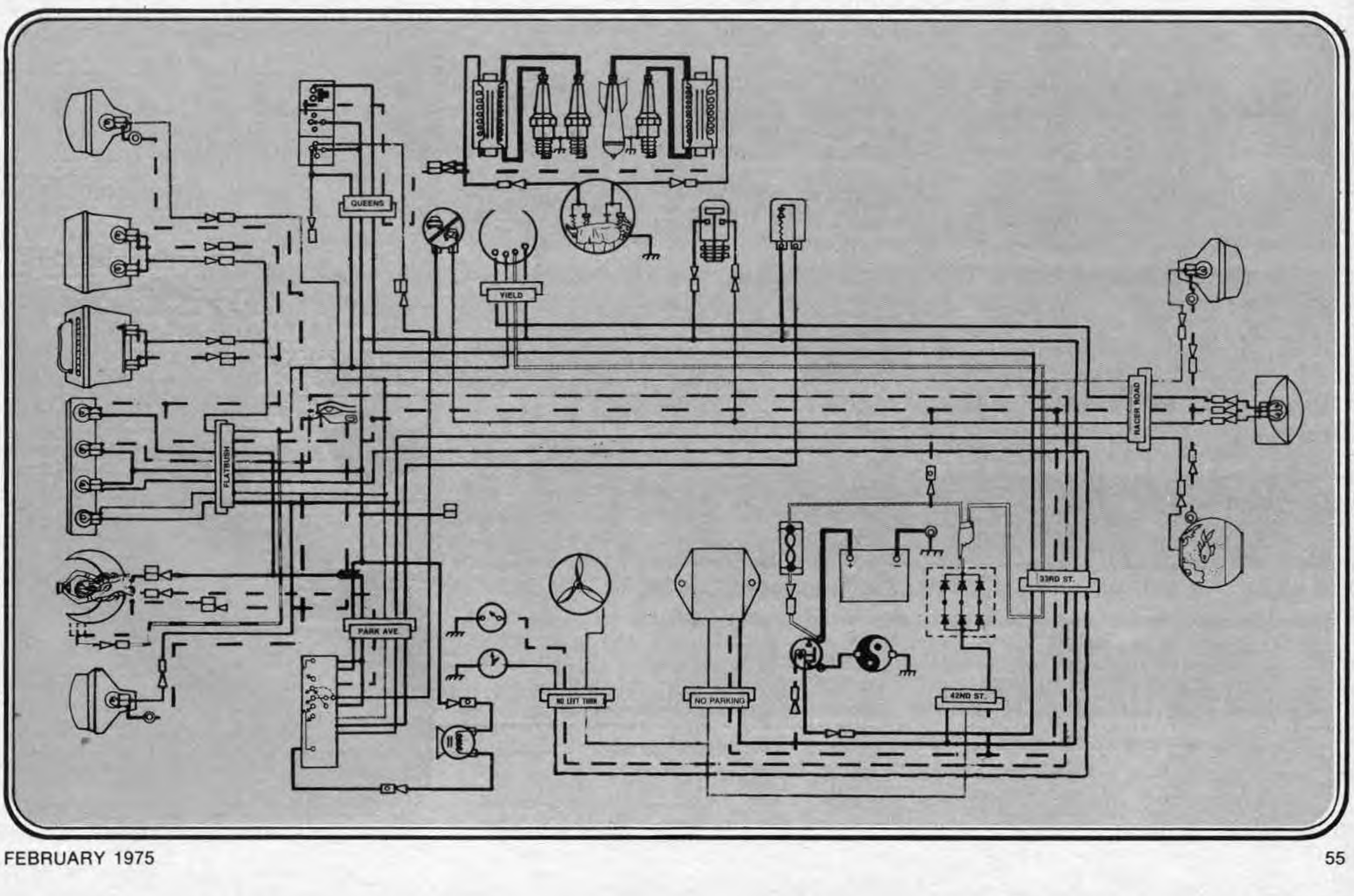
Basics

ELECTRICS

• Lurking somewhere in the back half of' the typical motorcycle owner's manual is one page certain to confuse your typical motorcycle owner. Most riders will slog through whatever a manual says about the mechanics of their bike without lapsing into brain fade, but then they reach the page titled "Wiring Diagram" and everything goes blank. All those lines and pictographs may well be intended to explain a bike's electrical system; for a majority of riders the whole mess could as easily be plans for a Tibetan prayer wheel, and is about as useful on those dread occasions when fuses blow and wires begin to send up wisps of smoke. In fact, wiring diagrams explain little except to people who already have acquired a basic knowledge of the systems in question. It's all a matter of knowing, at least in broad outline, how a motorcycle generates, regulates, stores, distributes, and ultimately uses the mysterious energy form we call electricity.

All but a very few of the motorcycles now in production employ a device called an "alternator" to power their lights, ignitions, horns, etc. These alternators make electricity by sweeping a magnetic field through coils of copper wire, in a classic application of the phenomenon we know as inductance. Until quite recently the motorcycle alternator's field almost invariably was supplied by a multi-pole permanent magnet cast into its rotor, and that still is the common arrangement in all but a few bikes. Typically, too, the alternator will be a built-in engine accessory: the rotor held and driven by the end of the crankshaft, and the stator—a laminated ring of soft iron plates on which the coils are carried—bolted into a cavity provided in the side of the crankcase. Because the rotor runs in close proximity to the stator laminations its rotation produces a rapid, alternating shift of the magnetic field in the stator windings. Inductance takes care of the rest, developing an alternating electrical potential in the coils. It's all very simple and reliable, and very far from being able to power a motorcycle's electrical system without some specialized assistance.

Alternators do not have the vulnerable commutator and brushes of old-fashioned



direct-current generators; neither is the alternator's output so closely a function of the speed at which it is driven. But there is inherently enough variation in alternator output voltage potential over the broad range of engine speeds to be an acute embarrassment, if uncontrolled, to the rest of the motorcycle's electrical system. Further, current flow from an alternator is one of constantly reversing polarity—no single output lead is consistently "positive" with respect to the others. Polarity is unimportant to the headlight, because it is the forced flow of electrons that heats its filament to incandescence, and low-frequency reversals in the direction of current flow are of no consequence; but the filament must be protected from excesses in alternator output. Batteries are less sensitive to voltage surges; they do demand that the current flowing to their terminals keeps moving in one direction. For these reasons we have the devices called "voltage regulators" and "rectifiers."

An electrical rectifier is anything that will convert alternating current into direct current, and a number of ways have been devised to handle this task—all of them involving what amounts to electrical check valves. Generators are nothing more than electrical pumps, and the kind we call alternators pump first in one direction, then reverse themselves. It's a kind of push-pull activity, and rectifiers—check valves—are needed to feed the push into a bike's electrical system but block the pull, creating an intermittent but one-directional flow of current. The problem here is to find or invent the right kind of check valve.

One of the earliest rectifiers used to make the AC-into-DC conversion was a vacuum tube containing a heated cathode plate and a cold anode. Electrons are very willing to leave a heated surface, and very reluctant to depart one that is cold. So the rectifier tube behaves as a conductor when its heated plate is charged positive and the cold plate negative, but has an extremely high resistance when the polarity is reversed. It's a very good electrical check valve—in some applications. Vacuum tubes are too fragile, their plates too sensitive to vibration, to be suitable for use in motorcycles. Worse, rectifier tubes big enough to handle the peaks of a motorcycle's current flow would be very expensive—which is why both bikes and automobiles continued to use direct-current generators for so many years.

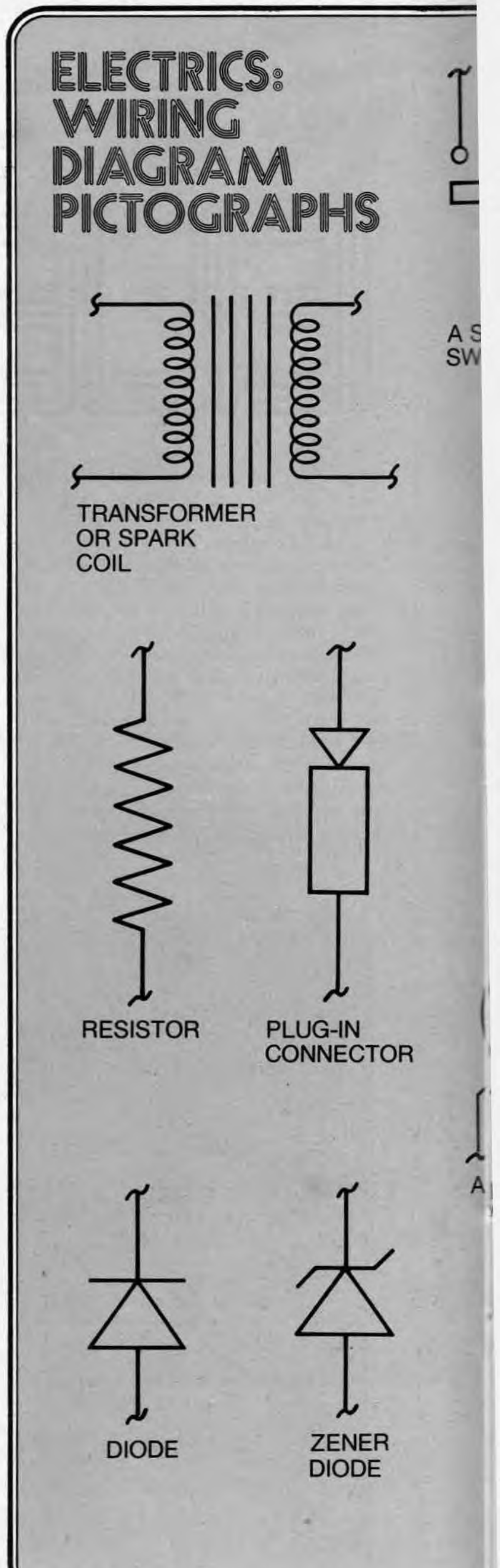
Wider, and now near-universal, use of alternators came about because engineers developed more rugged and less expensive replacements for the vacuum tube. We think of solid-state electronics, all the things involving semi-conductors, as a very recent scientific advance. Yet we have known for many years that certain selenium-based compounds, when coated on nickel under controlled conditions, would pass an electric current from the nickel to the selenium, but not the reverse. The same properties were observed in germanium and copper oxides; all could be employed in making rectifiers, and we still find the selenium rectifier doing the AC-DC converting in many motorcycles. These are easily identified by their appearance. Selenium rectifiers look like a bunch of evenly-spaced, thin discs or squares with a through-bolt holding them together—which is precisely what they are.

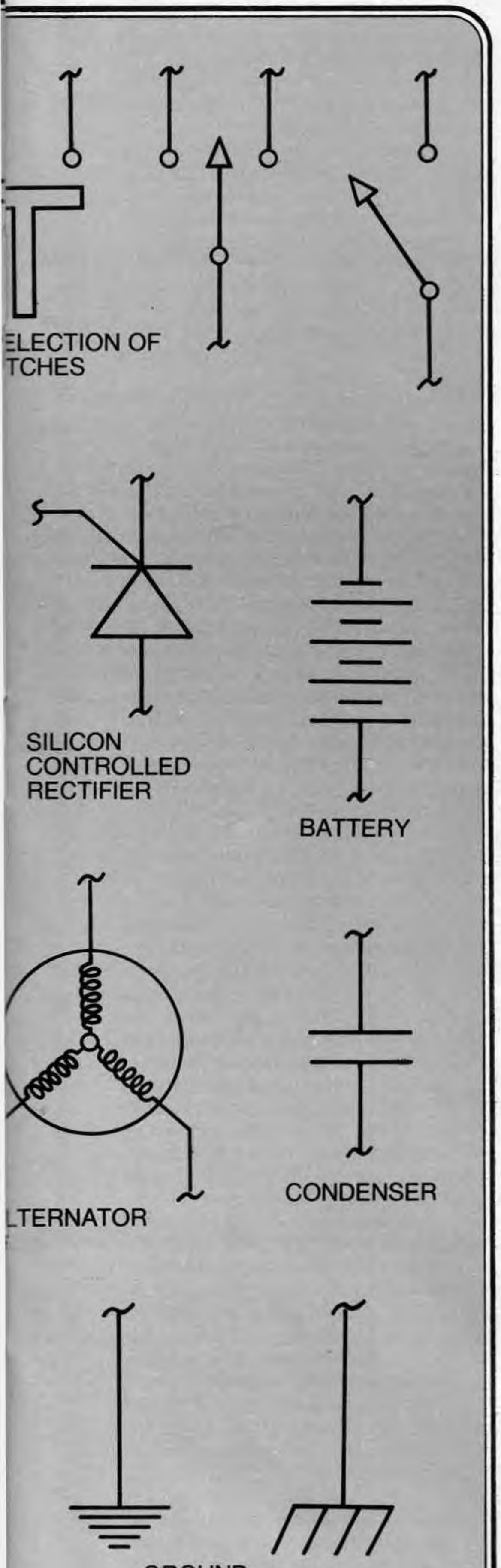
A common characteristic of the older solid-state rectifiers was an inability to handle much current or to block high reverse voltage, with overloads in either category likely to convert their status as semi-conductors into straightforward non-conductance. But now the selenium-based rectifier is being phased out, to be replaced with those built around a second-generation solid-state device, the silicon diode—which is smaller, more reliable, and will carry greater electrical loads.

Rectifiers, whether selenium- or silicon-based, are always used in multiples. The exact number varies, but the working principle is always the same: by providing multiple connections and multiple check valves, the alternator's constantly shifting polarity can be unscrambled and all of its output fed to the rest of the motorcycle's electrical system. Output from an ordinary single-phase alternator can be rectified with a single silicon diode, but that arrangement would waste half the electrical pulses developed in its windings. With four rectifier diodes the alternator's push-pull action can be filtered so that all the pushes emerge at one electrical terminal, all the pulls at another, and nothing is wasted.

Your own motorcycle's unit may have six or more silicon diodes, in which case you can be reasonably sure it also has a three-phase alternator. There is a problem involving a phenomenon called phase-displacement in the very simple form of alternator described earlier, in which a combination of capacitance and inductance causes the peaks of voltage and current to shift apart. Books available in any public library contain voluminous explanations of the phenomenon and related countermeasures, which in total is more than anyone in full possession of his faculties would ever want to know. Suffice it to say here that in the three-phase alternator the phasing is displaced to improve rather than hinder efficiency, and the results are worth the extra diodes in the rectifier unit and the third wire emerging from the windings.

Plenty of the less complex single-phase alternators also have three-wire connections, but for reasons unrelated to such





exotica as phase-displacement. It is, rather, a matter of output regulation. Alternators with permanent-magnet fields are simple and inexpensive, which is why they are in such wide use, but their output cannot be controlled except through indirect means. One method is to provide them with electrically separate generating coils, so that the number of windings actually involved in powering a motorcycle's electrical system can be varied with the system's demands. And the big change in demand occurs when the bike's lights are switched on. In a number of motorcycles, the 350 Honda being a typical example, switching the lights on also switches in an extra set of generating coils in the alternator—these being linked to the rectifier (*via* the light switch) by that third output lead.

Selective activation of the alternator's generating coils provides a crude matching of output and overall demand; it does not entirely bring the electrical system into balance. While the magnetic-rotor alternator's output voltage does not increase radically with rising engine speed, there *is* an increase, and it is more than the rest of the system can comfortably absorb. It would be possible to construct a relay capable of disconnecting some of the alternator's coils automatically when output voltage exceeds the desired maximum. However, mechanical relays are expensive and solid-state technology has provided a very cheap alternative: the Zener diode. Ordinary silicon rectifiers are electrical check valves; the Zener diode functions as an electrical pressure regulator. At anything below its built-in level of critical electrical pressure, or voltage, the Zener acts like any other silicon diode. But it will become a conductor of "reverse" voltages above that critical level, so if you include a 14-volt Zener diode, leading to ground in a 12-volt electrical system, then line voltage cannot rise above the Zener's 14-volt limit. Excess electrical pressure will simply be diverted to ground, which is wasteful but effective.

The combination of permanent-magnet alternator with coil-cutout output regulation and Zener diode control over maximum voltage works fairly well under average conditions. Problems arise when the motorcycle is being operated in a manner that does not conform to the manufacturer's anticipation of what will be average. If you do most of your riding around town, at night, that's not average—and you'll be operating at an alternator-output deficit, though not for long because soon your bike's battery will be very flat. Conversely, a lot of daytime riding over sporting-type roads (covered in a sporting manner) will mean relatively high average engine speeds and an alternator-output surplus, which won't hurt the battery but will overload the Zener diode. These diodes get warm when they are pushed to their limit and begin to conduct electricity to ground, and they'll overheat if asked to do too much voltage limiting. This system only works well within its designed limits, and if you do much non-average riding you're sure to discover its inherent shortcomings.

It should be obvious from the example provided by automobiles that vehicular electrical systems capable of coping with a broad variety of operating conditions actually do exist. Cars not only have lights and ignitions; they also have radios and air conditioning and numerous other accessories that require electrical power in intermittent and largely unpredictable amounts. Yet, despite the severity of the demands made upon it, the car's electrical system is vastly more reliable than those commonly provided for the motorcycles we know and love/hate. You are entitled to wonder why.

For one thing, cars do not rely on the simple but limited permanent-field alternator. They use the other kind of alternator, the good one, which has its field supplied by a second set of coils. And we are seeing more use of the excited-field alternator in motorcycles, although almost exclusively in the larger and costlier models at present.

Excited field alternators are a Good Thing on two counts: first, they have a very high output capability; second, and more important, their output can be very closely regulated. Some of them have their field coils wound into their rotors, which requires that they also have slip-rings and brushes to carry the current that electromagnetically produces their field. The fact that their slip-rings are smooth instead of being broken into sharp-edged blocks like a commutator gives them much better brush life than an old direct-current generator. Still the alternators with rotating field coils do have those brushes to wear away, and from that standpoint at least the second type of excited-field alternator—the type with fixed generating *and* field coils—is more attractive. The rotor in the fixed-field alternator spins between the field coils and generating coils (being cupped around the former and fitting inside the latter) and produces the necessary field shifts by means of its peculiar construction. This rotor is made up of two toothed castings welded to a ring—the semi-meshed position of the teeth creating, in effect, a zig-zag window. In operation the field coils' steady magnetic efforts get chopped into intermittent pulses by the toothed rotor, and the pulses induce an electrical potential in the surrounding generating coils, as happens when the rotor itself is permanently magnetized.

If the excited-field alternator has a shortcoming, apart from being more expensive to make than the permanent-field type, it is that battery failure puts the whole system into collapse. Without the battery to power the field coils there can be no magnetic excitation of the generating coils and therefore no alternator output to recharge an exhausted battery—which is not the case when a magnetized rotor supplies the field. But only rarely will a motorcycle's battery go completely flat; it usually will retain some vestige of its normal charge and that should be enough to tease the alternator into action. So the excited-field alternator's lack of complete self-sufficiency seldom becomes a real problem, and this one shortcoming is more than compensated by the ease and accuracy with which its output may be adjusted to suit demand.

The manner of adjusting alternator output involves varying the strength of the excited field, and this job is done by a mechanical relay—which interrupts the flow of current to the alternator's field windings when output rises above a certain level. Solid-state electronic regulators exist, but are comparatively rare especially in motorcycles. The regulators found on motorcycles with excited-field alternators are little more than an electromagnetically-operated two-way switch. Line voltage is given a path to ground through the windings of an electromagnet, which controls the position of a spring-mounted bar. At low engine speeds, when alternator output voltage is less than that of the battery, the electromagnet's pull is slight and the spring-mounted bar rests against an electrical contact that connects the battery with the alternator's field coils. The same condition exists when the motorcycle's key is turned on, before the engine is started. But then as engine speed rises, and voltage climbs with it, the pull of that electromagnet in the regulator tugs the bar away from its first contact. The alternator's field coils are then energized by its own rectified output, and this condition persists until line voltage rises to the limit for which the regulator has been set. At that limit the stronger pull of the electromagnet brings the movable bar against a second electrical contact and this one establishes a circuit that bypasses the alternator's field coils entirely. With the field coils inactive, alternator output drops to zero—but only for the briefest of moments, because line voltage also drops and then the electromagnet relaxes, which allows the bar to lift away from the second (field bypass) contact and reestablishes field current.

In practice, the regulator's contact bar spends most of its time vibrating against the second contact, giving the alternator field coils short bursts of current and boosting line voltage back to the regulated limit each time it lifts clear. Only when the battery is nearly depleted, and able to absorb a lot of excess voltage, will the regulator contact bar hover between the low-output and high-output contacts in a relative state of equilibrium, and even then it will frequently be pulled against the field-bypass contact. The difference between conditions prevailing at a low charge rate and those attending a very high flow into the battery is the frequency at which the bar rattles against the field-bypass contact.

People who are unfamiliar with automotive electrical systems may think that the voltage regulator described here is the ultimate in sophistication. In truth, it is no more than a meeting of minimum requirements, because the best motorcycle voltage regulators we've seen are *only* regulating voltage, and under certain circumstances that's not enough to protect a bike's battery. The problem arises when the battery loses its charge for some reason, which means that the voltage across its terminals will be rather low compared with alternator output voltage. When that situation exists the alternator will pour electricity into the battery at a rate too high to be tolerated. Batteries being charged at excessive ampere (current) inputs behave much like any other electrical conductor subjected to the same treatment: they overheat—which means that the electrolyte boils and the plates and outer case may be deformed. If the case develops a leak or the buckling of plates causes an internal short-circuit, the battery is forever ruined.

Overcharging is not a problem when a battery is maintained at something near the fully-charged level. The electrical pressure at the terminals of a 12-volt battery that is charged to 12 volts will prevent alternator output voltage, which will be regulated to about 14-14.5 volts, from forcing more electricity into the battery cells at more than a trickle. Danger exists only when the battery is substantially less than fully-charged, and automotive-type voltage regulators—unlike those provided for motorcycles—can handle even that problem. Automotive voltage regulators have much the same construction as those used on bikes, but in addition to the electromagnetic windings that control voltage, they have a very heavy-gauge outer winding that controls current flow. All the output from the alternator passes through this current-control winding (which consists of only a very few turns wrapped over the voltage-control electromagnet) and its influence is superimposed on the voltage regulation. The net result is that the battery is protected from too-fast charge rates, while the whole electrical system is regulated for a voltage level tolerable to all its components.

Considering that the motorcycle's battery is a tender, easily-ruined bit of equipment, it would be best if we could manage without the things. Unfortunately, that hardly seems possible in the context of presentday traffic conditions. It is quite possible to operate lights, horns, etc. directly from an alternator and use a magneto to provide the engine with sparks. The catch in this otherwise appealing scheme is that without a battery to power the electrical system when engine speed is low, the alternator would have to be absurdly large. Even then there could be trouble, because locking up the rear brake in a panic stop would stall the engine, drop the alternator output to zero, and leave you without lights at night or a horn to honk during the day. Also, a battery serves as a maximum voltage limiter in its own right, and without it our hypothetical battery-free motorcycle might well need a whole bank of Zener diodes to handle the voltage peaks from the alternator. If you have a 12-volt battery spliced into an electrical system it will maintain line voltage when the alternator output is low—and try to absorb the excess above 12 volts.

Because a motorcycle's battery is so important, it is necessary that you should know something about the way it works, how to check it for health, what makes it go bad, and how to revive one that is wounded less than mortally.

The electrical accumulator we call a battery is a device that functions due to a complex electrochemical process. It consists of a case containing lead plates submerged in a dilute sulphuric acid electrolyte, which forms a layer of lead sulphate on the plates. When the battery is charged the cathode plates (positive) are reduced to gray lead, while the anode (negative) plates acquire a coating of brown lead dioxide. This condition is unstable, and creates a buildup of electrons on the cathode plates—which emerges as an electrical potential across the terminals, one of which is linked to all the cathode plates and the other the anodes. If electrons are allowed to flow from cathode to anode, the coating of lead dioxide is transferred across—via the electrolyte—from the former to the latter. Reduced to its essentials, it's all a matter of withdrawing electricity from the battery by allowing the acid to etch away the lead dioxide on the anode plates; recharging the battery consists of electroplating the same material back on the anodes. Given care, the battery can repeat this process for years.

As you will have observed, the amount of electrolyte in a battery tends to diminish, and your owner's manual tells you to add water. There generally is a caution against the use of tap water for topping off batteries, and it should be heeded. Electrolysis converts the water diluting the battery's sulphuric acid to gases, which escape out the case vent. That's why you have to add water, and you should add *only* water. The stuff you get from a faucet will include percentages of disolved minerals, which may find their way onto the battery plates or become an unwelcome addition to the electrochemical process. Distilled water is what you should trickle into your bike's battery, and you should maintain the electrolyte level within the specified linits. If you overfill, the battery may overflow and the electrolyte certainly will be more dilute than it should be. Let the level fall too low and you'll have the top edges of the battery plates drying and out of action, with the lower portions of the plates exposed to an overly concentrated sulphuric acid.

(Continued on page 92)

BASICS: *Continued from page 58*

Battery electrolyte has a higher density than pure water, and its density changes according to the percentage of full charge in the battery. Most batteries are fully charged if their electrolyte has a specific gravity of 1.26 at 68°F. (1.26-times the density of water.) Half-charged the hydrometer—an instrument used to measure the specific gravity of fluids—would read only 1.16. It should be noted that these figures are for 68°F. At lower temperatures the specific gravity reading will be misleadingly high, and the reverse is true when the battery is warmer. You can find conversion charts in most shop manuals.

The most common cause of battery failure in motorcycles is winter. Electrolyte will freeze and burst the battery case at very low temperatures—but usually only if the battery has lost its charge. The catch here is that you don't ride your bike in really cold weather, and its battery will slowly go flat when the bike is in storage (it should be recharged at least once each month). And even if Ol' Man Winter doesn't get your battery directly, through freezing, long neglect will bring ruination. In a battery that is close to being completely discharged the plates "sulphate," their surfaces becoming coated with a white lead compound that can destroy their ability to function. Sometimes a battery that is quite badly sulphated can be restored to some semblance of health by first charging it at a high rate, then discharging at an equally high rate. This will shock the sulphates off the battery plates (bumping the case gently against your work bench may speed the process) and let them fall down to collect in a kind of sludge. If the sludge is deep enough to bridge between the plates it will create short circuits inside the battery, and should be removed by flushing the battery case with distilled water, after which a fresh volume of electrolyte must be added.

In all contacts with batteries you must assume that you're going to spread a little of the sulphuric acid here and there. You already may have learned that where the acid is, numerous other substances aren't—like paint and cloth and sometimes skin. So when you're doing battery work first make up a batch of baking soda (sodium bicarbonate) in solution with water. Brush or wipe this soda solution over a battery and surrounding areas until it stops fizzing in reaction to the acid and everything will be nicely neutralized. Another acid-related problem (which gets an assist from another kind of electrolysis) is corrosion between the battery posts and the battery cable and fittings. That moldy looking powder is an insulator, and that's the last thing you want in an electrical connection. Smearing the battery posts with a film of petroleum jelly will prevent this form of corrosion.

Vibration will ruin a motorcycle's battery, by shaking its plates apart, but this no longer seems to be the problem it once was. More rugged battery construction and carefully designed, rubber-cushioned mounting boxes have made plate fractures a comparitive rarity.

That leaves one path to the destruction of a battery, and that's the direct-shunt electrical load. Just as too-rapid charging will damage a battery's plates, things get very hot and bothered if something creates a direct, low-resistance path from the battery's positive and negative terminals. Can't happen? Sure it can: batteries share most motorcycle's underseat storage area with a tool-roll and other oddments a rider doesn't want to carry in his pockets, and if a wrench works its way down into contact with the positive terminal post and the frame (ground) there's going to be an almighty sparking, and a direct shunt.

Fuses are provided in motorcycle electrical systems to protect against less-direct shunts, which occur when a wire's insulation frays away and provides a direct wire/ground contact. You find these beauties with an ohmmeter, which is the most useful circuit-checking instruments a rider can have. Disconnect the bike's battery (to protect the meter) and start checking for electrical continuity between electrical leads and ground, or between, say, the red wire at one end of a long wiring loom and the lead with the same color coding at some other point along the loom. Of course, if you get this deeply into electrical trouble-shooting, you'd better have a shop manual to go along with the ohmmeter, because the typical owner's manual doesn't give you values for what the various circuit resistances should be.

On the subject of lights there isn't much to be said because you can't fix a broken headlight filament. But you may lose a tail-light some dark night and drop into a service station to inquire if, by some chance, they have a replacement. Chances are they will, if by a replacement you only mean a bulb that will fit into your bike's tail-light socket and do the kind of lighting expected of it. You'll be delighted, for a while, but chances are that bulb won't last very long. Ordinary automotive bulbs fit motorcycle light sockets; they don't have filaments strong enough to survive long when subjected to motorcycle-level vibration. Neither are automotive headlights entirely suitable for motorcycles, as they often have a beam pattern that just doesn't do much to illuminate the road ahead when you have your bike heeled over carving around a turn.

This is about as far as we can take you with basics, and generalities. Each motorcycle has its own electrical peculiarities (often inflicted by its maker) and you need some instrumentation, at least an ohmmeter and voltmeter, along with the mandatory workshop manual to find your way through the maze. Just remember that electricity flows from the alternator to the rectifier (which, if one of its diodes fails, cuts charging efficiency enough to give problems with chronically low battery voltage) and then to the battery. Flow goes from the battery to all the system's elements, and the bike's frame is a common return conduit to the battery's ground terminal. And remember that defective switches are one of the most common of all electrical problems, if we ignore the battery problems made possible by all the manufacturers' electrical system economies, and made certain by the typical owner's lighthearted neglect. ◉