THEN AND NOW: STEERING

Some of the early automobiles could reach surprisingly high speeds. From a safety standpoint, the steering systems used in these vehicles were very primitive. Direct linkage from a tiller to the drag link could result in a broken arm when you hit a bump. The first domestic vehicle equipped with a steering wheel was the 1901 Packard.

Even after the tiller evolved to the less lethal steering wheel, automobile steering systems were not satisfactory. Various types of steering mechanisms were designed to reduce kickback and improve mechanical advantage. These included a *chain drive* and the *worm-and-sector steering gear* found on some cars still on the road today. The best idea was the *recirculating ball steering gear*, which made its debut on V-16 Cadillacs. Migrating ball bearings on the steering shaft reduced the high friction that occurred between the internal gears of the earlier gearboxes. The recirculating ball steering gear also resists the shock of running over a pothole.

There were earlier attempts at *power steering*, but quality systems did not appear until after World War II. The war effort resulted in much research on hydraulics for aircraft servos and tank controls. In 1951, Chrysler applied this new technology to the production of the first automotive power steering system.

The *rack-and-pinion* steering gear used on many vehicles today uses a round gear on the steering wheel shaft. It meshes with a long, flat gear cut into the top of a long shaft that connects between the front wheels. Rack-and-pinion steering is not a new idea. In fact, it was used on huge steam tractors in the mid-19th century. The 1886 Daimler used a curved-rack version to control its center-pivoted axle. The planetary steering used on Ford’s Model T was based on the same principle.

Rack-and-pinion steering was abandoned on early vehicles due to severe kickback and its limited mechanical advantage. It was not until the 1950s that European engineers began to rediscover its potential and improve its design to eliminate these problems. In 1971, Ford showed its European connection by producing the Pinto, the first high-volume domestic car to come with rack-and-pinion steering.

An electrically powered, electronically controlled rack and pinion steering gear is found on some vehicles. They are especially found on hybrid-electric and fuel-cell electric vehicles. When a hybrid’s internal combustion engine (ICE) shuts off at idle and low speed, the electric steering gear can still provide steering assist using battery power. An electric motor assists the rotation of the pinion, giving fast response and eliminating the pump and hoses. This system has not come into widespread general use in gasoline engine vehicles due to the excessive amount of electrical energy required.
INTRODUCTION

The vehicle chassis includes the frame, shocks and springs, steering parts, tires, brakes, and wheels. The suspension system is part of the chassis (Figure 63.1). There are several suspension designs in use today. Over the years, there have been many part names associated with these designs. The names used in this chapter are those that have become standard. As you read the chapter, become familiar with the names of the suspension parts.

SUSPENSION

The suspension supports the vehicle, cushioning the ride while holding the tire and wheel correctly positioned in relation to the road. Suspension system parts include the springs, shock absorbers, control arms, ball joints, steering knuckle, and spindle or axle.

Sprung and Unsprung Weight

Sprung weight is the weight that is supported by the car springs. Anything not supported by the springs is unsprung weight.

OBJECTIVES

Upon completion of this chapter, you should be able to:

■ Identify parts of typical suspension systems.
■ Describe the function of each suspension system component.
■ Compare the various types of suspension systems.

KEY TERMS

A-arm  active suspension system  adaptive suspension system  aeration  ball joint  body roll  center bolt  chassis  coil spring  composite spring  compression  control arm  dive  double-acting shock absorber  follower ball joint  gas shock  independent suspension  jounce  leaf spring  load carrier ball joint  Macpherson strut  monoleaf spring  overload leaves  passive suspension system  rebound  rigid axle  shackle  shock absorber  squat  sub-frame  suspension  torsion bar

CHAPTER 63

Suspension Fundamentals

Figure 63.1 Suspension and steering systems.
Unsprung weight includes the tires and wheels, brakes (on most vehicles), bearings, axles, and the differential.

Advantages to Unsprung Weight
If unsprung weight can be decreased, vehicle control improves. The tire and wheel assemblies react to irregularities in the road surface, while the sprung components are relatively insulated from those effects (Figure 63.2). Having low unsprung weight means that inertia has less of an effect on those parts as they react to potholes and bumps in the road. This means the springs will have less work to do.

FRAME AND SUSPENSION DESIGNS
Cars are designed to be as lightweight as possible to improve fuel economy. Almost all older, heavier cars had rear-wheel drive. This design is still used in many luxury automobiles. A majority of new cars, however, have front-wheel drive.

Various frame designs are used in cars and trucks. Front-wheel-drive cars, as well as later-model rear-wheel-drive cars, rarely have a frame running the entire length of the car. The newer design, called unibody, or monocoque, uses a sheet metal floor pan with sections of sub-frame at the front and rear. A front sub-frame includes the engine, transaxle, and steering/suspension system (see Chapter 65).

SPRINGS
Springs support the load of the vehicle, absorbing the up-and-down motion of the wheels that would normally be transmitted directly to the frame and body. A bounce is an up or down motion. When the wheel moves up as the spring compresses, this is called compression or jounce. Rebound is when the wheel moves back down.

When a tire hits a bump in the road, it can absorb some of the shock. However, the tire passes over the bump so fast that the spring needs to absorb the rest of the shock. Four types of springs are used in vehicles: the coil spring, the torsion bar, the leaf spring, and the air spring.

Coil Spring
The coil spring is the most common spring type used in passenger cars (Figure 63.3). It is made from a spring steel rod that has been wound into a coil. Springs are painted or coated with vinyl or epoxy to reduce noise and prevent rust or nicks, which could stress the spring and cause it to break.

A coil spring is dependable and relatively inexpensive. It can carry a heavy load, but it is relatively light in weight, especially when compared to a leaf spring.

SCIENCE NOTE
An alloy is a metal mixed with other metals. Coil springs are an alloy of different types of steel, usually mixed with silicon or chromium. Springs are tempered, which hardens the steel alloy. Tempering is a very precise process where the spring is heated to a specific temperature and then cooled at a precise rate. If the spring is cooled too slowly, it will anneal, or become soft. Cooling it too fast will make it brittle.

There are different ways to make variable-rate springs (also called progressive-rate springs). One method uses a tapered rod. The coils at the ends of the spring do not work as hard as its center coils. As the spring is compressed, it becomes stiffer. This provides a smoother ride when going over smaller bumps but allows for heavier carrying capacity when needed.

The most commonly used variable-rate spring is made of steel rod of a consistent diameter. It has unequally spaced coils with tighter spacing on one
end than the other (Figure 63.4). At one end of the spring, the more closely spaced coils do not function until the spring is compressed sufficiently at the other end and in the middle to cause them to produce force. The active coils work throughout the complete range of spring compression. The transitional coils are the ones that are more widely spaced. They progressively bottom out, becoming inactive once they are compressed to their maximum capacity.

When a vehicle has leaf springs, it maintains the position of the axle. When a coil spring is used with a rigid rear axle, however, the axle wants to move out of its correct position. Therefore, a coil spring is equipped with lower control arms or trailing arms to control fore and aft movement (Figure 63.5). A reinforcement bar, or track bar, is sometimes used to keep the coils in a stable side-to-side position.

**Torsion Bar Spring**

Rather than compressing, a torsion bar spring is a straight rod that twists. When the wheel moves up during jounce, the torsion bar twists in one direction. When the wheel rebounds, the torsion bar unwinds. Torsion bars are made of heat-treated alloy steel with a hex head or splines at each end (Figure 63.6). One end of the torsion bar fits into a mating surface at the frame. The other end attaches to the movable lower control arm of the vehicle’s suspension system.

Almost all torsion bar installations are on the front. Light-duty trucks and sport utility vehicles (SUVs) use longitudinal (front-to-rear) torsion bars. Transversely mounted torsion bars were used on some older cars. Some vehicles use torsion bars because they do not require much vertical space and the front of the car can be designed to be lower. Compared to coil and leaf springs, torsion bars can store more energy. A shorter, thicker torsion bar can carry more load than a longer, thinner one.

One advantage to a torsion bar suspension is that spring tension can be adjusted by turning a screw against a bracket mounted at one of the ends of the torsion bar. This allows the vehicle’s ride height to be restored before a wheel alignment.

**Leaf Spring**

Most leaf springs are mounted at a right angle to the axle (Figure 63.7). They resist lateral movement, so control arms or struts are not needed. A leaf spring is made of a long, flat strip of spring steel or composite fiber rolled at both ends to accept a pressed-fit rubber insulating bushing. The front end of the spring is attached directly to the frame, and the rear of the spring is connected to the frame with a spring shackles (Figure 63.8). The spring shortens and lengthens as it compresses and rebounds; the shackle compensates for these changes.
As a leaf spring deflects it becomes progressively stiffer. To provide a variable spring rate, extra springs of varying lengths, called leaves, are added to the master leaf. Each leaf is curved more than the one installed above. Only the master leaf is rolled at the ends.

A center bolt extends through a hole in the center of all of the leaves to maintain their position in the spring, and metal clips help to center the leaves. The main leaf is the strongest in the spring pack. The rest of the leaves are progressively shorter as they are positioned farther from the main leaf. Some trucks have one or more overload leaves that do not work until the other leaves have deflected enough under load to allow them to come into contact (Figure 63.9). 

When a multiple-leaf spring deflects, the lengths of its leaves change. Each leaf slides on the one next to it, so friction and noise can result. Spring oscillations are dampened by the friction between the leaves, but the friction also causes a rougher ride than a coil spring. A monoleaf spring is a single strip of steel, thicker in the center and gradually tapering thinner toward the outside ends. Making a leaf tapered gives it a variable spring rate, providing for a better ride. A single-leaf spring also has no problems with friction and noise. Monoleaf springs can be mounted longitudinally or transversely and can be used in front or rear suspensions.

Some vehicles made since the early 1980s have used composite springs, made of reinforced fiberglass or graphite reinforced plastic. Corvettes, for instance, use a composite leaf spring mounted transversely in the rear. Weight is about 30 pounds less per spring, and composite materials do not rust. They are expensive, but they can be easily manufactured to a taper across their length. Because they are a single leaf, they have no center bolt.

**Air Springs**

An air spring has a rubber air chamber attached by tubing to an air compressor. Air springs are found on suspension systems that control ride height. Some systems can control spring rate as well. Some vehicles use air springs as the only springs. Others use coil springs to support vehicle weight, while an auxiliary air spring enclosed within the coil spring adjusts ride height. Some light trucks and SUVs have used auxiliary air suspension systems as adjustable overload springs when used together with regular leaf springs. The different air spring designs are covered in more detail later in this chapter.

**SUSPENSION CONSTRUCTION**

There are different suspension designs and some parts are common to the different systems, whereas others are unique to one suspension design. The different suspension designs and parts are covered here.

**Independent and Solid Axle Suspensions**

Most rear-wheel-drive (RWD) vehicles use a rigid axle, called a straight axle or solid axle, at the rear. A rigid axle is also used at the rear of many front-wheel-drive (FWD) vehicles on the front suspensions of some heavy trucks.

A rigid axle on a truck is called an I-beam. I-beam axles are very strong and can support a great deal of weight. When a wheel attached to a rigid axle goes over a bump, the wheel on the other side is affected by that movement, too (Figure 63.10). Because the rigid axles on I-beam front ends are heavy, they increase the vehicle’s unsprung weight, which results in a rougher ride.

Independent suspensions are found on most passenger car front ends and on some rear ends. When a wheel on a car with independent suspension goes over a bump, only that wheel will move up and down (Figure 63.11). Independent suspension systems have less unsprung weight than rigid axle suspensions, which provides improved ride quality as well.
Control Arms

The control arms used with independent suspensions allow the springs to deflect (move up or down). They are called an A-arm when they are like the ones shown in Figure 63.12. A narrow control arm style used on lighter cars has a strut rod, or radius rod, to provide stability (Figure 63.13).

Bushings

Rubber bushings keep suspension parts separated. A suspension bushing has an outer and an inner metal shell (Figure 63.14). The outside of the bushing is pressed into the control arm and the inner part rides on a pivot shaft (Figure 63.15).

During compression or rebound, the control arm moves up or down. The rubber bushing can twist as needed to allow parts to bend against each other without metal-to-metal contact (somewhat like a vulcanized motor mount). Some of the suspension’s resistance to body roll comes from the resistance of the bushings to twisting.

Ball Joints

Ball joints (Figure 63.16) attach the control arm to the spindle. A ball joint allows motion in two directions, moving with the same up-and-down motion as the bushings on the other end of the control arm. A ball joint also allows the spindle to pivot for steering. Depending on the suspension design, a ball joint will...
either be pulled apart or compressed together as it supports its load. More information on types of ball joints is found later in this chapter.

**Suspension Types**

Two of the most popular suspension designs are the short-and-long arm (SLA) suspension and the Macpherson strut (Figure 63.17). Rear suspensions on cars are sometimes independent, but many SUVs have rigid axles. Some have leaf springs, but most have coil springs.

**Short-and-Long Arm (SLA) Suspension**

SLA suspensions are used on both front and rear wheels. Because both upper and lower control arms resemble the shape of a wishbone, this suspension system is called a “double wishbone.” An SLA double wishbone suspension has two control arms of unequal length that move in planes that are not parallel to each other. The top control arm, the shorter one, slants downward toward its outer end. As the vehicle travels over a bump, the spring compresses and the outer end of the control arm moves upward in its arc of travel. This causes the top of the wheel and tire to tilt slightly outward. The tread width between the front tires remains nearly constant as the spring deflects, however. Although the short upper control arm travels in an arc, the outer end of the longer lower control arm remains in relatively the same plane (Figure 63.18). If the control arms were both the same length, the tire would slide from side to side when going over bumps (Figure 63.19).

On unibody vehicles, some SLA suspension systems have the coil spring located above the upper control arm. When a vehicle has a frame, the spring is situated below the upper control arm.

Double wishbone suspensions are popular for several reasons:
- They have improved directional stability and steering control
- They react to body roll more easily than any other type of independent suspension.
- SLA suspensions maintain precise wheel position under all driving conditions and can have a large amount of vertical travel without scrub, a change in the distance between the treads of the two front tires.
- They are good at absorbing bumps; the tires maintain more surface area on the road.

Sometimes a double wishbone suspension is not an option because it requires more space than Macpherson struts or some multilink designs.
Macpherson Strut Suspensions

Smaller cars often use Macpherson strut suspensions. Although most consider the SLA suspension to be a better suspension, Macpherson struts provide an advantage in weight and space savings. They are also less costly to produce.

**HISTORY NOTE**

Earl Steele MacPherson designed the Macpherson strut suspension during the late 1940s. MacPherson, who was born in Britain, became an engineer, first working for Chevrolet and later with the European division of Ford. The Macpherson strut was first used on the 1949 French Ford Vedette.

A Macpherson strut incorporates the coil spring and shock absorber into its front suspension (Figure 63.20), using only a single control arm on the bottom; it has no upper control arm and upper ball joint. The spindle is attached to the strut housing. A bearing at the top of the strut allows the entire unit to rotate when steering. Shock absorbers are covered later in this chapter.

**HIGH-PERFORMANCE SUSPENSIONS**

Several suspension types have been used in sport and racing vehicles. The multilink and the double wishbone have proven to be the most popular.

**Multilink Suspensions**

Multilink suspensions allow the designer more options in suspension tuning. An independent suspension
Worn shock absorbers are known to aggravate potential SUV rollovers, especially with top-heavy vehicles like SUVs and vans. Shock absorbers are also important in helping to achieve better tire-to-road contact (Figure 63.23). This affects braking, steering, cornering, and overall stability. Antilock brake effectiveness is also determined in part by the good tire-to-road contact provided by shock absorbers.

Figure 63.20 A Macpherson strut assembly.

Figure 63.21 A multilink suspension. This one is a five-link suspension system.

Figure 63.22 When a compressed spring rebounds, it begins to oscillate.

Figure 63.23 Under load, the tire forms a mechanical interlock with the road surface.

with more than two control arms is called a multilink. The extra links keep the wheel in a more precise position duringcornering and on bumps. Steering control is improved and tire wear is minimized.

Several variations of the multilink suspension have been used on different luxury and sport vehicles beginning in the late 1980s. A multilink suspension is basically a double wishbone suspension that has each arm of the wishbone as a separate part. Figure 63.21 shows a complicated five-link suspension. It is a double wishbone suspension with a fifth control arm.

SHOCK ABSORBERS

Each corner of the vehicle has a shock absorber. Shock absorbers are also called shocks or dampers. Although their name implies that they absorb shock, this is not an accurate description of their function. Shock absorbers dampen spring oscillations by converting the energy from spring movement into heat energy. The normal motion of springs is uncomfortable to passengers. It causes cupped tire wear and can be unsafe.

Shock absorbers are designed to resist or damp out excess and unwanted motion in the suspension. When a spring is compressed, it absorbs energy. During spring rebound, this energy is released. The first cycle is followed by more compression/rebound cycles, called oscillations (Figure 63.22). Shock absorbers damp out the excess motion.
NOTE: Although shock absorbers are responsible for absorbing a good deal of road shock, the tires are a vehicle’s primary shock absorbers.

VINTAGE SUSPENSIONS

Early shock absorbers were mechanical friction devices. Friction material similar to that found on a clutch or brake was fitted between two levers. One of the levers was attached to the frame and the other to the spring mount or spring (Vintage Figure 63.1). They required frequent adjustment because they were prone to wear.

HYDRAULIC SHOCK ABSORBER OPERATION

In a modern hydraulic shock absorber, one end is attached to the suspension and the other is attached to the car body or frame (Figure 63.24). The shock absorber is mounted on rubber bushings to allow for slight changes to its angle of installation during compression and extension.

A hydraulic shock absorber dampens spring action by forcing oil through small passageways, controlled by valves, like water through a squirt gun (Figure 63.25). As it reduces unwanted motion, this action generates hydraulic friction, which converts motion energy to heat energy. Using energy in this fashion lessens the oscillations of the springs.

NOTE: A shock absorber only converts unwanted motion to heat. If it were to remove all of a spring’s energy, all motion would stop.

Shock Absorber Fluid Movement

A shock absorber has two chambers, with a piston that forces fluid through the valves from one chamber to the other. The faster the piston moves, the more resistance it encounters. Figure 63.26 shows the parts of a conventional shock absorber. A Macpherson strut shock absorber works in the same way. Figure 63.27 shows a Macpherson strut cutaway.

Shock Absorber Design

Shock absorbers are either twin-tube or monotube (single-tube) (Figure 63.28). Monotube shocks are not
The up-and-down suspension movements are called compression (or jounce) and extension (or rebound). Shock absorbers are called double-acting because they control motion when moving both up and down. Early friction shocks had a ratio of 50–50, controlling the motion of the springs equally on compression and rebound. Today, a typical shock provides

as common as twin-tube although they are still found in many applications. As the shock is compressed, the piston rod displaces oil. There must be a reserve space to accept the extra oil (Figure 63.29). In twin-tube shocks, the outer tube provides the reserve chamber. A monotube shock usually has the reserve chamber in the same column as the working piston. When the shock extends, oil returns once again to the pressure chamber.

Front and rear shocks are not the same. They usually have chambers and valves of different sizes to control the differences in weight between the front and rear of the vehicle. Also, the center of gravity shifts when the vehicle stops or is thrown into a turn. This causes the front shocks to do more of the work.

The up-and-down suspension movements are called compression (or jounce) and extension (or rebound). Shock absorbers are called double-acting because they control motion when moving both up and down. Early friction shocks had a ratio of 50–50, controlling the motion of the springs equally on compression and rebound. Today, a typical shock provides
more resistance on compression than rebound (70/30, for instance).

**COMPRESSION AND REBOUND RESISTANCE**

Unlike springs, which are sensitive to loads, hydraulic shocks are sensitive to velocity. The faster the shock absorber piston moves through its oil, the higher the resistance.

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**SCIENCE NOTE**

A basic formula says that the resistance to flow (oil through the piston) goes up as a square of the velocity. Aerodynamics engineers try to reduce resistance, while shock absorber engineers use it to control unwanted suspension motion. Air is also a fluid. At 100 mph, four times as much power is required to push a car through the air as is needed at 50 mph.

Shock absorbers deal with a wide variety of suspension motions and velocities. Resistance can be very high; a series of orifices and valves is necessary to manage the flow properly. Poor tire adhesion to the road can result from either too little or too much resistance. Too much resistance can cause a harsh ride. A defective shock will have too little resistance, which will allow excess body motion, poor control of unsprung weight, and wheel bounce.

A chart of resistances provided at various piston velocities is called a damping force curve ([Figure 63.30](#)).

**NOTE:** Most shock absorbers compress more easily than they extend.

- Compression damping is used to control the relatively light unsprung weight of the tires, wheels, and brakes. It works with the spring to keep the tire in contact with the road surface. A car with a wheel that hops off the pavement has a compression control problem with its shock absorber.

- Rebound damping controls excess chassis motion as the shock extends when the heavier weight of the car body is in motion. A car that floats as it travels down the road has a rebound control problem with its shock absorber.

Because piston velocities on the rebound side (body motion) tend to be much lower than on the compression side (hitting a chuck-hole), compression damping force is usually much lower than rebound resistance. The movement of fluid in the shock absorber will change, depending on whether the car hits a hole (fast fluid movement), or whether the car leans over (called body roll) as it goes through a turn (slow fluid movement). Virtually all shock absorbers use three stages of valving. The initial valve is the first damping stage. It is a small hole because little force is generated by low piston velocities. As the piston moves faster, a second stage valve opens at a level of pressure determined by the manufacturer. The final stage, or third stage, is called the high-speed restriction.

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**BUMP STOPS AND LIMITERS**

Shock absorber movement follows the travel of the rest of the vehicle’s suspension. If the shocks or struts reach their extreme travel limit by topping or bottoming, damage can result. Some vehicles use rubber bump stops, also called snubbers, on control arms to limit excessive travel. Internal bump stops are generally found only in monotube struts or strut cartridges.

Full shock absorber travel is considered to be a good thing as long as it is within the design limits of the vehicle. Altered vehicle height, however, is a typical cause of reduced total travel that allows a shock to top out or bottom out. Raising or lowering a vehicle excessively in either direction can force shocks and struts to their extreme travel points. This can result in damage to the shock as well as other suspension parts.

**Shock Absorber Fluid Aeration**

Aeration, or cavitation, is when hydraulic fluid becomes mixed with air. A shock absorber is installed in a nearly vertical position so when it extends, air from the outside reservoir will be drawn in to replace fluid. This would result in a “skip” as the shock moves through its range of motion.
As the piston moves, pressure builds up in the fluid in front of it. A drop in pressure happens behind the piston, causing air bubbles and making the fluid foamy. When driving on rough roads, fluid is rapidly forced through the check valves. The entire area of fluid around the piston becomes aerated, and shock operation suffers (Figure 63.31). During normal operation, the air will usually work its way back to the air chamber.

There are two ways that designers avoid the tendency toward aeration. One of them is to use spiral grooves or a flat spiral ring around the outside of the reservoir tube. Another way to avoid aeration of the shock fluid is to use gas shocks.

**GAS SHOCKS**

Gas shocks were invented to control aeration, cavitation, and foaming of the hydraulic fluid. All oil has some air or gas bound up in solution. Pressurizing the oil keeps the air in solution so the piston works in clear oil and can provide consistent damping.

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**HISTORY NOTE**

In 1953, French physicist Christian Bourcier de Carbon designed the monotube high-pressure gas shock absorber and founded the De Carbon Company the same year. A short time later, a license was sold to the German company Bilstein. The shocks became original equipment on the 1957 Mercedes-Benz. The patent has now expired, and many top companies use monotube technology.

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Pressurizing the oil column in the shock absorber keeps the bubbles in the solution. Compare this to what happens when a carbonated beverage is first opened. When the top is removed, the pressure drops and the bubbles come out of the soft drink. Pressurizing the shock keeps the shock oil clear and eliminates the skips that occur in the action of a conventional shock absorber.

Some gas shocks have a pressurized gas-filled cell. This is a plastic bag that takes the place of the free air in a normal shock. These bags usually have low pressure (10–20 psi) refrigerant gas in them. True gas shocks have a reservoir pressurized with nitrogen gas at 100–200 psi (Figure 63.32).

Nitrogen is used for several reasons. First of all, it is dry; there is no water vapor. It is also chemically inert at normal shock temperatures and is fairly inexpensive.

Twin-tube gas shocks are pressurized with nitrogen gas at 90–140 psi, depending on the manufacturer and the damping force desired. They are usually less expensive to manufacture than monotube shocks.

Monotube gas shocks have pressures between 250 and 400 psi. Because the monotube has no base...
In either of these ways, however. When shocks support the weight of the vehicle, the shocks and shock mounts are prone to breakage.

Air shocks (Figure 63.35) have a rubber bladder that, when filled with varying amounts of air, raises the rear of the vehicle to compensate for a heavier-than-normal load.

**NOTE:** A small amount of air must be kept in the bladder at all times. If the vehicle is driven while the bladder is empty, the bladder can be folded into the shock and become torn.

A coil spring shock (Figure 63.36) has a constant-rate spring that works the same during both extension and compression. Its action in preventing body roll is similar to that of a stabilizer bar (covered later in the chapter).

or bottom valve, it needs the high pressure to support the compression valving as well as control cavitation.

**NOTE:** Gas shocks are packaged with a strap to hold them in the compressed position. They extend on their own when the strap is removed for installation.

Monotube gas shock absorbers, also called De Carbon shocks after their inventor, offer better cooling of the shock fluid and can be mounted upside down. They are more susceptible to physical damage than twin-tube shocks.

**Rear Shock Mounts**

To minimize vibration and improve ride quality, rear shock absorbers on RWD vehicles are mounted in two ways. Sometimes they are slanted inward and toward the rear at the top (Figure 63.33). Other times one shock is mounted in front of the axle, with the other one mounted behind it (Figure 63.34).

**AIR SHOCKS/LEVELING DEVICES**

Shock absorbers are not normally designed to carry the weight of the vehicle. If they were, the height of the vehicle would be affected when they were removed or when they wore out.

Some aftermarket devices use the shock absorber as a means of correcting or adjusting the height of the vehicle. The two common ones are air shocks and coil springs that are mounted on the outside of the shock body. There is a disadvantage to leveling the vehicle
OTHER FRONT END PARTS

Other parts are attached to the suspension to help control the ride. Parts like stabilizers and strut rods are insulated from front suspension parts and the frame with rubber bushings (Figure 63.37).

STABILIZER BAR

A stabilizer bar, also called a sway bar or an anti-roll bar, is used on the front or rear of many suspensions (Figure 63.38). It connects the lower control arms on both sides of the vehicle together, reducing sway and functioning as a spring when the car leans to one side. When both tires move up or down an equal amount, the stabilizer simply rotates in its bushings (Figure 63.39). If one of the wheels moves up, the bar twists as it tries to move the other wheel along with it.

Stabilizer links and bushings provide some flexibility and softness to the sway control so the suspension can still operate somewhat independently during minor bumps.

Spindle and Ball Joints

The steering knuckle, also called the spindle support arm, includes the axle, or spindle that holds the wheel bearing. Ball joints (see Figure 63.16) attach the control arm to the steering knuckle. Depending on the design, ball joints can be located either on top of or under the control arm.

On a suspension with two control arms, a ball joint is either a load carrier or a follower (Figure 63.40). The ball joint on the control arm attached to the spring is the load carrier. A follower ball joint aligns the parts but does not support the load.

There are two styles of ball joints (Figure 63.41). Compression-type ball joints are compressed all the time. Tension-type ball joints are always pulling apart.

The Macpherson strut suspension system uses only one ball joint because it has only one control arm. A pivot bearing at the top of the strut allows the strut to rotate for steering (Figure 63.42). On a strut suspension, the pivot bearing carries the load and the ball joint is a follower.

SUSPENSION LEVELING SYSTEMS

Normal suspension systems are called passive systems. Passive systems have either a firm or soft ride. Their height varies according to mechanical forces on the suspension, and they do not adjust to these changes. Early leveling systems were manual, using air shocks and a compressor. A manual switch was used to change the height of the car body. Today’s systems are automatic, and they are called adaptive suspension systems.
Electronically controlled suspension systems are used by many manufacturers on some of their luxury vehicles. They keep the vehicle at the same height when weight is added to different parts of the car. Some of the advanced systems can vary the damping capability of the shock absorbers as well. Most of the systems have air or conventional springs.

**Automatic Suspension Leveling**

There are two-wheel and four-wheel automatic leveling systems. The simplest leveling systems use air shocks or air springs filled by air from a compressor (Figure 63.43). An air dryer is attached to the pump...
A G-sensor on some cars helps the system accommodate severe maneuvers with a change in spring rate.

To sense the rate of acceleration, an acceleration sensor uses the throttle position sensor or mercury switches.

A mode switch is installed in the dash of some cars. It lets the driver select the degree of ride harshness desired.

Some light trucks and SUVs have air suspension systems used in conjunction with the regular leaf springs. An air spring, which is positioned between the truck frame and the leaf spring, acts as an adjustable and overload spring (Figure 63.46).

Figure 63.43 An automatic leveling system that uses air shocks.

To condition the air before it enters the shocks, a height sensor connected to the frame and axle housing is used for vehicle height input (Figure 63.44). It can turn on the compressor or bleed air to correct changes in height.

With electronically controlled systems, a computer reacts to signals from sensors at all four wheels to change the amount of air in air springs at each wheel (Figure 63.45). The aim is to keep the vehicle level to the road from side to side and front to rear.

Several sensors are found with different systems. Some of them and their functions are listed here.

- Three or four height sensors are located at the wheels. They are often rotary Hall-effect sensors. When there are three sensors, one is for the solid rear axle. Height sensors electronically measure the distance between the control arm or axle and the frame. The computer can also use the height signals to prevent the vehicle from bottoming out when going over major variations in the road surface, like railroad tracks.

- Signals from brake and door sensors help the computer to decide to disable automatic height adjustment when the car is stopping or when passengers are getting in or out.

- Speed sensors are used in some systems to lower the vehicle in the front or both front and rear for high-speed aerodynamics. In some systems, spring rate is increased in response to higher speed, too.

- A photo diode and shutter located in the steering columns of some advanced systems cause the spring rate to change when the vehicle is turning.

A G-sensor on some cars helps the system accommodate severe maneuvers with a change in spring rate.

To sense the rate of acceleration, an acceleration sensor uses the throttle position sensor or mercury switches.

A mode switch is installed in the dash of some cars. It lets the driver select the degree of ride harshness desired.

Some light trucks and SUVs have air suspension systems used in conjunction with the regular leaf springs. An air spring, which is positioned between the truck frame and the leaf spring, acts as an adjustable and overload spring (Figure 63.46).
Electronically Controlled Shock Absorbers

Electronically controlled shock absorbers have variable valving. The amount of shock damping changes as the size of a metered orifice within the shock is manipulated by the computer. An actuating motor on the top of the shock (Figure 63.47) turns a control rod that changes the size of the orifice (Figure 63.48).

The newest adaptive systems use solenoid actuated shock valves, which allow almost instantaneous changes in the size of a shock’s damping orifice. The suspension can react to changes in body height in 0.010 second (10 milliseconds). These devices can be found on shocks and struts.

Some electronically controlled shocks use a variable orifice controlled by gas or air. Normal shock absorber valves are used.

Shock absorbers deflect in one direction to control fluid flow:

- At lower speeds, they operate normally (the valve is fully open). This is the comfort mode, and fluid flows unhampered through the orifice. The valves work as normal.
It uses a fluid that rapidly changes its viscosity in response to computer-controlled signals. The fluid is a synthetic oil with iron particles in suspension. The iron is dispersed throughout the fluid, allowing the shock to operate as a normal shock under ordinary driving conditions. Each shock has an electrical winding that can be energized by the control module in response to a signal from a wheel position sensor when a large bump in the road is encountered. This causes the iron particles in the shock fluid to align themselves (Figure 63.50), turning the fluid into a very viscous gooey mass. The current is supplied up to 1,000 times per second so it can very quickly vary the damping characteristics of the shock from firm to normal. You can find demonstration videos of magneto-rheological fluid on the Internet.

**Active Suspensions**

Active suspension systems were first developed by Lotus in England. Today, a few luxury cars have active suspensions. During hard braking, a vehicle wants to dive. The front of the car is pushed down and the rear of the car slides up. During hard acceleration the front of the vehicle lifts and the rear lowers. This is called squat. Advanced active suspensions help control some of the forces normally encountered in driving. They can reduce pitch and body roll as well as helping to control squat during acceleration and dive during braking. An active suspension system works with sensors, a computer, and activators to solve these problems.

An active suspension does not require conventional shock absorbers or springs. Each wheel has a double-acting hydraulic cylinder (high-speed actuator) to keep the car body level during all driving conditions. Shock

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**Magneto-Rheological Fluid Shock Absorbers**

An electronically controlled shock absorber that does not use electromechanical solenoids or valves is the magneto-rheological, or MR, shock absorber (Figure 63.49).
The computer uses signals received from sensors to track the position of each actuator. It can sense whether a wheel is in jounce or rebound. It also senses how heavily each wheel is loaded and whether the wheel is turning or pointing straight ahead. The computer sees a bump and immediately releases pressure from a control valve. It can release pressure instantly or relatively slowly, depending on what the computer program specifies. After the suspension absorbs the shock, pressure is forced back into the actuator to keep the tire contacting the road and maintain ride height.

**NOTE:** In case of a flat tire, the system can be told to raise the tire so a jack is not needed.

Sensors provide the computer with necessary information regarding extension and compression of each actuator and how heavily the vehicle is loaded.

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REVIEW QUESTIONS

1. Which kind of spring is adjustable?
2. What is the name of the suspension type that uses two different length control arms?
3. What is the name of the part that is used to control spring oscillations?
4. Hydraulic shock absorbers are sensitive to velocity/load (circle one).
5. Which shock absorber motion controls the least amount of weight, compression or rebound?
6. What is the term that describes the softness or harshness of the ride?
7. What kind of shock can be mounted upside down?
8. If a small amount of air is not kept in an air shock, what can happen?
9. What is the name of the kind of front suspension that has a built-in shock absorber and only one ball joint?
10. What is the name of the ball joint design that is always trying to pull apart?

ASE-STYLE REVIEW QUESTIONS

1. When one wheel of a vehicle goes into a pothole and the wheel on the other side of the vehicle moves too, the suspension system is:
   a. A rigid axle suspension
   b. An independent suspension
   c. Both A and B
   d. Neither A nor B
2. Which of the following is/are true about Macpherson strut suspensions?
   a. The ball joint is a follower.
   b. It typically has only one control arm.
   c. Both A and B
   d. Neither A nor B
3. A typical shock absorber will:
   a. Compress easier than it extends
   b. Extend easier than it compresses
   c. Only restrict movement as it is compressed
   d. Have extension and compression that are equal
4. Two technicians are discussing gas shocks. Technician A says that gas under pressure prevents oil from foaming. Technician B says that gas under pressure prevents cavitation within the fluid. Who is right?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
5. Technician A says that shock absorbers are designed to carry the weight of the vehicle. Technician B says that shock absorbers dampen spring oscillations. Who is right?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
6. Technician A says that the Macpherson strut provides a better ride and handling than the SLA suspension. Technician B says that a Macpherson strut suspension is often called a double wishbone suspension. Who is right?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
7. Technician A says that some types of ball joints carry a load and others do not. Technician B says that a load-carrying ball joint on an SLA suspension is on the control arm that has the spring attached to it. Who is right?
   a. Technician A
   b. Technician B
   c. Both A and B
   d. Neither A nor B
8. All of the following are true about unsprung weight except:
   a. Lower unsprung weight is desirable for better handling.
   b. Tires are unsprung weight.
   c. The engine is unsprung weight.
   d. Independent suspension systems have less unsprung weight than rigid axle suspensions.
9. Independent suspensions with more than two control arms are called multilink suspensions. True or False
10. “Dive” is when the front of the vehicle lifts and the rear lowers during hard acceleration. True or False