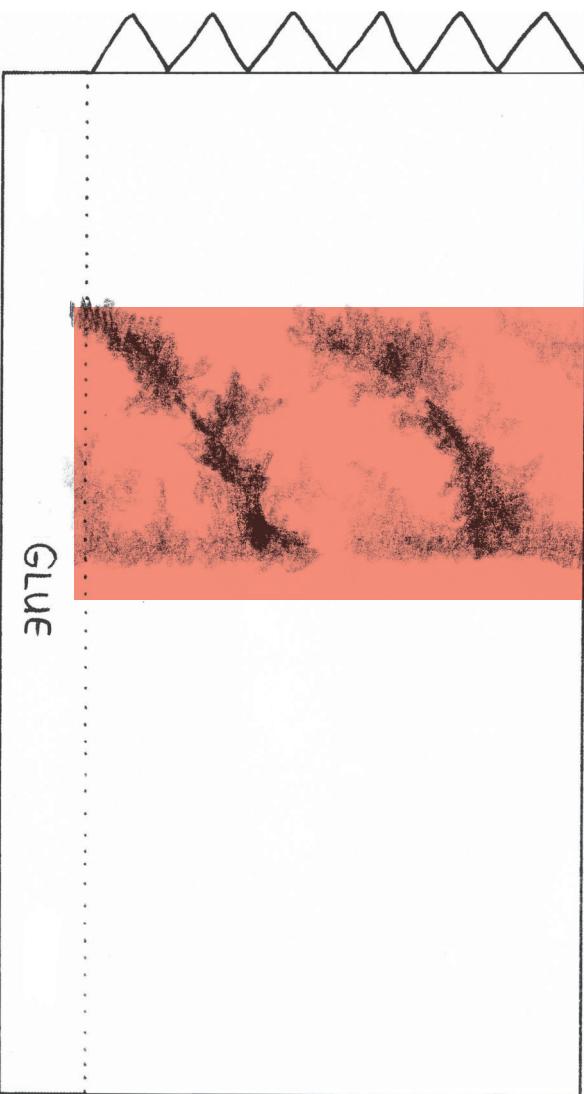
You may want carefully trim off the black lines around the edges of the tabs because they will visible on the floor of the model. If the tabs have no black on them, they will be less visible.

STATOR SUBUNIT

COPY ONTO CARD STOCK



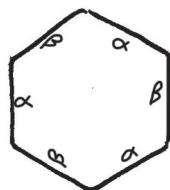
BOTTOM OF STATOR SUBUNIT



3) Pull out the  
recharged ATP.

2) Turn the FO/rotor  
shaft 120 degrees  
clockwise.

1) Push an (ADP + P)  
between an alpha  
and beta subunit.



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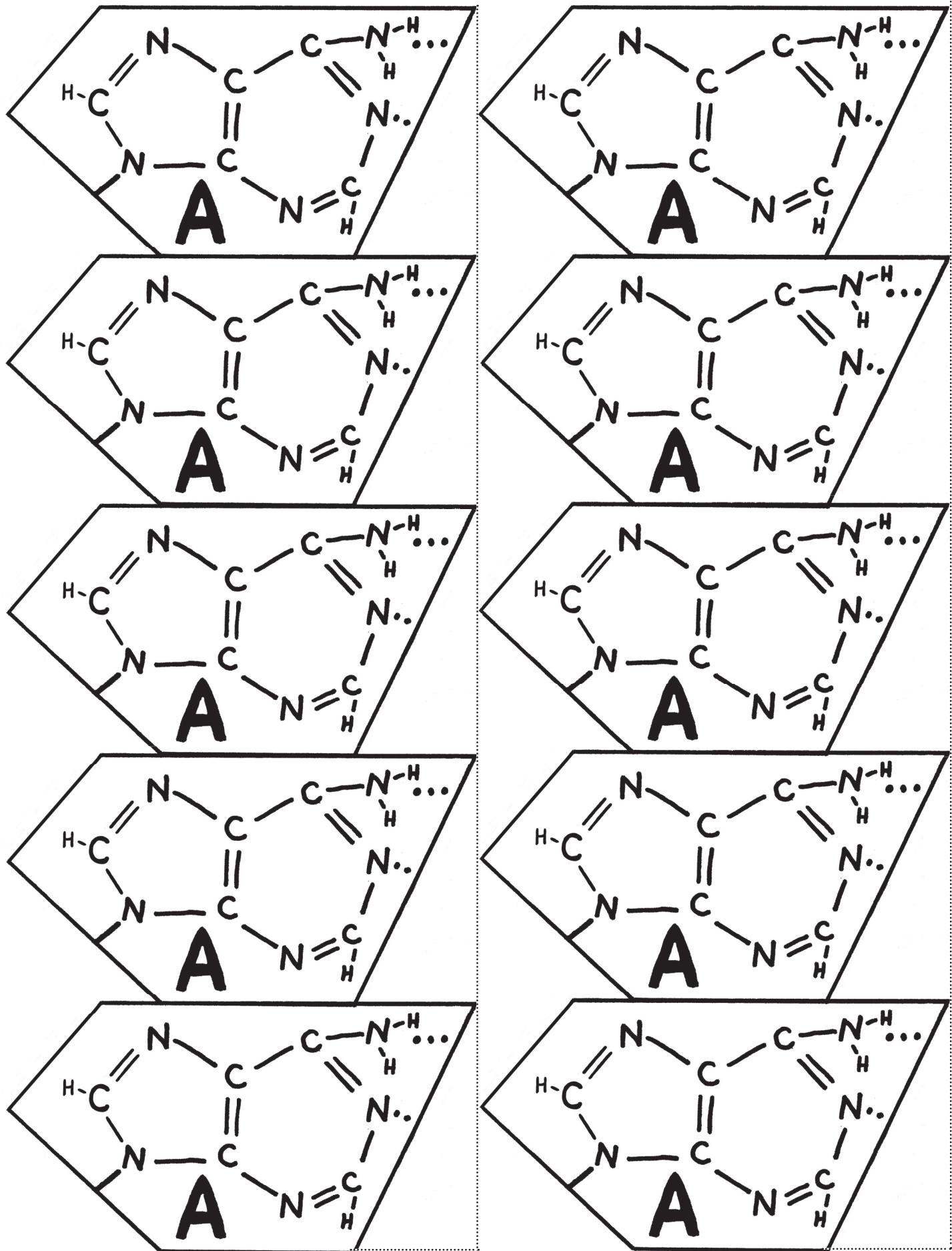
## ATP SYNTHASE

Found in the cristae membranes in mitochondria and in the thylakoid membranes of chloroplasts in plant cells, ATP synthase "recharges" ATP by putting the third phosphate back onto ADP.

ROTOR SHAFT

FLOOR OF MODEL

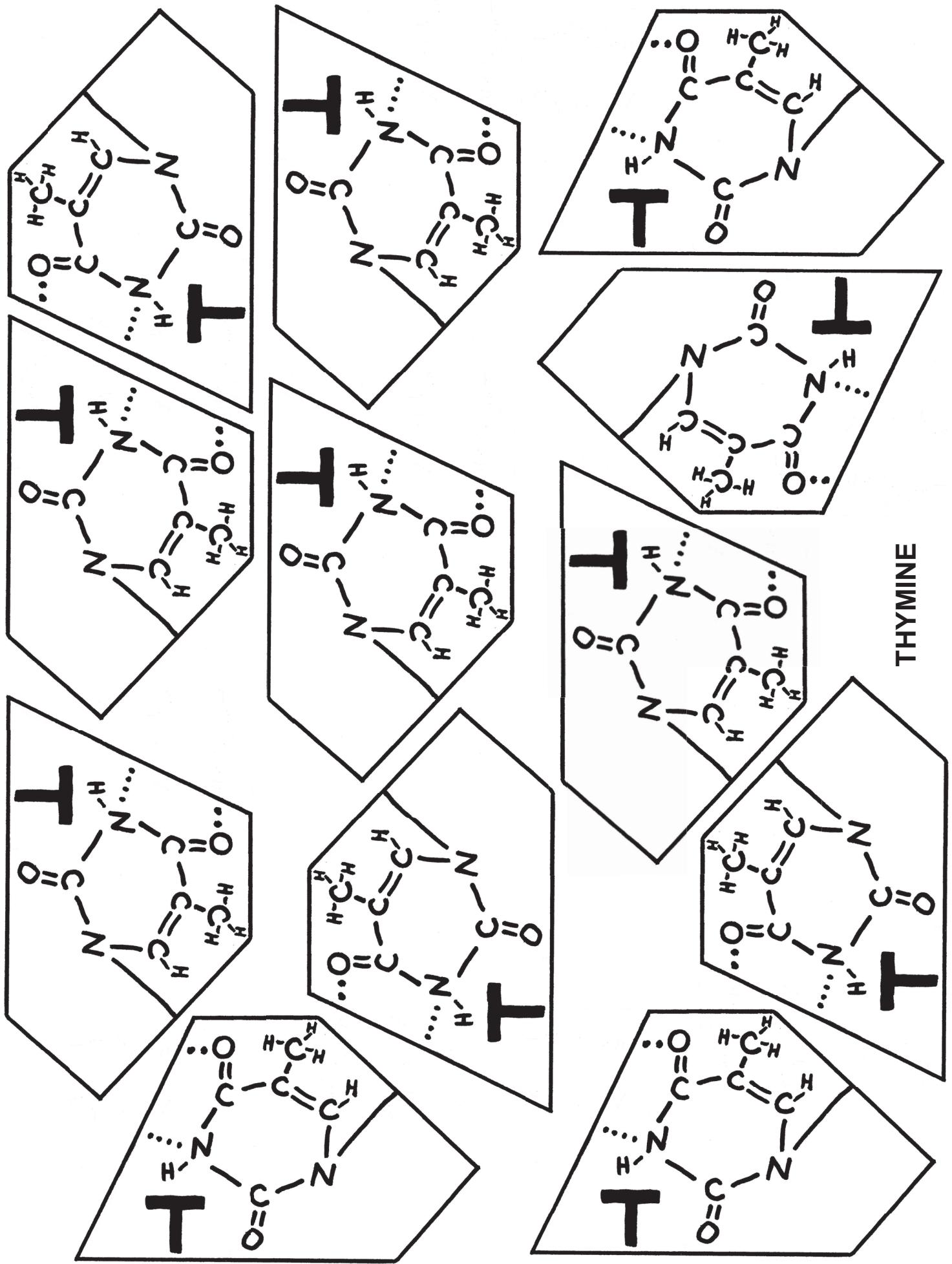
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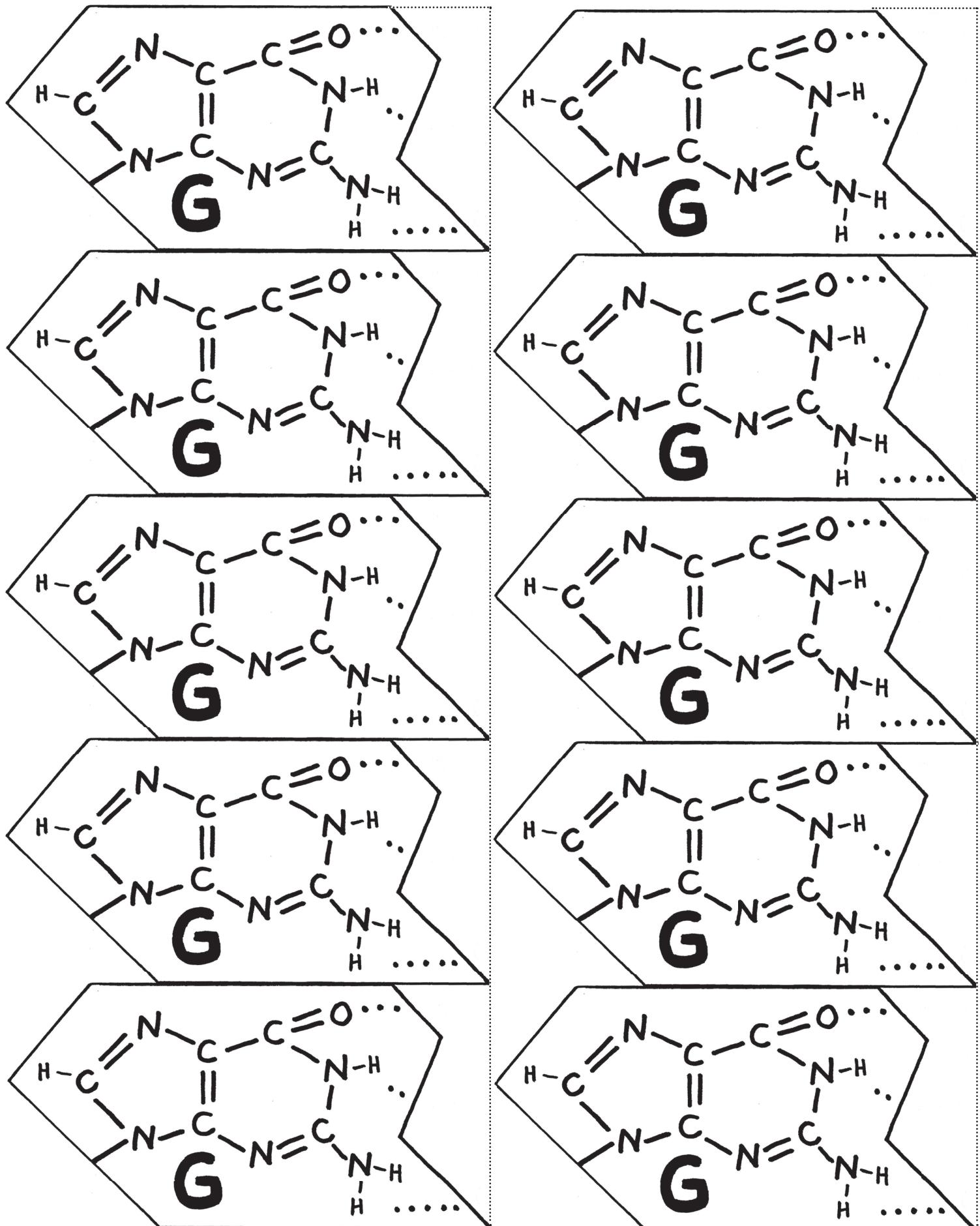


ADENINE

Do not cut off blank triangle area.

THYMINE

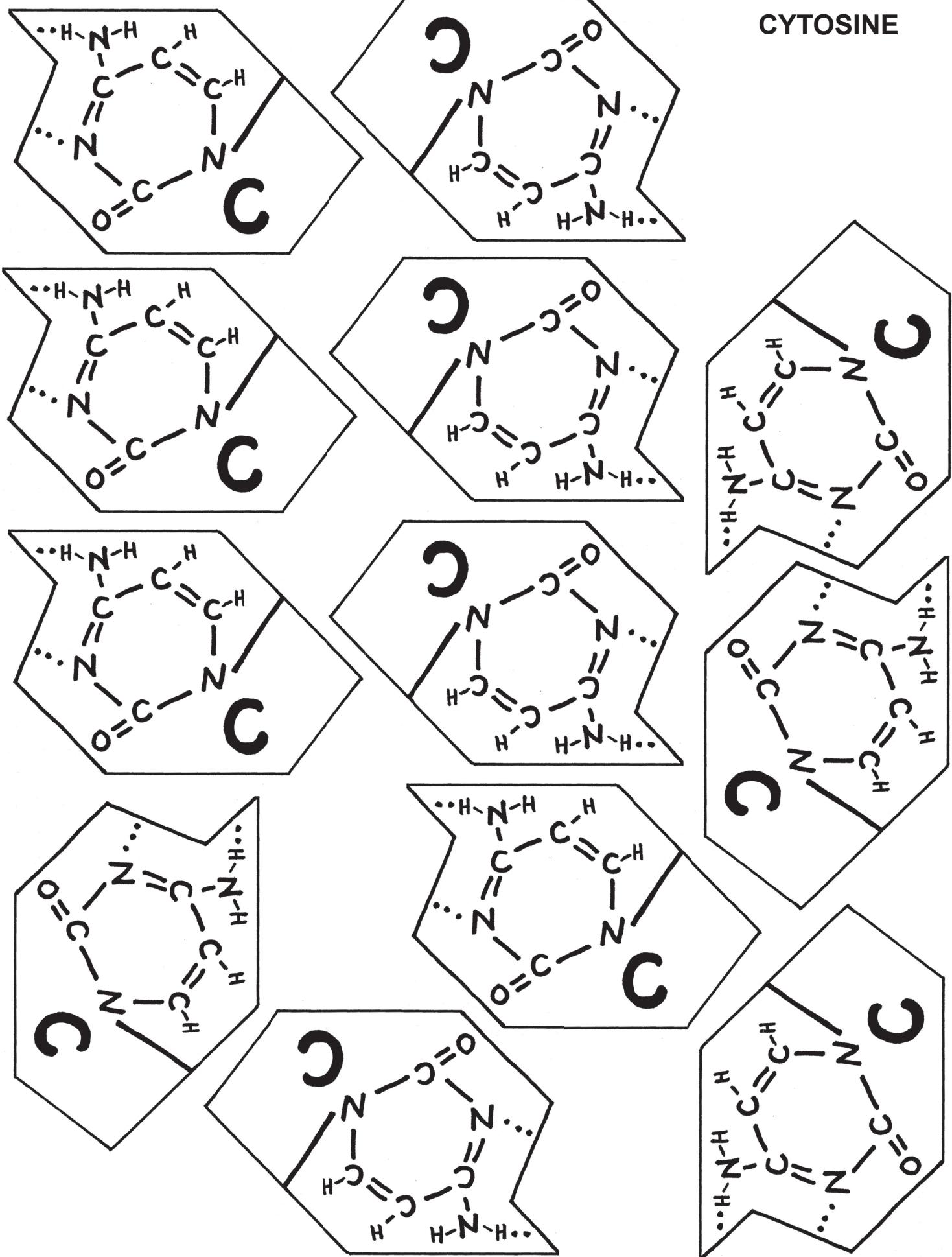


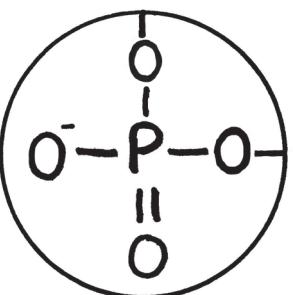
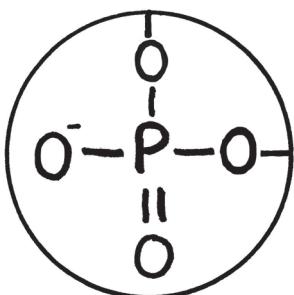
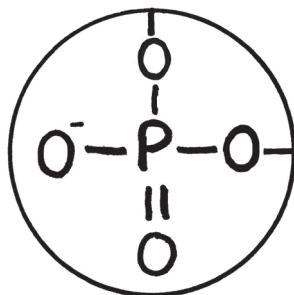
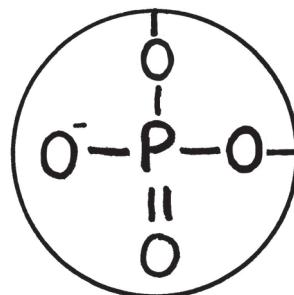
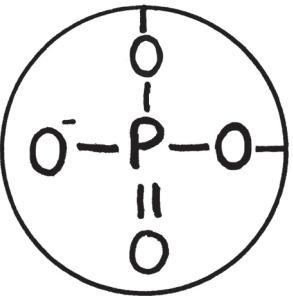
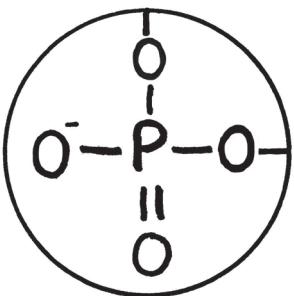
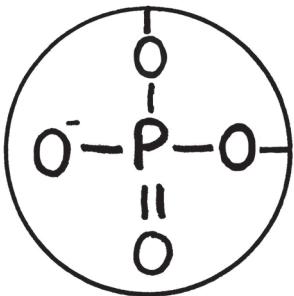
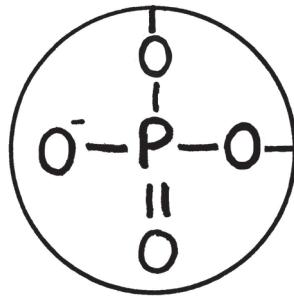
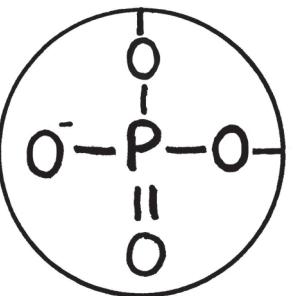
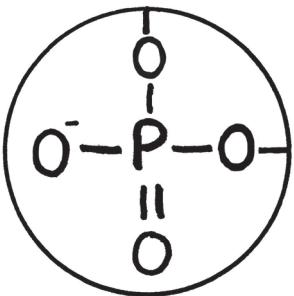
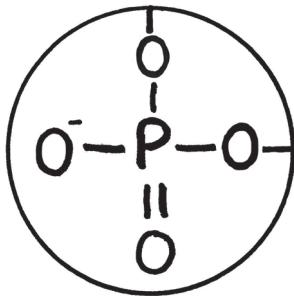
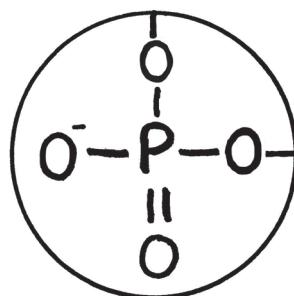
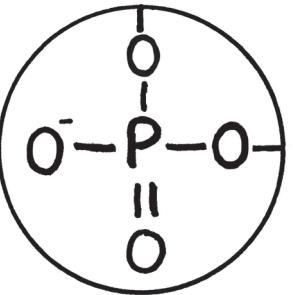
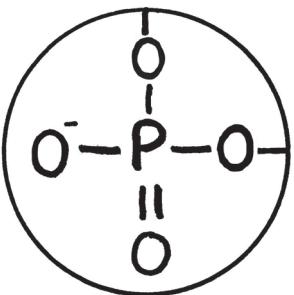
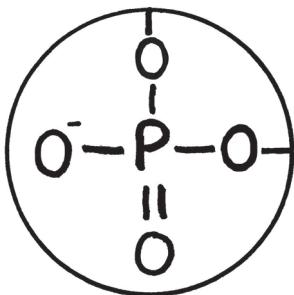
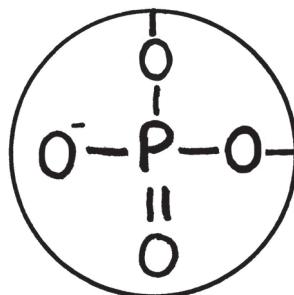
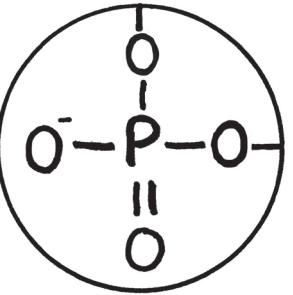
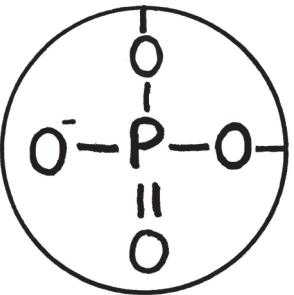
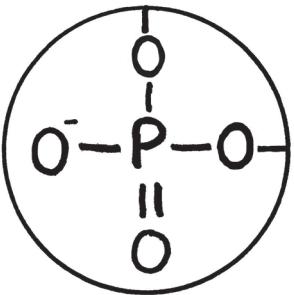
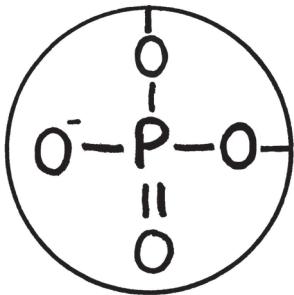
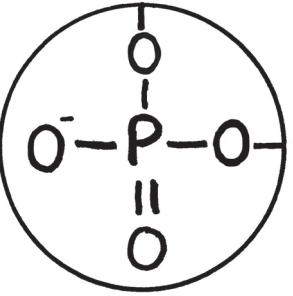
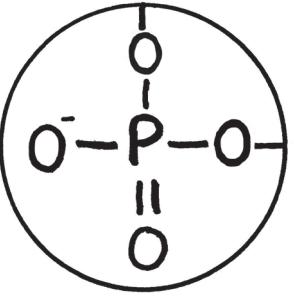
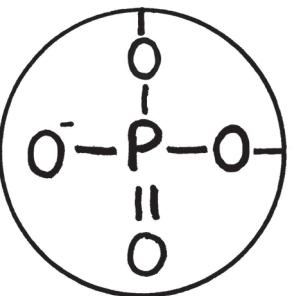
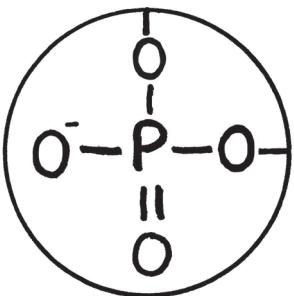


GUANINE

Include blank area inside dotted line.

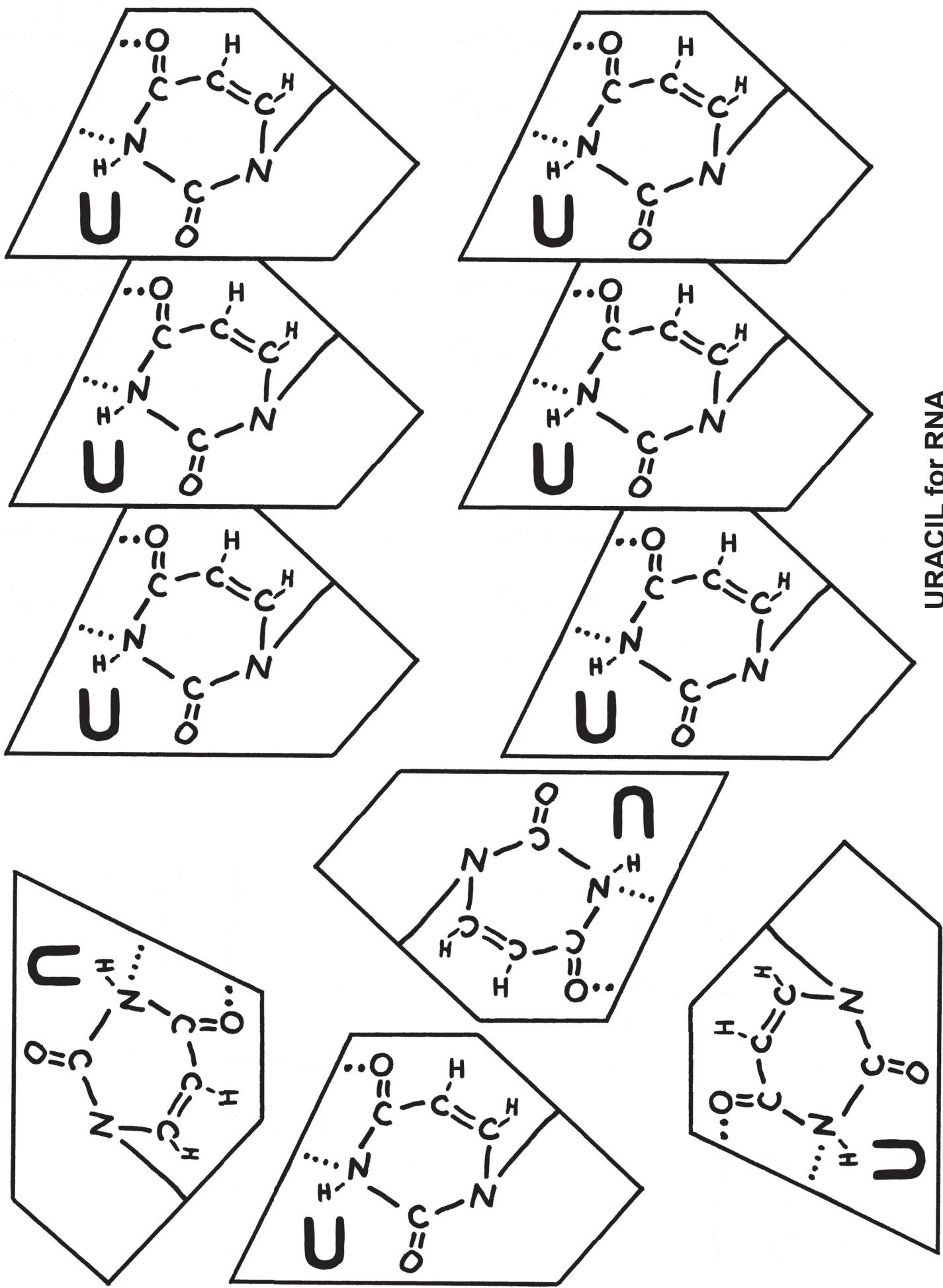
CYTOSINE

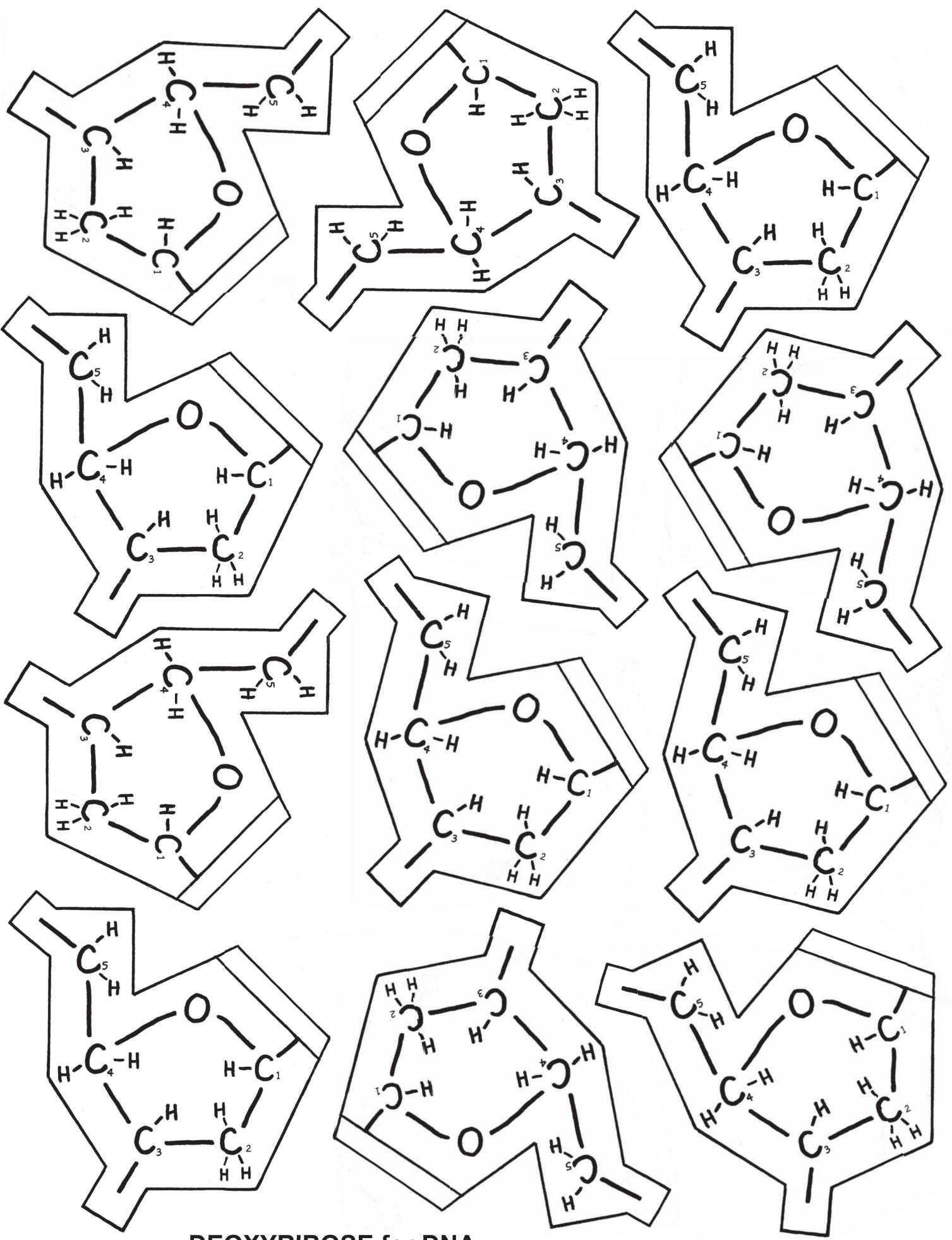




## PHOSPHATES

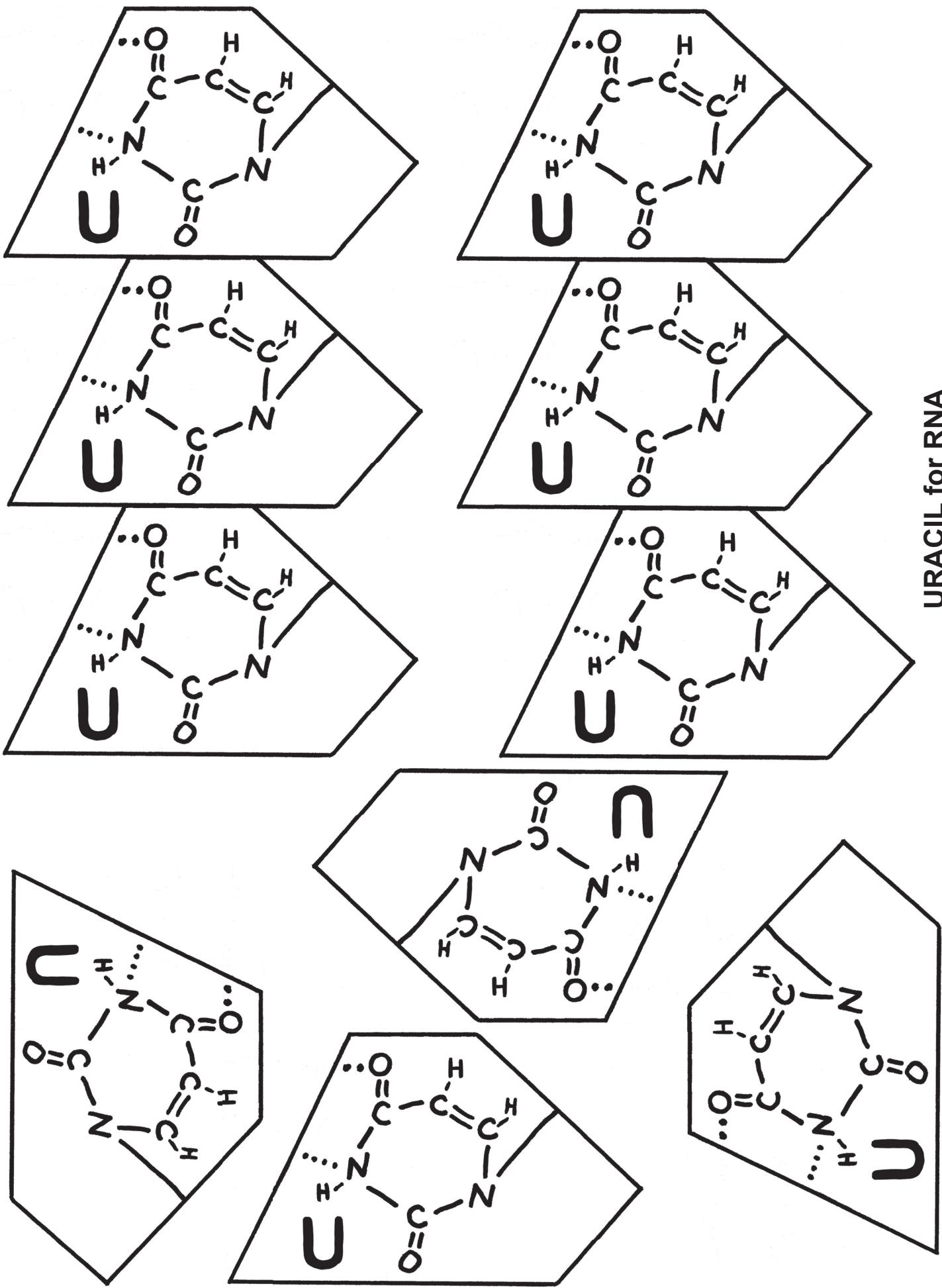
URACIL for RNA

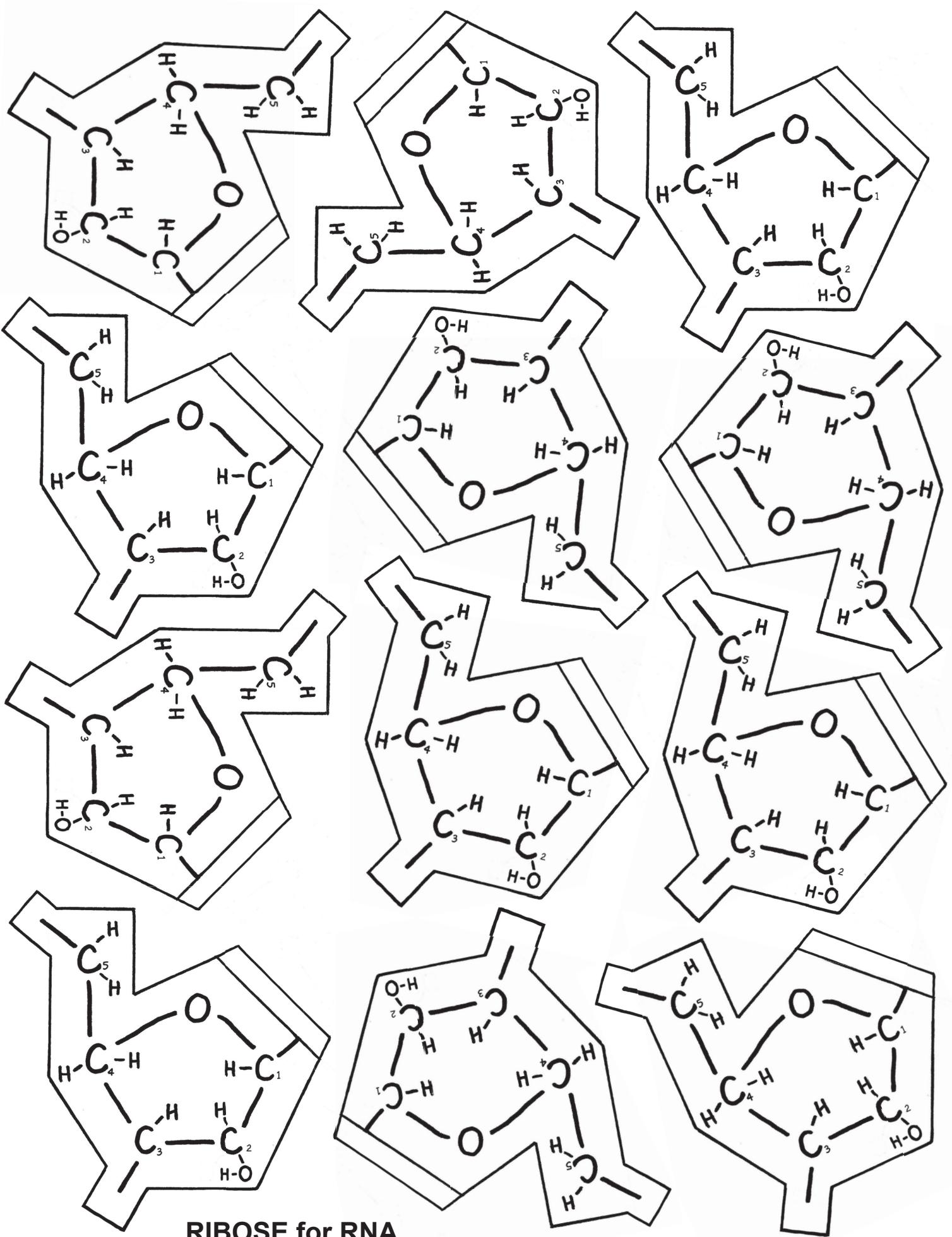




DEOXYRIBOSE for DNA

URACIL for RNA





RIBOSE for RNA

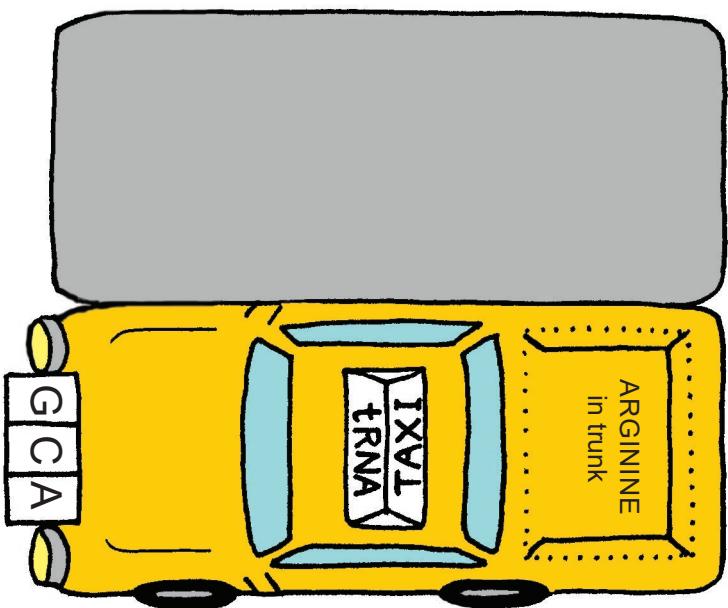
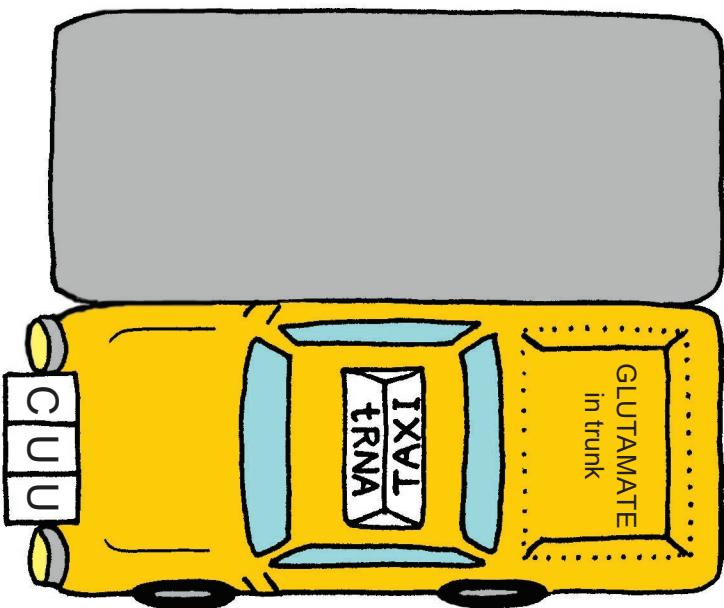
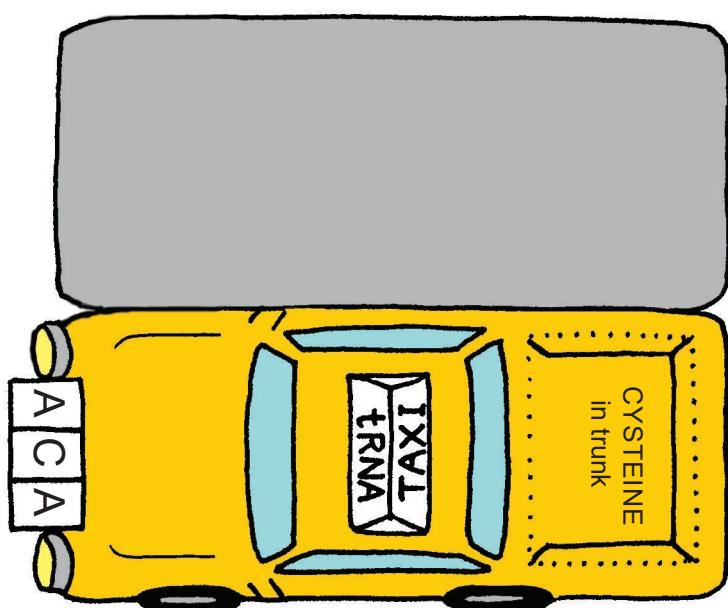
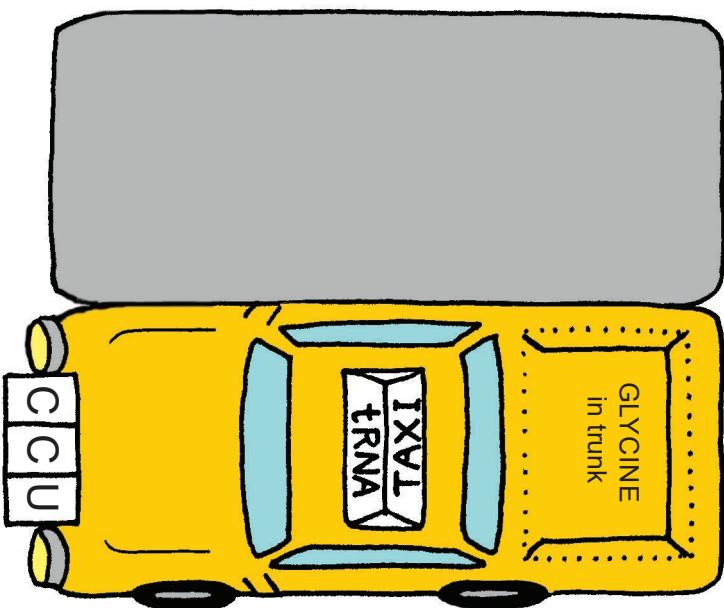
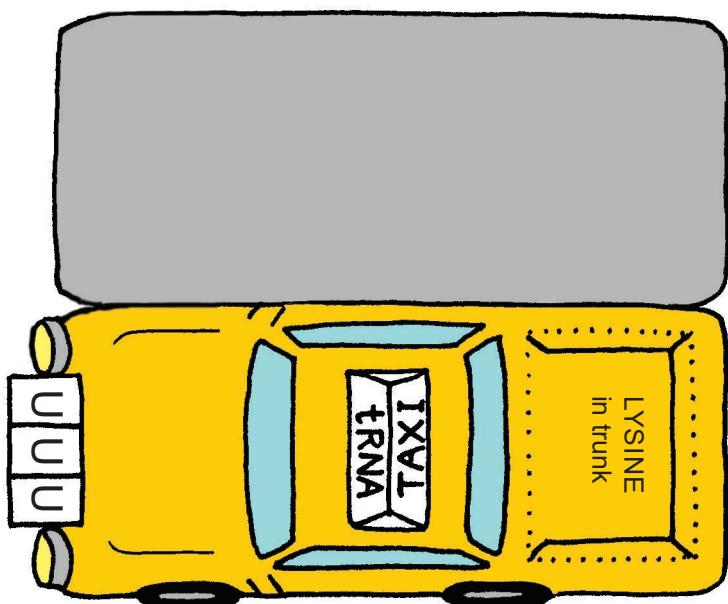
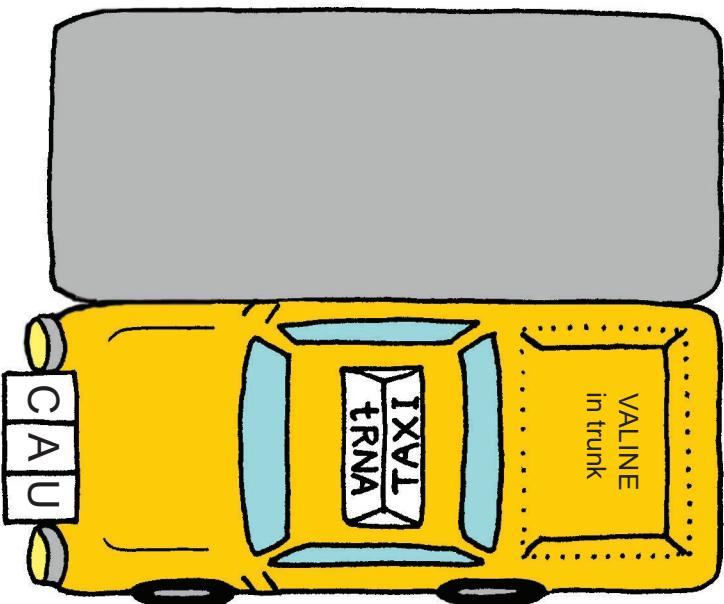
RIBOSOME

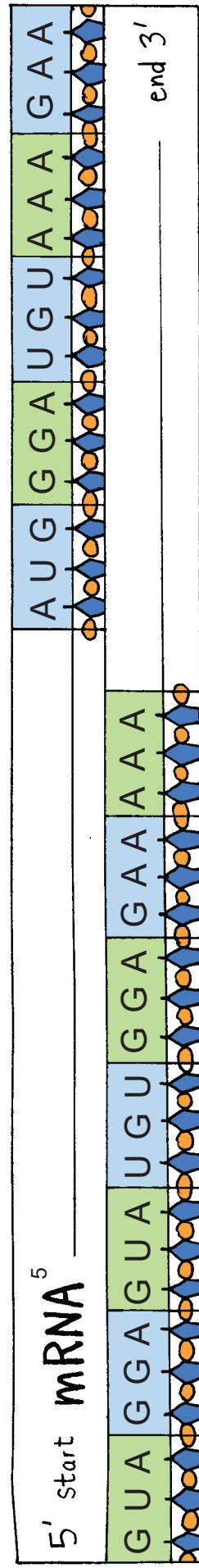
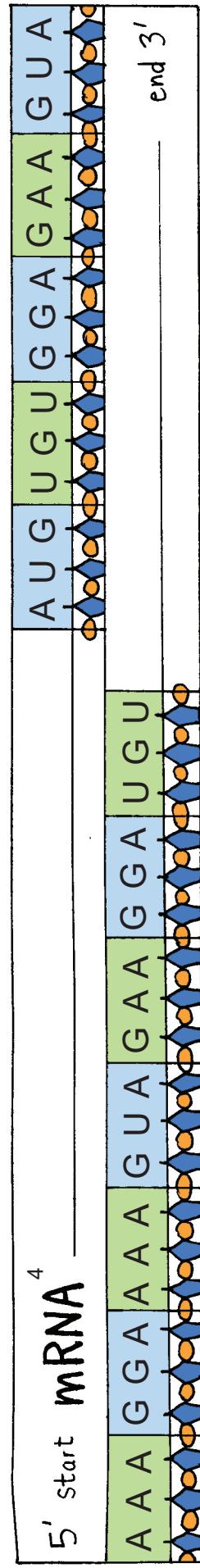
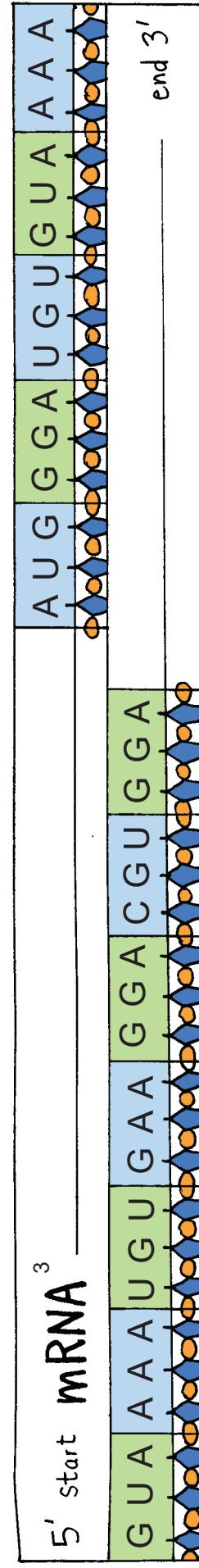
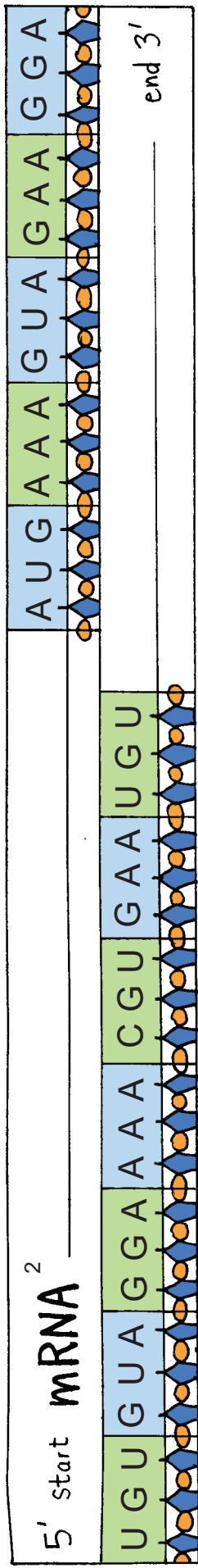
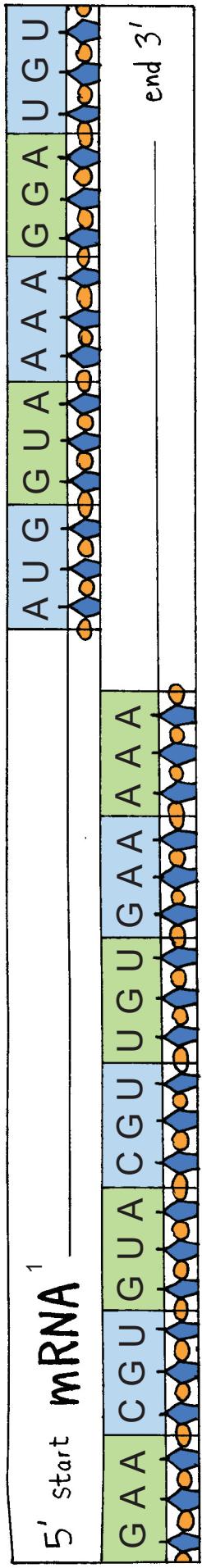
EXIT P

Acceptor

3'

5'





LYSINE	
VALINE	
CYSTEINE	

ARGININE	
GLYCINE	
GLUTAMATE	

<p>If you join an electron and a proton, what do you get?</p> <p>a) a water molecule *b) a hydrogen atom c) an acid</p>	<p>What does "hydrophobic" mean?</p> <p>a) made from water b) "loves" water *c) "fears" water</p> <p>a) store extra starch in fat cells *b) break down starches as part of digestion c) use light from the sun to make sugar</p>	<p>If amyloplasts are organelles in plant cells that store starch, what do you think the protein enzyme "amylase" might do in your body?</p> <p>A protein called "scramblase" is found in plasma membranes. Can you guess what it does?</p> <p>a) acts as a gateway or portal b) runs the proton pumps *c) mixes up phospholipid molecules by moving them from one side to the other</p>
<p>What happens when electrons pass through the pumps in the ETC?</p> <p>a) ATP is formed b) water is formed *c) two protons are pumped upward</p>	<p>What is the inside of the mitochondria called?</p> <p>a) membrane *b) matrix c) cytoplasm</p>	<p>What happens when the third phosphate is popped off ATP?</p> <p>*a) energy is released b) a molecule of water is formed c) a proton is released</p>

<p>If the Greek word for glue is “<i>kolla</i>”, where do you think the protein “collagen” might be found?</p> <ul style="list-style-type: none"> <li>a) in the brain</li> <li>*b) in connective tissues such as tendons and ligaments</li> <li>c) in heart muscles</li> </ul>	<p>What does the protein “transferrin” do?</p> <ul style="list-style-type: none"> <li>a) helps the body to fight viruses</li> <li>*b) carries iron in the bloodstream</li> <li>c) nothing</li> </ul>	<p>Where do you think you would find the protein called “pepsin”?</p> <ul style="list-style-type: none"> <li>*a) in the stomach, digesting food</li> <li>b) in the brain, transmitting signals</li> <li>c) in the eye, gathering light</li> </ul>
<p>What does the protein “insulin” do?</p> <ul style="list-style-type: none"> <li>a) regulates your heart beat</li> <li>b) regulates your body temperature</li> <li>*c) decreases the amount of glucose in your blood</li> </ul>	<p>What does the protein called “hemoglobin” do?</p> <ul style="list-style-type: none"> <li>a) acts as an identification flag on the plasma membrane</li> <li>*b) carries oxygen through the blood</li> <li>c) copies DNA to make mRNA</li> </ul>	<p>What do you think the protein called “elastin” does?</p> <ul style="list-style-type: none"> <li>*a) gives skin its flexibility</li> <li>b) help blood to clot</li> <li>c) help the liver to produce bile for digestion</li> </ul>
<p>What do cells make with the protein called “tubulin”?</p> <ul style="list-style-type: none"> <li>*a) microtubules</li> <li>b) cell membranes</li> <li>c) proton pumps</li> </ul>	<p>Take a guess as to what the protein “fibrin” does:</p> <ul style="list-style-type: none"> <li>a) makes the muscles contract</li> <li>*b) makes protein fibers that allow the blood to clot and form a scab</li> <li>c) acts as a messenger to other cells</li> </ul>	<p>What do you think the protein called “porin” does?</p> <ul style="list-style-type: none"> <li>a) digests lipids and sugars in the intestines</li> <li>b) starts the process of transcription</li> <li>*c) acts as a portal or gateway in the outer membrane of cells</li> </ul>

<p>What energy source was used to discover the shape of DNA?</p> <p>a) electrons *b) x-rays c) light</p>	<p>What is the most natural shape for a bunch of phospholipid molecules to form?</p> <p>a) a flat surface *b) a ball c) a long chain</p>	<p>Lipid rafts are made of phospholipids and...</p> <p>a) water *b) cholesterol c) microfilaments</p>
	<p>What does the centrosome do?</p> <p>a) acts as a gathering point for proteins that are floating around the cell b) sends and receives messages *c) acts as a central point of organization for the cytoskeleton</p>	<p>What kind of atom (meaning what element on the Periodic Table) marks an organic molecule as a protein?</p> <p>*a) nitrogen b) oxygen c) carbon</p> <p>What is the fluid inside a cell called?</p> <p>a) water b) matrix gel *c) cytosol</p>
	<p>What do you call a group of three amino acids?</p> <p>*a) a codon b) a secret code c) a nucleic acid</p>	<p>Glycine, alanine, lysine, proline and tyrosine are examples of ____.</p> <p>a) nucleic acids b) hydrochloric acids *c) amino acids</p> <p>What do you call a phosphorus atom with 4 oxygen atoms attached to it?</p> <p>a) phospholipid *b) phosphate c) glycerol</p>

<p>What is it called when a lot of something goes to a place where there is less of it?</p> <p>a) transcription b) combustion *c) diffusion</p>	<p>What does glycerol do in the phospholipid molecule?</p> <p>*a) keep the phosphate and lipid together b) keep the phosphate and lipid apart c) push the phosphate toward water</p>	<p>What is the most basic unit of energy used by living things?</p> <p>a) an amino acid *b) ATP c) sugar</p>
<p>How many proton pumps are in the electron transport chain?</p> <p>a) 1 b) 2 *c) 3</p>	<p>What did Watson and Crick discover?</p> <p>a) ATP synthase *b) the shape of DNA c) protein folding</p>	<p>What part of the cell helps it to keep its shape and also provides a network for transportation?</p> <p>a) cytoplasm *b) cytoskeleton c) plasma membrane</p>
<p>How many amino acids are there?</p> <p>a) 4 *b) 20 c) hundreds</p>	<p>What is the name of the shape that DNA forms?</p> <p>a) coil b) sheet *c) helix</p>	<p>What does the Greek word "soma" mean?</p> <p>*a) body b) cell c) center</p>

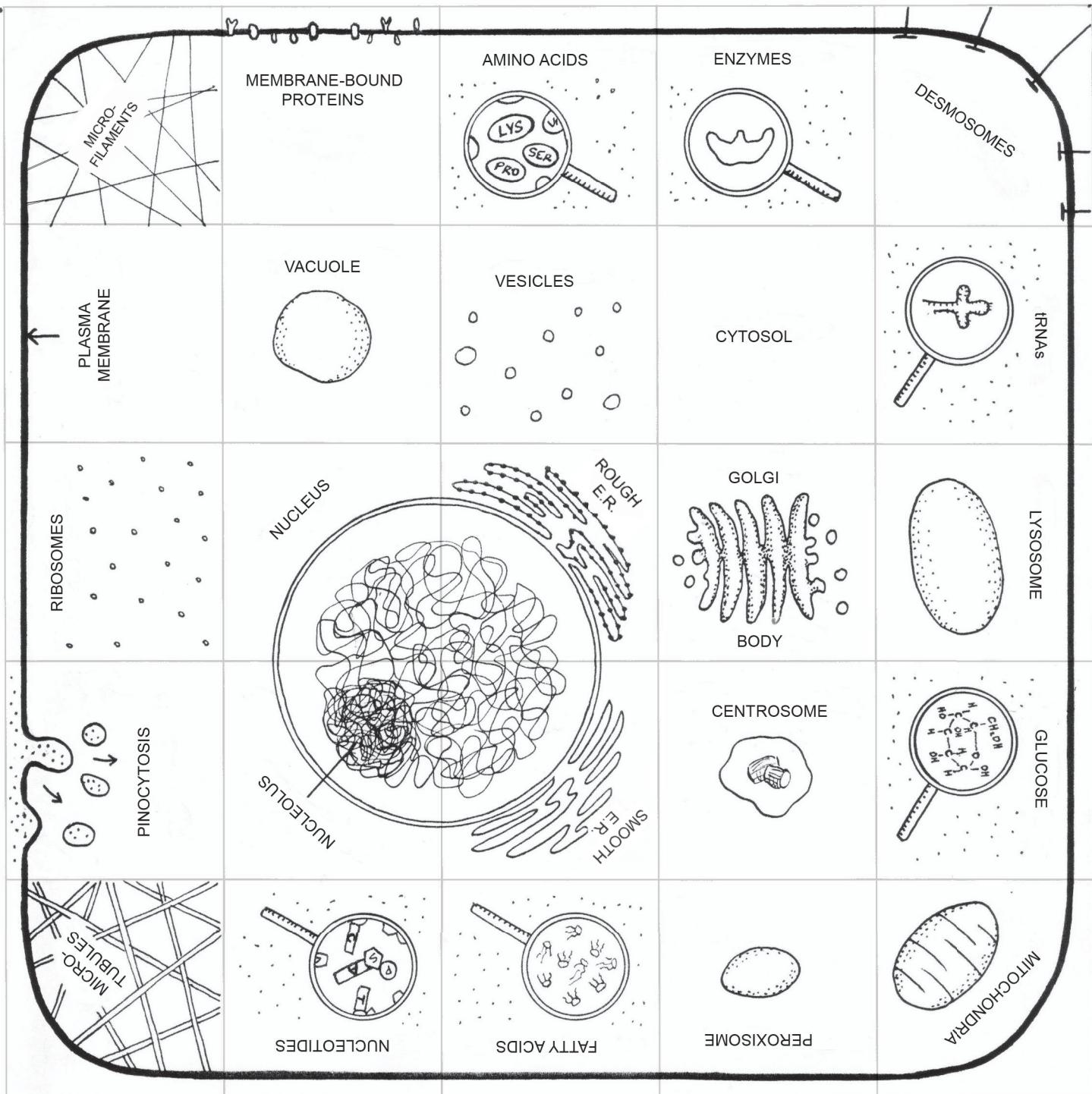
LIST OF CODONS:

FIRST LETTER	SECOND LETTER	THIRD LETTER	AMINO ACID	
A	A	A or G	Lysine	
		C or U	Asparagine	
	G	A or G	Arginine	
		C or U	Serine	
	C	A, G, C, or U	Threonine	
		A	Isoleucine	
		G	Methionine (START)	
		C or U	Isoleucine	
	U	A or G	Glutamic acid	
		C or U	Aspartic acid	
G	G	A, G, C or U	Glycine	
	C	A, G, C or U	Alanine	
	U	A, G, C or U	Valine	
	C	A or G	Glutamine	
C		C or U	Histidine	
		G	Arginine	
		C	Proline	
		U	Leucine	
U	A	A or G	STOP	
		C or U	Tyrosine	
	G	A	STOP	
		G	Tryptophan	
		C or U	Cysteine	
	C	A, G, C or U	Serine	
		A or G	Leucine	
	U	C or U	Phenylalanine	

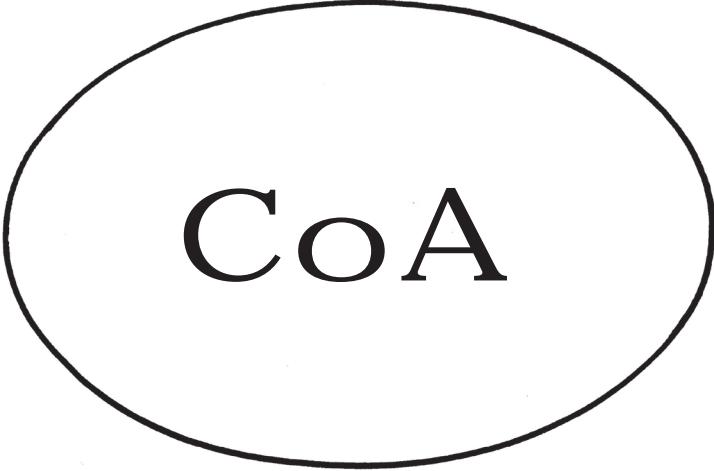
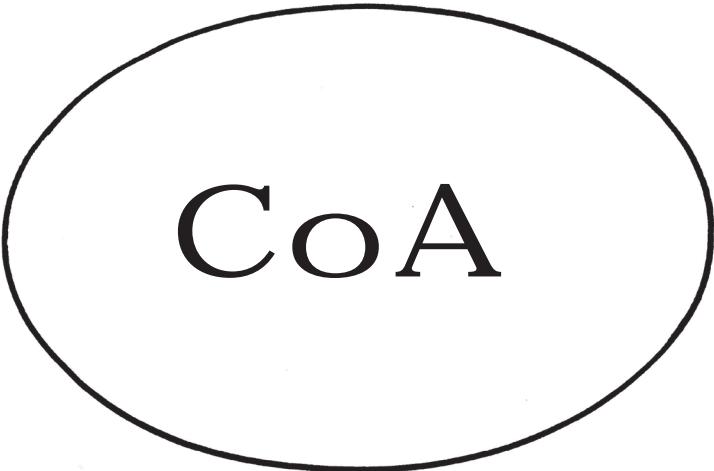
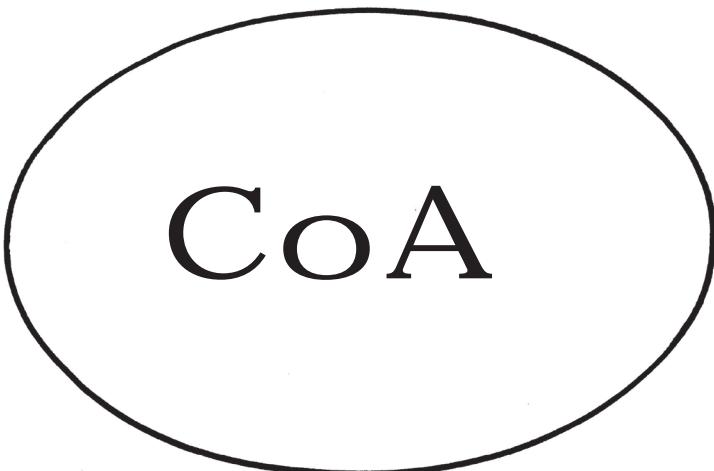
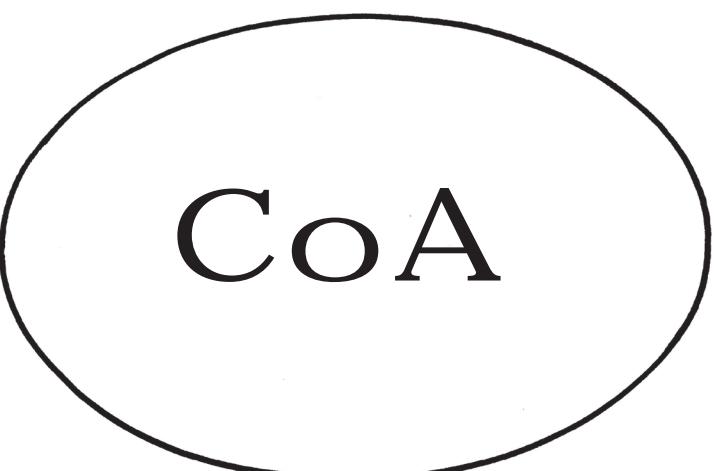
5) Decide how long you want to make your protein chain. I recommend making a chain that has about 20-30 amino acids (pieces of colored paper) so the total length would be about 7 feet (2 m) long. Make sure each player gets to contribute a link at least two times. If you are working with a small number of players, they might contribute a link five or six times.

6) To make the messenger RNA, roll out a long strip of paper that is just a bit longer than the length you want to make your protein chain. (If you don't have cash register tape, you can make a long strip by cutting strips of paper and taping them end to end.) This strip of messenger RNA has just come from the nucleus and is ready for translation in a ribosome.

Write "START" on one end of the strip, then begin marking off sections that are exactly the width of one of the tRNA cards. (If you are adapting this game to a smaller scale, adjust accordingly.) Count off the number of aminos you want in your chain then write "END" after the last one. (For my group of a dozen players I made the mRNA 24 aminos long.) Then go back and write a codon in each of the sections. You will need to use tRNA cards while you do this, making sure to use each codon at least once. I laid out the dozen tRNA cards along the first

## PYRUVATES



Coenzyme A molecule are very large and complicated—far too large to be shown here.

$\text{O}=\text{C}-\text{O}^-$	$\text{O}=\text{C}-\text{O}^-$
$\cdots \cdots \cdots$	$\cdots \cdots \cdots$
$\text{C}=\text{O}$	$\text{C}=\text{O}$
$\text{H}-\text{C}-\text{H}$	$\text{H}-\text{C}-\text{H}$

$\text{O}=\text{C}-\text{O}^-$	$\text{O}=\text{C}-\text{O}^-$
$\cdots \cdots \cdots$	$\cdots \cdots \cdots$
$\text{C}=\text{O}$	$\text{C}=\text{O}$
$\text{H}-\text{C}-\text{H}$	$\text{H}-\text{C}-\text{H}$

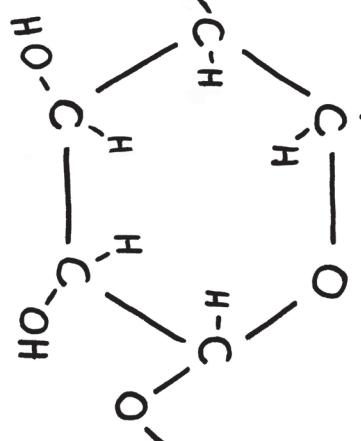
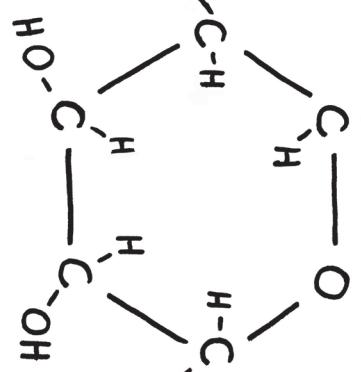
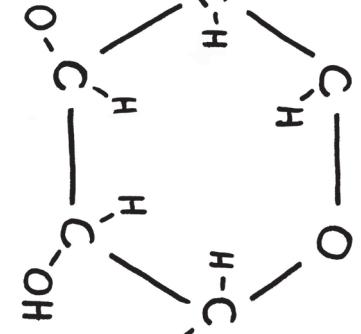
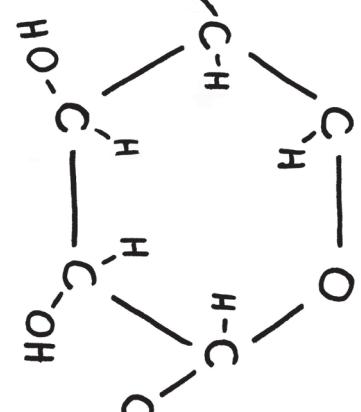
$\text{O}=\text{C}-\text{O}^-$	$\text{O}=\text{C}-\text{O}^-$
$\cdots \cdots \cdots$	$\cdots \cdots \cdots$
$\text{C}=\text{O}$	$\text{C}=\text{O}$
$\text{H}-\text{C}-\text{H}$	$\text{H}-\text{C}-\text{H}$

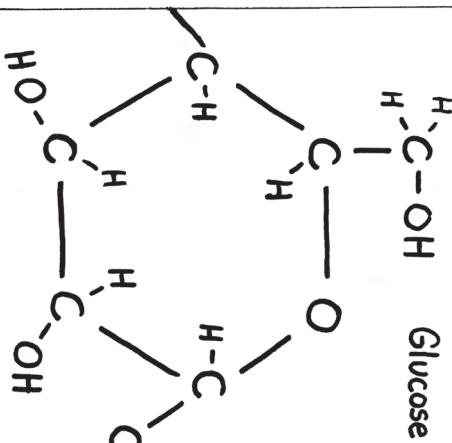
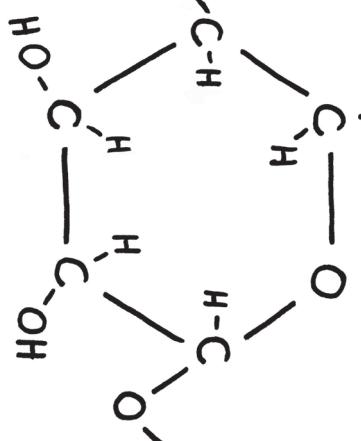
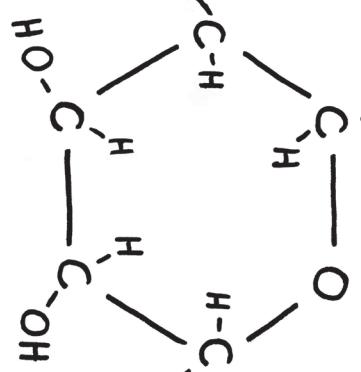
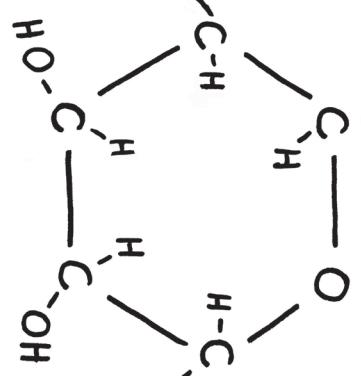
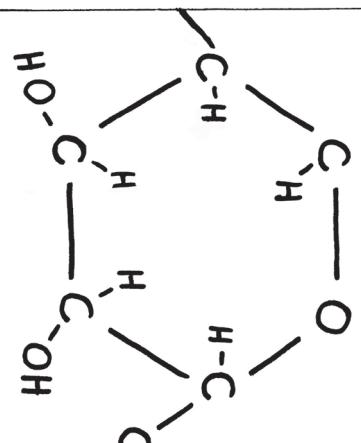
$\text{O}=\text{C}-\text{O}^-$	$\text{O}=\text{C}-\text{O}^-$
$\cdots \cdots \cdots$	$\cdots \cdots \cdots$
$\text{C}=\text{O}$	$\text{C}=\text{O}$
$\text{H}-\text{C}-\text{H}$	$\text{H}-\text{C}-\text{H}$



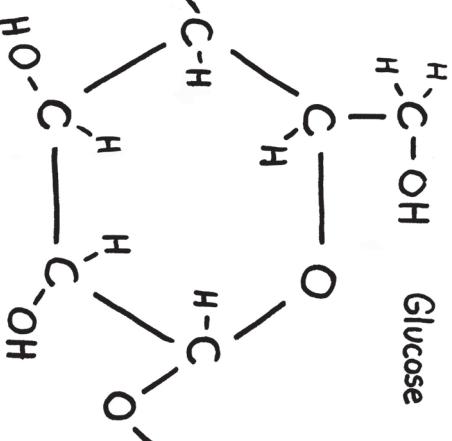
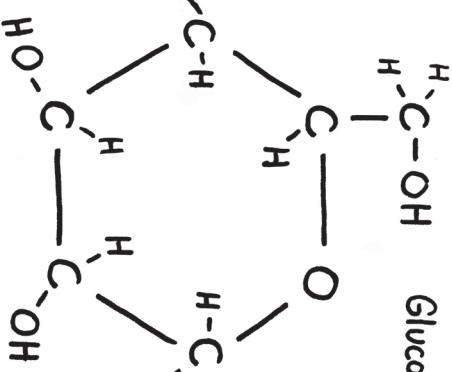
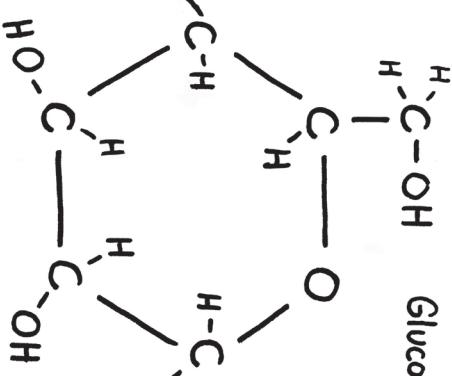
Glucose

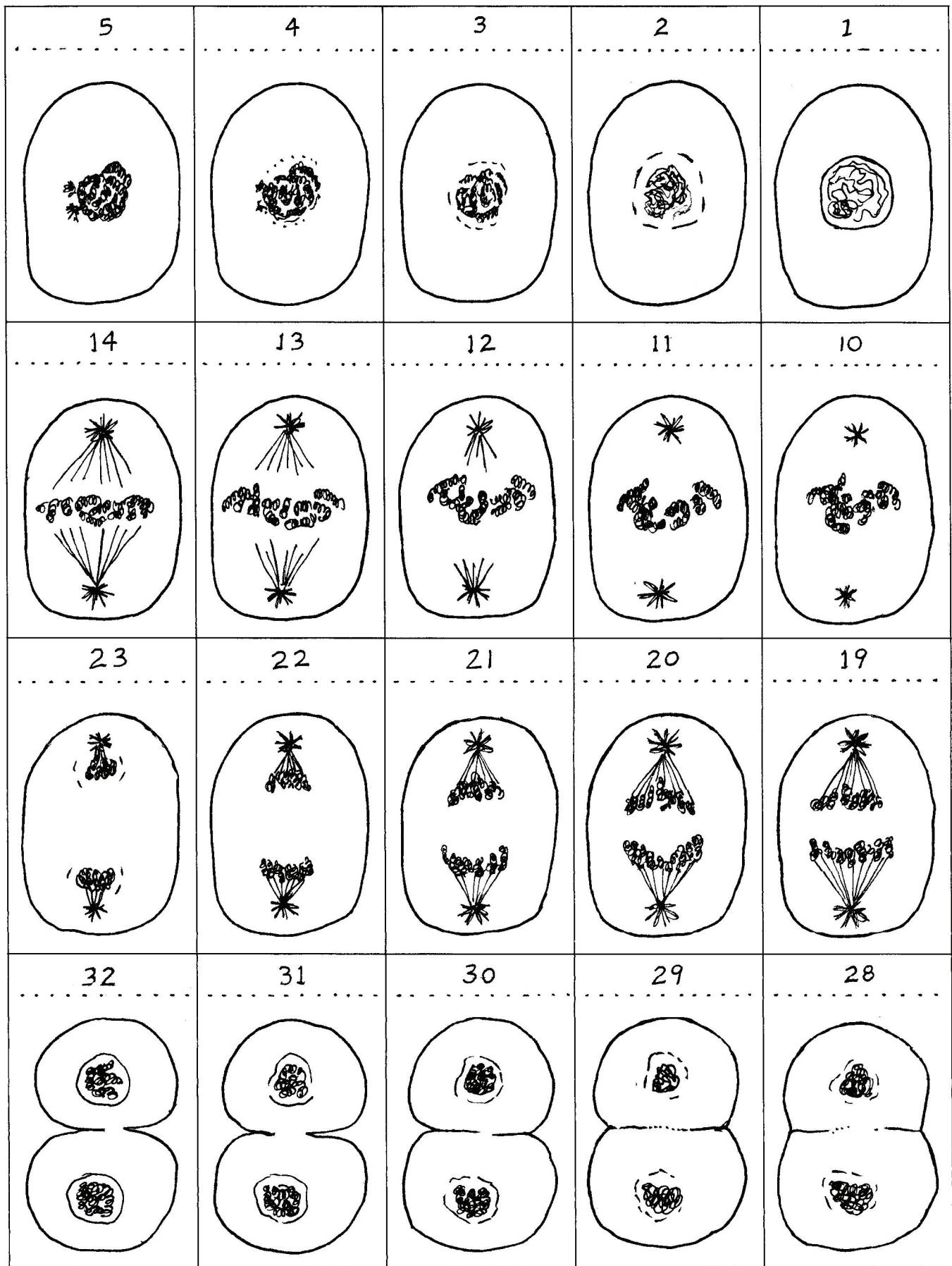


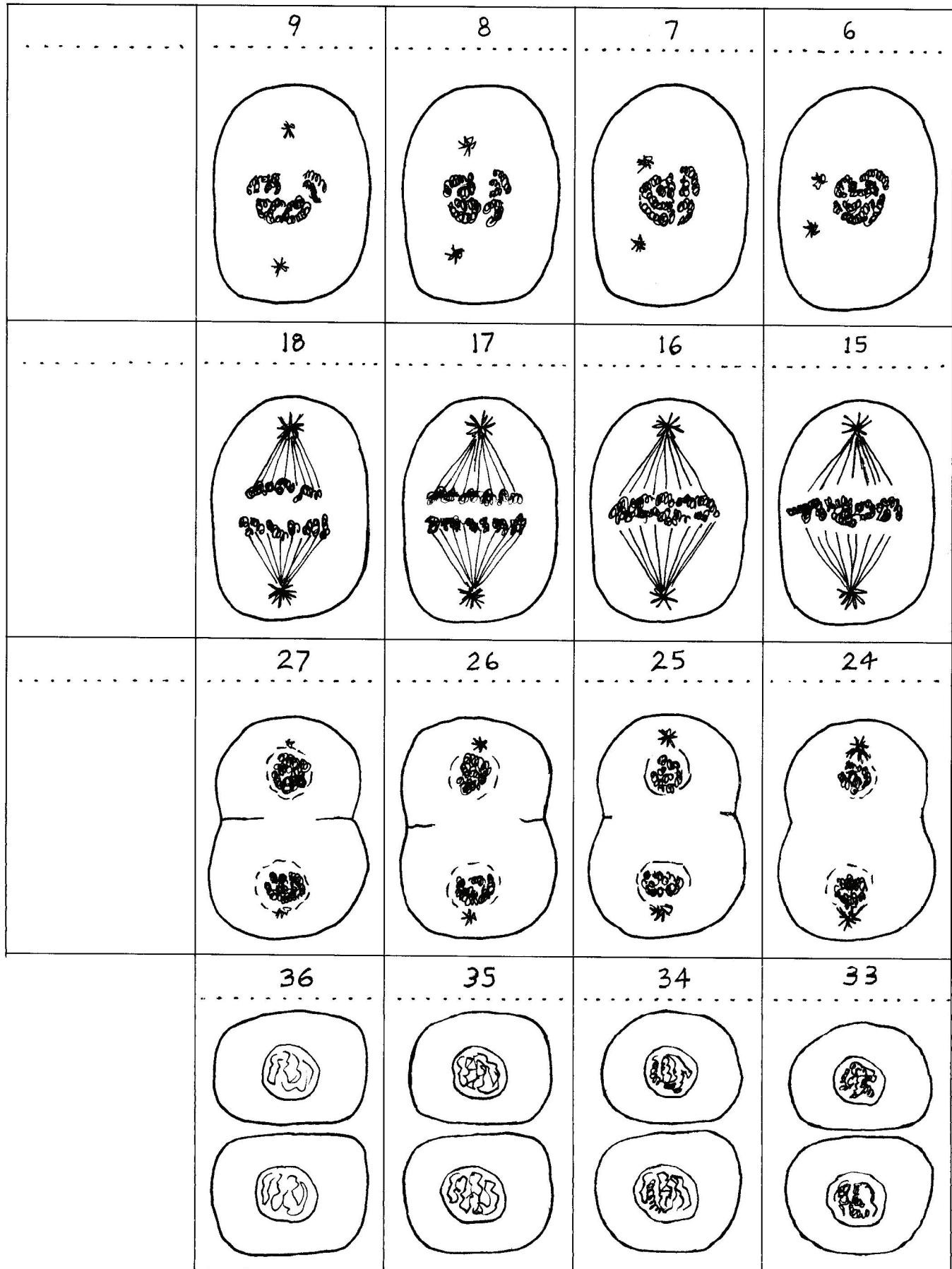
Glucose



Glucose



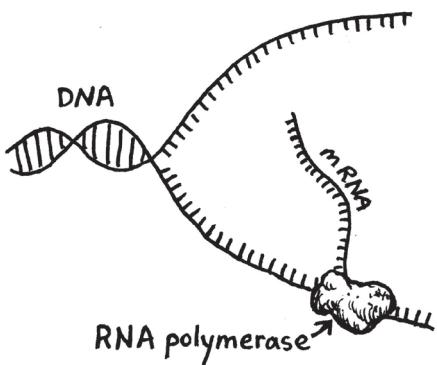




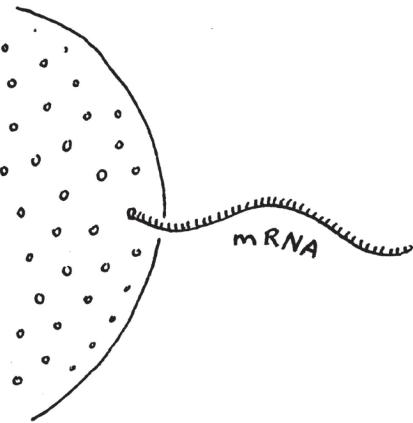

EPITHELIAL CELLS	SECRETORY CELLS	BONE CELLS	MUSCLE CELLS	BLOOD CELLS	
				NERVE CELLS	NERVE CELLS
100	100	100	100	100	100
200	200	200	200	200	200
300	300	300	300	300	300
400	400	400	400	400	400
500	500	500	500	500	500

# 1 TRANSCRIPTION

RNA polymerase copies a section of DNA

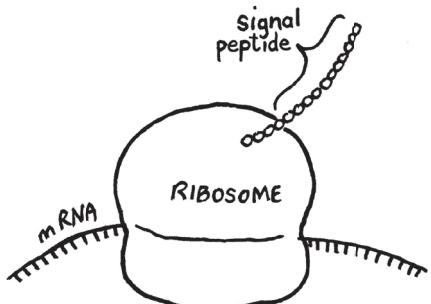


# 2 Messenger RNA EXITS NUCLEUS

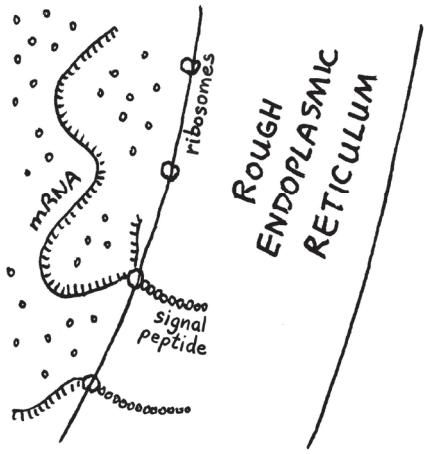


# 3 TRANSLATION in a RIBOSOME

The first part of the protein says, "Take me to the E.R.!"

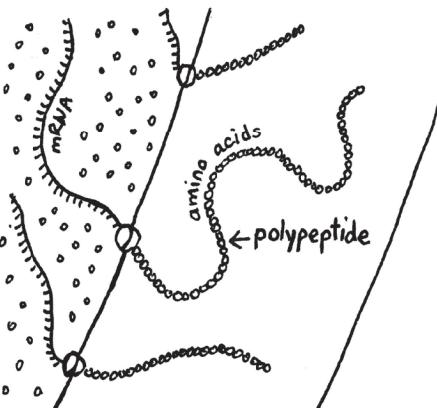


# 4 RIBOSOME DOCKS on the E.R.



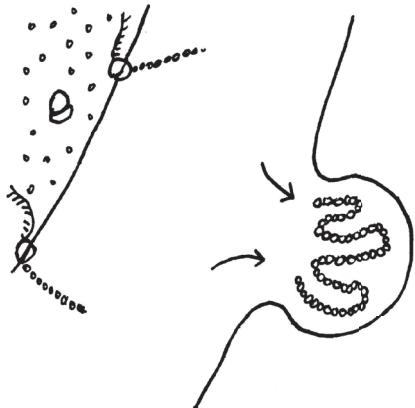
# 5 PROTEIN MADE INSIDE THE E.R.

The protein will be a neurotransmitter.

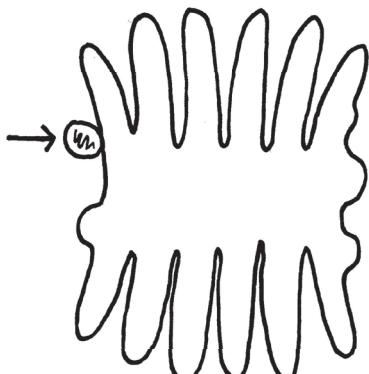


# 6 VESICLE BUDS OFF FROM E.R.

Vesicle contains neurotransmitter

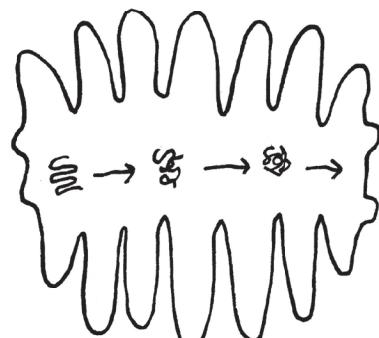


# 7 VESICLE MERGES INTO GOLGI BODY

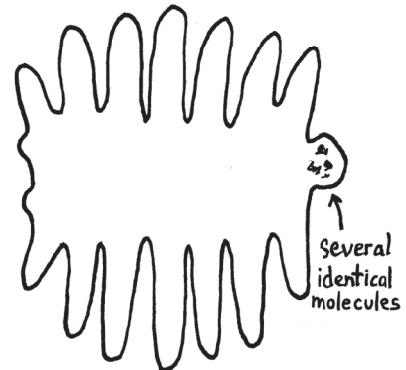


# 8 GOLGI MODIFIES PROTEIN

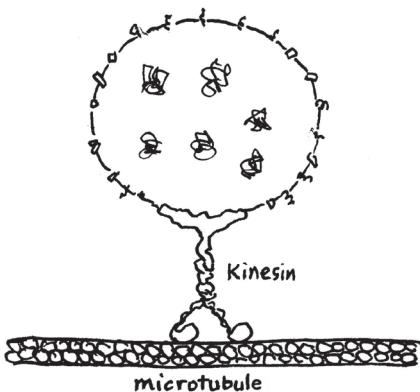
Golgi enzymes make changes such as folding or adding sugars and phosphates.



# 9 VESICLE BUDS OFF FROM GOLGI

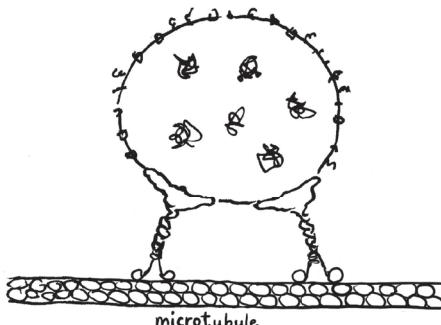


## 10 TRANSPORT BY A KINESIN



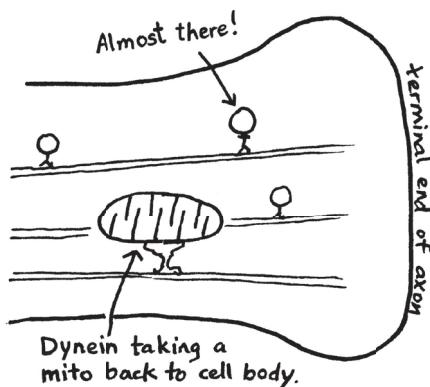
## 11 TRANSPORT BY A KINESIN

Vesicle is handed off to another kinesin



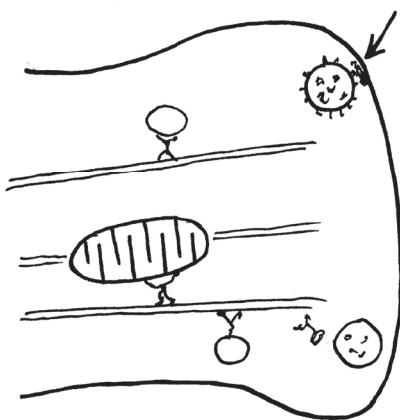
## 12 TRANSPORT BY A KINESIN

Vesicle is handed off to a final kinesin



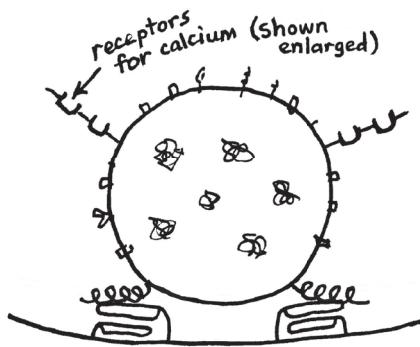
## 13 VESICLE DOCKS

There are docking proteins on vesicle and membrane



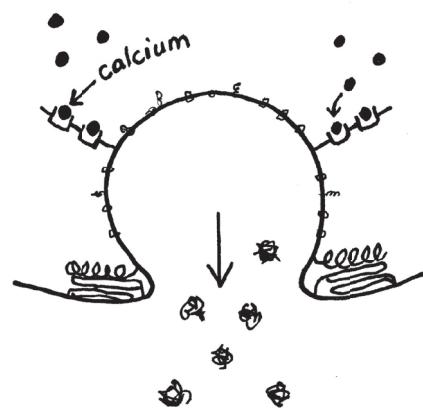
## 14 VESICLE PRIMED

Docking proteins change shape and get ready to receive calcium ions.



## 15 EXOCYTOSIS

Docking proteins change shape and get ready to receive calcium ions.



## STEAL

Your team may take a card from the other team at the beginning of a turn. The stolen card will count as one of your 3 draw cards.

After using this card, remove it from the game.

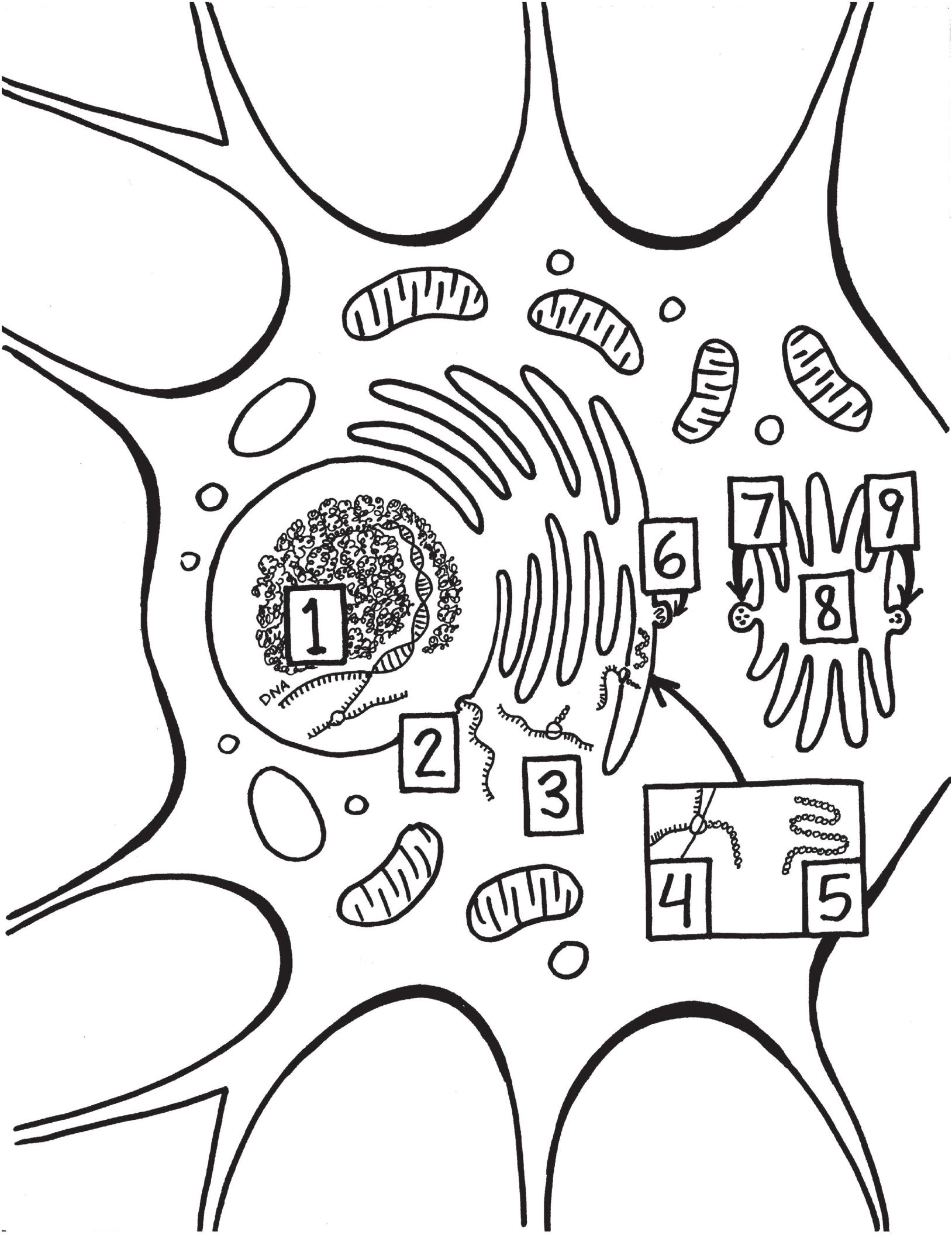
## TRADE

Your team may take a card from the other team but must also give them one. You may decide which card to give them.

After using this card, remove it from the game.

## NEURON GETS A FREE TURN

After this card is played, remove it from the game.



2

3

4

5

1

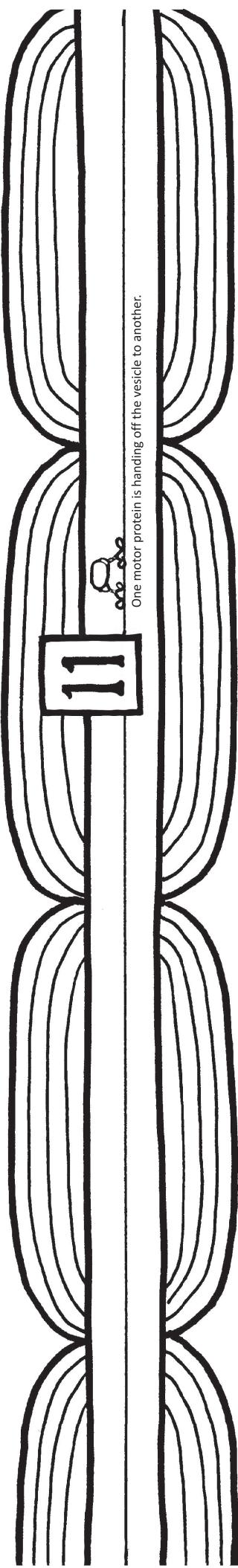
DNA

6

7

8

9



One motor protein is handing off the vesicle to another.

