PREFACE

PROFESSIONAL TECHNICIAN SERIES Part of Pearson Automotive's Professional Technician Series, the seventh edition of *Automotive Brake Systems* represents the future of automotive textbooks. The series is a full-color, media-integrated solution for today's students and instructors. The series includes textbooks that cover all 8 areas of ASE certification, plus additional titles covering common courses.

The series is also peer reviewed for technical accuracy.

NEW TO THIS SEVENTH EDITION As a result of comments and suggestions from reviewers and automotive instructors, the following changes have been made to the seventh edition:

- Over 40 new full-color photos and line drawings have been added to help bring the subject to life.
- All of the content throughout has been updated to meet the latest NATEF and ASE standards.
- The chapter on brake principles (Chapter 4) has been expanded and now includes the details on brake friction materials which are now in one location instead of being repeated in the drum and disc brake chapters.
- Qualifying a brake lathe information has been added to Chapter 15
- The three chapters on antilock brake systems (ABS) have been condensed and updated to two new chapters (Chapters 17 and 18) to make this topic more concise, which makes it easier to teach or learn this technical content.
- The chapter on regenerative brakes (Chapter 20) has been moved to the end of the book as suggested by automotive instructors.
- Many new review and chapter quiz questions were changed to match the new and updated content in each chapter.

Examples of what was changed and updated include:

1. The GM regular production code (RPO**)** information has been added to Chapter 3 (Braking System Components and Performance Standards)
2. Content related to ceramic brake pads and environmental concerns of copper in brake friction materials has been added to Chapter 4 (Brake Principles and Friction Materials).
3. Case studies have been updated to include the "three Cs" (complaint, cause, and correction).
4. The BCM control of the red brake warning light (RBWL) has been added to Chapter 6 (Hydraulic Valves and Switches).
5. Brake line corrosion reduction coating has been added to Chapter 7(Brake Fluid and Lines).
6. New disc brake photo sequence has been added to Chapter 13 (Disc Brake Diagnosis and Service)

ASE AND NATEF CORRELATED NATEF-certified programs need to demonstrate that they use course material that covers NATEF and ASE tasks. All Professional Technician textbooks have been correlated to the appropriate ASE and NATEF task lists. These correlations can be found in two locations:

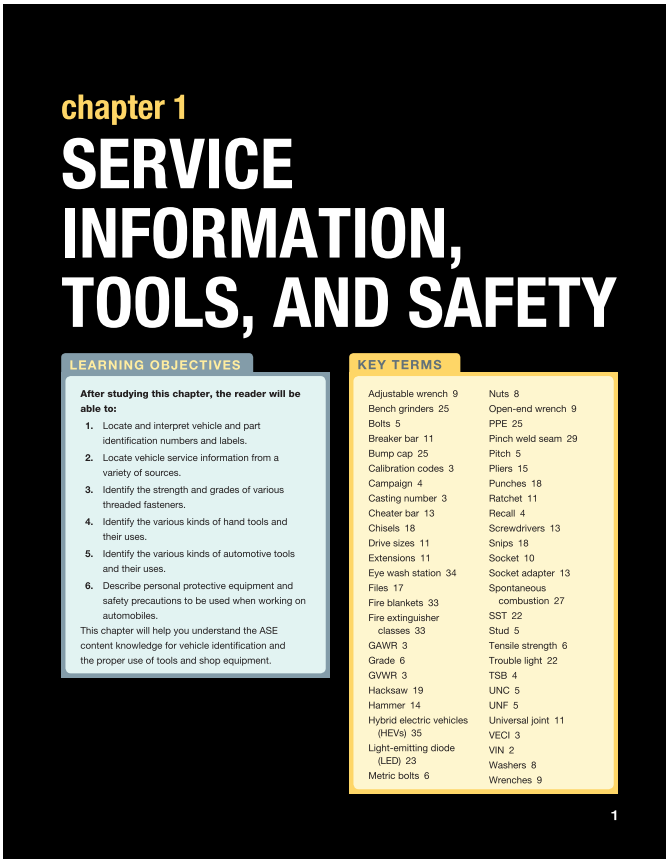
- As an appendix to each book
- At the beginning of each chapter in the Instructor's Manual

A COMPLETE INSTRUCTOR AND STUDENT SUPPLEMENTS PACKAGE All Professional Technician textbooks are accompanied by a full set of instructor and student supplements. Please see page vi for a detailed list of supplements.

A FOCUS ON DIAGNOSIS AND PROBLEM SOLVING The Professional Technician Series has been developed to satisfy the need for a greater emphasis on problem diagnosis. Automotive instructors and service managers agree that students and beginning technicians need more training in diagnostic procedures and skill development. To meet this need and demonstrate how real-world problems are solved, "Case Study" features are included throughout and highlight how real-life problems are diagnosed and repaired.

The following pages highlight the unique core features that set the Professional Technician Series book apart from other automotive textbooks.

IN-TEXT FEATURES



chapter 1

SERVICE INFORMATION, TOOLS, AND SAFETY

LEARNING OBJECTIVES

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

1. Locate and interpret vehicle and part identification numbers and labels.
2. Locate vehicle service information from a variety of sources.
3. Identify the strength and grades of various threaded fasteners.
4. Identify the various kinds of hand tools and their uses.
5. Identify the various kinds of automotive tools and their uses.
6. Describe personal protective equipment and safety precautions to be used when working on automobiles.

This chapter will help you understand the ASE content knowledge for vehicle identification and the proper use of tools and shop equipment.

KEY TERMS

Adjustable wrench 9
Bench grinders 25
Bolts 5
Breaker bar 11
Bump cap 25
Calibration codes 3
Campaign 4
Casting number 3
Cheater bar 13
Chisels 18
Drive sizes 11
Extensions 11
Eye wash station 34
Files 17
Fire blankets 33
Fire extinguisher classes 33
GAWR 3
Grade 6
GVWR 3
Hacksaw 19
Hammer 14
Hybrid electric vehicles (HEVs) 35
Light-emitting diode (LED) 23
Metric bolts 6
Nuts 8
Open-end wrench 9
PPE 25
Pinch weld seam 29
Pitch 5
Pliers 15
Punches 18
Ratchet 11
Recall 4
Screwdrivers 13
Snips 18
Socket 10
Socket adapter 13
Spontaneous combustion 27
SST 22
Stud 5
Tensile strength 6
Trouble light 22
TSB 4
UNC 5
UNF 5
Universal joint 11
VECI 3
VIN 2
Washers 8
Wrenches 9

1

LEARNING OBJECTIVES AND KEY TERMS appear at the beginning of each chapter to help students and instructors focus on the most important material in each chapter. The chapter objectives are based on specific ASE and NATEF tasks.

TECH TIP

It Just Takes a Second

Whenever removing any automotive component, it is wise to screw the bolts back into the holes a couple of threads by hand. This ensures that the right bolt will be used in its original location when the component or part is put back on the vehicle.

TECH TIPS feature real-world advice and "tricks of the trade" from ASE-certified master technicians.

SAFETY TIP

Shop Cloth Disposal

Always dispose of oily shop cloths in an enclosed container to prevent a fire. ● **SEE FIGURE 1-69.** Whenever oily cloths are thrown together on the floor or workbench, a chemical reaction can occur, which can ignite the cloth even without an open flame. This process of ignition without an open flame is called spontaneous combustion.

SAFETY TIPS alert students to possible hazards on the job and how to avoid them.

CASE STUDY

The Sinking Brake Pedal

This author has experienced what happens when brake fluid is not changed regularly. Just as many technicians will tell you, we do not always do what we know should be done to our own vehicles. While driving a four-year-old vehicle on vacation in very hot weather in a mountainous country, the brake pedal sank to the floor. When the vehicle was cold, the brakes were fine. But after several brake applications, the pedal became soft and spongy and sank slowly to the floor if pressure was maintained on the brake pedal. Because the brakes were okay when cold, I knew it had to be boiling brake fluid. Old brake fluid (four years old) often has a boiling point under 300°F (150°C). With the air temperature near 100°F (38°C), it does not take much more heat to start boiling the brake fluid. After bleeding over a quart (1 liter) of new brake fluid through the system, the brakes worked normally. I'll never again forget to replace the brake fluid as recommended by the vehicle manufacturer.

Summary:

- **Complaint**—Brake pedal would sink to the floor when driving in mountainous country.
- **Cause**—The brake fluid was boiling causing the loss of brakes.

Correction—The brake fluid was replaced and the system bled.

CASE STUDIES present students with actual automotive scenarios and show how these common (and sometimes uncommon) problems were diagnosed and repaired. Summary includes new elements called the "three Cs."

FREQUENTLY ASKED QUESTION

How Many Types of Screw Heads Are Used in Automotive Applications?

There are many, including Torx, hex (also called Allen), plus many others used in custom vans and motor homes. ● **SEE FIGURE 1-9**.

FREQUENTLY ASKED QUESTIONS are based on the author's own experience and provide answers to many of the most common questions asked by students and beginning service technicians.

NOTE: Most of these "locking nuts" are grouped together and are commonly referred to as *prevailing torque nuts*. This means that the nut will hold its tightness or torque and not loosen with movement or vibration.

NOTES provide students with additional technical information to give them a greater understanding of a specific task or procedure.

CAUTION: Never use hardware store (nongraded) bolts, studs, or nuts on any vehicle steering, suspension, or brake component. Always use the exact size and grade of hardware that is specified and used by the vehicle manufacturer.

CAUTIONS alert students about potential damage to the vehicle that can occur during a specific task or service procedure.

WARNING

Do not use incandescent trouble lights around gasoline or other flammable liquids. The liquids can cause the bulb to break and the hot filament can ignite the flammable liquid which can cause personal injury or even death.

WARNINGS alert students to potential dangers to themselves during a specific task or service procedure.

SUMMARY

1. Bolts, studs, and nuts are commonly used as fasteners in the chassis. The sizes for fractional and metric threads are different and are not interchangeable. The grade is the rating of the strength of a fastener.
2. Whenever a vehicle is raised above the ground, it must be supported at a substantial section of the body or frame.
3. Wrenches are available as open end, box end, and combination open and box end.
4. An adjustable wrench should only be used where the proper size is not available.
5. Line wrenches are also called flare-nut wrenches, fitting wrenches, or tube-nut wrenches and are used to remove fuel or refrigerant lines.
6. Sockets are rotated by a ratchet or breaker bar, also called a flex handle.
7. Torque wrenches measure the amount of torque applied to a fastener.
8. Screwdriver types include straight blade (flat tip), Phillips, and Torx.
9. Hammers and mallets come in a variety of sizes and weights.
10. Pliers are a useful tool and are available in many different types, including slip-joint, multigroove, linesman's, diagonal, needle-nose, and locking pliers.
11. Other common hand tools include snap-ring pliers, files, cutters, punches, chisels, and hacksaws.
12. Hybrid electric vehicles should be de-powered if any of the high-voltage components are going to be serviced.

REVIEW QUESTIONS

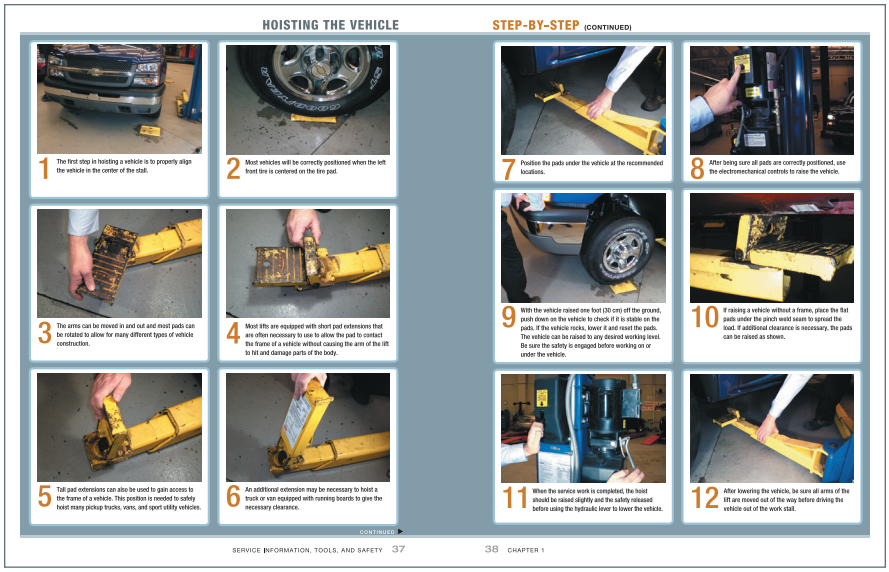
1. List three precautions that must be taken whenever hoisting (lifting) a vehicle.
2. Describe how to determine the grade of a fastener, including how the markings differ between fractional and metric bolts.
3. List four items that are personal protective equipment (PPE).
4. List the types of fire extinguishers and their use.
5. Why are wrenches offset 15 degrees?
6. What are the other names for a line wrench?
7. What are the standard automotive drive sizes for sockets?
8. Which type of screwdriver requires the use of a hammer or mallet?
9. What is inside a dead-blow hammer?
10. What type of cutter is available in left and right cutters?

CHAPTER QUIZ

1. The correct location for the pads when hoisting or jacking the vehicle can often be found in the _____.
   a. Service manual c. Owner's manual
   b. Shop manual d. All of the above
2. For the best working position, the work should be _____.
   a. At neck or head level
   b. At knee or ankle level
   c. Overhead by about 1 foot
   d. At chest or elbow level
3. A high-strength bolt is identified by _____.
   a. A UNC symbol c. Strength letter codes
   b. Lines on the head d. The coarse threads
4. A fastener that uses threads on both ends is called a _____.
   a. Cap screw c. Machine screw
   b. Stud d. Crest fastener
5. When working with hand tools, always _____.
   a. Push the wrench–don't pull it toward you
   b. Pull a wrench–don't push it away from you
6. The proper term for Channel Locks is _____.
   a. Vise-Grip c. Locking pliers
   b. Crescent wrench d. Multigroove adjustable pliers
7. The proper term for Vise-Grip is _____.
   a. Locking pliers c. Side cuts
   b. Slip-joint pliers d. Multigroove adjustable pliers
8. Two technicians are discussing torque wrenches. Technician A says that a torque wrench is capable of tightening a fastener with more torque than a conventional breaker bar or ratchet. Technician B says that a torque wrench should be calibrated regularly for the most accurate results. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. What type of screwdriver should be used if there is very limited space above the head of the fastener?
   a. Offset screwdriver c. Impact screwdriver
   b. Standard screwdriver d. Robertson screwdriver
10. What type of hammer is plastic coated, has a metal casing inside, and is filled with small lead balls?
   a. Dead-blow hammer
   b. Soft-blow hammer
   c. Sledge hammer
   d. Plastic hammer

SERVICE INFORMATION, TOOLS, AND SAFETY 39

THE SUMMARY, REVIEW QUESTIONS, AND CHAPTER QUIZ at the end of each chapter help students review the material presented in the chapter and test themselves to see how much they've learned.



STEP-BY-STEP photo sequences show in detail the steps involved in performing a specific task or service procedure.

SUPPLEMENTS

RESOURCES IN PRINT AND ONLINE

Automotive Brake Systems

Name of Supplement	*Print*	*Online*	*Audience*	*Description*
Instructor Resource Manual 0134072383		✔	Instructors	NEW! The Ultimate teaching aid: Chapter summaries, key terms, chapter learning objectives, lecture resources, discuss/demonstrate classroom activities, MyAutomotiveLab correlation, and answers to the in-text review and quiz questions.
TestGen 0134071298		✔	Instructors	Test generation software and test bank for the text.
PowerPoint Presentation 0134072561		✔	Instructors	Slides include chapter learning objectives, lecture outline of the text, and graphics from the book.
Image Bank 0134072529		✔	Instructors	All of the images and graphs from the textbook to create customized lecture slides.
NATEF Correlated Task Sheets - for Instructors 0134072847		✔	Instructors	Downloadable NATEF task sheets for easy customization and development of unique task sheets.
NATEF Correlated Task Sheets—for Students 0134072421	✔		Students	Study activity manual that correlates NATEF Automobile Standards to chapters and pages numbers in the text. Available to students at a discounted price when packaged with the text.

All online resources can be downloaded from the Instructor's Resource Center: **www.pearsonhighered.com/irc**

chapter 4

BRAKE PRINCIPLES AND FRICTION MATERIALS

LEARNING OBJECTIVES

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

1. Discuss the energy principles that apply to brakes.
2. Discuss the friction principles that apply to brakes.
3. Describe how brakes can fade due to excessive heat.
4. Describe how deceleration rate is measured.
5. Discuss the mechanical principles that apply to brakes.

KEY TERMS

Asbestos 68
Brake fade 66
Ceramic 69
Coefficient of friction 65
Copper 70
Edge codes 71
Energy 63
Kinetic energy 63
Leaf mark 71
Lining fade 66
Mechanical fade 66
Mu (μ) 65
Non-asbestos 69
Non-asbestos organic (NAO) 69
Non-asbestos synthetic (NAS) 69
Semimetallic 69
Weight bias 64
Work 63

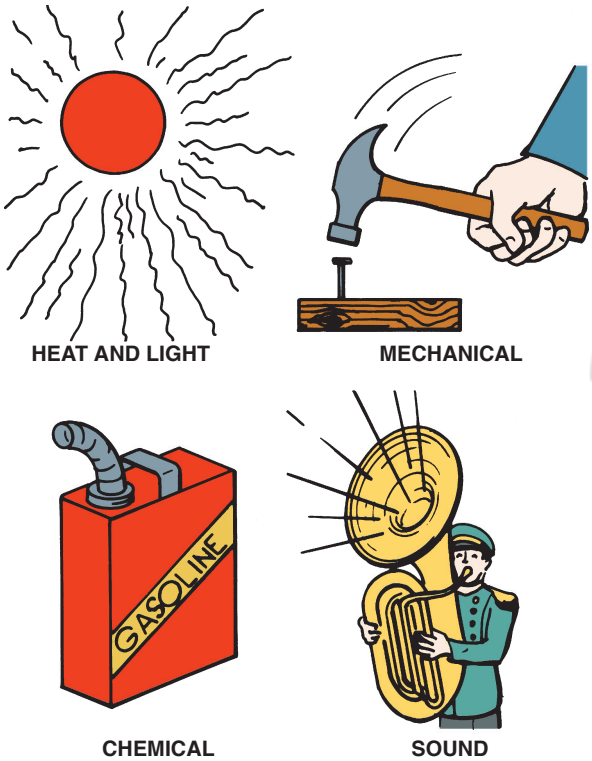


FIGURE 4–1 Energy, which is the ability to perform work, exists in many forms.

ENERGY AND WORK

ENERGY **Energy** is the ability to do work. There are many forms of energy, but chemical, mechanical, and electrical energy are the most familiar kinds involved in the operation of an automobile. ● **SEE FIGURE 4–1.**

WORK **Work** is the transfer of energy from one physical system to another—especially the transfer of energy to an object through the application of force. This is precisely what occurs when a vehicle's brakes are applied: The force of the actuating system transfers the energy of the vehicle's motion to the brake drums or rotors where friction converts it into heat energy and stops the vehicle.

KINETIC ENERGY Kinetic energy is a fundamental form of mechanical energy. It is the energy of mass in motion. Every moving object possesses kinetic energy, and the amount of that energy is determined by the object's mass and speed. The greater the mass of an object and the faster it moves, the more kinetic energy it possesses. Even at low speeds, a moving vehicle has enough kinetic energy to cause serious injury and damage. The purpose and function of the brake system is to dispose of that energy in a safe and controlled manner. Engineers calculate kinetic energy using the following formula:

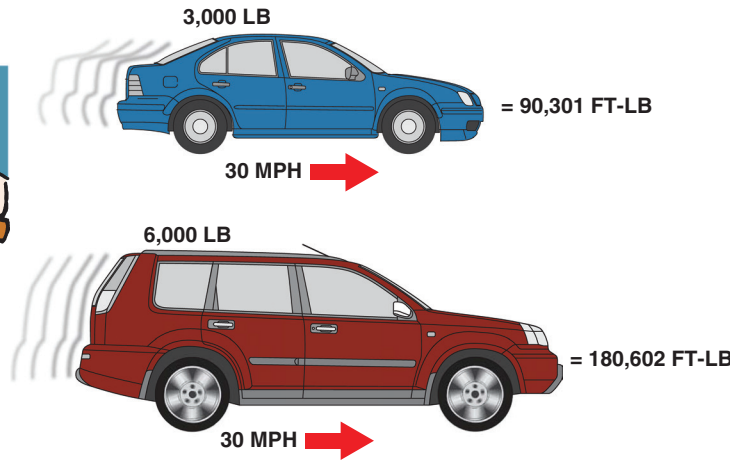


FIGURE 4–2 Kinetic energy increases in direct proportion to the weight of the vehicle.

TECH TIP

Brakes Stop Wheels, Not the Vehicle

Brakes are used to slow and stop the rotation of the wheels. The tires are attached to the wheels and the friction between the tire tread and the pavement is what actually stops the vehicle. If the vehicle is on a slippery surface such as gravel or snow, the wheels may be stopped by the brakes but the vehicle can continue without slowing if there is a lack of traction between the tires and the ground.

$$\frac{mv^2}{29.9} = E_k$$

where:

m = mass or weight of the vehicle in pounds (lb)

v = velocity of the vehicle in miles per hour

E_k = kinetic energy in foot-pounds (ft-lb)

Another way to express this equation is as follows:

$$\frac{\text{weight} \times \text{speed}^2}{29.9} = \text{kinetic energy}$$

KINETIC ENERGY EXAMPLE #1 A 3,000-lb vehicle traveling at 30 mph is compared with a 6,000-lb vehicle also traveling at 30 mph. ● **SEE FIGURE 4–2.**

The equations for computing their respective kinetic energies look like this:

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90{,}301 \text{ ft-lb}$$

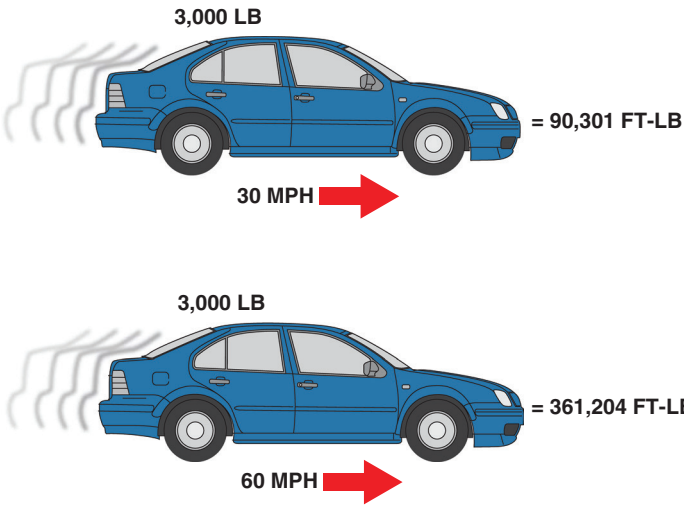


FIGURE 4–3 Kinetic energy increases as the square of any increase in vehicle speed.

$$\frac{6{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 180{,}602 \text{ ft-lb}$$

The results show that:

- When the weight of a vehicle is doubled from 3,000 to 6,000 lb, its kinetic energy is also doubled from 90,301 to 180,602 ft-lb.
- In mathematical terms, kinetic energy increases *proportionally* as weight increases. In other words, if the weight of a moving object doubles, its kinetic energy also doubles.
- If the weight quadruples, the kinetic energy becomes four times as great.

KINETIC ENERGY EXAMPLE #2 A 3,000-lb vehicle traveling at 30 mph is compared with the same vehicle traveling at 60 mph. ● **SEE FIGURE 4–3.**

$$\frac{3{,}000 \text{ lb} \times 30^2 \text{ mph}}{29.9} = 90{,}301 \text{ ft-lb}$$

$$\frac{3{,}000 \text{ lb} \times 60^2 \text{ mph}}{29.9} = 361{,}204 \text{ ft-lb}$$

The results show that the vehicle traveling at 30 mph has over 90,000 ft-lb of kinetic energy, but at 60 mph the figure increases to over 350,000 ft-lb.

- At twice the speed, the vehicle has exactly four times as much kinetic energy.
- If the speed were doubled again to 120 mph, the amount of kinetic energy would grow to almost 1,500,000 ft-lb! In mathematical terms, kinetic energy increases as the *square of its speed*.
- In other words, if the speed of a moving object doubles (2), the kinetic energy becomes four times as great ($2^2 = 4$).

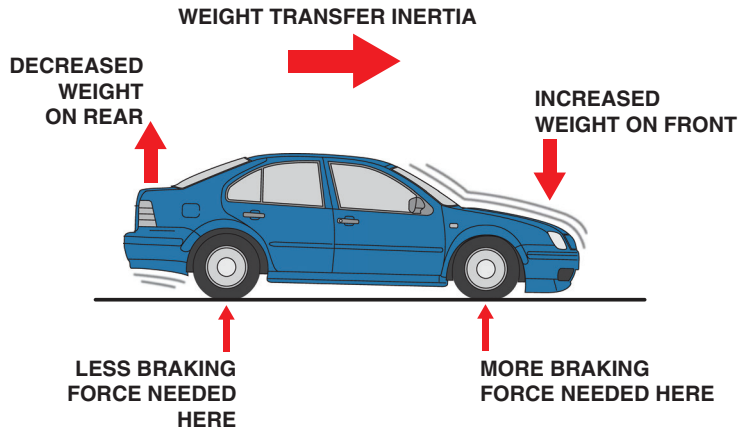


FIGURE 4–4 Inertia creates weight transfer that requires the front brakes to provide most of the braking force.

And if the speed quadruples (4), say from 15 to 60 mph, the kinetic energy becomes 16 times as great ($4^2 = 16$). This is the reason speed has such an impact on kinetic energy.

INERTIA

DEFINITION Inertia is defined by Isaac Newton's first law of motion, which states that a body at rest tends to remain at rest, and a body in motion tends to remain in motion in a straight line unless acted upon by an outside force.

WEIGHT TRANSFER Inertia, in the form of weight transfer, plays a major part in braking performance. Newton's first law of motion states, if applied to a vehicle:

> A moving vehicle will remain in motion unless acted upon by an outside force.

The sequence that occurs when the brakes are applied includes:

- The vehicle brakes provide that outside force, but when the brakes are applied at the wheel friction assemblies, only the wheels and tires begin to slow immediately.
- The rest of the vehicle, all of the weight carried by the suspension, attempts to remain in forward motion.
- The result is that the front suspension compresses, the rear suspension extends, and the weight is transferred toward the front of the vehicle. ● **SEE FIGURE 4–4.**

WEIGHT BIAS The total weight of the vehicle does not change during a brake application, only the amount supported by each axle. To compound the problem of weight transfer, most vehicles also have a forward **weight bias**, which means

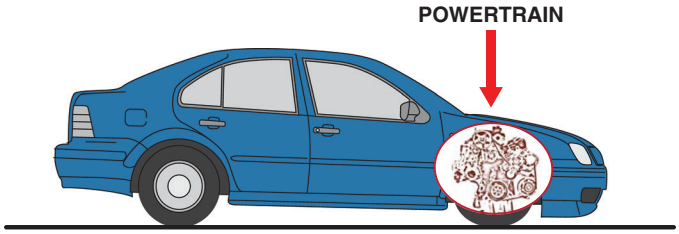


FIGURE 4–5 Front-wheel-drive vehicles have most of their weight over the front wheels.

that even when stopped, more than 50% of their weight is supported by the front wheels. This occurs because the engine, transmission, and most other heavy parts are located toward the front of the vehicle. ● **SEE FIGURE 4–5.**

Front-wheel-drive (FWD) vehicles, in particular, have a forward weight bias. Whenever the brakes are applied, weight transfer and weight bias greatly increase the load on the front wheels, while the load on the rear wheels is reduced. This requires the front brakes to provide 60% to 80% of the total braking force. To deal with the extra load, the front brakes are much more powerful than the rear brakes.

COEFFICIENT OF FRICTION

DEFINITION The amount of friction between two objects or surfaces is commonly expressed as a value called the **coefficient of friction** and is represented by the Greek letter **mu (μ)**, pronounced "mYOO." The coefficient of friction, also referred to as the *friction coefficient*, is determined by dividing tensile force by weight force. The tensile force is the pulling force required to slide one of the surfaces across the other. The weight force is the force pushing down on the object being pulled. The complete friction assembly (including lining and backing) is often called a *brake pad* or *brake shoe*. The friction coefficient (μ) for most standard brake pads is usually in the range of 0.25 to 0.55.

STATIC AND KINETIC FRICTION There are actually two measurements of the coefficient of friction: the static friction coefficient and the kinetic friction coefficient. The static value is the coefficient of friction with the two friction surfaces at rest. The kinetic value is the coefficient of friction while the two surfaces are sliding against one another. The coefficient of static friction is always higher than that of kinetic friction, which explains why it is harder to *start* an object moving than to *keep* it moving. ● **SEE FIGURE 4–6.**

It takes 100 lb of tensile force to start the wooden block sliding, but once in motion, it takes only 50 lb to keep it sliding. The relatively high static friction is harder to overcome than the

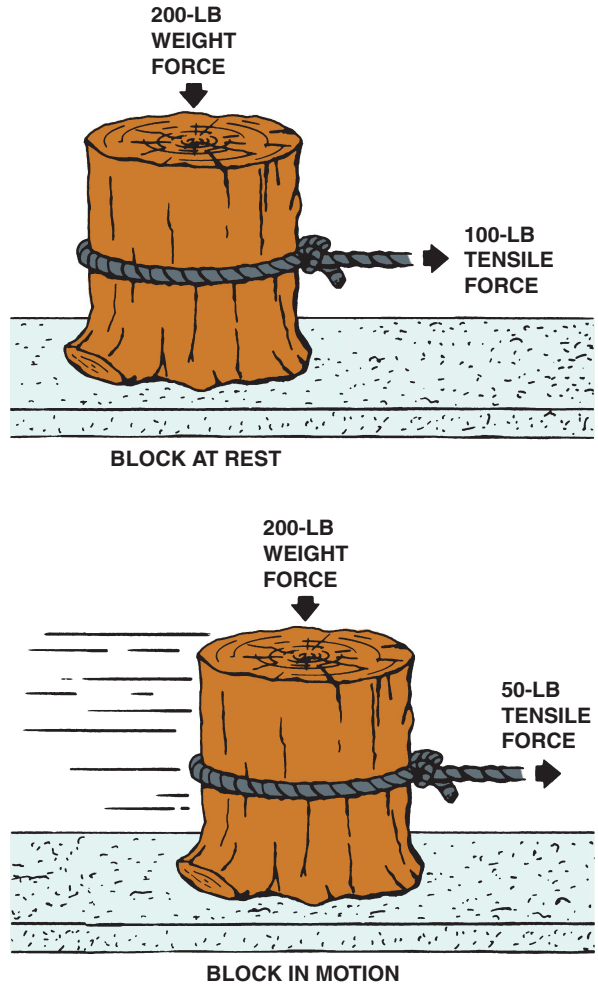


FIGURE 4–6 The static coefficient of friction of an object at rest is higher than the kinetic (dynamic) friction coefficient once in motion.

CONTACTING SURFACES	STATIC COEFFICIENT OF FRICTION	KINETIC COEFFICIENT OF FRICTION
STEEL ON STEEL (DRY)	0.6	0.4
STEEL ON STEEL (GREASY)	0.1	0.05
TEFLON ON STEEL	0.04	0.04
BRASS ON STEEL (DRY)	0.5	0.4
BRAKE LINING ON CAST IRON	0.4	0.3
RUBBER TIRES ON SMOOTH PAVEMENT (DRY)	0.9	0.8

CHART 4–1

Every combination of materials has different static and kinetic friction coefficients.

somewhat lower kinetic friction. The static and kinetic friction coefficients for several combinations of materials are shown in ● **CHART 4–1.**

The difference between static and kinetic friction explains why parking brakes, although much less powerful than service

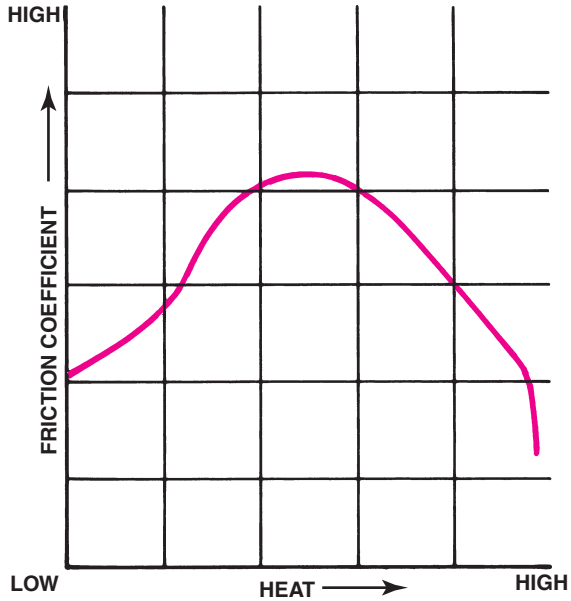


FIGURE 4–7 Some heat increases the coefficient of friction but too much heat can cause it to drop off sharply.

brakes, are still able to hold a vehicle in position on a hill. The job of the parking brakes is relatively easy because:

- The stationary vehicle has no kinetic energy.
- The brake lining and drum or discs are not moving when they are applied.
- To start the vehicle moving, enough force would have to be applied to overcome the relatively high static friction of the parking brakes.

The service brakes, however, have a much more difficult job. The moving vehicle has a great deal of kinetic energy, and the fact that the brake friction surfaces are in relative motion means that kinetic friction makes them less efficient.

BRAKE FADE

DEFINITION If repeated hard stops are performed, the brake system components can overheat and lose effectiveness or possibly fail altogether. This loss of braking power is called **brake fade**.

MECHANICAL FADE **Mechanical fade** occurs when a brake drum overheats and expands away from the brake lining. To maintain braking power, the brake shoes must move farther outward, which requires additional brake pedal travel. When the drum expands to a point where there is not enough pedal travel to keep the lining in contact with the drum, brake fade occurs. Mechanical fade is not a problem with disc brakes because as a brake rotor heats up it expands toward the brake pads rather than away from them.

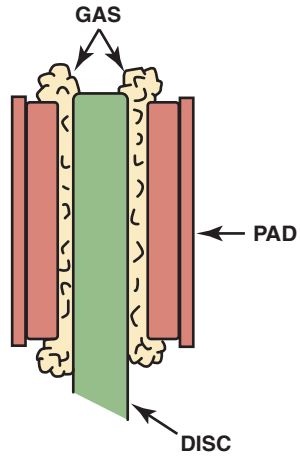


FIGURE 4–8 One cause of brake fade occurs when the phenolic resin, a part of the friction material, gets so hot that it vaporizes. The vaporized gas from the disc brake pads gets between the rotor (disc) and the friction pad. Because the friction pad is no longer in contact with the rotor, no additional braking force is possible.

LINING FADE **Lining fade** affects both drum and disc brakes and occurs when the friction material overheats to the point where its coefficient of friction drops off. ● **SEE FIGURE 4–7.**

When lining fade occurs on drum brakes, partial braking power can sometimes be restored by increasing pressure on the brake pedal, although this may only make matters worse since the extra pressure increases the amount of heat and fade. With disc brakes, lining fade is possible, but is less of a problem because of disc brakes' superior ability to dissipate heat. The rotor friction surfaces are exposed to the passing air, and most rotors have internal ventilation passages that further aid in cooling.

GAS FADE Gas fade is a relatively rare type of brake fade that occurs under very hard braking when a thin layer of hot gases and dust particles builds up between the brake drum or rotor and linings. The gas layer acts as a lubricant and reduces friction. ● **SEE FIGURE 4–8.**

- As with lining fade, greater application force at the brake pedal is required to maintain a constant level of stopping power.
- Gas fade becomes more of a problem as the size of the brake lining increases because gases and particles have a harder time escaping from under a drum brake shoe than a disc brake pad.
- Some high performance brake shoes and pads have slotted linings to provide paths for gas and particles to escape.

FIGURE 4–9 The gear selector is often called the "PRNDL," pronounced "prindle," regardless of the actual letters or numbers used.

In most cases, brake fade is a temporary condition and the brakes will return to normal once they have all been allowed to cool.

WATER FADE If a vehicle is driven through deep water or during a severe rainstorm, water can get between the brake drum and the linings. When this occurs, no stopping power is possible until the water is pushed out and normal friction is restored. While water fade is most likely to occur with drum brakes, it can also occur on disc brakes. After driving through deep water, the wise driver should lightly apply the brakes to check the operation and to help remove any water trapped between the friction material and the rotor or drum.

DECELERATION RATES

TERMINOLOGY Deceleration rates are measured in units of "feet per second per second" (No, this is not a misprint). What it means is that the vehicle will change in velocity during a certain time interval divided by the time interval. Deceleration is abbreviated "ft/sec^2" (pronounced "feet per second per second" or "feet per second squared") or meters per sec^2 (m/sec^2) in the metric system.

TYPICAL DECELERATION RATES Typical deceleration rates include the following:

- Comfortable deceleration is about 8.5 ft/sec^2 (3 m/sec^2).
- Loose items in the vehicle will "fly" above 11 ft/sec^2 (3.5 m/sec^2).

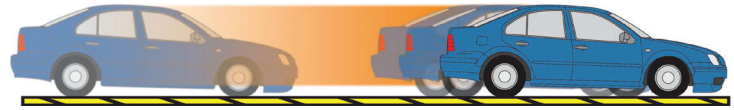


FIGURE 4–10 Rapid braking causes the brake friction material to wear more compared to gentle less aggressive braking.

TECH TIP

How to Reduce Possible Brake Fade

To help prevent possible brake fade while descending long hills, place the gear selector into a lower drive range such as "2" or even "1" if going slowly enough. This action allows for additional engine braking and takes the load off of the wheel brakes. ● **SEE FIGURE 4–9.**

- Maximum deceleration rates for most vehicles and light trucks range from 16 to 32 ft/sec^2 (5 to 10 m/sec^2).

An average deceleration rate of 15 ft/sec^2 (3 m/sec^2) can stop a vehicle traveling at 55 mph (88 km/h) in about 200 ft (61 m) in less than 4 seconds. ● **SEE FIGURE 4–10.**

BRAKE TEMPERATURE Temperatures at the front brake pads can reach:

- 1,300°F (700°C) or higher during normal driving
- as high as 1,800°F (980°C) during braking from a high speed or during long descents

Brake fluid and rubber components may reach 300°F (150°C) or higher.

BRAKE FRICTION MATERIALS

PURPOSE AND FUNCTION Brake friction materials are composed of relatively soft but tough and heat-resistant material to provide the friction between the moveable part of the braking system (drum or rotor) and the stationary part of the braking system. The brake friction material has to provide the friction needed to slow and stop the vehicle quietly and still provide a long service life.

BRAKE LINING COMPOSITION Brake shoes and pads operate under the most extreme conditions in the entire brake system and are subject to wear. Friction materials such as

disc brake pads or drum brake shoes contain a mixture of ingredients. These materials include a binder such as:

- thermosetting resin
- fibers (for reinforcement)
- friction modifiers (to obtain a desired coefficient of friction)

BRAKE BLOCKS The various ingredients in brake lining are mixed and molded into the shape of the finished product. The fibers in the material are the only thing holding this mixture together. A large press is used to force the ingredients together to form a brake block, which eventually becomes the brake lining/pads.

ASBESTOS

DEFINITION **Asbestos** is the term used to describe naturally occurring silicate minerals that consist of long fibers. Asbestos mining began more than 4,000 years ago, but did not start large scale until the end of the nineteenth century when manufacturers and builders began using asbestos for:

- sound absorption
- its resistance to fire, heat, electrical, and chemical damage
- affordability

It was used in such applications as electrical insulation for hotplate wiring and in building insulation. When asbestos is used for its resistance to fire or heat, the fibers are often mixed with cement or woven into fabric or mats. These desirable properties made asbestos a very widely used material, and its use continued to grow throughout most of the twentieth century until the carcinogenic (cancer-causing) effects of asbestos were discovered which caused its effective demise as a mainstream construction and fireproofing material in most countries.

ASBESTOS HAZARDS Asbestos exposure can cause scar tissue to form in the lungs. This condition is called asbestosis. It gradually causes increasing shortness of breath, and the scarring to the lungs is permanent. Even low exposures to asbestos can cause mesothelioma, a type of fatal cancer of the lining of the chest or abdominal cavity. Asbestos exposure can also increase the risk of lung cancer as well as cancer of the voice box, stomach, and large intestine. It usually takes 15 to 30 years or more for cancer or asbestos lung scarring to show up after exposure.

TECH TIP

Competitively Priced Brakes

The term "competitively priced" means lower cost. Most brake manufacturers offer "premium" as well as lower-price linings to remain competitive with other manufacturers or with importers of brake lining material produced overseas by U.S. or foreign companies. Organic asbestos brake lining is inexpensive to manufacture. In fact, according to warehouse distributors and importers, the box often costs more than the brake lining inside. Professional brake service technicians should only install brake linings and pads that will give braking performance equal to that of the original factory brakes. For best results, always purchase high-quality brake parts from a known brand-name manufacturer.

INGREDIENT	TYPICAL FORMULA RANGE
Phenolic resin (binder)	9–15%
Asbestos fiber	30–50%
Organic friction modifiers (rubber scrap)	8–19%
Inorganic friction modifiers (barites, talc, whiting)	12–26%
Abrasive particles (alumina)	4–20%
Carbon	4–20%

CHART 4–2

Typical brake compositions for asbestos (organic) lining.

ASBESTOS BRAKE LININGS Asbestos was a popular component for vehicle brakes because of its heat resistance and strength. Brake friction materials that used asbestos were called *organic* linings/pads. The U.S. Environmental Protection Agency (EPA) has not banned the use of asbestos in drum brake linings or disc brake pads even though it has banned its use in corrugated paper, roll board, commercial paper, specialty paper, and flooring felt.

The concentration of asbestos in brake lining was estimated at 30% to 50%. The routine tasks of "blowing out" brake surfaces (using an air hose to clean the surfaces) were considered to be the most common way workers were exposed. The use of asbestos for brake linings was never abandoned completely. ● **SEE CHART 4–2.**

INGREDIENT	FORMULA RANGE
Phenolic resin	15–40%
Graphite or carbon particles	15–40%
Steel fibers	0–25%
Ceramic powders	2–10%
Steel, copper, brass metal powders	15–40%
Other modifiers (rubber scrap)	0–20%

CHART 4–3

Typical brake compositions for semimetallic disc brake pads.

SEMIMETALLIC FRICTION MATERIALS

DEFINITION The term **semimetallic** refers to brake lining material that uses metal rather than asbestos in its formulation. It still uses resins and binders and is, therefore, not 100% metal, but rather semimetallic. Semimetallic pads are commonly called "semi-mets."

CONSTRUCTION The metal in most metallic linings is made from metal particles that have been fused together without melting. This process is called *sintering* and the result is called *sintered metal linings*. Most semimetallic linings do not contain asbestos. Semimetallic linings require a very smooth finish on the rotor because the metal in the lining does not conform to the surface of the rotor, as does asbestos lining. A major disadvantage of semimetallic disc brake pads is that it causes a lot of brake dust which discolors the vehicle wheels. ● **SEE CHART 4–3.**

NON-ASBESTOS/CERAMIC FRICTION MATERIALS

TERMINOLOGY Brake pads and linings that use synthetic material such as aramid fibers instead of steel are usually referred to as:

- **non-asbestos**
- **non-asbestos organic (NAO)**
- **non-asbestos synthetic (NAS)**

INGREDIENT	FORMULA RANGE
Phenolic resin	15–40%
Graphite or carbon	20–30%
Copper	0–22% (Being phased out)
Ceramic powders	5–30%
Aluminum, barium, calcium, iron, potassium, magnesium, sodium	Each <2%
Fillers (barium sulfate, aramid fibers, ceramic fibers, other mined mineral powders)	5–10%

CHART 4–4

Typical compositions for NAO/Ceramic friction materials.

These friction materials are often called **ceramic** in the American aftermarket because they include ceramic fibers which are usually potassium titanite.

CONSTRUCTION Linings are called synthetic because synthetic (man-made) fibers are used. These linings use aramid fiber instead of metal as the base material. Aramid is the generic name for aromatic polyamide fibers. Kevlar is the Dupont brand name of aramid and a registered trademark of E.I. Dupont de Nemours and Company.

- Non-asbestos linings are often quieter than semimetallic pads and cause less wear to brake rotors as do semimetallic pads.
- Brake dust from NAO disc brake pads is less than from semimetallic pads. ● **SEE CHART 4–4.**

CARBON FIBER FRICTION MATERIALS

TERMINOLOGY Carbon fiber brake lining is the newest and most expensive of the lining materials.

Carbon fiber material is often called CFRC (carbon fiber-reinforced carbon). It is composed of a carbon mix into which reinforcing carbon fibers are embedded. CFRC is commonly used in the brakes of jet aircraft and racing cars. CFRC brakes provide constant friction coefficient whether cold or hot, low wear rates, and low noise development.

FREQUENTLY ASKED QUESTION

What Are Ceramic Pads Exactly?

NAO/Ceramic friction materials contain some ceramic powders or fibers. They are not "ceramic matrix composites" but rather they are an organic matrix composite molded using a phenolic resin. NAO materials typically exhibit low friction and/or high wear rates at high temperatures. To counteract this behavior, they sometimes contain many other raw materials (such as abrasives and metal sulfides) to maintain thermal stability. Metal sulfides generally provide lubrication and reduce noise created by these friction materials. Ceramic compounds provide much quieter braking because the ceramic compound helps dampen noise by generating a frequency beyond the human hearing range.

Another characteristic that makes ceramic materials attractive is the absence of noticeable dust. All brake pads produce dust as they wear. The ingredients in ceramic compounds produce a light-colored dust that is much less noticeable and less likely to stick to the wheels. Ceramic pads meet or exceed all original equipment standards for durability, stopping distance, and noise.

This is quite an improvement over organic and semimetallic brake materials that typically sacrifice pad life to reduce noise, or vice versa.

BRAKE PADS AND ENVIRONMENTAL CONCERNS

USE OF COPPER IN BRAKE PADS **Copper** is a soft metal with very high thermal and electrical conductivity and is used in most brake lining/pads because it:

- Helps transfer heat efficiently and increases brake effectiveness in cold weather
- Helps prevent brakes from squeaking and shuddering
- Adds strength to the brake pad material
- Helps reduce fade so that brakes remain effective through extended braking events.

Not all brake pads contain copper. Copper content varies from manufacturer to manufacturer and even among pads made by the same manufacturer for different applications.

FREQUENTLY ASKED QUESTION

What Do D^3EA and BEEP Mean?

Original equipment brake pads and shoes are required to comply with the Federal Motor Vehicle Safety Standard (FMVSS) 135, which specifies maximum stopping distances. There is also a requirement for fade resistance, but no standard for noise or wear. Aftermarket (replacement) brake pads and shoes are not required to meet the FMVSS standard. However, several manufacturers of replacement brake pads and shoes are using a standardized test that closely matches the FMVSS standard and is called the "Dual Dynamometer Differential Effectiveness Analysis" or D^3EA. This test is currently voluntary and linings that pass the test can have a "D^3EA certified" seal placed on the product package. BEEP stands for "Brake Effectiveness Evaluation Procedure" and is a series of tests on aftermarket brake components that is similar to the FMVSS tests and SAE J2430 standards.

ENVIRONMENTAL CONCERN Tiny amounts of copper from brakes fall onto the streets and parking lots every time the brakes are used. Copper is a pollutant because:

- It is toxic to certain sensitive species of algae (phytoplankton) that form the base of the aquatic food chain.
- Copper also directly damages the sensory capabilities of salmon, making it difficult for them to avoid predators or find their way back to their spawning grounds.

Copper is not necessarily harmful to the environment because it is vital to the health of both plants and animals. Copper from brakes account for anywhere from 35% to 60% of copper in California's urban watershed runoff. In some urban watersheds, this added copper may be enough to cause water concentrations to exceed the water quality standard for copper. This led to determining a course of action that would address the issue.

LEGAL REQUIREMENTS TO REDUCE COPPER The issue of cooper in the environment has been under consideration since the 1990s when cities south of San Francisco were having trouble meeting Clean Water Act (CAA) requirements to reduce copper in urban runoff flowing into San Francisco Bay. Studies indicated that brake pads were a major source of copper in that runoff. California and Washington in 2010 passed laws mandating a reduction in the amount of copper

FIGURE 4–11 All boxes of brake linings and pads should be labeled with the leaf mark, which gives a visual clue as to the standard under which the brake friction materials meet certain state laws regarding the amount of copper.

used in automotive brake pads. Both bills mandate that brake pads sold in each state contain no more than 0.5% of copper by weight and must meet all applicable safety standards. The laws differ in timing. In California, the law takes effect in no later than January 1, 2025.

LEAF MARK Washington State legislation mandates that all brake pads and shoes manufactured after January 1, 2015, are required to have a **leaf mark** icon indicating the level of compliance with state friction material content legislation. To demonstrate brake manufacturers' compliance with new state regulations, the Brake Manufacturers Council (BMC) of the Automotive Aftermarket Suppliers Association and the Motor and Equipment Manufacturers Association (MEMA) have selected NSF International to serve as its official registrar. NSF International is an independent organization that writes standards, tests, and certifies products for the food, water, and consumer goods industries to minimize adverse health effects and protect the environment (www.nsf.org). In addition to copper, all of the new standards restrict the following from brake friction materials:

- Asbestos fibers, less than 0.1% by weight
- Cadmium and its compounds, less than 0.01% by weight
- Chromium (VI)-salts, less than 0.1% by weight
- Lead and its compounds, less than 0.1% by weight
- Mercury and its compounds, less than 0.1% by weight

The leaf marks refer to the following ratings:

- **Level "A" standard (one leaf)**: Contains more than 5% of copper by weight (2015 Standard)

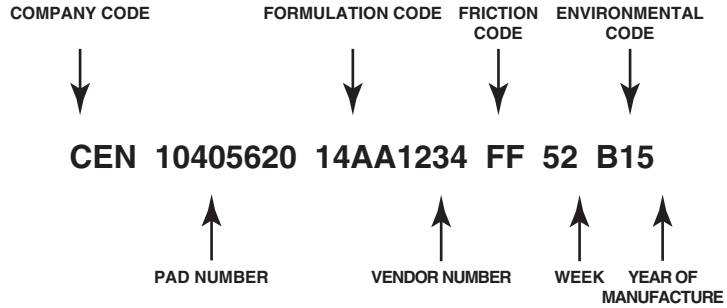


FIGURE 4–12 The edge codes include a lot of information about the brake friction material.

- **Level "B" standard (two leafs)**: Contains between 0.5% and 5% of copper by weight (2021 Standard)
- **Level "N" standard (three leafs)**: Contains less than 0.5% of copper by weight (2025 Standard)

● **SEE FIGURE 4–11.**

EDGE CODES

PURPOSE Starting in 1964, brake linings have been using a standardized way to identify the brake lining materials. The **edge codes** follow the Society of Automotive Engineers (SAE) Standard J866a.

EDGE CODE INFORMATION After January 1, 2014, all brake shoes and pads were required to have manufacturer's edge codes which indicate all of the following:

- Company code
- Pad number
- Formulation code
- Vendor number
- Friction code
- Week number that the brakes were made
- Environmental code (A, B, or N)
- Year of manufacture

Because these edge codes now contain so much information, many manufacturers of brake friction material print this information on the backing of the friction material instead of on the edge of the lining to make it easier to see and read. ● **SEE FIGURES 4–12 AND 4–13.**

COEFFICIENT OF FRICTION EDGE CODE The edge codes for the coefficient of friction include letters that represent a range of coefficient of friction. ● **SEE CHART 4–5.**

FIGURE 4–13 The "edge codes" are now printed on the backing of the brake pad because there is so much required information that it often does not fit on the edge of the brake pad or shoe.

CODE LETTER	COEFFICIENT OF FRICTION RANGE
Code C	0.00–0.15
Code D	0.15–0.25
Code E	0.25–0.35
Code F	0.35–0.45
Code G	0.45–0.55
Code H	0.55 and above
Code Z	Ungraded

CHART 4–5

Edge code letters represent a range of coefficient of friction of the linings.

FIGURE 4–14 Typical drum brake lining edge codes, showing the coefficient of friction codes for cold and hot circled.

TECH TIP

Edge Codes Do Not Represent Quality

The coefficient of friction letters do not mean the relative quality of the lining material. Lining wear, fade resistance, tensile strength, heat recovery rate, wet friction, noise, and coefficient of friction must be considered when purchasing high-quality linings. For best brake performance, always purchase the best-quality brake pads and lining from a well-known brand name.

COLD AND HOT COEFFICIENT OF FRICTION There are always two letters used side by side and the first letter indicates the coefficient of friction when brakes are cold (250°F/121°C), and the second letter indicates the coefficient of friction of the brake lining when the brakes are hot (600°F/316°C). For example, FF indicates that the brake lining material has a coefficient of friction between 0.35 and 0.45 when both cold and hot. ● **SEE FIGURE 4–14.**

SUMMARY

1. Energy is the ability to do work. A vehicle in motion represents kinetic energy, which must be absorbed by the braking system during a stop.
2. The front brakes must provide a higher percentage of the braking force due to weight bias and weight transfer.
3. Brake fade results when the heat generated by the brakes causes changes in the friction materials that reduce the braking force or by water that can get between the brake drum and the linings.
4. Deceleration rates are expressed in feet per second per second or ft/sec^2.
5. Brake friction materials are composed of relatively soft but tough and heat-resistant material to provide the friction between the moveable part of the braking system (drum or rotor) and the stationary part of the braking system.
6. The amount of friction between two objects or surfaces is commonly expressed as a value called the coefficient of friction and is represented by the Greek letter mu (μ).
7. Friction creates heat during a stop and the braking system must be able to absorb this heat.
8. "Asbestos" is the term used to describe naturally occurring silicate minerals that consist of long fibers. Asbestos

exposure can cause scar tissue to form in the lungs and can also cause cancer.

9. Semimetallic refers to brake lining material that uses metal rather than asbestos in its formulation.
10. Brake pads and linings that are called non-asbestos, non-asbestos organic (NAO), or non-asbestos synthetic (NAS) use synthetic material such as aramid fibers instead of steel. These friction materials are often called ceramic in the American aftermarket because they include ceramic fibers which are usually potassium titanite.
11. Studies indicated that brake pads were a major source of copper in the runoff. California and Washington in 2010 passed laws mandating a reduction in the amount of copper used in automotive brake pads. Washington State legislation mandates that all brake pads and shoes manufactured after January 1, 2015, are required to have a leaf mark icon indicating the level of compliance with state friction material content legislation.
12. After January 1, 2014, all brake shoes and pads were required to have manufacturer's edge codes which indicate all of the following:
    - Company code
    - Pad number (part number)
    - Formulation code
    - Vendor number
    - Friction code
    - Week number that the brakes were made
    - Environmental code (A, B, or N)
    - Year of manufacture

REVIEW QUESTIONS

1. What is kinetic energy?
2. What is meant by the coefficient of friction?
3. Why do brakes fade due to excessive heat or water?
4. Why is asbestos being restricted in brake friction materials?
5. What is the difference between semimetallic and non-asbestos organic (NAO) brake friction materials?
6. Which type of brake pad material is often referred to as ceramic?
7. Why is copper being removed from brake friction material?
8. What is the meaning of the friction code letter printed on the edge of brake linings and pads?

CHAPTER QUIZ

1. Which Greek letter is used to represent the coefficient of friction?
   a. Mu (μ) **c.** Delta (Δ)
   b. Omega (Ω) **d.** Pie (π)
2. The amount of asbestos in brake friction material is being restricted because_____.
   a. It does not transfer heat to the drum/rotor
   b. It is a health hazard
   c. Asbestos worn from brakes contaminate rivers and streams
   d. It causes excessive brake drum/rotor wear
3. What type of binder is used in all brake friction materials?
   a. Rubber scrap **c.** Phenolic resin
   b. Carbon **d.** Ceramic powders
4. An edge code reading for coefficient of friction is EF. This means_____.
   a. The coefficient of friction is 0.50
   b. The coefficient of friction is higher when the brakes are cold
   c. The coefficient of friction is higher when the brakes are hot
   d. A higher quality brake would have a code of FF
5. Brake pads and linings that use synthetic material such as aramid fibers instead of steel are usually referred to as_____.
   a. NAO **c.** Ceramic
   b. NAS **d.** Any of the above
6. What can the driver do to reduce the possibility of brake fade caused by heat?
   a. Ride the brakes to keep the shoes and pads against the drum or rotor
   b. Pump the brake pedal while descending a steep hill
   c. Select a lower transmission gear
   d. Shift the transmission into neutral and allow the vehicle to coast down long or steep hills
7. Brake fade can occur due to_____.
   a. Mechanical fade **c.** Water fade
   b. Gas fade **d.** Any of the above
8. Why is copper being reduced in brake friction materials?
   a. Because it is a health concern when it becomes airborne
   b. It can affect life in rivers and streams
   c. To help reduce the weight of the vehicle
   d. To help reduce the cost of the brake linings/pads
9. The lowest level of copper in brake friction material is shown on the leaf mark as_____
   a. A singe leaf **c.** Three leafs
   b. Two leafs **d.** Four leafs
10. Disc brake pads can reach temperatures as high as _____.
    a. 300°F (150°C)
    b. 1,000°F (540°C)
    c. 1,300°F (700°C)
    d. 1,800°F (980°C)