CHAPTER 3

INTRODUCTION TO DRIVETRAINS

OBJECTIVES

After studying Chapter 3, the reader should be able to:

1. Identify the major components of an automotive drivetrain.
2. Describe the purpose of the major components of the automotive drivetrain.
3. Explain gear ratios and their effect.
4. Calculate gear ratios.
5. Discuss the variety of drivetrains in use in today's vehicles.

KEY TERMS

Aerodynamic drag (p. 48)
All-wheel drive (AWD) (p. 40)
Annulus gear (p. 45)
Automatic transmission (p. 52)
Bevel gear (p. 44)
Clutch (p. 51)
Constant-velocity (CV joint) (p. 55)
Continuously variable transmission (CVT) (p. 52)
Differential (p. 55)
Drive axle (p. 56)
Driveshaft (p. 55)
Final drive (p. 56)
Four-wheel drive (4WD) (p. 40)
Front-wheel drive (FWD) (p. 40)
Gear ratio (p. 41)
Gear ratio spread (p. 48)
Grade resistance (p. 48)
Half shaft (p. 56)
Helical gear (p. 44)
Hypoid gear (p. 44)
Independent rear suspension (IRS) (p. 56)
Internal gear (p. 45)
Manual transmission (p. 51)
N/V ratio (p. 48)
Overdrive (p. 46)
Pinion gear (p. 44)
Pitch diameter (p. 43)
Planetary gear set (p. 45)
Power transfer unit (p. 56)
Rack and pinion gear set (p. 45)
Rear-wheel drive (RWD) (p. 40)
Ring gear (p. 45)
Rolling friction (p. 48)
Spiral bevel gear (p. 44)
Spur bevel gear (p. 44)
Spur gear (p. 44)
Standard transmission (p. 51)
Torque (p. 41)
Torque converter (p. 52)
Tractive effort (p. 46)
Tractive resistance (p. 48)
Transaxle (p. 40)
Transfer case (p. 56)
Transmission (p. 51)
Universal joint (U-joint) (p. 55)
Worm gear (p. 44)

INTRODUCTION

Every vehicle has a drivetrain that transfers power from the engine to the drive wheels. The drivetrain, also called a *power train,* serves several functions:

- It allows the driver to control the power flow.
- It multiplies the engine's torque.
- It controls the engine's speed.

Traditionally, the drivetrain delivered power to the rear wheels; this was called **rear-wheel drive (RWD)** (Figure 3-1). Most modern passenger vehicles drive the front wheels using **front-wheel drive (FWD)** (Figure 3-2). Some vehicles can drive two wheels all of the time and all four wheels part of the time; this is called **four-wheel drive (4WD)** (Figure 3-3). Older 4WD vehicles were intended for off-road use where traction is poor. A few vehicles will drive all four wheels all of the time; this is called **all-wheel drive (AWD)** or *full-time 4WD.* AWD and full-time 4WD vehicles are designed for improved traction on wet or icy roads during daily use.

The drivetrain can use a clutch and manual transmission or a torque converter and automatic transmission. Either transmission is used with one or more driveshafts with universal joints or constant-velocity joints and drive axle reduction and differential gears. In FWD vehicles, the transmission with the drive axle and differential gears are combined in a **transaxle**.

The clutch allows the engine's power flow to be stopped. The transmission provides the gear ratios to multiply the engine torque so a vehicle can be moved forward or backward from a stop. Both a transaxle and drive axle include the final drive ratio that increases torque and determines engine speed when cruising at highway speed. Differential gears in the drive axle and transaxle allow the drive wheels to be driven at different speeds while a vehicle turns a corner.

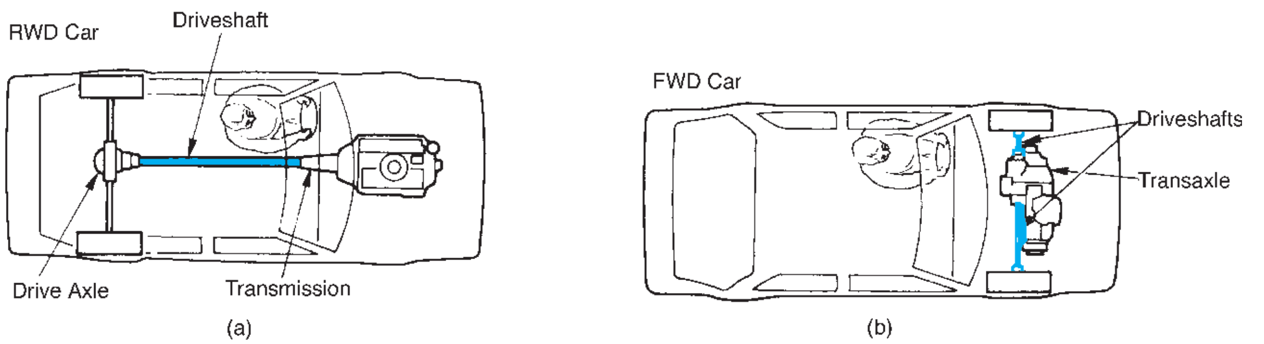

FIGURE 3-1 A RWD drivetrain uses a transmission to provide the necessary gear ratio and a single driveshaft to transfer power to the rear axle (a). A FWD drivetrain uses a transaxle that combines the transmissions final drive, and differential (b). A driveshaft is used for each front drive wheel.

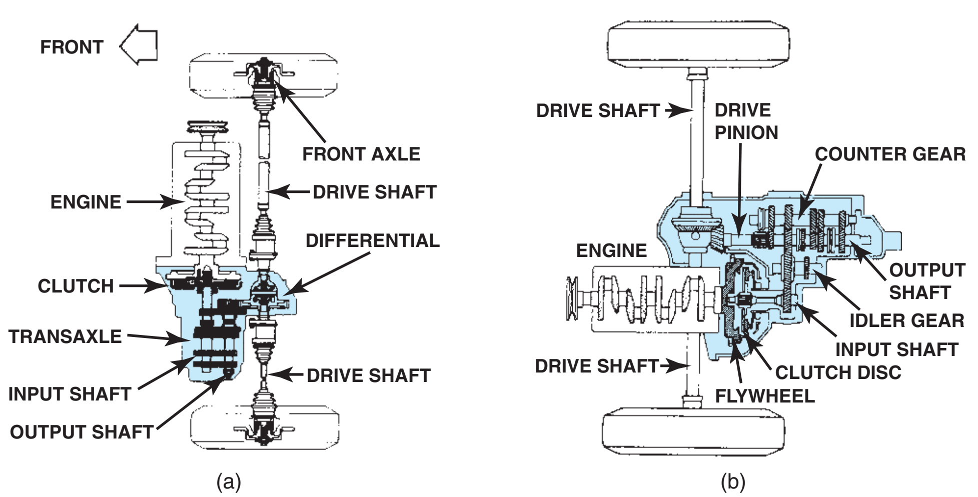

FIGURE 3-2 Transverse (a) and longitudinal (b) mounted FWD drivetrains. Note that (b) can easily be redesigned to drive a shaft to the rear wheels of a 4WD or AWD vehicle.

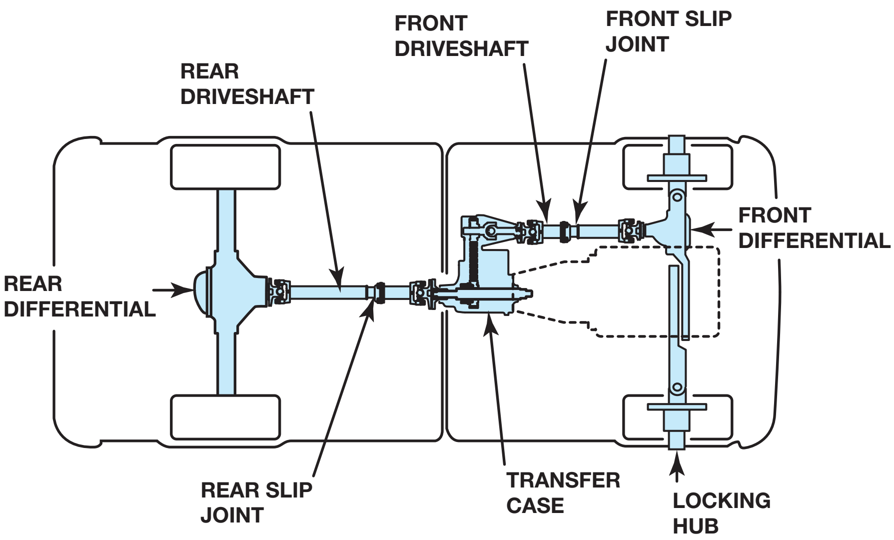

FIGURE 3-3 This four-wheel-drive (4WD) vehicle drivetrain consists of the components of a RWD drivetrain plus a transfer case, front driveshaft, and front drive axle.

TORQUE

The rotating, mechanical power that is modified by the drivetrain is called **torque**. You exert torque each time you turn a doorknob or rotate a screwdriver. An automobile moves because of the torque the drive axle exerts on the wheels and tires to make them rotate. Being a form of mechanical energy, torque cannot be created or destroyed—it is converted from one form of energy to a different form of energy.

An engine's torque is developed when combustion pressure pushes a piston downward to rotate the crankshaft (Figure 3-4). The amount of torque will vary depending on the size and design of the engine and the throttle opening. Torque is measured in newton-meters (N-m) or foot-pounds (ft-lb). One newton-meter of torque is equal to 0.737 ft-lb. A factor that greatly affects drivetrain design is that very little or no torque is developed at engine speeds below 1000 rpm (revolutions per minute). As shown in Figure 3-5, an engine begins producing a usable amount of torque at about 1200 rpm and peak torque at about 2500 to 3000 rpm, with an upper usable speed limit of 4500 to 5000 rpm. The gear ratios in the transmission and drive axle are used to match the engine speed and torque output to the vehicle's speed and torque requirement.

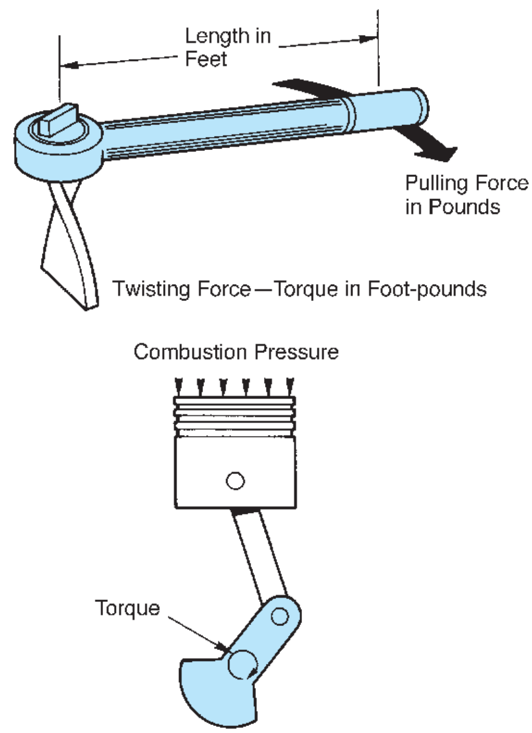

FIGURE 3-4 Torque, a twisting force, is produced when you pull on a wrench. An engine produces torque at the crankshaft as combustion pressure pushes the piston downward.

TORQUE MULTIPLICATION

Gears, belts and pulleys, and chains and sprockets can be used to change the speed or torque of a rotating shaft (Figure 3-6). These three devices are fairly similar in operation. In this book we concentrate on gears, the most popular method of torque multiplication used in drivetrains.

The teeth of gears in a gear set are cut proportional to the diameter of the gear. If one of two mating gears were twice as large as the other, it would have twice as many teeth. For example, if the smaller gear has 10 teeth, the larger gear will have 20. If the teeth of these gears are intermeshed, 10 teeth of each gear will come into contact when the smaller gear rotates one revolution. This will require one revolution of the small gear and one-half revolution of the larger gear. It will take two revolutions of the small gear to produce one revolution of the larger gear. This is a **gear ratio** of 2:1, assuming that the

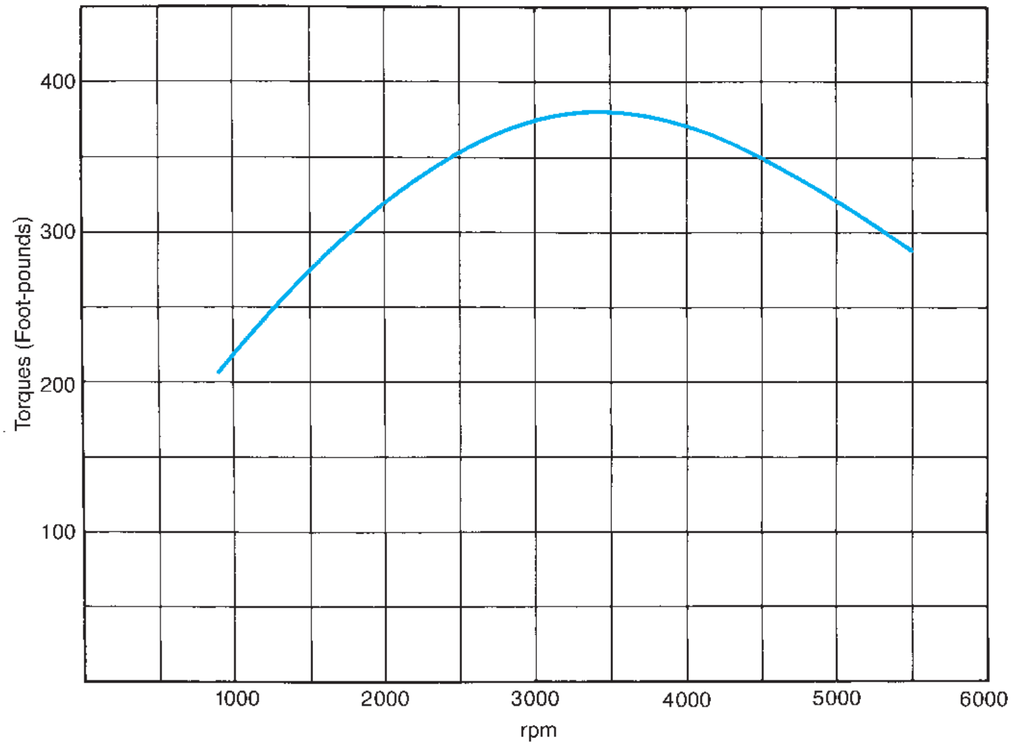

FIGURE 3-5 This curve shows the torque produced by a 350-in^3 (5.7-L) engine. Note that it begins producing usable torque at 1000 to 1200 rpm and a maximum torque (381 ft-lb) at 3500 rpm. The amount of torque drops off at higher rpm.

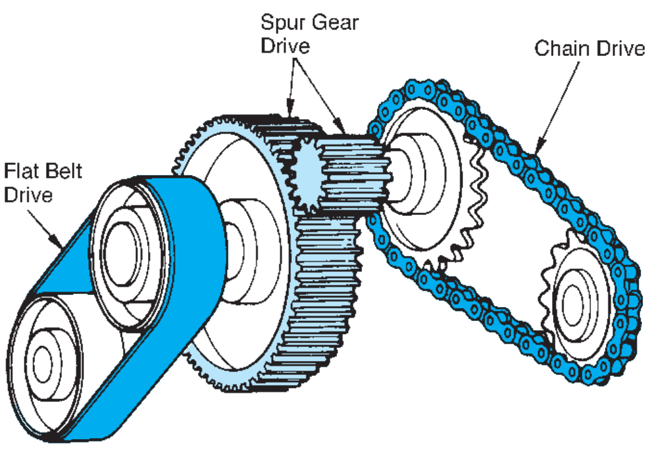

FIGURE 3-6 Torque can be transferred between shafts, and the amount of torque can be increased or decreased by belts and pulleys, gears, or chains and sprockets. *(Reproduced with permission of Deere & Company, © 1972, Deere & Company. All rights reserved)*

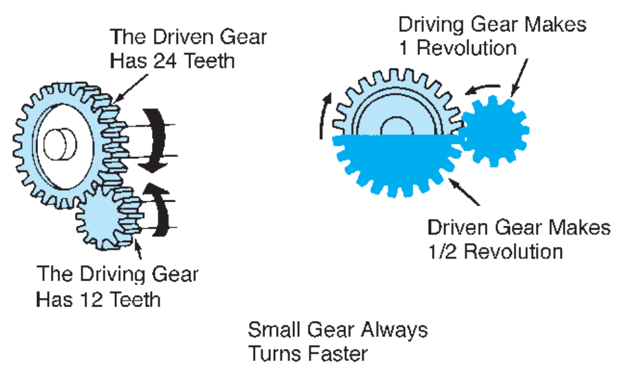

FIGURE 3-7 If the driving gear has one-half the number of teeth of the driven gear, the ratio will be 2:1 (24 ÷ 12 = 2) and the driven gear will rotate in a direction opposite to the driving gear. *(Reproduced with permission of Deere & Company, © 1972, Deere & Company. All rights reserved.)*

small gear is the drive gear. To determine a gear ratio, we always divide the driven gear by the driving gear (Figure 3-7).

Torque is increased because of the length of the gear lever. Think of each tooth as a lever, with the fulcrum being the center of the gear. The lever lengths of the two gears can provide leverage much like that of a simple lever (Figure 3-8).

Also, simple physics does not allow energy to become lost in a gear set, other than what is changed to heat through friction; whatever power that comes in one shaft goes out the other. Gears are a very efficient means for torque transfer. If the speed is reduced, the amount of torque will be increased a like amount, or vice versa. For example, if the driving gear has 20 ft-lb (27 N-m) of torque at 500 rpm and the ratio is 2:1, the driven gear will have 40 ft-lb (54 N-m) of torque (twice as much) at 250 rpm (half the speed).

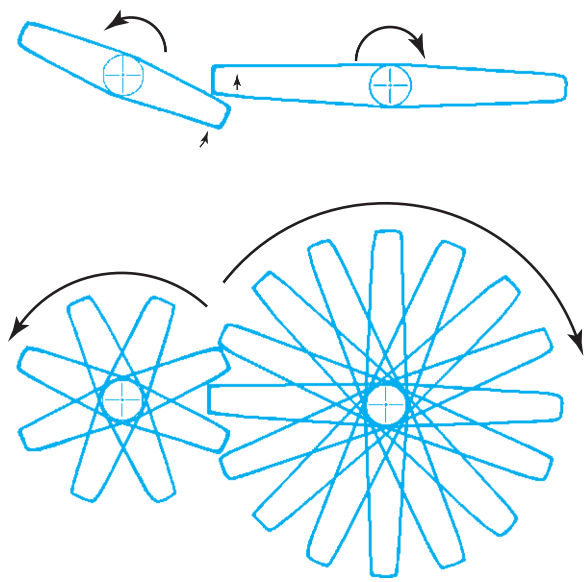

FIGURE 3-8 Torque is increased through a gear set because of the leverage of the gear teeth. Gears can be thought of as a series of levers.

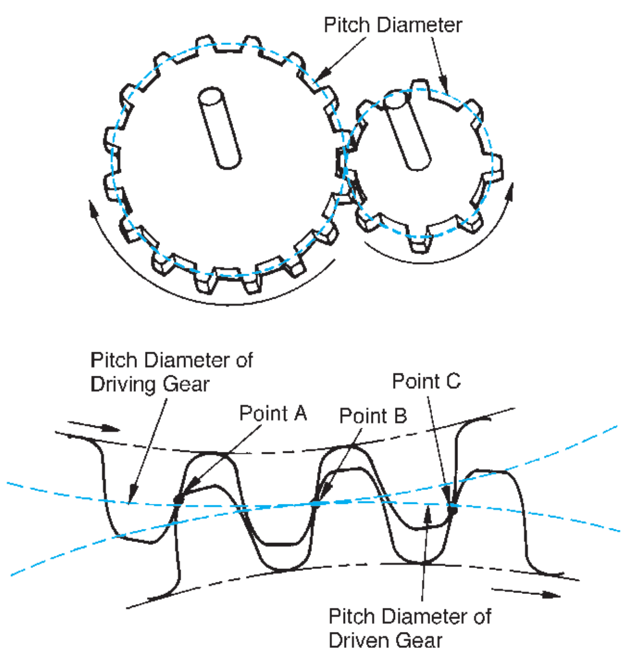

FIGURE 3-9 The pitch diameter is the effective diameter of the gear. Note how the contact points slide on the gear teeth as they move in and out of contact.

The effective diameter of a gear is the **pitch diameter** (or pitch line) (Figure 3-9). The pitch diameter is the point where the teeth of the two gears meet and transfer power. The gear teeth are shaped to be able to slide in and out of mesh with a minimum amount of friction and wear.

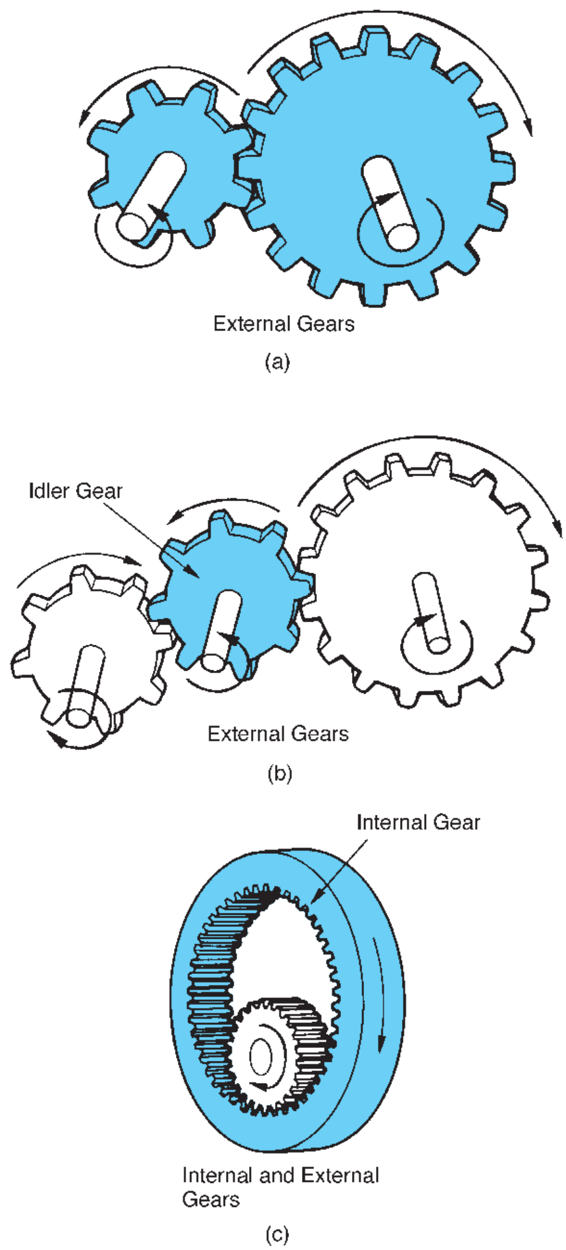

FIGURE 3-10 (a) When one external gear drives another, the direction of rotation is always reversed. (b) An idler gear also reverses the direction of rotation so that the driving and driven gears rotate in the same direction. (c) When an external gear drives an internal gear, the two gears will rotate in the same direction.

Remember that the driven and driving gears will rotate in opposite directions. External gears will always reverse shaft motion (Figure 3-10). If same-direction motion is required, the power will be routed through two gear sets, or an internal and external combination of gears will be used. When power goes through a series of gears, an even number of gears (2, 4, 6, 8) will cause a reversal; an odd number of gears (3, 5, 7, 9) will produce same-direction rotation.

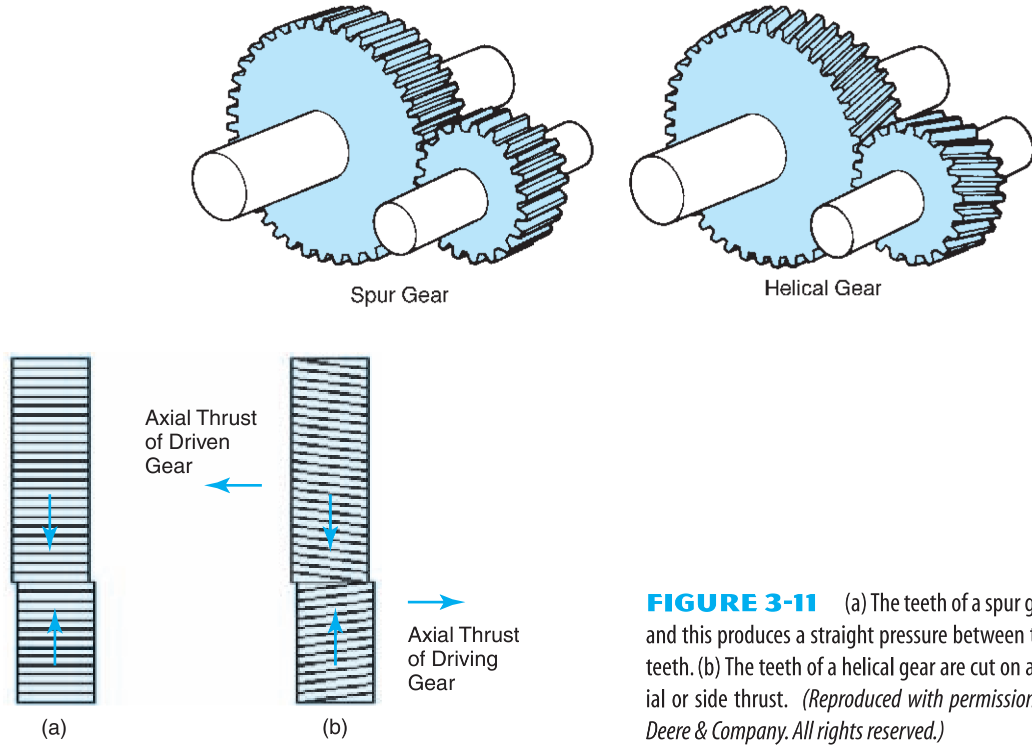

FIGURE 3-11 (a) The teeth of a spur gear are cut parallel to the shaft, and this produces a straight pressure between the driving and the driven gear teeth. (b) The teeth of a helical gear are cut on a slant, and this produces an axial or side thrust. *(Reproduced with permission of Deere & Company, © 1972, Deere & Company. All rights reserved.)*

GEAR TYPES

Gears come in different types depending on the cut and relationship of the teeth to the shafts. **Spur gears**, the simplest gears, are on parallel shafts with teeth cut straight or parallel to the shaft (Figure 3-11a). Most gears used in modern transmissions are **helical gears**, which have the teeth cut in a spiral or helix shape (Figure 3-11b). Helical gears are quieter than spur gears, but helical gears generate axial or end thrust under a load. A helical gear is stronger than a comparable-sized spur gear and has an almost continuous power flow because of the angled teeth. When discussing gears, a **pinion gear** is the smaller gear of a pair.

A little-used version of a helical gear is the *herringbone gear,* which is essentially a right-hand and a left-hand helical gear mounted together so that the thrust loads are canceled (Figure 3-12). To identify a right-hand helical gear, the thumb of your right hand will align with the slant of the teeth if you put your hand on the gear with your fingers pointing in the direction of rotation. A left-hand gear is the opposite.

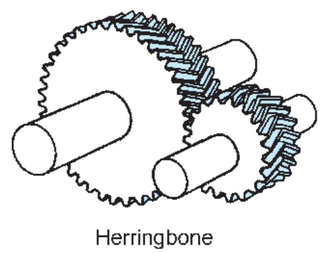

FIGURE 3-12 A herringbone gear looks like a combined left- and right-hand helical gear. It transfers force quietly with no axial thrust. *(Reproduced with permission of Deere & Company, © 1972, Deere & Company. All rights reserved.)*

Bevel gears are used on nonparallel shafts. The outer edge of the gear must be cut on the angle that bisects the angle of the two shafts (Figure 3-13). In other words, if the two shafts meet at a 90° angle and the two gears are the same size, the outer edge of the gears will be cut at a 45° angle. The simplest bevel gears have teeth cut straight and are called **spur bevel gears**. They are inexpensive but noisy. **Spiral bevel gears**, like helical gears, have curved teeth for quieter operation. A variation of the spiral bevel gear is the **hypoid gear**, also called an offset-bevel gear. Hypoid gears are used in most drive axles and some transaxles for longitudinal mounted engines. This design places the drive pinion gear lower in the housing than the ring gear and axle shafts.

Drivetrain engineers usually do not use even ratios like 3:1 or 4:1; ratios are commonly at least 10 percent greater or less than even numbers. An even ratio, like 3:1, repeats the same gear tooth contacts every third revolution. If there is a damaged tooth, a noise will be repeated continuously, and most drivers will not like the noise. A gearset with a ratio like 3.23:1 is called a hunting gearset, and a tooth of one gear contacts all of the other gear's teeth, which produces quieter operation.

Another gear set used with shafts that cross each other but do not intersect is the **worm gear** (Figure 3-13d). The worm gear or drive pinion is cut in a rather severe helix, much like a bolt thread, and the ring gear or wheel is cut almost like a spur gear. This gear set is commonly used to drive the speedometer shaft, and it provides a rather large ratio in one step. To determine the

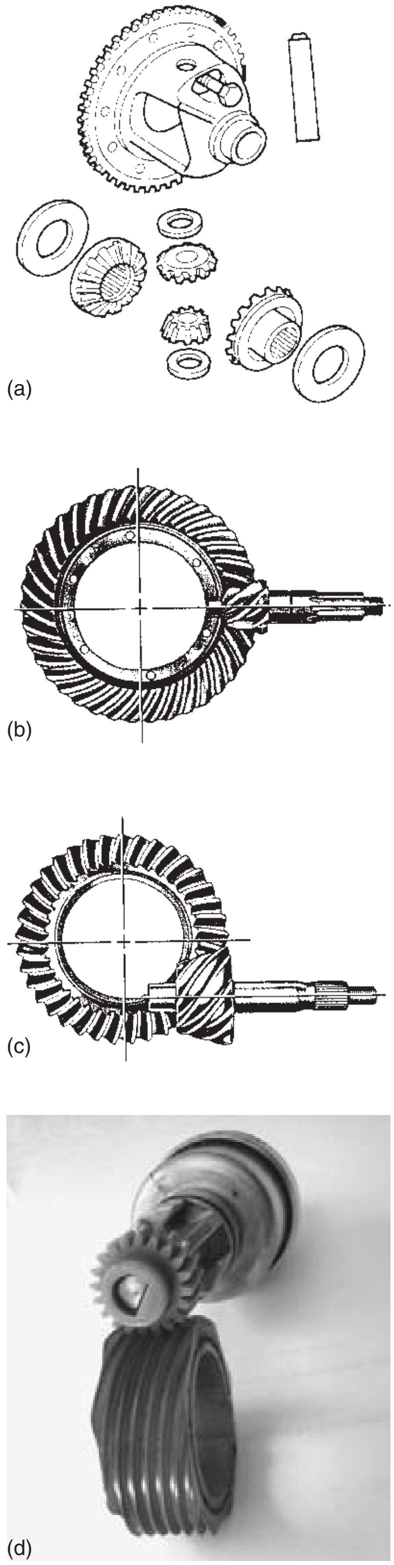

FIGURE 3-13 The three major styles of bevel gears are spur or plain bevel gears (a), spiral bevel gears (b), and hypoid gears (c). Note the different tooth shapes. A worn gearset (d) is also used to transmit power between angled shafts.

ratio, divide the number of teeth on the wheel by the pitch of the worm gear. For example, a single-pitch worm gear tooth driving a 20-tooth ring gear will have a ratio of 20:1, a very low ratio, and the wheel does not have to be 20 times larger than the worm gear. A 20:1 ratio in most gear sets requires the driven gear to be 20 times larger than the driving gear.

Most gears have external teeth. A few have the teeth cut on the inside of the gear's outer edge and are called **internal gears**. When they are used in a combination called a **planetary gear set**, the internal gear is called a **ring** or **annulus gear**. A planetary gear set is commonly used in automatic transmissions, and it consists of:

- a single sun gear in the center,
- two or more planet pinion gears meshed with the sun gear and mounted so they can rotate in the planet carrier, and
- the ring gear meshed with the planet pinions (Figure 3-14).

A **rack and pinion gear set** consists of a straight gear; the rack, which is meshed with the pinion gear (Figure 3-15).

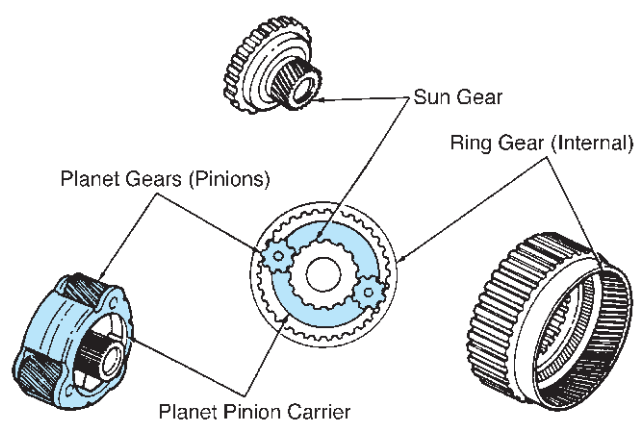

FIGURE 3-14 A planetary gear set is a combination of an internal ring gear, a sun gear, and a planet carrier with two or more planet pinion gears. *(Courtesy of Ford Motor Company.)*

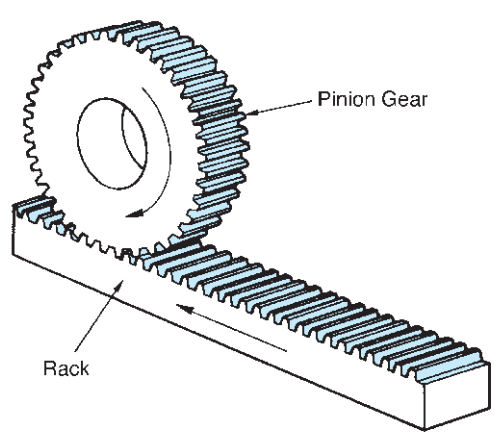

FIGURE 3-15 In a rack and pinion gear set, when the pinion gear rotates, the rack moves sideways. *(Reproduced with permission of Deere & Company, © 1972, Deere & Company. All rights reserved.)*

When the pinion gear rotates, the rack will slide sideways in the housing. This gear set changes the rotary motion of the pinion gear into a reciprocating, back-and-forth motion of the rack. This gear set is commonly used in steering systems with the rack connected to the tie-rods of the front wheels and the pinion gear connected to the steering wheel.

GEAR RATIOS

Gear ratios are determined by dividing the number of teeth on the driven, output gear by the number of teeth on the driving, input gear. Most of the time, this means dividing a larger number, such as 20, by a smaller number, such as 5. In this case, 20 ÷ 5 = 4, so the ratio will be 4:1. The driving gear will turn four times for each revolution of the driven gear. This results in a speed **reduction** and a torque increase. The higher the number, the lower the ratio. A 5:1 ratio is higher numerically, but, in terms of speed of the driven gear, it is a lower ratio than 4:1 (Figure 3-16).

If the driving gear has 20 teeth and the driven gear 5, there will be an increase in speed and a reduction in torque. This is called an **overdrive**. The ratio is computed by dividing 5 by 20, 5 ÷ 20 = 0.25; so the ratio would be 0.25:1. The driving gear will turn 0.25 or one-fourth of a revolution for each turn of the driven gear. Note that a gear ratio is always written with the number 1 to the right of the colon. This represents one turn of the output gear, while the number to the left represents the revolutions of the input gear. The motoring public likes the term *overdrive*; it has helped sell automobiles since the 1930s when a car with a three-speed transmission with overdrive was first sold.

Most of the time, the ratio will not end up in easy, whole numbers. It will be something like an 11-tooth driving gear and a 19-tooth driven gear, which gives a ratio of 19 divided by 11, which equals 1.7272727 and can be rounded off to 1.73. The automotive industry commonly rounds off gear ratios to two decimal points for consistency. A simple pocket calculator makes the mathematics very easy.

When power goes through more than one gear set, two or more ratios are involved. In most cases, the simplest way to handle this is to figure the ratio of each set and then multiply one ratio by the other(s). An example of this is a vehicle with a first-gear ratio of 2.68:1 and a rear axle ratio of 3.45:1. The overall ratio in first gear is 2.68 × 3.45 or 9.246:1. The engine will rotate at a speed that is 9.246 times faster than the rear axle shafts. The overall ratios for the other transmission gears would be figured in the same manner (Figure 3-17).

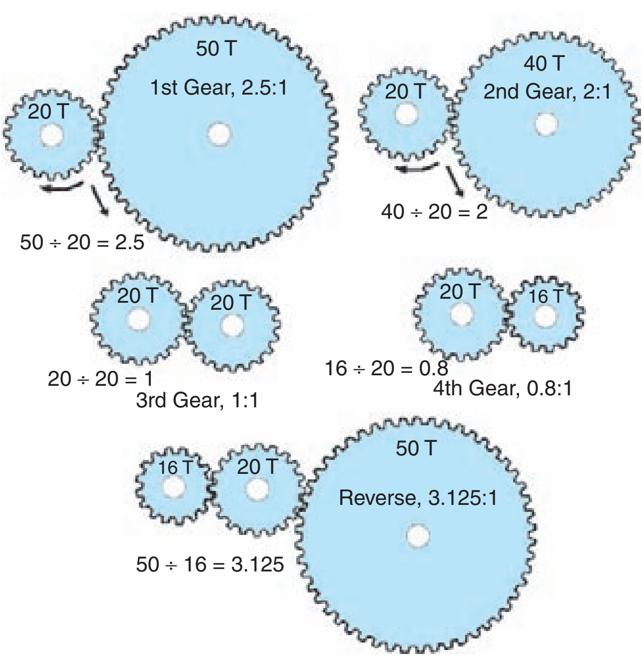

FIGURE 3-16 The gear ratio is determined by dividing the number of teeth on the driven (output) gear by the number of teeth on the driving (input) gear.

TRACTIVE EFFORT

Tractive effort, also called *motive force* or *motive power*, is the engineering term that describes the amount of thrust that the engine and drivetrain can generate at the road surface. This is a product of how much torque is generated by the engine, how much this torque is increased by the drivetrain, and how much this torque is reduced by the size of the drive wheels. The formula used to determine the actual amount of tractive effort for a particular vehicle is

$$TF = \frac{T_e \times R_t \times R_a}{r}$$

where:

TF = tractive force in pounds
T_e = engine torque in foot-pounds
R_t = gear ratio, transmission
R_a = gear ratio, axle
r = effective loaded radius of drive wheel in feet

This formula simply determines the amount of torque that is available at the drive wheels, and then it divides that amount of torque by the lever arm of the wheel. It is important to use the wheel-loaded radius, the distance from the center of the wheel to the ground, because the weight of the vehicle and the pneumatic nature of the tire will shorten this distance. This distance also determines the speed of the car. For each revolution of the tire, the vehicle will travel a distance equal to the circumference of a circle with this radius

Axle ratio: 3.08:1						
	Transmission: Close Ratio		*Mid Ratio*		*Wide Ratio*	
Gear	*Trans. Ratio*	*Overall Ratio*	*Trans. Ratio*	*Overall Ratio*	*Trans. Ratio*	*Overall Ratio*
1st	2.95:1	9.09:1	3.35:1	10.32:1	3.97:1	12.23:1
2nd	1.94:1	5.97:1	1.93:1	5.94:1	2.34:1	7.21:1
3rd	1.34:1	4.13:1	1.29:1	3.97:1	1.46:1	4.5:1
4th	1:1	3.08:1	1:1	3.08:1	1:1	3.08:1
5th	0.73:1	2.25:1	0.68:1	2.09:1	0.79:1	2.43:1

Axle ratio: 3.45:1						
	Transmission: Close Ratio		*Mid Ratio*		*Wide Ratio*	
Gear	*Trans. Ratio*	*Overall Ratio*	*Trans. Ratio*	*Overall Ratio*	*Trans. Ratio*	*Overall Ratio*
1st	2.95:1	10.18:1	3.35:1	11.56:1	3.97:1	13.7:1
2nd	1.94:1	6.69:1	1.93:1	6.66:1	2.34:1	8.07:1
3rd	1.34:1	4.62:1	1.29:1	4.45:1	1.46:1	5.04:1
4th	1:1	3.45:1	1:1	3.45:1	1:1	3.45:1
5th	0.73:1	2.52:1	0.68:1	2.35:1	0.79:1	2.72:1

Axle ratio: 3.73:1						
	Transmission: Close Ratio		*Mid Ratio*		*Wide Ratio*	
Gear	*Trans. Ratio*	*Overall Ratio*	*Trans. Ratio*	*Overall Ratio*	*Trans. Ratio*	*Overall Ratio*
1st	2.95:1	11:1	3.35:1	12.49:1	3.97:1	14.81:1
2nd	1.94:1	7.24:1	1.93:1	7.2:1	2.34:1	8.73:1
3rd	1.34:1	4.5:1	1.29:1	4.81:1	1.46:1	5.45:1
4th	1:1	3.73:1	1:1	3.73:1	1:1	3.73:1
5th	0.73:1	2.72:1	0.68:1	2.54:1	0.79:1	2.95:1

FIGURE 3-17 The overall gear ratio is determined by multiplying the transmission ratio by the axle ratio. This chart shows the overall ratios that result from combining three different transmissions with three different axle ratios. The left columns show a transmission with the close ratios; the right columns show the wide-ratio version. The highest drive axle ratio is at the top; the lowest is at the bottom.

(Figure 3-18). You can use the following formulas to determine the vehicle's speed based on the gear ratio and engine speed, or vice versa:

$$\text{mph} = \frac{\text{rpm} \times \text{tire diameter}}{\text{gear ratio} \times 336}$$

$$\text{engine rpm} = \frac{\text{mph} \times \text{gear ratio} \times 336}{\text{tire diameter}}$$

If accuracy is important when using these formulas, you should use the loaded tire radius times 2 for the tire diameter.

By plotting the driveshaft torque in chart form, as in Figure 3-19, we get an interesting way to look at the torque

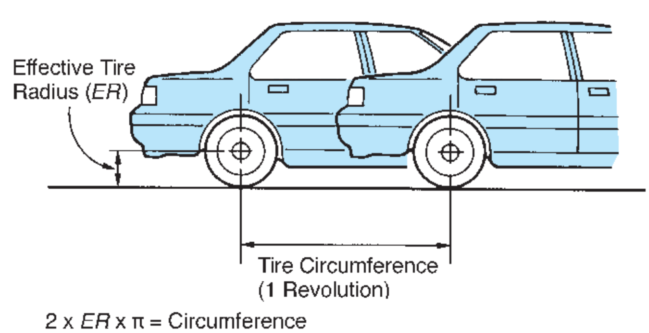

FIGURE 3-18 Vehicle speed is determined by the diameter and speed of the drive wheels. It can be computed as shown here.

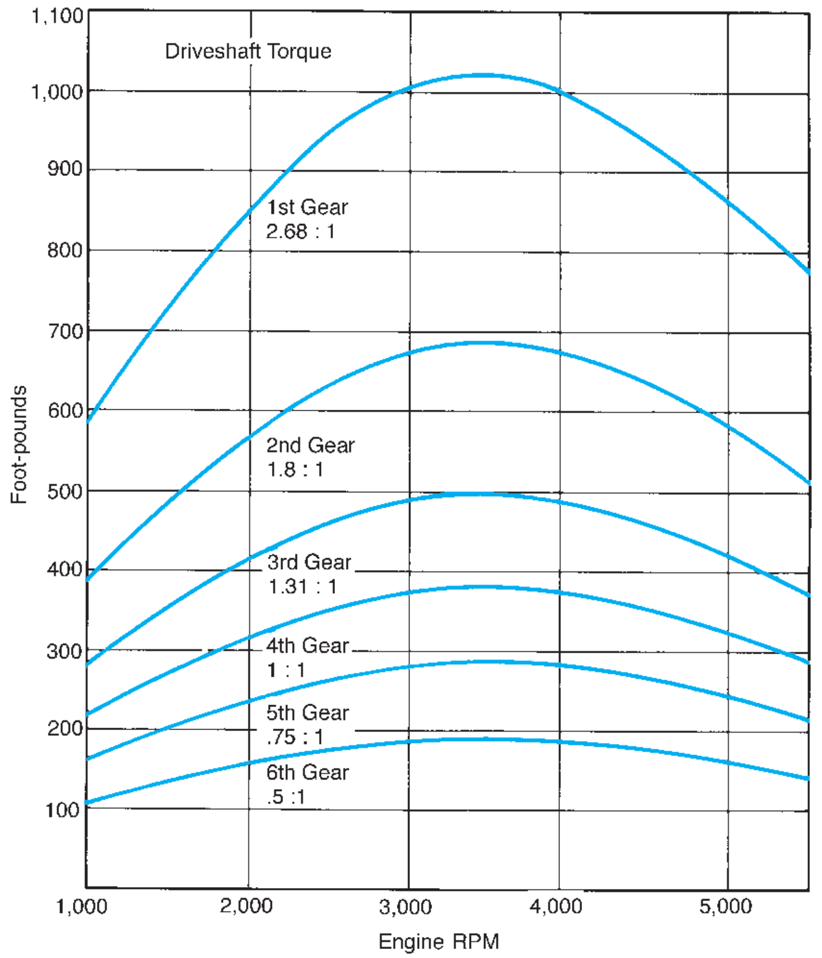

FIGURE 3-19a Multiplying the engine's torque (from Figure 3-5) by the transmission gear ratio gives the driveshaft torque for the various gears.

available in the drivetrain. This chart is plotted for the torque curve shown in Figure 3-5, equipped with a six-speed transmission. In the chart shown in Figure 3-20, we plotted tractive effort and added the vehicle speed, which illustrates how the torque in each transmission gear relates to the speed of the vehicle. The torque in first gear is greatest but is usable only up to about 45 mph if engine rpm is limited to 5500 rpm. Second gear gives a greater usable speed range but less torque, third gear gives still greater speed range but less torque, and so on.

The load that the drivetrain works against is called the **tractive resistance**. An engineer will use the formula

$$\text{tractive resistance} = F_r \times D_a \times G_r$$

where:

F_r = rolling friction
D_a = aerodynamic drag
G_r = grade resistance

Rolling friction is the drag of the tires on the road plus bearing friction. It increases at a constant rate, doubling as the speed is doubled. **Aerodynamic drag** is the wind resistance of air moving over the size and shape of the vehicle. It increases at a rapid rate, roughly four times as the speed is doubled (actually, velocity squared). **Grade resistance** is an amount equal to 0.01 times the vehicle weight times the angle of the grade in percent.

As you drive a vehicle, you adjust the throttle so the engine produces the proper torque, and you select the gear needed to overcome the tractive resistance. If you are concerned with speed and acceleration rate, use lower gears and higher engine speeds. If you are concerned with fuel economy, use the highest gear to give the lowest practical engine speed.

Comparing Drivetrains

Two useful tools you can use to compare vehicle drivetrains are **N/V ratio** and **gear ratio spread**.

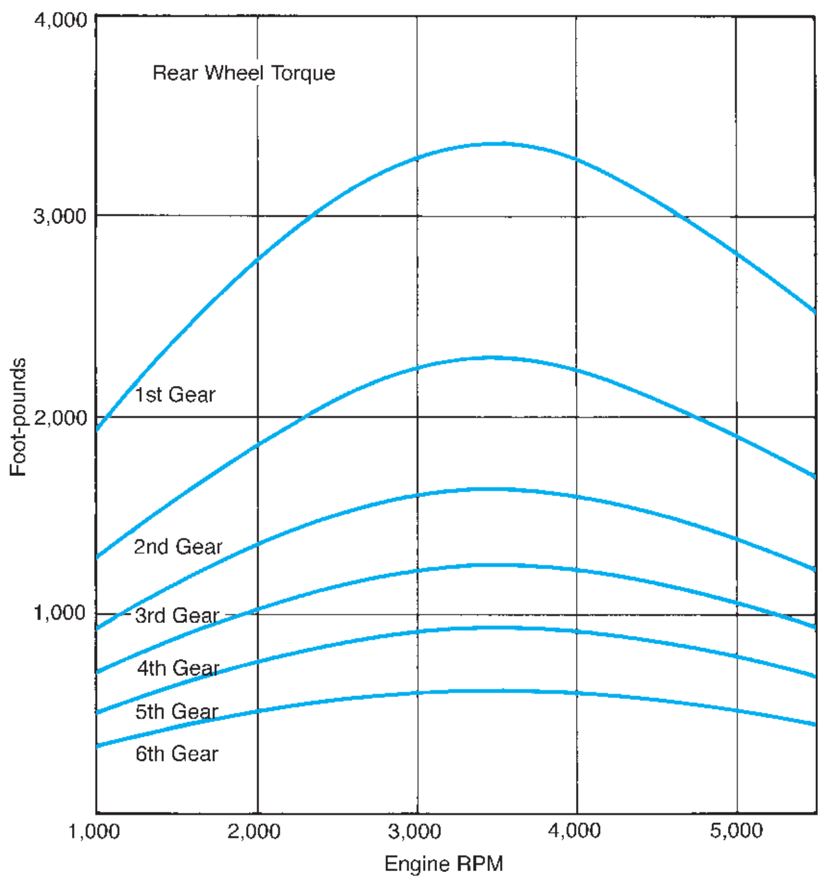

FIGURE 3-19b Multiplying the driveshaft torque by the axle ratio gives the torque available at the drive wheels. These curves are for a modern, domestic sports car.

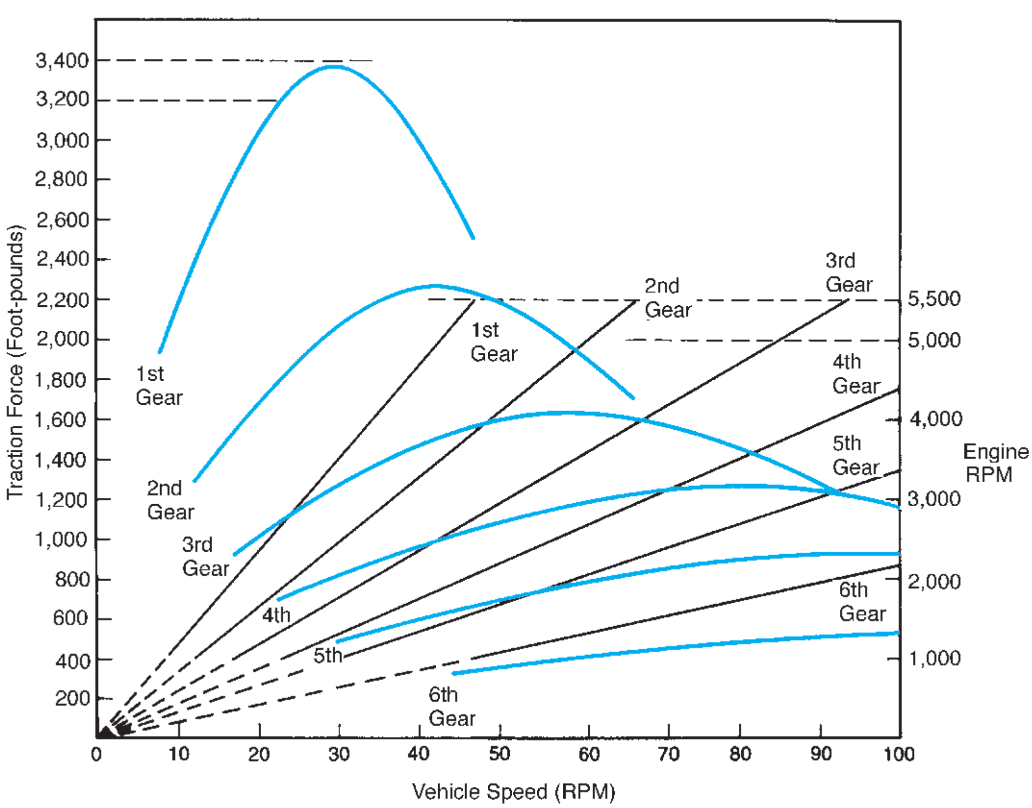

FIGURE 3-20 Dividing drive-wheel torque by the tire diameter gives the tractive force at the drive wheels. Combining this with the vehicle speed shows the available torque at the various speeds. Also note that five of the six gears can be used at 55 mph; second gear will produce the highest engine speed and sixth gear the slowest.

In an N/V ratio, the N is engine rpm (Number) and V is velocity (vehicle speed). The N/V ratio provides the number of engine rpm per mph. You can use the following formula to compute the N/V ratio:

$$\text{N/V Ratio} = \frac{5{,}280/Tc \text{ X } Rt \text{ X } Ra}{60}$$

where:

Tc = Tire circumference in feet

Rt = Gear ratio, transmission

Ra = Gear ratio, axel

Plotting the N/V ratio on a spread sheet allows an easy evaluation/comparison of things like vehicle performance, red line speeds, shift points, and load pulling ability (Figure 3-21).

Gear ratio spread, GRS, is the difference between the lowest and highest ratios or, to say it differently, the overall range of a transmission's gear ratios. In gear transmissions, it is fairly easy to visualize the difference between a 3.59:1 first gear and a 0.83:1 fifth gear. This becomes more difficult for a CVT transmission with a 2.37:1 starting ratio and a 0.44:1 final ratio. Gear ratio spread is determined by dividing the low gear ratio by the high gear ratio. The GRS for the gear transmission is 3.59/0.83 = 4.33, and the GRSs for the CVT is 2.73/0.44 = 5.39. Comparing the two GRS shows us that the vehicle with the CVT will have a lower first gear, a higher cruising gear, or both.

Transmission Efficiency

Increased fuel costs and stringent emission requirements are forcing manufacturers to build more efficient vehicles. Five- and six-speed transmissions are more efficient than three- and four-speed transmissions. Manual transmission efficiency is affected by gear and bearing friction. An automatic transmission is also affected by the hydraulic pump and torque converter. Depending on the gear ratio, an automatic transmission is about 60 to 95% efficient actually, about 80 to 86% in average use. This means that about 14 to 20% of the power that enters the transmission is lost to friction and heat. In comparison, a manual

P 2.45/75R 16		Circum =	7.984875	Rotation in one mile		661.2502			
N/V =Number/Velocity = Engine RPM/Vehicle Speed									
3.73 Rear Axle						4.10 Rear Axle			
	Overdrive	3rd Gear	2nd Gear	1st Gear		Overdrive	3rd Gear	2nd Gear	1st Gear
N/V	30.83079	41.10772	60.83943	101.9471		33.88907	45.18543	66.87444	112.0599
MPH		**Engine RPM**					**Engine RPM**		
5	154	206	304	510		169	226	334	560
10	308	411	608	1019		339	452	669	1121
15	462	617	913	1529		508	678	1003	1681
20	617	822	1217	2039		678	904	1337	2241
25	771	1028	1521	2549		847	1130	1672	2801
30	925	1233	1825	3058		1017	1356	2006	3362
35	1079	1439	2129	3568		1186	1581	2341	3922
40	1233	1644	2434	4078		1356	1807	2675	4482
45	1387	1850	2738	4588		1525	2033	3009	5043
50	1542	2055	3042	5097		1694	2259	3344	5603
55	1696	2261	3346			1864	2485	3678	6163
60	1850	2466	3650			2033	2711	4012	
65	2004	2672	3955			2203	2937	4347	
70	2158	2878	4259			2372	3163	4681	
75	2312	3083	4563			2542	3389	5016	
80	2466	3289	4867			2711	3615	5350	
85	2621	3494	5171			2881	3841		
90	2775	3700				3050	4067		
95	2929	3905				3219	4293		
100	3083	4111				3389	4519		
	320 Horse Power at 5000 rpm								
	440 Lbs of Torque at 3200 rpm								

FIGURE 3-21 This number/velocity (N/V) spread sheet shows the engine rpm to vehicle speed relationship for two different rear axle ratios. *(Courtesy of John Brunner)*

transmission averages about 95% efficiency, so it generally transfers more power to the wheels. Efficiency in gear reduction and overdrive ratios is 92–97%, and 93-99% in a 1:1 ratio.

The driving public prefers automatic transmissions. Automated manual transmissions (AMT) and two-clutch manual transmissions have been developed and are offered in a few vehicles. These units provide driving ease, similar to automatic transmissions, with the efficiency of a manual transmission. Continuously variable transmissions (CVT) that are currently used in some vehicles are more efficient than gear transmissions. These use either a steel belt with two variable-width pulleys or toroidal-shaped driving and driven members. CVTs promise to be more efficient than manual transmissions. CVTs are described in the section on Automatic transmissions and torque converters.

MANUAL TRANSMISSIONS

The **transmission** provides the various gear ratios necessary for a vehicle's operation, and it gives the driver a means of controlling the engine speed. It must have a ratio low enough (when multiplied by the axle ratio) to produce sufficient torque to get the vehicle moving. It must also have a ratio that will allow economical operation at cruise speeds without excessive engine rpm. There must also be enough intermediate ratios so that overrevving in the lower gear or lugging in the higher gear is not a problem. The weight of the vehicle, the amount of engine torque, the usable speed range of the engine, and the operating speed of the vehicle are used to determine if three, four, five, or even more speeds are necessary in the transmission. In addition to these forward-speed ratios, a transmission must provide a reverse for backing up and a neutral so the engine can run without moving the vehicle.

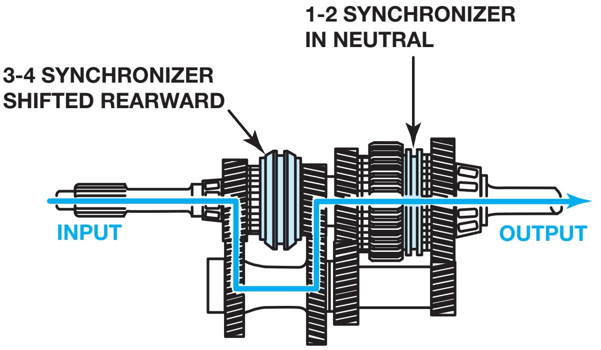

FIGURE 3-22 Gearset of a four-speed transmission showing the power flow for third gear. Shifting the 1–2 and 3–4 synchronizers selects the gear speed.

A **manual transmission**, also called a **standard transmission**, is constructed with a group of paths through which power can flow; each path is a different gear ratio (Figure 3-22). Synchronizer assemblies or sliding gears and the shift linkage are used to control or engage these power paths. When a shift is made, the power must be interrupted by a clutch. In Chapter 6 we provide a more thorough description of standard transmission operation.

The **clutch** interrupts the power flow to allow the transmission to be shifted. It is also used to ease the engagement of the power flow when the vehicle starts from a standstill. Remember that the engine does not produce usable torque until above 1000 rpm and that the engine speed with a vehicle in gear at 0 mph would be 0 rpm. The slight slippage as the clutch engages allows the engine speed to stay up where it produces usable torque as the vehicle begins moving.

Most vehicles use a foot-pedal-operated single-plate clutch assembly that is mounted on the engine flywheel (Figure 3-23).

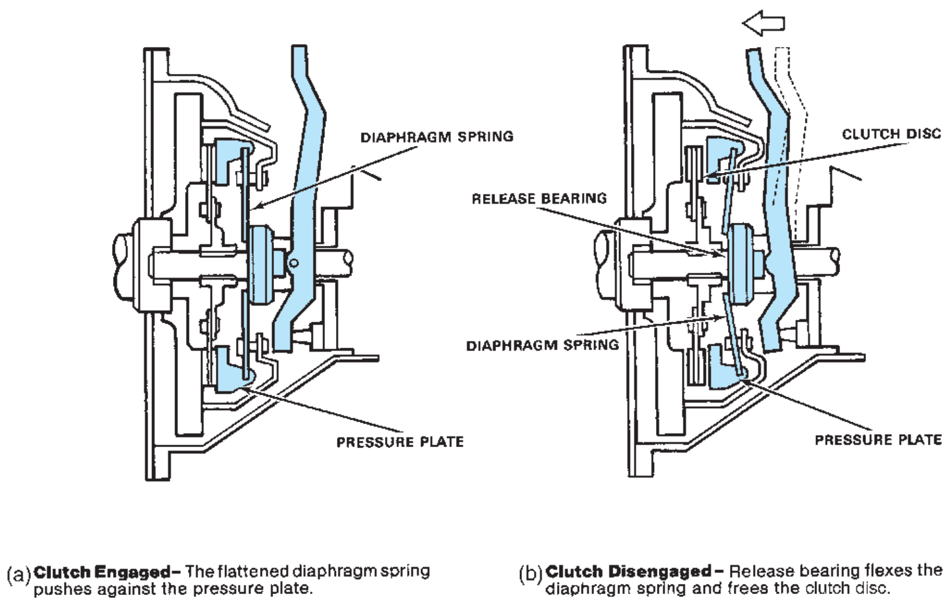

FIGURE 3-23 A clutch cover (pressure plate assembly) is bolted onto the flywheel with the clutch disc between them (a). The release bearing and fork provide a method to release the clutch. When the clutch is engaged, the disc is squeezed against the flyweel by the pressure plate (b). Releasing the clutch separates the disc from the flywheel and pressure plate.

When the pedal is pushed down, the power flow is disengaged; when the pedal is released, power can flow from the engine to the transmission through the engaged clutch. Clutch operation is described more completely in Chapter 4.

AUTOMATIC TRANSMISSIONS AND TORQUE CONVERTERS

An **automatic transmission** also has various gear ratios, but the paths of power flow are different from those of a standard transmission. Planetary gear sets are used and combined in a complex manner so that up to seven speeds forward plus reverse are in one complex gear set and the gears remain in constant mesh. Shifts are made by engaging or releasing one or more internal clutch packs that drive a part of the gear set, or by engaging or releasing other clutches or bands that hold a part of the gear set stationary. An automatic transmission might have as many as seven power control units. One-way clutches are also used. These self-release and overrun when the next gear is engaged. These clutches or bands are operated as needed to engage a certain gear. These control units can operate without an interruption of the power flow (Figure 3-24).

Automatic transmission control units are operated by hydraulic pressure. To make a shift, hydraulic valves direct fluid to apply or release the proper clutch or band at the correct time. Newer transmissions are computer controlled and linked to the engine controls, which allows the engine and transmission to operate closer to each other's requirements.

A **torque converter** replaces the clutch. It is a type of fluid coupling that can release the power flow at slow engine speeds and also multiply the engine's torque during acceleration. Torque converters in newer vehicles include a friction clutch that locks up to eliminate slippage at cruising speeds, improving fuel economy and reducing emissions.

A few automatic transmissions have a gear arrangement resembling a standard transmission. A friction clutch is used with each forward gear. The friction clutch is applied to engage the vehicle's gear. One clutch is released and another is applied to shift gears (Figure 3-25). A torque converter is used, and the operation of these clutches is by hydraulic pressure like other automatic transmissions.

CONTINUOUSLY VARIABLE TRANSMISSIONS

Some vehicles use a **continuously variable transmission (CVT)**. A CVT varies the gear ratio in a continuous manner instead of in a series of steps or gear ratios. The power flow is through a V-belt between two pulleys that change their width and effective diameter. When the vehicle accelerates from a standing start, the driving pulley is small and the driven pulley

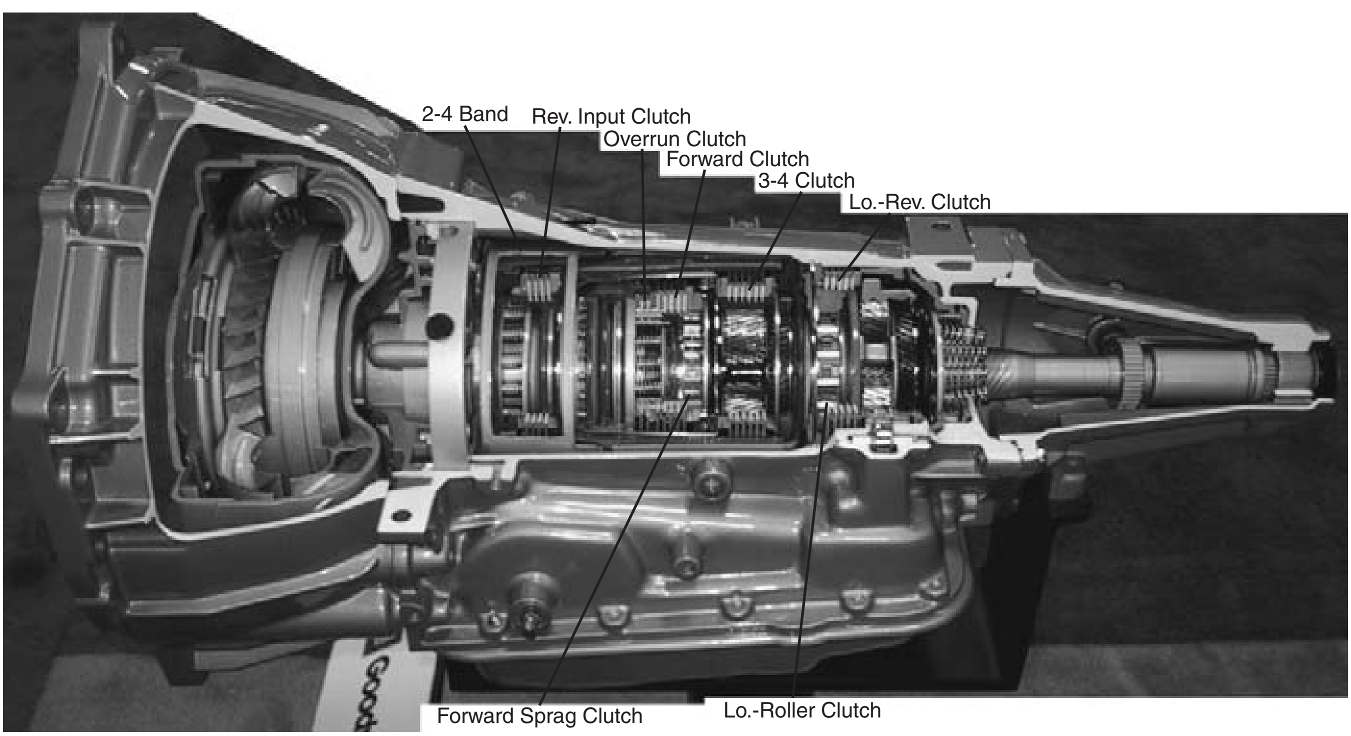

FIGURE 3-24 A sectioned view of a four-speed, RWD transmission.

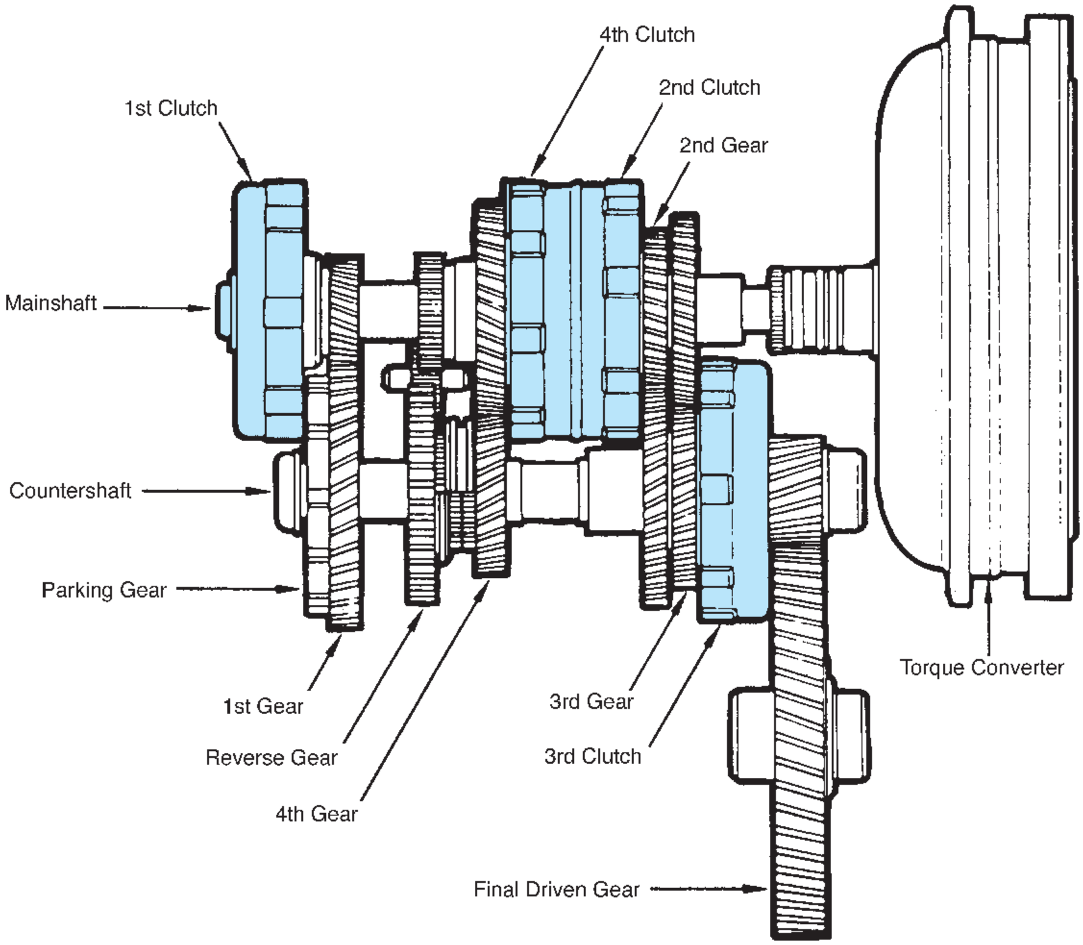

FIGURE 3-25 Gear train of a fourspeed Honda-Matic transaxle. Note that the various speeds occur as the clutches are applied or released. *(Courtesy of American Honda Motor Company.)*

is large. This gives a gear reduction identical to a small gear driving a large gear. As the speed increases, the effective diameter of the driving pulley increases as the sides of the pulley move together. While this happens, the driven pulley is made wider and therefore smaller in diameter. At cruising speeds, the driving pulley is larger than the driven pulley, which produces an overdrive ratio (Figure 3-26).

The pulleys change size smoothly and evenly, which produces a somewhat odd sensation when the vehicle accelerates for a stop. As the throttle is depressed, the engine speed increases to the point of good torque output, and then it stays at this rpm while the vehicle accelerates. The pulleys move to higher ratios as vehicle speed increases. This is a different sensation than the familiar engine speed increase in each gear and the engine speed decrease after an upshift.

Toroidal transmissions are also of the traction-drive type. A toroidal transmission uses an input toroid and an output toroid that have the same shape, similar to part of a doughnut. There is a set of idler-like rollers, also called *variators,* that are pushed against the toroids. The rollers transmit power from one toroid to the other, and they can be twisted so the driving and driven radii can be changed (Figure 3-27). This design requires very exact machining of the two toroids and the variator rollers and is extremely sensitive to the type of lubricant used.

TRANSAXLES

A transaxle is a compact combination of a transmission and the final drive gear reduction and differential. It can be either a standard, automatic, or continuously variable transaxle. Transaxles are used in nearly all FWD vehicles, some mid-engine vehicles, and even a few RWD vehicles. A transmission normally has one output shaft that couples to the rear axle through the driveshaft (Figure 3-28a). A transaxle has two output shafts that couple to the two front wheels through a pair of driveshafts (Figure 3-28b).

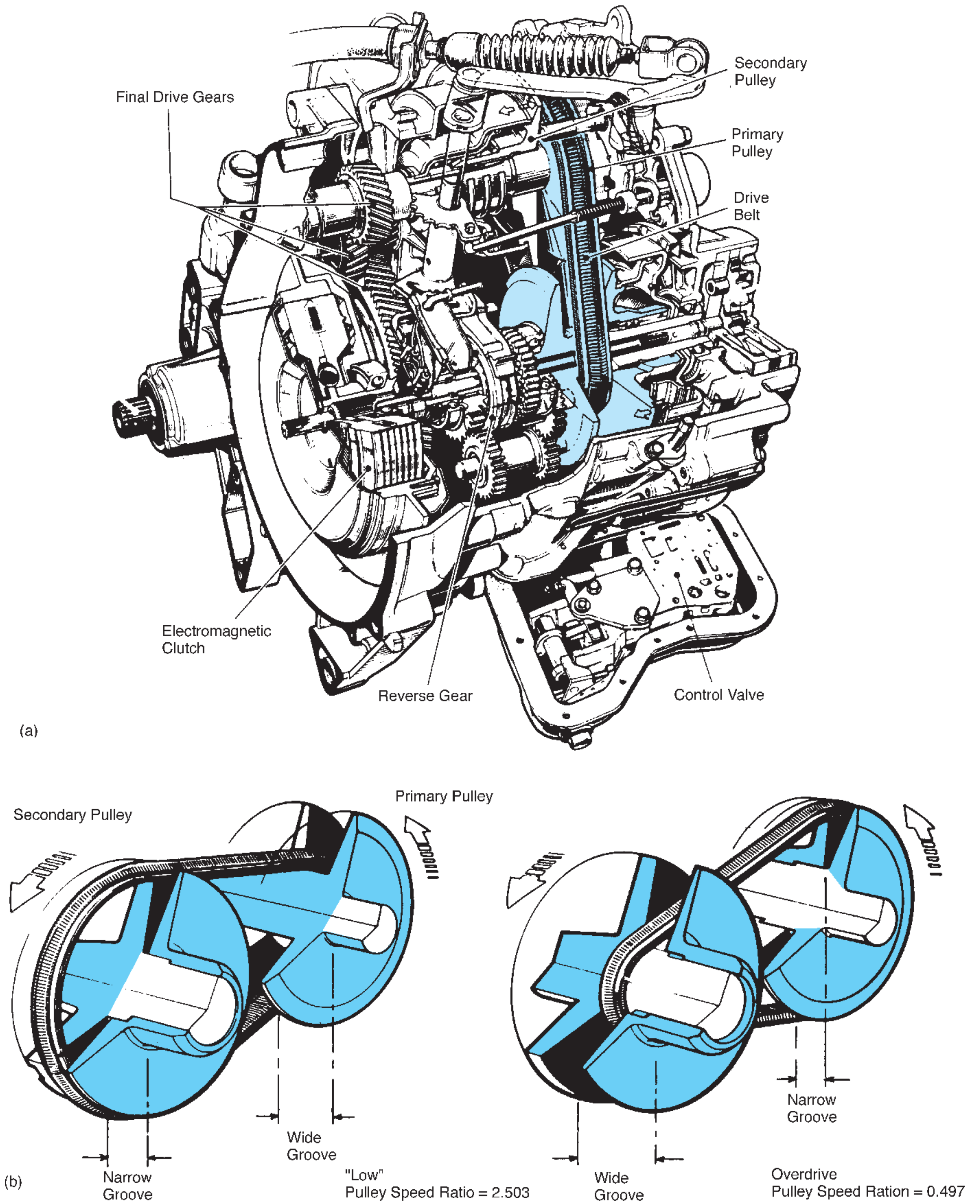

FIGURE 3-26 (a) CVT transaxle. (b) Note how the pulley diameters are changed to produce changes in the gear ratio. *(Courtesy of Subaru of America, Inc.)*

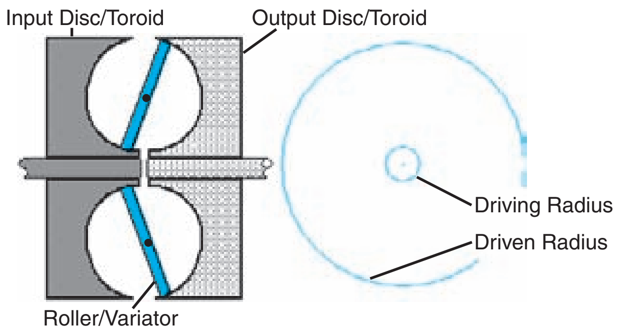

FIGURE 3-27 The rollers are pushed against the input and output toroids so they can transfer power. They are in low ratio as shown. The rollers will be twisted, the top one counterclockwise and the lower one clockwise to shift to a higher ratio.

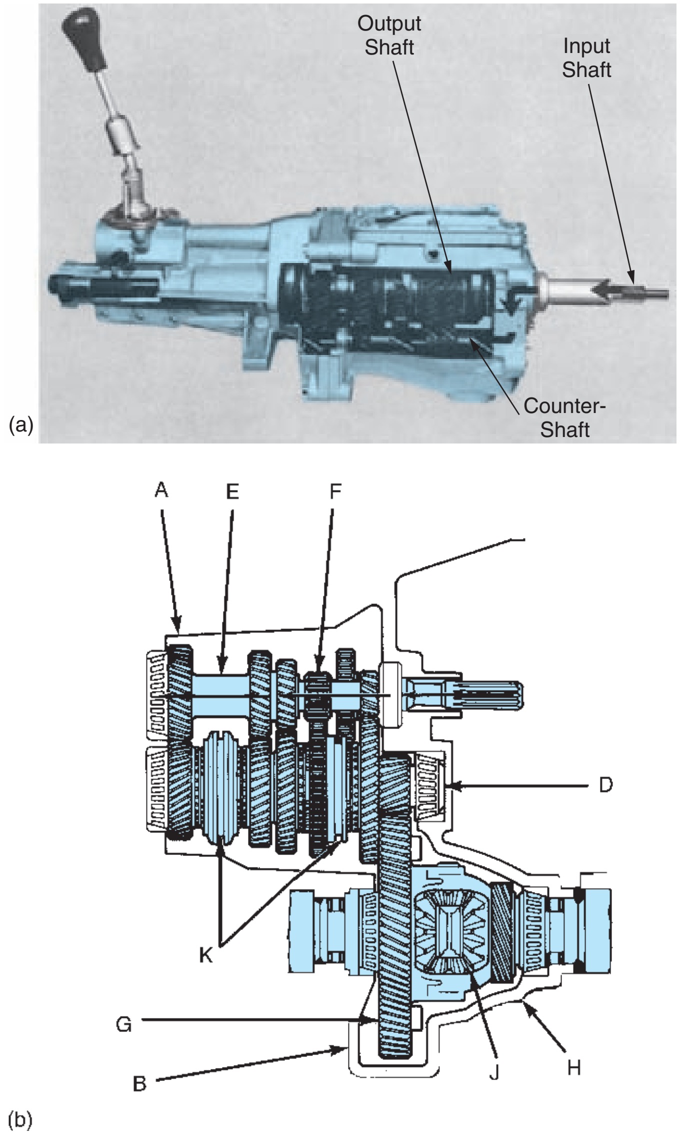

FIGURE 3-28 A transmission has one output shaft for the driveshaft to the rear axle (a). A transaxle combines a transmission section (a) and a reduction section (b) with the differential (J). *(Courtesy of Ford Motor Company.)*

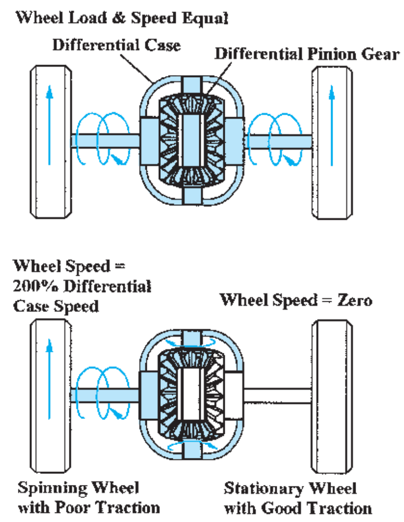

FIGURE 3-29 Normally, an equal load from each wheel keeps the differential pinion gears stationary on their shaft (top). An unequal load will cause the differential pinion gears to rotate and drive the axle shafts at unequal speeds (bottom).

The **differential** used in transaxles or drive axles is a torque-splitting device that allows the two axle shafts to operate at different speeds so that a vehicle can turn corners. When a vehicle turns a corner, the wheel on the outer side of the turning radius must travel farther than the inner wheel, but it must do this in the same period of time. Therefore, it must travel faster while turning. Most differentials are composed of a group of four or more gears. One gear is coupled to each axle and two are mounted on the differential pinion shaft (Figure 3-29). Differential operation is explained in Chapter 7.

DRIVESHAFTS

Driveshafts transfer power from one component to another. RWD driveshafts are usually made from steel tubing, and normally have either a **universal joint (U-joint)** or a **constant-velocity (CV) joint** at each end (Figure 3-30). Most FWD driveshafts are a solid shaft; some are hollow tubing. A U-joint allows the shaft to bend as the drive axle moves up and down (relative to the vehicle's body) when the wheels travel over bumps. Speed fluctuations occur in the driveshaft as the U-joints transfer power at an angle, but these fluctuations are canceled out or eliminated by the joint at the other end of the shaft.

A FWD driveshaft must use a CV joint at its ends because the front wheels must be steered at sharp angles. Jerky steering wheel or drive wheel motion would occur if U-joints were used. As their name implies, CV joints transfer power without velocity change or speed fluctuation. Because CV joints are rather expensive and require a clean, well-lubricated environment, they are enclosed in a special boot. The short driveshafts used with transaxles and independent rear suspension

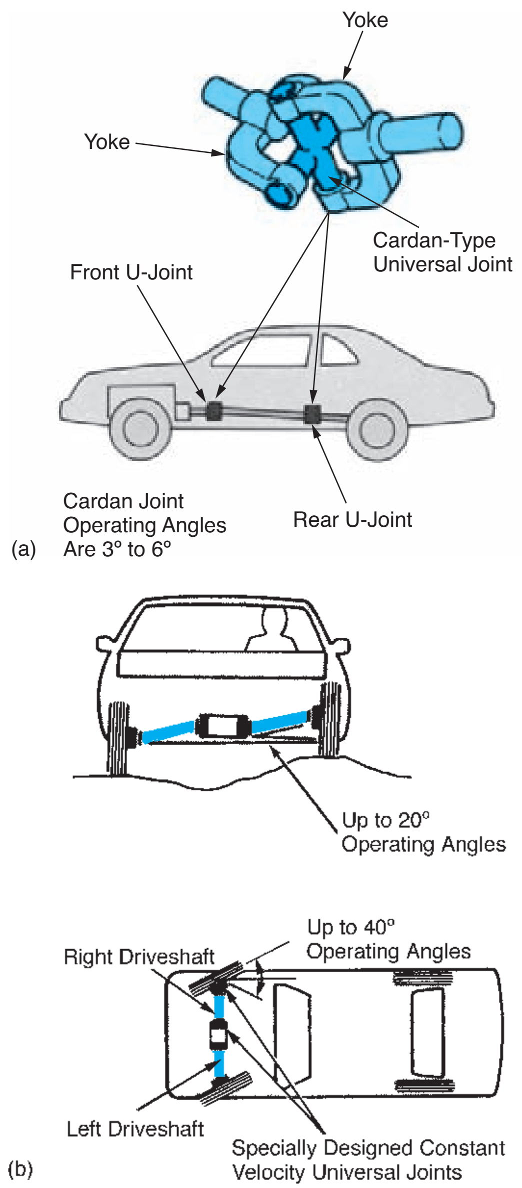

FIGURE 3-30 (a) An RWD driveshaft uses a pair of universal joints to allow the rear axle to move up and down. (b) A FWD driveshaft uses a pair of constant-velocity joints to allow the front wheels to move up and down and steer. *(Courtesy of Ford Motor Company)*

drive axles are often called **half shafts**. Driveshafts, U-joints, and CV joints are described more completely in Chapter 9.

DRIVE AXLES

RWD vehicles use a drive axle assembly at the rear (Figure 3-31). A **drive axle** serves several functions:

1. It supports the weight of the rear of the vehicle.
2. It contains the final drive reduction gears.
3. It contains the differential.

Many people call the drive axle assembly the *differential*. Most axle assemblies use strong axle shafts to transfer the torque from the differential gears to the wheel and tire. A bearing at the outer end of the axle housing serves to transfer vehicle weight to the axle and then onto the wheel and tire while allowing the shaft to rotate.

The term **final drive** refers to the last set of reduction gears in a gear train. The term is commonly used when discussing truck and heavy equipment drivetrains. These reduction gears, along with the drive wheel diameter, determine the cruise speed engine rpm and, along with the transmission gear ratios, the tractive force of the drivetrain.

Some vehicles have **independent rear suspensions (IRS)**. This type of suspension allows one wheel to move vertically without affecting the opposite wheel. The drive axles used with IRS have separate wheel bearing assemblies. Since the drive axle does not support the weight of the vehicle, it only serves as the final reduction and the differential.

FOUR-WHEEL DRIVE

A vehicle will have more pulling power and traction if all of its wheels are driven. This requires a drive axle at each end of the vehicle, another driveshaft, and a **transfer case** or **power transfer unit** to drive the additional shaft and axle. A 4WD can be built into a front-engined RWD, a front-engined FWD, and a rear-engined RWD (Figure 3-32). The term *4×4* refers to a vehicle that has four wheels and that drives four wheels. The first 4 indicates that the vehicle has 4 wheels, and the second 4 indicates that 4 wheels are driven.

If 4WD is to be used all the time, a problem arises when a vehicle turns a corner, because each of the wheels must rotate at a different speed (Figure 3-33). The fastest wheel will be the outer front, followed by the outer rear and the inner front, and the slowest is the inner rear. Three differentials must be used to solve this, one in each drive axle assembly plus an inner axle differential between the two drive axles. If a 4WD vehicle is operated on pavement in 4WD, the different speeds of the front and rear tires will cause scuffing of the tires and a bindup of the gear train. Most 4WD vehicles are used in 2WD on pavement where the extra traction is not needed and shifted into 4WD when poor traction requires its use. When used with poor traction, tire slippage takes care of any tire scuffing or gear bind. Many all-wheel-drive (AWD) vehicles are designed for improved on-road handling, and these vehicles include a center/interaxle differential to allow the front-to-rear speed differential.

The added drive axle used with 4WDs based on a RWD platform is almost the same as a rear axle except that when used as a front axle, the outer ends must steer. This requires a steering knuckle at the outer end of the housing and a U-joint or CV joint at the outer end of the axle shaft. If a U-joint is used, a steering wheel fluctuation and a fluctuation in the tires' rotation is usually noticeable on sharp turns.

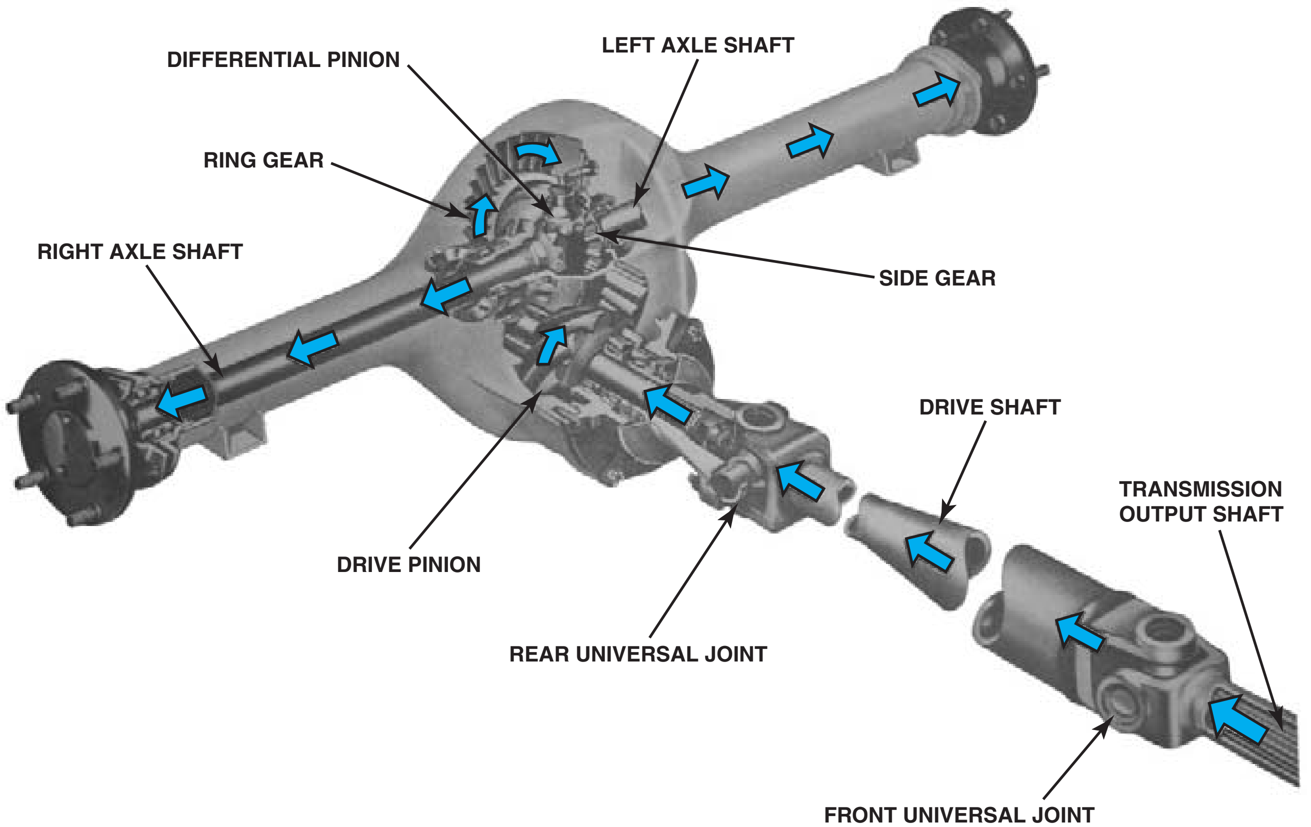

FIGURE 3-31 A drive axle includes a ring and pinion gear to produce a lower gear ratio as it turns the power flow 90°and a differential (differential pinion and side gears) to allow the drive wheels to rotate at different speeds. *(Courtesy of Ford Motor Company.)*

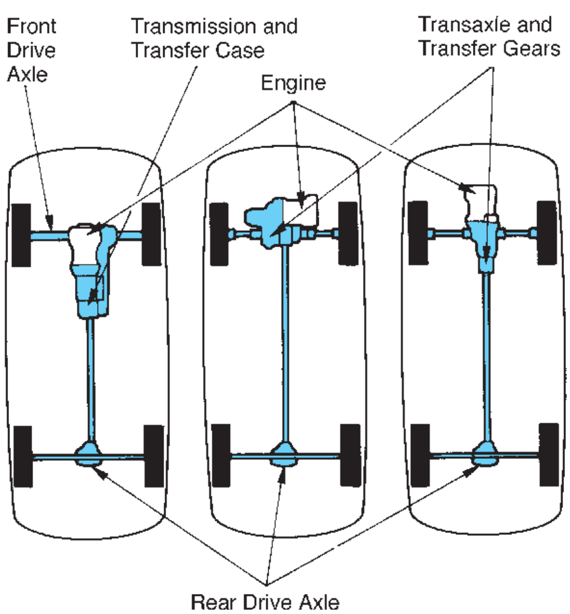

FIGURE 3-32 Common 4WD drivetrain arrangements.

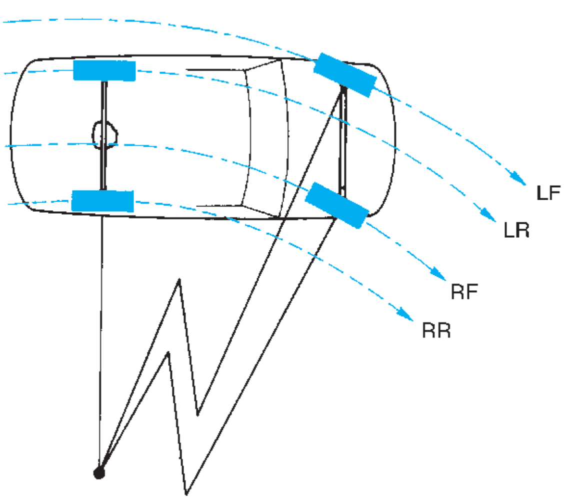

FIGURE 3-33 Each wheel travels at a different speed as a vehicle turns a corner. The outside front (LF) wheel must rotate the fastest, and the inside rear (RR) wheel moves the slowest. An all-wheel-drive vehicle requires three differentials. *(Courtesy of Ford Motor Company.)*

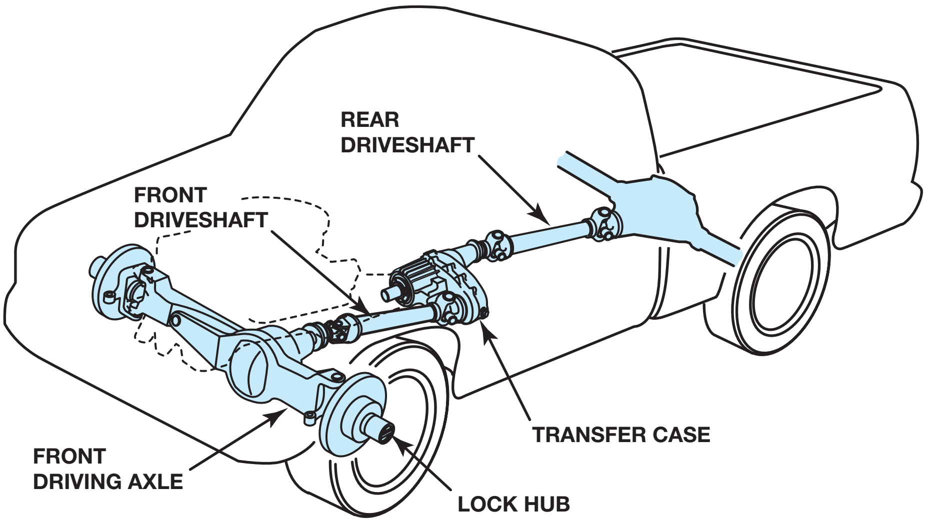

FIGURE 3-34 This 4WD pickup uses a transfer case to provide the power flow to the front driveshaft and drive axle.

The transfer case is normally attached to the rear of the transmission (Figure 3-34). It has a single input shaft from the transmission and two output shafts, one to the front and one to the rear drive axle. A dog clutch is used to engage the power flow to the second axle when 4WD is desired. A dog clutch is a simple mechanical clutch that resembles one internal gear that is slid over an external gear. Some newer transfer cases include a magnetic friction clutch that allows 4WD engagement while the vehicle is moving. Some transfer cases are two-speed and include a set of reduction gears for lower-speed, higher-torque operation.

All-wheel drive (AWD), also called full-time 4WD, vehicles are 4WD vehicles equipped with CV joints on the front axles and an inner-axle differential so they can be operated on pavement in 4WD. Some of the more expensive vehicles use a very sophisticated inner-axle differential that can change the amount of torque going to each drive axle depending on traction conditions. 4WD and AWD are described more completely in Chapter 13.

SUMMARY

1. Vehicles are RWD, FWD, 4WD, or AWD.
2. Engines develop torque; drivetrains modify that torque to move the vehicle.
3. A variety of gears are used to modify torque. The gear ratio is determined by dividing the number of driven gear teeth by the number of teeth on the driving gear.
4. Transmissions contain the gear ratios that a driver can select. Manual transmissions with a clutch and automatic transmissions are used.
5. Transaxles combine the final drive gears and differential with the transmission.
6. Driveshafts and the drive axle complete the drivetrain. 4WD and AWD vehicles have a transfer case or transfer gears and a second drive axle.

REVIEW QUESTIONS

1. The gear ratios in the transmission are used to match the engine ____________ and ____________ to the requirements of the vehicle.
2. ____________ gears have their teeth cut in a spiral.
3. ____________ gears have their teeth cut straight.
4. ____________ gears are used in most rear drive axles.
5. To determine a gear ratio, ____________ the ____________ gear by the ____________ gear.
6. Which is the lower ratio: 5:1 or 3:1? ____________
7. The transmission provides the gear ratio that will multiply the ____________ sufficiently enough to move the vehicle.
8. The ____________ allows the driver to interrupt the power flow to the transmission.
9. An automatic transmission is operated by ____________ pressure.
10. The ____________ ____________ replaces the clutch for an automatic transmission.
11. A transaxle is a combination of a ____________ and the final drive and ____________.
12. ____________ are used to transfer power from one component to another.
13. The driveshafts used with independent rear suspension are often called ____________ ____________.
14. A four-wheel-drive vehicle has a ____________ ____________ attached to the rear of the transmission to drive the front axle.
15. All-wheel-drive vehicles require an additional ____________ to allow for the speed difference of the four tires.

CHAPTER QUIZ

1. A car's drivetrain can send power to the (A) rear wheels; (B) front wheels. Which is correct?
   - **a.** A only
   - **b.** B only
   - **c.** Either A or B
   - **d.** Neither A nor B
2. The turning form of mechanical power that passes through a rotating shaft is called (A) horsepower; (B) torque. Which is correct?
   - **a.** A only
   - **b.** B only
   - **c.** Both A and B
   - **d.** Neither A nor B
3. The power output from an automotive engine
   - **a.** is almost constant from 0 rpm up to the maximum rpm.
   - **b.** begins at about 1000 rpm and is almost constant up to the maximum rpm.
   - **c.** begins at about 1000 rpm, increases until about 2500 rpm, and then decreases.
   - **d.** begins at about 1000 rpm and increases up to the maximum rpm.
4. Gear ratios can be used to increase (A) horsepower; (B) torque. Which is correct?
   - **a.** A only
   - **b.** B only
   - **c.** Both A and B
   - **d.** Neither A nor B
5. If a gear with 20 teeth is driving a gear with 60 teeth, the gear ratio is
   - **a.** 2:6.
   - **b.** 3:1.
   - **c.** 1:3.
   - **d.** 0.33:1.
6. Two students are comparing spur and helical gears. Student A says a helical gear is stronger. Student B says a helical gear runs noisier. Who is correct?
   - **a.** Student A
   - **b.** Student B
   - **c.** Both A and B
   - **d.** Neither A nor B

7. A gear set used to transmit power between two shafts that meet at a right angle is the (A) hypoid gear set; (B) spiral bevel gear set. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B

8. The transmission is in first gear, which has a 2.5:1 ratio, and the rear axle has a ratio of 2:1. The overall gear ratio is (A) 4.5:1; (B) 5:1. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B

9. Drive-tire and wheel diameter will affect (A) vehicle speed; (B) tractive force. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B

10. Which car requires the most transmission gear ratios?
   a. light car, small engine
   b. light car, big engine
   c. heavy car, small engine
   d. heavy car, big engine

11. Two students are discussing clutch application. Student A says they must engage completely, all at once. Student B says there must be a small amount of slipping. Who is correct?
   a. Student A
   b. Student B
   c. Both A and B
   d. Neither A nor B

12. A continuously variable transmission uses (A) planetary gears like an automatic transmission; (B) special gears that can change diameter. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B

13. Two students are discussing front driveshafts. Student A says CV joints are used so the front wheels can turn sharp corners. Student B says CV joints are used to prevent jerky steering wheel motions while turning. Who is correct?
   a. Student A
   b. Student B
   c. Both A and B
   d. Neither A nor B

14. A differential (A) provides the gear reduction needed in the drive axle; (B) drives two wheels at different speeds. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B

15. An AWD car must have a differential (A) in each drive axle; (B) between the two drive axles. Which is correct?
   a. A only
   b. B only
   c. Both A and B
   d. Neither A nor B