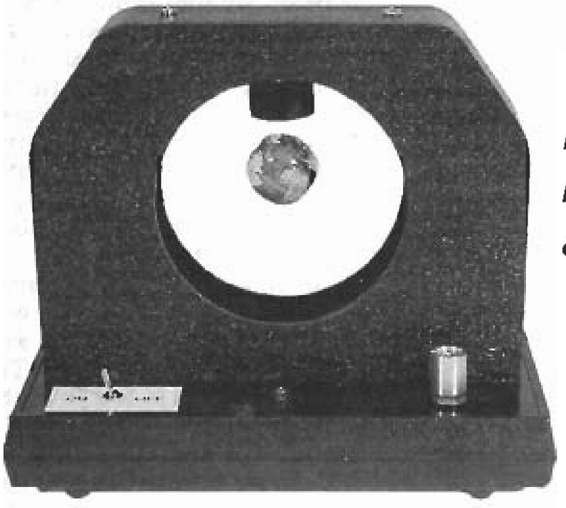
ELECTROMAGNETIC LEVITATOR



Build this electromagnetic levitator, and you can defy gravity and make objects float in mid air!

DAVID WILLIAMS

MAGNETISM AND A CLOSED-LOOP control system are the secrets to the stunning presentation produced by this electromagnetic levitator.

An electromagnet creates a magnetic field that attracts a hollow steel globe or similar object upward. The globe doesn't crash against the magnet, however. Instead, as it draws near, the magnet's intensity weakens, letting the globe drop slightly. As it drops, the magnet's intensity again increases, pulling the globe up again. The process is so smooth, however, that the globe appears to float, held in space by invisible forces.

An infrared emitter and detector mounted across from each other create an invisible beam that passes slightly below the coil. As the object rises towards the electromagnet, it begins to block the beam. When the beam becomes blocked, the output of the detector is reduced which in turn reduces the current in the electromagnet's coil. The reduced current weakens the magnetic field, the object begins to drop and the detector once again sees more of the beam. This causes the circuit to increase the magnetic field and the cycle repeats as the object is attracted upwards again.

The circuit is designed so that eventually an equilibrium is reached where the magnetic attraction exactly balances the force of gravity pulling on the object. The object then remains perfectly suspended in the infrared beam's path with no visible means of support!

Basics of closed-loop control

Open- and closed-loop control systems surround us. An open-loop system is one in which the signal that controls the output

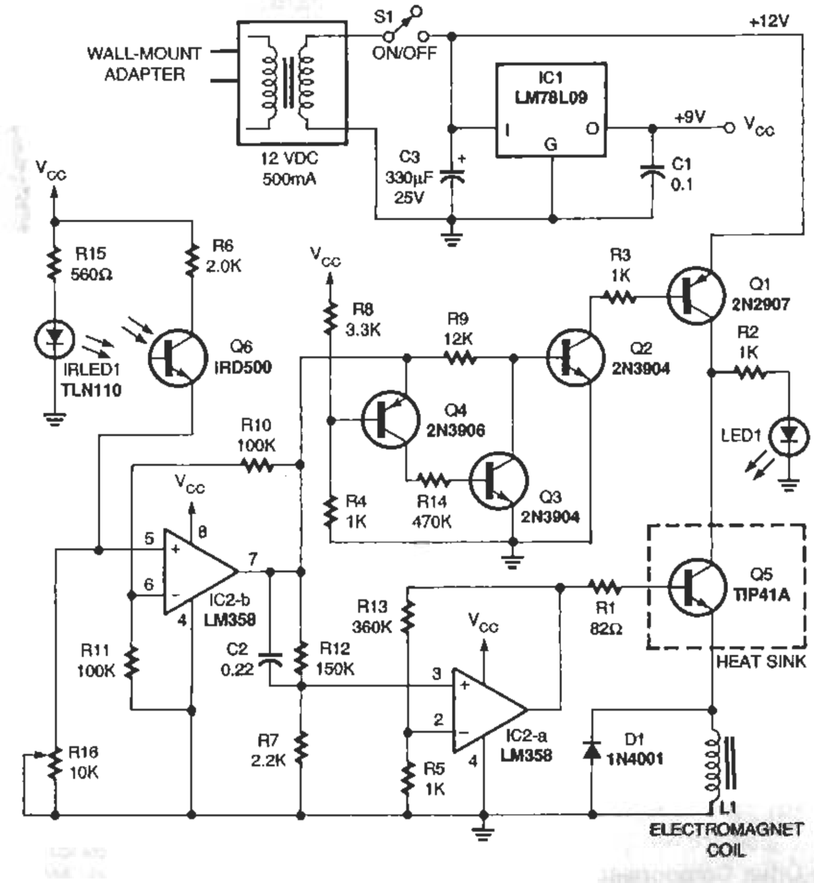


FIG. 1—THE LEVITATOR CIRCUIT. IRLED1 and photodetector Q6 are used to sense where the globe is in relation to the electromagnet.

is independent of the output itself. By contrast, the signal controlling the output of a closed-loop system is dependent on the system's output.

A space heater or table-top fan are examples of open loop control systems. They are controlled by a switch, and once they are turned on, their output remains constant regardless of how hot or cold it gets.

A home furnace and air conditioner are examples of closed-loop control systems. Both monitor their outputs—the hot or cold air—with a thermostat, and regulate their outputs accordingly. The thermostat closes the loop by feeding back an *error signal* to the furnace or air conditioner.

Circuit details

Figure 1 is the levitator's schematic. Power is supplied by a wall mounted AC/DC adapter with an output of 12 volt DC at 500 milliamperes. The electromagnet coil draws most of the current in this circuit, so it is powered directly from the 12-volt output of the power adapter. Stable voltage for the rest of the circuit is obtained by regulating the adapter's output to 9 volts with IC1, a LM78L09 voltage regulator that is capable of supplying up to 100 milliamperes of current. Capacitors C1 and C3 provide additional voltage filtering.

IRLED1 is an infrared light emitting diode, much like those used in infrared remote controls for consumer-electronic equipment. Resistor R2 limits the forward current to IRLED1 to about 15 milliamperes. The IRLED emits a constant, invisible beam whenever switch S1 is turned on. Phototransistor Q6 detects the infrared beam; it is wired with R6 and potentiometer R16 to convert the infrared beam into a DC voltage. Potentiometer R16 adjusts the output voltage of Q6, which is fed to pin 5 of IC2-b, one half of an LM358 operational amplifier.

The op-amp, which is configured for a gain of two, [(R11 + R10)/R11] buffers and amplifies the output of Q6. The output of IC2-b is fed to a second amplifier stage, IC2-a through C2 and R12. The output signal from IC2-a drives transistor Q5 to vary the current to the electromagnet coil. Because Q5 gets very warm during operation, it requires a good heat sink. Diode D1 protects Q5 from reverse voltage spikes from the coil.

Mylar capacitor C2 plays an important role in this circuit. It forms a differentiator with IC2-a. The capacitor blocks slow voltage changes, but passes any rapid changes in the input signal and allows them to be amplified by IC2-a. The slow voltage changes are attenuated by R12 and R7 before being amplified by IC2-a.

The purpose of this part of the circuit is to perform closed-loop control using a combination of proportional and derivative modes. Both modes are needed to insure that the levitation is stable.

The rest of the circuit functions as a voltage-level detector that uses Q1 to switch the 12-volts to Q5 on or off. The level detector keeps the electromagnet powered off when there is no object in the beam. This is to prevent overheating of the coil. The level detector also turns the electromagnet off if the object rises too far and completely blocks the beam.

When nothing is blocking the infrared beam, the output of IC2-b will be greater than 2.7 volts. This causes Q4 and Q3 to

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PARTS LIST

All resistors are ¼-watt, 5% unless otherwise indicated.
R1—82 ohms
R2, R3, R4,R5—1000 ohms
R6—2000 ohms
R7—2200 ohms
R8—3300 ohms
R9—12,000 ohms
R10,R11—100,000 ohms
R12—150,000 ohms
R13—360,000 ohms
R14—470,000 ohms
R15—560 ohms, ½ watt
R16—10,000 ohms, panel-mount potentiometer

Capacitors
C1—0.1 µF, ceramic disc
C2—0.22 µF, 50 volts, polyester film
C3—330 µF, 25 volts, electrolytic

Semiconductors
IC1—LM78L09, 9-volt DC regulator (TO-92)
IC2—LM358N, dual op-amp
Q1—2N2907 (or MPS2907) PNP transistor
Q2,Q3—2N3904 (or 2N4401) NPN transistors
Q4—2N3906 (or 2N4403) PNP transistors
Q5—TIP41A, NPN power transistor
Q6—IRD500 infrared photo detector (Jameco No. 112168 or equiv.)
D1—1N4001 (or 1N4004) silicon diode
LED1—Red light-emitting diode
IRLED—TLN110 infrared LED (Jameco No. 106526 or equiv.)

Other Components
L1—Electromagnet coil—relay coil, 6-volts (P&B: KUP11D15—see text)
Adapter—12 volts DC, 500 mA
S1—SPST sub-miniature toggle switch

Miscellaneous: etched printed-circuit board, heat sink for Q5 (TO-220), plastic enclosure (PacTec K-HPL), hollow metal globe, aluminum bracket, LED panel bezel mount (2 ea.), plastic LED clip mount, knob for potentiometer, No. 6-32 × ⅜ inch screw, No. 6-32 × 1.0 inch screw (2 ea.), No. 6-32 × ¼ in. screw (2 ea.), No. 6 hex nut (2 ea.), No. 4-male/female, ¼ inch hex standoff (4 ea.), No. 4-40 × ¼ inch screw (5 ea.), No. 4 hex nut (5 ea.).

Note—The following items are available from: LNS Technologies, 20993 Foothill Blvd, Suite 307R Hayward, CA 94541-1511 Phone: 1-(800)-886-7150.
- Complete kit of parts for the Levitator (LEV-KIT), including etched and drilled circuit board, relay coil, wall transformer, aluminum bracket, enclosure, metal globe and all other components listed above: $75.00
- Etched and drilled printed-circuit board (LEV-PCB), $10
- Electromagnet coil (LEV-COIL) $10.
- Drilled aluminum bracket (LEV-BKT), $5.

Please add $5.00 shipping and handling charges to all orders. California residents add local sales tax. MC/VISA orders accepted. No C.O.D. orders.

LEVITATOR

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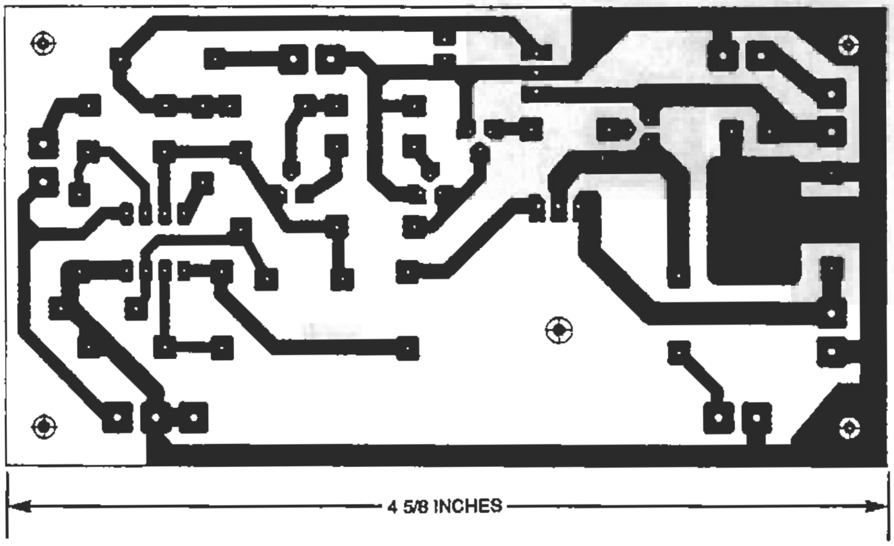
turn on, which turns Q2 and Q1 off, so the electromagnet coil receives no current. Likewise, if the beam is completely blocked, the output of IC2-b will drop below 0.7-volts. Again Q4 and Q3 will be on which forces Q2 and Q1 off. However, when the object is partially blocking the beam during levitation, the voltage out of IC2-b should be somewhere between the 0.7 and 2.7-volt thresholds. In that case, Q4 and Q3 will be off, with Q2 and Q1 on. Whenever Q1 is on, the red LED indicates that Q5 and the coil are receiving current.

Building the levitator

The easiest way to build your own anti-gravity levitator is to use an etched circuit board. The foil pattern for a suitable board is shown here. However, if you don't want to fabricate your own board, a pre-etched and drilled board can be purchased from the source given in the Parts List.



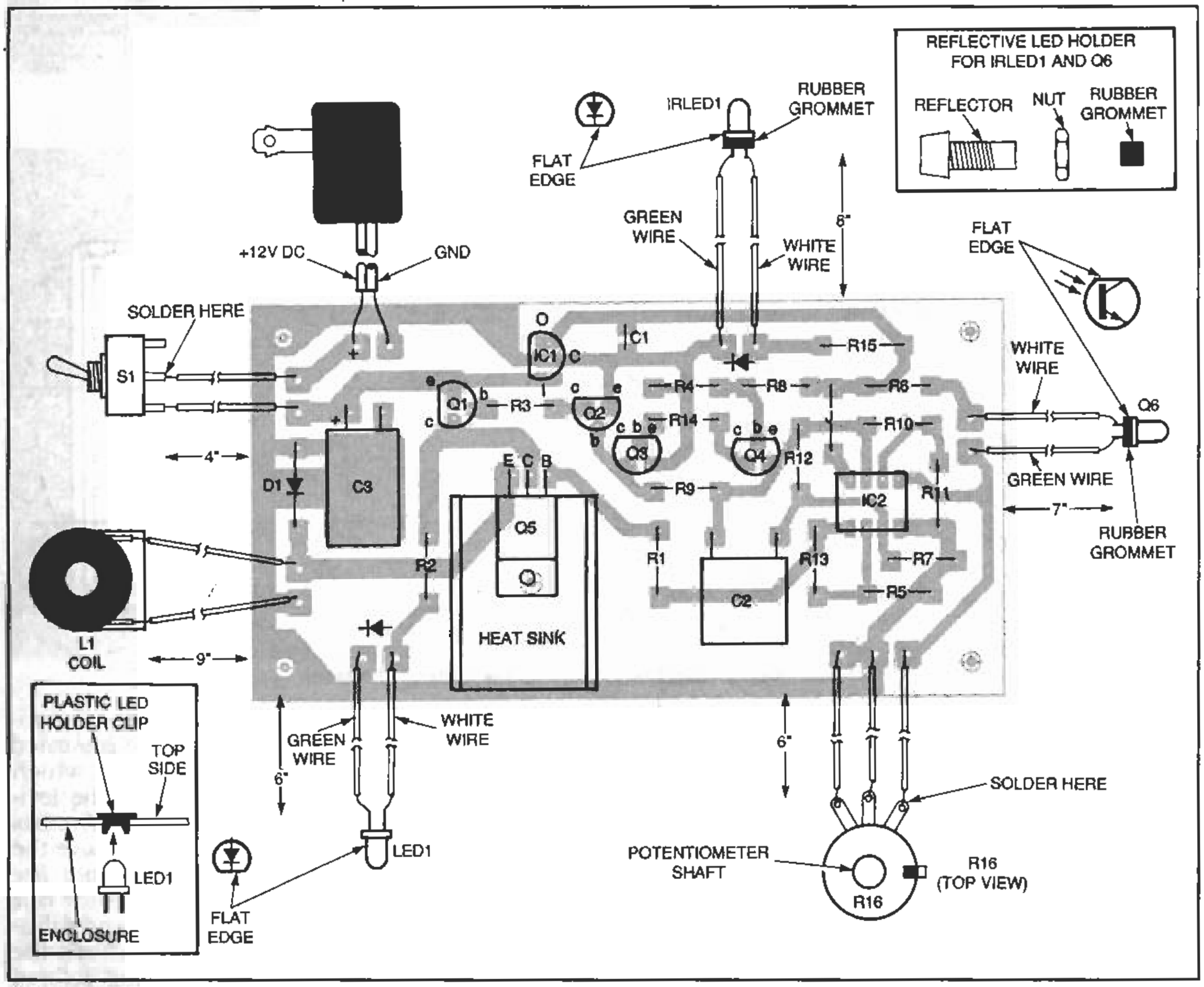


FIG. 2—PARTS-PLACEMENT DIAGRAM and wiring details for off-board components.

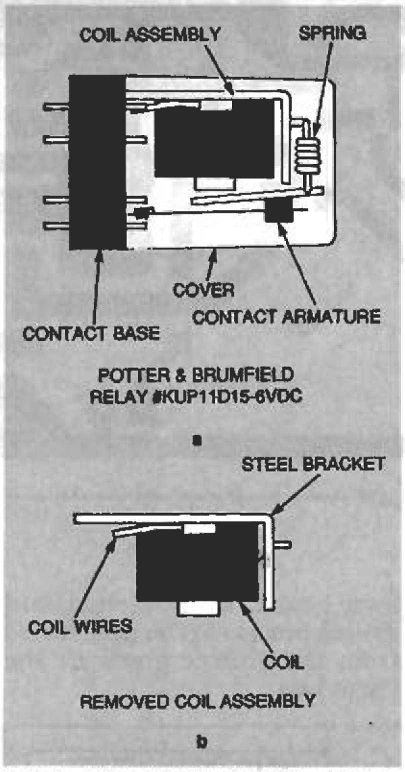


FIG. 3—THE ELECTROMAGNET that is used in the levitator is obtained by disassembling a relay as shown.

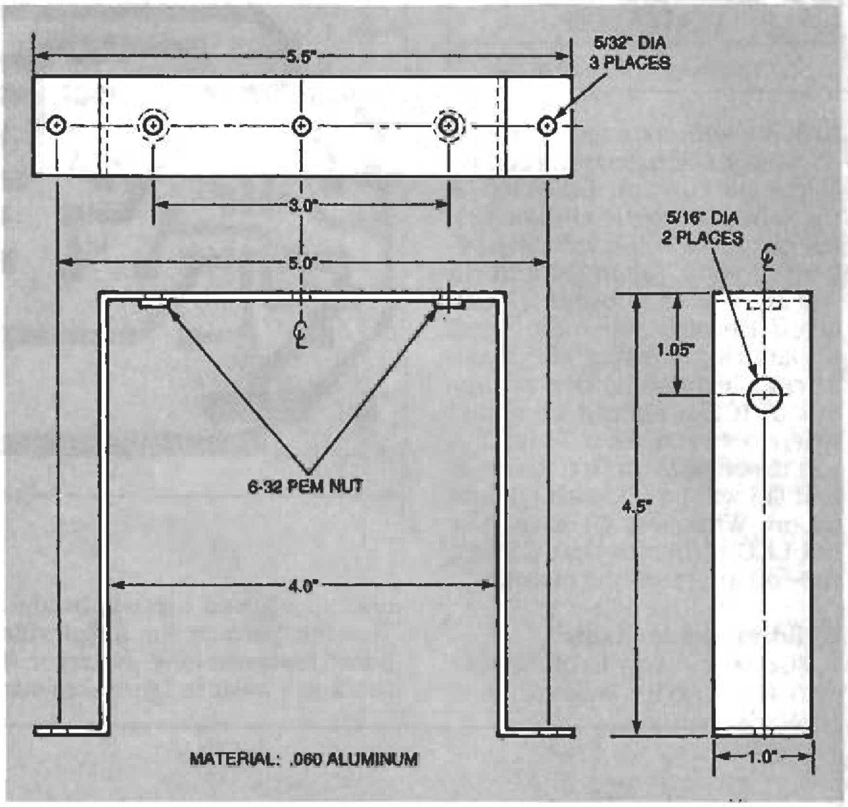


FIG. 4—AN ALUMINUM BRACKET should be fabricated as shown.

Locate all the components shown in the Parts List and use the parts-placement diagram of Fig. 2 to determine their proper location on the PC board. First solder a solid-wire jumper at the location marked J. Next install diode D1, paying close attention to its orientation. Then install and solder resistors R1 to R15. Trim the excess leads before proceeding to the next step.

Locate the 0.1 µF capacitor C1. Again using Fig. 2 as a guide, install it and solder in place. Next locate the 8-pin IC socket and install it at the location marked IC2. Don't install IC2 in the socket, however. Move on to transistors Q1, Q2, Q3, and Q4. Install each with the proper orientation indicated on the parts placement diagram. Then locate and solder the 9-volt regulator IC1 in place. Capacitors C2 and C3 are large and should be bent to lie against the PC board after installation. The TO-220 transistor Q5 and its heat sink also mount against the board and are held down with a No. 4-32 screw and nut.

Figure 2 also contains details

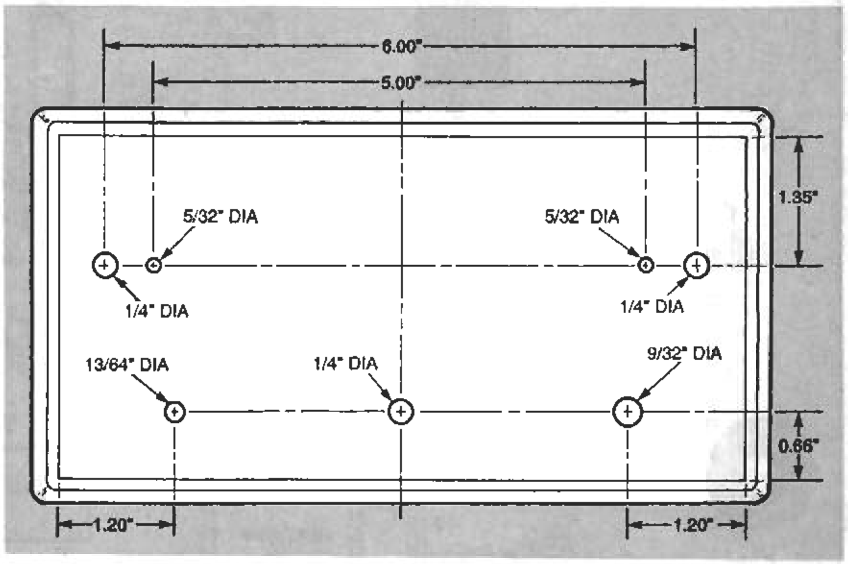


FIG. 5—DRILLING GUIDE for the levitator enclosure.

on wiring off-board components S1, R16, LED1, IRLED1, Q6 and the AC adapter. Use No. 24 AWG stranded hookup wire and solder wires from the PC board to S1 and R16 as shown. The infrared emitter and detector (IRLED1 and Q6) need special preparation before they are attached to the PC board. To form a directed beam that will not be affected by external infrared energy, the two components will need to be mounted in reflective LED holders, which are then mounted to the levitator's metal bracket. At this point, however, just remove the round rubber pieces from the reflective holders and slide one each onto IRLED1 and photodetector Q6. Then attach the wires as shown. Using colored wire will help you keep the polar-

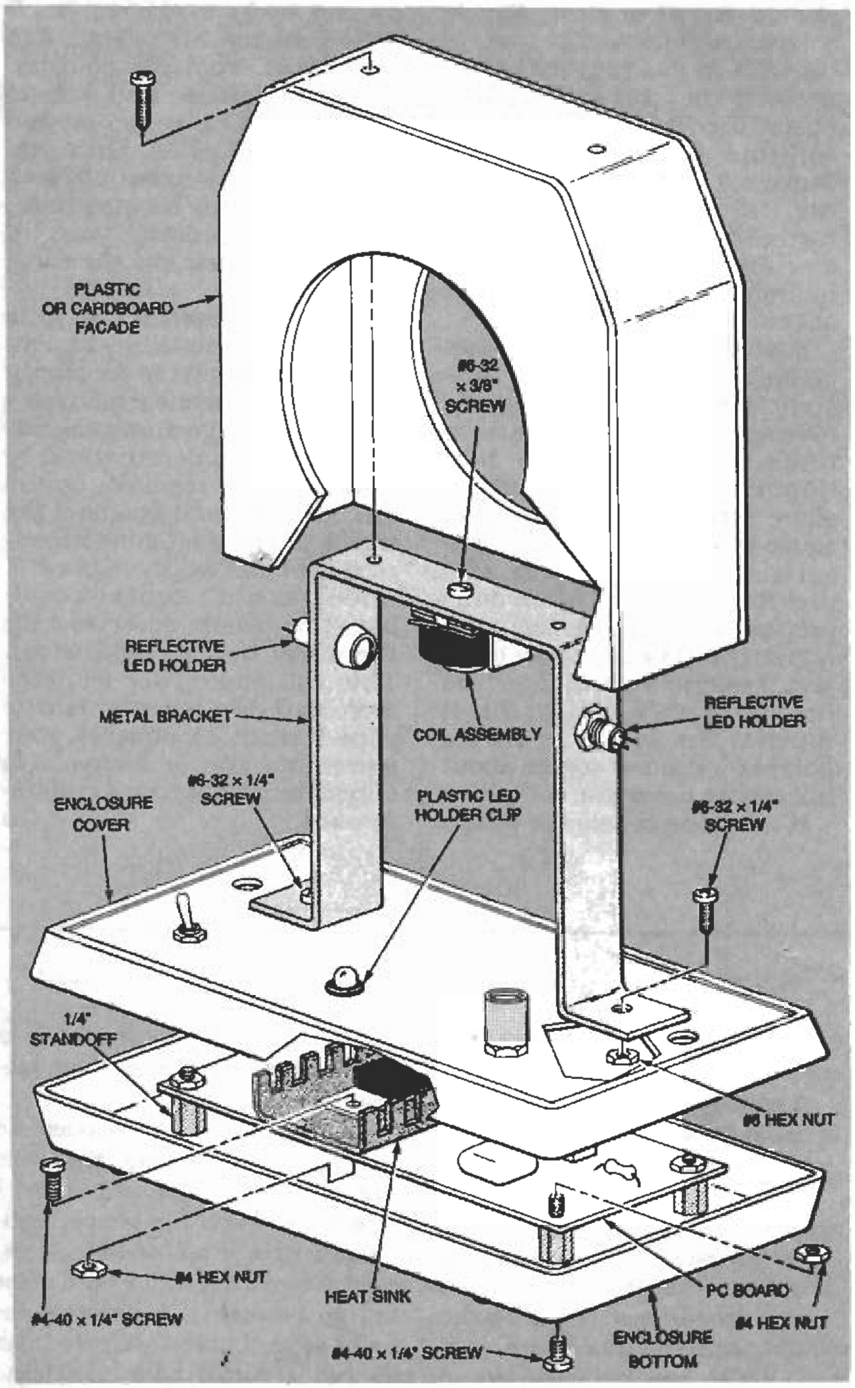


FIG. 6—A PLASTIC OR CARDBOARD COVER hides some of the levitator's components, enhancing the illusion that the globe is floating as if by magic.

ities correct.

Use two more pieces of wire to attach the red LED to the PC board. Again, use colored wire to make sure the connections match those shown in Fig. 2. Lastly, solder the two wires from the 12-volt adapter to the PC board, observing the proper polarity. Now locate the LM358 dual op-amp, IC2. Use the notch in the plastic package to orient pin-1 and install the IC firmly into the 8-pin socket.

The electromagnetic coil for this project should have a DC resistance between 25 and 35 ohms, and a steel or iron core. Winding such a coil can be tedious, so a readily available source for this part was located. A Potter & Brumfield relay (Model: KUP11D15- 6V) contains a coil that works fine. The relay should be disassembled and all parts discarded except the coil and metal "L" bracket as shown in Fig. 3. At this point solder the two wires for the coil to the PC board, but don't attach the coil to the other ends until after the board has been mounted in the plastic case.

Final assembly

Because the magnetic field from the coil loses strength rapidly with distance, it is important that the center of the infrared beam formed by IRLED and IRDET be no more than 0.2 inches below the coil. Otherwise, the coil will not be able to overcome the weight of the metal globe. This distance was determined by experimentation using the specific components shown in the Parts List. If you use a different coil or try to levitate objects of different weights, you will have to experiment on your own to find the best beam position.

The aluminum bracket shown in Fig. 4 is a convenient mounting support for the coil and the reflective LED holders. The dimensions shown will ensure that the infrared beam is the correct distance below the coil. This bracket is available from the source shown in the parts list or you can use Fig. 4 to fabricate your own.

Figure 5 shows how to drill the top cover of the plastic enclosure to accept the aluminum bracket and provide mounting holes for S1, LED1 and R15.

Figure 6 shows how everything fits together for the final assembly. Mount the PC board inside the enclosure bottom using 1/4 inch standoffs and the appropriate hardware. Next attach the metal bracket to the top of the enclosure with two No. 6-32 × ¼ inch screws and nuts. Remove the nuts from the reflective LED holders and mount both of them as shown in the diagram. Then attach the coil assembly to the top of the bracket with another No. 6-32 screw. Lastly, push the plastic LED holder clip into the center hole of the cover as shown.

Feed the IRLED and its wires through the ¼-inch hole in the top cover and insert the infrared LED into the reflective holder. Push the IRLED in until the rubber piece fits snugly. Repeat the process with Q6 on the other end. Next feed the coil wires from the PC board through the cover and solder them to the coil. Then mount S1, LED and R16 to the enclosure cover. Before putting the enclosure halves together, file a small notch in the back edge to allow the adapter's cord to exit. Attach the plastic knob to the potentiometer R16.

Operation

Place the anti-gravity levitator in a location that has normal room lighting. Try to keep it away from strong sources of infrared energy such as full sunlight or a bright desk lamp. Plug the adapter into a 120-volt AC outlet and turn R16 fully counter-clockwise before switching S1 on. Make sure nothing is under the coil that would block the infrared beam. The red LED should be off at first. Slowly turn R16 clockwise and observe the LED. As you turn the potentiometer the LED should come on and then turn back off as you continue to increase the Q6 threshold with R16. Stop turning R16 as soon as the LED turns off again. (The potentiometer should be between one-quarter to one-half of its range at this point).

Now take a small hollow steel globe, place it on your outstretched hand and lift it *slowly* towards the coil until it starts to break the infrared beam. It is important NOT to hold the globe between your fingers because your fingers will accidentally break the beam and prevent levitation. When done properly, the coil's field will gently grab the globe from your hand and suspend it in mid-air! Do not lift the globe so high that it touches the coil. The proper point of levitation will be about 0.2 inches below the coil.

If the globe constantly jumps up and sticks to the coil, then R16 is set too high. Start R16 once more from the counter-clockwise position and stop as soon as the LED comes on and goes back off again. Once you have the globe successfully levitating, try gently blowing on it. With a little practice you can make it spin just like the earth does.

Some non-metallic objects can also be levitated by attaching a small magnet to the object. This will take some experimentation. The magnet must be facing in the direction that will be attracted, not repelled, by the coil. Also the total weight of the object and magnet must not exceed the coil's ability to lift.

You may want to make a cardboard or plastic cover to hide the metal bracket and wires. This will make your levitator more attractive when you invite your friends to observe your power over gravity! Everyone is sure to be both amazed and impressed. Ω