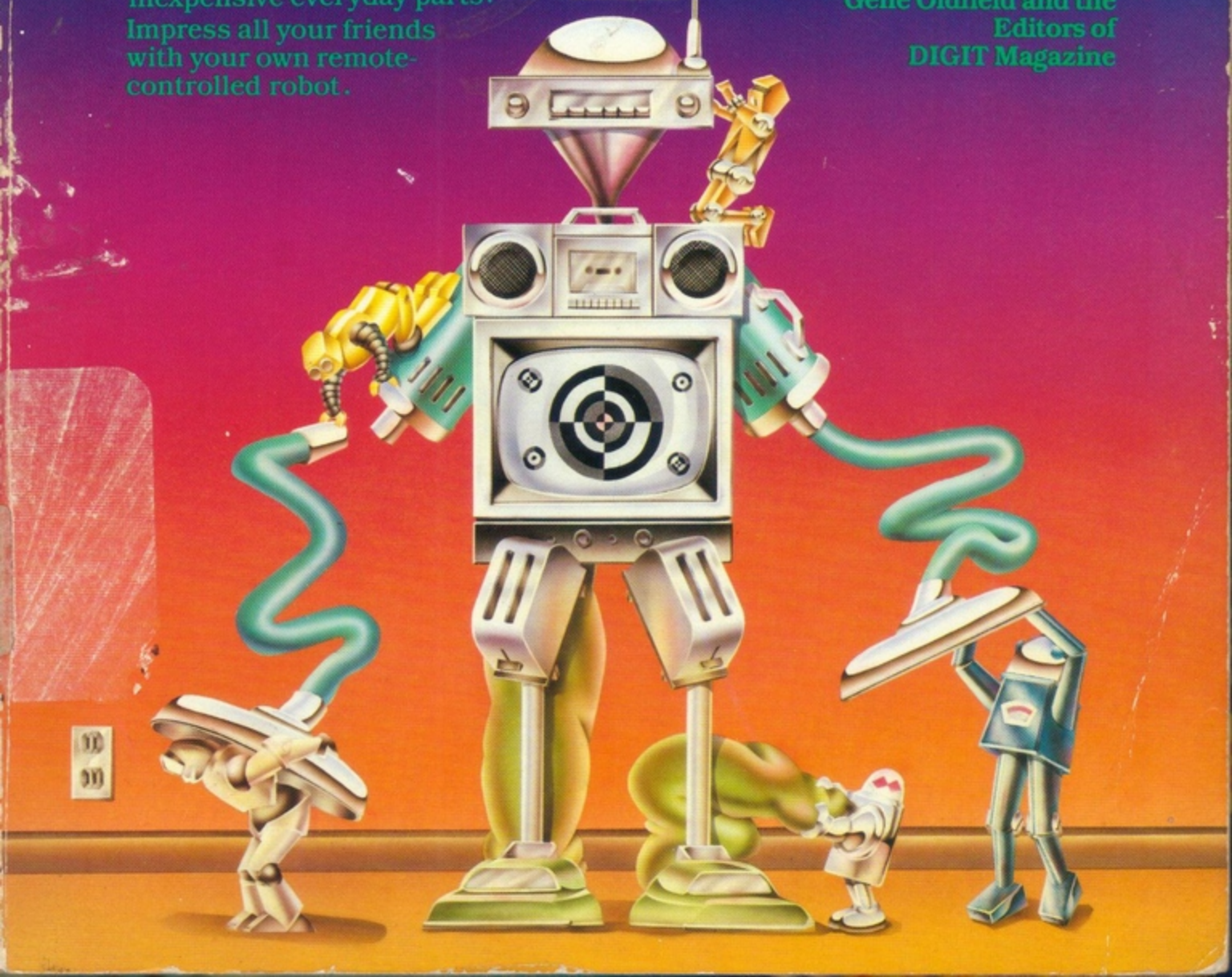
THE Everyone Can Build a ROBOT BOOK

Easy to build from inexpensive everyday parts. Impress all your friends with your own remote-controlled robot.

by Kendra Bonnett, Gene Oldfield and the Editors of DIGIT Magazine



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BUILDING THE MOTH—A LIGHT-SEEKING ROBOT

We all have observed that moths are attracted to light. We've watched moths and other small insects flit about a kerosene flare. They are drawn instinctively to the light and begin a dance of death that ends when they fly straight into the fire.

As a robot builder, you might wonder, if you can duplicate something like the moth—something that responds to light. Let us consider a moth to be a motorized, mobile platform with light sensors that steer it toward maximum light. Batteries are needed to power the robot. A couple of small transistors will amplify the signals that the light sensors generate in order to create enough power to drive the moth's motors. The gearhead motors, in turn, drive the wheels.

Let's start with the complete parts list on the next page. We have used Radio Shack parts when possible. Note that our list is for a basic moth. As you become more familiar with robot building, you may wish to change the design or add special features, such as LEDs.

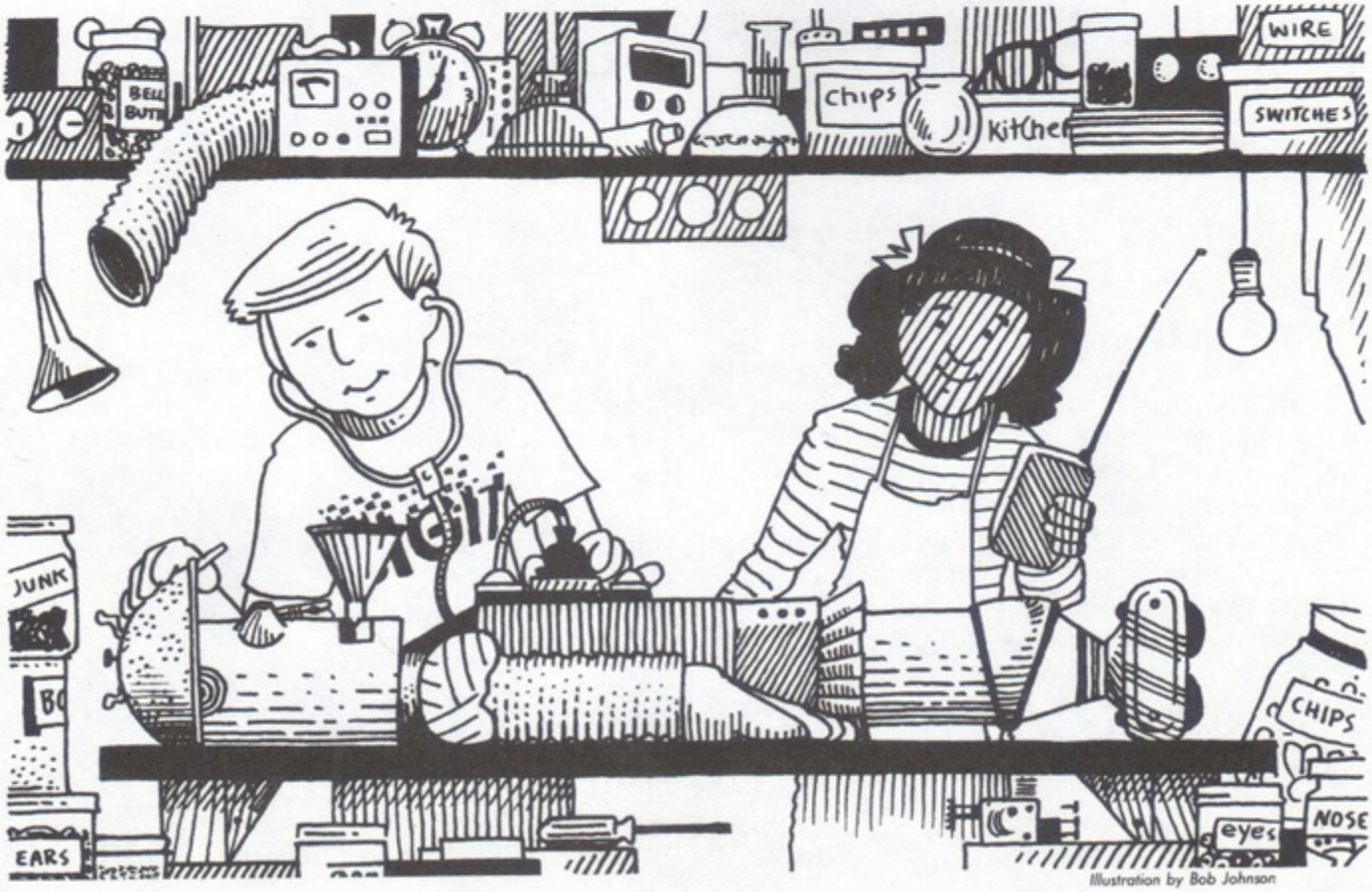
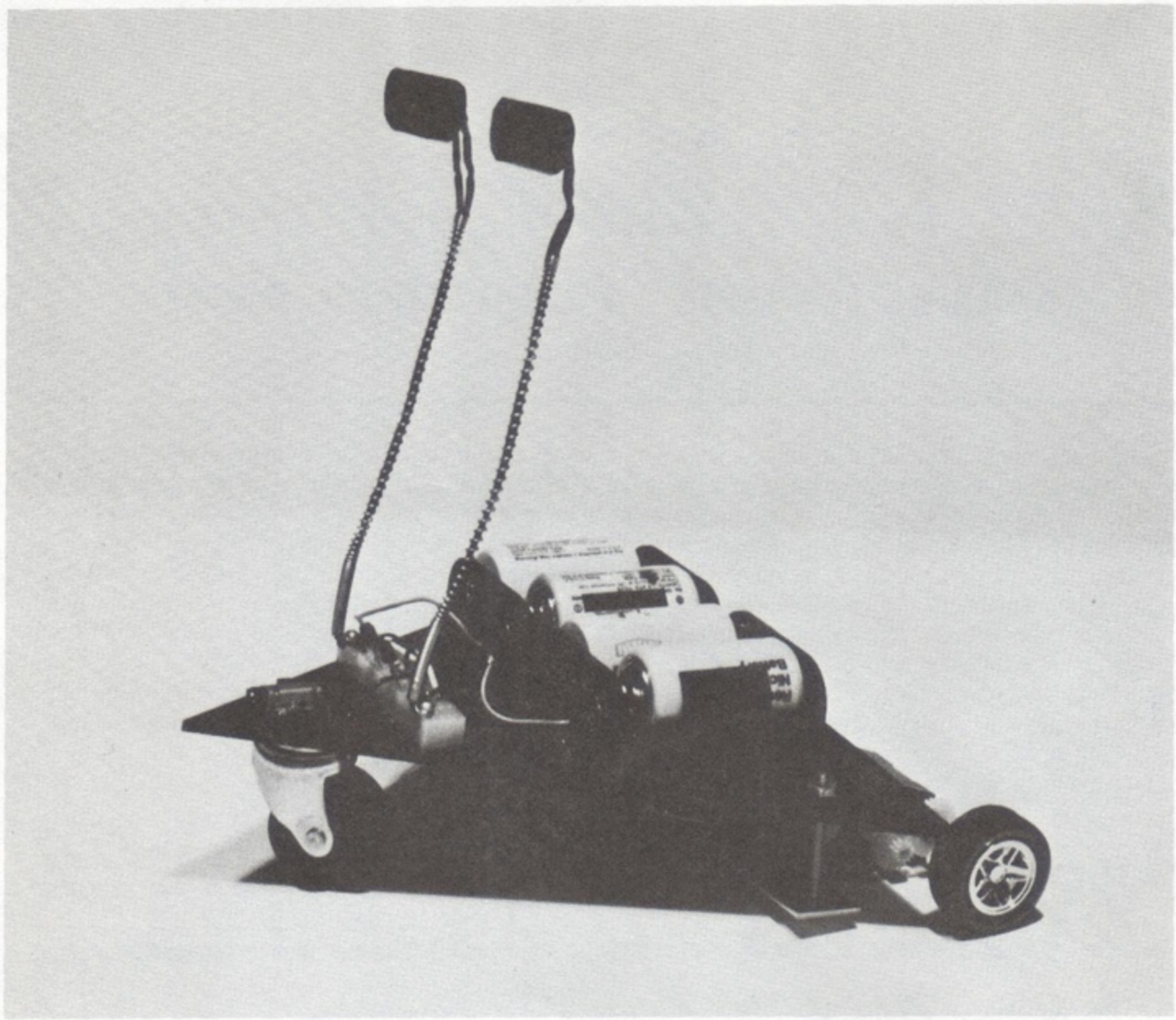


Illustration by Bob Johnson



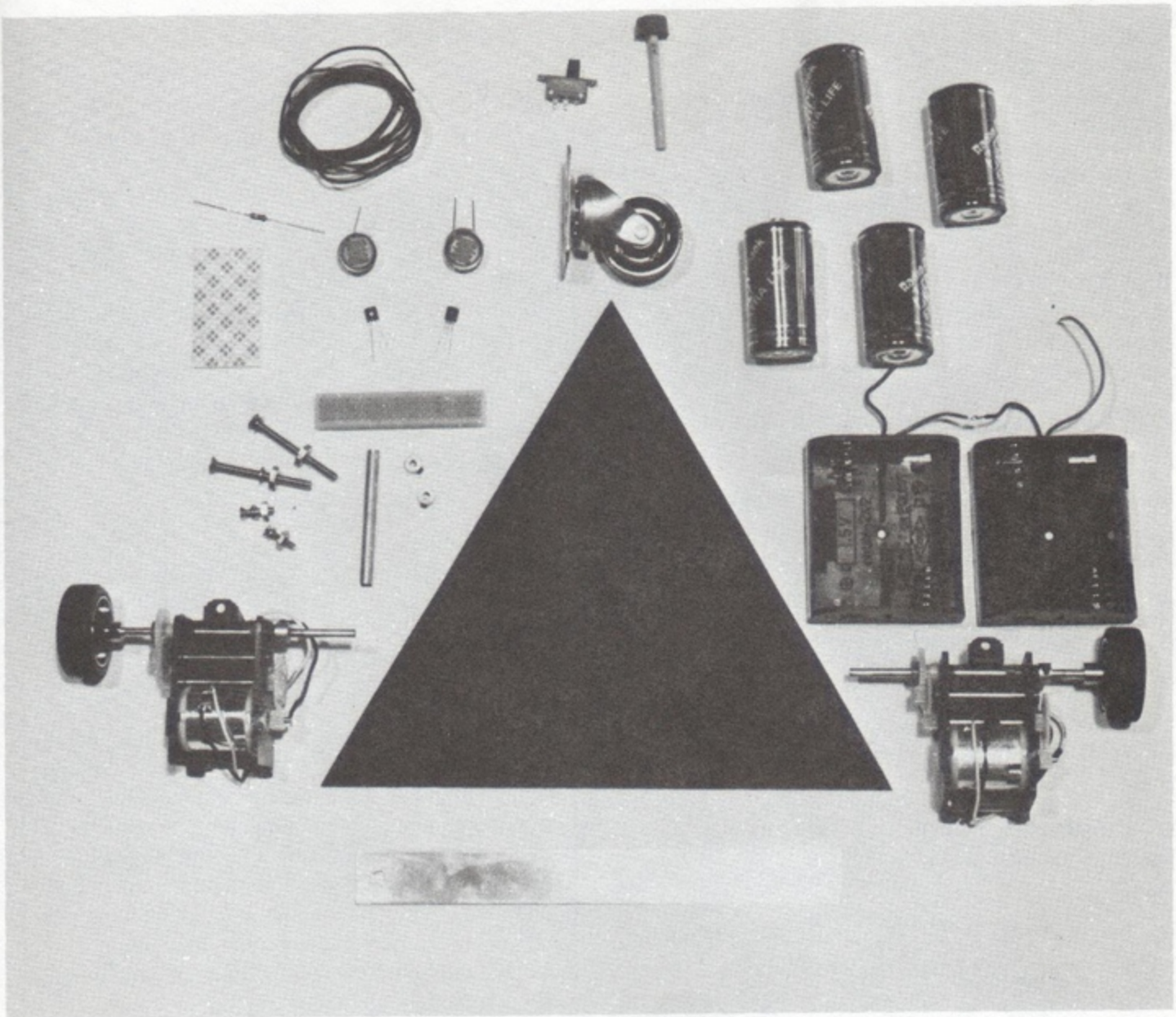
SHOPPING LIST

1. Triangular platform (wood, plastic, any non-conductive surface) about 1/8" thick and 8"x8"x8"—The advantage of plexiglas is that most metal and plastic objects (except polyvinyl chloride) will adhere with a super glue (e.g., Crazy Glue). The plastic pegboard screen in the Lite Brite toys works well too. All the screw holes have been drilled. *WARNING—do not try burning or melting polyvinyl chloride plastics. They give off a poisonous gas.* Colored plexiglas costs about $7 (includes cutting).

2. 1 small, **protoboard** (also called a breadboard or experimenter's board)—Minimum size is 12 holes x 4 holes; you may want one slightly bigger to allow for future circuit experimentation. The Radio Shack board is a bit too large. If you cannot find a smaller one, you can cut it to size. BEFORE CUTTING: Strip part of the backing off and remove the metal clips in the columns you plan to cut through. A small board costs about $4.

3. Super glue (e.g., Crazy Glue)—If you are using a plastic or plexiglas platform, you can attach most components with glue; $1.50.

4. 2 plastic **battery holders** (for 4 C batteries)—Radio Shack #270-385, $.99 each.



5. Package each of #4-40 x 1/2" **flat head steel machine screws**; #4-40 x 1/4" x 3/32" steel **hex nuts**; #4 steel **split lock washers**—When assembling, put washer on just before nut. This helps keep screws from loosening.

6. Small, furniture caster for front wheel, about 1-1/8" diameter—If you cannot scrounge one, go to a hardware store. Make sure it has a flat base, not a shaft, so it can be screwed or glued to the Moth's platform.

7. 2 **gearhead motors** 3-6 VDC (volts DC) and gear units from 2 radio-controlled toys—These are the very best and easiest to use.

8. 2 **disc capacitors** (.05 μF)—Don't buy capacitors, if the motors (above) already have them. See step 7A for an explanation. Radio Shack #272-134, $.85 for two.

9. Brass strip .064 x 3/4"—Hobby store $1.25.

10. 3 steel **flat head screws** (6/32 x 2"); #6.32 steel hex nuts; #6 steel split lock washers—Hardware store $.50.

11. Brass tubing 3/16"—A 7-8" piece will do; hobby store $.45.

12. 2 **toy car or airplane wheels, 1-½" d**—Scavenge these from radio-controlled toy or buy at hobby store for around $2.50.

13. Plated brass Dura-collars 3/32"—Hobby store $.80 for four. If you can't find them: Du-Bro Products Inc., 480 Bonner Rd., Wauconda, IL 60084.

14. Double-sided adhesive foam strip—The foam should be very thin; hardware or hobby store $1.15.

15. 1 **index card or a thin piece of plastic, such the plastic lid on a box of greeting cards or stationary**—This will be used to make blinders for the photocells.

16. 2 **cadmium-sulfide photocells**—Radio Shack #276-116, $1.29 each.

17. 1 small bottle of **flat black enamel paint** (model-builder's paint)—Hobby store $.49.

18. 2 **general-purpose, amplifier transistors** Radio Shack #276-2014, $.89 each, or #276-2009, $.79 each.

19. 1 **1/4 watt, 100K resistor** (brown-black-yellow)—Radio Shack #271-1347, $.39 for 5.

20. Insulated, solid-core copper wire, 22-gauge—Radio Shack #278-1295, $2.19 for 100 ft.

21. Slide switch SPST (single pole-single throw) 3A @ 125 VAC—Radio Shack #275-401, $.89 for two.

22. 4 **nickel-cadmium (Nicad) batteries** (C size)—Any electronics store, $6.50 for 2. You can use regular batteries (C size); you'll just have to replace them more often.

23. Square plastic stick 1/8"—Hobby store $.40.

24. Small piece of **foam rubber** to serve as a bumper on the front of the Moth—Scrounge something around the house.

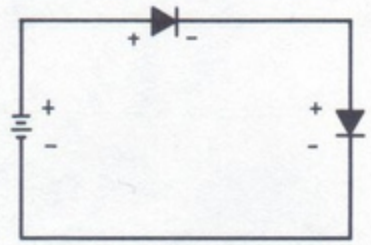
BUILDING THE MOTH

In describing the location of items on the moth, we will be looking down on the platform with the forward angle pointing away from your body.

WIRING IN SERIES AND PARALLEL

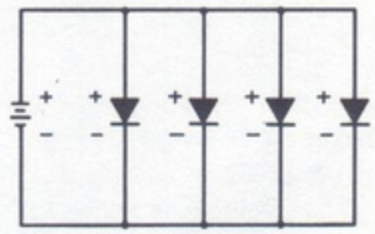
When working with electricity, you must always consider the polarity of the components in your circuit. Do you want to hook up the negative lead to the positive or vice versa? In our Moth project, most of the wiring is in series.

In a *series* circuit, you connect the positive to negative, positive to negative, positive to negative, and so on. The same current is flowing through one loop of a circuit. Think of a string of Christmas tree lights. If they are wired in series and one light burns out, they all go out. The circuit is no longer complete.



SERIES

In a *parallel* circuit, you connect the positive to positive, positive to positive, positive to positive, and negative to negative, negative to negative, negative to negative, and so on. The voltage will read the same throughout one loop of the circuit. If the tree lights are wired in parallel and one light burns out, the rest remain lit. Current can still flow through the circuit.

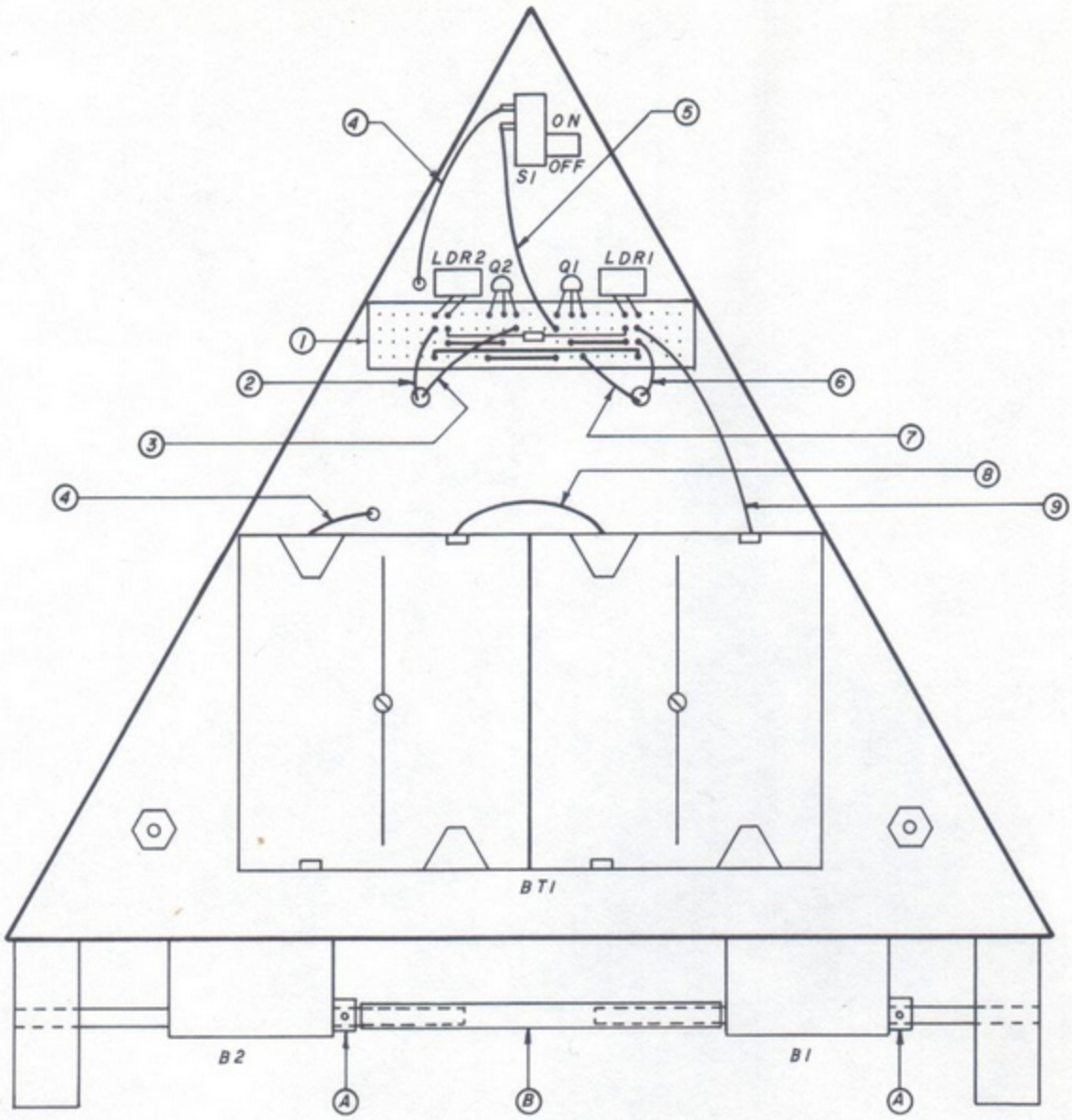


PARALLEL

1. THINK AHEAD

A) An 8" equilateral triangle should be large enough to hold all of the components. But just in case, cut out an 8" triangle from a piece of paper or cardboard and practice laying out all the parts.

B) Read all of the directions before starting to build. You'll have a better chance of



Top View of Moth

NOTES:

1. BREADBOARD CIRCUIT (SEE DETAILED DRAWINGS)
2. LEAD FROM B1 TO LDR2
3. LEAD FROM B1 TO COLLECTOR Q2
4. NEGITIVE LEAD FROM BT1 TO S1
5. LEAD FROM S1 TO EMITTER
6. LEAD FROM B2 TO LDR1
7. LEAD FROM B2 TO COLLECTOR Q1
8. CONNECT INSIDE POSITIVE AND NEGITIVE LEADS
9. POSITIVE LEAD FROM BT1 TO LDR1

A. COLLAR

B. SLEEVE

catching those steps that may snag you up later.

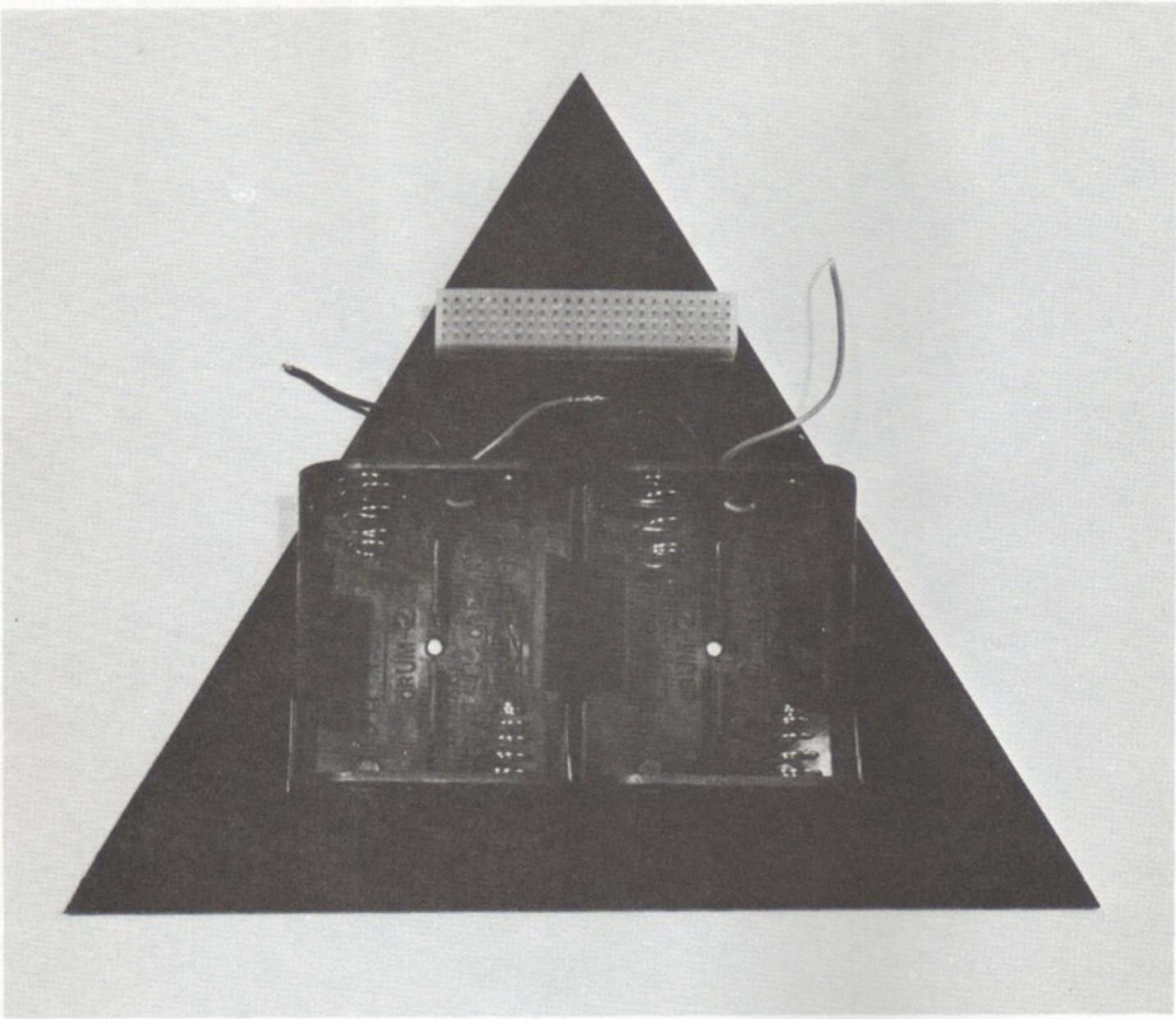
2. CUT THE PLATFORM

If all the parts appear to fit on an 8" triangle, go ahead and have the plastic or wood platform (#1) cut.

3. MOUNT PROTOBOARD

A) On the top of the platform, mount protoboard (#2). Mount board about 2" from front of platform. If using plexiglas or plastic, adhere the protoboard to the platform using a super glue (#3).

B) *If your platform is wooden,* place pro-

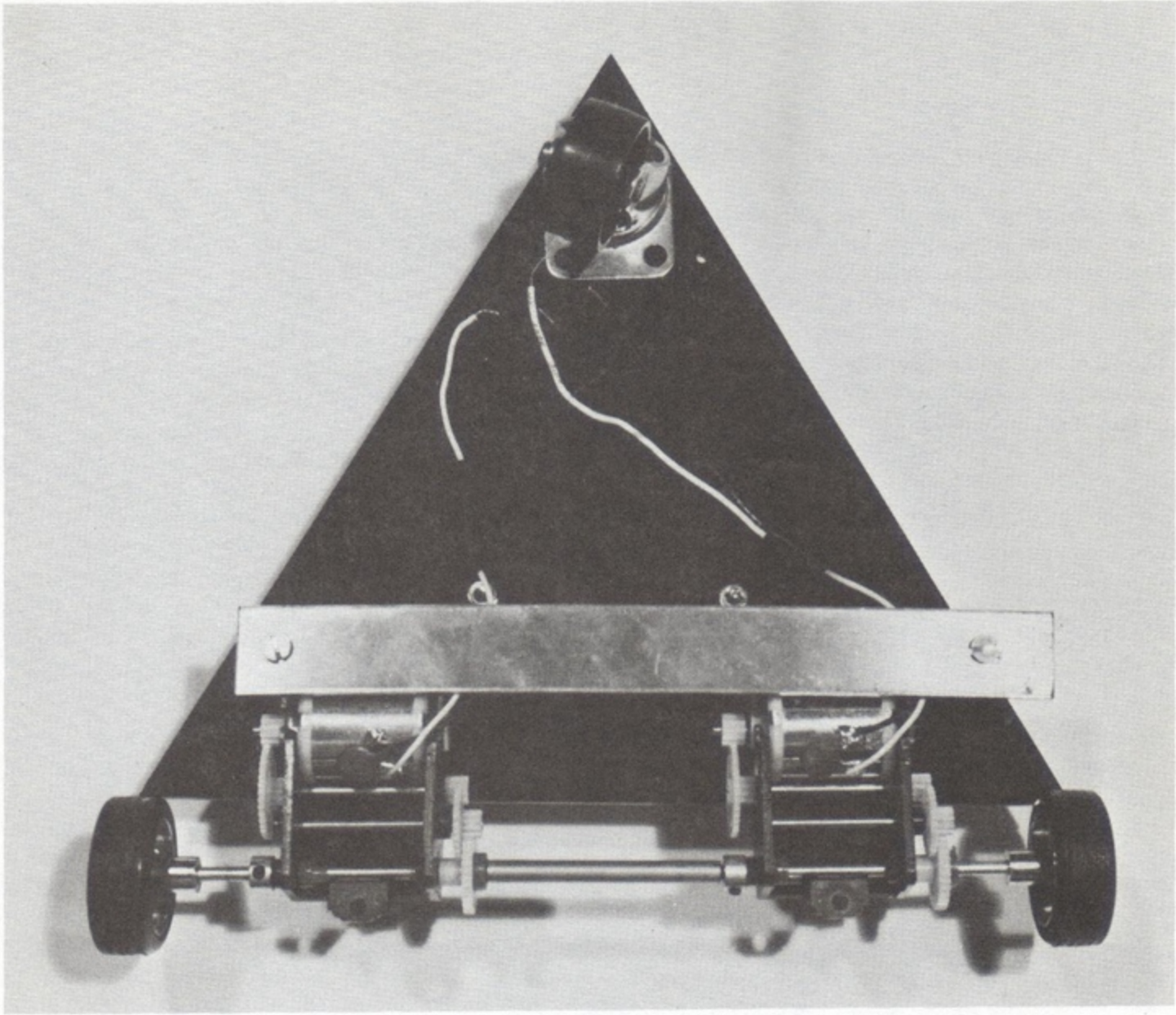


toboard on platform, orient screw holes so they go through the outermost column at each end of board. Mark underside of platform accordingly and remove board. Use a 3/32" bit to drill holes in platform. REMOVE THE METAL CLIPS FROM THE OUTERMOST COLUMN ON EACH END OF PROTOBOARD. (THE SCREWS GO THROUGH THESE COLUMNS). PEEL BACK THE PROTOBOARD'S BACKING TO WHERE YOU CAN PRY CLIPS OUT USING A SMALL SCREWDRIVER. TRIM BACKING SO THAT THESE OUTSIDE COLUMNS ARE EXPOSED. Place protoboard back on platform and run 2 small (about 1/4" self-tapping or wood screws up from underneath the platform. Screw down until snug.

C) Another technique on wood—Catch the board snuggly between a couple of round-head wood screws. Just be sure that the lip of the screw head catches the edge of the protoboard.

4. MOUNT BATTERY HOLDERS

A) Mount plastic battery holders (#4) with red and black leads facing forward. You will have to bolt them to the platform. Orient them so that their edge is flush with the back edge of the platform. Leave about a 1/4" gap between the two holders. Mark platform so that you can drill a hole in the platform that



goes through the center hole in each battery holder.

B) Remove battery holders and drill holes using a 7/64" bit. Place holders back on platform and run machine screws (#5) down from the top. Secure with washers and nuts (#5). Wire the battery holders in series by connecting and soldering only the two *inside* leads (one red and one black). DO NOT CONNECT THE OUTSIDE LEADS AT THIS TIME.

5. MOUNT THE FRONT CASTER WHEEL

A) Refer to Drawing 2 for orientation. If the caster (#6) has a square or rectangular mounting base, you may want to use a hacksaw to taper its base to the shape of the Moth's platform. This way the caster base will not protrude out from the platform. Or, just mount it a little farther back so that the entire base is hidden under the platform. If using plexiglas or plastic, glue the caster to platform. Be careful not to get glue in ball bearings.

B) If you need to use screws, you will have to select a machine screw and nut of the appropriate size. (Since we cannot know what brand of caster you will buy, it's impossible to tell you what size screw and drill

bit to use.) Follow directions for orienting and drilling holes as listed above.

6. SALVAGE THE TOY MOTORS

A) Once you have two radio-controlled toys, take them apart and salvage the gearhead motor assemblies. *Save other parts from the cars—you never know when they will come in handy!* If a capacitor is connected across the two motor leads, leave it in place. In removing the motors from the toys, if you can't salvage the original wires running from the motors leads, cut four 6" pieces of wire (two for each motor), strip 1/4" of insulation off one end of each. Solder the stripped ends to the four motor leads.

B) Hold a battery across the two motor leads to see that the motor runs.

7. MOUNT THE TWO GEARHEAD MOTOR ASSEMBLIES TO THE MOTH'S PLATFORM.

A) Gearhead motor assemblies will vary from toy to toy. Some will have small brackets, others will completely enclose gears. Therefore, we can only offer general instructions for mounting the gearhead motors. You may have to be inventive, as all homebrewers must sooner or later.

B) If your motors do not already have a small capacitor across the motor leads, use the two disc capacitors (#8) (one for each motor), cut the capacitors' leads fairly short and solder across the motor leads, right where they attach to the motor. This routes any noise or interference (produced by the motors' brushes) around the motors. Ac current passes through the capacitors, circumventing the motors. A small amount of DC current is used to charge the capacitors. Once charged, all DC current flows through the motors. *Ceramic disc capacitors do not have polarity and can be mounted in either direction.*

C) Mount the gearhead motors underneath the Moth's platform. Exact placement will depend on the motors, but generally you will locate them toward the rear of the platform. The axle can even extend about 3/4" past the trailing edge of the platform. The units also must be spaced widely enough apart to prevent the tires from rubbing against the platform. You may want to trim the back corners of the platform.

D) Once oriented, you may be able to attach the motor brackets directly to the platform. If you use this technique, drill two 7/64" holes through each bracket and platform. Otherwise the units may move out of alignment. Bolt brackets to platform with machine screws, lock washers, and nuts (#5).

E) Another technique is to cut a piece of the brass strip (#9) to create a sling holding the motors in place. A 6-1/2" piece ought to be long enough, *but measure before cutting.* Make sure enough of the strip extends beyond the motors for a couple of 2" screws (#10) to come down from the platform through the ends of the strip, thus holding the whole unit in place. Orient the motors, run the strip along the underside of the brackets— creating the sling. Drill two 5/32" holes in the platform and in the ends of the strip. DO NOT ASSEMBLE.

F) Most gearhead motors have an axle that extends out both sides of the bracket. This makes it easy to use the units interchangably. Cut a 2" piece of brass tubing (#11) and slip it over the two inside axles (length may vary). This sleeve adds greater stability to the axle unit. Slip the wheel/tire assemblies (#12) onto the outer axles—you want a tight fit. Use the wheels that came with the radio-controlled toys, and you will be assured of a snug fit. If you need wheels with a larger diameter, try airplane wheels.

G) If the axle slides from side to side and disengages from the gears, slip a couple of collars (#13) on the axle. Exact placement depends on the design of your gearhead motors. The collar has a small screw in its side. Slide the collar against the motor bracket and tighten.

H) ASSEMBLE THE UNIT. If your motor leads touch the brass strip, they will short out. Run a length of black electrical tape along the strip. Cut two 3/4" pieces of adhesive foam (#14) and attach to brackets or motors as a cushion between platform and motors. Reorient the motors. IF THE SLEEVE (#11) BETWEEN THE TWO IN-

SIDE AXLES DOES NOT MOVE FREELY, THE MOTORS ARE NOT WELL ALIGNED. With motors in place, put the strip across. Run screws (#10) down from the top. Secure with washers and nuts. If the screws are too long, mark length, remove one at a time, and cut with a hacksaw. Keep the nut on the screw as you cut. Remove nut after cutting to clean screw's threads.

I) If the brass strip bows out too much in the middle, you can drill another 5/32" hole in the middle of the strip and a companion hole in the platform. Catch the middle of the strip with another machine screw (#10).

8. PREPARE BLINDERS FOR PHOTOCELLS

A) Using an index card or thin piece of flexible plastic (#15), make blinders to go around the two photocell resistors (#16). These will help block peripheral light sources from interfering with the Moth's operation. The pattern below is sized for Radio Shack photocells.

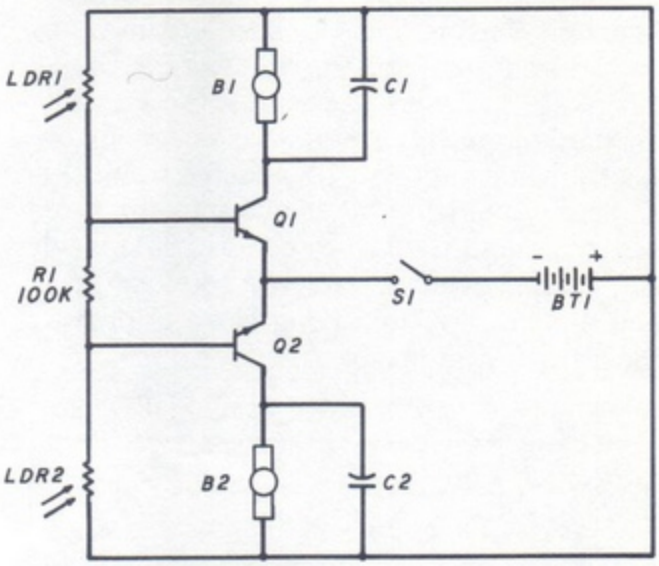
Pattern for Blinder (full size)

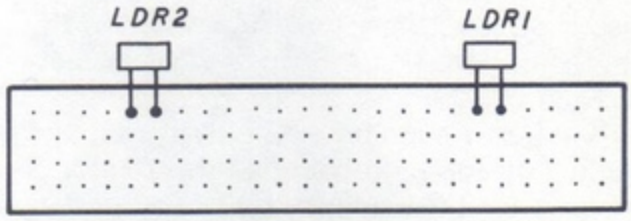
B) Wrap a blinder around each cell. The flat edge is flush with the back of the cell; the blinder is widest at the top of the cell and tapers toward bottom. Fasten with tape. Trim tape where it extends beyond blinder. Once in place, paint the blinder (inside and out) and the back of the photocell with flat black enamel (#17). DO NOT PAINT THE PHOTOCELL'S WINDOW. Let dry.

9. WIRE THE PROTOBOARD

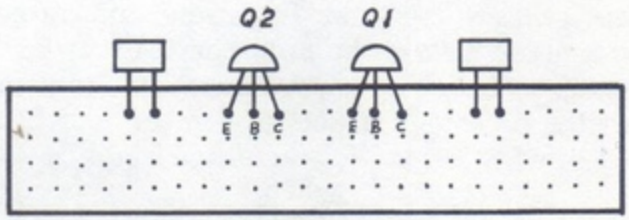
With the undercarriage in place, begin wiring the Moth's protoboard. Refer to the schematic, Drawing 3.

A) Insert two photocells (#16) into the protoboard. These are referred to as LDR1 and LDR2 on the schematic. The wire leads should go into adjacent holes at each end of the board's first row. MAKE SURE THE CELLS FACE FORWARD.



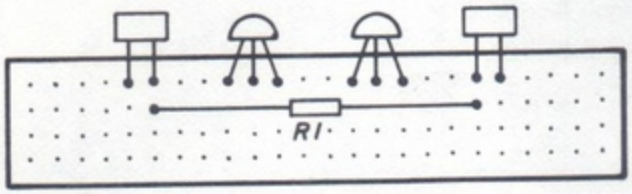


B) Insert two transistors (#18) in the middle of the first row of the board (between the two photocells). These are labelled Q1 and Q2 on the schematic. If you use Radio Shack #276-2014 or #276-2009 transistors, the transistor's flat side will face toward the back of the protoboard. If you use different NPN transistors or PNP transistors, make sure the leads are in the same order (emitter-base-collector) as the example.



C = Collector
B = Base
E = Emitter

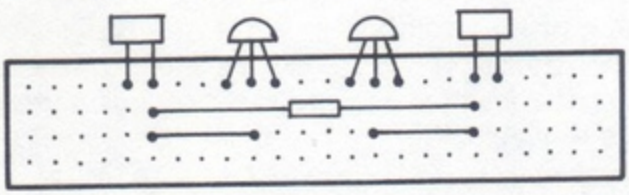
C) The photocells are wired in series with a resistor across the two inside leads. This resistor is designed to limit the amount of current flowing into the base of the transistors to an acceptable level. Take a 100K resistor (#19). Insert one end of the resistor into the hole in the protoboard's second row directly behind the left photocell's (LDR2) inside lead. Insert the other end into the hole directly behind the right cell's (LDR1) inside lead. If the resistors leads are too long and keep the resistor from lying close to protoboard, trim the leads slightly.



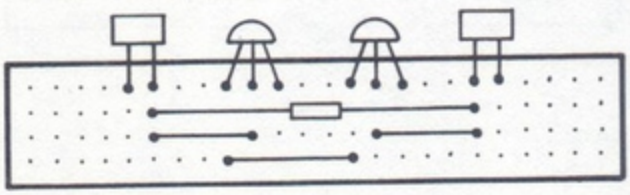
D) Check the schematic. See how the inside lead of each photocell comes into the base lead of a transistor. Cut two 3/4 - 1" lengths of wire (#20). Strip 1/4" of insulation off each end.

—Insert one end of the first wire into the hole in the protoboard's third row directly behind LDR2's inside (right) lead. Insert the other end into the hole in the third row directly behind Q2's base (middle) lead.

—Insert one end of the second wire into the hole in the protoboard's third row directly behind LDR1's inside (left) lead. Insert the other end into the hole in the third row directly behind Q1's base (middle) lead.

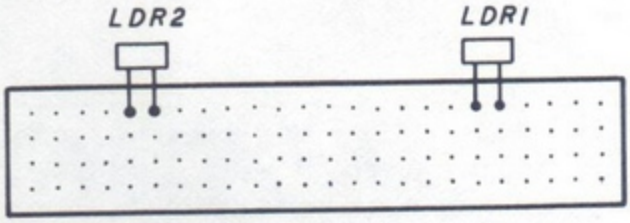


E) Cut a 1" length of wire, strip 1/4" of insulation off each end. Insert one end of the wire in the hole in the protoboard's fourth row directly behind the Q2's emitter lead. Insert the other end in the hole in the fourth row directly behind Q1's emitter lead.

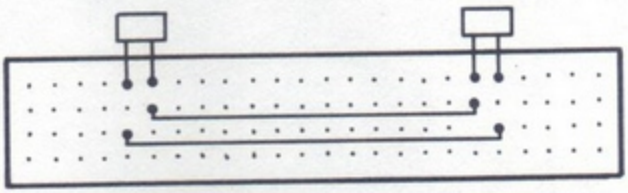


A WORD ABOUT PROTOBOARDS

You may want to experiment with the protoboard before wiring the Moth. Here is how the protoboard works. Orient the board in front of you so that the length runs right and left. Holes that run the length of the protoboard (the rows) are not connected to one another. Holes that run the width of the board (the columns) are connected. In other words, when leads are plugged into holes in the same column, they are connected just as if you had soldered the two leads together. Leads all lined up in a row across a protoboard are not connected.

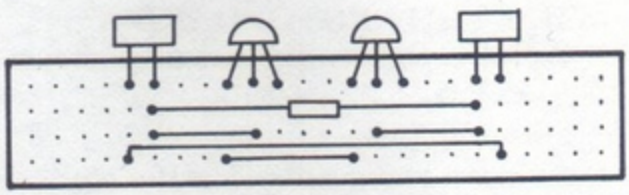


All these photocell leads are inserted in the same row. They are not connected.

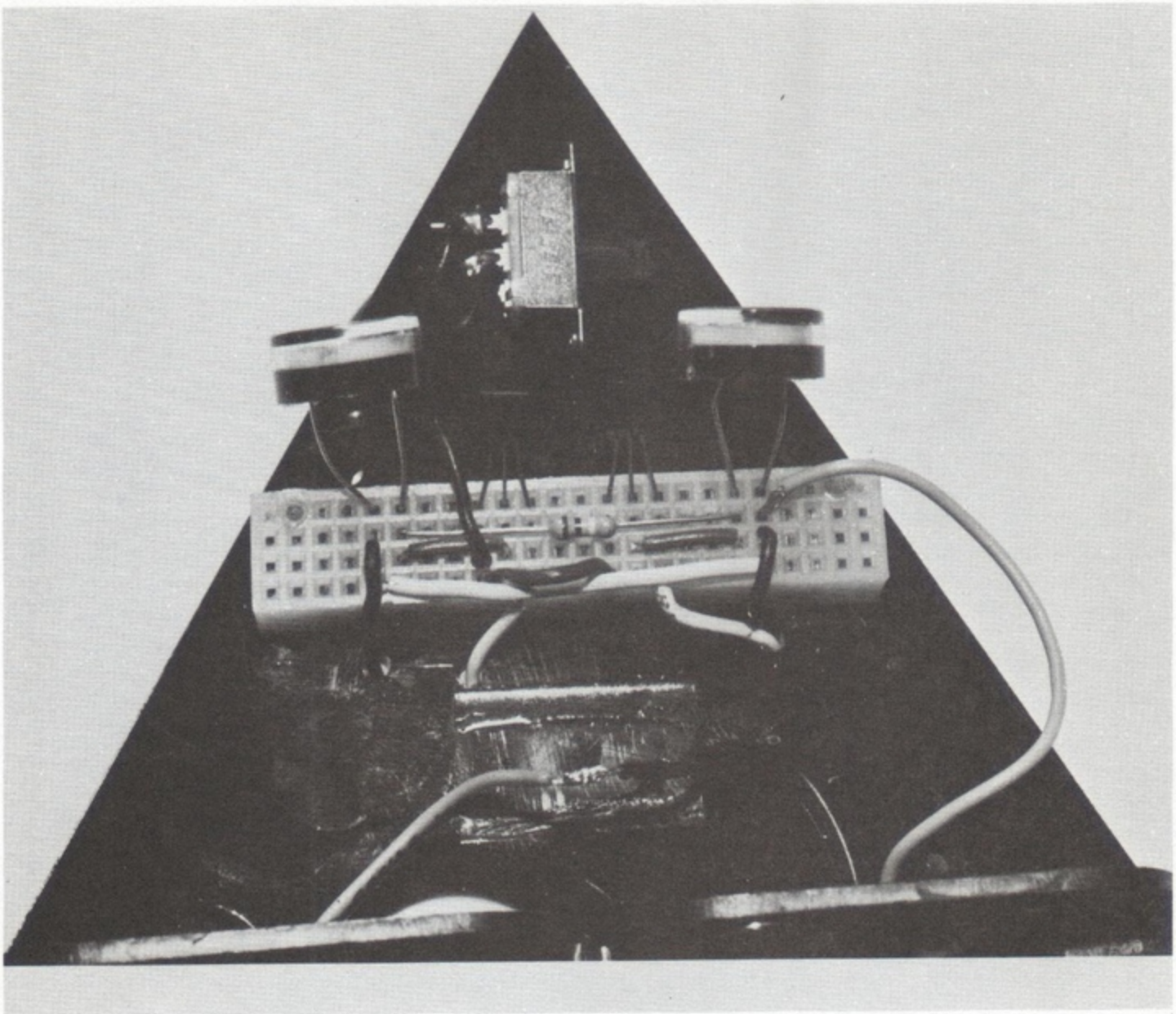


These same cells are now connected. The ends of the wires are in the same columns as the leads of the cells.

F) Connect the two outside leads of the photocells. Cut a 2" piece of wire, strip 1/4" of insulation off each end. Insert one end of the wire into the hole in the fourth row directly behind LDR2's outside (left) lead. Insert the other end of the wire into the hole in the fourth row directly behind LDR1's outside (right) lead.



AT THIS POINT, THE PHOTOCELLS ARE WIRED IN SERIES WITH A

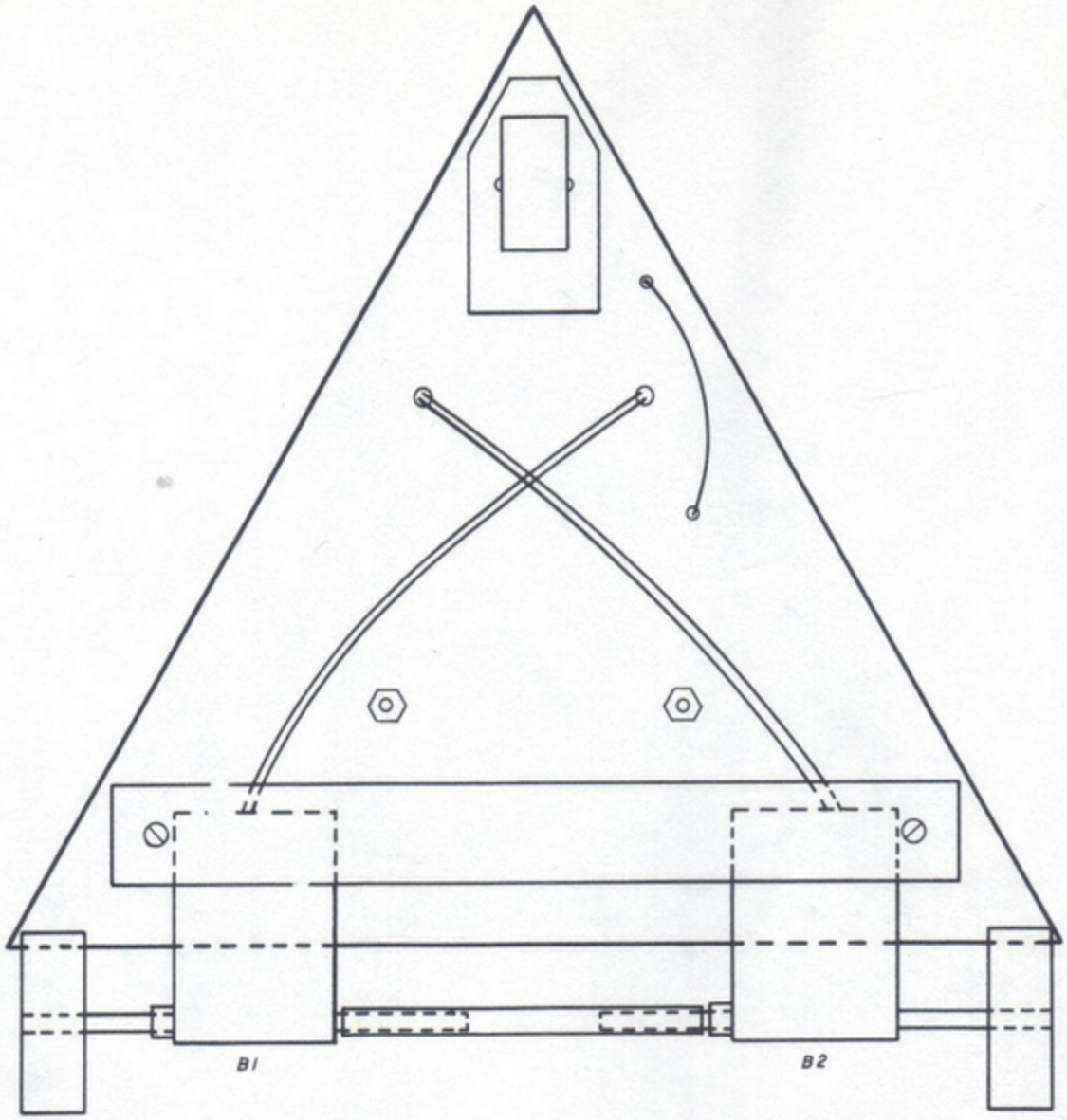


RESISTOR ACROSS THE INSIDE LEADS AND A WIRE ACROSS THE OUTSIDE LEADS. THE TRANSISTORS' EMITTER LEADS ARE CONNECTED, AND THE PHOTOCELLS ARE WIRED TO THE TRANSISTORS' BASE LEADS.

10. CONNECT THE MOTORS TO THE TRANSISTORS

One lead on each motor must be connected to the collector lead on each transistor. We are going to be tricky here. Instead of wiring the right motor to the right transistor and the left motor to the left transistor, we are going to cross the wires. This way, when you stand in front of the Moth and shine a flashlight into the right photocell, the Moth will turn right. Think about this—for the Moth to turn right, the left wheel must drive it to the right, and vice versa.

A) Now for trial and error: Your motor's polarity is regulated by the battery. Hook the motor leads to a battery one way and the motor shaft turns clockwise. Reverse the leads and it spins counter-clockwise. You could check the polarity by hooking the motor to a VOM and battery. But in the time it takes, you could just hook up the motors on the protoboard, test the system, and reverse the leads on a motor if the wheel spins the wrong direction.



Bottom View of Moth

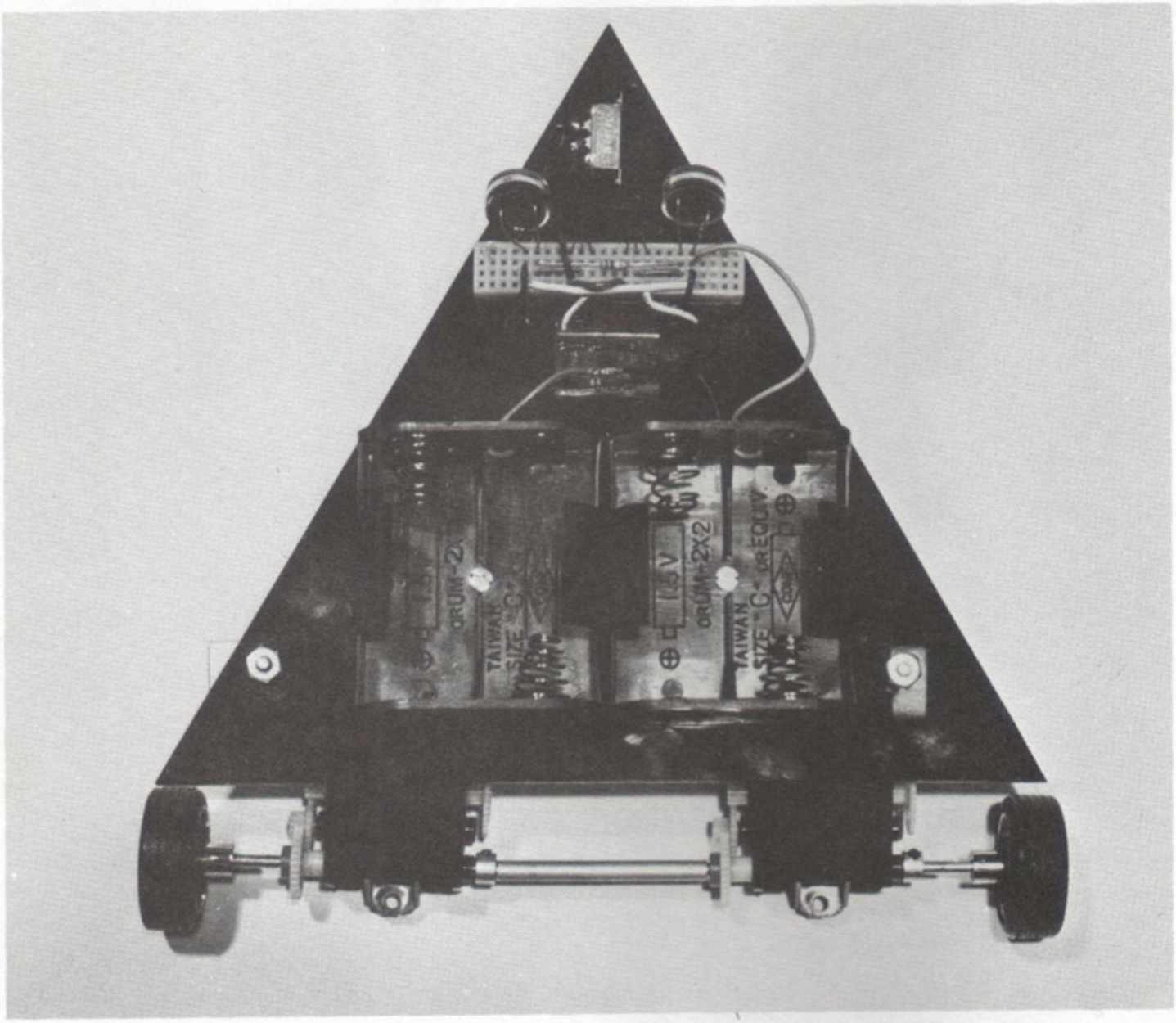
B) Take the remaining lead on the *left* motor (B2), strip off 1/4" of insulation, and slip through the same hole in the platform as the other B2 lead. Insert end in the protoboard's third row directly behind the outside lead of the *right* photocell (LDR1).

12. CONNECT BATTERY LEADS TO THE CIRCUIT

A) Insert the positive (red) lead from the battery holder (#4) into the protoboard's second row directly behind the outside lead of the right photocell (LDR1). The lead can be connected to the outside lead on either cell (since the two cells are wired in series), but LDR1 is closer to the positive lead on the battery holder. The lead from the battery holder is not solid core wire. If you have trouble inserting it in the protoboard, twist the end tightly and coat with a little solder.

B) Connect the negative (black) lead on the battery holder to the switch (#21). Neatness counts, so drill a 7/64" hole in the platform just in front of the left battery holder and another one in front of the protoboard. Avoid drilling through the base of the caster! Run the battery lead down through the first hole and back up through the second.

C) Connect the battery lead to the switch. There are two leads on the switch. Solder the battery lead to the switch lead



that is closest to the edge.

13. CONNECT SWITCH TO THE PROTOBOARD

A) Cut a 3" piece of wire, strip 1/4" of insulation off each end. Solder one end of the wire to the remaining (inside) lead on the switch.

B) Insert the other end of the wire into the protoboard's first row directly behind either transistors' emitter lead. Don't let the exposed end of this wire touch the resistor lead. You'll short the circuit, and the Moth won't run.

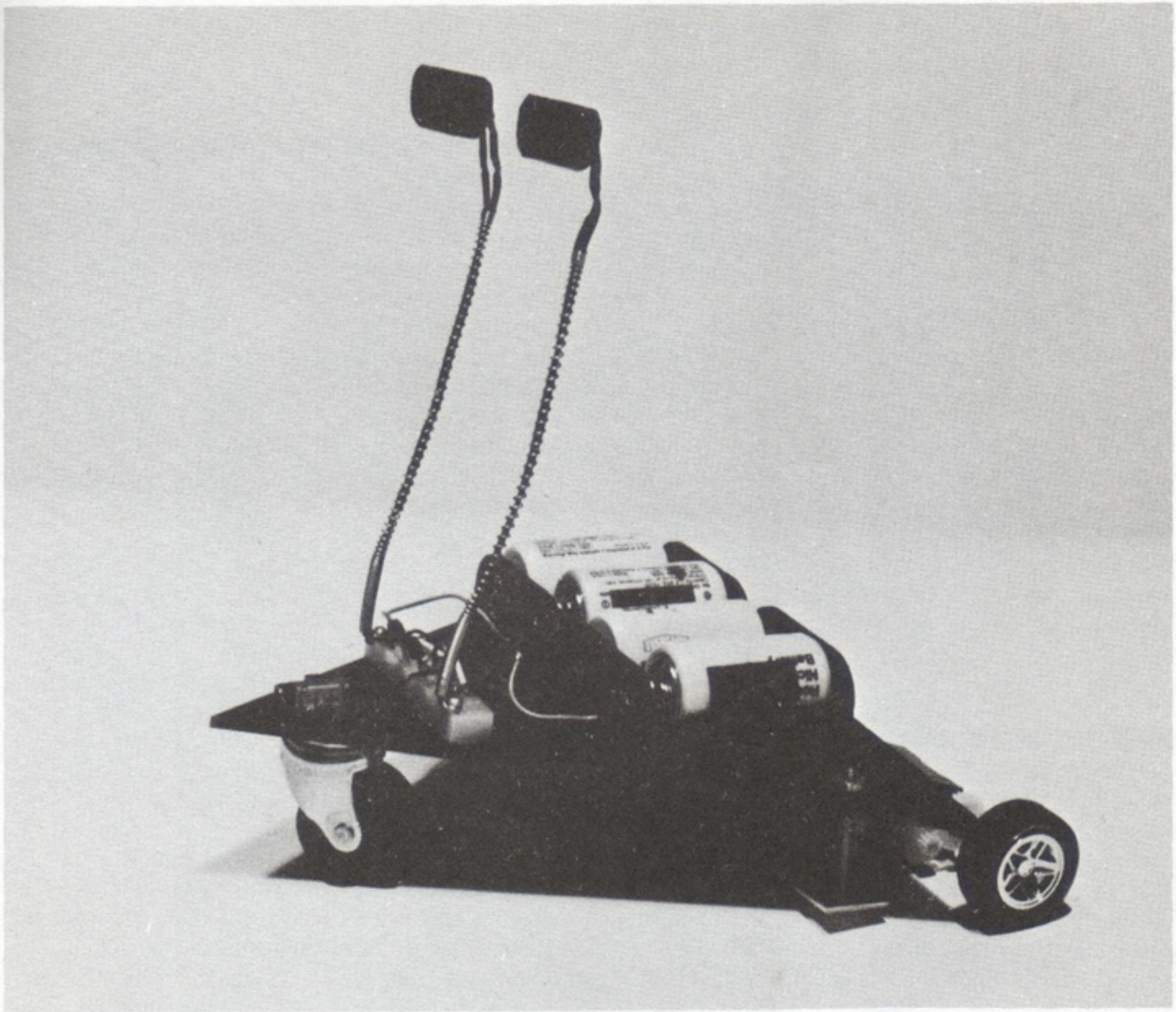
14. INSERT BATTERIES AND GO

A) Insert batteries (#22), taking care to observe the polarity as indicated on the battery holders. Switch on Moth. When you direct a flashlight at the photocells, the wheels should spin.

B) If either wheel spins in the wrong direction, turn off Moth and reverse leads on the motor that is spinning in the wrong direction.

15. GLUE DOWN THE SWITCH

14) Glue switch to the front of the Moth. Position the switch so that the "on" position



is toward the front of the Moth and "off" is toward the back. Cut a 2" length of plastic stick (#23) and glue to the lever on the switch. One end of the stick must protrude beyond the front end of the Moth, creating a "dead man's switch." If the Moth bangs into something, the stick will hit the object first and turn off the Moth. To soften the blow even more, put a piece of foam rubber (#24) on the end of the stick.

CHECKLIST FOR TROUBLESHOOTING THE MOTH

If your Moth does not work when you turn it on, don't worry. You may have to go through a little debugging process the way you do when writing a computer program.

You should first make certain that the batteries are in and connected properly. Are the nicads charged? Did you turn on the switch? If the answer is yes to the above questions, examine the wiring carefully. Check the schematic against your Moth. Is there a complete circuit for the electricity to flow through? Are all the components connected correctly? Are any wires touching that should not be touching? This could short out the system. Check the 100K resistor particularly closely. Its leads are not insulated.

Don't let this process frustrate you. Make a game out of troubleshooting the

Moth. Later, when you are developing your own robots, you will have to devise a checklist of your own.

Assuming you said yes to the above questions, let's check some other possibilities:

1. If you turn on the switch and nothing happens, make sure the transistors are in properly. The collectors of NPN transistors are connected to the motors. (See steps 10B and 10C)

2. Perhaps there is a bad connection somewhere and the electricity is not getting through the circuit. Use the VOM to check the current at various points in the circuit.

3. If one or both wheels are spinning in the wrong direction, reverse the leads coming out of the motors. (See step 10)

4. If the batteries are smoking you have either wired the battery holders (#4) incorrectly or put the batteries in backwards. The smoking is a result of reversed polarity.

HOW THE MOTH WORKS

The concept behind the Moth is very simple. When you turn on the robot in a dark room, the photocells have a high resistance rate that blocks the flow of electricity. The Moth does not move. When exposed to light, however, the resistance is diminished. Current flows through the photocells to the transistors.

The transistors act like amplifiers and increase the amount of current. The collectors send this boosted signal directly to the motors, which drive the Moth.

The schematic does not show it, but each motor is connected to the opposite transistor. The reason for this is that when you shine a flashlight at the right cell, you instinctively expect the Moth to move to the right (or toward the light). But it is actually the left wheel that pushes the Moth to the right, and vice versa. Because the crossed wires are not actually necessary to make the Moth run, we opted for simplicity in the schematic and did not cross the wires.

You may notice too that the brighter the light source, the faster the Moth moves. This is because a brighter light lowers the photocells' resistance even more and permits more current to flow through the circuit.

IDEAS FOR IMPROVING AND CUSTOMIZING YOUR MOTH

1. Make the photocells look like antennae by mounting them up away from the Moth's platform. We salvaged a couple of 6" springs from two toy tanks. Then, we cut four lengths of wire, soldered one to each of the photocells' leads, and covered the exposed wire leads with heat shrink. We ran the two leads from each photocell down the length of the springs, screwed the springs to the protoboard, and plugged the wires into the protoboard.

2. Use the basic Moth to power models and toys. We built a plastic car model kit. The kit was powered by a DC gearhead motor. We redesigned the wiring a bit and mounted a photocell in place of one of the headlights. When we shined a flashlight at the car's front end it moved. A larger car model would have had room for two motors, and we could have steered the car by flashlight.

3. Mount a plastic robot model on a clear, plexiglas platform. The wheels and motors will have to be located on the platform, but you could try hiding the wiring, photocells, transistors, switch, and batteries inside the robot. This way you could animate one of your favorite models.

4. Decorate your robot with flashing LEDs. Start by inserting a couple of LEDs in series between the photocells and the transistors. Remember, LEDs have polarity like any diode. Also, you will have to insert resistors to keep the LEDs from burning out. Use Ohm's Law to determine what size resistor to use.