**Section Seven - - Solar Motor**


## Instructional Information:

### Overview:

Placed in bright sunlight or under a 100-watt bulb, this motor will spin up to 65 RPMs. The black ribs stretched across the cups are made from ordinary plastic bags. These polyethylene polymer strips of plastic contract as they are heated. This action changes the center of gravity of the rotor; the assembly becomes unbalanced and starts to turn exposing other ribs that continue the process.

### Student Skills:

**Observation** Students will observe that the movement of the motor is dependent on full light or sun light directed onto the solar wheel. Students may also stretch a piece of the plastic for themselves and then hold it near some heat. They will observe the plastic shrinks as it is warmed.
**Measurement** Students will make measurements of the work done by the motor and then determine the minimal amount of power exerted.
**Trial and Error** Students will build their own motors and test methods to make the motor more efficient.
**Research** Students can investigate methods of converting sunlight into other forms of energy.
**Application** Students can look for other methods of turning sunlight into energy.

**Related Concepts or Processes:**

Expansion of matter
Polymers
Solar energy
Center of gravity

**Prior Knowledge:**

This piece of equipment can be of interest to students at all levels. This solar motor is an excellent way of demonstrating the Laws of Thermodynamics, as well as one method of changing solar energy directly into motion. However, for students to understand its operation, there are some basic concepts that they need to understand. One idea is that matter can contract or expand due to temperature changes. Most materials expand as they are heated, and then contract as they are cooled. There are some substances that are unique and do not follow this principle; for example, some plastics fit into this category. Another idea is that light is a form of energy. For energy to perform work, it must be changed from one type into another. Another concept that students need to know is that gravity is a force that pulls on all objects.

**Suggestions for Pre-Demonstration Discussion:**

There are several areas of science that can utilize this motor as part of a curriculum lesson. It may be introduced in the study of methods of technology; it can be used in chemistry in the study of polymers. Physics could use it in the study of mechanics--energy changes, power studies, center of gravity, etc. It can also be used in lessons that are reviewing alternative energies. The limitations of current energy supplies, increasing demand, the need for cleaner energy production are also topics that make this piece relevant for student studies. Most students have probably already seen examples of devices that convert sunlight in mechanical energy. Radioscopes, Stirling engines, and solar cells can be presented as examples of devices that can convert solar energy into mechanical energy. Some general questions that may be discussed prior to demonstrating this solar motor might include:

- What are some different types of energy?
- What is radiant energy?
- What colors are the most efficient at converting light into thermal energy?
- What is meant by alternative energy?
- How can we change sunlight into other forms of energy?
- What are some ways that solar energy can be incorporated in people’s homes?
- What is passive solar energy?
- Where does most of the country’s energy come from?

**Suggestions for Presentation:**

This piece works well in direct full sunlight indoors or can be used outdoors on calm days. It can be used in summer or winter and will operate for most of the day. If sunlight is not available, a lamp with a 100-watt bulb can be used if care is taken not to get it too close to the plastic strips. Before the solar motor is put into direct light, check to make sure the cup assembly is finely balanced. This will ensure that it operates properly. As the motor is put under an electric light source, it might be helpful to give it a gentle push to get it started and to keep the plastic from being heated too much and melted.

To explain the operation, start by taking a short strip of the plastic material and stretch it for the students to observe. Additional samples should be passed around for students to try. A discussion of polymers can be added at this time. Students can also discuss how most materials expand when heated. If the long piece of the stretched polymer is held under a 100-watt light bulb and brought near the bulb, the plastic can be observed contracting. The next step in the explanation is to observe what happens to the cup assembly when it becomes top heavy. To do so, tape a paper clip to the top of the assembly to demonstrate that the heavier side of the cup rotor will rotate to the bottom. Students can be questioned about what the strips will do to the cup assembly as the strips are exposed to light. Some other questions that can be asked of students include:

- Why are the ribs black?
- What happens to this plastic when it is gently heated?
- What do you think might happen if this material is cooled?
- Would this device work if a clear plastic were used instead of a black color?
- What happens to the cup assembly if it becomes top heavy?
- What force causes the cup assembly to rotate?
- What changes might we try to make this motor spin faster?

**Post-Demonstration Activities and Discussion:**

- As a writing assignment, have students explain the process of how the motor operates.
- Students can do additional research on the characteristics of polymers.
- Students can research other methods of converting solar energy into other useful forms.
- A design problem might include designing other uses for the contracting ability of the polymer.
- Students may try building their own model and can then test variables such as additional mass on the flywheel, changes in the size and types of cups.

- The strips can be tested and altered by changing the color, the brand type, the thickness, the width, and the number.
- Try using mirrors to direct more sunlight onto the top strips; this additional energy can increase the performance. Using this method, the motors have reached speeds up to about 86 RPMs.

**Discussion of Results:**

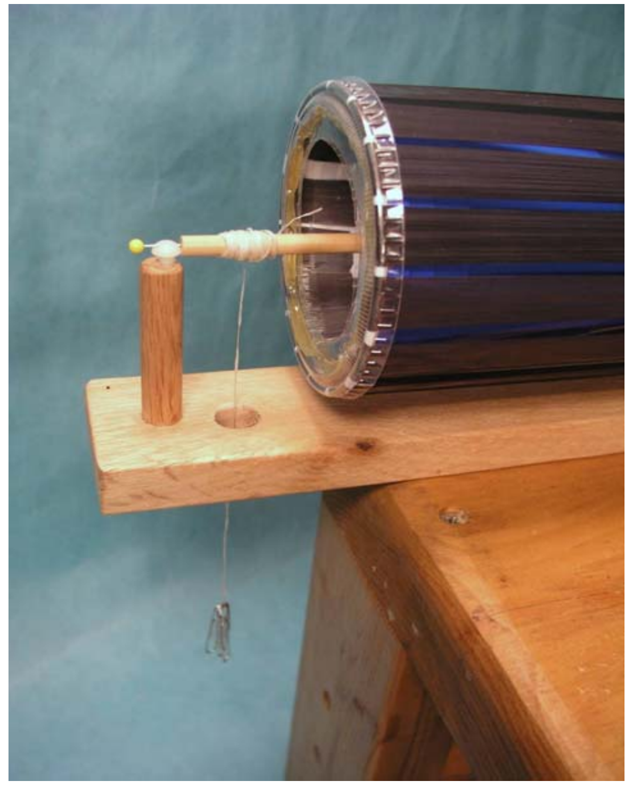
The movement of this motor is dependant on the unique property of the stretched trash bag strips. These strips are made from a plastic material called polyethylene. This chemical is a common example of a polymer. One of its characteristics is that it is made of very long molecular chains. These long molecules are stretched to their elastic limit during the stretching process. If more pressure is applied, these long chains are broken when the plastic tears apart. By heating the strips, the polymer chains contract, pulling the molecules closer together. They do not expand due to cooling as some students may suggest. The action of the polyethylene contracting is quite different from a uniform expansion of matter as a result of kinetic energy. As this plastic is heated temporarily, the material pulls tighter and shrinks to a smaller size. The plastic remains “shrunken” until pressure is applied to stretch the molecular chains out again.

The movement of the motor is due to the materials at the top of the cup assembly contracting slightly; this action is pulling the cups together at the top. The action is not noticeable since it is so slight. It is noticeable if the plastic is heated sufficiently, but do not try it with the cup assembly. With the cups pulled together, the assembly becomes unbalanced. The motor is now top heavy and starts to turn and fall toward the bottom. As the assembly turns, a new section is then exposed to light and is heated. This new spot becomes top heavy causing this section to fall. The action is continually repeated making the top section always unbalanced; the cups are constantly trying to adjust to become
balanced. The end result is the motor turning because it is trying to right itself. The highest speed for the cups in direct summer sunlight seems to top out around 65 RPMs.

The addition of mass to the flywheel as suggested at the end of the assembly directions has some benefits and drawbacks. This addition can make the cup more efficient, but it will not make it spin faster. The “good news” is that it can enable this tiny motor to perform small tasks; the bad news is that it becomes more finicky and will require more adjustments for balancing.

**Additional Suggested Activities:**

After the basic assembly and operation of the solar motor have been mastered, it may be time to put this motor to some useful tasks. The first project to tackle could be calculating the horsepower that one of these mini-dynamos is putting out.



To calculate power, the solar motor needs some adjustment made to the design. The first suggested change would be to replace the drinking straw support posts with something sturdier. A wooden dowel with nylon screws is an excellent choice for replacing the straw supports.

The flywheel will need the additional mass added to it to make it more efficient. The cup lid on the opposite side should be changed; instead of cutting out a large hole in the lid, reduce it to a 1/4 inch size hole, the same diameter as the axle. This will direct all forces to the heavy flywheel.

The next change would be to extend the shaft by about two inches on one of the sides. A very small hole is drilled into the wood shaft and then a half-inch hole is drilled directly below it into the base.

Tie a meter long string onto the motor shaft

The calculations of power require that the motor do some work. In this case, the motor is lifting two or three paper clips. The formula for work is force x distance (Newtons x meters). Measure the mass of the paper clips in grams and convert to Newtons. Measure how high the paper clips will be lifted, one half meter is a suitable distance. Multiply the weight times the distance to get the work done in joules.

Power can be calculated by dividing the time in seconds into the work done (seconds into joules). Use a stopwatch to time how long it takes the motor to lift the paper clips. The calculations will yield the power in watts. It will be a very small amount.

Students will find it interesting to calculate the horsepower. One horsepower is equal to 746 watts. To calculate the horsepower, divide the number of watts by 746.
A reasonable number is about 1.5 millionths of a h
1.5 micro-horsepower.

**Additional Neat Activities:**

**Morning Alarm**

Here a striker is attached to the solar motor along with a separate bell. As the sun shines through the window, the motor begins to spin, and strikes the bell.

**Bouncing Lights**

Another idea is to add a crystal ball to the end of the motor shaft. As the motor turns in the sunlight, the crystal has many faceted sides that act like prisms and separates the light into bouncing colored spots that are scattered throughout the room.

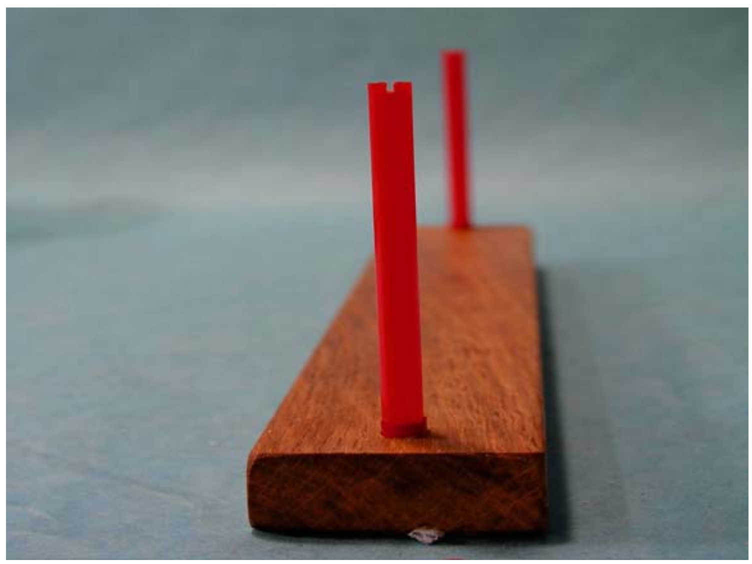
The crystal ball was purchased at a hardware store; it is a plastic cabinet handle.

## Directions for Assembly:

**Materials Needed:**

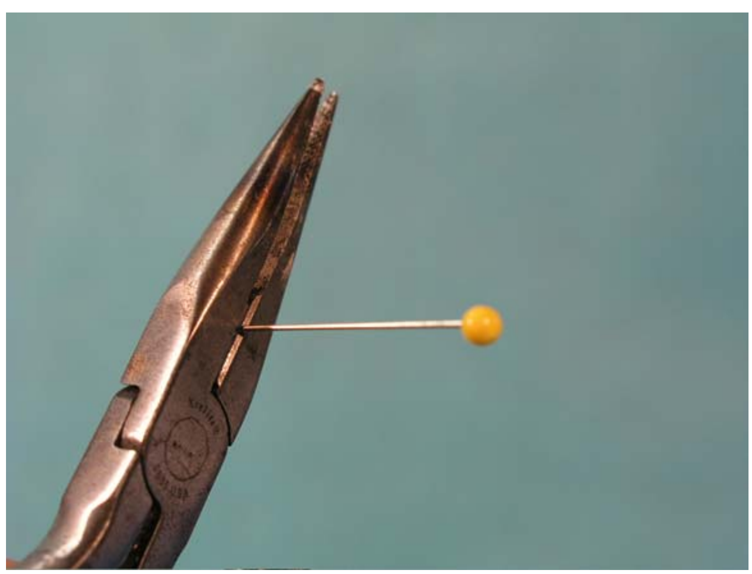
2 16 oz plastic cups with lids
1 Piece of rigid foam insulation, 1/2 inch to 3/4 inch thick
1 Black thin plastic trash bag
1 1/4 in. wood dowel, 11 inches long
1 Wood block for base, 3 x13 inches
1 Piece aluminum metal tape
2 1/4 inch nylon washers
1 1/4 inch push nuts
2 5/16 inch clear plastic tubes or drinking straws, 4 inches long
2 Large straight pins

**1.** Start by cutting and sanding the wood for the base. The dimensions are 3 inches by 13 inches. Drill holes about one half inch deep for the straws to fit into. They should be spaced about 11 and 1/4 inches apart. Put the straws into these holes, and then hold the wood dowel between the two supports to check the size. The dowel should fit loosely between the two straws. If the dowel is a tight fit, remove a small piece from one end of the dowel. The straws have small notches cut into them to hold the pin axle assembly. These are cut into the straw using a nail file like a small saw.

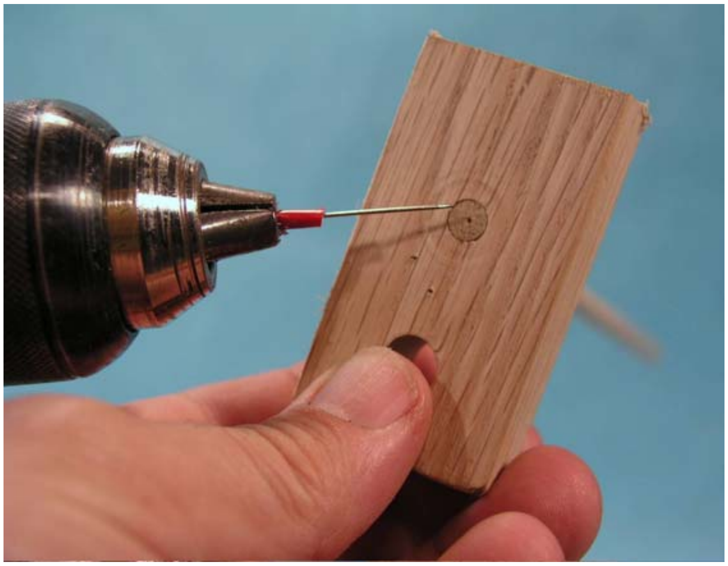


**Safety Note:**
**The following safety equipment is strongly suggested:**
**Goggles for eye protection**
**Dust mask to guard against breathing in airborne sawdust**
**Gloves whenever power tools are used.**

**2.** The pin axles are going to extend out from the dowel rod and rest in the straw supports. Both ends of the dowel need to be drilled with holes before inserting the pin axles into them. Without pilot holes the pins tend to bend when trying to insert them into the dowels. Cutting off the ends of a straight pin can make a homemade drill bit. Wrap a bit of tape around one end so that it will fit tightly into the drill chuck. With the pin in the drill chuck, cut the point off of the pin; this cut edge will act like a regular drill bit.

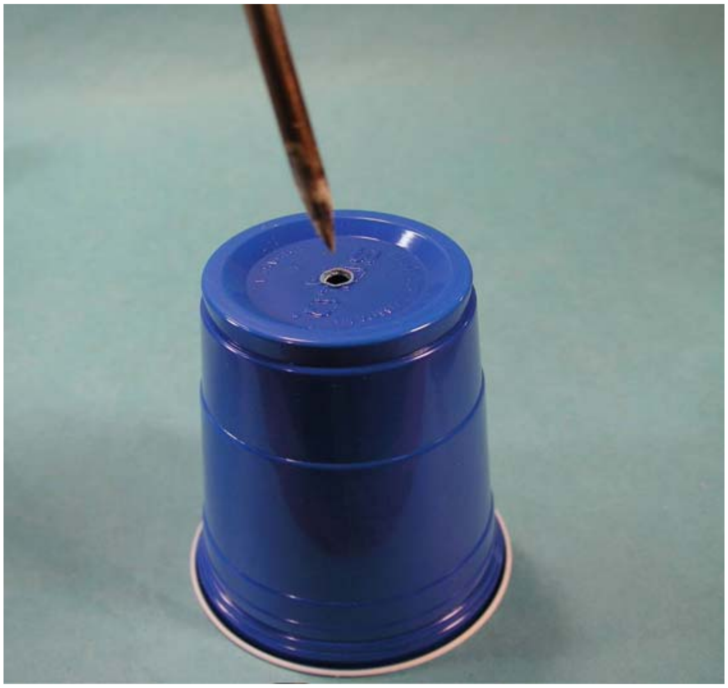


**3.** Do not attempt to drill holes into the dowel by holding it in your hand. The dowel can be clamped into a vise to hold it steady.  Another method for holding the dowel during the drilling process can be made by drilling a 1/4 inch hole into a scrap piece of wood.  Use this to hold the piece by inserting the dowel into it. The end of the dowel should be flush with the surface.  Both ends of the dowel rod need to be drilled with the homemade drill bit.

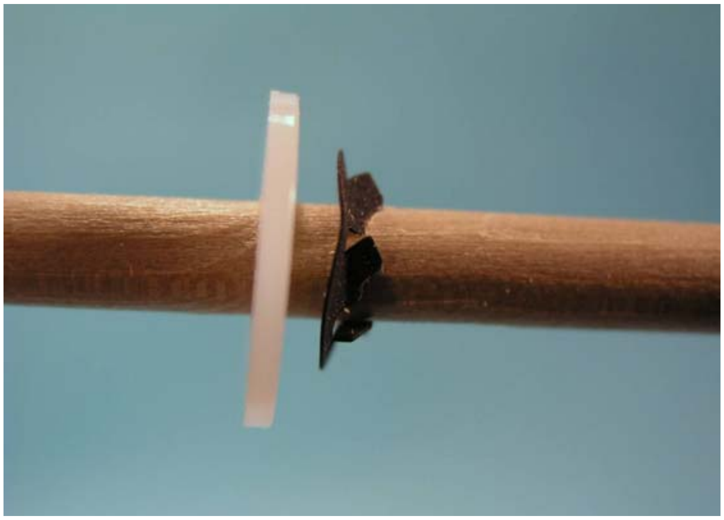


**Safety Note:**
**Wear gloves when performing the next step:**

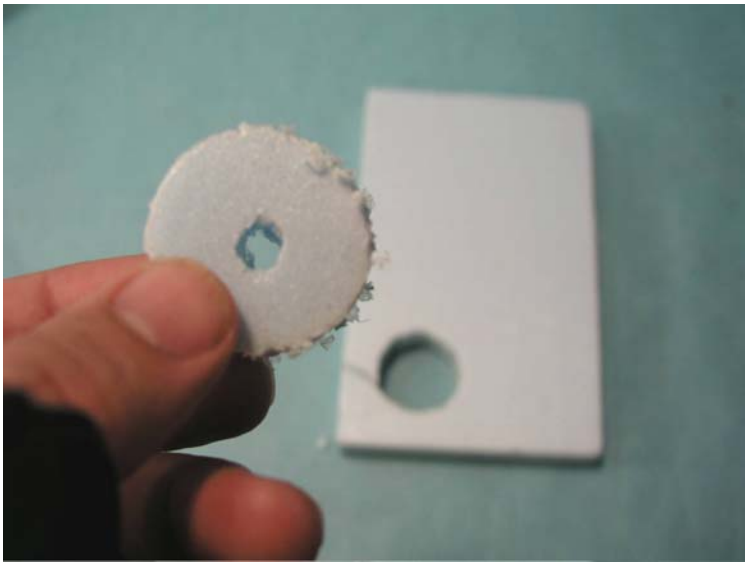
**4.** Before the cups can be mounted onto the dowel rod, they will need a quarter inch hole made in the center of the cup bottom. Do not use a drill bit as it may end up tearing up the bottom of the cup making the holes too large and useless.  The best method is to melt a hole through the cup by heating the nail or screwdriver just hot enough to push it through the plastic material. Before starting the hole, locate the center of the bottom and then trace a pattern using the end of the dowel rod as a guide.



**5.** The construction of the cup assembly starts with the first slide nut and nylon washer forced onto the wooden dowel.  The slide nut takes some effort to get it onto the dowel.  The nuts may bend slightly as they are wrestled onto the dowel; this is normal and will not hurt their integrity.

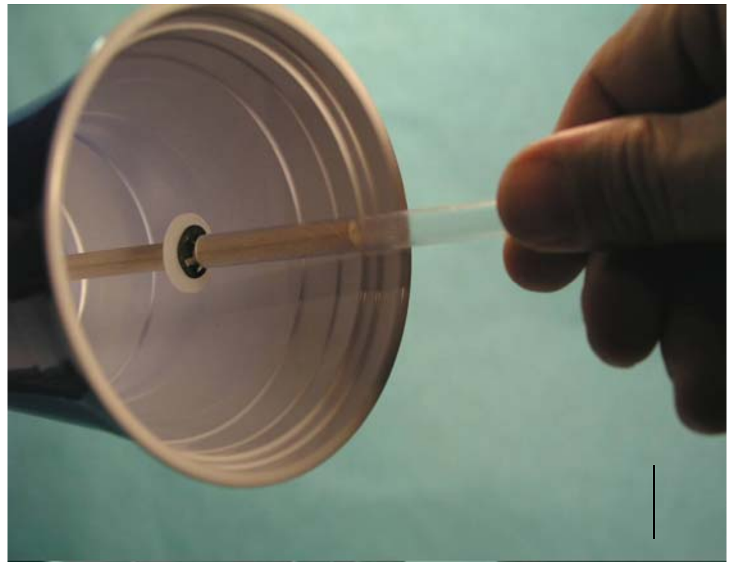


**6.** The position of the washer and slide nut can be determined by holding the dowel next to one of the cups. The dowel rod should extend past the mouth of the cup by about 1/2 inch. If the slide nuts have been pushed too far on the dowel rods, remove them by sliding them all the way off the dowel and start again.

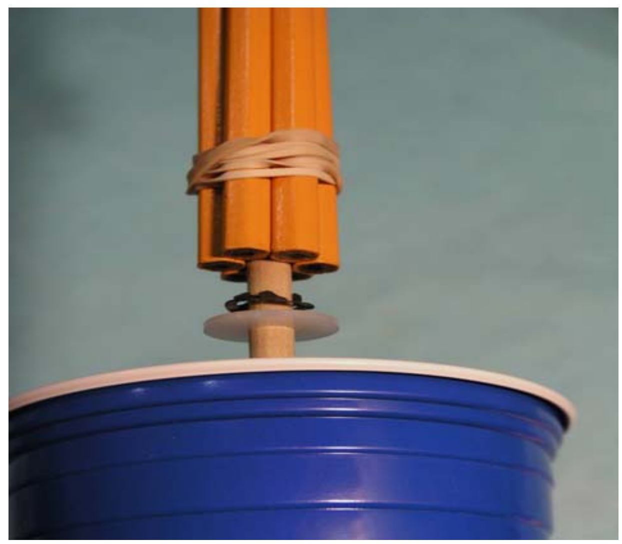


**7.** For this motor to operate properly, the bottoms of both cups must be separated by at least one-quarter to one half-inch during the motion of the motor. The spacer that will sit between the cup bottoms is cut out of the piece of Styrofoam insulation material. The diameter of the circle is one inch and the hole in the center is 1/4 inch. This spacer was made out of a scrap of foam insulation material and was cut out with a sharp knife blade used in a sawing motion.

**8.** With the first cup in place on the dowel rod, the next step is to slide the foam spacer onto the rod and then follow it with the second cup. With both cups in the correct position on the dowel rods, the rods should extend out of the cups by an equal amount, preferably about a half-inch. If the ends of the rods do not extend out the same length, take the cups off of the dowel rod and adjust the position of the first slide nut. Since the nut only slides in one direction, you may have to slide it off the dowel and start over.



**9.** Once the cups have been adjusted to the correct position, it is now time to permanently attach the second washer and nut. Slide the second washer onto the dowel followed by the nut into the second cup. Once this second nut is slid onto the dowel rod, it will not be able to be removed. The whole cup assembly needs to be tightly held together. This requires that the second slide nut must be pushed firmly down against the bottom of the second cup. A 5/16-inch plastic or metal tube can be used to do this.

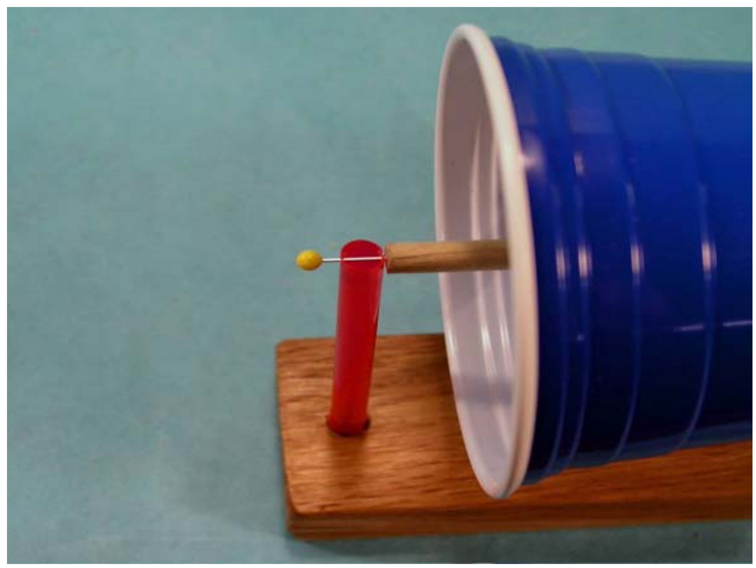


**10.** If a tube is not available, an alternative method is to position 6 pencils around the dowel and then wrap a rubber band around them to hold them in place. This can be used to push the slide nut down tight against the bottom of the cup.

**11.** When pushing the slide nut into position, it is helpful to position one end of the dowel down against the table while pushing against the slide nuts. Push firmly with the tube or pencil assembly to make the slide nuts tight against the cup bottom. Turn the whole cup and shaft assembly over and try this procedure from the opposite side.

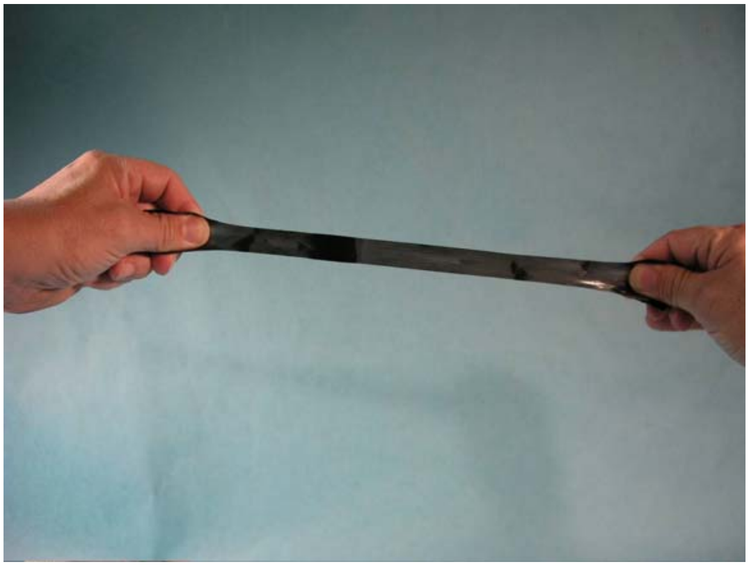
**12.** The washers and nuts must be seated firmly against the bottom of each cup. The dowel rods must extend outside of the lip of the cup by at least one-half inch.

**13.** The dowel rods are now ready to have the pins inserted as the final portion of the axle. Try pushing the first pin into one of the ends of the dowel rod. It may be difficult to push the pins into the ends of the dowels more than half an inch. The pins used as the axles may have to be shortened depending on their length. Use the cutting edge of the pliers to clip off the extra section of pin. With the pin axles in place, the assembly can be placed onto the base. The cup assembly should turn freely and should not rub against the straw supports. If the dowel rubs against the straws, take out one of the pin axles and sand or cut off a small section of the dowel rod and try it again.



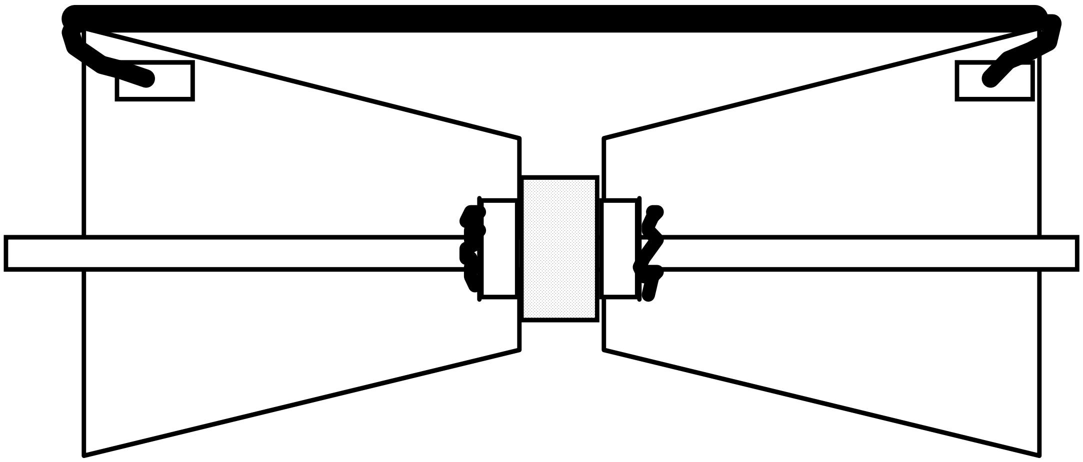
**14.** It is now time to make the plastic strips that are responsible for the action of the motor. The ribs are cut from a thin black plastic garbage bag. I have found the cheapest bags quite often are the best. The strips are 1.5 inches wide and are cut parallel to the top of the bag. The length should be about 4 inches long. Cut about 20 strips, as a few extra will be needed for practice. The edges must be cut smoothly with no jagged edges, or these will cause the plastic to tear during the next procedure.

**15.** The stretching of the plastic has a certain satisfying feel to it and can be quite entertaining. This plastic material is a polyethylene polymer and needs to be stretched to near its breaking point. To stretch the plastic to the required thinness, grasp each end of the strip with a thumb and finger and pull very slowly and very firmly. It feels almost like stretching taffy or chewing gum. As the plastic is pulled, it will become much thinner and longer and will stretch out about four to five times its original length. The plastic will let you know when it has reached its elastic limit and will break if it is pulled too far.



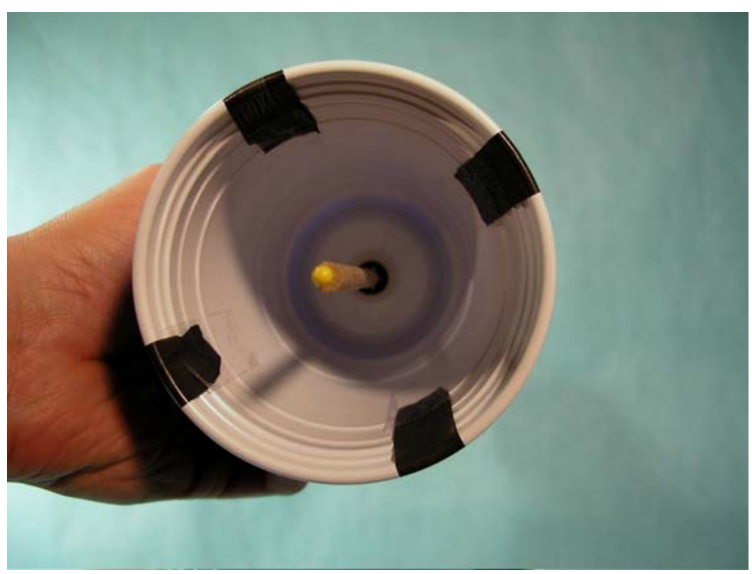
**16.** There are two methods that will be used to fasten the ribs permanently to each of the cups. The first of the two methods will be to use a one-inch piece of plastic tape to attach the cut end of the plastic strip to the inside of a cup. About one inch of the strip should be taped inside the first cup.

**17.** Determine the length of the strip by stretching it to the inside of the second cup. Pull it gently to the inside of this second cup and cut the strip long enough to have a one-inch overlap inside the cup. Use the plastic tape to attach the strip to the inside of the second cup. It should be firm, but not too tight. These strips will adjust themselves to the right tension when they are heated.



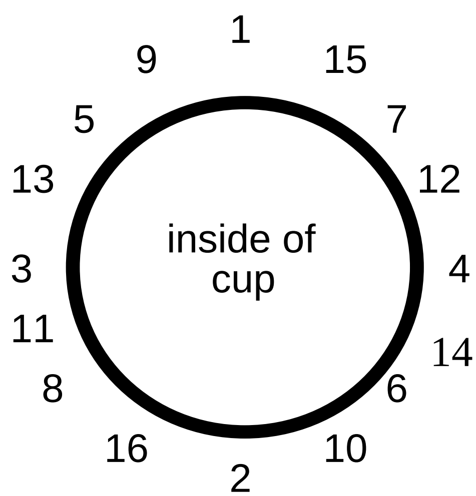

**18.** When the first strip is attached to both cups, it should bend the cups slightly toward each other on one side more than the other. Repeat the steps for stretching the rest of the plastic strips to get them ready for attaching to the cups. The placement of strip number two is directly on the opposite side from strip number one. Strip number two should be stretched tight enough to center and align the cups once again.

**19.** The third and then fourth strips should be added to the cup assembly an equal distance between the first two strips. These first four strips should be evenly spaced around the cups.

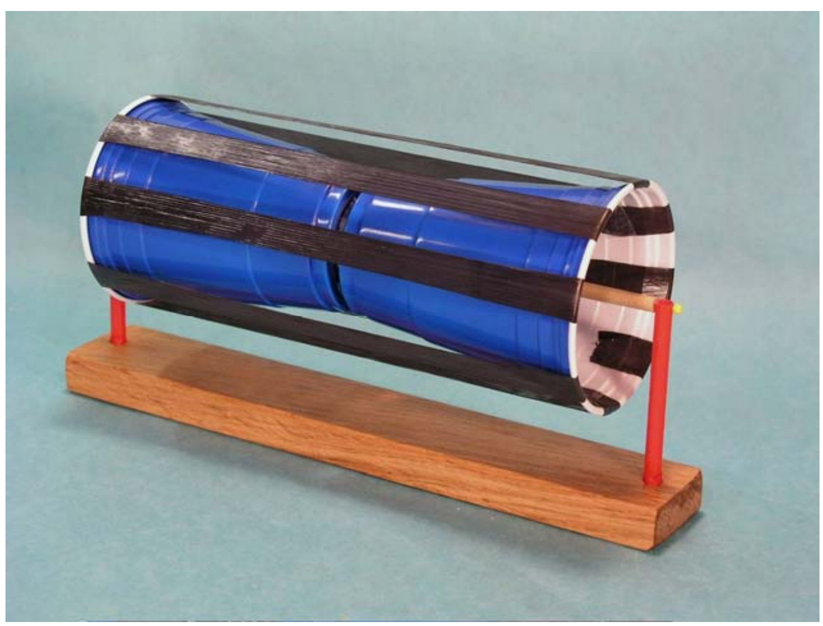


**20.** Put the assembly on the stand. The cups should be approximately centered and balanced on the dowel. Turn the cup assembly a half turn and let it go. If the assembly is unbalanced, the heavy side will rotate to the bottom. To balance the cups, remove the tape from one end of the strip at the top of the cup assembly. Reapply the strip and tape again but slightly looser to balance the cups.

**21.** The drawing at the right shows the suggested order for applying the strips to the cup assembly. The sequence will help to ensure that the cups are approximately balanced during the assembly.

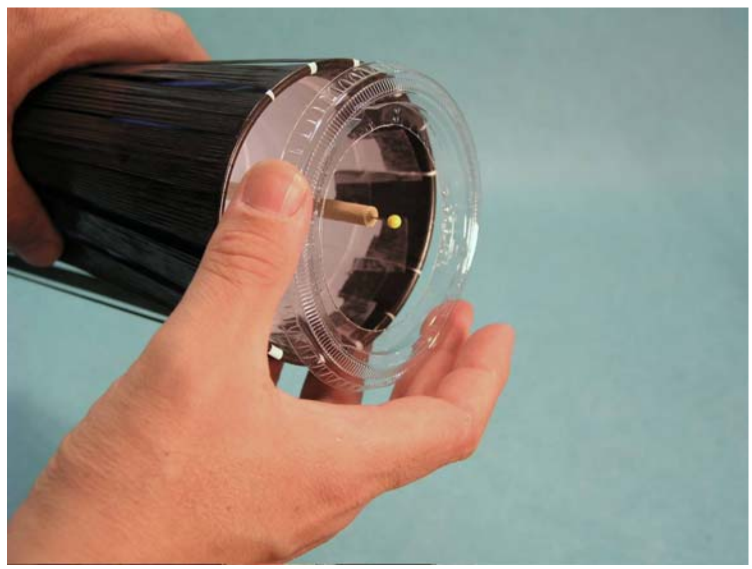



**22.** After completing the eight strips, place the assembly back on its stand again to see that it is balanced. If the assembly appears to be unbalanced, loosen the strips toward the topside of the assembly and then reattach them. Complete the rotor by attaching the remaining eight strips to the cup assembly. After they are added, check the balance and make any final adjustments if needed. It is difficult to get the assembly perfectly balanced. As part of the last step, an application of counterweights will fine-tune the balance of the assembly.

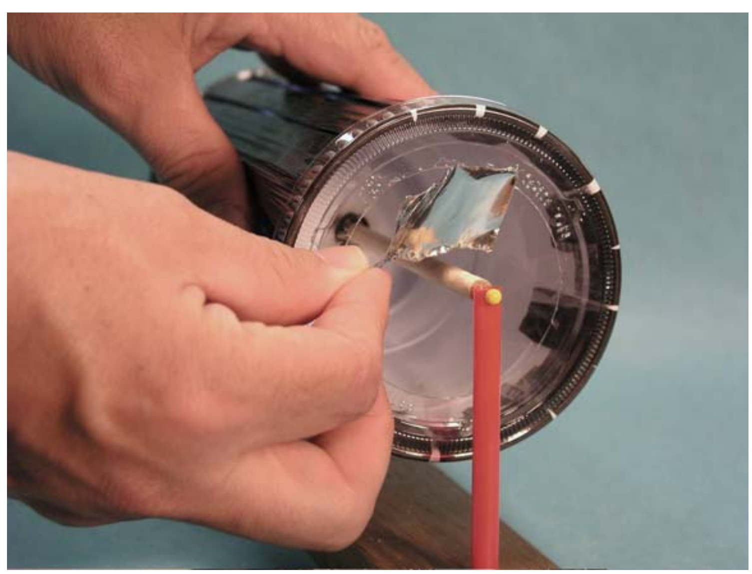


**23.** The second method of securing the strips onto the cups will be attaching the plastic lids over the cups and strips. Use scissors to cut out most of the center portion of each cup lid. Leave the outer one-inch of the cup intact.

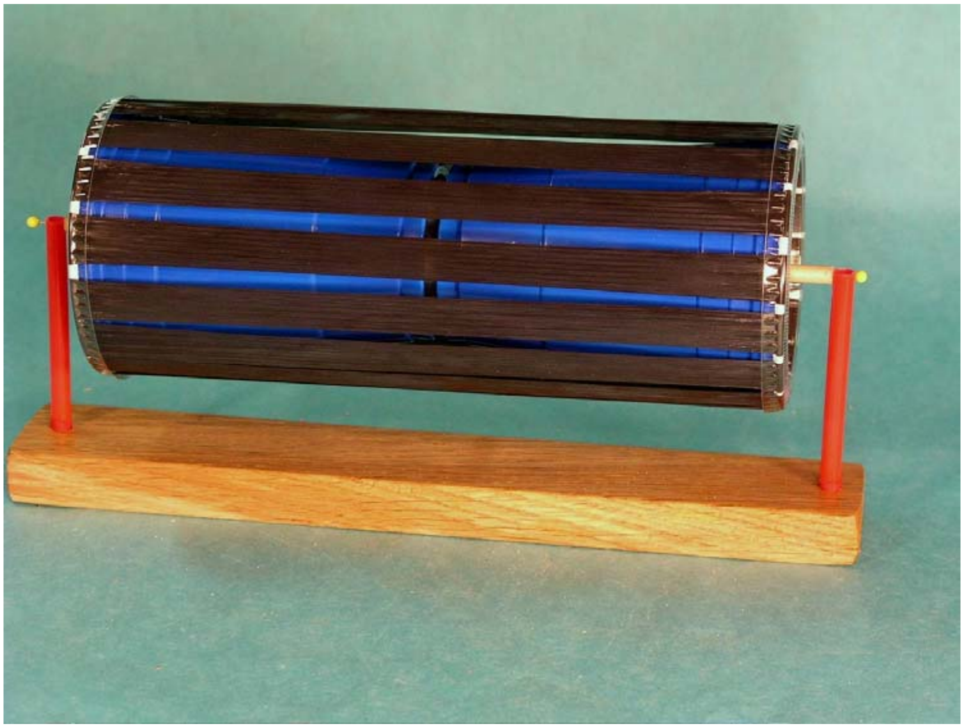
**24.** The lid can now be pressed onto the cup mouth and over the sixteen strips. The lid will help lock the strips in place in case the tape fails to hold.



**25.** It is very important to the operation of the motor to have the cup assembly finely balanced. To do so, place the assembly back on the stand once again. If the assembly is unbalanced, the heavier side will rotate to the bottom. To balance out the assembly the portion of the cups facing up needs to be made heavier. To act as counter weights, tear off tiny slips of metal foil and stick them inside the lighter portion of the cup. Keep adding small pieces until the assembly is balanced. It is very important that the assembly be evenly weighted all around.



**26.** It is now time for the final test. Place the completed assembly directly under a lit 60-watt bulb, about 5–6 inches away. If the motor does not start turning immediately, give it a gentle push, and it should continue to spin on its own. Do not let the motor sit under a light for extended periods of time if it is not turning.



**27.** Occasionally the cup assembly may become unbalanced. Add additional counter weights as needed. Store the assembly off the stand.

**28.** For advanced studies, additional weight can be added to the plastic lids to act as a flywheel. Solder used for plumbing can be wrapped around a cup circumference to bend it into a circular shape. A hot glue gun is used to permanently attach this additional mass to the plastic lid.

**Safety note: Caution hot glue can burn fingers**