The CARBON-14 GAME

Purpose of game: To review (or learn) information about the formation of Carbon-14 from nitrogen, its beta decay back into nitrogen. The game works best as a review to previous study, but could be played with only a short introduction to the topic.

Age recommendation: 12 and up (possibly 10 or 11 if they are very familiar with atoms and elements)

Time required for set up: about 30 minutes for one person, less if you divide the labor

Time required to play: allow at least 30 minutes

Number of players: 2 to 4

Materials needed: Copies of these pattern pages printed onto card stock, scissors, tape and/or glue stick, hole puncher, "sticky notes" in two colors, paper fastener, colored pencils or crayons that match the colors of your sticky notes

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Background information

Atoms of carbon normally have 6 protons and 6 neutrons in their nucleus. We call this "normal" version Carbon-12, or C-12. About 1% of all carbon atoms have 7 neutrons, making them Carbon-13. The extra neutron makes no practical difference and these C-13 atoms behave and function exactly like C-12. About one carbon atom in every trillion has 8 neutrons, and is Carbon-14. C-14 atoms are not stable and one of their neutrons will eventually turn into a proton. This change is called beta decay. During beta decay a high energy electron (known as beta particle) is also emitted, along with an incredibly small, and somewhat mysterious, particle called an anti-neutrino.

We know that Carbon-14 atoms are made in the upper atmosphere when fast-moving neutrons put out by the sun (in the solar wind) hit the nuclei of nitrogen atoms. The traveling neutron takes the place of one of the nitrogen's protons. The reduces the atom's number of protons from 7 to 6. Since the number of protons is what defines an atom's identity, this means that the nitrogen atom turns into a carbon atom. The original number of neutrons is preserved so the total number of neutron becomes 8. The atom thus turns into a heavy, unstable form of carbon, C-14.

This newly formed C-14 atom immediately lets go of the nitrogen atom it was bonded to (as N_2) and goes off to find an oxygen atom, forming carbon monoxide, CO. Soon the carbon monoxide finds another oxygen and becomes carbon dioxide, CO_2. After floating around in the sky for months or years, the carbon dioxide molecule might eventually end up being taken in by a plant. The plant uses carbon atoms to form products such as glucose, starches, proteins and oils. Animals then consume these plant products, and the carbon atoms end up either being exhaled as CO_2, a by-product of respiration, or being used to make molecules such as DNA and proteins, with collagen being one of the most abundant types of protein, and the one most resistant to decay.

As long as an animal is alive, it is constantly taking in carbon atoms. Some of these are carbon-14. This means the supply of carbon-14 in constantly being replenished. When the animal dies, it no longer takes in any new carbon atoms. The C-14 atoms in its dead body begin to decay and turn back into nitrogen atoms. This decay process has been described, and involves a neutron suddenly turning back into a proton and emitting an electron. (These "beta" electrons can travel about 22 centimeters through the air.) We can calculate that in 5730 years, half of the C-14 atoms in that dead body (or dead plant material) will have decayed back into nitrogen. In another 5730 years, half of that remaining half will have decayed, leaving one fourth of the original amount. In another 5730 years, half of that remaining amount will have decayed, leaving one eighth of the original number. After about 100,000 there would be almost no remaining C-14.

Accelerated Mass Spectrometer (AMS) machines are used to count the number of C-14 atoms in a specimen. By comparing this number to the estimated percentage of C-14 atoms in the atmosphere, scientists can come up with a guess as to when a plant or animal died. This dating method works really well for things that are only hundreds of years old and moderately well for things that are a few thousand years old. The estimated dates depend on a good guess as to how much C-14 was in the air when the organism died, so events that put extra C-14 into the air, such as the atomic bomb testing in the 1950s, can skew the results. If the C-14 in atmosphere thousands of years ago was different from what we have today, our age estimates will be off.

Carbon-14 can be produced in labs and is useful as a "tracer" to research biochemical processes. For example, C-14 atoms were used to investigate photosynthesis. Plants were given carbon dioxide that had a very high C-14 content and the scientists were able trace those carbon atoms to find out exactly what the plant did with them. They discovered that the plants used the carbon atoms to make glucose molecules.

When a C-14 atom decays, the "weak force" allows a neutron to turn into a proton, emitting a high-energy electron (which we call a "beta" particle) and a tiny anti-neutrino (a mysterious particle we have not really be able to actually observe). The weak force is the least well understood of the four forces (gravity, electromagnetism, strong force, weak force). The strong force is what holds the nucleus together, binding the protons. The weak force can only be explained by discussing particle physics concepts, so if you want to find out more about it, you might want to check out the videos by Don Lincoln of Fermi Labs. (Search your favorite video sources, such as YouTube.)

Protons and neutrons are made of even smaller particles called quarks. A proton is made of two UP quarks and one DOWN quark. A neutron is made of two DOWN quarks and one UP quark. If one of the quarks is flipped from UP to DOWN or DOWN to UP, this changes its identity. If we want to refer to a particle in the nucleus without saying whether it is a proton or neutron we use the word "nucleon." In this game a nucleon changes from a proton to a neutron, and then back again. (Once again, if you want an explanation of how this happens, try searching for the video called "What's the smallest thing in the universe?" by Ted-Ed.

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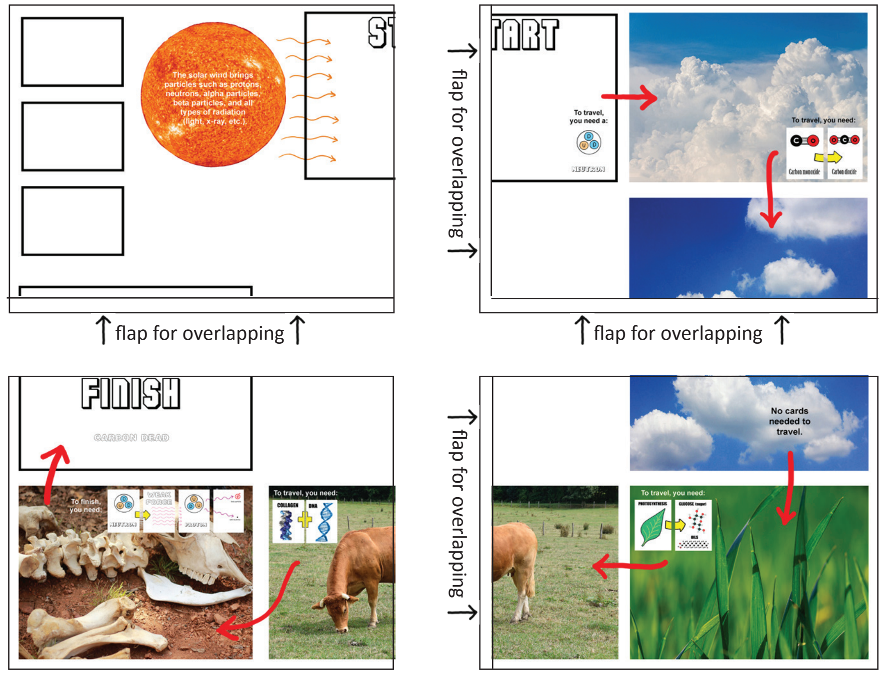
How to make the game:

1) Make copies of the pattern pages onto card stock. Each pages is marked as to how many copies you will need to make one game. If you are making multiple games, you'll need more copies, of course.
TIPS:
--The four pages that go together to make the board can be printed onto regular paper if need be.
--Print the quiz questions onto colored card stock so they look different from the cards that you collect. If you have to print everything on white, you might want to consider drawing a question mark on the reverse side of the quiz cards.
--If you are making multiple copies of the game for a classroom, make sure to put an identifying mark on the sets of cards. For example, have a set where each card has a tiny yellow dot in one corner, a set where they all have red dots in the corner, etc. This will make the sets very easy to sort out if they get mixed up.
---If you want to laminate the cards, make sure you use a laminating technique where the plastic actually sticks to the paper. Some laminating machines just seal around the edges of the paper.

2) To assemble the board, trim the four board pieces so that you have glue flaps as shown, and either glue or tape them together using these overlaps.

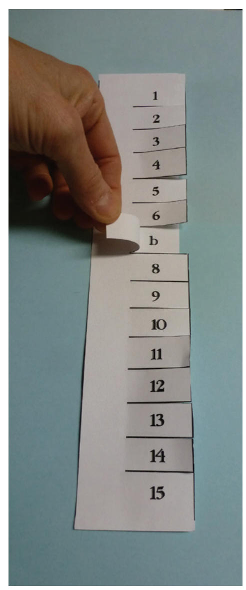


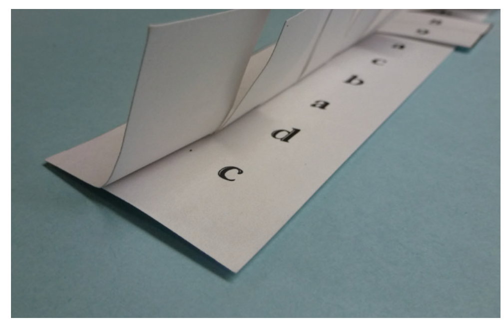
3) Cut apart all the cards (the 16 quiz cards, and the sets of picture cards, one set for each player)

4) Cut out the square atom cards, which will be the tokens that move around on the board. The cards emphasize the nucleus, showing all the protons and neutrons as clumps of 3 quarks.

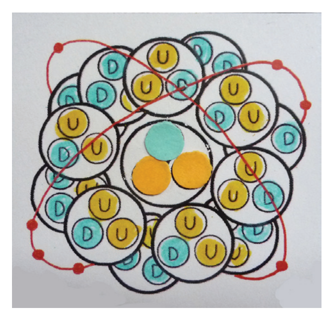
5) Cut out the two parts for the spinner and assemble as shown on the spinner page. You will need a paper fastener.

6) Cut off the strips that will be assembled to make the answer key for the quiz questions. Assemble as shown in photos. The close up photo shows that only the left side of the strips will be glued together. The idea is that the players can check one answer at a time without revealing other answers accidentally. (If the answers were simply given as a list, every time you checked the key you would unintentionally see other answers on the list.)

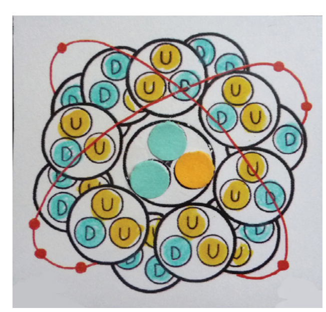




7) Use a paper punch to punch out dots from two different colors of sticky notes. You will using only the sticky part of the notes. The goal is to make colored dots that can be stuck and unstuck to the central nucleon of the token pieces, turning it into a neutron and then back into a proton. Put these sticky dots onto a slip of paper that will be made available to the players during the game.



token as proton



token as neutron

Set up before playing:

1) Shuffle the quiz cards.
2) Shuffle all the picture cards together (all sets go into one well-shuffled draw pile).
3) Put the quiz cards and the draw pile onto two of the blank rectangles on the board. The third rectangle will be the discard pile.
4) Put the spinner in the blank space in the middle of the board.
5) Finishing tokens: Have each player color the U and D dots in the six circles around the central one. (see photos at right) If you can, try to approximate the colors of your sticky dots. I chose a bright color (orange) for my UP quarks, and a cool color (blue) for the DOWN quarks. It's a silly mnemonic, but I remember that protons are made of two UPs and one DOWN by thinking about "Pro" as being active, positive and "up." Protons are then more "up" than down.
6) To start, your cenral nucleon will be a proton, so put two UP dots and one DOWN dot in the center circle (top photo).

How to play:

The goal of the game is to advance from square to square, following the red arrows until you get to FINISH. Most squares will require you to be holding certain cards before you can leave. These cards are marked on each box. They tell you what happens in that square. The game is over when one player reaches FINISH.

There is no limit to how many cards you can have in your hand, but you will be discarding them as you use them.

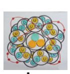
Players will take turns spinning the spinner, but everyone plays on every turn. Have each player choose a colored wedge on the spinner, and they follow whatever the arrow points to inside that color wedge.

"Travel" means that you can follow a red line on this turn IF you have the necessary cards to leave the square you are on. Sometimes you'll get "Travel" and be unable to do anything on that turn.

"Draw Card" means take a card from the draw pile. If you draw something you already have, place the card on the discard pile, face up, and draw another card. Draw until you get something you don't yet have.
NOTE: One type of card in the draw pile allows you to look through the discard pile and choose a card you nee

If the spinner lands on "Quiz" the person who spun takes the top card off the quiz card pile and reads the question out loud. Players are encouraged to discuss the question and try to figure out the right answer. You can announce a group answer, or, if there is disagreement, each player can state their choice. When ready, the answer is revealed by picking up corresponding number tag on the answer strip. If the collective answer was correct, everyone gets to draw a card. If only certain players were correct, they get to draw a card. The used quiz card is returned to the bottom of the pile.

Optional rule: If the spinner lands on the thick lines between the wedges, so that it isn't really on any colors, this means that the players will get this turn to trade one card with another player if they want to. Trade is voluntary. (I found that in my group players really wanted to cooperate like this, so we agreed to this rule and it worked out well.)

Let's start! 

1) Put all the tokens in the box marked START. Make sure they look like protons, with two UP quarks and one DOWN quark in the center.

2) The first player spins the spinner. If the directions on your wedge say "Draw a card" then you take a card from the draw pile. If you get "Travel" you will not be able to do so because you don't have a Neutron card yet. Don't get discouraged if it takes a while to get a neutron, just keep collecting cards you will need on future turns.

NOTE: There are two types of neutron cards. One of them has a bit of yellow arrow on it. This is the neutron card you will need on the last square. In the START square, you will need one of the neutrons that does not have any yellow arrow on it.

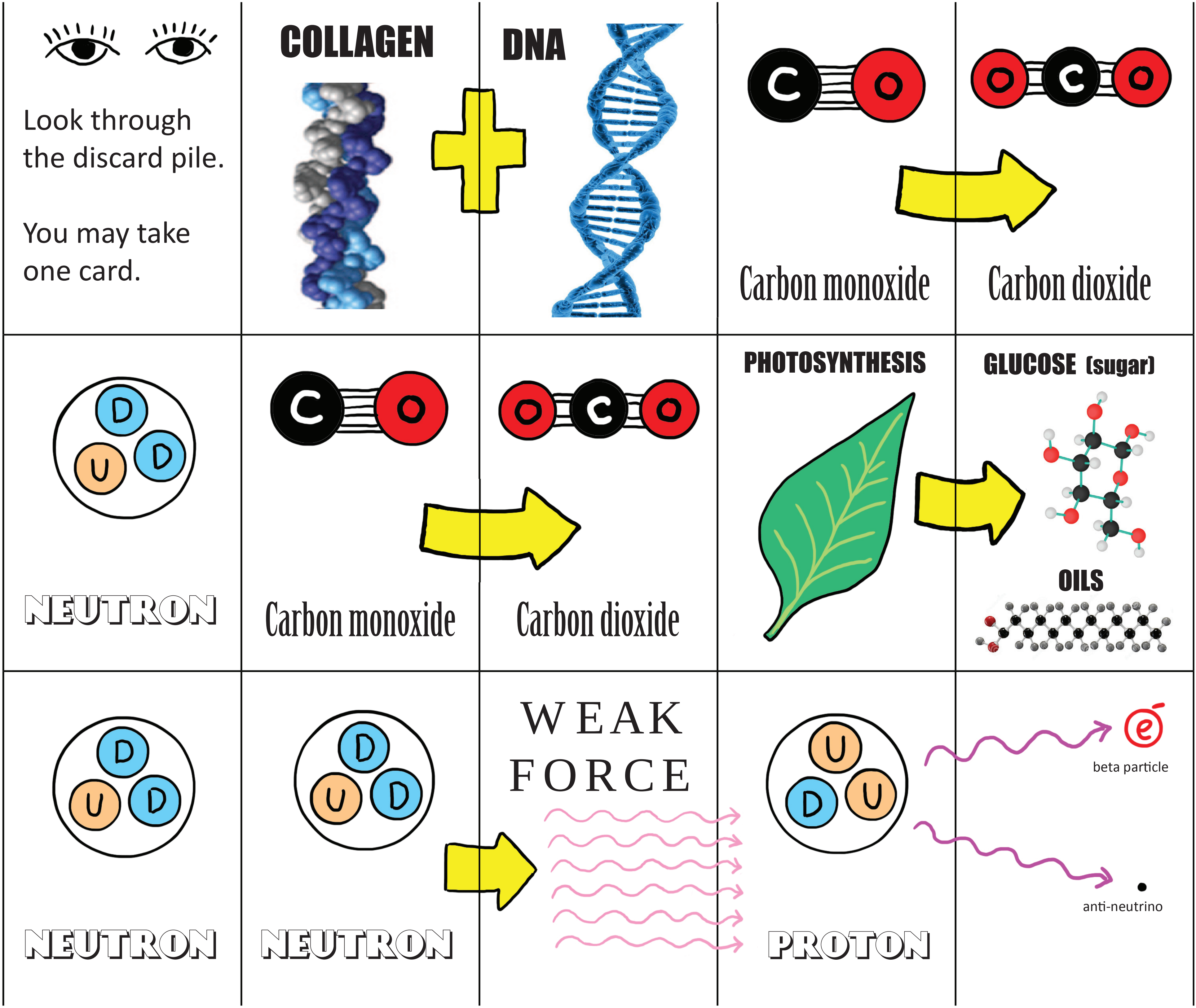
3) Once you acquire a neutron card, you can prepare to leave the START square. Change your central proton into a neutron by pulling off an UP quark sticky dot and replacing it with a DOWN quark sticky dot.

4) If you have your nitrogen atom changed into a carbon-14 atom, the next time to get "Travel" you can follow the red arrow and move to the high atmophere square. Notice that you don't need any cards to move down into the lower atmosphere. (Carbon dioxide can float around a long time before being taking up by a plant.)

5) Play continues like this, with players collecting cards then using them to leave the squares. Once cards have been used to leave a square, return them to the bottom of the draw pile. (Cards that you don't need when you are drawing, go face up in the discard pile.)

6) When you read the last square and have all four cards, change your neutron back into a proton by replacing a DOWN quark sticky dot with an UP quark sticky dot. You can then land on FINISH the next time you spin "Travel."
(An old specimen in which all the C-14 has decayed and is gone is called "carbon dead.")

Make a copy for each player.



You have C-14 atoms decaying in your body right now. About how many decays happen per second?
a) 1
b) 100
c) 1,000
d) a million

1

You have another radioactive element in your body right now. This element is found in many healthy foods such as nuts and bananas.

a) Fe, iron
b) K, potassium
c) Na, sodium

2

Most carbon atoms in the atmosphere and in living things are regular C-12 atoms. How rare are C-14 atoms?

a) 1 in a thousand
b) 1 in ten thousand
c) 1 in a million
d) 1 in a trillion

3

What happened in 1954 that put a huge amount of C-14 into the atmosphere?

a) rockets beign launched
b) testing of nuclear warheads
c) increase in car manufacturing
d) destruction of forests

4

Carbon 14 was used to discover which of these processes?

a) photosynthesis
b) digestion
c) circulation
d) pollination

5

If you eat a potato chip, which part of it would NOT contain any carbon atoms?

a) potato
b) frying oils
c) salt

6

C-13 is another natural isotope of carbon, along with C-12. How much of the earth's carbon is C-13?

a) .01%
b) 1%
c) 10%

7

If someone was born during a time when the atmosphere contained a high level of C-14, would C-14 dating say that they were younger or older than they really are?

a) younger
b) older

8

C-14 is found in some surprising places. This is sometimes blamed on "contamination." Which of these cannot be contaminated, as far as we know?
a) methane (natural gas)
b) coal
c) diamonds
d) limestone

9

To use C-14 for dating objects, what must be assumed?

a) The amount of C-14 in the atmosphere has always been constant.
b) There isn't any C-13 in the sample being tested.
c) The sample is very old.

10

If you measure the level of C-14 in a bone, how long will it be until that level drops by half?

a) 14 years
b) 573 years
c) 5730 years
d) over a million years

11

If a C-14 atom in your skin suddenly decays, how far from your body will the beta particle (electron) travel?

a) 22 millimeters
b) 22 centimeters
c) 22 meters

12

TRUE or FALSE? Scientists can create C-14 in the lab, to use for experiments.

a) TRUE
b) FALSE

13

Which of these substances can't be tested using C-14 dating? (To use C-14 dating, the sample must contain carbon!)

a) limestone
b) methane (natural gas)
c) diamonds
d) quartz crystals

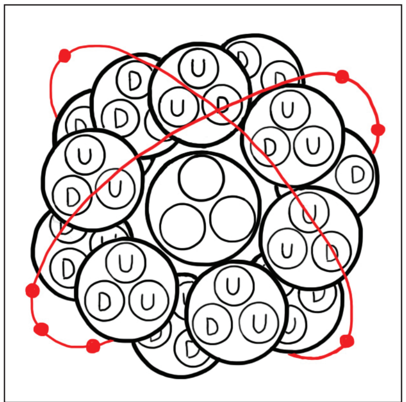
14

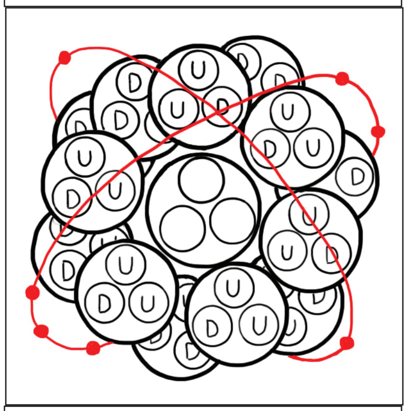
After C-14 is formed in the atmsphere it can go into any of these <u>except</u> one. Which one?

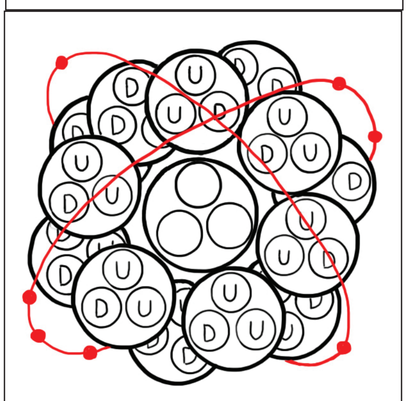
a) the ocean
b) dirt
c) rocks
d) glaciers

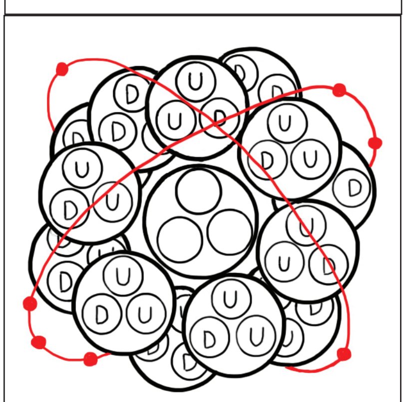
15

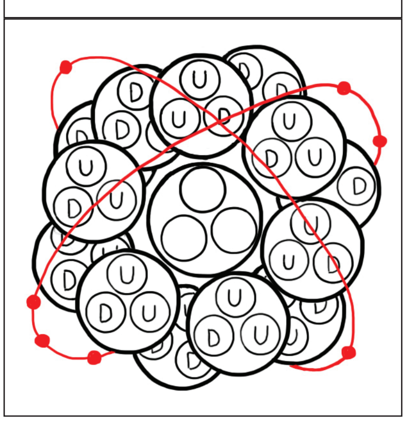
Make 1 copy on card stock











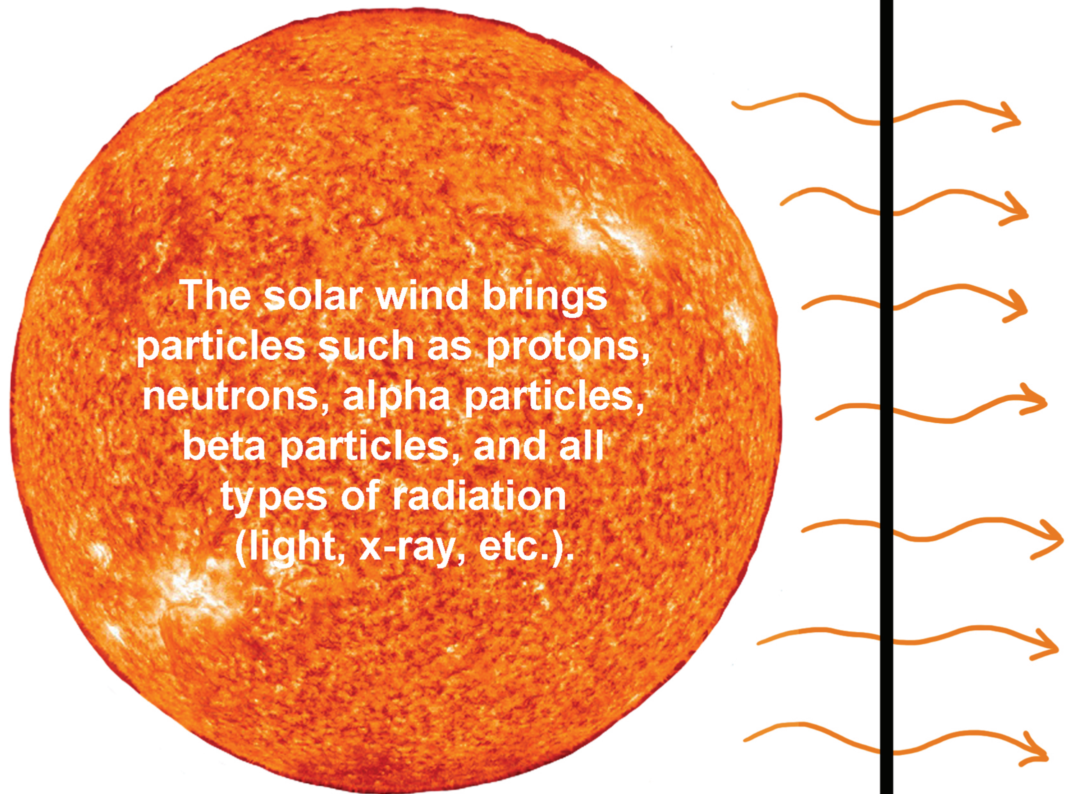
Make 1 copy on card stock

These squares represent atoms, and will be the “tokens” that the players move around the board.

Make all the U’s one color and the D’s another color. Do not color the blank circles in the center. These will have sticky dots applied to them.

Each player should put an identifying mark in one corner of their atom so they can keep track of which one is theirs.

1	c
2	b
3	d
4	b
5	a
6	c
7	b
8	a
9	c
10	a
11	c
12	b
13	a
14	d
15	c

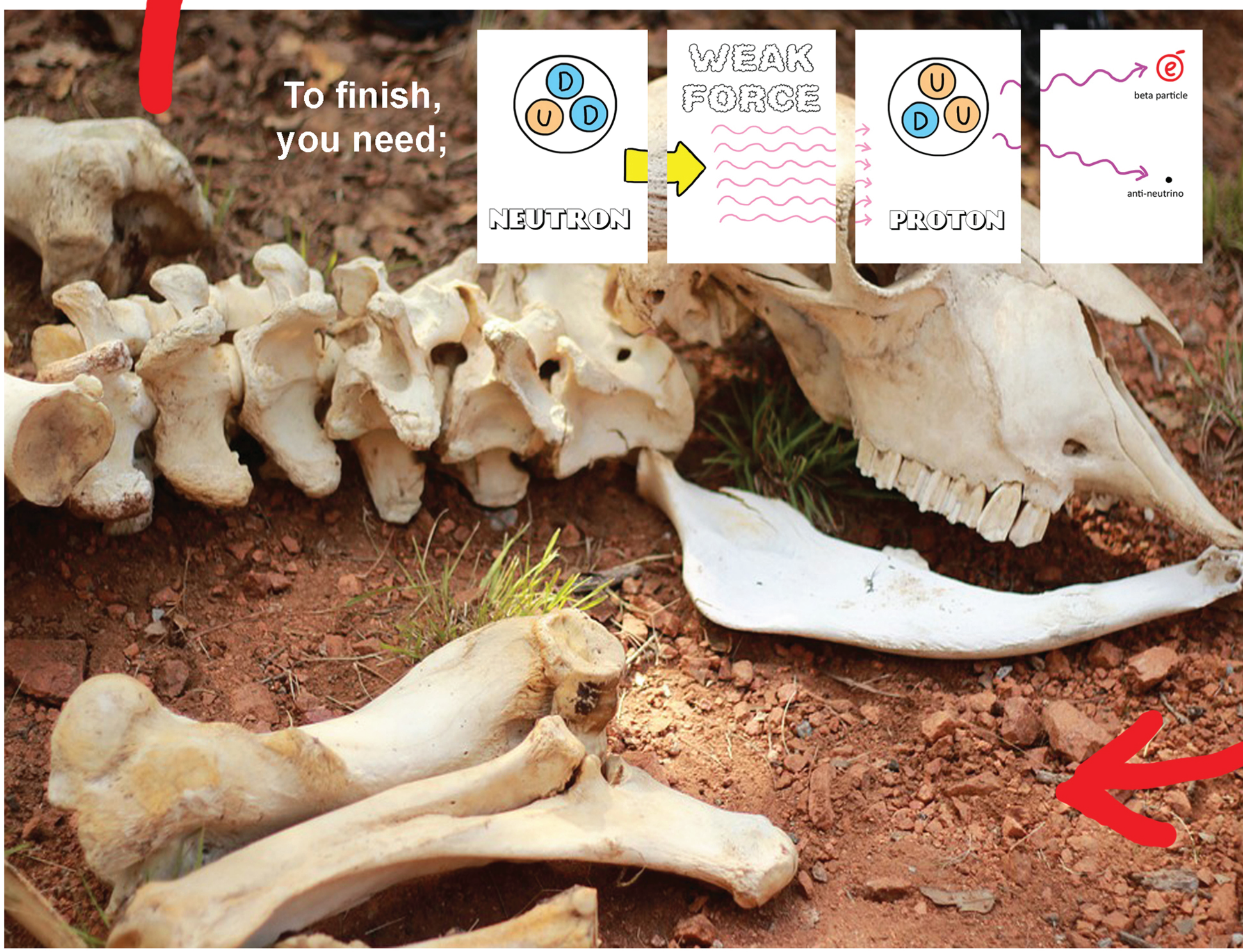


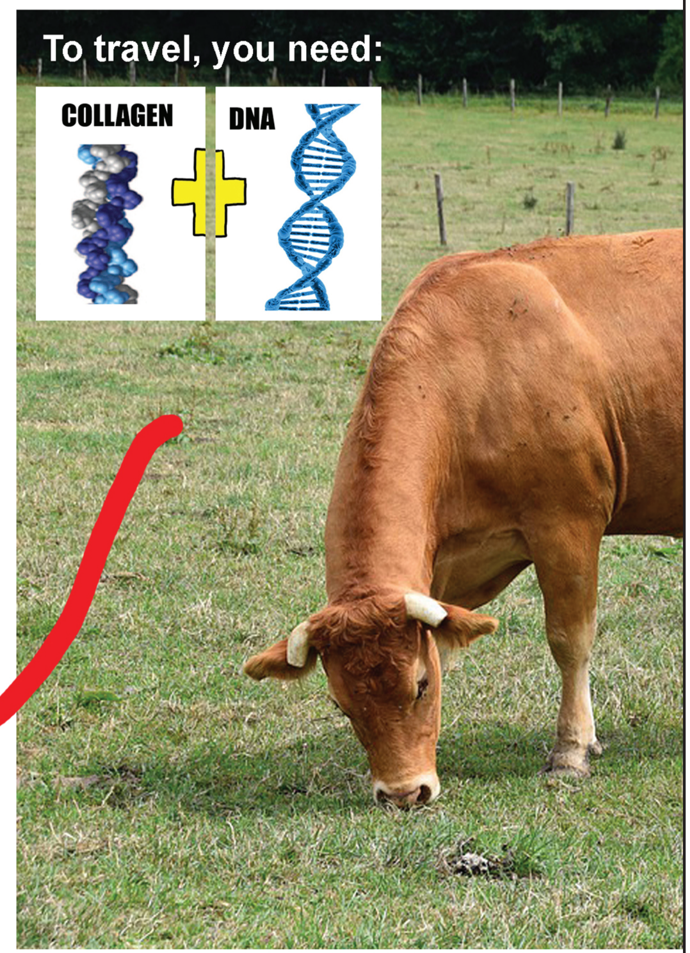
Traveling neutrons smash into nuclei of nitrogen atoms and kick out a proton.

THE CARBON-14 GAME

FINISH

CARBON DEAD

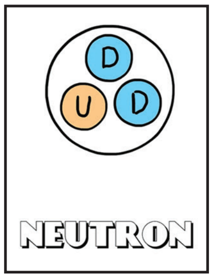


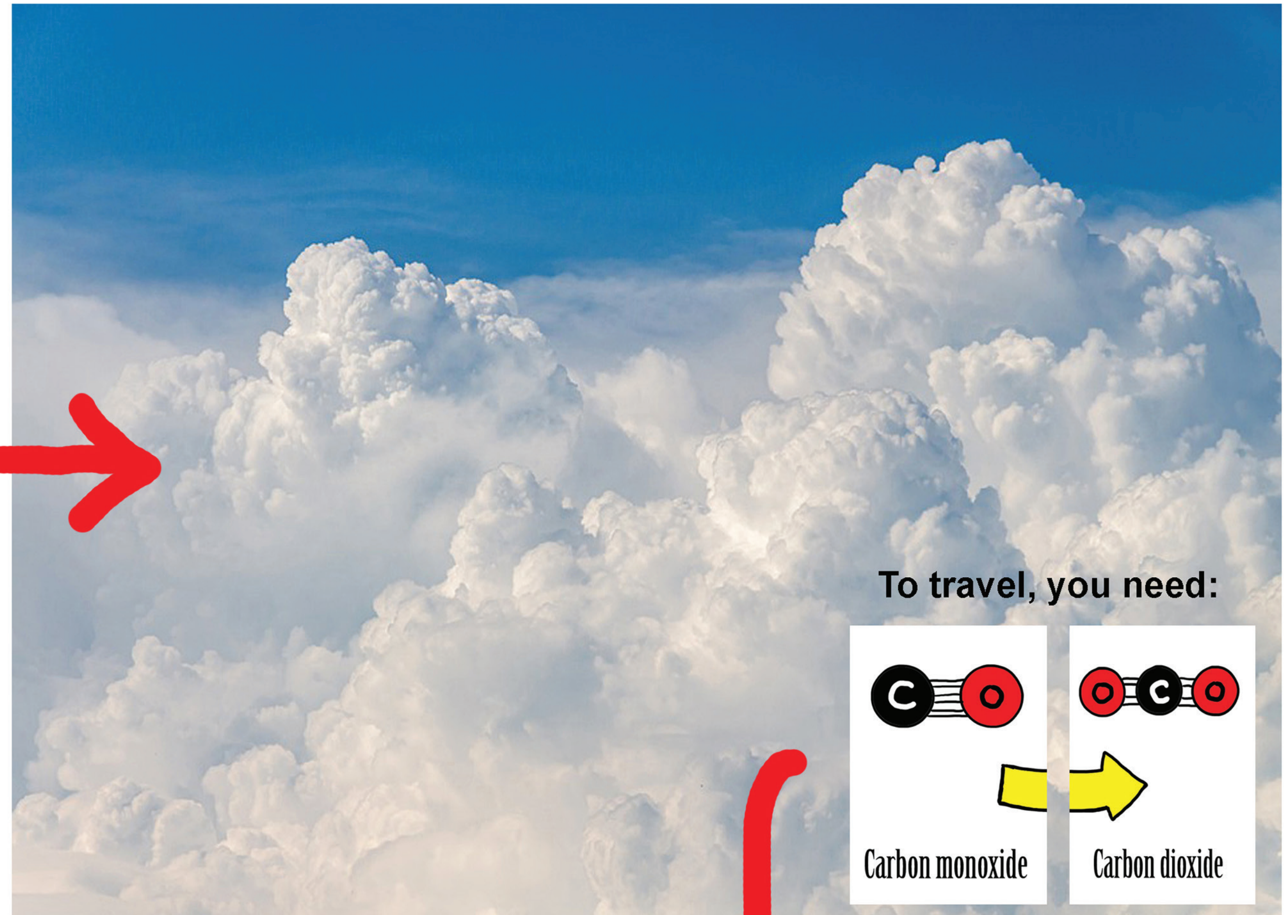


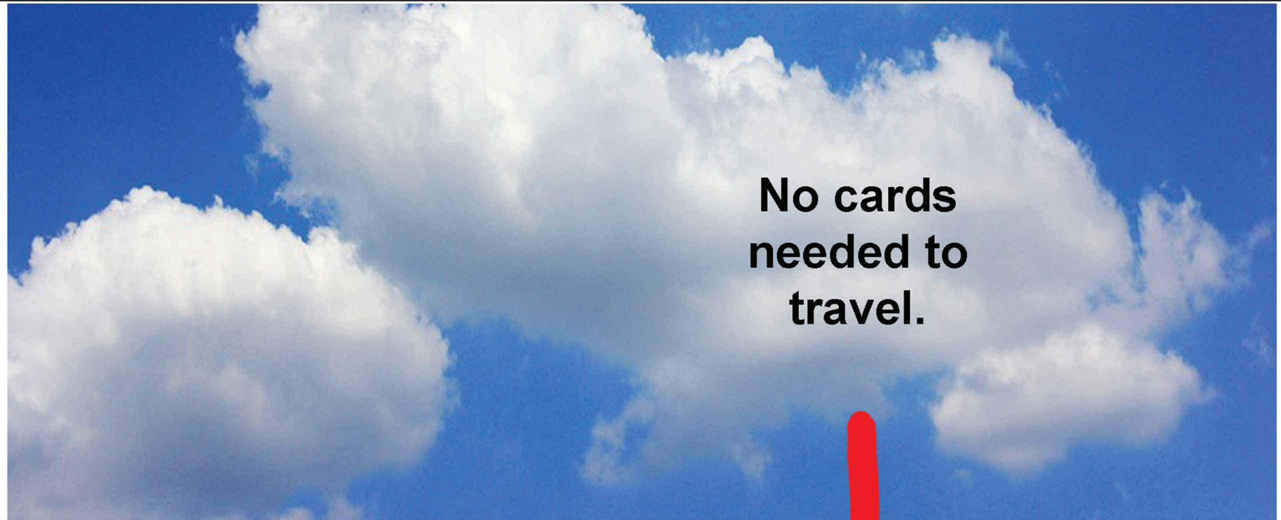
TART

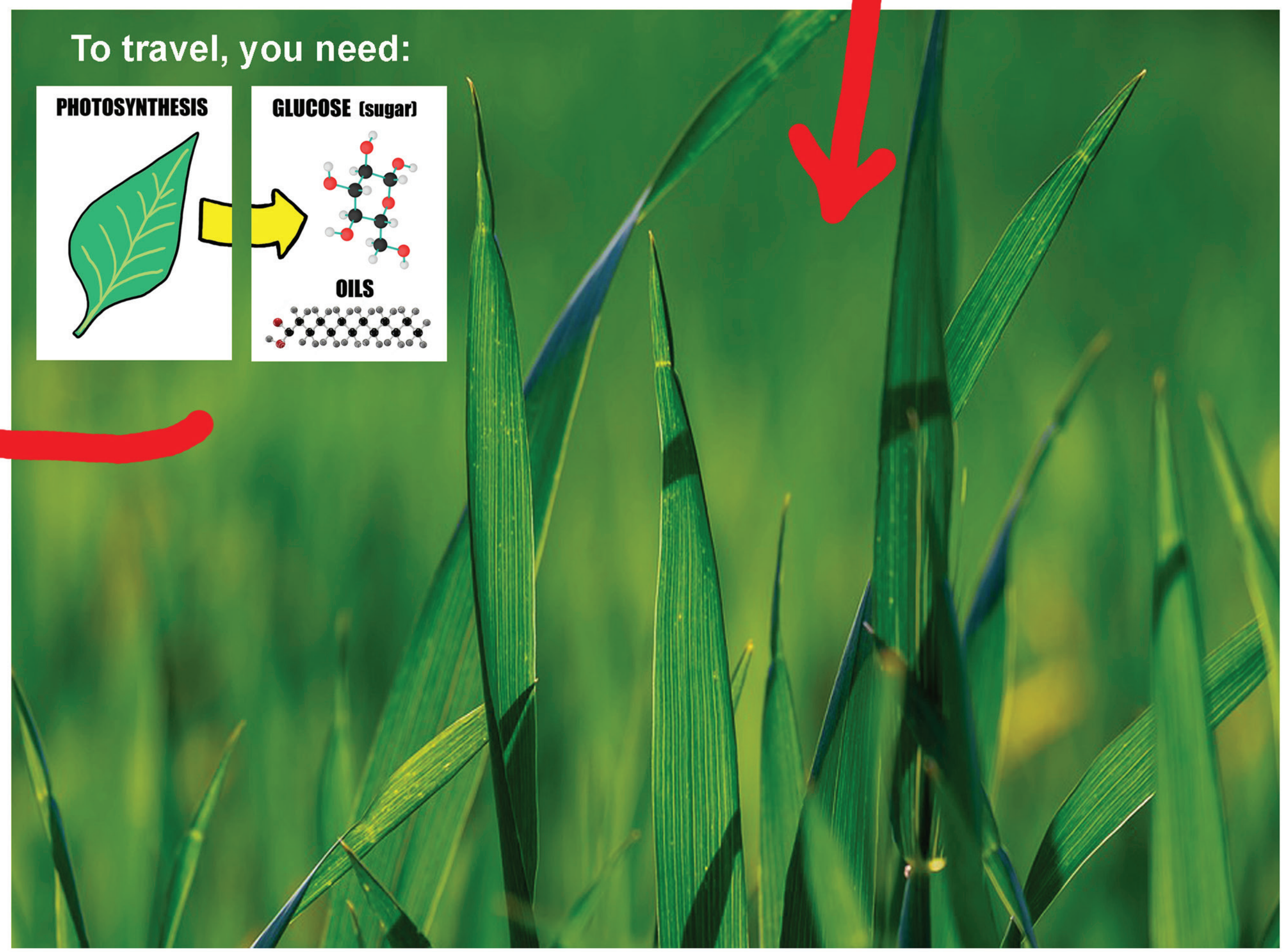
Indicate that a neutron has replaced a proton by replacing an up quark with a down quark.

To travel, you need a:

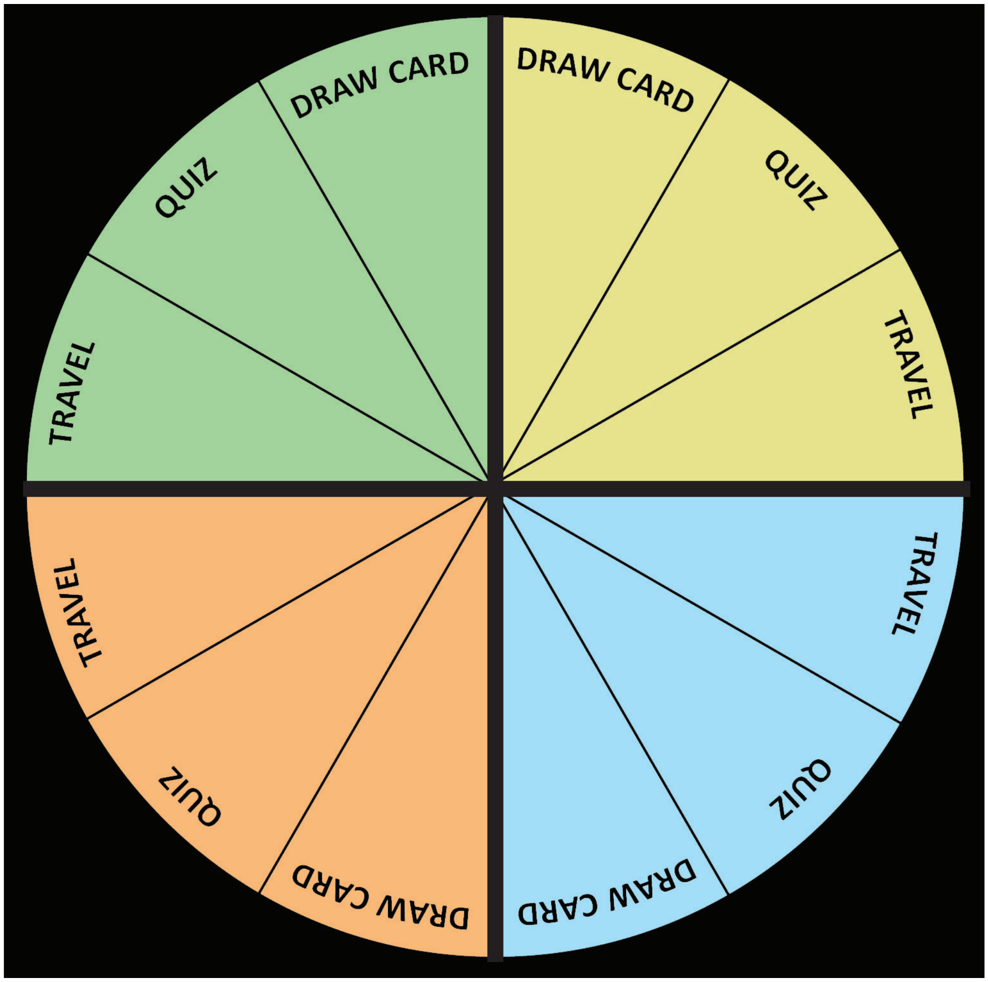




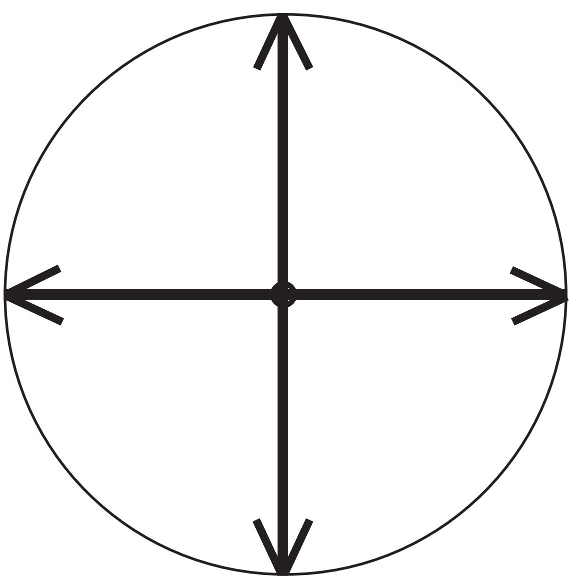

No cards
needed to
travel.


To travel, you need:
PHOTOSYNTHESIS
GLUCOSE (sugar)
OILS

COPY THIS PAGE
ONTO CARD STOCK



Cut around the outside of the black square. DON'T cut out the circle!



Use a paper fastener to attach the arrow circle to the colored spinner. Make the hole in the arrow circle big enough to allow it to spin freely. Don't pin too tightly.

If the circular shape is hard to spin, try cutting it as seen in this photo, so that the arrow points stick out a bit. That gives you a catch point for your finger.

To make the center hole large and smooth, gently bend the circle in half just enough to be able to use a scissor to cut a tiny half-circle along the fold, right where the center dot is.