chapter 1

INTRODUCTION TO DRIVETRAINS

LEARNING OBJECTIVES

After studying this chapter, the reader should be able to:

1. Define torque, and explain the relationship between torque and horsepower.
2. Describe the various gear types and their effect on speed, torque and direction of rotation.
3. Explain gear ratios and their effect on vehicle operation.
4. Discuss the types of manual transmissions and transaxles that are currently in use.
5. Discuss automatic transmissions and the planetary gear sets used for automatic transmissions.
6. Compare rear-wheel drive, front-wheel drive, four-wheel drive, and all-wheel drive systems.
7. Explain the characteristics of drive shafts and drive axle assemblies.

KEY TERMS

All-wheel drive (AWD) 16
Automatic transmission 9
Bevel gear 6
Clutch 8
Constant-velocity (CV) joint 14
Differential 14
Dynamometer 4
Drive axle 14
Driveshaft 14
Final drive 13
Four-wheel drive (4WD) 16
Front-wheel drive (FWD) 13
Gear ratio 7
Half shaft 13
Helical gear 5
Horsepower 3
Hypoid gear 6
Manual transmission 8
Overdrive 7
Pinion gear 8
Pitch diameter 4
Planet carrier 11
Planetary gear set 11
Power transfer unit 16
Rear-wheel drive (RWD) 13
Ring gear 11
Spiral bevel gear 6
Spur gear 5
Sun gear 11
Torque 2
Torque converter 11
Transaxle 13
Transfer case 16
Transmission 8
Universal joint (U-joint) 14
Worm gear 6

DRIVETRAINS

PURPOSE AND FUNCTION The purpose of a vehicle drivetrain is to transfer power from the engine to the drive wheels. The drivetrain, also called a powertrain, serves the following functions:

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

FREQUENTLY ASKED QUESTION

Is It Lb-Ft or Ft-Lb of Torque?

The unit for torque is expressed as a force times the distance (leverage) from the object. Therefore, the official unit for torque is lb-ft (pound-feet) or Newton-meters (a force times a distance). However, it is commonly expressed in ft-lb and most torque wrenches are labeled with this unit.

TORQUE

DEFINITION **Torque** is a rotating or twisting force that may or may not result in motion. A vehicle 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 another form of energy.

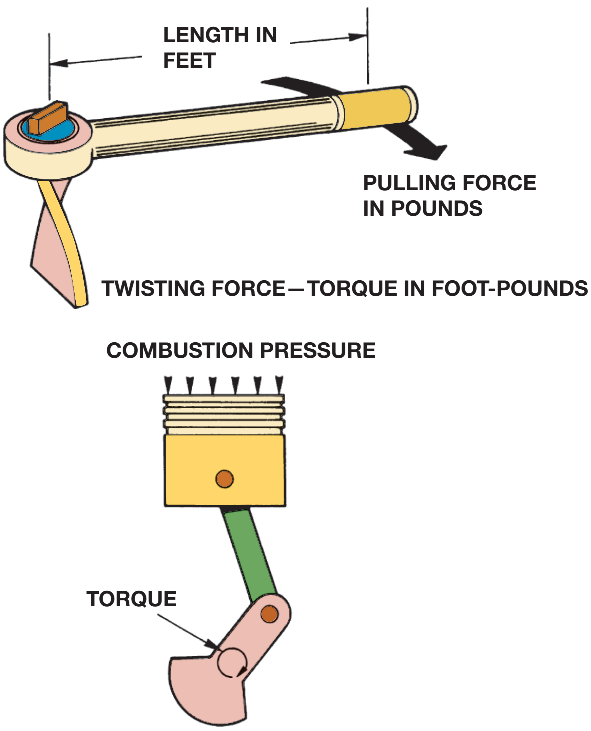


FIGURE 1–1 Torque, a twisting force, is produced when you pull on a wrench. An engine produces torque at the crankshaft as combustion pressure pushes the piston downward.

UNITS OF TORQUE Engine torque is developed when combustion pressure pushes a piston downward to rotate the crankshaft. **SEE FIGURE 1–1.**

The amount of torque produced will vary depending on the size and design of the engine and the throttle opening. Torque is measured in pounds-feet (lb-ft) or Newton-meters (N-m). One Newton-meter of torque is equal to 0.737 lb-ft. 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). An engine begins producing usable torque at about 1200 RPM and peak torque at about 2500 to 4000 RPM, with an upper usable speed limit of 5000 to 7000 RPM. The gear ratios in the transmission and drive axle are used to match the engine speed and torque output to the vehicle speed and torque requirements. **SEE FIGURE 1–2.**

DRIVE VS. DRIVEN GEARS The *drive* gear is the gear that is the source of the engine torque and rotation. The *driven* gear is the gear that is driven or rotated by the drive gear. Two gears meshed together are used to transmit torque and rotational motion. The driven gear can then rotate yet another gear. In this case, the second gear becomes the drive gear and the third gear is the driven gear.

TORQUE MULTIPLICATION The gear teeth are cut proportional to the diameter of the gear. If one of two mating gears was twice as large as the other, it would have twice as many teeth. For example, if the smaller gear has 10 teeth, a gear twice as large will have 20 teeth. 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 small gear is the drive gear. To determine a gear ratio, divide the driven gear by the driving gear. **SEE FIGURE 1–3.**

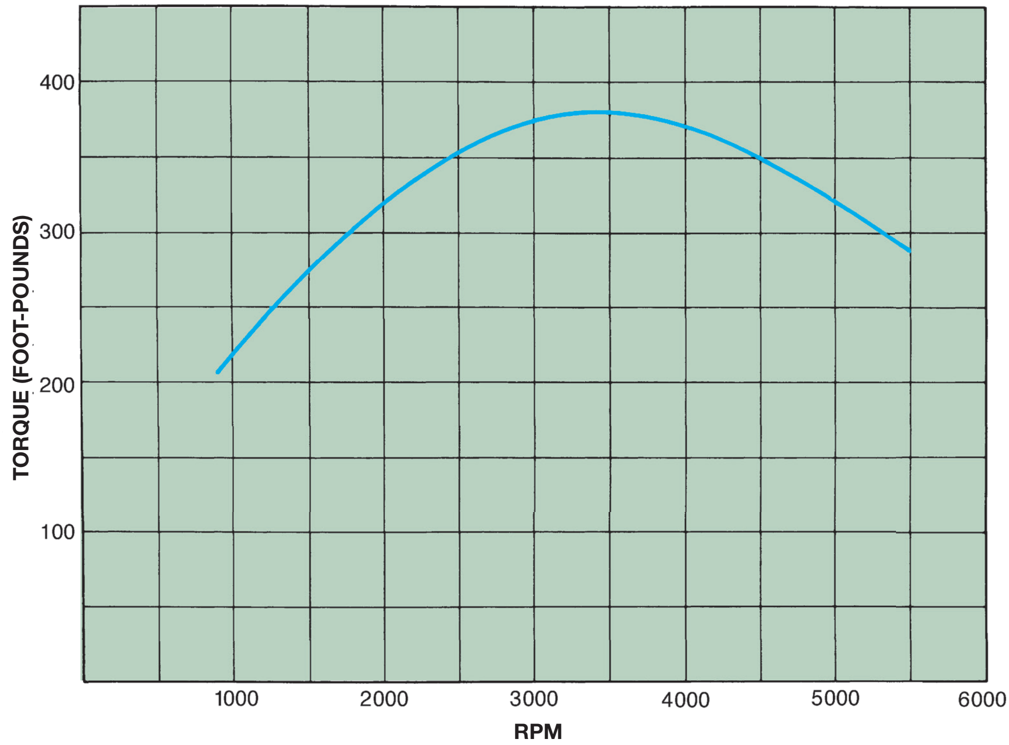


FIGURE 1–2 The torque produced by a 5.7 L engine as plotted on a graph. Note that the engine begins producing usable torque at 1000 to 1200 RPM and a maximum torque (381 ft-lb) at 3500 RPM. The torque produced by the engine decreases at higher RPM due to a decrease in volumetric efficiency.

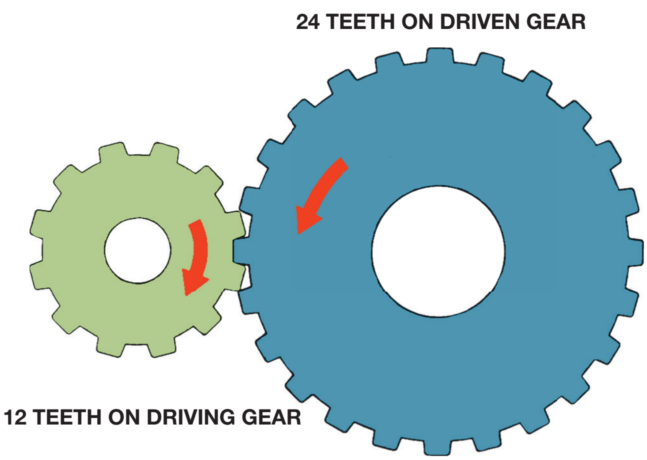


FIGURE 1–3 Gear ratio is determined by dividing the number of teeth of the driven (output) gear (24 teeth) by the number of teeth on the driving (input) gear (12 teeth). The ratio illustrated is 2:1.

GEARS ARE LEVERS Torque is increased because of the length of the gear lever, as measured from the center of the gear. 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. Physics does not allow energy to become lost in a gear set, other than what is lost as heat in overcoming friction. Therefore, whatever power that comes in one shaft, goes out through another.

- If the speed is reduced, torque will increase by the same amount.
- If speed is increased, torque will decrease by the same amount.

For example, if the driving gear has 20 lb-ft (27 N-m) of torque at 500 RPM and the ratio is 2:1, the driven gear will have 40 lb-ft (54 N-m) of torque (twice as much) at 250 RPM (half the speed).

HORSEPOWER

DEFINITION The term power means the rate of doing work. Power equals work divided by time.

- Work is done when a certain amount of mass (weight) is moved a certain distance by a force. Whether the object is moved in 10 seconds or 10 minutes does not make a difference in the amount of work accomplished, but it does affect the amount of power needed. **SEE FIGURE 1–4.**
- Power is expressed in units of foot-pounds per minute. One **horsepower** is the power required to move 550 pounds one foot in one second, or 33,000 pounds one foot in one minute (550 lb $\times$ 60 sec $=$ 33,000 lb). This

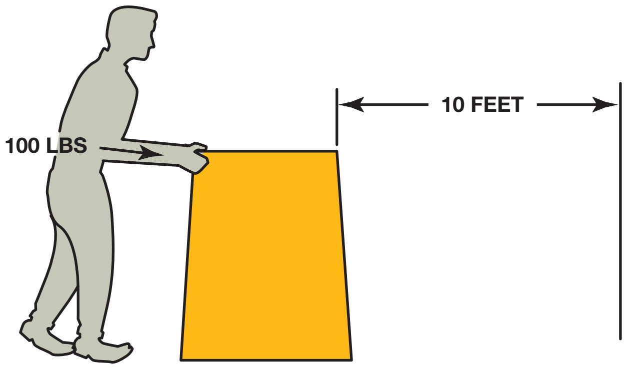


FIGURE 1–4 Work is calculated by multiplying force times distance. If you push 100 pounds 10 feet, you have done 1,000 foot-pounds of work.

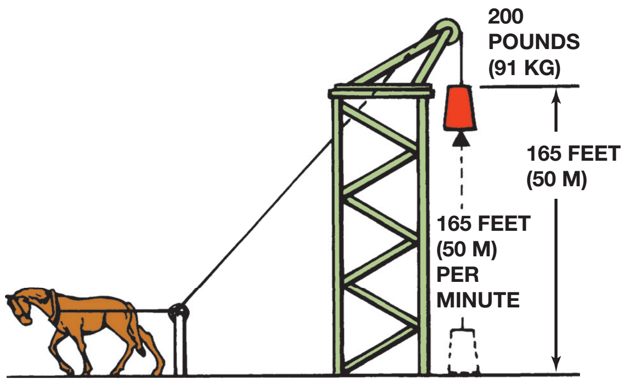


FIGURE 1–5 One horsepower is equal to 33,000 foot-pounds (200 lbs × 165 ft) of work per minute.

is expressed as 550 foot-pounds (ft-lb) per second or 33,000 foot-pounds per minute. ● **SEE FIGURE 1–5.**

HORSEPOWER AND TORQUE RELATIONSHIP To determine horsepower, a **dynamometer** is used to measure the amount of torque an engine can produce at various points through its operating range. The formula used to convert torque at a certain revolution per minute (RPM) into a horsepower reading is

Horsepower = Torque × RPM/5,252

NOTE: To determine how the constant "5,252" was derived, perform an Internet search to see an explanation.

The various readings are then plotted into a curve. A typical horsepower and torque curve shows us that an engine does not produce very much torque at low RPM. The most usable torque is produced in the mid-RPM range. Torque decreases with an increase in horsepower at a higher RPM.

The torque from an engine can be increased or decreased through the use of gears, belts, and chains. Gears, belts, or chains cannot increase horsepower; they can only modify its effect. A gear set can increase torque, but it will decrease speed by the same amount.

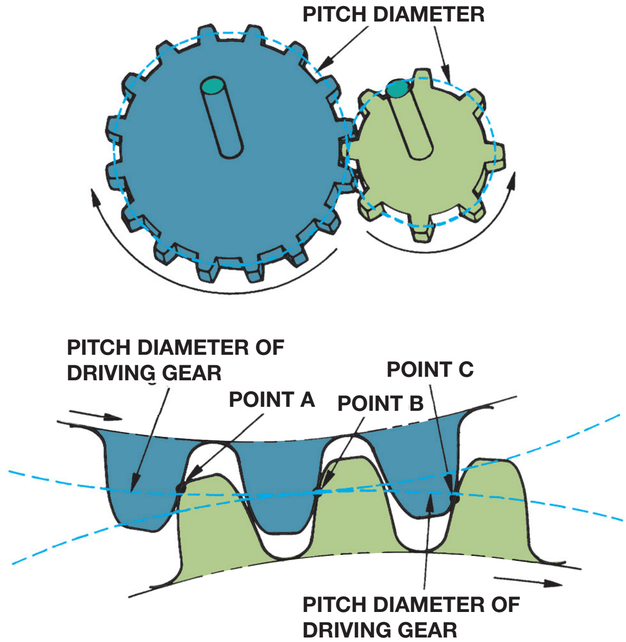


FIGURE 1–6 The pitch diameter is the effective diameter of the gear. Note how the contact points slide on the gear teeth as they move in and out of contact.

TECH TIP

How to Explain the Difference between Horsepower and Torque

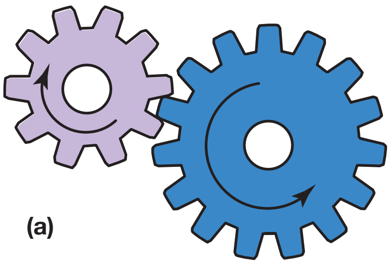
As Carroll Shelby, the well-known racer and business owner, said, "Horsepower sells cars, but torque wins races." Torque determines how fast the vehicle will accelerate, and horsepower determines how fast the vehicle will go.

GEARS

TERMINOLOGY The effective diameter of a gear is the **pitch diameter** (or *pitch line*). ● **SEE FIGURE 1–6.**

The pitch diameter is the diameter of the gear at 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. Major points include:

- Driven and driving gears will rotate in opposite directions.



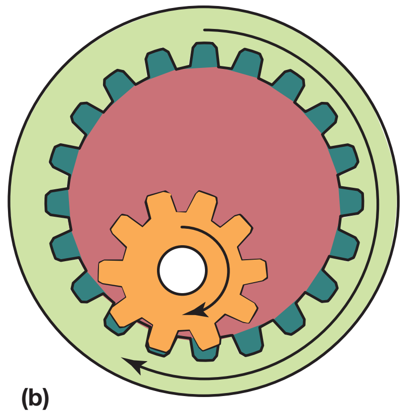


FIGURE 1–7 (a) When one external gear drives another, the direction of rotation is always reversed. (b) When an external gear drives an internal gear, the two gears will rotate in the same direction.

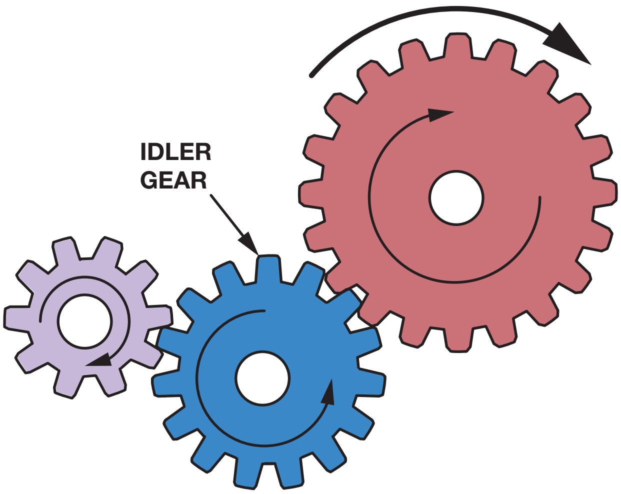


FIGURE 1–8 An idler gear reverses the direction of rotation so that the driving and driven gears rotate in the same direction.

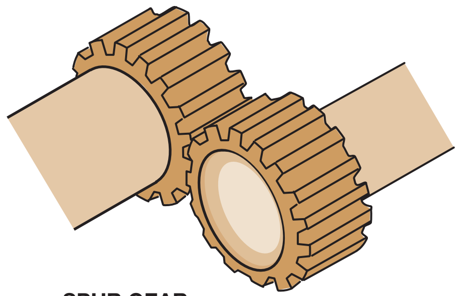


FIGURE 1–9 The teeth of a spur gear are cut parallel to the shaft, and this produces a straight pressure between the driving and the driven gear teeth.

- External gears will always reverse shaft motion.
- If same-direction motion is required, the power will be routed through two gear sets.
- When power goes through a series of gears, an even number of gears (2, 4, 6, and 8) will cause a reversal in direction and an odd number of gears (3, 5, 7, and 9) will produce same direction of rotation.

  ● **SEE FIGURE 1–7.**

REVERSING DIRECTION OF ROTATION External gears reverse the direction of rotation when the drive gear transfers power to the driven gear. When it is necessary to change the ratio without changing the direction of power flow, an idler gear is added. An idler gear changes the rotational direction but does not affect the ratio. ● **SEE FIGURE 1–8.**

GEAR TYPES Gears come in different types depending on the cut and relationship of the teeth to the shafts.

- **Spur gears**—Spur gears, the simplest gears, are on parallel shafts with teeth cut straight or parallel to the shaft. ● **SEE FIGURE 1–9.**
- **Helical gear**—Helical gears are the most used of all gears used in transmissions. These gears have teeth cut in a spiral or helix shape. ● **SEE FIGURE 1–10.**

Helical gears are quieter than spur gears, but 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. ● **SEE FIGURE 1–10.**

NOTE: When discussing gears, a pinion gear is the smaller gear of a pair.

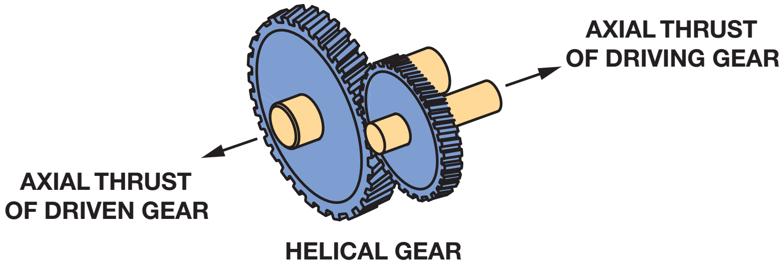


FIGURE 1–10 The teeth of a helical gear are cut on a slant, and this produces an axial or side thrust.

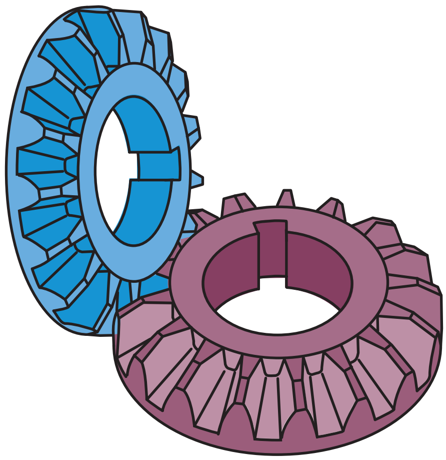


FIGURE 1–11 Bevel gears are commonly used in differentials.

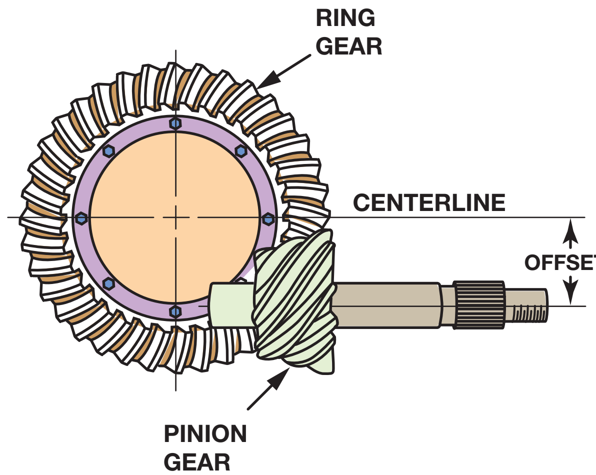


FIGURE 1–12 A hypoid gear set uses a pinion gear that is located below the centerline of the ring gear and is commonly used in drive axles.

- **Bevel gears**—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. In other words, if the two shafts meet at an angle of 90° and the two gears are the same size, the outer edge of the gears will be cut at 45°. The simplest bevel gears have teeth cut straight and are called spur bevel gears. They are inexpensive but noisy. ● **SEE FIGURE 1–11.**
- **Spiral bevel gears**—Spiral bevel gears, like helical gears, have curved teeth for quieter operation.
- **Hypoid gear**—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 transaxles that have longitudinal mounted engines. The hypoid gear design places the drive pinion gear lower in the housing (below the centerline) of the ring gear and axle shafts. ● **SEE FIGURE 1–12.**
- **Worm gear**—A gear set used with shafts that cross each other but do not intersect is the worm gear. 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. Worm gears are used in vehicle speed sensor drives. To determine the ratio of a worm gear, 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. ● **SEE FIGURE 1–13.**

? FREQUENTLY ASKED QUESTION

What Is a “Rock Crusher” Transmission?

A manual Muncie (M22) four-speed manual transmission in the muscle car era, was called the *rock crusher* because it used straight cut spur gears.

It was designed as a racing transmission because by using spur gears, the end thrust loads were reduced. However, spur gears are noisy and sounded like rocks being chewed up so therefore, the slang term “rock crusher” for this once popular transmission.

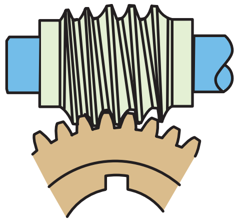


FIGURE 1–13 A worm gear set is also used to transmit power between angled shafts.

GEAR RATIOS

TERMINOLOGY **Gear ratios** are determined by the following methods:

- Dividing the number of teeth on the driven gear (output) by the number of teeth on the driving gear (input). 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.
- Gear ratio = driven gear/drive gear.
- 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 speed of the output will be 4 times slower than the input speed but, the output torque will be four times more than the input torque. The higher the ratio number, the lower the gear 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. ● **SEE FIGURE 1–14.**

Most of the time, the ratio will not end up as whole numbers. It will be something like an 11-tooth driving gear and a 19-tooth driven gear, which results in a ratio of 19 divided by 11, which equals 1.7272727 and can be rounded off to 1.73.

COMMONLY USED RATIOS The automotive industry commonly rounds off gear ratios to two decimal points. Drivetrain engineers usually do not use even ratios like 3:1 or 4:1 but instead use ratios that are 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 gear set with a ratio such as 3.23:1 is called a hunting gear set, and a tooth of one gear contacts all of the other gear teeth, which produces quieter operation.

OVERDRIVE If the driving gear has more teeth (20) than 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 expressed as 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.

CALCULATING OVERALL RATIOS 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 the ratios. An

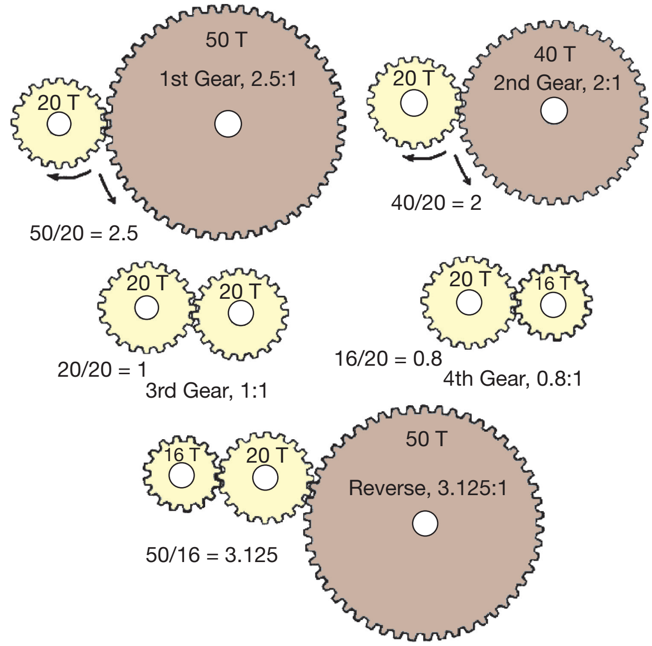


FIGURE 1–14 The gear ratio is determined by dividing the number of teeth on the driven (output) gear by the number of teeth on the driving (input) gear.

FREQUENTLY ASKED QUESTION

What Is the Relationship between Speed and Gear Ratio?

The following formulas can be used to determine the vehicle speed based on the gear ratio and engine speed, or the engine speed based on the gear ratio and MPH:

- MPH = (RPM × tire diameter) ÷ (gear ratio × 336)
- Engine RPM = (MPH × gear ratio × 336) ÷ tire diameter

NOTE: The constant 336 is used to convert the units from inches (tire diameter) to feet and MPH to feet per hour.

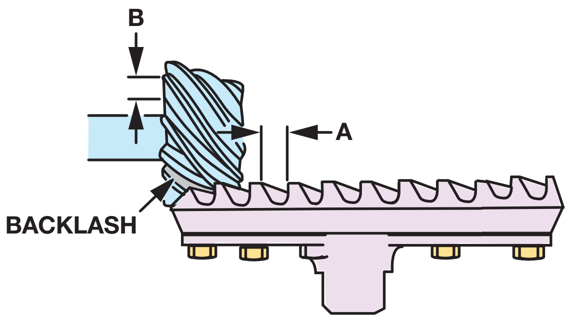


FIGURE 1–15 Backlash is the clearance between the teeth of two meshing gears. There has to be some clearance (backlash) to prevent the gears from getting into a bind condition when they are transmitting torque.

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.

- At the same time there will be 9.246 times as much torque at the rear wheels than the engine produced.
- 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.

GEAR SET SUMMARY Typical rules about gear sets include the following:

- Two mated external gears will always rotate in opposite directions.
- Gear sets will multiply torque, but at a reduced speed.
- An idler gear allows the drive and driven gears to rotate in the same direction.
- To find the ratio, divide the driven gear by the drive gear.
- When power transfers through an even number (two or four) of gears, the input and output gears will rotate in opposite directions.
- When power transfers through an uneven number (one, three, or five) of gears, the input and output gears will rotate in the same direction.
- To find the overall ratio of multiple gear sets, multiply the ratios of the gear sets.
- Two gears transferring power push away from each other in an action called *gear separation*. The gear separation force (thrust) is proportional to the torque being transferred.
- The smaller gear(s) in a gear set may also be called a **pinion gear**.
- All gear sets *must* have backlash to prevent binding. ● **SEE FIGURE 1–15.**

TRANSMISSIONS

PURPOSE AND FUNCTION The purpose and function of gears in a **transmission** include the following:

- Low/first gear must provide enough torque to get the vehicle moving.
- High gear should provide an engine speed for fuel-efficient operation at highway speeds.
- The intermediate ratios should be spaced to provide adequate acceleration while minimizing the potential of overrevving the engine before the shift or lugging the engine after the shift.

TRENDS The majority of vehicles up to the 1970s used three-speed transmissions while some added an overdrive unit for a fourth gear ratio to lower engine RPM at cruise speeds. As the need to improve fuel economy and reduce exhaust emissions has improved, four-, five-, and six-speed transmissions have been introduced to provide lower first gears, overdrive, and/or smaller steps between gear ratios.

MANUAL TRANSMISSIONS

PURPOSE AND FUNCTION A **manual transmission**, also called a *standard transmission*, is constructed with a group of paths through which power can flow with each path used being a different gear ratio. ● **SEE FIGURE 1–16.**

Synchronizer assemblies or sliding gears and the shift linkage are used to control or engage the power paths.

CLUTCH Engine power must be stopped when making a shift in a manual transmission. The **clutch** is used to stop 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. 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. When the pedal is pushed down, the power flow is disengaged and

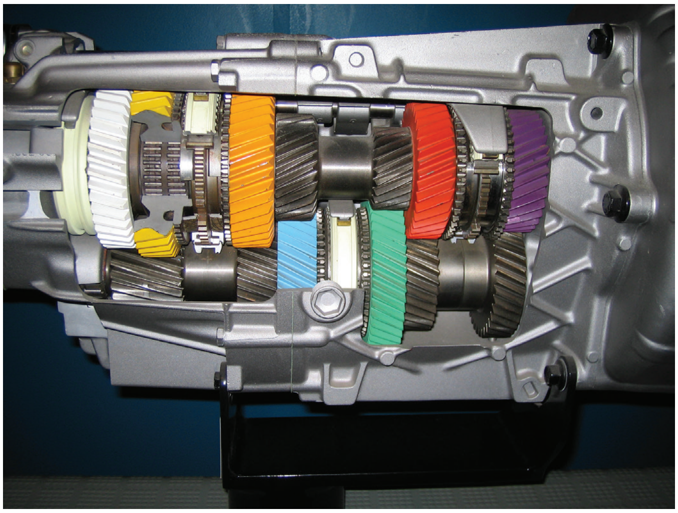


FIGURE 1–16 A manual transmission provides several gear ratios and a method to shift them.

FIGURE 1–17 A Muncie four-speed manual transmission on a restored muscle car is an example of a close-ratio manual transmission.

FREQUENTLY ASKED QUESTION

What Is a "Close-Ratio" Transmission?

Gear ratio spread (GRS), is the difference between the lowest and highest ratios or, in other words, the overall range of the transmission gear ratios. In transmissions, it is fairly easy to visualize the difference between a 3.59:1 first gear and a 0.83:1 fifth gear. 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. RPM change/drop is fairly easy to determine:

- Subtract the higher ratio from the lower ratio and divide the product by the lower ratio.
- A close-ratio Muncie four-speed has ratios spaced fairly close together (25% or less), closer than the wide-ratio version. ● **SEE FIGURE 1–17.**

FREQUENTLY ASKED QUESTION

What Is an Automated Manual Transmission?

An automated manual transmission is a type of automatic transmission/transaxle that uses two clutches and a manual transmission-type gears and is shifted hydraulically by computer-controlled solenoids. This type of transmission is commonly called a *dual clutch* or an *electronically controlled manual transmission*.

when the pedal is released, power can flow from the engine to the transmission through the engaged clutch. ● **SEE FIGURE 1–18.**

AUTOMATIC TRANSMISSIONS

PURPOSE AND FUNCTION The purpose and function of an **automatic transmission** is to provide the forward and reverse gear ratios needed without requiring the driver to make the change in gearing as with a manual transmission. An automatic transmission has various gear ratios, but the paths of power flow are different from those of a manual transmission.

SHIFT MODES The transmission provides the various gear ratios for forward and reverse operations as well as two methods for the engine to run without moving the vehicle. Most automatic transmissions and transaxles include the following shift modes. ● **SEE FIGURE 1–19.**

- **Park.** In the park position, the output shaft is locked to the case of the transmission/transaxle which keeps the vehicle from moving. No power is transmitted through the unit so the engine can remain running while the vehicle is held stationary.

  In the park position

  1. The engine can be started by the driver.
  2. To move the shifter out of the park position on a late model vehicle, the brake pedal must be depressed to release the transmission shift interlock.

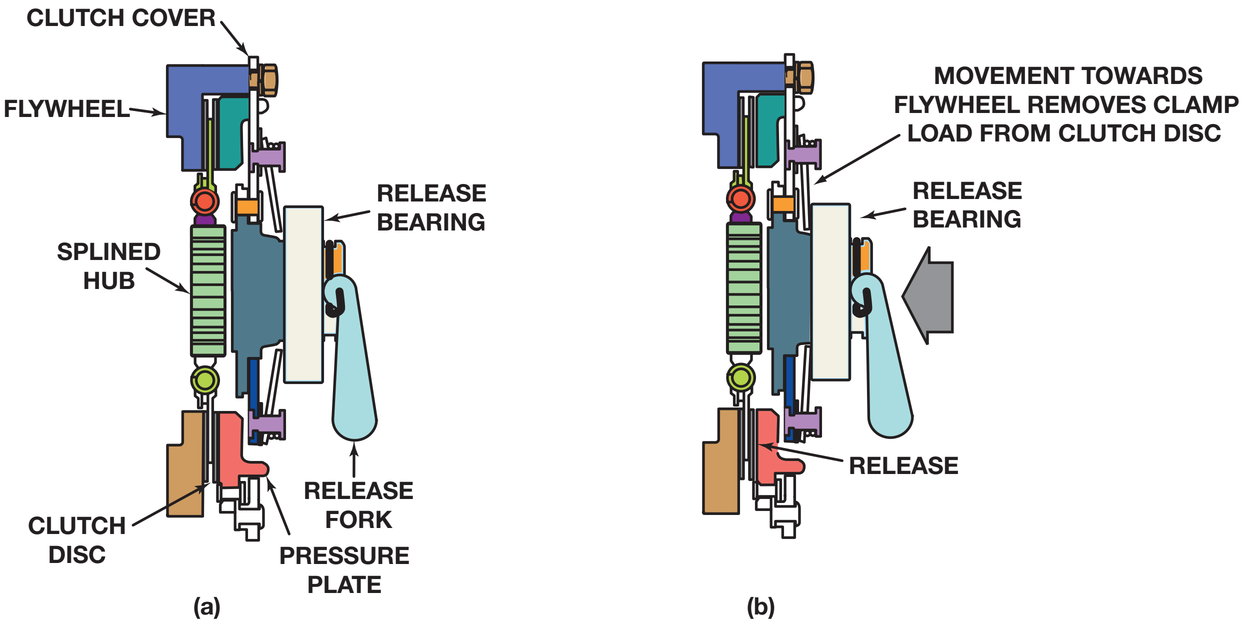


FIGURE 1–18 (a) A clutch cover (pressure plate assembly) is bolted onto the flywheel with the clutch disc between them. The release bearing and fork provide a method to release (disengage) the clutch. (b) When the clutch is engaged, the disc is squeezed against the flywheel by the pressure plate. Releasing the clutch separates the disc from the flywheel and pressure plate.

FIGURE 1–19 The gear selector is often called the "PRNDL," pronounced "prindle," regardless of the actual letters or numbers used.

- **Reverse.** The reverse gear selector position is used to move the vehicle in reverse. Reverse usually uses a gear ratio similar to first gear.
- **Neutral.** In the neutral position, no torque is being transmitted through the automatic transmission/transaxle. In this position the engine can be started by the driver.

CAUTION: The vehicle is free to roll when the gear selector is placed in the neutral position unless the brake pedal is depressed to prevent the vehicle from moving.

- **Overdrive (OD).** The OD is the normal position for the shift selector for most driving conditions. This position allows the transmission or transaxle to shift through all forward gears as needed for the best fuel economy and lowest exhaust emissions.

NOTE: The overdrive button used on many automatic transmissions is used to turn off overdrive and is used while towing or when driving in city traffic to prevent the transmission from shifting in and out of overdrive.

- **Drive (D).** The D position includes the overdrive ratios in most vehicles. If there is an overdrive shift mode, however, then D is used to provide all forward gears except overdrive. Use this position when driving on the highway.
- **Third (3).** In third position the transmission/transaxle will upshift normally to third gear, but will not upshift to a higher gear. When the third position is selected while driving in a higher gear, the transmission will downshift into third if the vehicle speed is low enough to prevent the engine from being overrevved. This gear selection is used for gentle grades at a moderate vehicle speed when engine braking is needed.
- **Second (2).** The second position is used for slowing the vehicle while descending long grades. In this gear selection, the vehicle speed is controlled and the engine speed is increased to provide engine braking. This gear selection is used for the gentle grades at a moderate vehicle speed.

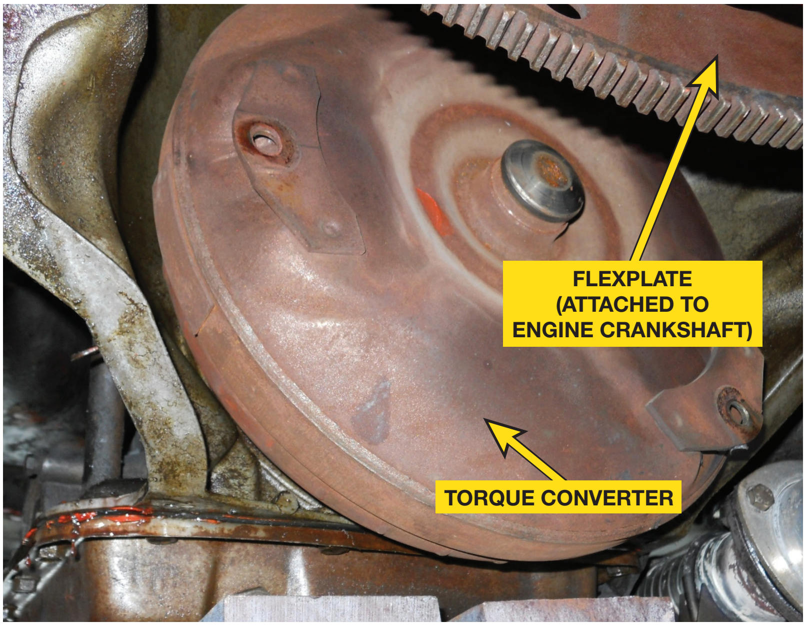


FIGURE 1–20 A torque converter is attached to the engine crankshaft and the other end is splined to the input shaft of the automatic transmission. The torque converter is used to transmit engine torque to the transmission, yet slip when the engine is at idle speed.

- **First (1 or Low).** The first (or low) position is used for slowing the vehicle while descending steep grades. In this gear selection, the vehicle speed is controlled and engine braking is used to slow the vehicle. This gear selection is used for the steepest grades at the lowest possible speed.

TORQUE CONVERTERS A **torque converter** replaces the manual transmission clutch. It is a type of fluid coupling that can release the power flow at slow engine speeds and also multiply the engine 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 exhaust emissions. ● **SEE FIGURE 1–20.**

PLANETARY GEAR SETS Most automatic transmissions use **planetary gear sets**, which are a combination of gears. When the gear set is assembled, the sun gear is in the center and meshed with the planet gears, which are located around it, somewhat like the planets in our solar system. The ring gear is meshed around the outside of the planet gears. The three main members of the planetary gear set include the following:

1. **Sun gear**—It is the gear in the center.
2. **Ring gear**—It is also called an *annulus gear* or *internal gear.*
3. **Planet carrier**—It holds the planet gears (also called *pinions*) in position. ● **SEE FIGURE 1–21.**

Each of these gears can have two possible actions: They can rotate or stand still.

The planet gears/pinions have the following three possible actions.

1. They can rotate on their shafts in a stationary carrier and act like idler gears.
2. They can rotate on their shafts in a rotating carrier; the planet gears are walking.
3. They can stand still on their shafts and rotate with the carrier.

Planetary gear sets are used and combined in a complex manner so that transmissions with seven or eight speeds forward plus reverse are possible. Shifts are made by engaging or releasing one or more internal clutches that drive a gear set member, or by engaging or releasing other clutches or bands that hold a gear set member stationary. An automatic transmission might have as many as seven of these power control units (clutches or bands). One-way clutches are also used that self-release and overrun when the next gear is engaged. The control units can operate without the interruption of the power flow.

PLANETARY GEAR SET OPERATION Planetary gear sets are so arranged that power enters through one of the members and leaves through one of the other members while

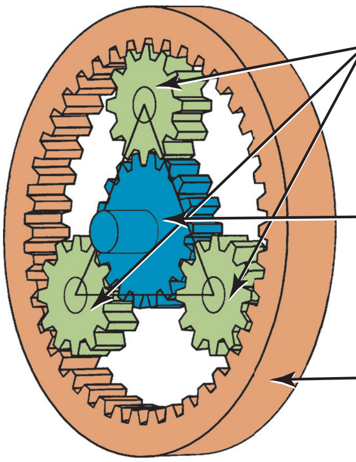


FIGURE 1–21 A typical planetary gear set showing the terms that are used to describe each member.

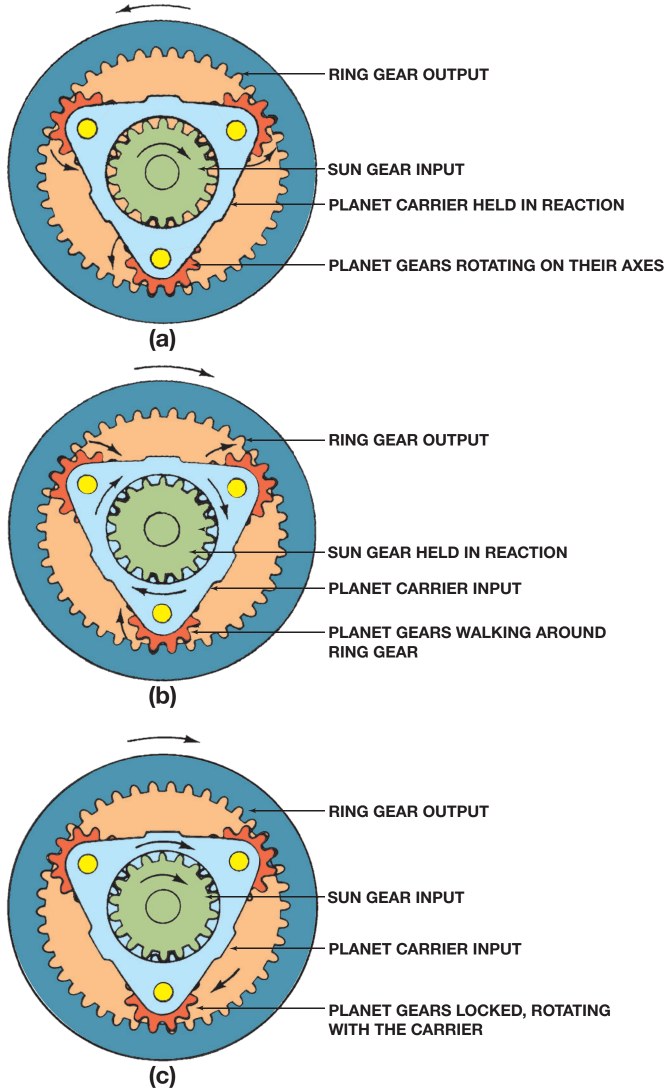


FIGURE 1–22 (a) If the planet carrier is held with the sun gear rotating, the planet gears simply rotate in the carrier and act as idler gears between the sun and ring gears. (b) If the sun or ring is held, the planet gears will walk around that stationary gear; they rotate on their shafts as the carrier rotates. (c) If two parts are driven and no parts are held, the planet gears are stationary on their shafts, and the whole assembly rotates as a unit.

the third member is held stationary in reaction. Power flow through a planetary gear set is controlled by clutches, bands, and one-way clutches. One or more clutches will control the power coming to a planetary member and one or more reaction members can hold a gear set member stationary. The third planetary member will be the output. ● **SEE FIGURE 1–22.**

PLANETARY GEAR SET RATIOS A simple planetary gear set can produce one of the following:

- A neutral if either the input clutch or reaction member is not applied
- Two reduction ratios
- Two overdrive ratios
- Two reverse ratios, one a reduction and one an overdrive
- The reduction, overdrive, and reverse ratios will require one driving member, one output member, and one reaction member in the gear set

NOTE: A 1:1, direct-drive ratio is achieved if two gear set members are driven.

ADVANTAGES OF PLANETARY GEAR SETS Planetary gear sets offer several advantages over conventional gear sets.

1. Because there is more than one gear transferring power, the torque load is spread over several gear teeth.
2. Also, any gear separation forces (as gears transfer power, they tend to push away from each other) are contained within the planetary gear set, preventing this load from being transmitted to the transmission case.
3. Another advantage is the small relative size of the planetary gear set. Conventional gears are normally side by side, and for a 2:1 gear ratio, one gear has to be twice the size of the other. A planetary gear set can easily produce this same ratio in a smaller package.
4. Also, planetary gear sets are in constant mesh and no coupling or uncoupling of the gears is required.

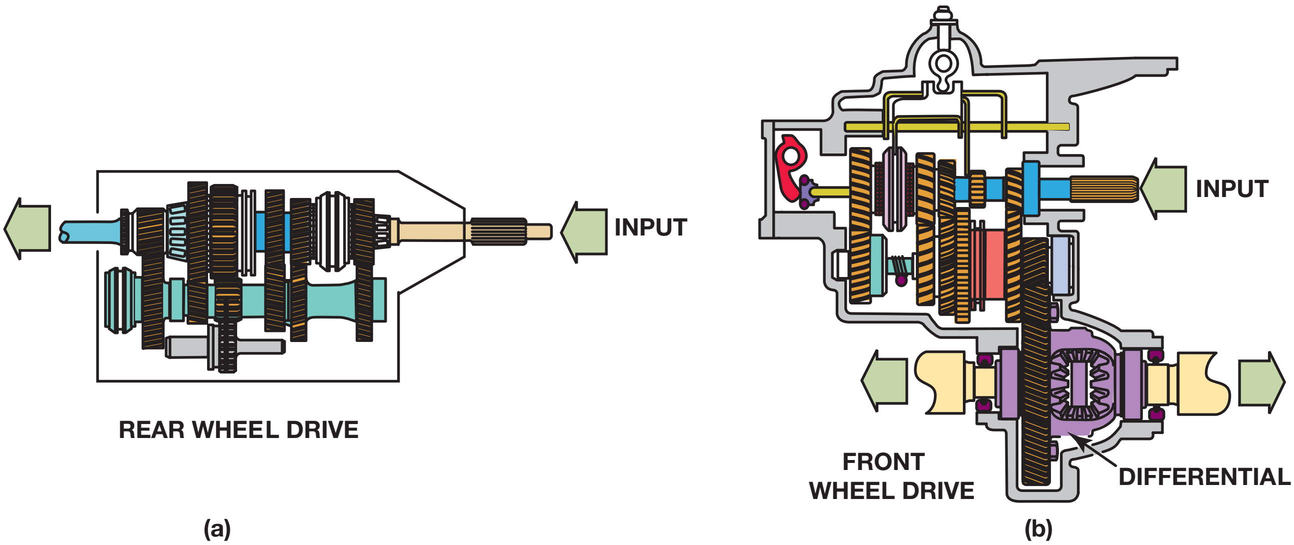


FIGURE 1–23 A RWD drivetrain uses a transmission to provide the necessary gear ratio and a single driveshaft to transfer power to the rear axle (a). A FWD drivetrain uses a transaxle that combines the transmission's final drive, and differential (b). A driveshaft is used for each front drive wheel.

? FREQUENTLY ASKED QUESTION

What Do All the Letters and Numbers Mean in Transmission Designations?

The numbers and letters usually mean the following:

- **Number of forward speeds.** The number of forward speeds may include four, five, or six such as the GM 4T60-E four-speed unit and the ZF 5HP24 five-speed unit.
- **Front-wheel drive or rear-wheel drive.** The letter **T** usually means *transverse* (front-wheel-drive transaxle) such as the Chrysler 41-TE; the **L** means *longitudinal* (rear-wheel-drive transmission) such as the General Motors 6L80; and the **R** means *rear-wheel drive* such as the Ford 5R55E.
- **Electronically controlled.** The letter **E** is often used to indicate that the unit is electronically controlled, and **M** or **H** is used to designate older mechanically (hydraulically) controlled units. Most automatic transmissions built since the early 1990s are electronically controlled and therefore the **E** is often included in the designation of newer designs of transmission or transaxles.
- **Torque rating.** The torque rating is usually designated by a number where the higher the number, the higher the amount of torque load the unit is designed to handle. In a GM 6L80-E, the torque rating is 80. Always check service information for the exact transmission designation for the vehicle being studied.

REAR-WHEEL DRIVE VS. FRONT-WHEEL DRIVE

At one time, most vehicles had the transmission mounted behind the engine and used a driveshaft to transfer power to the rear axle and driving wheels. This drivetrain is called **rear-wheel drive (RWD)**.

Many vehicles use a transaxle to drive the front wheels, called **front-wheel drive (FWD)**. Most FWD vehicles have the engine mounted in a transverse position, crosswise in the vehicle. Some are longitudinally mounted, in a lengthwise position as in RWD vehicles.

Two short driveshafts, called **half shafts**, are used to connect the transaxle to the front wheels. Driving only two wheels is adequate for most driving conditions. When the roads are slippery or driving off-road, driving all four wheels provides better vehicle control. ● **SEE FIGURE 1–23.**

TRANSAXLES

TERMINOLOGY A **transaxle** is a compact combination of a transmission, the **final drive** gear reduction, and the differential. It can be either a manual, automatic, or continuously variable transaxle. Transaxles are used in nearly all front-wheel-drive vehicles, some mid-engine vehicles, rear engine, and even a few rear-wheel-drive vehicles. ● **SEE FIGURE 1–24.**

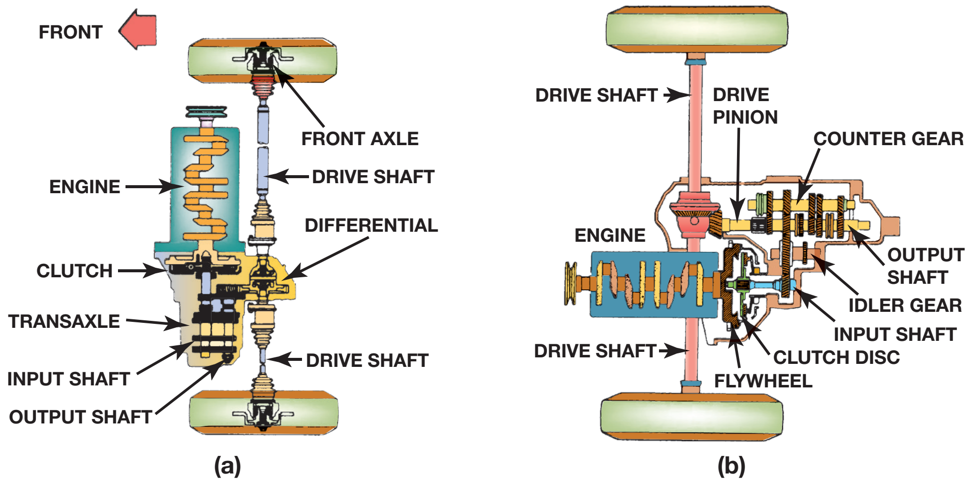


FIGURE 1–24 Transverse (a) and longitudinal (b) mounted front-wheel-drive (FWD) drivetrains.

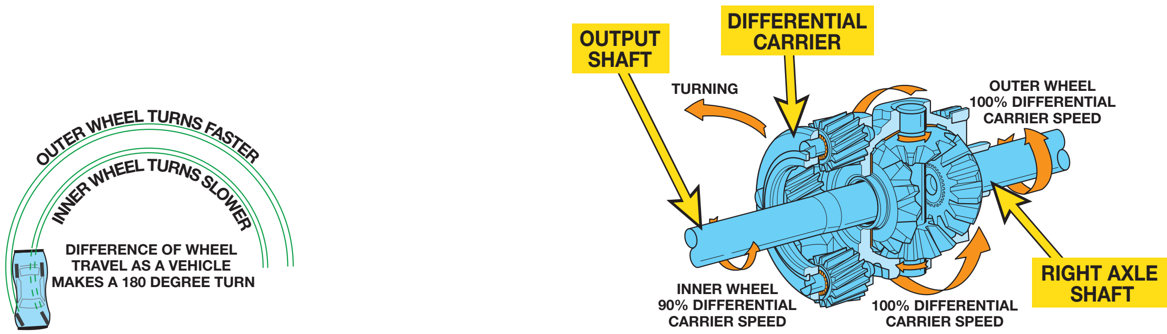


FIGURE 1–25 What happens when a vehicle makes a turn.

OPERATION A transmission normally has one output shaft that couples to the rear axle through the driveshaft. A transaxle has two output shafts that couple to the two front wheels through a pair of driveshafts. 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 rotate 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. ● **SEE FIGURE 1–25.**

or a **constant-velocity (CV) joint** at each end. Most front-wheel-drive vehicles use driveshafts that are a solid shaft or hollow steel tubing. A U-joint allows the shaft to change angle as the drive axle moves up and down 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 position of the U-joint at the other end of the driveshaft.

A front-wheel-drive vehicle driveshaft must use a CV joint at its ends because the front wheels must be steered at sharp angles. The short driveshafts used with transaxles and independent rear suspension drive axles are often called half shafts. ● **SEE FIGURE 1–26.**

DRIVESHAFTS

TERMINOLOGY **Driveshafts**, also called a *propeller shaft* or *prop shaft*, transfer power from one component to another. Rear-wheel-drive vehicle driveshafts are usually made from steel tubing, and normally have either a **universal joint (U-joint)**

DRIVE AXLE ASSEMBLIES

TERMINOLOGY Rear-wheel-drive vehicles use a drive axle assembly at the rear. A **drive axle** performs four functions:

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

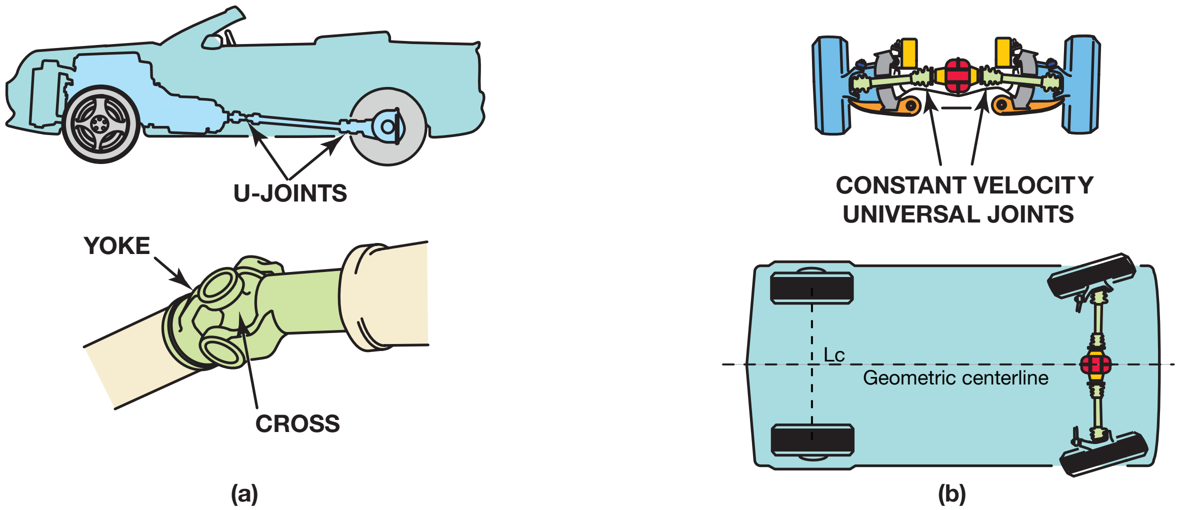


FIGURE 1–26 (a) A rear-wheel-drive (RWD) driveshaft uses a pair of universal joints to allow the rear axle to move up and down. (b) A front-wheel-drive (FWD) driveshaft uses a pair of constant-velocity joints to allow the front wheels to move up and down and steer.

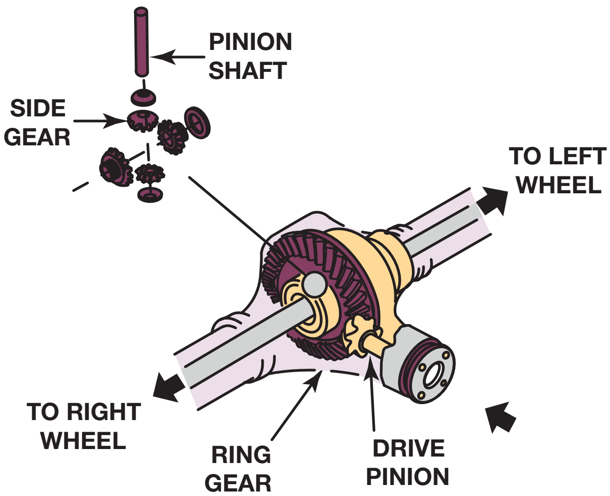


FIGURE 1–27 A drive axle includes a ring and pinion gear to produce a lower gear ratio. The drive axle also turns the power flow 90° and a differential (differential pinion and side gears) to allow the drive wheels to rotate at different speeds.

3. It contains the differential, which transfers torque to both drive wheels and allows the wheels to rotate at different speeds when cornering.

4. It allows the power to turn 90 degrees.

Most axle assemblies use strong axle shafts to transfer the torque from the differential gears to the wheels and tires. A bearing at the outer end of the axle housing serves to transfer vehicle weight to the axle and then to the wheels and tires while allowing the shaft to rotate.

The term final drive refers to the last set of reduction gears in a gear train. The torque that is applied to the drive wheels, and cruising speed engine RPM, is determined by the reduction gears and the drive wheel diameter. ● **SEE FIGURE 1–27.**

? FREQUENTLY ASKED QUESTION

What Must the Powertrain Overcome to Move the Vehicle?

To propel the vehicle, the engine and drivetrain must overcome the following:

- Rolling friction, which is the drag of the tires on the road, and bearing friction. These frictions increase at a constant rate, doubling as the speed is doubled.
- Aerodynamic drag, which 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, which is equal to 0.01 times the vehicle weight times the angle of the grade in percent.

TOWING CAPABILITY

DRIVETRAIN REQUIREMENTS Trucks are often used to tow trailers or heavy loads. In order for a vehicle to tow a heavy load, the vehicle must have the following features:

- An engine that can produce the needed torque and horsepower.
- A strong frame to withstand the forces involved.
- A strong trailer hitch properly installed and attached to the frame of the vehicle.

- A strong drivetrain (transmission, driveshaft, and drive axle(s)) that can transmit the engine torque to the drive wheels.
- Heavy-duty brakes so that the heavy load can be slowed and stopped safely.

SAE J2807 STANDARD Starting in 2013, the Society of Automotive Engineers (SAE) established a standardized test procedure to determine the tow rating for vehicles. The standard includes three vehicle performance standards including:

1. **Climbing test.** During the climbing test, the vehicle with the loaded trailer (at the specified rating that the vehicle manufacturer states is the capacity of the vehicle) has to climb a hill that rises 3,000 feet (900 m) over a length of 11.4 miles (18 km) without dropping below 40 MPH (64 km/h). This test is based on the Davis Dam grade, a stretch of road in Arizona southeast of Las Vegas.
2. **Acceleration test.** During this test, the vehicle with loaded trailer must accelerate from 0 to 30 MPH (48 km/h) in 12 seconds and less than 30 seconds to reach 60 MPH (100 km/h).
3. **Launching.** This test is used to test the vehicle and loaded trailer in both forward and reverse. The test places the vehicle at the base of a long hill with a 12% grade. The vehicle must be able to climb the grade 16 feet (5 m) from a stop five times within five minutes.

These tests not only test the power of the vehicle but also that the engine and transmission can be kept at the proper temperature, meaning that the engine and transmission (if automatic) be equipped with a cooler.

NOTE: Not all vehicle manufactures adhere to the SAE standard when reporting their recommended tow rating, because while standardized, the use of the SAE J2807 is voluntary.

FOUR-WHEEL DRIVE

TERMINOLOGY **Four-wheel drive (4WD)** is often designated as "4 × 4" and refers to a vehicle that has four driven wheels.

- The first 4 indicates that the vehicle has four wheels.
- The second 4 indicates that all four wheels are driven.

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 driveshaft and drive axle. The transfer case is normally attached to the rear of the transmission. It has a single input shaft from the transmission and two output shafts, one to the front drive axle and one to the rear drive axle. Some transfer cases are two-speed and include a set of reduction gears for lower-speed, higher-torque operation.

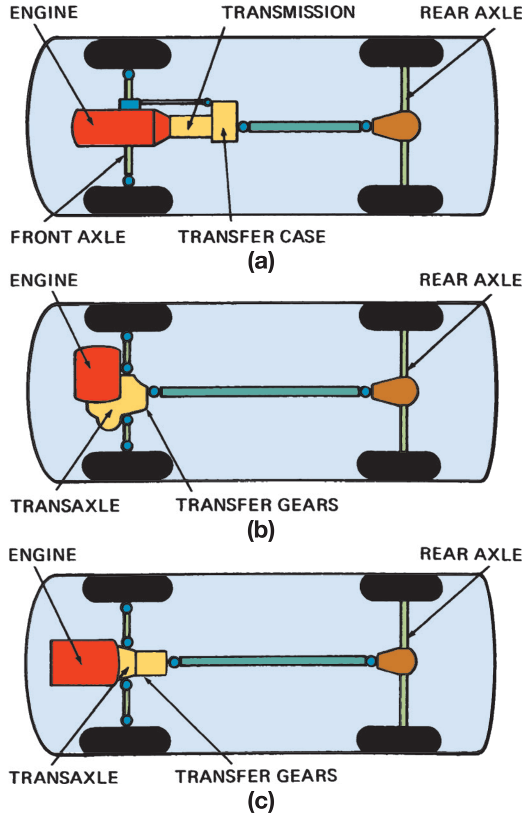


FIGURE 1–28 Three major 4WD configurations. The traditional form (a) uses a transfer case to split the torque for the front and rear drive axles. Both (b) and (c) are typical AWD configurations.

Four-wheel drive can be built into

- A front-engine rear-wheel drive
- A front-engine front-wheel drive
- A rear-engine rear-wheel drive

● **SEE FIGURE 1–28.**

ALL-WHEEL DRIVE **All-wheel-drive (AWD)**, also called full-time four-wheel drive, vehicles are four-wheel-drive vehicles equipped with a center (inner-axle) differential so they can be operated on pavement in four-wheel drive. Full-time four-wheel drive is another name for all-wheel drive. All-wheel-drive vehicles are designed for improved on-road handling. There will be one differential in each drive axle assembly plus a differential between the two drive axles. The inter-axle differential allows the front-to-rear wheel speed differential. Because all wheels are driven, these vehicles are excellent for use in rain and snow where added control is needed.

SUMMARY

1. Vehicles are built as rear-wheel drive, front-wheel drive, and four- or all-wheel drive.
2. Engines develop torque and the drivetrains modify that torque to move the vehicle.
3. A variety of gears are used to modify torque.
4. The gear ratio is determined by dividing the number of driven gear teeth by the number of teeth on the driving gear.
5. Transmissions have gear ratios that a driver can select.
6. Manual transmissions use a clutch and automatic transmissions use a torque converter.
7. Transaxles combine the final drive gears and differential with the transmission.
8. Driveshafts and the drive axle complete the drivetrain.
9. Four-wheel-drive and all-wheel-drive vehicles have a transfer case or transfer gears and a second drive axle.

REVIEW QUESTIONS

1. What is the difference between torque and horsepower?
2. How is a gear ratio calculated?
3. What are the common shift modes used in an automatic transmission?
4. What is an inter-axle differential?

CHAPTER QUIZ

1. Torque is ______.
   a. A twisting force
   b. The rate of doing work
   c. Results in motion
   d. The gear ratio
2. Gears can be used to ______________.
   a. Increase speed
   b. Increase torque
   c. Reverse direction
   d. All of the above
3. 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
4. Technician A says a helical gear is stronger than a spur gear. Technician B says a helical gear is noisier than a spur gear. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
5. Which type of gear may be found in a rear-wheel-drive axle?
   a. Hypoid
   b. Spiral Bevel
   c. Spur
   d. Helical
6. The transmission is in first gear, which has a 2.5:1 ratio, and the rear axle has a ratio of 2:1. What is the overall ratio?
   a. 2:1
   b. 2.5:1
   c. 4.5:1
   d. 5:1
7. The type of gear set used in most automatic transmissions is ______________.
   a. Spur gears
   b. Planetary gears
   c. Helical gears
   d. Any of the above
8. What shift mode should be used when descending a steep hill slowly?
   a. Drive (D)
   b. Second (2)
   c. Neutral (N)
   d. Low (L)
9. Full-time four-wheel-drive vehicles use ______________.
   a. Transfer case
   b. Spiral bevel drive axles
   c. Three differentials
   d. Both a and c
10. What is used to transfer engine torque to all four wheels?
    a. Four driveshafts
    b. A transfer case or power transfer unit
    c. Four differentials
    d. All of the above