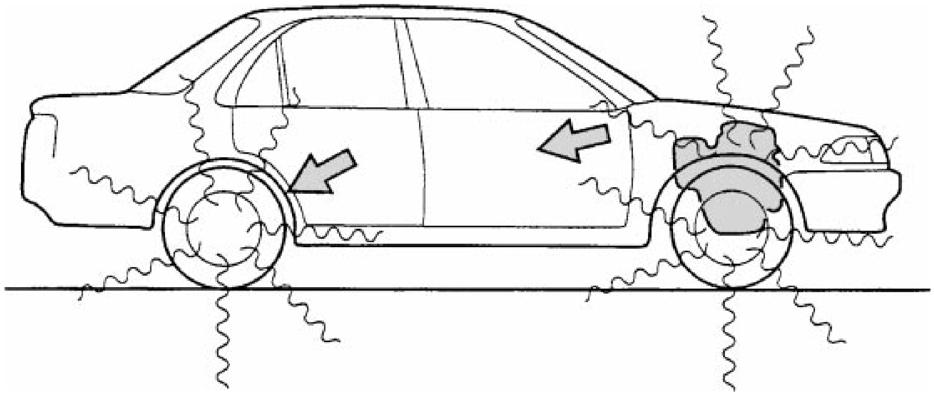
Section 1

FUNDAMENTAL PRINCIPLES



Lesson Objectives

1. Describe the cycle of heat as it applies to automotive brakes.
2. Explain the effect of heat transfer as it relates to brake fade.
3. Describe how the coefficient of friction affects the rate of heat transfer.
4. Relate the effect of hydraulic theory as it applies to a closed hydraulic circuit.
5. Explain how output force in a hydraulic circuit can be tailored for specific applications by changing the diameter of the output piston.
6. List the requirements of brake fluid in an automotive brake system.

Fundamental Principles

The most important safety feature of an automobile is its brake system. The ability of a braking system to provide safe, repeatable stopping is the key to safe motoring. A clear understanding of the brake system is essential for anyone involved in servicing Toyota vehicles.

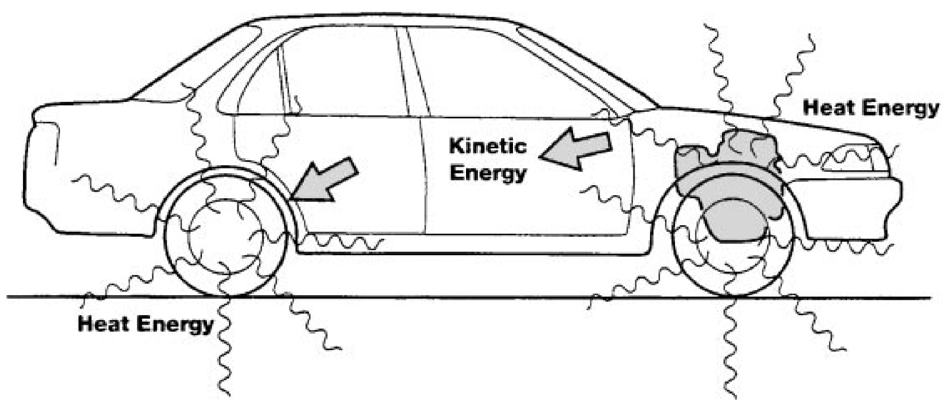
The basic principle of brake operation is the conversion of energy. Energy is the ability to do work. The most familiar forms of energy in automotive use are; chemical, electrical and mechanical. For example starting an engine involves several conversions. Chemical energy in the battery is converted to electrical energy in the starter. Electrical energy is converted to mechanical energy in the starter as it cranks the engine.

Cycle of Heat Energy

Burning hydrocarbons and oxygen in the engine creates **heat energy**. Nothing can destroy energy once it is released, it can only be converted into another form of energy. Heat energy is converted into **kinetic energy** as the vehicle is put into motion. Kinetic energy is a fundamental form of mechanical energy; it is the energy of a mass in motion. Kinetic energy increases in direct proportion to weight increase and increases by four times for speed increases.

Cycle of Heat

Heat energy converts to kinetic energy which converts back to heat energy.



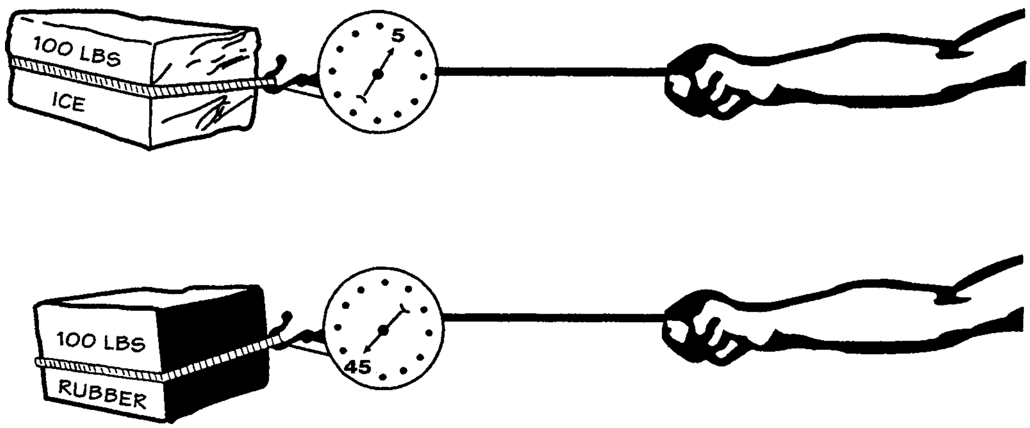
Friction is the resistance to movement between two objects in contact with each other. It also converts energy of motion to heat. If we allow the vehicle to coast in neutral on a level surface, eventually the kinetic energy would be converted to heat in the wheel bearings, drivetrain bearings, and at the tire and road surface to bring the vehicle to a complete stop. The brake system provides the means of converting kinetic energy through stationary brake shoes or pads which press against a rotating surface, generating friction and heat.

The amount of friction produced is proportional to the pressure between the two objects, composition of surface material and surface condition. The greater the pressure applied to the objects, the more friction and heat is produced. The more heat produced by friction, the sooner the vehicle is brought to a stop which results in stopping control.

The **coefficient of friction** is a measurement of the friction between two objects in contact with each other. Force is the effort required to slide one surface across the other. It is determined by dividing the force required to move an object by the weight of an object.

Coefficient of Friction

Coefficient of friction varies based on composition of material and condition of the surface.



The following example illustrates how the type of friction surface can influence the coefficient of friction (COF).

100 pounds of ice pulled across a concrete floor may require 5 pounds of force to move.

5 / 100 = 0.05
COF = 0.05

However 100 pounds of rubber pulled across a concrete floor may require 45 pounds of force to move.

45 / 100 = 0.45
COF = 0.45

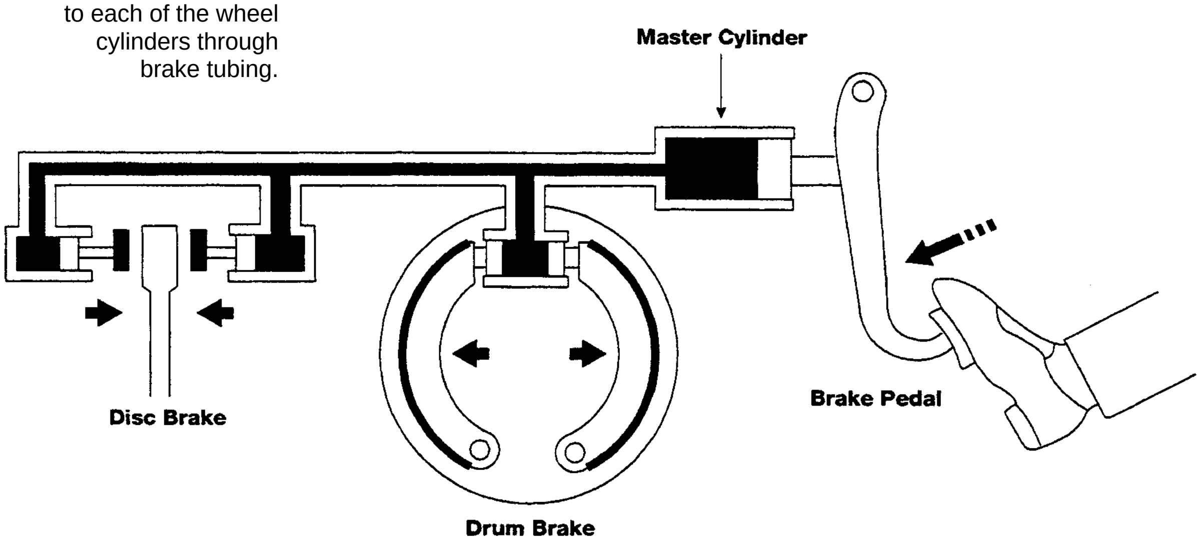
The coefficient of friction varies in the two examples above based on the materials used. The same is true in a brake system, the coefficient of friction varies on the type of lining used and the condition of the drum or rotor surface.

Basic Brake System

The most widely utilized brake systems at present are the foot operated main brake and manual type parking brake. The main brake actuates the brake assemblies at each wheel simultaneously using hydraulic pressure. Fluid pressure created at the master cylinder is transmitted to each of the wheel cylinders through brake tubing. The wheel cylinders force the shoes and pads into contact with a drum or rotor spinning with the wheels generating friction and converting kinetic energy to heat energy. Large amounts of heat is created resulting in short distance stopping and vehicle control. The converted heat is absorbed primarily by the brake drums and dissipated to the surrounding air.

Foot Operated Brake System

Fluid pressure is transmitted to each of the wheel cylinders through brake tubing.



Brake Fade

Brake drums and rotors are forced to absorb a significant amount of heat during braking. Brake fade describes a condition where heat is generated at a faster rate than they are capable of dissipating heat into the surrounding air. For example, during a hard stop the temperature of drums or rotors may increase more than 100 degrees F in just seconds. It may take 30 seconds to cool these components to the temperature prior to braking. During repeated hard stops, overheating may occur and a loss of brake effectiveness or even failure may result.

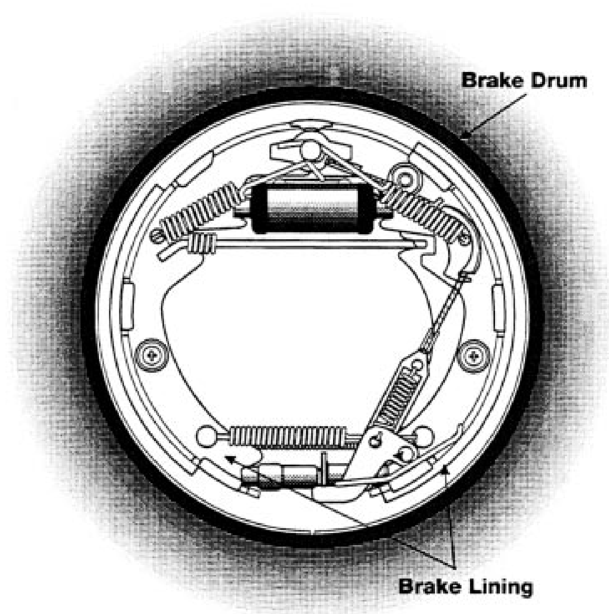
There are primarily two types of brake fading caused by heat;

- Mechanical fade.
- Lining fade.

Mechanical fade occurs when the brake drum overheats and expands away from the brake lining resulting in increased brake pedal travel. Rapidly pumping the pedal will help to keep linings in contact with the drum.

Brake Fade

Drums and rotors are forced to absorb heat during braking at a faster rate than they are capable of dissipating the heat.



Lining fade affects both drum and disc brakes and occurs when the friction material overheats to the point where the coefficient of friction drops off. When the coefficient of friction drops off, friction is reduced and the brake assemblies ability to convert added heat is reduced.

Brake fade is the primary reason for weight limits for towing and trailer brake requirement for vehicles above a given trailer weight. The added kinetic energy resulting from increased vehicle mass requires added heat conversion capacity when the brakes are applied.

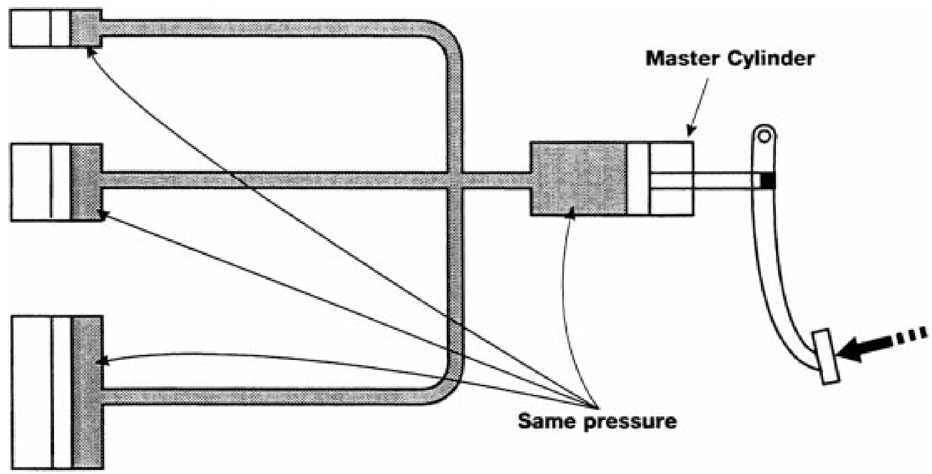
Basic Hydraulic Theory

Brake systems use hydraulic fluid in a closed system to transmit motion. The hydraulic brake system is governed by physical laws that makes it efficient at transmitting both motion and force. Blaise Pascal discovered the scientific laws governing the behavior of liquids under pressure. Pascal's Law states that pressure applied anywhere to an enclosed body of fluid is transmitted equally to all parts of the fluid. In other words, 100 psi generated at the master cylinder is the same at each wheel cylinder as well as anywhere within a static system.

A feature of hydraulic theory can be seen in the illustration below which demonstrates the pressure in the master cylinder is transmitted equally to all wheel cylinders.

Pascal's Law

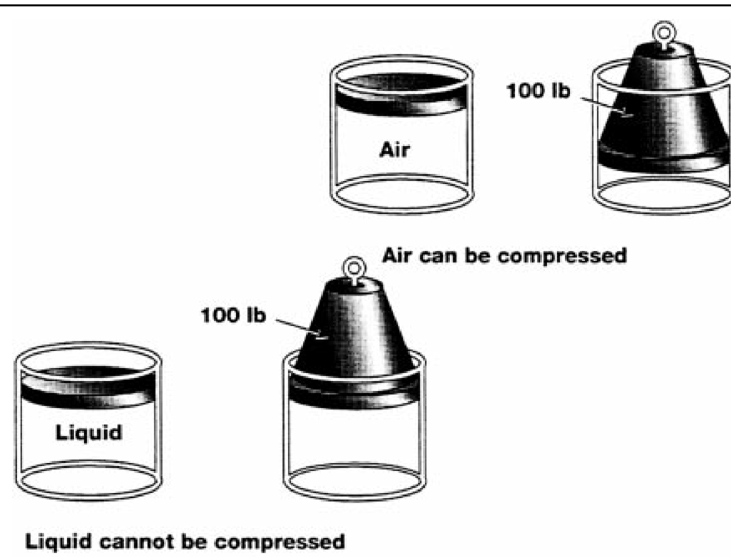
Pressure applied anywhere to an enclosed body of fluid is transmitted equally to all pans of the fluid.



Another important distinction to make is that liquids cannot be compressed, whereas, air is compressible. A hydraulic system must be free of air in order to function properly. Pedal travel will increase as air in the system is compressed.

Air is Compressible

Liquids cannot be compressed, whereas, air is compressible.



Fluid pressure is indicated in pounds per square inch (psi). It is determined by dividing the input force applied to a piston by the area of the piston. (force/area = pressure in psi) If a force of 100 pounds is applied to a master cylinder piston, an area of 2 square inches, the resulting pressure will be 50 psi. This pressure is transmitted to all parts of the fluid in the container equally.

force / area = psi
100 / 2 = 50 psi

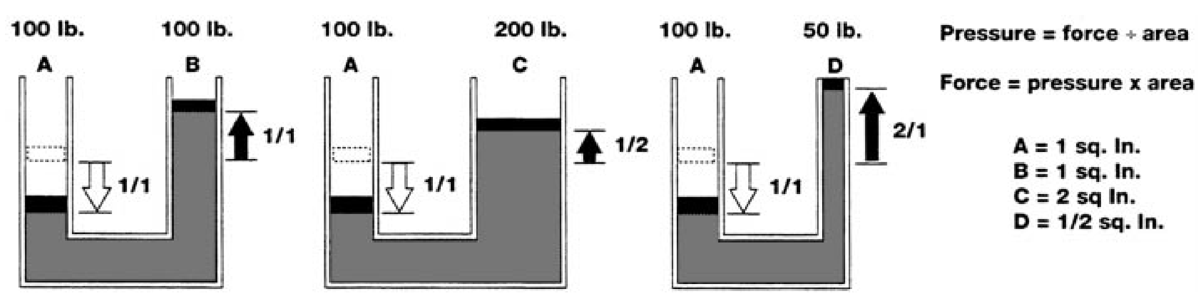
In the series of examples below we are examining working force and transfer of motion based on different working piston diameters. In each example, piston A is the same diameter (1”) and the same 100 lb. input force is applied. When the force is applied to piston A, piston B has 100 psi of output force and travels an equal distance to piston A.

By contrast piston C will have an output force of twice that of piston A because piston C has twice the area. In addition, piston C transfers only half the distance of piston A.

Yet another contrast is piston D which is half the area of piston A. The system pressure is the same as the two previous examples but since piston D is half the area of piston A, the pressure is half the apply pressure and the motion transfer is twice that of piston A.

Working Force and Transfer of Motion

The braking force varies, depending on the diameter of the wheel cylinders.



Hydraulic brakes deliver equal braking force to all wheels with a minimum of transmission loss. Hydraulic brakes have a wide design flexibility because braking force can be changed merely by changing the diameter of the master cylinder and wheel cylinders.

Brake Fluid

Brake fluid is specifically designed to be compatible with its environment of high heat, high pressure and moving parts. Standards for brake fluid have been established by the Society of Automotive Engineers (SAE) and the Department of Transportation (DOT). Requirements of a fluid used in automotive brake applications must include the following:

- remain viscous.
- have a high boiling point.
- act as lubricant for moving parts.

The Federal Motor Vehicle Safety Standard (FMVSS) states that by law, brake fluid must be compatible regardless of manufacturer. Fluids are not necessarily identical however, any DOT approved brake fluid can be mixed with any other approved brake fluid without damaging chemical reactions. Although the fluid may not always blend together into a single solution, it does not effect the properties of liquid under pressure.

Brake Fluid Types

Two types of brake fluid are used in automotive brake applications, each having specific attributes and drawbacks. **Polyglycol** is clear to amber in color and is the most common brake fluid used in the industry. It is a solvent and will immediately begin to dissolve paint. Flush the area with water if brake fluid is spilled on paint.

One of the negative characteristics of polyglycol is that it is hygroscopic, that is, it has a propensity to attract water. Water can be absorbed through rubber hoses and past seals and past the vent in the master cylinder reservoir cap. Moisture in the hydraulic circuit reduces the boiling point of the fluid and causes it to vaporize. In addition, moisture causes metal parts to corrode resulting in leakage and /or frozen wheel cylinder pistons.

Extra caution should be taken with containers of brake fluid because it absorbs moisture from the air when the container is opened. Do not leave the container uncapped and close it tightly.

Silicone is purple in color. It is not hygroscopic and therefore has virtually no rust and corrosion problems. It has a high boiling point and can be used in higher heat applications. It will not harm paint when it comes in contact with it.

Silicone has a greater affinity for air than polyglycol. Because the air remains suspended in the fluid it is more difficult to bleed air from the hydraulic system.

DOT Grades

There are three grades of brake fluid which are determined by Federal Motor Vehicle Safety Standard 116. Fluid grades are rated by the minimum boiling point for both pure fluid (dry) and water contaminated fluid (wet):

- DOT 3 – Polyglycol
  - minimum boiling point – 401°F dry, 284 °F wet
  - blends with DOT 4
- DOT 4 – Polyglycol
  - minimum boiling point – 446 °F dry, 311 °F wet
  - blends with DOT3
- DOT 5 – Silicone
  - minimum boiling point – 500 °F dry, 356 °F wet
  - compatible by law with DOT 3 and 4 but will not blend with them

Toyota recommends the exclusive use of Polyglycol DOT 3 brake fluid in all its products.