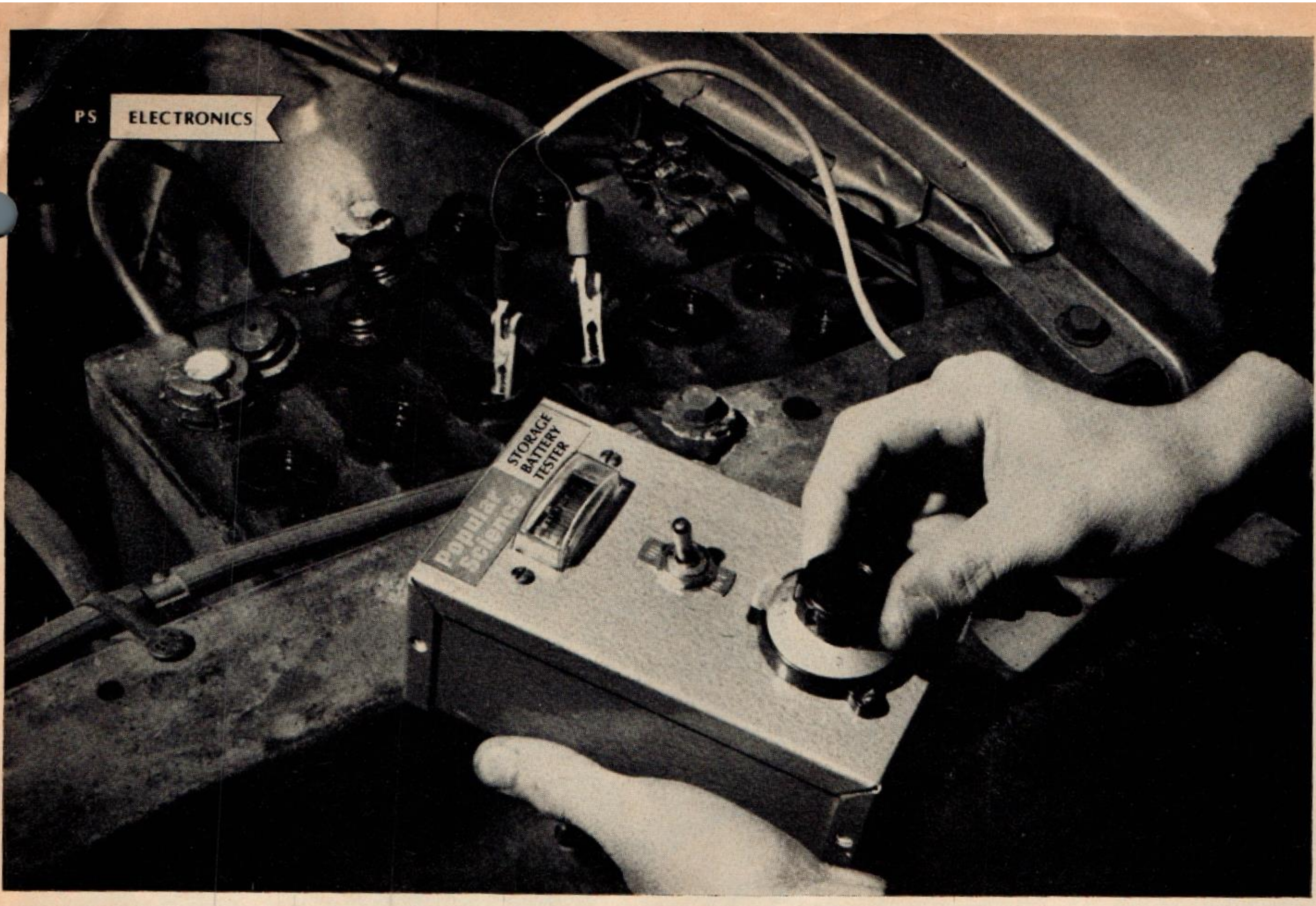


Don't play winter roulette. Know the condition of your battery, before it's too late, with this—

# Battery Tester for Your Car

By RONALD M. BENREY

Cold weather is with us, and Jack Frost usually finds a way to boggle some automotive part at just the moment you need your car most. Your storage battery is one of the most common cold-weather victims. A slow grinding start, a familiar clicking under the hood, or that deafening silence as you turn the key is your battery telling you it's in trouble.

Generally, however, your battery doesn't go dead all at once. It's a relatively slow process in which the cold weather just acts as a catalyst. And here's where the tester comes in.

**What will it do for you?** Performing this quick, but highly accurate, voltage test on your battery every so often during the winter months can l you a great deal about the status your battery and how good your chances are for a quick start in the morning.

The test is used to indicate the condition of the positive and negative plates inside the cell.

It would be impossible, however, to run an individual cell test on your car battery, since there is no access to the individual cell terminals on modern batteries. But, it *is* possible to do a kind of "back-to-back" cell test—between the electrolytes of adjacent cells.

This test simultaneously monitors the condition of the positive plate in one cell, and the negative plate in the adjacent cell. By taking a string of adjacent cell readings and comparing the results, you'll find that any weakness of your battery will be quickly apparent.

The battery tester is designed to perform such a test. It is a simple —but very accurate—potentiometric-type voltmeter that will measure the voltage between two cadmium electrodes that are dipped into the electrolytes of adjacent cells in any lead-acid battery. You can read the voltage with a resolution of 1/100 volt.

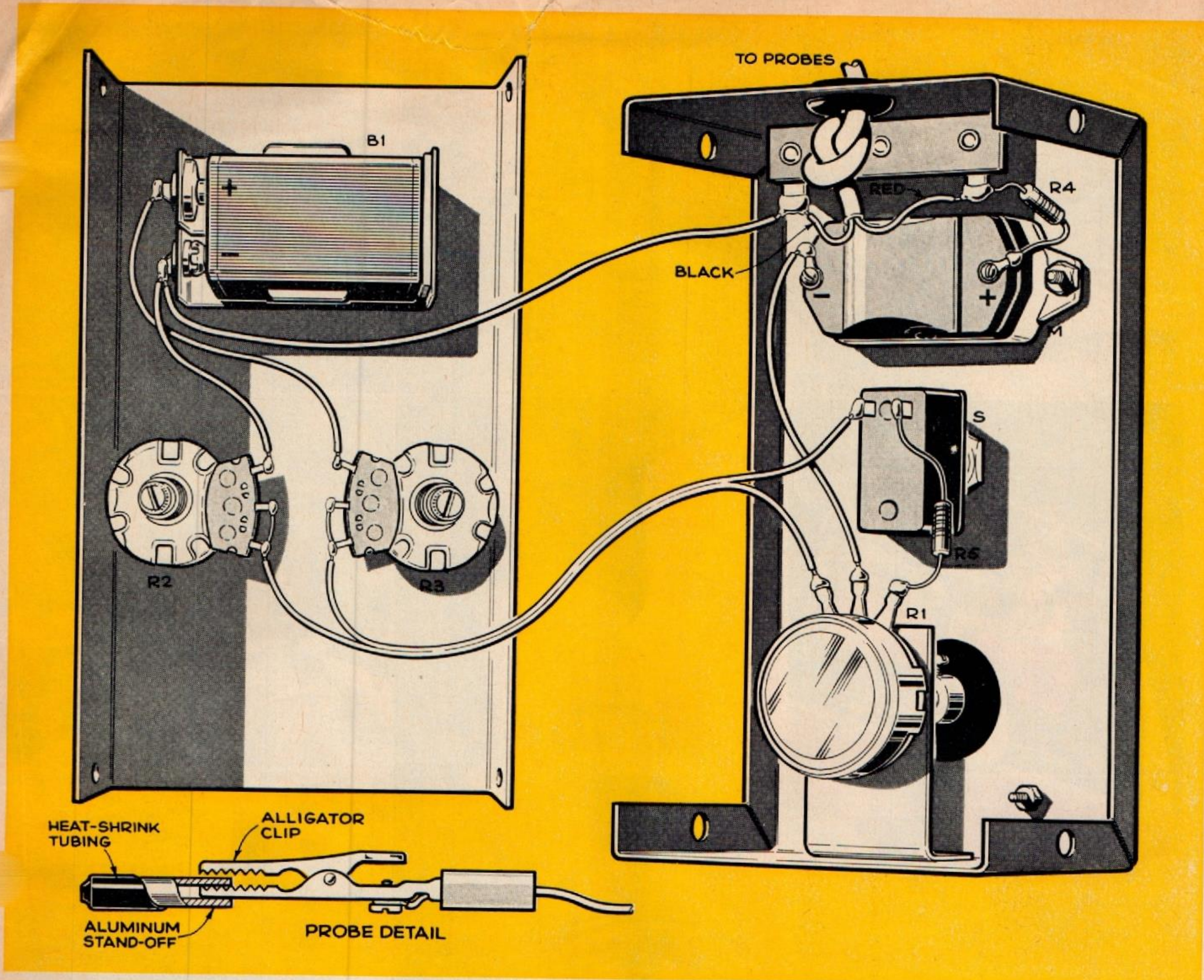
Use it faithfully, and the device will quickly point out inconsistencies within the battery that indicate coming failure, or at the least, reduced performance. And, it will help you to determine whether a battery that has been badly serviced, or abused, has been damaged.

**How it works.** Cadmium metal rods are difficult to come by, so our tester uses cadmium-plated brass spacers as electrodes. These are readily available from electronics part houses. Do *not* substitute nickel- or zinc-plated hardware.

The voltmeter is a bridge-type circuit that is very accurate. It is calibrated so that "0" on the vernier dial corresponds to an input of 1.5 volts DC, and the "100" reading equals 2.5 volts DC. The vernier then covers a linear range of one volt with 100 scale dimensions—each step equal to 1/100 volt.

When the electrodes are immersed

*Continued*



in the electrolytes, the voltage between them is applied to one side of the "zero center" meter movement. You then adjust potentiometer R1 (by turning the vernier dial knob) until the voltage across its wiper balances out the electrode voltage. When this happens, the meter needle rests at dead center. You then read the voltage off the vernier dial scale and add 1.5 to get the cadmium voltage. You should find most of your readings in the vicinity of two volts.

**Building it.** The simple circuit fits neatly into the 5"-by-2"-by-3" aluminum minibox specified. Mount the vernier dial on the faceplate as shown and center R1 just behind it on a scrap piece of aluminum.

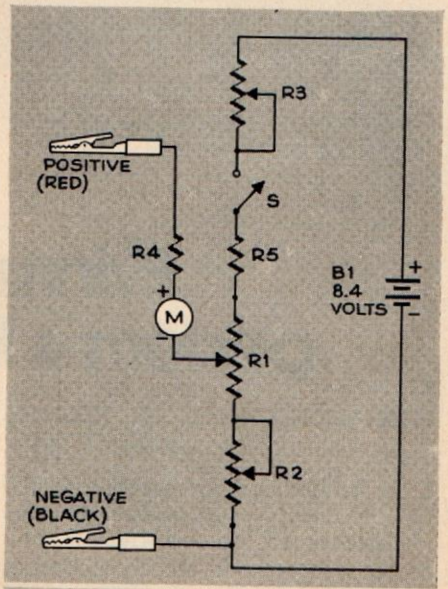
Cut the shaft to the proper length and pass it through the bushing hole into the rear of the vernier dial. Before you tighten the bushing setscrew, turn the vernier to read "100" on the dial and turn the shaft of R1 fully clockwise. This insures readings on the vernier in step with the turning of the potentiometer.

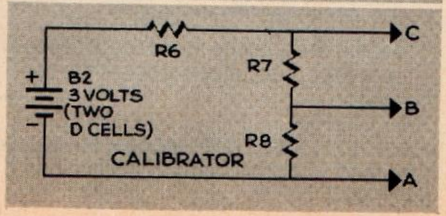
Cement the two calibration potentiometers R2 and R3 in place with dabs of contact cement. Be careful that you get no cement inside the bodies.

The test lead is a length of two-conductor cable terminated by a pair of colored (one red, one black) alligator clips.

Make the cadmium electrodes by covering the cadmium-plated spacers with shrink-fit tubing. (This is a plastic tubing that shrinks to half its original diameter when heated.) Insert each spacer in a short length of

[*Continued on page 117*]





## PARTS LIST

R1—1,000-ohm, linear-taper, carbon potentiometer
—2,000-ohm, linear-taper, carbon potentiometer
R3—5,000-ohm, linear-taper, carbon potentiometer
R4—1,000-ohm, ½w carbon resistor
R5—2,200-ohm, ½w carbon resistor
R6—100-ohm precision resistor (see text)
R7—200-ohm precision resistor (see text)
R8—300-ohm precision resistor (see text)
M—zero center tuning meter (Lafayette 99 F50346)
S—SPST toggle switch
Battery: 8.4-volt mercury battery (Mallory TR-164X or equal)
Misc.: Aluminum 5"-by-2"-by-3" minibox; 1½" vernier dial; alligator clips; cadmium-plated brass spacers (H. H. Smith 2104 or equal); ½" o.d. shrink-fit tubing

# CAR BATTERY TESTER

## *Build this simple meter to estimate your car battery's cranking amps.*

**THOMAS R. FOX**

EVEN THE LATEST AND MOST SOphisticated automobiles have an Achilles heel—the battery. Improvements in lead-acid batteries have been glacial compared with advances in the rest of the car—regardless of the country of origin. Recent advances in electronics have improved engine and emission control, made anti-lock braking affordable, and have put high-quality entertainment systems into the passenger compartment. Unfortunately, all of these improvements have added to rather than decreased the battery load.

If your car fails to start in your garage, it's usually just an aggravating situation. But if you stall out or can't get started at a vast shopping mall or, worse yet, out along an interstate, the situation becomes more serious. And if you're unfortunate enough to be caught in a crime-stricken urban area or on any highway at night, you could be facing danger. Getting help takes time and can be expensive even under the best of conditions. The point is that it pays to know that your battery is in top form—even more if it's not!

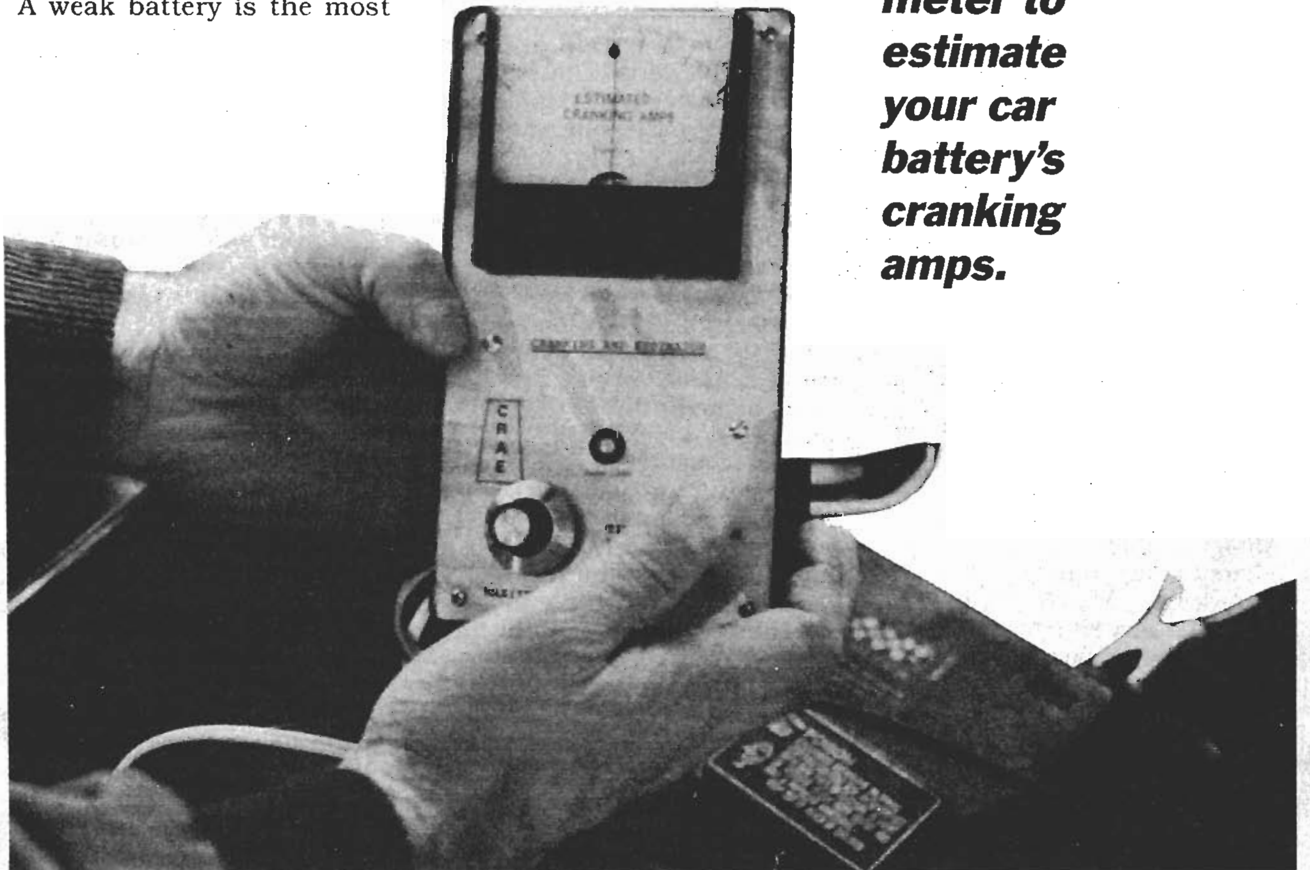
A weak battery is the most common cause of an automobile's failure to start. The battery remains the most failure-prone component in any automotive (and boat, for that matter) ignition system. A properly maintained engine can last for hundreds of thousands of miles, but few lead-acid storage batteries are at top performance for more than about three years. Even that time will be shortened if you live in a northern climate where your car is exposed to long winter cold "soaks" and hard starts.

Don't think that just because you bought a new battery last month that it's immune to failure. However, batteries rarely fail without such warning clues as occasional slow cranking. Unfortunately, many drivers are either unaware of these clues or, if they are aware, they put off recharging or replacing the battery until it is too late.

### CRAE to the rescue

The CRanking Amp Estimator (CRAE) described here is a test instrument that will give you a reasonable estimate of your battery's power capacity. While CRAE is not a precision instrument, it will save you from being stranded in a hostile environment.

Both the graph of relative power vs. temperature (Fig. 1) and the GW BASIC listing (Listing 1) will, with a knowledge of the ambient temperature, give you a reliable estimate of your battery's cold-cranking ampere (CCA) rating. The BASIC program is capable of estimating the CCA of a battery at all normal ambient temperatures if the CCA at one temperature is known. Both Fig. 1 and the



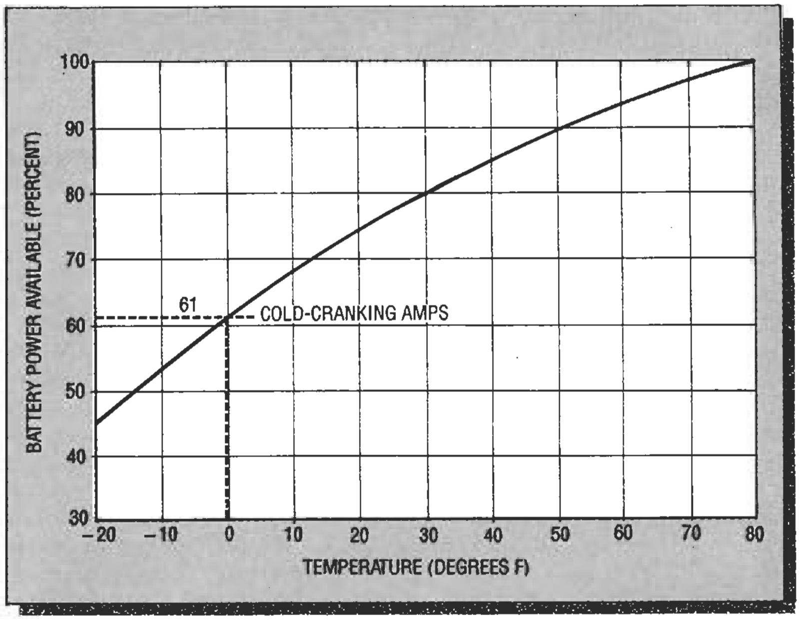


**FIG. 1—RELATIVE POWER CAPACITY in a battery at temperatures from −20°F to +80°F where 100% available power is assumed. Cold-cranking amps (CCA) are read at a temperature of 0°F.**

BASIC program are based on General Motors Corp. studies.

CRAE's drain on your battery is only a slight 2.5 amperes, so it is much safer to use than instruments that test the load. Also, CRAE will not significantly discharge your battery if it is used as directed. Remember that CRAE is *not an ammeter* so its readings will only give you an intelligent estimate of the *potential* CCA of your battery without actually measuring it.

After you have learned how to use CRAE, all you need is a digital voltmeter and a thermometer to keep you informed on the condition of your 12-volt car or boat battery—if it has a CCA rating from 150 to 1000.

## Cold-cranking amps

Cold cranking amps (CCA) is the value for the amount of current a battery can deliver for 30 seconds at 0°F without dropping below a specified cutoff voltage. Figure 1 shows that the battery power output increases significantly from 0°F to 80°F. In fact, a battery rated at 600 CCA (at 0°F) should be able to deliver 1/0.61 × 600 or 984 cranking amps at 80°F!

An approximate guide in determining the CCA rating for a battery that will start an engine reliably at 0°F depends upon engine displacement, typically measured in cubic inches. However, If your engine displacement is specified in liters, multiply that figure by 61 to get cubic inches before using the following guide:

- An eight-cylinder engine requires one cranking ampere per cubic inch of engine displacement. For example, to start an eight-cylinder 350 cubic-inch engine, the battery must deliver 350 CCA.
- A six-cylinder engine has a CCA rating that is eight times the cubic-inch displacement *per cylinder*. For example, if a six-cylinder engine has a displacement of 231 cubic inches, the displacement per cylinder is approximately 39 cubic inches. Therefore, the battery must deliver 39 × 8 = 312 CCA.
- A four-cylinder engine has a CCA requirement that is twice the engine's displacement in cubic inches. For example, if a four-cylinder engine has a displacement of 180 cubic inches, the battery must deliver 360 CCA.

If the ambient temperature is consistently below 0°F, the battery should have a CCA rating that is 20% higher than that which would be calculated for warmer conditions.

In addition to CCA, there are other battery ratings in use today. For example, the MCA, for marine cranking amps, is a rating developed for boat batteries that is based on 32 °F instead of 0°F for CCA. An MCA rating for the identical CCA-rated battery is typically 25 to 30% lower.

Another specification is reserve capacity, given in minutes. It describes a battery's ability to continue supplying power to the engine and accessories if the car's charging system fails. That test drains the battery at a 25 ampere rate until the battery voltage drops from more than 12 volts to 10.5 volts.

## A 12-volt battery model

Most text books show a 12-volt storage battery equivalent circuit either as an ideal 12-volt source or as that source in series with a small resistance, perhaps 20 milliohms or less. An ideal voltage source provides a constant voltage regardless of current flow. It can deliver infinite current and infinite power. Unfortunately, there is no such thing as an ideal voltage source.

The equivalent circuit for a battery shown in Fig. 2 is a satisfactory model for the design of a CCA meter. However, the more realistic equivalent circuit shown in Fig. 3 includes a large capacitor and an additional resistor. That model accounts for changes in battery output with respect to time.

An even more elaborate model would include a time- and current-dependent voltage source as well as time-dependent resistors and capacitors. However, accounting for all of those additional variables would complicate the design of a simple, easy-to-use meter. Moreover, taking into account all of those additional variables would add little to the accuracy of the meter.

## How CRAE works

CRAE's objective is to estimate the size of $R_{INT}$ as shown in Fig. 4. There is an inverse relationship between this resistor and battery capacity: the

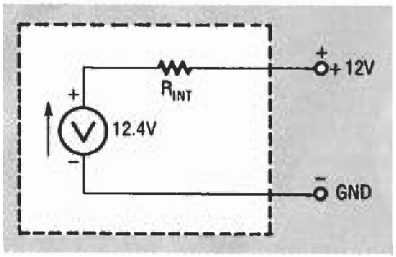


**FIG. 2—EQUIVALENT CIRCUIT FOR a 12-volt lead-acid storage battery. $R_{INT}$ limits the battery current.**

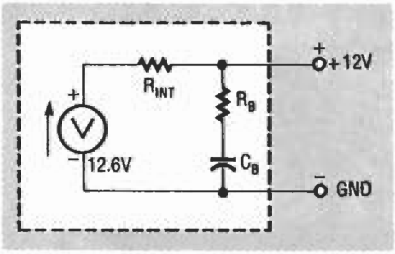


**FIG. 3—CRAE EQUIVALENT CIRCUIT for a 12-volt lead-acid battery. The one-minute test reduces the measurement error caused by $C_B$ and $R_B$.**

smaller the value of $R_{INT}$, the higher the battery's capacity. In the absence of $C_B$ and $R_B$, $R_{INT}$ could easily be estimated by applying a load to the battery, measuring voltage and current, and making a few calculations. (CRAE does this for you automatically.) However, it is first necessary to discharge $C_B$, the reason that CRAE has a timing circuit.

There are three basic parts to CRAE: The first, the voltage-measuring circuit, is a sensitive voltmeter that measures an adjustable voltage from 11.9 to 12.5 volts. The second is a solid-state, constant-current load that is adjusted to draw 2.5 amperes load regardless of the voltage. The third is a one minute timer that lights an LED to indicate measurement readiness.

The voltage-measuring circuit consists of op-amp IC1-a (¼ LM324) connected in a differential amplifier circuit. The voltage reference for this circuit is the 5-volt regulator IC2 (LM2931Z). Resistor R13, the MAX ADJ potentiometer, trims this reference voltage to maximize voltage readings under no-load conditions. Resistor R3 is a PC-mount trimmer that adjusts current flow through the meter and is a sensitivity control on Fig. 4.

Resistor R20 is a 1K PC-mount trimmer that sets the meter's zero point (0.05 milliampere). Resistors R5 and R6 raise the meter's negative terminal above ground level, allowing the meter to be zeroed. Diodes D2 and D3 protect the meter, and D1 protects other sensitive parts of the circuit from accidental damage when the test leads are first connected to the battery.

The primary component of the constant-current load is Q2. When momentary two-position toggle switch S1 is switched to the TEST position, current flows through Q1's emitter circuit because IC1-c provides base current. That emitter current also flows through Q2's base circuit, resulting in considerable current flow. Resistor R17 both directly and indirectly controls the constant current.

As in any transistor with an emitter resistor, Q2's current is essentially constant because, as emitter current increases, emitter voltage follows. This means that $V_{BE}$ and $V_{CE}$ are smaller, thus tending to reduce emitter current. Nevertheless, this effect is not sufficient to provide a constant-current load. Op-amp IC1-c completes that task. Moreover, IC1-c helps to provide a near ideal constant current load, and it also simplifies load-current adjustment.

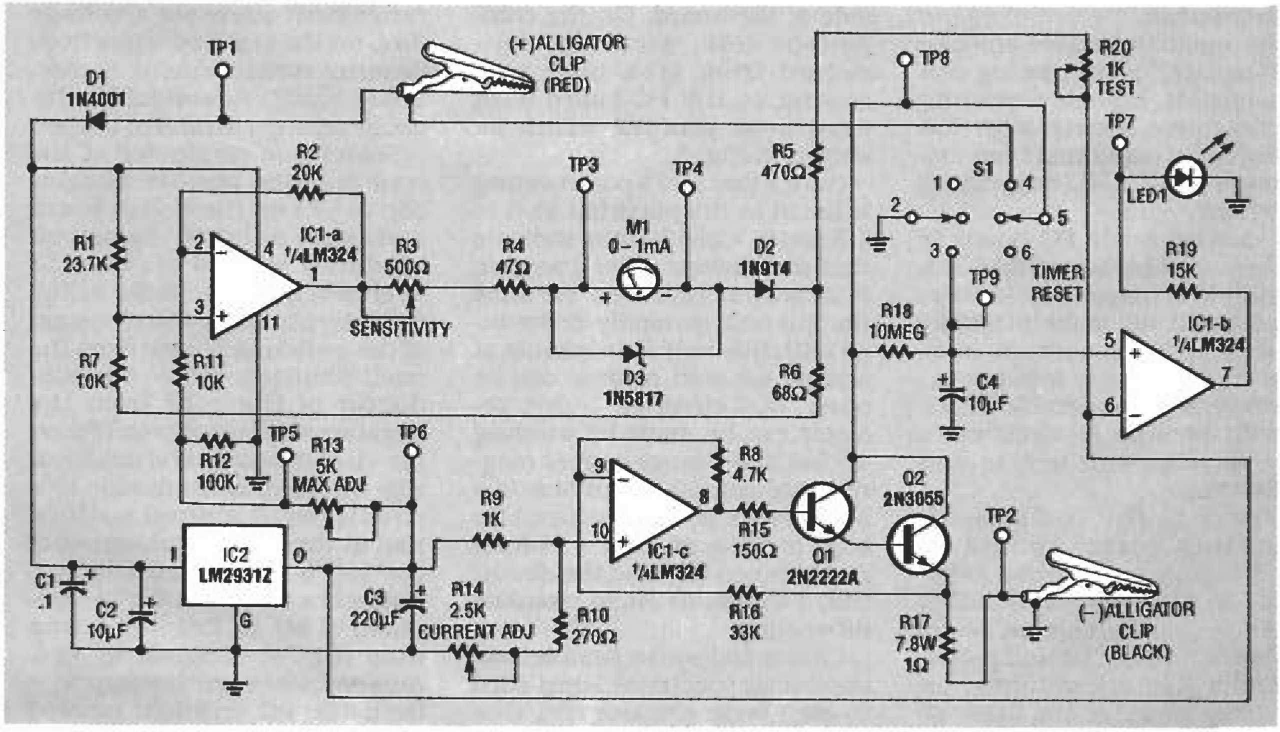


**FIG. 4—SCHEMATIC FOR CRAE showing contact points for external connections.**

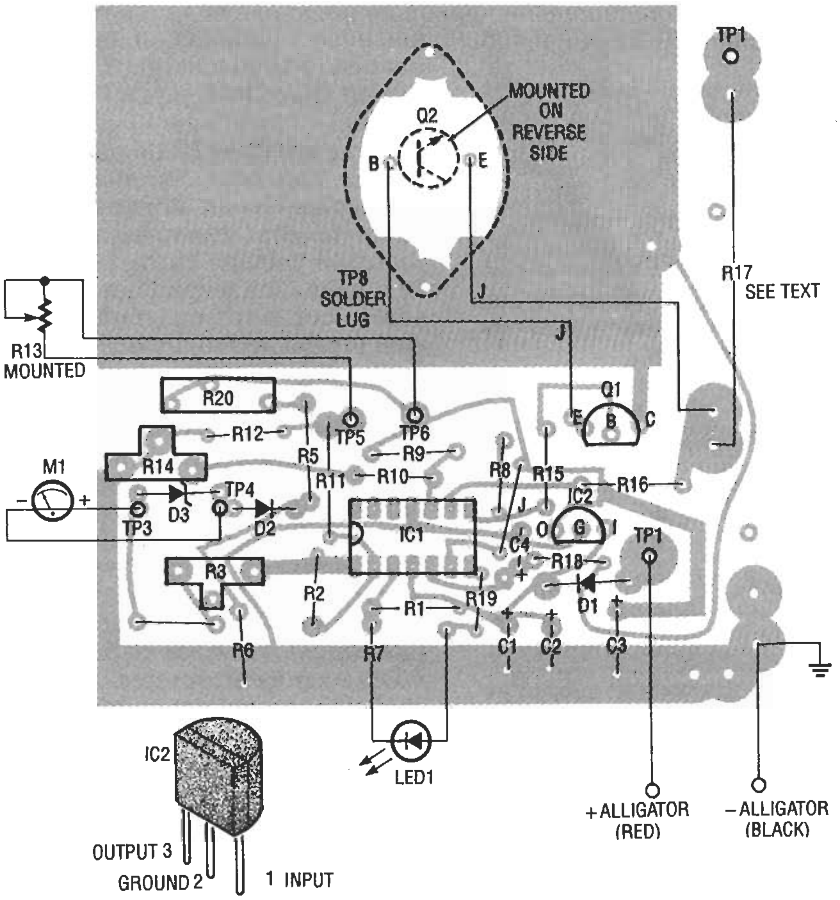


**FIG. 5—PARTS-PLACEMENT DIAGRAM for printed circuit board of CRAE.**

Examination of the schematic reveals that the inverting input is connected through R16 to Q2's emitter. As Q2's emitter current increases, the voltage at the inverting input of IC1-c increases, resulting in a lower voltage output at pin 8 and less current at Q1's base. That causes a reduction in current at Q2's base and the resulting decrease in Q2's collector and emitter current. R14 adjusts the voltage on IC1-c's non-inverting input, and thus provides adjustment for the current through Q2's emitter.

The timing circuit was designed so that the timing period would vary with voltage. (Low readings on CRAE's meter are related to low battery voltage and longer timing periods.) This, in part, compensates for a fully charged (high open-circuit voltage) battery's tendency to show somewhat smaller CCA values than if it were slightly discharged.

The timing circuit consists of IC1-b, C4, and R18. When S1 is in the TEST position, C4 starts to charge through resistor R18. When the voltage across C4 exceeds 5 volts, the op-amp's output switches "on" and lights LED1.

## Construction

The most expensive component in CRAE is the moving-coil ammeter M1, capable of reading 1 milliampere. A meter with this rating could could cost from $10 to more than $50, depending upon size.

A custom-made PC board is not required because CRAE is a simple low-frequency instrument, but it will make assembly easier and faster, perhaps in as short a time as a few hours. However, if you assemble CRAE rapidly, be sure to allow extra time for thorough testing and calibration.

Figure 5, the component-mounting guide, should be used together with the schematic in Fig. 4 when building CRAE to avoid problems. Meter M1, switch S1, LED1 and potentiometer R13 are mounted on the front panel of the case; all other parts are mounted on the PC board. Be sure that the heat sink is in place when soldering Q2. The heat sink with Q2 attached is mounted on the foil side of the board. On the component side, wires are connected from Q2's base and emitter to the PC board with insulated jumper wires as shown in Fig. 5.

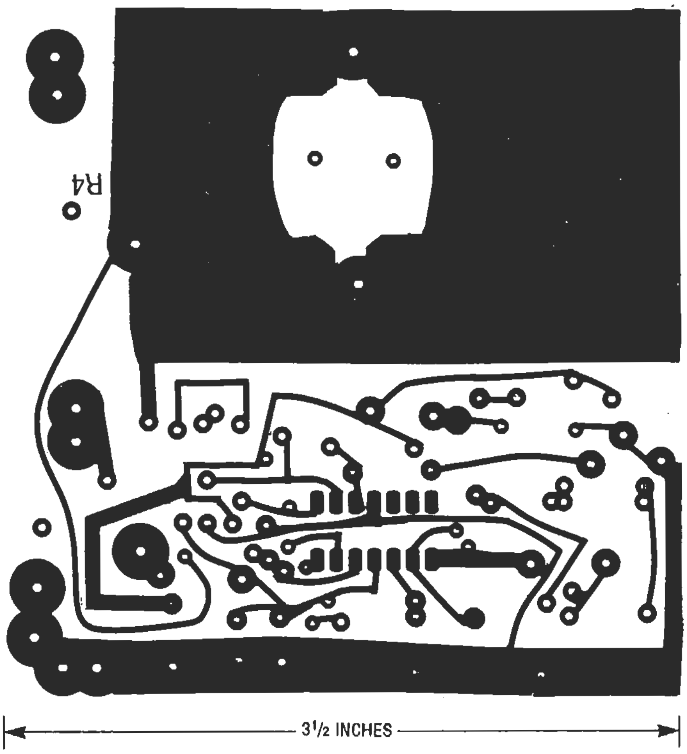
Notice that R17's power rating is listed in the parts list as 5 to 7.5 watts. Calculations indicate that the resistor must dissipate 6.25 watts. However, because the current generally flows intermittently only for a minute at a time, a 5-watt resistor can be used. (An effective 1-ohm resistor can be made by winding 40 feet of 24-gauge copper magnet wire around the outside of a large-value power resistor.) Be sure to leave at least a ⅜-inch gap between R17 and the circuit board to permit air to circulate for cooling.

Crimp and solder flexible two-conductor electrical lamp cord to each large alligator clip. One conductor from each clip is attached to the voltage-measuring circuit, and the other conductor is attached to the load circuit. That 4-wire arrangement prevents a voltage drop on the test lead wires from causing measurement errors. Those conductors should be 18-gauge or larger stranded copper.

Solder one conductor of the cord from the positive alligator clip to TP1 on the circuit board and solder or crimp the second conductor to pin 4 of switch S1 as shown in Fig. 4. (Refer to Fig. 6 for the pin numbering system of the switch as shown from the rear.) Similarly, solder one conductor of the cord from the negative alligator clip to TP2 on the circuit board, and solder or clip the second conductor to a circuit-board ground such as that at the lower right corner of the foil on the circuit board. Connect a wire from the "+" terminal of M1 to TP3 and a wire from the "–" terminal to TP4. Also connect some hookup wire from the left terminal (viewed from the rear) of R13 to TP5 and a wire from the center terminal to TP6.

In performing the following steps refer to Fig. 6, switch S1's pin-numbering guide. (The pin numbering shown is for the switch in the Parts List.) Connect a wire from pin 2 of S1 to a circuit board ground. Also, connect wires from pin 3 to TP9 and pin 5 to TP8. Finally, connect a wire from the LED's anode (long lead) to TP7, and a wire from LED's cathode (short lead) to a circuit ground. (The LED should be a high-efficiency GaAsP or GaP lamp that draws minimal current because the circuit is sensitive to small voltage changes.)

You'll want to calibrate the meter and, perhaps relabel the meter's face with the term "Estimated Cranking Amp" markings, for a more professional appearance. Table 1 is a set of data for guidance in calibrating the meter. The photograph shows the end result.



SOLDER-SIDE FOIL PATTERN for PC board shown actual size.

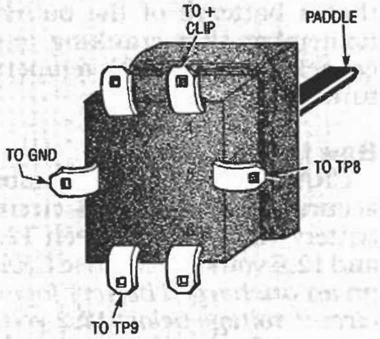


FIG. 6—REAR CONNECTIONS for S1, a 3-way toggle switch.

There are several ways to label a meter face. In one you can use a PC and an appropriate computer-aided design program to relabel the graduations and set up the estimated cranking amps legend. That can be printed out on adhesive-backed paper or plastic with a laser printer for direct application. The only drawback to this method is that the paper might be thick enough to interfere with the meter's moving needle.

Another method is to erase the numbers on the meter face with a pencil or ink eraser, and then use dry-transfer lettering to relabel it. However, you can simply use a soft pencil to add the cranking amp markings to the meter's markings.

### TABLE 1—GUIDE TO LABELING AMMETER

| Milliamps | Cranking Amp Markings |
|---|---|
| 0.00 | 150 (or below) |
| 0.30 | 200 |
| 0.48 | 300 |
| 0.60 | 450 |
| 0.70 | 650 |
| 0.80 | 800 |
| 0.94 | 1000 |
| 1.00 | Infinite |

Double-momentary toggle switch S1, the MAX(INF)ADJ potentiometer R13 and LED1 should be mounted on the front panel. Potentiometer R13 can be a stock single-turn potentiometer, but a multiturn potentiometer with dial makes CRAE easier to use. In labeling this potentiometer on the panel "max" stands for maximum, "inf" means infinite and "adj" means adjust. See the photograph of the front of the instrument.

### LISTING 1—PROGRAM FOR ESTIMATING CRANKING AMP CAPACITY

```
1 'THIS GW BASIC PROGRAM ESTIMATES THE CRANKING AMP CAPACITY OF A 12V LEAD-ACID
2 'STORAGE BATTERY AT MOST PRACTICAL TEMPERATURES ASSUMING YOU SUPPLY IT DATA OF
3 'THE CRANKING AMP CAPACITY AT A SPECIFIC TEMPERATURE.  IF ALL YOU KNOW IS THE
4 'MANUFACTURER'S "CCA" RATING, MAKE SURE YOU ENTER "0" WHEN ASKED
5 '  "What is the temperature of the battery, in degrees F?"
10 INPUT "What is the temperature of the battery, in degrees F";TFOT
15 IF TFOT>120 GOTO 100
16 IF TFOT>80 THEN TFOT=80
20 INPUT ;"Estimated Cranking Amps at this temperature";CAOT
30 PRINT "What temperature due you want the new estimate for cranking amps?"
40 INPUT "PRESS RETURN FOR 0 F.(This will give you the CCA)";TFNT
45 IF TFNT>120 GOTO 100
46 IF TFNT>80 THEN TFNT=80
50 LET KTFOT=.61+.0082*TFOT-.0000417*TFOT*TFOT
60 LET KTFNT=.61+.0082*TFNT-.0000417*TFNT*TFNT
70 LET CANT=KTFNT*(CAOT/KTFOT)
80 PRINT "Estimated Cranking Amps at ";TFNT;"F is "; CINT(CANT)
90 END
100 PRINT "Storage batteries should not be exposed to this high a temperature!";
110 END
```

## Testing and calibration

First, preset all potentiometers (R3, R13, R14, and R20) to their center positions. Next, set the output of a regulated power supply capable of at least 12.6 volts with a digital voltmeter (with minimum 0.5% DC voltage accuracy.) If a regulated power supply is not available, substitute a fully charged 12-volt storage battery with a 100-ohm potentiometer across the terminals. The desired voltage can be taken from the center wiper arm. Connect the positive alligator clip (red) to the supply's positive terminal and the other clip to the negative terminal. *Do not use the test switch at this time!*

Slowly increase the supply's voltage for a 12.5-volt reading on the DC volts scale of a digital multimeter. Set R3 for a maximum (1 milliampere) reading on meter M1. Now lower the voltage to 11.9V and adjust R20 for a 0.05 milliampere reading. Again apply 12.5 volts and adjust R3 and/or R20 to obtain a 1.0 milliampere reading. Repeat this step for 11.9 volts. After several adjustments of R20 and R3, M1 should register 1.0 milliamperes when the voltage at the alligator clips is 12.5 volts and 0.05 milliamperes when the voltage is 11.9 volts.

The DMM should then be used to set R14 for a 2.5 ampere current flow through R17. Connect CRAE's alligator clips to a 12-volt storage battery or a 12-volt source that can deliver at least 5 amperes. (Be sure the red clip is connected to the plus terminal and the black clip to the negative terminal.) Next place the DMM's leads across the 1-ohm power resistor R17 and adjust R14 for a 2.5-volt display on the DMM. (You are actually adjusting the current for 2.5 amperes flowing through R17.). This completes the basic calibration of CRAE.

### PARTS LIST

**All resistors are 1/4-watt, 5%, unless otherwise indicated.**
R1—23,700 ohms, 1/4-watt, 1%
R2—20,000 ohms, 1/4-watt, 1%
R3—500 ohms PCB trimmer
R4—47 ohms
R5—470 ohms
R6—68 ohms
R7, R11—10,000 ohms
R8—4700 ohms
R9—1000 ohms
R10—270 ohms
R12—100,000 ohms
R13—5000 ohms potentiometer (panel-mount)
R14—2500 ohms PCB trimmer
R15—150 ohms
R16—33,000 ohms
R17—1 ohm, 5.0 to 7.5 watt
R18—10 megohm
R19—15,000 ohms
R20—1000 ohms, PCB trimmer, 15 turn

**Capacitors**
C1—0.1μF, 25 volts
C2—10μF, 25 volts, electrolytic
C3—220μF, 16 volts , electrolytic
C4—10μF, 25 volts +/- 10%, tantalum

**Semiconductors**
IC1—LM324 quad op-amp
IC2—LM2931Z 5-volt voltage regulator
Q1—2222A NPN transistor
Q2—2N3055 NPN transistor
LED1—Light-emitting diode (High-efficiency GaAsP on GaP)D1—IN4001 silicon rectifier
D2—IN914 silicon diode
D3—IN5817 schottky barrier rectifier

**Other components**
S1—DPDT momentary action with off at center
M1—Panel meter, moving coil, 0 to 1 mA.

**Miscellaneous:** two alligator clips (1-inch jaw length), two lengths of two-conductor parallel flexible 18 AWG stranded copper lamp cord with PVC or rubber insulation (approx. 3 feet long), PC board, case—Radio Shack Cat. No. 270-232 or equivalent, control potentiometer knob, aluminum heat sink, LED mounting hardware insulated hook-up wire, solder, etc.

If the meter faceplate conversion table in Table 1 is used, CRAE should have an accuracy better than 20%. The prototype CRAE was calibrated and tested with four different batteries of known CCA capacity. Two batteries were new (600 CCA and 165 CCA ratings, respectively), one was of average age (410 CCA), and one was older but still functional (400 CCA). The batteries were tested with commercial test equipment which confirmed the battery manufacturers' ratings for the three newer batteries.

The old 400-CCA battery tested 420 CCA at 50° F with commercial equipment. This suggests that its true rating is about 280 CCA and that its service life is probably at or very close to its end. While only four batteries were in the test sample, CRAE was more extensively tested than this would imply because the tests were made at different ambient temperatures on each battery.

The accuracy rating of CRAE can be increased if you calibrate it with the output of three batteries of known capacity. Accuracy of calibration can also be improved if CRAE's results are compared to those of a commercial battery tester and adjusted accordingly.

You can also increase CRAE's accuracy by connecting it to a battery whose cranking amp capacity is known, and then adjusting trimmer R14 so that CRAE's meter reading equals that a battery's of the battery. Remember that cranking amp capacity changes with temperature.

## How to use CRAE

CRAE's reading will be most accurate when the open- circuit battery voltage is between 12.4 and 12.6 volts. *Do not use CRAE on an uncharged battery (open-circuit voltage below 12.2 volts) or a new, freshly charged battery (open-circuit voltage above 12.65 volts). because the readings will be erroneous.* To avoid starting problems, replace any battery whose open-circuit voltage falls below 12.2 volts within minutes of charging. Open-circuit voltages should be taken under no-load conditions. That usually requires that the ground cable be disconnected from the terminals of the battery before it is tested.

If you want to test a new, recently charged battery, discharge it slightly for a few hours at a discharge current of a few amperes. A safe way to do this is to make up a simple load by soldering insulated wires to the

*Continued on page 71*

## BATTERY TESTER

*continued from page 62*

base terminals of a standard #1157 automotive incandescent lamp and crimping alligator clips to the other ends of the wires. This load can then be clipped across the battery's terminals for several hours. (The assembly is also a handy, inexpensive trouble-shooting light that you can use for working under the hood of your car.) After disconnecting the load, wait until the voltage stabilizes before doing the CCA test. Ideally, the open, circuit voltage of a new battery should be 12.6 volts (±0.02 volt).

**CRAE test procedure**

When using CRAE to test a battery, follow these steps:

1. Determine the manufacturer's CCA rating for the battery. This information is a reference that will help you to determine if the battery should be replaced. Also, estimate the ambient temperature of the battery by taking the air temperature of the battery's location immediately before you begin the test.
2. Disconnect the ground cable from the battery if it is connected to the electrical system of a vehicle before doing the test.
3. Using an accurate digital multimeter with a basic DC-voltage accuracy of at least 0.5%, measure the open-circuit voltage of the battery. If the voltage is below 12.25 volts, recharge the battery and recheck the voltage.
4. Under some conditions the battery voltage will exceed 12.65 volts. In that case, discharge it slightly as explained earlier in the text. Because CRAE itself is a light (2.5 ampere) load, it can be used to discharge the battery. However, *Do not use CRAE for sustained periods of more than two minutes because it is not designed for continuous use !* To measure the output of the battery most accurately, the battery's open-circuit voltage should be between 12.4 and 12.6 volts.
5. Connect CRAE's positive (red) alligator clip to the "+" terminal of the battery and the negative (black) clip to the "–" terminal. Adjust the MAX(INF)ADJ knob on the panel so that the needle points to the maximum deflection. Be sure that all connections are *secure*. A poor alligator clip connection will cause CRAE to give an erroneous reading.
6. Throw switch S1 to the TIMER RESET (left) position and then let it snap back to the center "off" position. Remember that S1 has three positions: center is "off" and the others are momentary action.
7. To test the battery, hold S1 in the TEST position until the LED lights in about 1 minute. When that occurs, take the reading and let S1 return to the center "off" position.
8. For the most accurate retest the battery. Any difference between the first and second readings on a satisfactory battery is insignificant. However, expect that the second reading on a weak battery will be lower than the first. The second reading is the *most accurate*. If you want to retest the battery a third time, be sure to wait at least two minutes between the tests to avoid stressing CRAE.
9. *Do not use the MAX(INF)ADJ knob for the second or subsequent readings on the same battery.* (The 1-minute, 2.5-ampere load of the initial test has changed the battery's open-circuit voltage.) However, if you want to test another battery proceed as stated originally. Also, if the subsequent test on the same battery occurs an hour or more later, reset the meter needle to the INF position. A general rule is that if the open-circuit voltage voltage of the battery is constant—no matter when tested—use the MAX (INF) ADJ knob to set the meter needle to the INF position.

After determining the cranking amp capacity and temperature, use either the GW BASIC program in Table 1 or the graph in Fig.1 to determine the battery's CCA capacity. *Replace the battery if the calculated CCA is substantially lower than the manufacturer's rating.* **R-E**