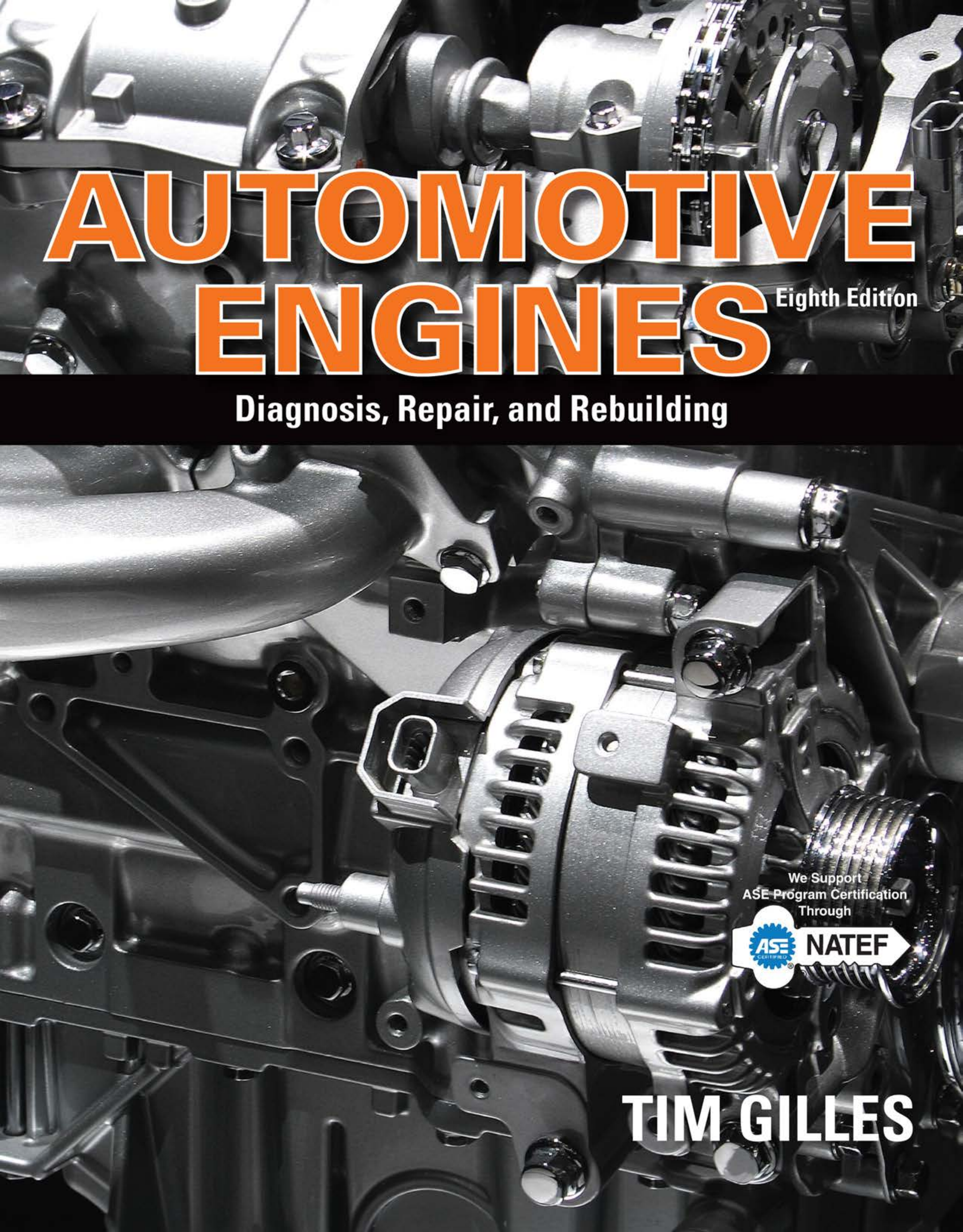
AUTOMOTIVE ENGINES

Eighth Edition

Diagnosis, Repair, and Rebuilding



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TIM GILLES

AUTOMOTIVE ENGINES

Diagnosis, Repair, and Rebuilding

EIGHTH EDITION

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Santa Barbara City College
Santa Barbara, CA

CENGAGE

Australia • Brazil • Mexico • Singapore • United Kingdom • United States

***Automotive Engines: Diagnosis, Repair, and Rebuilding*, 8th edition**

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DEDICATION

The completion of this book was made possible with the help of a great many individuals. *Automotive Engines* is dedicated to them and especially to my parents for the inspiration, and to my wife, Joy, and children, Jody and Terri, without whose help the book would not have been completed. Special appreciation is due to my wife, Joy, who has managed the organization of the art package, spending countless hours developing and organizing all the spreadsheets, captions, photos, and sketches, making certain they are in their correct locations—a substantial task.

This book is also dedicated to four important mentors: Lloyd Corliss, my first automotive teacher, who shared his love of engines and whose integrity and example inspired me to become an automotive teacher; Roger Aylesworth, who became a big brother to me while I worked in his automotive business and who shared, by example, his attitude that, with knowledge, a good mechanic can fix just about anything; and Bob Barkhouse, another big brother and good friend. Bob is a retired automotive teacher and the author of a very fine best-selling textbook on the upper end of engines. His example is one of generosity. He has been a big help and an inspiration to me and countless other teachers. My good friend and mentor, Joe Schuit, began helping the engine-rebuilding students at Santa Barbara City College shortly after he retired from his automotive machine shop business. Joe was an inventor with a gifted mind for automotive engines and an enthusiasm that was contagious. He always had something new and valuable to share from his vast library of knowledge and experience.

Contents

Preface

ABOUT THIS BOOK

It is often said that engines never change. Although large changes are not the norm, the internal combustion engine (ICE) is constantly evolving. When the first edition of this text was being written in 1980, futurists were questioning whether the four-stroke cycle engine would still be around in 20 years. The long history of this well-proven engine has shown continuous small refinements, and ICEs still power most of today's vehicles. Compared with the engines that powered the muscle cars of 1980, today's engines are more refined, lighter, and offer improved performance and durability.

Automotive Engines, Eighth Edition, provides the reader with the comprehensive knowledge needed to repair and rebuild these automotive engines. The most complete book of its kind, it takes a generic, rather than product-specific, approach. The text provides all of the need-to-know information in an easy-to-understand format. Much effort has gone into organizing this book to make it easily readable, like a story. To facilitate learning, all items related to a given topic are included within a single chapter. Appropriate for entry-level as well as more experienced technicians and machinists, this text also provides opportunities for the reader to develop critical diagnostic and problem-solving skills.

Organization of This Edition

This text is divided into five sections and is designed so that the student can begin working in the shop right away. Section 1 covers engine construction, disassembly, inspection, and parts ordering. Diagnosis techniques, both before and after disassembly, are covered in detail. Also included are repair procedures that can be performed while the engine is still in the vehicle. Tools and equipment procedures, as well as safety issues, are covered throughout. Section 2 deals with the valvetrain, cylinder head repair, camshafts, and cam drives. Section 3 discusses the cylinder block assembly with a focus on lower-end repair procedures. The lubrication and cooling systems are also covered. Section 4 deals with final reassembly and starting the engine. Gaskets and miscellaneous repair procedures are covered in this section as well. Section 5 covers engine power and performance, including intake and exhaust systems, turbochargers and superchargers, varying valve timing, and measuring power and torque.

New to This Edition

This eighth edition of *Automotive Engines* has been updated and refined to reflect changes in the marketplace. The seventh edition was produced in a four-color design for the first time with many new and updated photos and illustrations. This has been a tremendous improvement. An emphasis on photos and art anticipates the needs of those with different learning styles and encourages student interest in reading the related text. New color photos and illustrations have been added to this eighth edition to continue improving this project.

The design and engineering of the internal combustion engine is continuing to evolve, with enhancement of high-performance sport compact cars and vehicle restoration accounting for a substantial part of the industry.

Here is a listing of some of the highlights:

- The updated high-performance Section 5 includes three chapters with updated information on engine breathing, including intake and exhaust manifolds, turbocharging, supercharging, high-performance camshafts, and variable valve timing.
- Up-to-date information on cooling and lubrication systems is included in this edition of the text. Engines last far longer than they did 25 years ago. Maintenance is important to vehicle owners; cooling system failures that result in serious engine damage must be avoided.
- Metric micrometer reading has been expanded in Chapter 6.

- New or updated case histories highlight real-world situations, providing more critical thinking practices.
- Vintage Engines additions help put newer technologies in historical perspective by offering interesting facts about older technologies while separating them from the core text, along with accompanying photographs.

Use of the Text

A goal of *Automotive Engines* is to fill the needs of many, merging commonplace and vintage content with the latest high-tech information. Some schools have smaller engine course offerings, whereas others have large programs with classes of long enough duration to complete the entire text. Some instructors assign certain chapters, leaving others to be covered in an introductory course. Others use some of the chapters in a prerequisite introductory engines course, saving others for an advanced engine-rebuilding course. For instance, Chapter 9 covers all of the camshaft-related items that would be needed for an entry-level automotive apprentice, whereas the Engine Power and Performance Chapters, 17, 18, and 19, consist of more advanced technical material for aspiring engine machinists and high-performance specialists.

There are many new and updated photos of engine disassembly and reassembly on newer vehicles. Students need to learn to diagnose an engine during disassembly so they can assess its suitability for repair prior to spending a lot of money and wasting a lot of time. Analyzing unusual wear or part failure will also help them correct problems so they do not recur.

The camshaft chapter emphasizes timing belt service, including cam lobe position identification, so you can be sure you are doing the right thing. This is something all good technicians should know, but many do not.

This book is used in schools that teach NATEF A-1 (Engine Repair). Coverage emphasizes procedures that would be performed in a typical automotive facility that does engine repairs. The book is also used in schools that teach in-depth engine machining processes. One of my challenges as an author is to present machining tips in a way that will benefit all students who study the book. Instructions on the use of a particular machine are avoided; they are available in video form or in the online pdf manual for the machine.

The primary aim of the text is to provide a student with adequate preparation for entry-level employment with emphasis on the ASE A1 Engines area, including ASE test preparation.

To the Student

Restoration and improvement is a very popular automotive technology area and you should be prepared to capitalize on that interest. Most cities and towns have residents who can afford to spend money on their cars and light trucks. You will need a good understanding of performance and vintage material to be successful in this field. Additionally, you need a good grounding in the broad area covering four-stroke cycle engine basics if you are to be successful as an engine diagnostician. During engine diagnosis and disassembly, the text gives an emphasis to analyzing worn and damaged parts. The aim is to improve your diagnostic ability and develop a method of approaching things in an inquisitive manner. Get into the habit of asking yourself, “What caused this to happen?” You will want to take measures so it does not happen again. This can be applied to more advanced topics as you further your automotive studies.

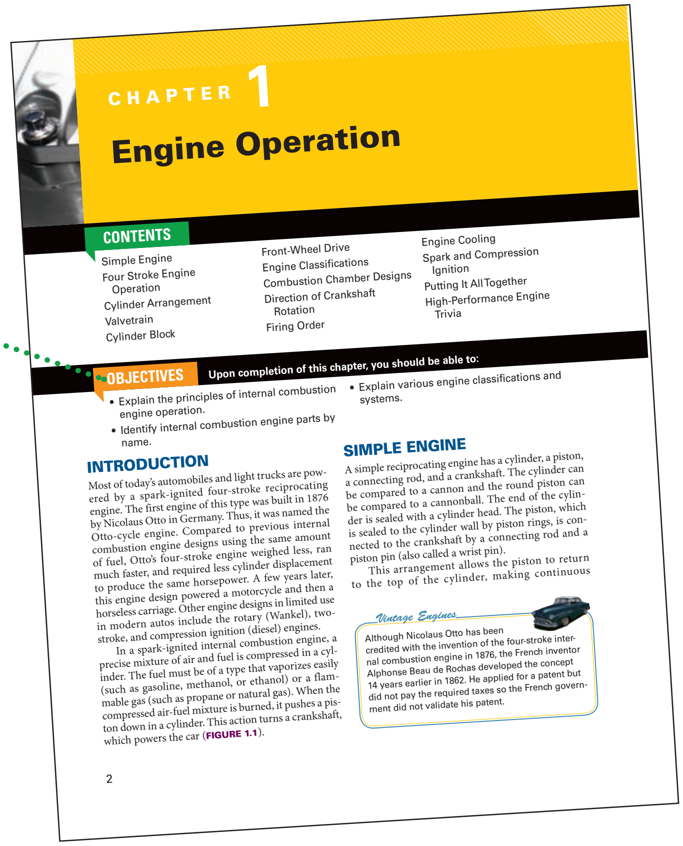
You will also find that learning about automotive internal combustion engines will prepare you for work in the heavy-duty market. Working on heavy trucks or on marine engines is not that much different than working on cars. The principles are the same.

Features of the Text

Learning the theory, diagnosis, and repair procedures for today's complex engines can be challenging. To guide readers through this material, a series of features are included that will ease the teaching and learning processes.

Objectives

Each chapter begins with a list of objectives. The objectives state the expected outcome that will result from completing a thorough study of the contents of the chapter.


CHAPTER 1

Engine Operation

CONTENTS

Simple Engine
Four Stroke Engine Operation
Cylinder Arrangement
Valvetrain
Cylinder Block
Front-Wheel Drive
Engine Classifications
Combustion Chamber Designs
Direction of Crankshaft Rotation
Firing Order
Engine Cooling
Spark and Compression Ignition
Putting It All Together
High-Performance Engine Trivia

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

- Explain the principles of internal combustion engine operation.
- Identify internal combustion engine parts by name.
- Explain various engine classifications and systems.

INTRODUCTION

Most of today's automobiles and light trucks are powered by a spark-ignited four-stroke reciprocating engine. The first engine of this type was built in 1876 by Nicolaus Otto in Germany. Thus, it was named the Otto-cycle engine. Compared to previous internal combustion engine designs using the same amount of fuel, Otto's four-stroke engine weighed less, ran much faster, and required less cylinder displacement to produce the same horsepower. A few years later, this engine design powered a motorcycle and then a horseless carriage. Other engine designs in limited use in modern autos include the rotary (Wankel), two-stroke, and compression ignition (diesel) engines.

In a spark-ignited internal combustion engine, a precise mixture of air and fuel is compressed in a cylinder. The fuel must be of a type that vaporizes easily (such as gasoline, methanol, or ethanol) or a flammable gas (such as propane or natural gas). When the compressed air-fuel mixture is burned, it pushes a piston down in a cylinder. This action turns a crankshaft, which powers the car (FIGURE 1.1).

SIMPLE ENGINE

A simple reciprocating engine has a cylinder, a piston, a connecting rod, and a crankshaft. The cylinder can be compared to a cannon and the round piston can be compared to a cannonball. The end of the cylinder is sealed with a cylinder head. The piston, which is sealed to the cylinder wall by piston rings, is connected to the crankshaft by a connecting rod and a piston pin (also called a wrist pin).

This arrangement allows the piston to return to the top of the cylinder, making continuous

Vintage Engines

Although Nicolaus Otto has been credited with the invention of the four-stroke internal combustion engine in 1876, the French inventor Alphonse Beau de Rochas developed the concept 14 years earlier in 1862. He applied for a patent but did not pay the required taxes so the French government did not validate his patent.

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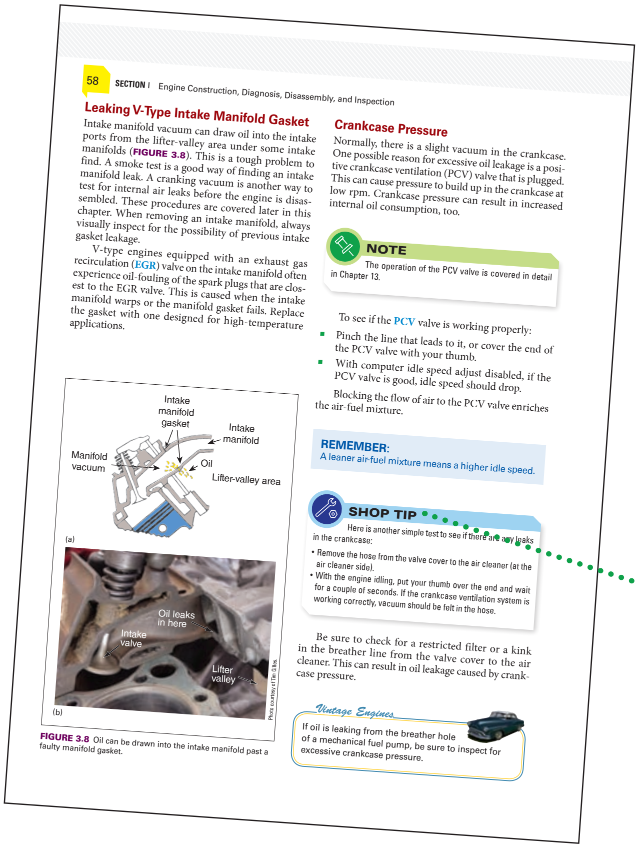

58 SECTION I Engine Construction, Diagnosis, Disassembly, and Inspection

Leaking V-Type Intake Manifold Gasket

Intake manifold vacuum can draw oil into the intake ports from the lifter-valley area under some intake manifolds (FIGURE 3.8). This is a tough problem to find. A smoke test is a good way of finding an intake manifold leak. A cranking vacuum is another way to test for internal air leaks before the engine is disassembled. These procedures are covered later in this chapter. When removing an intake manifold, always visually inspect for the possibility of previous intake gasket leakage.

V-type engines equipped with an exhaust gas recirculation (EGR) valve on the intake manifold often experience oil-fouling of the spark plugs that are closest to the EGR valve. This is caused when the intake manifold warps or the manifold gasket fails. Replace the gasket with one designed for high-temperature applications.

FIGURE 3.8 Oil can be drawn into the intake manifold past a faulty manifold gasket.

Crankcase Pressure

Normally, there is a slight vacuum in the crankcase. One possible reason for excessive oil leakage is a positive crankcase ventilation (PCV) valve that is plugged. This can cause pressure to build up in the crankcase at low rpm. Crankcase pressure can result in increased internal oil consumption, too.

NOTE

The operation of the PCV valve is covered in detail in Chapter 13.

To see if the PCV valve is working properly:

- Pinch the line that leads to it, or cover the end of the PCV valve with your thumb.
- With computer idle speed adjust disabled, if the PCV valve is good, idle speed should drop.

Blocking the flow of air to the PCV valve enriches the air-fuel mixture.

REMEMBER:
A leaner air-fuel mixture means a higher idle speed.

SHOP TIP

Here is another simple test to see if there are any leaks in the crankcase:

- Remove the hose from the valve cover to the air cleaner (at the air cleaner side).
- With the engine idling, put your thumb over the end and wait for a couple of seconds. If the crankcase ventilation system is working correctly, vacuum should be felt in the hose.

Be sure to check for a restricted filter or a kink in the breather line from the valve cover to the air cleaner. This can result in oil leakage caused by crankcase pressure.

Vintage Engines

If oil is leaking from the breather hole of a mechanical fuel pump, be sure to inspect for excessive crankcase pressure.

Shop Tips

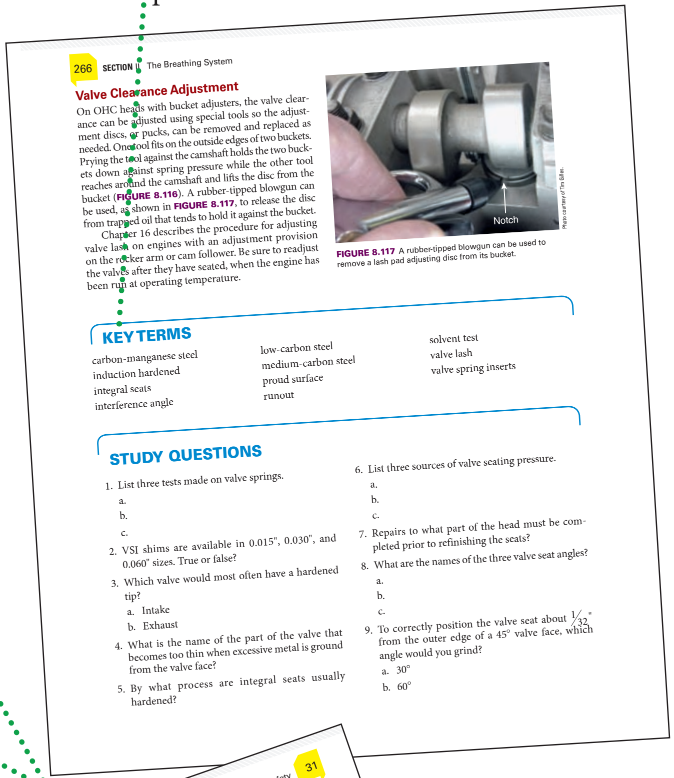
Found throughout the chapters, these tips cover things commonly performed by experienced technicians.

Safety Notes and Cautions

Safety is a major concern in any automotive shop, so safety notes and cautions are listed throughout to focus the reader's attention on important safety information.

Key Terms

Each chapter ends with a list of the terms that were introduced in the chapter. These terms are highlighted in the text upon first use.


266 SECTION II The Breathing System

Valve Clearance Adjustment

On OHC heads with bucket adjusters, the valve clearance can be adjusted using special tools so the adjustment discs, or pucks, can be removed and replaced as needed. One tool fits on the outside edges of two buckets. Prying the tool against the camshaft holds the two buckets down against spring pressure while the other tool reaches around the camshaft and lifts the disc from the bucket (FIGURE 8.116). A rubber-tipped blowgun can be used, as shown in FIGURE 8.117, to release the disc from trapped oil that tends to hold it against the bucket.

Chapter 16 describes the procedure for adjusting valve lash on engines with an adjustment provision on the rocker arm or cam follower. Be sure to readjust the valves after they have seated, when the engine has been run at operating temperature.

FIGURE 8.117 A rubber-tipped blowgun can be used to remove a lash pad adjusting disc from its bucket.

KEY TERMS

carbon-manganese steel, induction hardened, integral seats, interference angle, low-carbon steel, medium-carbon steel, proud surface, runout, solvent test, valve lash, valve spring inserts

STUDY QUESTIONS

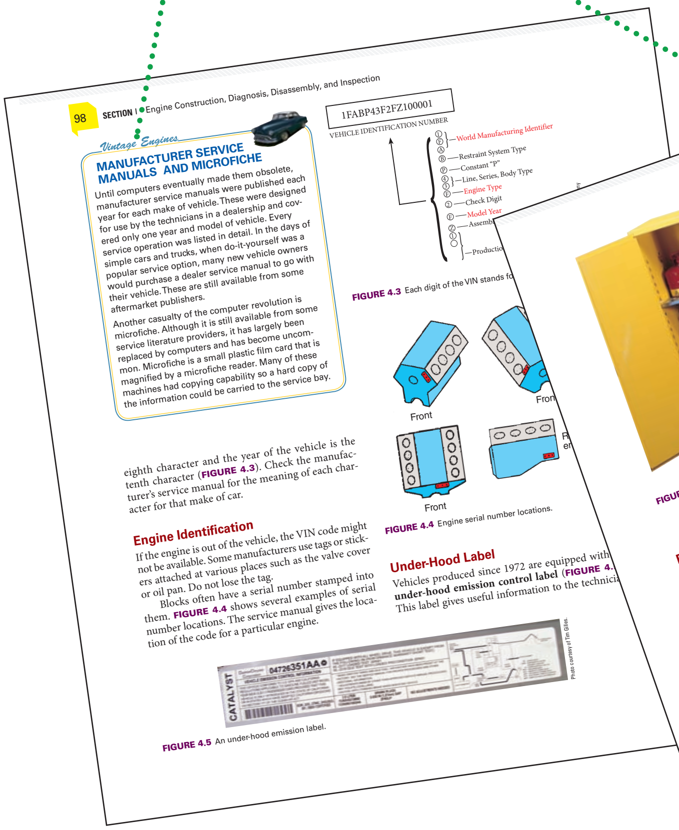
1. List three tests made on valve springs.
a.
b.
c.
2. VSI shims are available in 0.015", 0.030", and 0.060" sizes. True or false?
3. Which valve would most often have a hardened tip?
a. Intake
b. Exhaust
4. What is the name of the part of the valve that becomes too thin when excessive metal is ground from the valve face?
5. By what process are integral seats usually hardened?
6. List three sources of valve seating pressure.
a.
b.
c.
7. Repairs to what part of the head must be completed prior to refinishing the seats?
8. What are the names of the three valve seat angles?
a.
b.
c.
9. To correctly position the valve seat about 1/32" from the outer edge of a 45° valve face, which angle would you grind?
a. 30°
b. 60°

Vintage Engines

These text boxes place newer technologies in historical perspective by offering interesting facts about older technologies while separating them from the core text. Vintage figures are also included within the boxes.

Case Histories

These true stories describe automotive situations encountered by the author and others. They provide the reader with insight into the critical thinking skills necessary to diagnose automotive engine problems.


98 SECTION I Engine Construction, Diagnosis, Disassembly, and Inspection

Vintage Engines

MANUFACTURER SERVICE MANUALS AND MICROFICHE

Until computers eventually made them obsolete, manufacturer service manuals were published each year for each make of vehicle. These were designed for use by the technicians in a dealership and covered only one year and model of vehicle. Every service operation was listed in detail. In the days of simple cars and trucks, when do-it-yourself was a popular service option, many new vehicle owners would purchase a dealer service manual to go with their vehicle. These are still available from some aftermarket publishers.

Another casualty of the computer revolution is microfiche. Although it is still available from some service literature providers, it has largely been replaced by computers and has become uncommon. Microfiche is a small plastic film card that is magnified by a microfiche reader. Many of these machines had copying capability so a hard copy of the information could be carried to the service bay.

FIGURE 4.3 Each digit of the VIN stands f...

eighth character and the year of the vehicle is the tenth character (FIGURE 4.3). Check the manufacturer's service manual for the meaning of each character for that make of car.

Engine Identification

If the engine is out of the vehicle, the VIN code might not be available. Some manufacturers use tags or stickers attached at various places such as the valve cover or oil pan. Do not lose the tag.

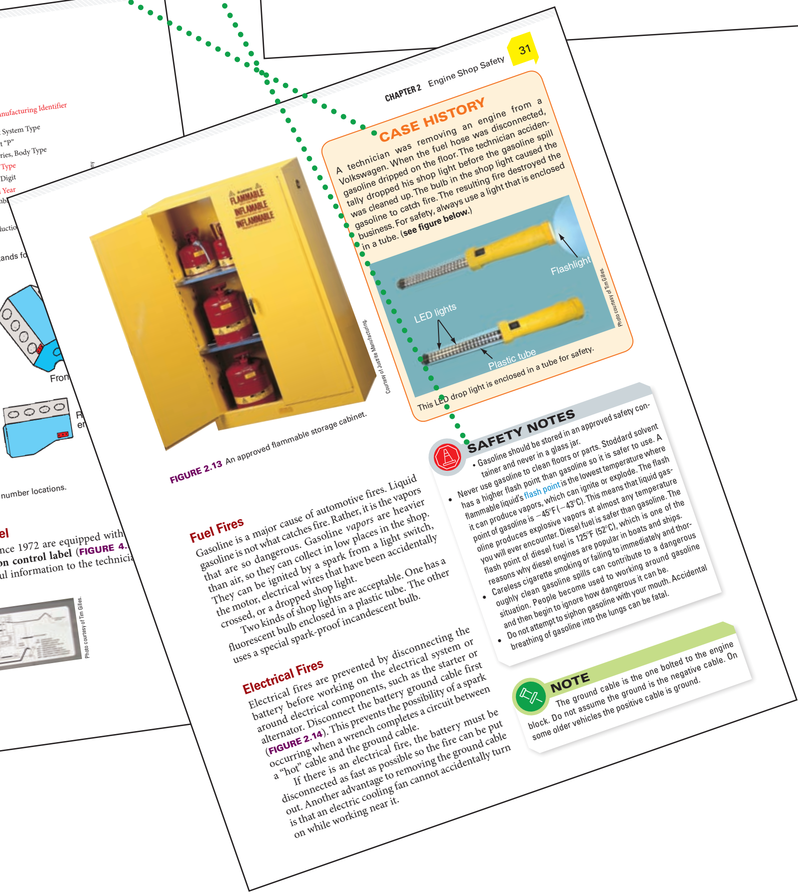
Blocks often have a serial number stamped into them. FIGURE 4.4 shows several examples of serial number locations. The service manual gives the location of the code for a particular engine.

FIGURE 4.4 Engine serial number locations.

Under-Hood Label

Vehicles produced since 1972 are equipped with under-hood emission control label (FIGURE 4... This label gives useful information to the technici...

FIGURE 4.5 An under-hood emission label.


CHAPTER 2 Engine Shop Safety 31

CASE HISTORY

A technician was removing an engine from a Volkswagen. When the fuel hose was disconnected, gasoline dripped on the floor. The technician accidentally dropped his shop light before the gasoline spill was cleaned up. The bulb in the shop light caused the gasoline to catch fire. The resulting fire destroyed the business. For safety, always use a light that is enclosed in a tube. (see figure below.)

This LED drop light is enclosed in a tube for safety.

FIGURE 2.13 An approved flammable storage cabinet.

Fuel Fires

Gasoline is a major cause of automotive fires. Liquid gasoline is not what catches fire. Rather, it is the vapors that are so dangerous. Gasoline vapors are heavier than air, so they can collect in low places in the shop. They can be ignited by a spark from a light switch, the motor, electrical wires that have been accidentally crossed, or a dropped shop light.

Two kinds of shop lights are acceptable. One has a fluorescent bulb enclosed in a plastic tube. The other uses a special spark-proof incandescent bulb.

Electrical Fires

Electrical fires are prevented by disconnecting the battery before working on the electrical system or around electrical components, such as the starter or alternator. Disconnect the battery ground cable first (FIGURE 2.14). This prevents the possibility of a spark occurring when a wrench completes a circuit between a "hot" cable and the ground cable.

If there is an electrical fire, the battery must be disconnected as fast as possible so the fire can be put out. Another advantage to removing the ground cable is that an electric cooling fan cannot accidentally turn on while working near it.

SAFETY NOTES

- Gasoline should be stored in an approved safety container and never in a glass jar.
- Never use gasoline to clean floors or parts. Stoddard solvent has a higher flash point than gasoline so it is safer to use. A flammable liquid's flash point is the lowest temperature where it can produce vapors, which can ignite or explode. The flash point of gasoline is −45°F (−43°C). This means that liquid gasoline produces explosive vapors at almost any temperature you will ever encounter. Diesel fuel is safer than gasoline. The flash point of diesel fuel is 125°F (52°C), which is one of the reasons why diesel engines are popular in boats and ships.
- Careless cigarette smoking or failing to immediately and thoroughly clean gasoline spills can contribute to a dangerous situation. People become used to working around gasoline and then begin to ignore how dangerous it can be.
- Do not attempt to siphon gasoline with your mouth. Accidental breathing of gasoline into the lungs can be fatal.

NOTE

The ground cable is the one bolted to the engine block. Do not assume the ground is the negative cable. On some older vehicles the positive cable is the ground.

Notes ▼

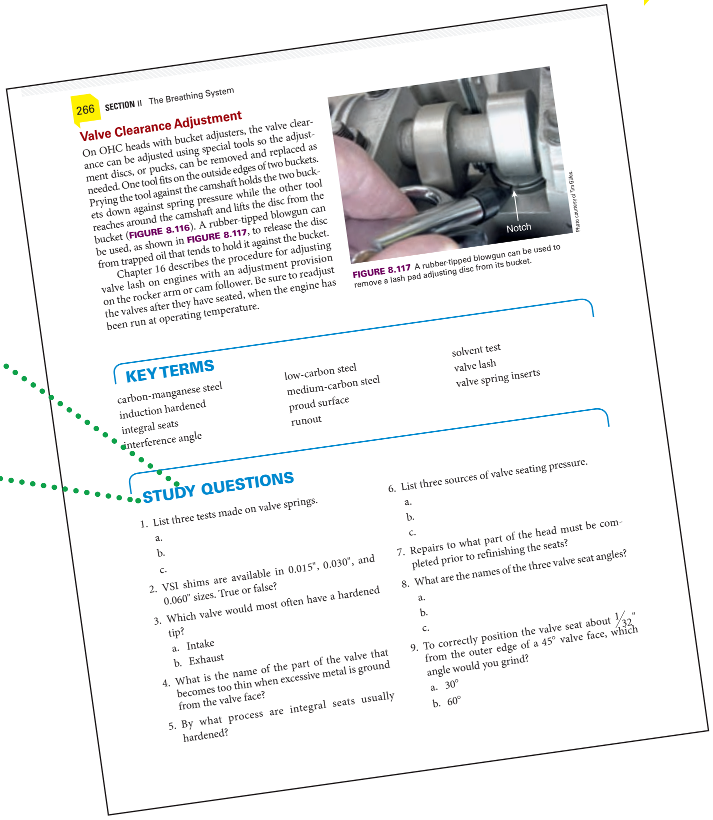
Throughout the text, notes are included to call attention to need-to-know information.

Ase-Style Review Questions ▶

Each appropriate chapter concludes with ten ASE-style review questions to help the reader prepare for the ASE Certification Exam.

Study Questions ▶

At the end of each chapter, there are 15 study questions of varying types. The questions provide an opportunity for reinforcement and review of key concepts presented in the chapter.



266 SECTION II The Breathing System

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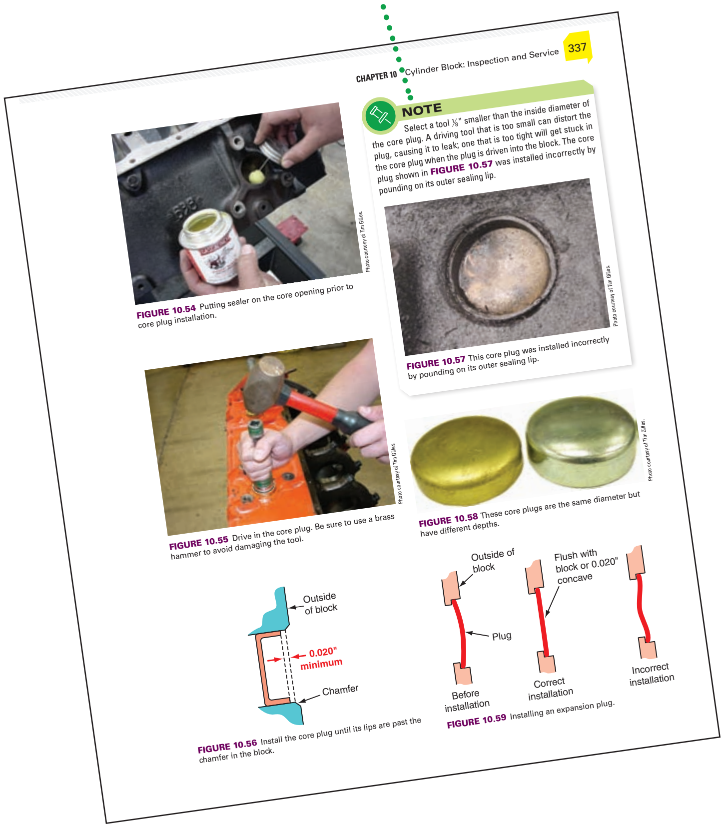
   a. 30°
   b. 60°

Instructor Resources

An Instructor Companion Website is available to instructors at login.cengage.com and includes the following components: an electronic Instructor's Guide with answers to all end-of-chapter questions, Word files of all end-of-chapter questions, Cengage Testing, Powered by Conero(R), with hundreds of questions for quizzes or exams, chapter presentations in PowerPoint for each chapter of the text, an Image Gallery with hundreds of illustrations to support in-class presentations, a NATEF AST/MAST correlation grid connecting the chapter content with the most current A1 task list, and electronic job sheets to guide students through common engine diagnosis and repair procedures.

Additional teaching materials are available for teachers at http://timgilles.com/.



CHAPTER 10 Cylinder Block: Inspection and Service 337

NOTE

Select a tool 1/8" smaller than the inside diameter of the core plug. A driving tool that is too small can distort the plug, causing it to leak; one that is too tight will get stuck in the core plug when the plug is driven into the block. The core plug shown in FIGURE 10.57 was installed incorrectly by pounding on its outer sealing lip.

FIGURE 10.54 Putting sealer on the core opening prior to core plug installation.

FIGURE 10.57 This core plug was installed incorrectly by pounding on its outer sealing lip.

FIGURE 10.55 Drive in the core plug. Be sure to use a brass hammer to avoid damaging the tool.

FIGURE 10.58 These core plugs are the same diameter but have different depths.

FIGURE 10.56 Install the core plug until its lips are past the chamfer in the block.

FIGURE 10.59 Installing an expansion plug.

MindTap for Automotive Engines: Diagnosis, Repair, and Rebuilding, 8th Edition

MindTap for *Automotive Engines* provides a customized learning experience with relevant assignments that will help students learn and apply concepts while it allows instructors to measure skills and outcomes with ease.

MindTap for *Automotive Engines* meets the needs of today's automotive classroom, shop, and student. Within the MindTap, faculty and students will find a variety of engaging activities including videos, animations, matching exercises, and gradable assessments. MindTap also offers students the opportunity to practice diagnostic techniques in a safe environment while strengthening their critical thinking and troubleshooting skills with the inclusion of diagnostic scenarios from Delmar Automotive Training Online (DATO).

About the Author

Tim Gilles has authored and coauthored several textbooks. He recently retired from the Automotive Technology Department at Santa Barbara City College, after having been a teacher for 38 years. He holds a Master of Arts degree in Occupational Education from Chicago State University and a Bachelor of Arts degree in Industrial Arts from California State University, Long Beach. He has held the industry certifications of ASE Master Engine Machinist and ASE Master Automotive Technician.

Tim has been active in professional associations for many years, serving as president and board member of the California Automotive Teachers (CAT) and as a board member and election committee chair of the North American Council of Automotive Teachers (NACAT). He has been a frequent seminar presenter at association conferences. Tim was a longtime member of the California Community College Chancellor's Trade and Industry Advisory Committee. He has been active in industry associations and groups, including AERA, ARC, ASCCA, and IATN, and served several terms as education representative on the board of the Santa Barbara Chapter of the Independent Automotive Professionals Association (IAPA).

ASE Certification Tests

The National Institute for Automotive Service Excellence (ASE) certifies automotive technicians in eight specialty areas of automotive and light truck repair. The engine repair certification test is A1. Tests are given on the Internet at proctored centers during eight months of the year. For more information, check the following URL: http://www.ase.com/Tests/ASE-Certification-Tests/Certification-Testing.aspx.

To become certified in one of the specialty areas, you must correctly answer between 60% and 70% of the questions, depending on the difficulty of the particular test. To become a Master Auto Technician, you must pass all eight tests. To receive certification, you must also have at least 2 years of automotive work experience and submit a reporting form to ASE. Your automotive education can count for one of those years. If you do not have the work experience, you can still take the tests. ASE will provide you with the test results and will certify you as soon as your experience requirement is met.

Many employers ask for ASE certification when they advertise a job opening. ASE certification provides a technician with a means of showing a prospective employer that he or she has a validated training background. The practice tests at the end of the chapters in this text provide examples of the types of questions that will be found on the ASE A1 test on Engine Repair. There is also a bank of sample ASE Engine test questions and explanations of the correct answers included at the back of this book.

AERA Engine Rebuilding and Machining Certificate Program

For many years, ASE and AERA developed and administered an Engine Machinist test series. The last administration of these tests was in November 2010. In the absence of ASE machinist certification following 2015, AERA has offered a comprehensive online self-paced training program leading to diploma-quality certificates in Cylinder Heads and Engine Machinist. Contact AERA at http://www.aera.org/ or phone 815-526-7600 for more information.

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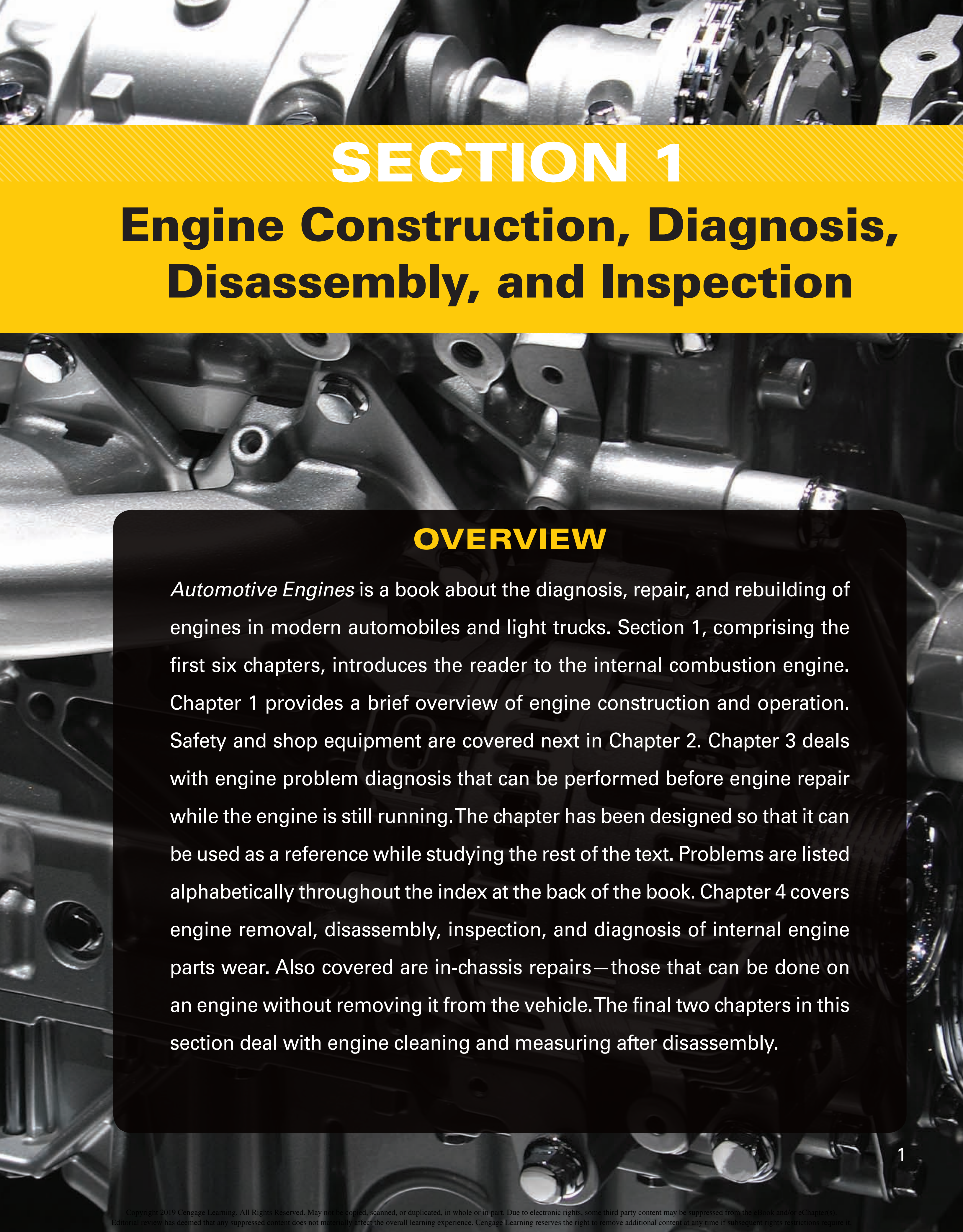
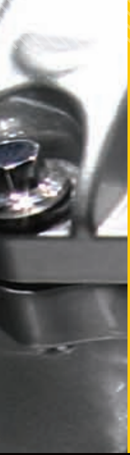


SECTION 1

Engine Construction, Diagnosis, Disassembly, and Inspection

OVERVIEW

Automotive Engines is a book about the diagnosis, repair, and rebuilding of engines in modern automobiles and light trucks. Section 1, comprising the first six chapters, introduces the reader to the internal combustion engine. Chapter 1 provides a brief overview of engine construction and operation. Safety and shop equipment are covered next in Chapter 2. Chapter 3 deals with engine problem diagnosis that can be performed before engine repair while the engine is still running. The chapter has been designed so that it can be used as a reference while studying the rest of the text. Problems are listed alphabetically throughout the index at the back of the book. Chapter 4 covers engine removal, disassembly, inspection, and diagnosis of internal engine parts wear. Also covered are in-chassis repairs—those that can be done on an engine without removing it from the vehicle. The final two chapters in this section deal with engine cleaning and measuring after disassembly.



CHAPTER 1

Engine Operation

CONTENTS

OBJECTIVES

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

- Explain the principles of internal combustion engine operation.
- Identify internal combustion engine parts by name.
- Explain various engine classifications and systems.

INTRODUCTION

Most of today's automobiles and light trucks are powered by a spark-ignited four-stroke reciprocating engine. The first engine of this type was built in 1876 by Nicolaus Otto in Germany. Thus, it was named the Otto-cycle engine. Compared to previous internal combustion engine designs using the same amount of fuel, Otto's four-stroke engine weighed less, ran much faster, and required less cylinder displacement to produce the same horsepower. A few years later, this engine design powered a motorcycle and then a horseless carriage. Other engine designs in limited use in modern autos include the rotary (Wankel), two-stroke, and compression ignition (diesel) engines.

In a spark-ignited internal combustion engine, a precise mixture of air and fuel is compressed in a cylinder. The fuel must be of a type that vaporizes easily (such as gasoline, methanol, or ethanol) or a flammable gas (such as propane or natural gas). When the compressed air-fuel mixture is burned, it pushes a piston down in a cylinder. This action turns a crankshaft, which powers the car (**FIGURE 1.1**).

SIMPLE ENGINE

A simple reciprocating engine has a cylinder, a piston, a connecting rod, and a crankshaft. The cylinder can be compared to a cannon and the round piston can be compared to a cannonball. The end of the cylinder is sealed with a cylinder head. The piston, which is sealed to the cylinder wall by piston rings, is connected to the crankshaft by a connecting rod and a piston pin (also called a wrist pin).

This arrangement allows the piston to return to the top of the cylinder, making continuous

Vintage Engines

Although Nicolaus Otto has been credited with the invention of the four-stroke internal combustion engine in 1876, the French inventor Alphonse Beau de Rochas developed the concept 14 years earlier in 1862. He applied for a patent but did not pay the required taxes so the French government did not validate his patent.

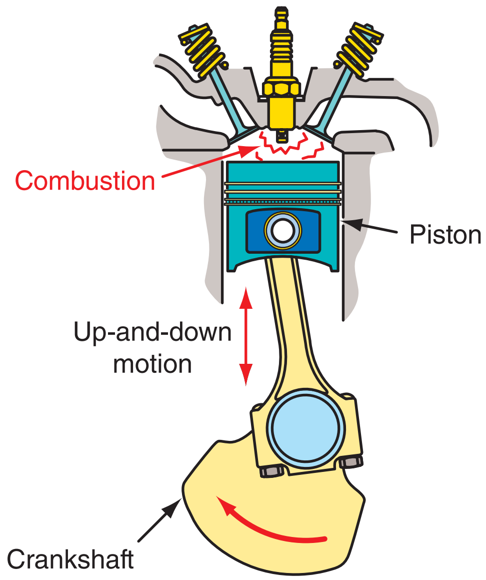


FIGURE 1.1 A piston forces a crankshaft to turn.

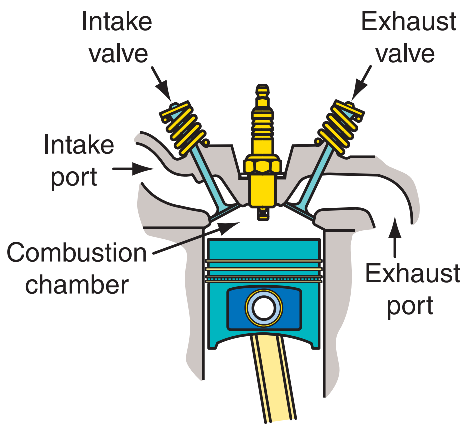


FIGURE 1.3 Valves seal off the valve ports.

rotary motion of the crankshaft possible. Because of the powerful impulses on the piston as the fuel is burned in the cylinder, a heavy flywheel is bolted to the rear of the crankshaft (**FIGURE 1.2**). The weight of the flywheel blends the power impulses together into one continuous motion of the crankshaft.

The cylinder head has one combustion chamber for each cylinder (**FIGURE 1.3**). An intake valve port allows a mixture of air and fuel to flow into the cylinder, and an exhaust valve port allows the burned gases to flow out. Each port is sealed off by a poppet-style valve. The head is sealed to the cylinder block with a head gasket (**FIGURE 1.4**). The opening of the valves is controlled by the camshaft (**FIGURE 1.5**).

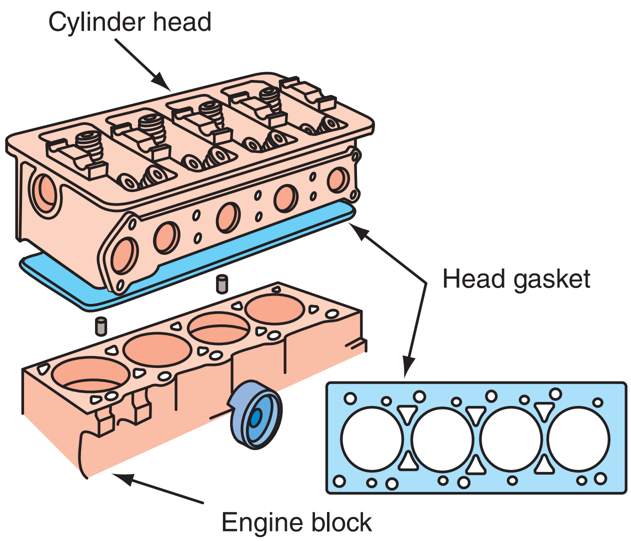


FIGURE 1.4 A head gasket seals the head to the block.

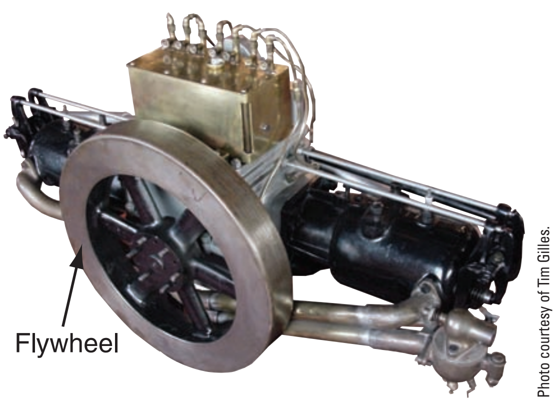


FIGURE 1.2 A flywheel is installed at the end of the crankshaft. This is a Buick opposed engine from the early 1900s.

FOUR-STROKE ENGINE OPERATION

A stroke is the movement of the piston from **TDC** (top dead center) to **BDC** (bottom dead center), or from BDC to TDC. There are four strokes in one four-stroke cycle of the engine. They are called the intake stroke, compression stroke, power stroke, and exhaust stroke.

- *Intake Stroke*. Gasoline will not burn unless it is mixed with the correct amount of air. It is very explosive when 1 part is mixed with about 15 parts of air. Shortly before the piston reaches TDC, the intake valve begins to open. As the crankshaft turns, it pulls the rod and piston down in the

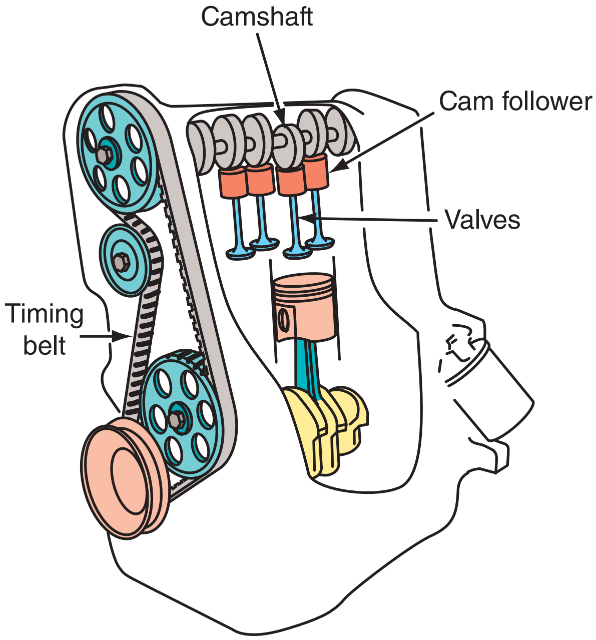


FIGURE 1.5 The opening of the valves is controlled by the camshaft.

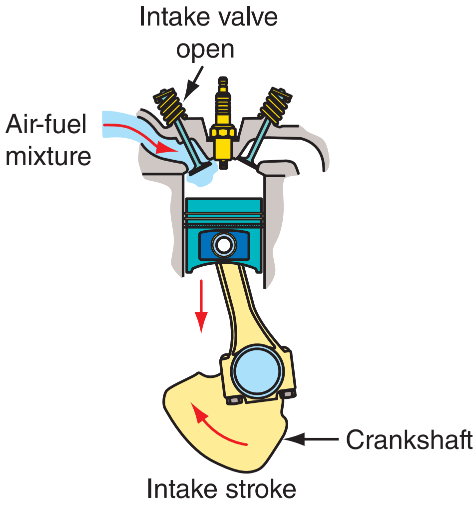


FIGURE 1.6 The air-fuel mixture is drawn into the cylinder.

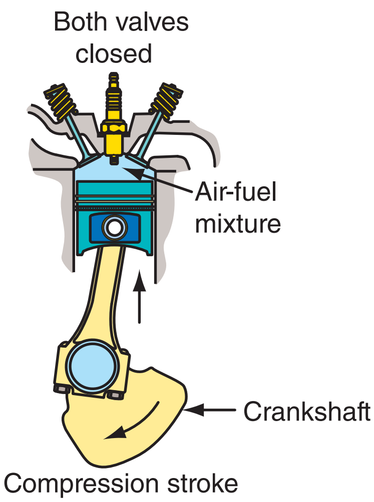


FIGURE 1.7 The air-fuel mixture is compressed as the piston moves up in the cylinder.

cylinder toward BDC (**FIGURE 1.6**). This action creates a low-pressure void that is filled by atmospheric air pressure and fuel through the open intake valve. About 10,000 gallons of air is drawn in for every 1 gallon of fuel supplied by the fuel system. The ideal mixture (called stoichiometric) for the combined purposes of engine performance, emission control, and fuel economy is about 14.7:1 (at sea level).

Older vehicles had carburetors and newer vehicles manufactured since the mid-1980s have fuel injection systems with computer controls. The computer monitors the oxygen content in the vehicle's exhaust and then adjusts the fuel supply to provide the correct amount of fuel and air for each intake stroke.

As the crankshaft continues to turn, the piston begins to move back up in the cylinder and the intake valve closes.

- *Compression Stroke*. The piston moves up in the cylinder, compressing the air-fuel mixture (**FIGURE 1.7**). If you light a puddle of gasoline on fire in open air, it does not produce power. If it is confined in a cylinder, however, usable power can be produced. Compressing the mixture of air and fuel into a smaller area makes it easier to burn. The compression stroke begins at BDC after the intake stroke is completed. As the piston moves toward TDC, both of the valves are closed as the mixture is compressed to about $\frac{1}{8}$ of the volume it occupied when the piston was at BDC. In this case, the **compression ratio** is said to be 8:1 (**FIGURE 1.8**). If the mixture is compressed to $\frac{1}{12}$ its original volume, the compression ratio is then 12:1.
- *Power Stroke*. As the piston approaches TDC on its compression stroke, the compressed air-fuel mixture becomes very explosive (**FIGURE 1.9**). When the ignition system generates a spark at the spark plug, the fuel ignites. The air-fuel mixture burns,

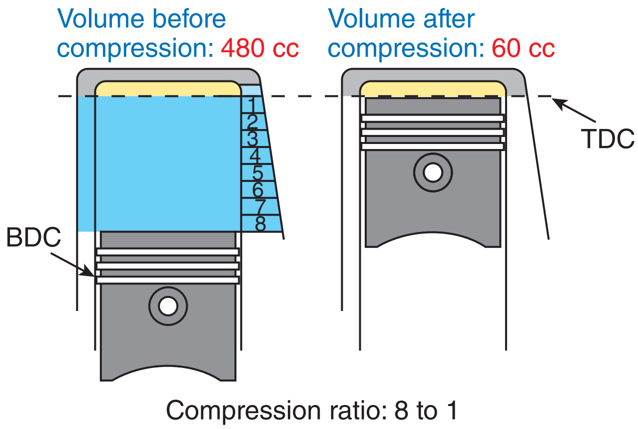


FIGURE 1.8 Compression ratio is a comparison of the volume of the air space above the piston at BDC and at TDC. In this example the compression ratio is 8:1.

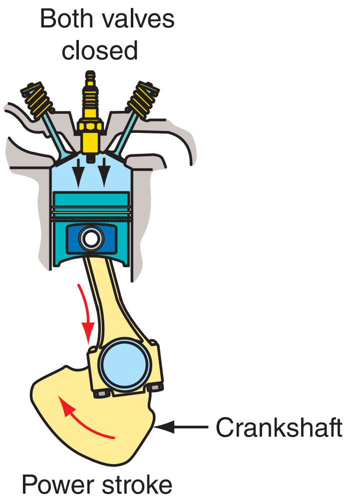


FIGURE 1.10 The air-fuel mixture ignites, pushing the piston down.

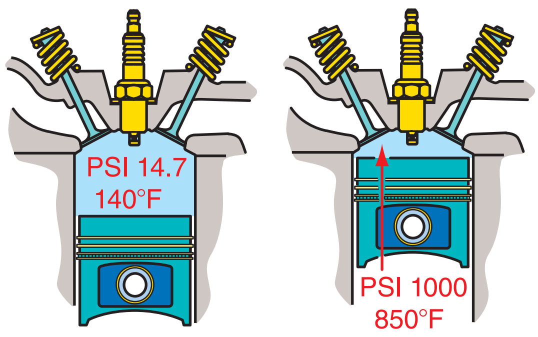


FIGURE 1.9 The air-fuel mixture heats up as it is compressed.

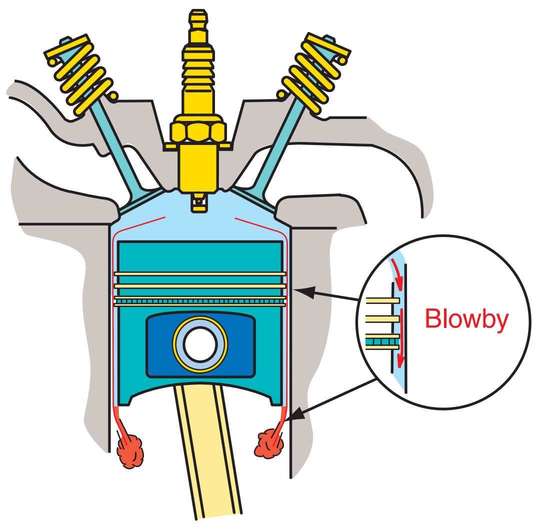


FIGURE 1.11 Blowby into the crankcase is leakage of gases past the piston rings. It starts in the combustion chamber in gasoline and diesel engines.

but it must not explode. As the mixture burns, it expands, forcing the piston to move down in the cylinder until it reaches BDC (**FIGURE 1.10**). The action of the piston turns the crankshaft to power the car. The power stroke is sometimes called the expansion stroke.

Some leakage of gases past the rings occurs during the power stroke. This leakage, called **blowby**, causes pressure in the crankcase (**FIGURE 1.11**). Blowby starts in the combustion chamber in both gasoline and diesel engines.

- *Exhaust Stroke*. As the piston nears BDC on the power stroke, the exhaust valve opens, allowing the spent gases to escape. Because the burning gases are still expanding, they are forced out through the open exhaust valve. As the crankshaft continues to turn past BDC, the piston moves up in the cylinder, helping to push the remaining exhaust gases out through the open exhaust valve (**FIGURE 1.12**). A few degrees after the piston passes TDC, the exhaust valve closes. The entire four-stroke cycle repeats itself, starting again as the piston moves down on the intake stroke.

The four-stroke cycle is considerably more complicated than this simple explanation. When the engine is running, the timing of the opening and closing of the valves actually determines when each stroke effectively begins. Valve timing is discussed in much greater detail in Chapter 9.

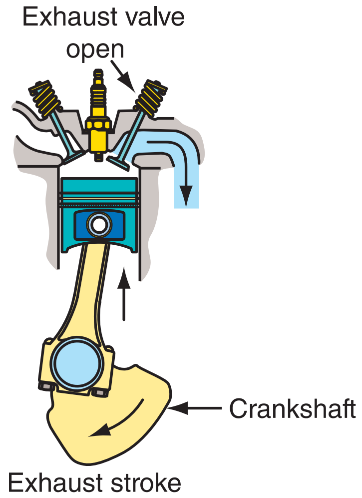


FIGURE 1.12 The exhaust valve opens and exhaust gases escape as the piston comes up.

CYLINDER ARRANGEMENT

Automobile and light truck engines have three, four, five, six, eight, or more cylinders. Cylinders are arranged in one of three ways: in-line, in a "V" arrangement, or opposed to each other (**FIGURE 1.13**). In-line six-cylinder and V6 engines are shown in **FIGURE 1.14**.

The V arrangement is popular with designers when an engine has more than four cylinders because this design can be considerably shorter in length.

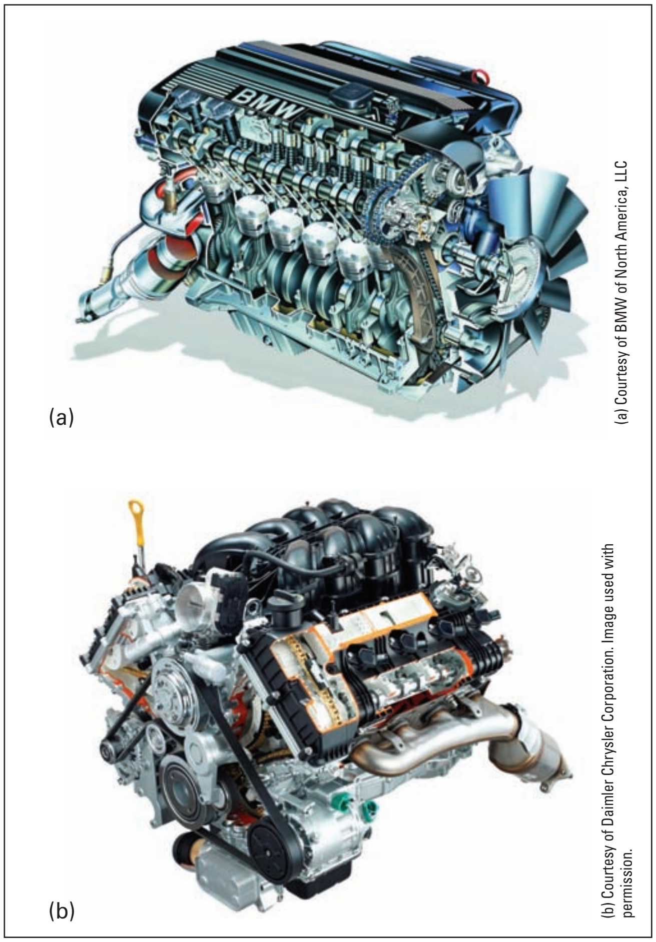


FIGURE 1.14 (a) Section view of an in-line six-cylinder engine. (b) Section view of a V8 engine.

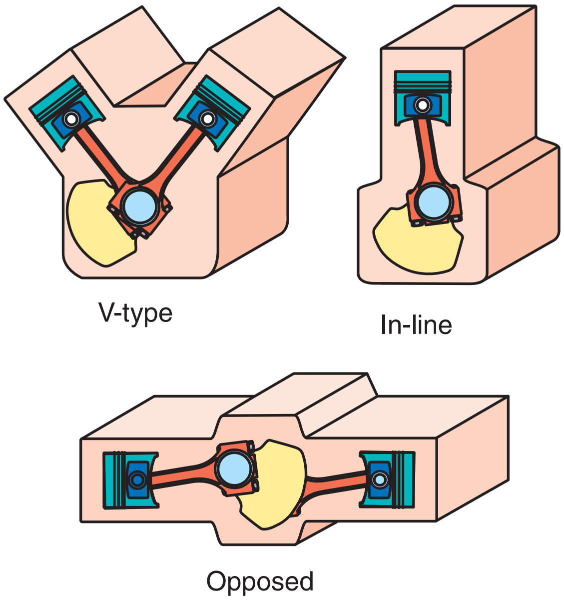
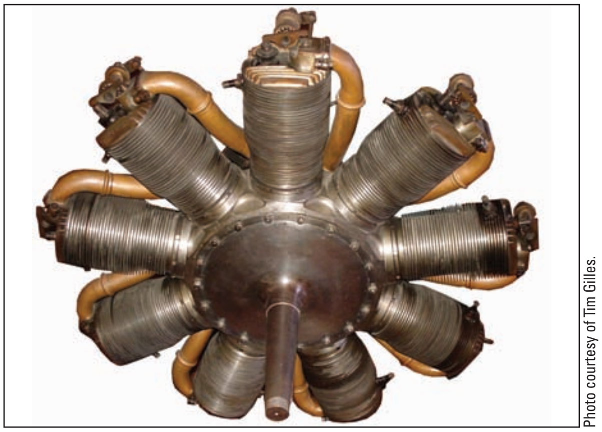


FIGURE 1.13 Cylinder arrangements.

Vintage Engines

In the first half of the 20th Century, before the jet age, airplane engines had cylinders arranged in a radial arrangement. (**see figure below**.)



A radial engine from a vintage airplane.

A completely assembled V-type engine typically weighs less than an in-line engine with the same number of cylinders.

V-type engines have connecting rods from two cylinders on opposite sides of the engine that share one crankpin (see Chapter 11). This allows the engine block to have fewer supports for the crankshaft main bearings. An in-line six-cylinder engine might have seven main bearings; a V6 block is shorter and will typically have only four main bearings. A V8 block will usually have five main bearings.

VALVETRAIN

One complete four-stroke cycle requires the crankshaft to rotate two times. Two 360° crankshaft revolutions means the crankshaft travels a total of 720° to complete one cycle. During these two revolutions, each cylinder's intake and exhaust valves open once. The valves are opened by the camshaft, commonly called the "cam," which is considered the "heart" of the engine. The cam has lobes that are off-center and push against the valvetrain parts, causing the valves to open at precise times (**FIGURE 1.15**).

The camshaft controls the rate at which the engine breathes. Its design can be for best operation at maximum power and high speed, or for fuel economy and best low-speed operation. A production engine is an engine produced at the factory. Production engines are a compromise between these two concerns, and this is the reason many late-model vehicles use variable valve timing. Chapter 19 deals with different "cam grinds" and variable valve timing in detail.

Camshafts can be located either in the block (see **FIGURE 1.15a**) or in an overhead cam cylinder head (see **FIGURE 1.15b**). One or more camshafts are driven via crankshaft rotation using one of several combinations, including gears or sprockets and chains or belts. The crank must turn twice for every one turn of the cam, so there are half as many teeth on the crank drive as there are on the cam drive (**FIGURE 1.16**).

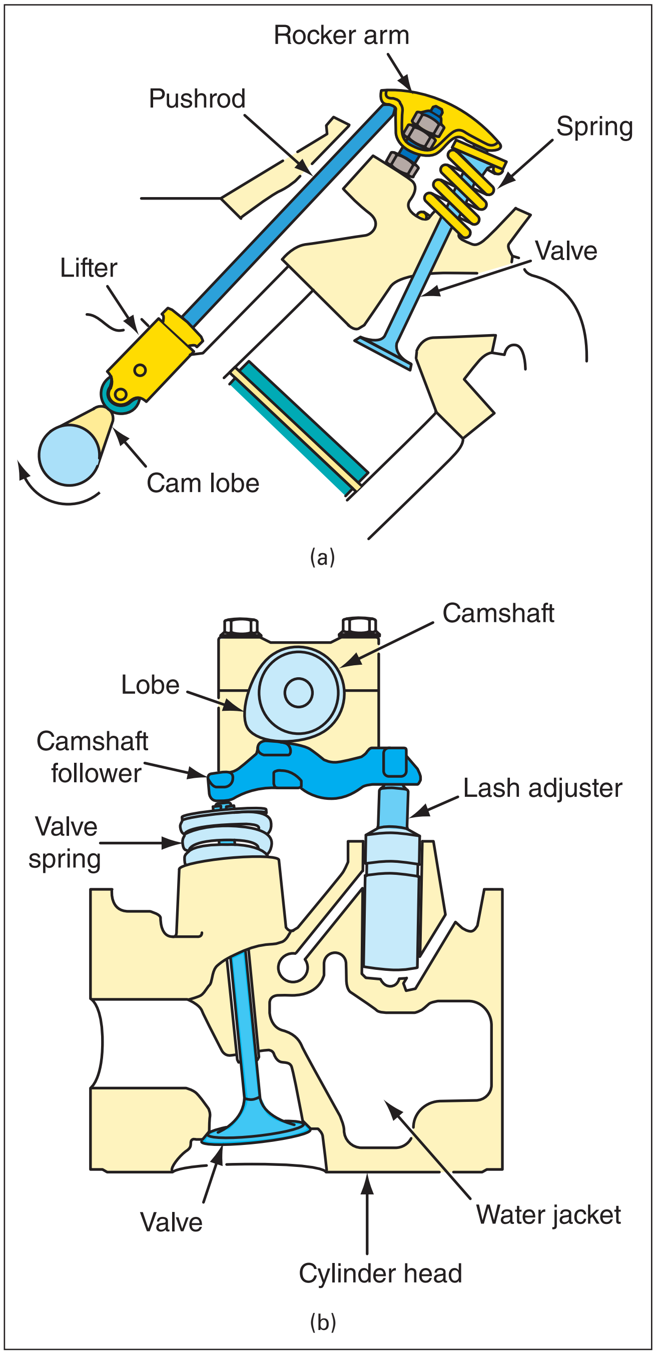


FIGURE 1.15 A cam lobe forces the valve open. (a) The cam-in-block design uses pushrods to open valves. (b) In the overhead cam design, the camshaft is located in the cylinder head.

Vintage Engines

A V-type engine uses a carburetor more efficiently than an in-line engine. This is because the intake manifold runner lengths are more equal (see Chapter 17).

CYLINDER BLOCK

The cylinder block is an intricate casting that includes oil galleries as well as jackets for coolant, which are commonly called *water jackets*. Cylinder blocks are made of cast iron or aluminum, cast into a mold. Many engine blocks today are made of aluminum with iron

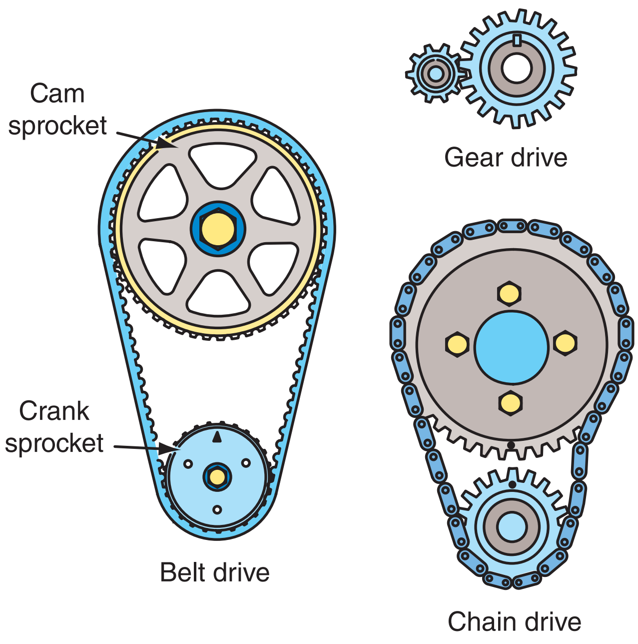


FIGURE 1.16 There are half as many teeth on the crank drive as there are on the cam drive.

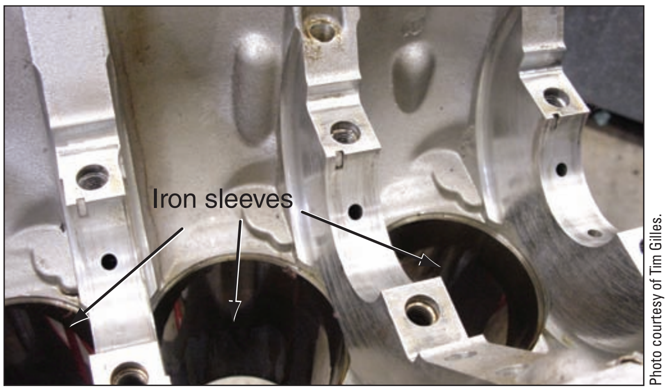


FIGURE 1.17 An aluminum block with cast iron sleeves.

cylinder bore liners called sleeves (**FIGURE 1.17**). This allows for the weight savings provided by aluminum, coupled with the durability and trueness of cast iron in the cylinder bore area. Some aluminum blocks do not have iron sleeves because aluminum cylinder wall surfaces can be made very hard.

There are different casting processes for engine parts, including sand and foam.

Sand Casting

The sand casting process uses a zircon sand mold made up of several sections, called cores (**FIGURE 1.18**). The mold is suspended in a container, or core box, with a liner that will provide the shape for the outside surface of the engine block. The mold is supported at several points around the outside of the core box; the supports will leave core holes in the finished block. Glue binders and a hardener hold the grains of sand together. They are mixed with the sand and blown into an iron master mold. Next a gas is injected to cure the sand into a hard core mold.

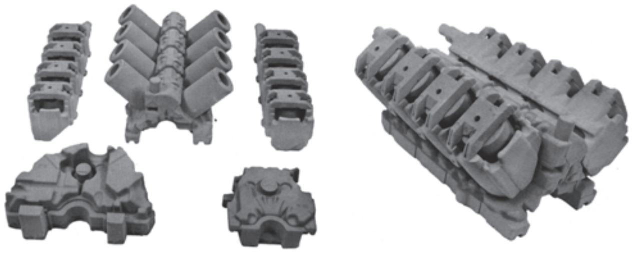


FIGURE 1.18 Sand casting cores.

Most of today's blocks are made of aluminum alloy. When iron liners are used in aluminum blocks, they are inserted into the cylinder block core. They are heated before the pour to help them bond to the molten aluminum. Oil gallery areas of the core are coated with talcum powder to prevent sand from sticking to the aluminum during the pour. Otherwise, the sand might contaminate engine lubricating oil.

Molten aluminum is poured into the mold at 1,500°F. The mold cavity is filled from the bottom to prevent oxidation when the molten aluminum contacts air. If the mold was filled from the top, aluminum oxide would contaminate the pour. Following the pour, the aluminum casting is placed for a few hours in an oven for heat treating to strengthen the block. This process also bakes the binder that holds the sand mold together, loosening the sand. Then a robot rotates and vibrates the casting to expel the loose sand. The casting is rough machined before sending it to another plant that does the finish machining and assembly.

Lost Foam Casting

In another casting process, *lost foam casting (LFC)*, a foam mold pattern, is "lost" or burned up as it is replaced by molten metal during the pour. General Motors first experimented with LFC in 1982 and since then has refined the process for use in casting blocks, heads, and crankshafts. GM's now-defunct Saturn line used this process since its beginning in 1990 and GM has been routinely casting aluminum heads and blocks in its other divisions using LFC since 1999. With conventional sand casting, oil galleries must be machined in the block casting. With LFC, the oil galleries and coolant passages can be cast into the part. Foam also provides a more accurate casting compared to sand casting. The completed casting is smoother in appearance and there are no parting lines. The mold is often made in pieces, which are fastened together using hot-melt glue to make up the finished model. These more intricate castings are possible because the pattern does not need to be removed as was the case with sand castings.

The LFC pattern is made of expendable polystyrene beads, otherwise known as Styrofoam. Patterns are made by injecting the beads into a die and then superheating them with steam to bond them together and form the finished mold. The foam pattern is coated with a refractory coating, which smoothes the surface of the pattern. Gates and risers are attached to the pattern to allow for the pouring and venting of the molten metal. Unlike the conventional sand casting process, which uses binders to hold the sand together, LFC uses dry, unbonded sand that is poured around and into the internal passages in the pattern. The sand is vibrated and compacted to thoroughly fill the voids around the pattern. During the pour, the molten metal replaces the pattern as it vaporizes. When the finished casting has cooled and become solid, the unbonded sand is dumped out. It can be reused, unlike conventional casting sand, which requires disposal.

A typical passenger car engine today uses a cast aluminum cylinder block with cast iron cylinder sleeves. The sleeves are ground to size on the outside diameter (O.D.), chilled, and pressed into machined holes in the aluminum block. This allows the iron liners to dissipate heat into the aluminum casting and water jackets. The inside diameter (I.D.) of the cast iron sleeves is bored and honed to approximately 1.5 mm thick when finished, providing an excellent wear surface for the piston rings.

Core Plugs and Gussets

Gussets to add strength are cast in strategic positions on the block. Core holes in the block and head(s) are closed off with core plugs (**FIGURE 1.19**). Core plugs are usually made of steel or brass, although rubber and copper expandable plugs are available, too. Brass core plugs are superior because they do not rust. Brass plugs are not used in new cars because of their extra cost and because new engines are filled with coolant, which prevents rust. Core plugs are sometimes referred to as expansion plugs, welsh plugs, freeze plugs, or soft plugs.

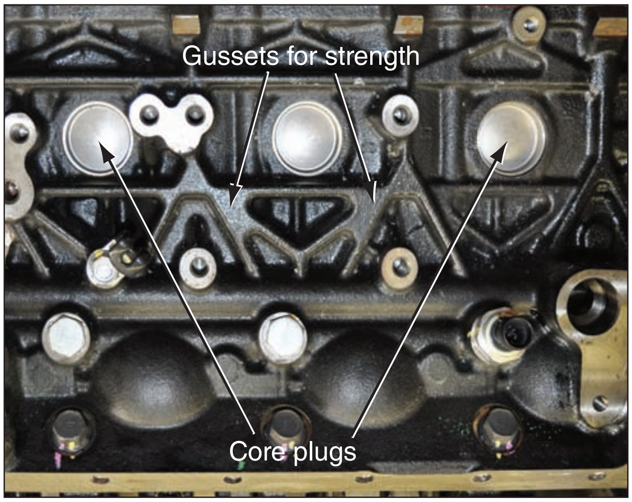


FIGURE 1.19 Core plugs.

V-Type Cylinder Banks

On V-type blocks, cylinders are cast in two rows called left and right banks.

NOTE

The location of the left and right banks is determined when viewing from the transmission end of the engine.

V8 blocks are cast with the cylinder banks separated by a 90° angle. V6 blocks have either 60° or 90° between banks. There are also unusual engine designs, such as Volkswagen's V6, which has 15° between banks.

There are *big block* and *small block* engine designs. Smaller, lighter blocks are more popular in passenger cars because of their fuel efficiency. Some intake manifolds cover the area between the heads known as the *valley* (**FIGURE 1.20**), whereas others use covers and a separate intake plenum.

A complete block assembly with the entire valvetrain (cylinder heads and related parts) included is called a *long block*.

Short Block and Long Block

The cylinder block assembly (without the heads installed) is called a *short block*. The short block includes the crankshaft, piston and rod assembly, and all bearings. On pushrod engines, the camshaft, timing sprockets, and timing chain are also part of the short block (**FIGURE 1.21**).

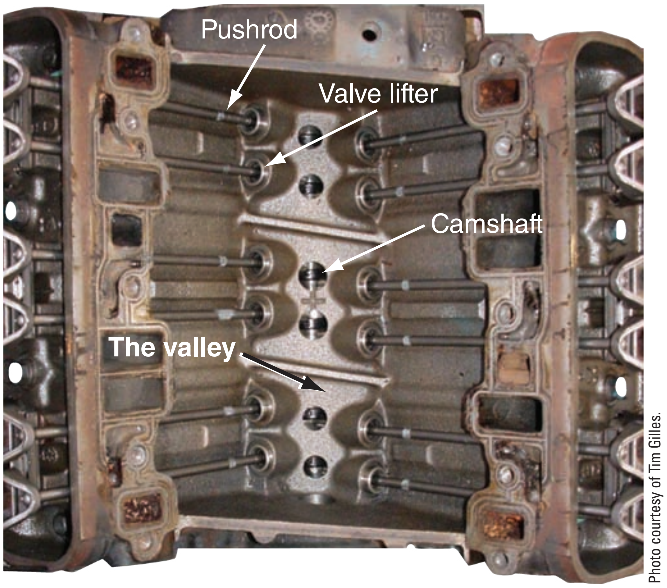


FIGURE 1.20 The area between the heads of a V-type engine is known as the valley.

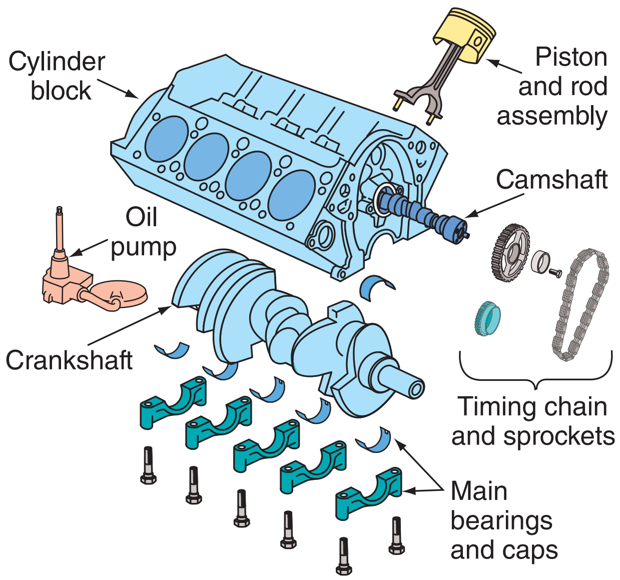


FIGURE 1.21 Exploded view of a short block for a cam-in-block engine.

The lower area of the cylinder block surrounded by the oil pan is called the *crankcase* because the crankshaft is located there. Main bearing bore holes are precisely align-bored in the lower end of the block to provide a mounting place for the main bearings and crankshaft. Main bearing caps are removable, but they must be replaced in exactly the same location. At the factory, the camshaft bore holes, cylinder bores, cylinder head mounting surface, all threaded holes, and all gasket surfaces are machined automatically and in perfect alignment to each other. During rebuilding, the technician or machinist's job is to maintain the original alignment.

The following lists typical components common to both short and long blocks:

- *Oil Pan*. The oil pan is a stamped sheet metal or cast aluminum part that encloses the crankcase (**FIGURE 1.22**). It provides a reservoir where the engine oil is cooled as air passes across its surface. Oil pans are sometimes damaged when driving or during engine removal and replacement. Sometimes a sheet metal oil pan can be bent enough so that the crankshaft comes in contact with it. After a rebuild, the resulting noise can cause a great deal of worry when the engine is first started.
- *Flywheel*. Mounted on the rear of the crankshaft is a flywheel or flexplate. The weight of the flywheel helps carry the crankshaft beyond BDC after the power stroke and smoothes out the power impulses of multiple cylinders. A flywheel is used with a standard transmission. It also provides a surface for the clutch to work upon. When the vehicle is equipped with an automatic transmission, a torque converter and flexplate are used (see Chapter 4). A ring gear on the circumference of the flywheel or flexplate provides a gear drive for the starter motor. Ring gears on flywheels and flexplates are sometimes damaged by faulty starter motors. Replacement of a flywheel ring gear or a

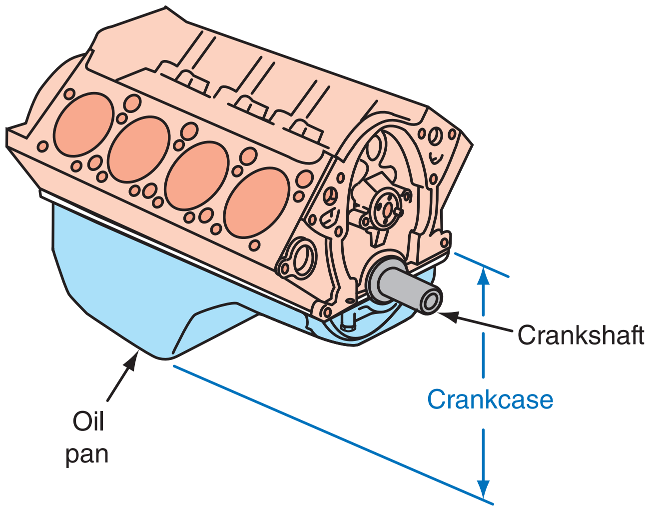


FIGURE 1.22 The oil pan encloses the crankcase.

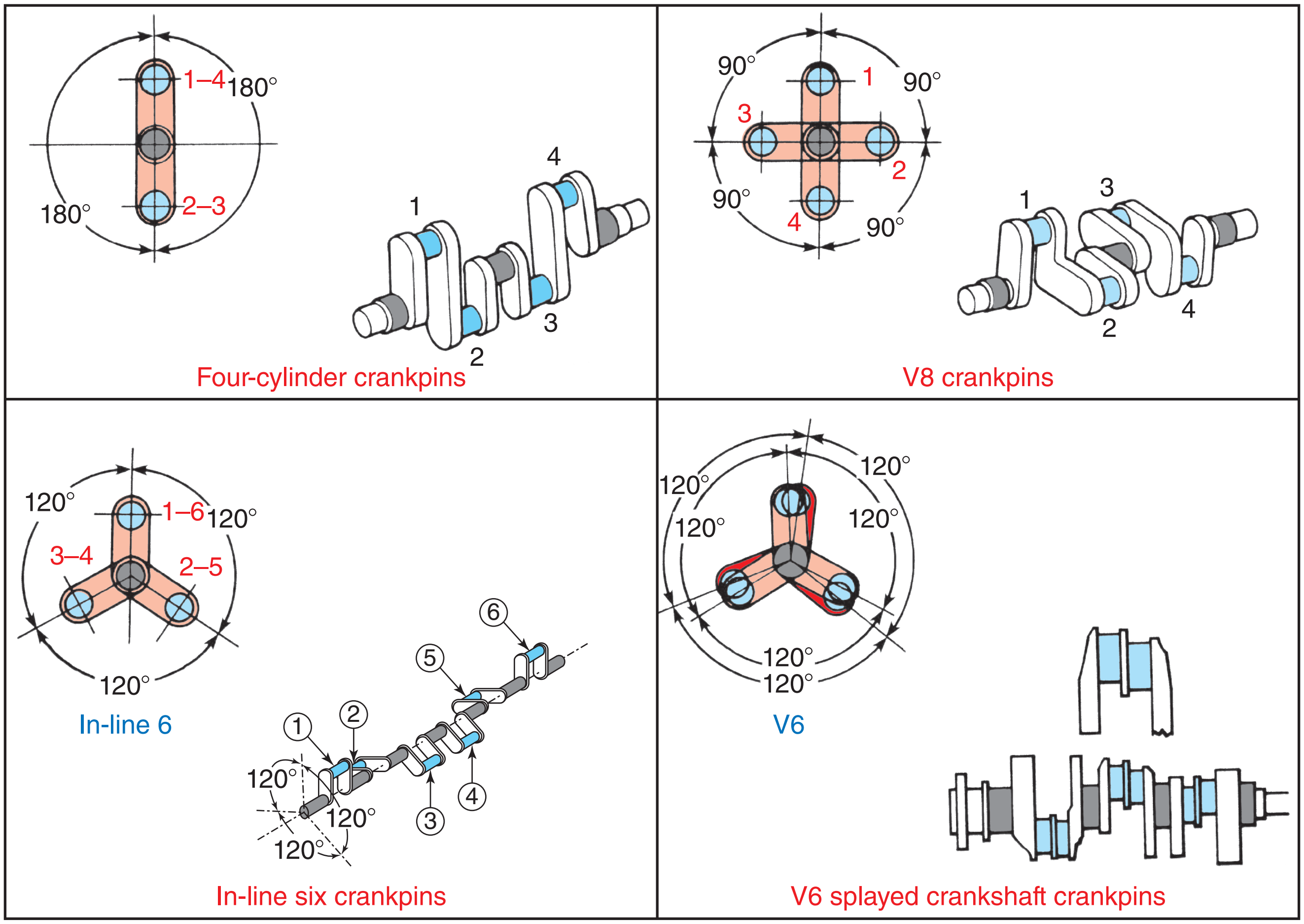


FIGURE 1.23 Crankshaft rod journals are offset 180° for four cylinders, 120° for six cylinders, and 90° for eight cylinders.

flexplate is a relatively easy job while the engine is out of the vehicle.

- *Vibration Damper*. The vibration damper, also called a *harmonic balancer*, is mounted on the front of the crankshaft on V-type and in-line six-cylinder engines. The power impulses on the pistons cause the crankshaft to twist and untwist in much the same manner as a tuning fork vibrates. The damper dampens out these torsional vibrations, which could result in a broken crankshaft if allowed to continue. Most four-cylinder engines do not require a damper and use only a pulley.
- *Crankshaft*. The crankshaft is made of either cast iron or forged steel. Its bearing surfaces for the main and rod bearings are called *journals*. The main bearing journals are those that run down the centerline of the crankshaft, in line between the front and rear journals. Oil galleries provide lubrication to the main bearing journals through oil holes in the main bearings. Holes are drilled in the crankshaft, from the main bearing journals to the connecting rod bearing journals, to provide the rod bearings with pressurized lubrication.

Rod journals, also called crankpins, are offset 90°; on V8s, 180° on four-cylinders, and 120° on six-cylinders (**FIGURE 1.23**). Some V6s have offset crankpins (also see Chapter 11).

FRONT-WHEEL DRIVE

Front-wheel drive (FWD) vehicles often use a **transverse** (sideways) **engine** (**FIGURE 1.24**). The smaller four-cylinder engines and the 60° V6 are suited for small car, FWD use, although there are some 90° V6 engines in FWD vehicles; larger engines tend to be used in rear-wheel drive (RWD) vehicles. Some manufacturers have used large engines in FWD cars. If FWD drive shafts are not of equal length, a car with substantial horsepower will experience torque steer. Torque steer is when the vehicle pulls to one side under heavy acceleration.

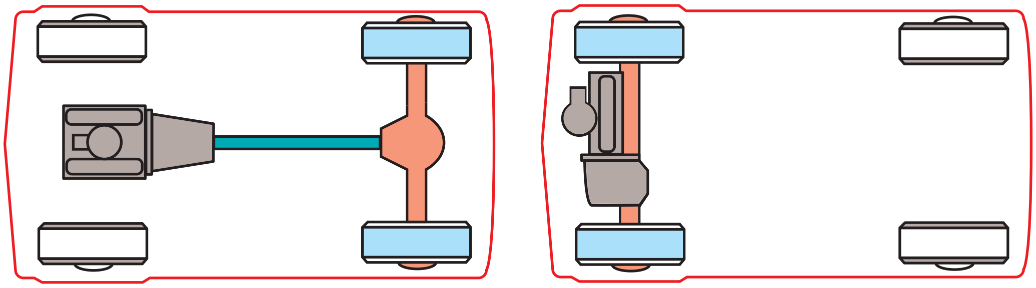


FIGURE 1.24 Rear-wheel drive (RWD) and front-wheel drive (FWD) engines.

ENGINE CLASSIFICATIONS

Engines are classified according to their displacement and valve arrangement. **Displacement** refers to the volume that the piston displaces in the cylinder (**FIGURE 1.25**). The engine's total displacement is determined by multiplying:

$$\text{Bore}^2 \times \text{Stroke} \times 0.7854 \times \text{Number of Cylinders} = \text{Displacement}$$

The larger the displacement, the larger the engine. Engine size in North American vehicles used to be described in CID, or cubic inch diameter. In late-model vehicles, volume is described in liters or cubic centimeters. One liter is approximately 61 cubic inches. Converting between metric system measurements and English system measurements is covered in Chapter 6.

Another means of determining displacement is to multiply the swept volume of the cylinder by the number of cylinders. Swept volume is determined by multiplying:

$$\frac{\text{Bore}}{2} \times \frac{\text{Bore}}{2} \times \text{Stroke} \times \pi\,(3.14) = \text{Swept Volume}$$

Valve Arrangement

Modern engines use an *overhead valve (OHV)* arrangement known as *I-head* or *valve-in-head* (**FIGURE 1.26**). This design has a more direct path of air-fuel flow than earlier engine designs. Fewer exhaust emissions are produced because of the smaller amount of surface area in the combustion chamber. When cool engine surfaces are exposed to unburned fuel, a *skin effect* occurs and the unburned fuel ends up in the exhaust stream.

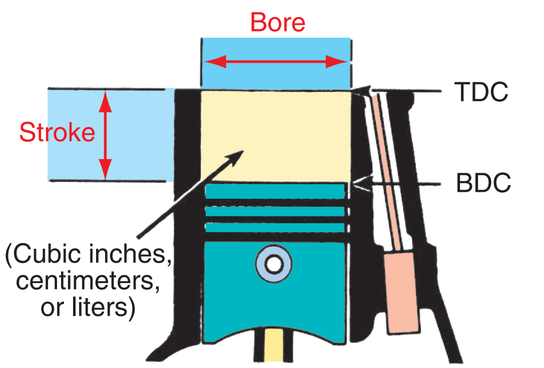


FIGURE 1.25 Displacement is a measurement of the cylinder's volume.

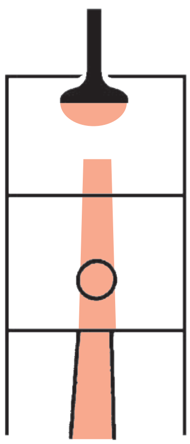


FIGURE 1.26 When the valves are in the cylinder head, the engine is known as an I-head engine.

Increasing the valve opening, called *valve lift*, to a certain point is necessary to allow enough air-fuel mixture into the cylinder to develop maximum power. Increased valve lift is possible with the I-head engine design. This is because as the intake valve opens, the piston is moving down in the cylinder, providing clearance. When the exhaust valve is wide open, the piston is near the bottom of the cylinder, providing plenty of piston-to-valve clearance as well. If more air-fuel mixture is packed into the cylinder, more power will be developed. This is called volumetric efficiency, which is the reason that supercharging is so effective in producing extra power from relatively small engines. In supercharged engines, an air pump compresses more air-fuel mixture into the cylinder (see Chapter 18).

Cam-in-Block or Overhead Cam

Some I-head engines have the camshaft located in the block. This engine design is called a *pushrod engine*, or *cam-in-block engine*. Cam lobes raise valve lifters that act on pushrods to operate rocker arms and open the valves (**FIGURE 1.27**). In late-model vehicles, pushrods are found most often on V-type engines.

A more popular type of valve operating arrangement for late-model engines is the *overhead cam* design, or OHC. This engine has the camshaft mounted on top of the cylinder head just above the valves (**FIGURE 1.28a**). It has the advantage of having fewer parts and less weight. *An engine running on the freeway at 3,000 rpm has to open and close a valve 25 times per second*, so valvetrain weight is very

Vintage Engines

Until the early 1950s many automobiles had L-head engines whose valve configuration resembles the letter L upside down (**FIGURE A**). These engines, also called *flatheads* or *sidevalves*, are still used in lawnmowers, generators, and other industrial engines. L-head engines are less expensive to manufacture, but they produce more smog due to the high amount of surface area exposed to unburned fuel. Flatheads are also limited in their compression ratio and valve lift. Increased valve lift requires more clearance in the combustion chamber, which lowers compression.

The photo in **FIGURE B** shows an L-head Studebaker engine with the cylinder head removed. Notice how the valves are located in the block. Flatheads were very popular with early hot rodders and racers (**FIGURE C**). A popular hot-rodding trick was to remove the cylinder head (a relatively easy thing to do) and mill it to increase the compression ratio.

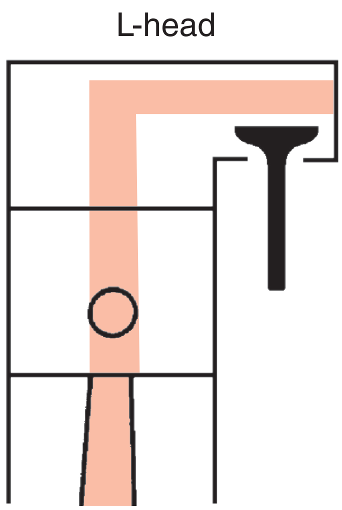


FIGURE A An L-head, or flathead, engine has the valves in the block.

Photo courtesy of Tim Gilles.

FIGURE B A flathead Studebaker block with the head removed.

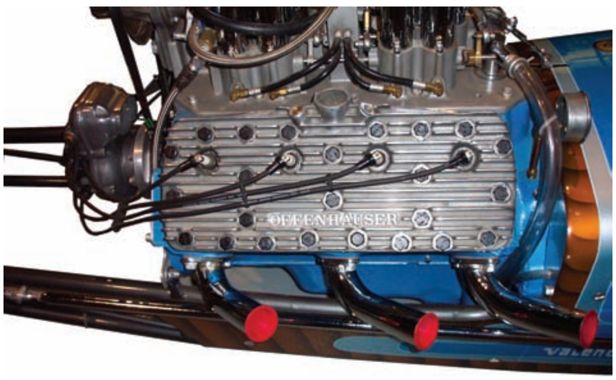


Photo courtesy of Tim Gilles.

FIGURE C A flathead V8 engine from a vintage dragster.

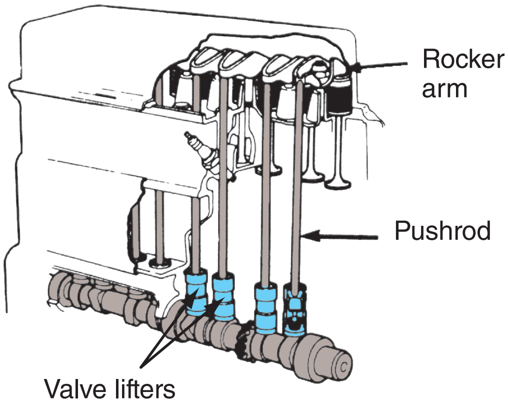


FIGURE 1.27 Some overhead valve (I-head) engines use pushrods to operate rocker arms.

important. It is even more important in high-speed engines.

Some OHC engines have a single cam (SOHC). Each cylinder is provided with two separate lobes to operate the intake and exhaust valves. High-performance OHC engines often have two cams per cylinder head. On this design, known as dual overhead cam (DOHC), one camshaft operates the intake valves and the other operates the exhaust valves (**FIGURE 1.28b**). DOHC engines have become more common in recent years as the base engine of many vehicle manufacturers.

The OHC engine uses a long chain or belt from the crankshaft to the cylinder head to drive the cam(s) (**FIGURE 1.29**). When the ignition system uses a distributor, some OHC engines use an auxiliary shaft to drive it, whereas others have a crankshaft-driven distributor.

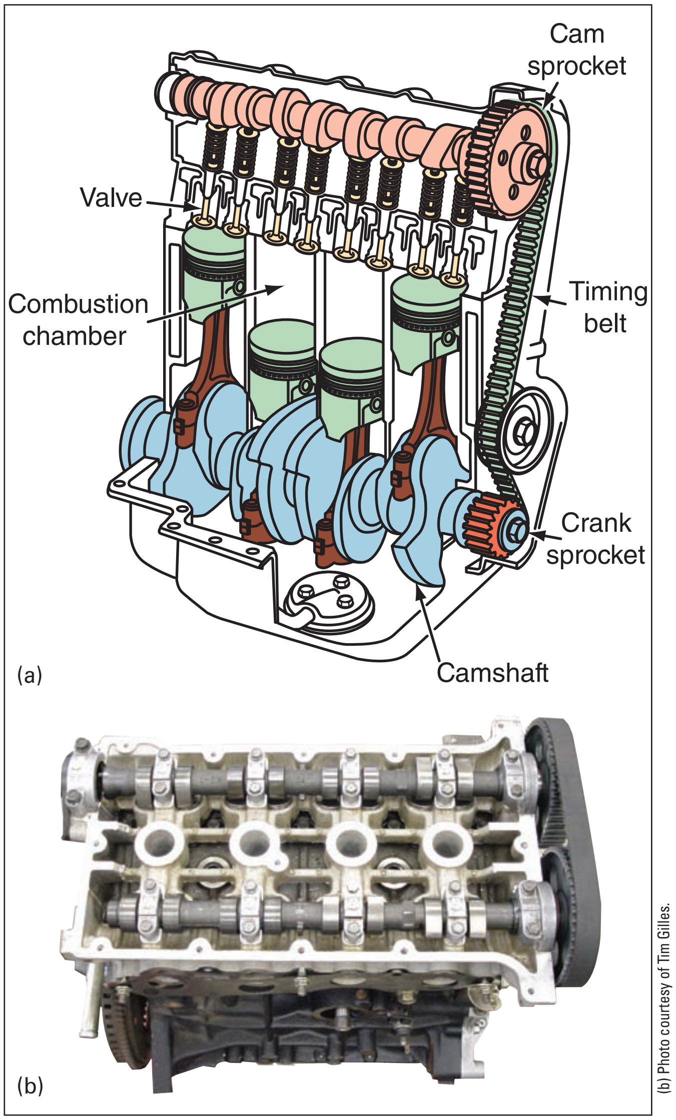


FIGURE 1.28 In-line four-cylinder overhead cam engine designs. (a) An OHC engine with the cam positioned over the valve. (b) A dual overhead cam (DOHC) engine.

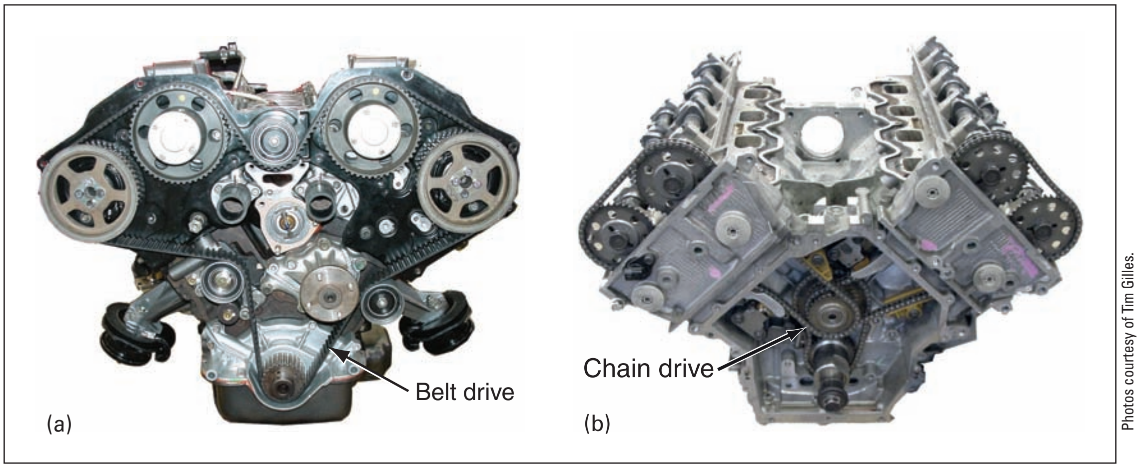


FIGURE 1.29 V-type overhead cam engines. (a) Belt-driven overhead cam V6. (b) Chain-driven overhead cam V8.

Vintage Engines

OHC was limited in the past to smaller, in-line engines, except for its use in luxury or racing automobiles. In recent years, belt-driven OHC engines have become commonplace. The first DOHC engine was in a 1912 Peugeot.

COMBUSTION CHAMBER DESIGNS

The principal combustion chamber designs are the hemi, the wedge, and the pent-roof. There are also some combustion chamber designs with "D" or heart shapes. The wedge is the most common combustion chamber design with pushrod engines (**FIGURE 1.30**). It has a squish/quench area that causes movement (turbulence) of the air-fuel mixture and cooling of the gases to prevent abnormal combustion (see Chapter 3). This movement causes more complete burning at lower speeds with less chance of detonation.

There are turbulent and nonturbulent combustion chambers. Turbulent combustion chambers, like the wedge, can cause air and fuel to separate from each other at high speeds. A nonturbulent combustion chamber, the hemispherical (hemi) design, is more efficient for high-speed use (**FIGURES 1.31** and **1.32**). Because the mixture is centered near the spark plug, the flame spreads evenly. A hemi chamber allows the use of bigger valves, too. Sometimes hemis have a tendency to "spark knock" on lower octane fuels (see Chapter 3).

Diesel engines have no chamber in the cylinder head itself; the combustion chamber side of the head is virtually flat. Turbulence and squish in the cylinder are controlled by the shape of the piston head.

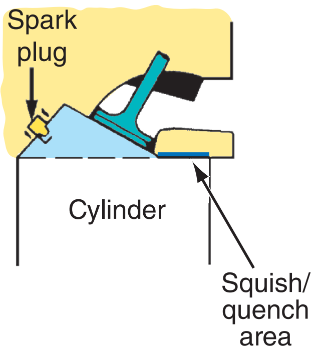


FIGURE 1.30 A wedge, or turbulent, combustion chamber has a squish/quench area to cause mixing of the air and fuel.

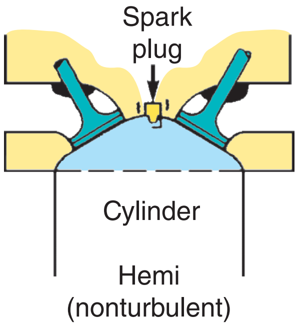


FIGURE 1.31 A hemispherical combustion chamber.

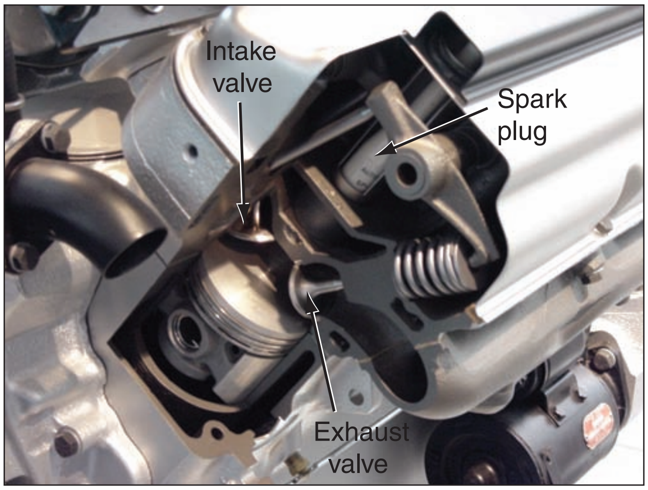


Photo courtesy of Tim Gilles.

FIGURE 1.32 A cutaway of a Chrysler hemi head. The valves are on opposite sides, with the spark plug in the center.

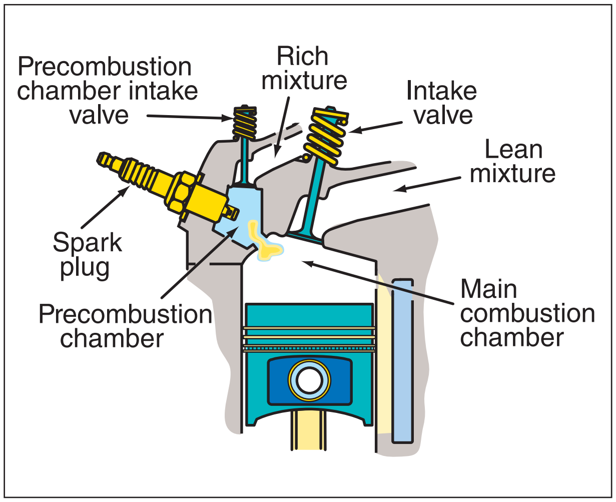
A pent-roof combustion chamber is shaped like a "V." This design is popular for use with four-valve-per-cylinder designs. The pent-roof and other newer designs are designed for more efficient combustion and better emission control. In a high swirl chamber, like in the wedge chamber, areas on the head surface are raised to cause a planned turbulence of the air-fuel mixture.

DIRECTION OF CRANKSHAFT ROTATION

The front of the engine is the side opposite the transmission. The front of most engines includes the camshaft drive, a timing cover or front cover, and the crankshaft vibration damper or pulley. Volkswagen has some engines that have the timing cover at the rear of the engine.

Vintage Engines

The stratified charge design is the type pioneered by Honda (**see figure below**). The name comes from the stratification, or layering, of different densities of air-fuel mixtures. Honda and Mitsubishi used a very small amount of rich mixture to ignite a very lean (normally unburnable) mixture in a small precombustion chamber. When it was ignited by the spark plug, the advancing flame front from this small, rich mixture ignited the leaner mixture in the main cylinder. This made it possible for the engine to run on an air-fuel mixture leaner than normal. Today's direct-injected engines (covered later in this chapter) use a stratified fuel charge.



In this stratified charge head, a small valve in the precombustion chamber provides the rich air-fuel mixture needed to ignite the lean mixture in the main combustion chamber.

The Society of Automotive Engineers (SAE) standard for engine rotation says that automotive engines rotate counterclockwise when viewed from the flywheel end of the engine. This means that longitudinally mounted engines (called front to rear or north to south) turn clockwise when viewed from the front. Transverse-mounted (sideways) engines also follow this standard, although a few engines (Honda, for instance) rotate in the opposite direction.

FIRING ORDER

To make a smooth-running engine, multiple-cylinder engines have their power strokes spaced at specified intervals. In a four-cylinder engine, one cylinder starts a power stroke at every 180° of crank rotation (**FIGURE 1.33**). This interval between power strokes is known as the ignition interval.

Cylinders are fired in a sequential order known as the **firing order**. The firing order does not usually follow the order of cylinder numbering. **FIGURE 1.34** shows several ways of determining an engine's firing order. Sometimes the firing order is found cast into the surface of the intake manifold for easy reference.

SHOP TIP

Most V-type engines have one bank of cylinders positioned farther forward than the others. The cylinder closest to the front is usually the one denoted as number 1 (**FIGURE 1.35**).

	First Stroke	Second Stroke	Third Stroke	Fourth Stroke
	720°			
	360°		360°	
	180°	180°	180°	180°
First cylinder	Power	Exhaust	Intake	Compression
Second cylinder	Compression	Power	Exhaust	Intake
Third cylinder	Intake	Compression	Power	Exhaust
Fourth cylinder	Exhaust	Intake	Compression	Power

FIGURE 1.33 A four-cylinder engine has one cylinder on a power stroke during every 180° of crankshaft rotation.

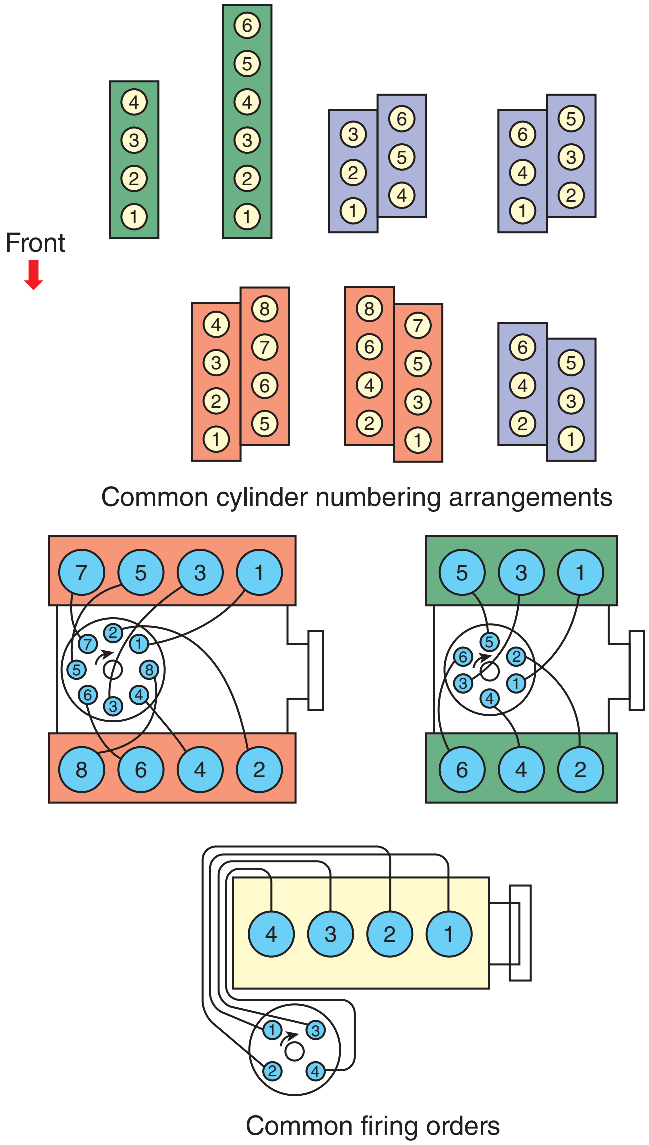


FIGURE 1.34 Several cylinder numberings and firing orders.

Companion Cylinders

Engines with an even number of cylinders have pairs of cylinders called **companion cylinders**, or running mates. Pistons in companion cylinders go up and down in pairs. When one piston is starting its power stroke, its companion piston is at the start of its intake stroke. To find out which cylinders are companions, take the first half of the engine's firing order and place it above the second half. For a V8 with a 1 8 4 3 6 5 7 2 firing order, put numbers 1, 8, 4, and 3 above numbers 6, 5, 7, and 2. The resulting pairs are companions.

first revolution	1	8	4	3
	|	|	|	|
second revolution	6	5	7	2

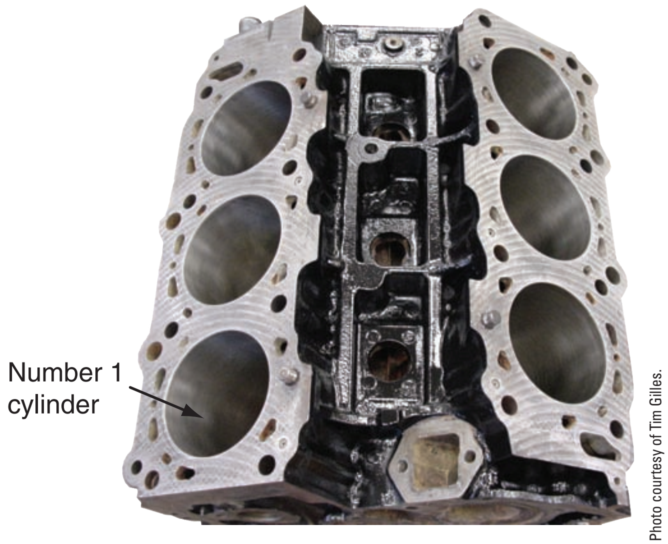


FIGURE 1.35 The number 1 cylinder is the closest to the front of the engine on almost all V-type engines.

Vintage Engines

On a few older engines, the number 1 cylinder was positioned behind the front cylinder in the opposite cylinder bank. These include Ford's Y-block engines from the mid-1950s to mid-1960s as well as Ford and Mercury L-head engines and some older Pontiacs.

Remember, during a complete four-stroke cycle the crankshaft will revolve twice (720°). The first half of the firing order represents the first crankshaft revolution (360°), and the second half of the firing order represents the second revolution (360°).

In the preceding example, when cylinder number 7 is beginning its intake stroke, cylinder number 4 is beginning its power stroke. This is an eight-cylinder engine so one power stroke occurs during every 90° of its 720° four-stroke cycle.

$$\frac{720^\circ}{8\,(\text{cyl.})} = 90^\circ$$

It appears at first glance that a single-cylinder engine would require the same airflow into its cylinder as a four-cylinder engine with cylinders of the same displacement because the four-stroke engine only uses the intake manifold during the intake stroke. In actual practice, however, the engine breathes air and fuel for a

Vintage Engines

The V-type engine uses a two-barrel intake manifold. On most V8s each barrel serves four cylinders. In theory, the V8 is actually two four-cylinder engines operating together and a V6 is two three-cylinder engines. An in-line engine with more than four cylinders would require fuel injection or multiple carburetors to distribute fuel more efficiently. Intake manifolds are covered in detail in Chapter 17.

period longer than the intake stroke's 180° of crankshaft rotation (refer to the chart in FIGURE 1.34). The valve starts to open before TDC and closes after BDC when the crankshaft has traveled considerably into the compression stroke. The reason for this is to allow the cylinder to fill with as much air-fuel mixture as possible.

An in-line six-cylinder engine has one power stroke every 120° of its 720° four-stroke cycle.

$$\frac{720^\circ}{6\,(\text{cyl.})} = 120^\circ$$

If the engine were carbureted instead of fuel injected, a single carburetor on this engine would have to be larger so it could serve more than one cylinder at a time because of the overlapping intake strokes.

ENGINE COOLING

Power produced at the crankshaft is called gross horsepower. Accessories that rob power include the alternator (charging system), air conditioning, coolant pump, cooling fan, power steering pump, and smog pump. Combined, these absorb about 25% of the power available at the crankshaft. The power remaining to be used is called net horsepower. Power is also lost through friction in the driveline (transmission and differential), wind resistance, increased vehicle weight, tires, and weather.

In a spark ignition engine, only about one-third of the energy of the burning fuel is converted to work at the crankshaft. The remainder is wasted as heat; half of it goes out the exhaust and the other half is carried off through the cooling system and by air contact with the metal castings (**FIGURE 1.36**).

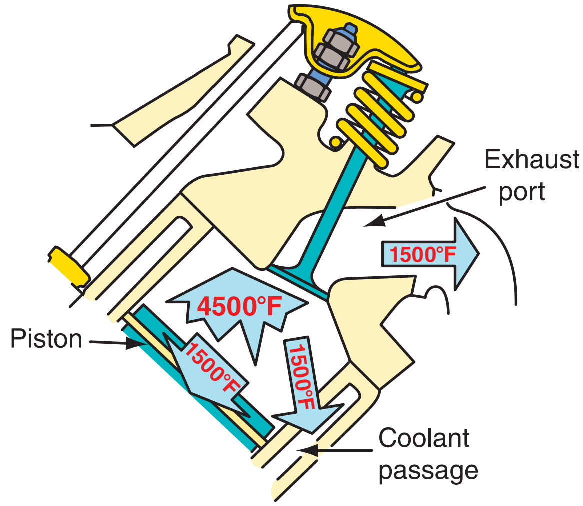


FIGURE 1.36 One-third of the heat energy produced is converted to work. The other two-thirds go to the cooling system, exhaust, and metal castings.

Automotive engines use liquid cooling systems. Air-cooled engines are found in lawnmowers, motorcycles, and some older automobiles.

Liquid-cooled engines have water jackets to cool the areas around all cylinders and throughout the cylinder head, especially around the valve seats. Coolant is pumped throughout by a coolant pump, commonly called a water pump. A thermostat regulates the flow of coolant between the engine and the radiator to maintain a specified temperature.

Freezing and boiling protection is provided by a mixture of water and coolant in a concentration of about 50% water and 50% coolant. One of coolant's important jobs is to inhibit rust and electrolysis, which cause corrosion. The **bimetal engine**, found in some of today's cars and trucks, combines iron cylinder blocks and aluminum cylinder heads. These two dissimilar metals promote electrolysis, or the creation of an electrical current. Electrolysis causes much faster deterioration of metals.

SPARK AND COMPRESSION IGNITION

Although this text does not deal specifically with diesel engines, most of the automobile engine information included here applies to light-duty diesel engines found in some passenger cars and light trucks. Diesel-cycle and Otto-cycle engines share the same basic principles of operation. The difference is in the way the fuels are introduced to the cylinder and ignited. The gasoline engine is called a spark ignition (SI) engine.

Diesel Engine

The diesel engine was invented by Rudolf Diesel in 1892 in Germany. Diesel engines, which can be either two-stroke or four-stroke cycle, are used extensively

Vintage Engines

The vintage dragster engine shown in **FIGURE A** is a "hemi." Note the spark plug cables entering at the center of the cylinder heads, indicating the hemispheric combustion chamber design. The first automotive production hemi was a 180 HP model, introduced by Chrysler in 1951. By 1956, the Chrysler 300-B hemi had 340 HP. Hemi engines were popular in stock car racing and drag racing throughout the 1950s, 1960s, and 1970s. The four-engine dragster shown in **FIGURE B** has wedge cylinder heads.

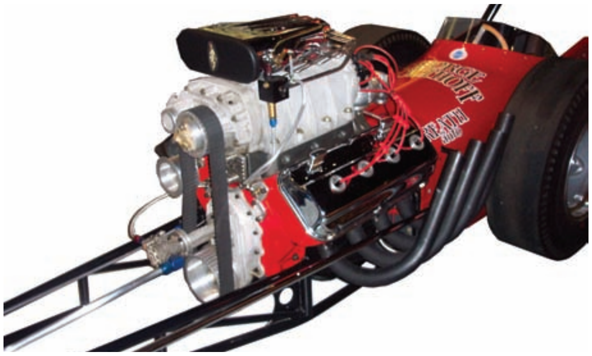


Photo courtesy of Tim Gilles.

FIGURE A A vintage dragster with a hemi engine.

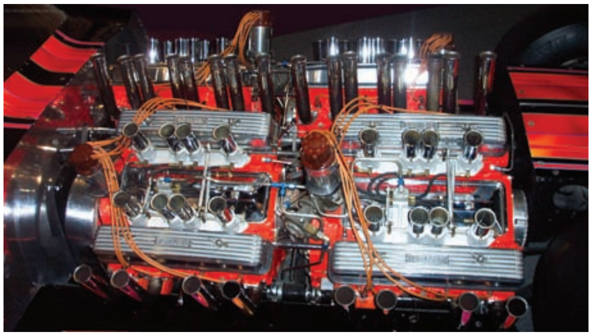


Photo courtesy of Tim Gilles.

FIGURE B This vintage four-engine dragster has wedge cylinder heads.

in heavy equipment and were not used in automobiles until the 1930s. In operation and appearance, the diesel engine is very similar to the gasoline engine.

A diesel is a compression ignition (CI) engine. It does not use a spark to ignite the fuel. Diesel engines use fuel injectors (**FIGURE 1.37**). When air is compressed in the cylinder and high-pressure fuel is injected into it, the fuel ignites. Whereas gasoline engine compression ratios most often range between 8:1 and 10:1, diesel compression ratios range from 15:1 to 22:1 (**FIGURE 1.38**). When air is compressed, it heats up. In a diesel engine the temperature of the compressed air can be approximately 1,000°F. An air-fuel mixture will explode if it is compressed too much, so the diesel engine compresses only air. Diesel fuel

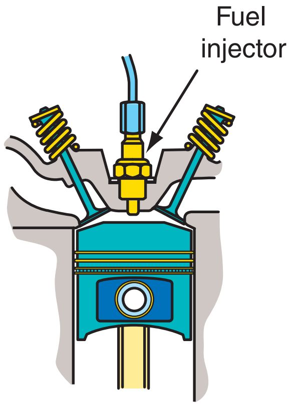


FIGURE 1.37 A diesel engine has a timed, high-pressure fuel injector to control the point of ignition.

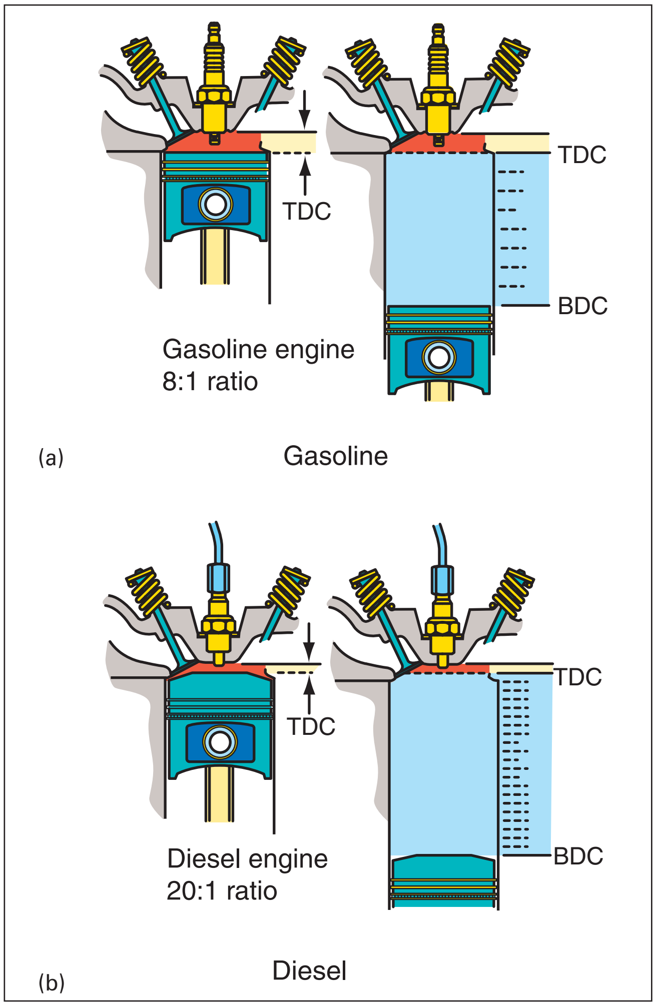


FIGURE 1.38 Comparison of gasoline and diesel enginecompression ratios.

does not burn at room temperature; its autoignition temperature is 410°F (210°C). However, when diesel fuel is injected into the cylinder at the exact moment when ignition is desired, it burns easily in the hot environment of the compressed air.

Diesels use different types of injection systems, all of which must have injector pressure that is very high so it can overcome the cylinder pressures reached during the compression stroke. Older diesel engines had unit injectors operated by a camshaft (**FIGURE 1.39**). Later engines used a precision fuel distributor and individual injectors. The most recent diesel engines use high-pressure, common rail direct injection similar to gasoline direct injection described earlier.

Diesel engines can run at very lean mixtures at idle and are generally about one-third more efficient on fuel, although they produce less power than a gasoline engine. In gasoline engines the amount of air entering the engine is changed to control speed and power. In a diesel engine, the amount of air remains the same while the fuel mixture is changed to control speed and power. The mixture can be as rich as 20:1 under load and as lean as about 80:1 at idle.

Problems with older diesel engines were their high particulate emissions (soot) and the high temperature of combustion, which produces high levels of oxides of nitrogen (NOx) emissions. Diesels also have starting problems in cold weather and require more frequent oil changes and other maintenance.

Modern diesel engines have been mandated to have exhaust emissions that are nearly free of particulates. Engine manufacturers have been able to accomplish this using computerized engine controls with altered engine designs. *Common rail direct injection* diesels first appeared in the mid-1990s.

A tube or passage called a *common rail* connects the fuel injectors with diesel fuel under very high pressure, often over 30,000 psi (2,068 bar). The fuel system injects a small amount of high-pressure fuel before and after the main fuel charge. High pressure in the common rail thoroughly atomizes the diesel fuel, mixing it with air. This results in less unburned fuel and cleaner exhaust gas. Electronic piezoelectric injectors precisely control the fuel. Direct injection engines have lower emissions, are very responsive, and get better fuel economy than the old diesel engines.

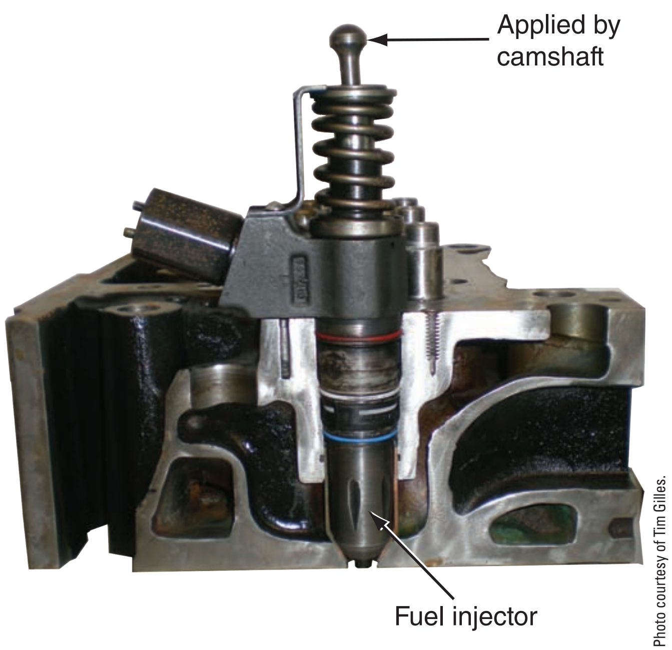


FIGURE 1.39 This diesel head cutaway shows an electronic unit injector that is activated by a cam lobe.

Gasoline Direct Injection Systems

Direct injection into the combustion chamber is not new, but until recently it was only done with diesel engines. Gasoline direct injection (GDI) allows an engine to run under very lean conditions when cruising. GDI has the ability to run the engine with a variable air-fuel mixture that can be extremely lean with an overall average ratio of around 40:1. This can increase fuel economy by as much as 30%, and exhaust emissions are reduced substantially.

In GDI systems, fuel is under very high pressure. Due to the pressure, the gasoline does not boil and it vaporizes as it is injected into the cylinder. Special fuel injectors are designed to close against this high pressure (**FIGURE 1.40**). Direct injectors are exposed to the high pressure of combustion so they need to be able to inject fuel at even higher pressure. They must also close completely after spraying their fuel charge to prevent combustion pressure from entering the fuel system. The engine-driven fuel pump is supplied with fuel by an in-tank electric fuel pump and a computer controls the timing of ignition and injection for each cylinder.

With normal sequential fuel injection (SFI), fuel is injected just before the intake stroke begins. With high-pressure direct injection, computer control of fuel timing means that the fuel can be injected at any time. Injectors can be pulsed more than once, even during the power stroke, to help maintain combustion. **FIGURE 1.41** shows how this provides a stratified fuel charge that concentrates around the spark plug and insulates the rest of the cylinder with a layer

FIGURE 1.40 A special fuel injector designed to close against high pressure.

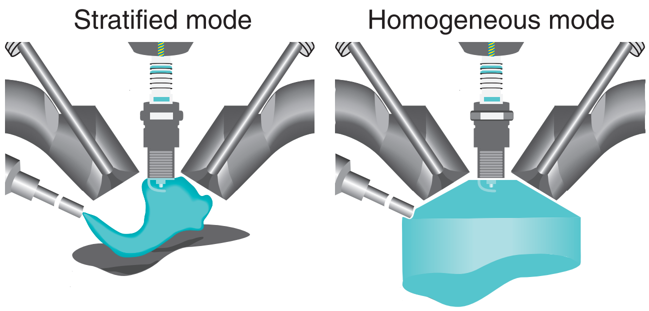


FIGURE 1.41 Computer control of the direct injector makes it possible to stratify the fuel charge.

of air, resulting in lower exhaust emissions. Under conditions of light load, the intake stroke brings in air only, and fuel is injected near the end of the compression stroke just before the spark causes ignition. During part load, vaporization of the fuel helps cool the cylinder. Under heavier load, the computer calls for more fuel to be injected during the intake stroke. The resulting homogeneous fuel charge is not efficient at light loads and engine idle. GDI's precise control of fuel timing cools combustion under heavy loads, lowering the fuel's tendency to knock, so lower octane fuel can be used. Engines can be designed with higher compression ratios to increase torque and power output while maintaining fuel economy and acceptable exhaust emissions.

GDI service is covered in Chapter 4.

Two-Stroke Cycle

Two-stroke engines have been used for years in diesel engines, outboard engines, chainsaws, and motorcycles (**FIGURE 1.42**). Other than a basic explanation of their operation, two-stroke engines are not covered in this text. Future automobile engines might use the two-stroke cycle because it has several advantages. A two-stroke engine can be made smaller and lighter than a four-stroke engine of comparable displacement. Theoretically, a two-stroke engine only requires half of the displacement of a four-stroke engine.

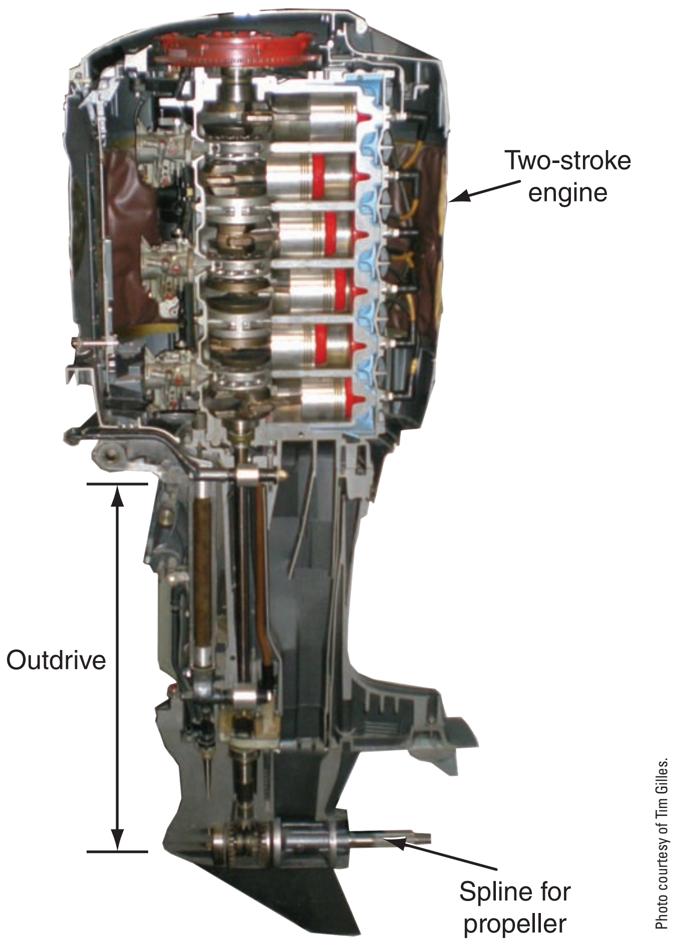


FIGURE 1.42 Cutaway of a two-stroke in-line six-cylinder outboard engine.

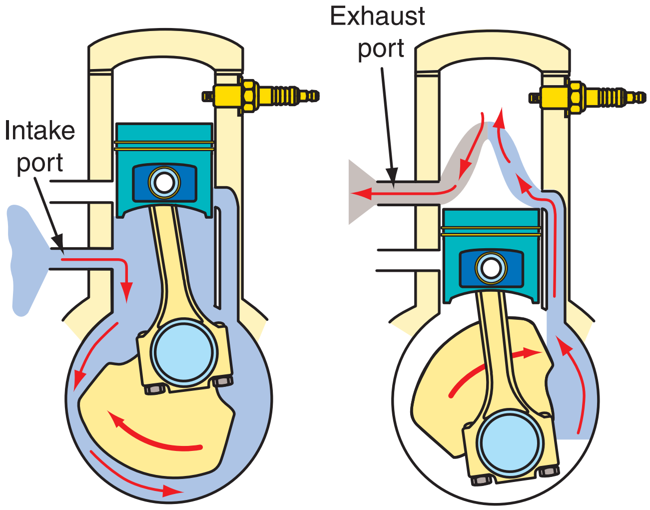


FIGURE 1.43 Two-stroke cycle engine operation.

A two-stroke engine has a power stroke every crankshaft revolution. The two-stroke cycle begins with the piston at TDC on the power stroke. The cylinder has intake and exhaust ports, which are openings in the side of the cylinder (**FIGURE 1.43**). As the piston reaches the bottom of the power stroke, the exhaust port is opened to release exhaust gases. Shortly after the exhaust port opens, the intake port opens to force the air-fuel mixture to enter the cylinder. This action also helps to push the exhaust out. As the piston moves up on its compression stroke, both the intake and exhaust ports are covered.

Most nonautomotive two-stroke engines use a mixture of oil and gasoline for lubrication. The oil and fuel mixture lubricates the **lower end** (crankshaft and bearings) as it flows through the crankcase on its way to the cylinder. New direct-injected two-stroke engines use fuel injectors to put fuel into the combustion chamber. Air is pushed into the cylinder using a supercharger. The crankcase is pressure-lubricated in these engines just like in four-stroke engines.

PUTTING IT ALL TOGETHER

- Most of today's cars and light trucks are powered by Otto-cycle engines. During one four-stroke cycle, the intake, compression, power, and exhaust strokes are completed. This action takes 720°, or two crankshaft revolutions.
- In a simple one-cylinder engine, the reciprocating (up-and-down) motion of the piston is changed to usable rotary motion by the connecting rod and crankshaft. A flywheel gives momentum to the crankshaft between power strokes. Valves control the engine's intake and exhaust.
- Cylinders are arranged in-line, in a V-type, or opposed to each other. The most popular automotive engines have four, six, or eight cylinders.
- The camshaft controls the opening and closing of the valves and, thus, the way that the engine breathes. Different cam grinds provide better low-speed or better high-speed operation.
- The camshaft is driven by a chain, a belt, or gears.

REMEMBER:

The sprocket or gear on the crankshaft has half as many teeth on it as the cam sprocket or gear. This is because the camshaft turns 360° (one turn) during one four-stroke cycle, whereas the crankshaft turns 720° (two turns).

- Cylinder rows, called banks, are determined from the flywheel end of the engine. A complete engine assembly including the heads is called a long block; without heads it is called a short block.
- The crankcase houses the crankshaft and bearings. It is enclosed by the oil pan. The crankshaft has a flywheel on one end and a vibration damper or pulley on the other end. The part that the bearing rides against is called the main or rod bearing journal. Crankpins on four cylinders are offset from each other by 180°, in-line six cylinders by 120°, and V8s by 90°.
- Engine sizes are described by their cylinder displacement, usually in liters. Engine breathing determines the power that the engine develops.
- Camshafts are located either in the block (pushrod engine) or above the cylinder head (OHC). Pushrods are often found in V-type engines, whereas in-line engines are most often of the overhead cam design.

REMEMBER:

An engine running at 3,000 rpm has to open and close a valve 25 times per second! Each spark plug must also fire at this same speed.

- Most crankshafts turn counterclockwise when viewed from the flywheel end of the engine. Engine cylinders are fired in one of several firing orders. Pairs of pistons that go up and down together but fire 360° from each other are called companions.

- Most engines have liquid cooling systems that use coolant to prevent rust and corrosion and provide additional protection against freezing and boiling.

HIGH-PERFORMANCE ENGINE TRIVIA

Top fuel dragster engines reach the upper end of their rev range somewhere between 7,000 and 9,000 rpm. Some Formula One engines approach 20,000 rpm. These are four-stroke cycle engines so the pistons must stop and start during every revolution of the crankshaft. At 18,000 rpm, each valve will have to open and close 150 times per second!

Vintage Engines

Until emission requirements curtailed their use, air-cooled automobile engines were produced in vehicles like Volkswagen, Porsche, and Corvair. Air-cooled engines operate at higher temperatures than liquid-cooled engines. Higher running temperatures result in increased NOx (oxides of nitrogen) emissions (a major component in photochemical smog).

KEY TERMS

BDC	companion cylinders	firing order	transverse engine
bimetal engine	compression ratio	lower end	
blowby	displacement	TDC	

STUDY QUESTIONS

1. What is the movement of the piston from top dead center (TDC) to bottom dead center (BDC) called?
2. What is the ratio called that compares the volume of the air space above the piston at TDC and BDC?
3. The crankshaft turns __________ as the camshaft.
   a. half as fast
   b. twice as fast
4. Where would an L-head engine be found today?
5. What does OHC mean?
6. How many times in 1 second will a valve open in an engine running at 6,000 rpm?
7. What are four other names for a core plug?
   a.
   b.
   c.
   d.
8. What is a complete engine assembly called?
9. List three functions that a flywheel performs.
   a.
   b.
   c.
10. Do all engines use a vibration damper?
11. How many degrees are rod journals offset on the following engines?
    V8s __________°
    in-line six-cylinder engine __________°
    in-line four-cylinder engine __________°
12. What type of engine is a compression ignition engine?
13. What are the normal ranges of compression ratios for the following?
    Otto-cycle engine __________:1
    diesel-cycle engine __________:1
14. In a four-stroke, four-cylinder engine, how many degrees must the crankshaft turn before the next cylinder in the firing order is fired?
15. What causes ignition to occur in a diesel engine?

ASE-STYLE REVIEW QUESTIONS

1. Technician A says that the Otto-cycle gasoline engine has four strokes per cycle. Technician B says that the crankshaft makes four revolutions during the four-stroke cycle. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

2. Technician A says that the purpose of the flywheel is to control the twisting of the crankshaft. Technician B says that the purpose of the vibration damper is to help provide a continuous flow of power. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

3. Technician A says that an in-line six-cylinder engine is usually longer and heavier than a V8 engine of the same displacement. Technician B says that there are twice as many teeth on the crankshaft sprocket as there are on the camshaft sprocket. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

4. An eight-cylinder engine has a 1 8 4 3 6 5 7 2 firing order. Technician A says that cylinder number 3 is cylinder number 1's companion. Technician B says that cylinder number 5 is cylinder number 8's companion. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

5. A six-cylinder engine has a 1 5 3 6 2 4 firing order. Technician A says that after cylinder number 1 begins its intake stroke, the crankshaft will have to travel 240° before cylinder number 3 begins its intake stroke. Technician B says that when cylinders number 3 and 4 are at TDC, cylinders number 5 and 2 are at BDC. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

6. Technician A says that diesel engines have compression ratios that are about twice as high as those found in gas engines. Technician B says that diesel engines require less maintenance than gasoline engines. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

7. Technician A says that "blowby" consists of gases that leak past the valves. Technician B says that blowby reduces the pressure in the crankcase. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

8. Technician A says that the intake and exhaust valves are both closed during most of the power stroke. Technician B says that the intake and exhaust valves are both closed during most of the compression stroke. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

9. Two technicians are discussing the part installed on the front of the crankshaft to control its twisting. Technician A says that it is called a harmonic balancer. Technician B says that it is called a vibration damper. Who is right?
   a. Technician A only
   b. Technician B only
   c. Both A and B
   d. Neither A nor B

10. Technician A says that the crankshaft turns 720° during one four-stroke cycle. Technician B says that the camshaft turns 360° during one four-stroke cycle. Who is right?
    a. Technician A only
    b. Technician B only
    c. Both A and B
    d. Neither A nor B

CHAPTER 2

Engine Shop Safety

CONTENTS

OBJECTIVES

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

- Use shop tools and equipment safely.
- Determine whether a chemical is safe to use.
- Locate and read a material safety data sheet.

INTRODUCTION

An engine shop has many tools, pieces of equipment, and chemicals. This chapter deals with their proper uses and safe shop practices. The number one priority of any business should be the health and safety of its employees. Safety issues are covered here first, followed by a safety test at the end of the chapter. The information provided will help you understand how to protect yourself from hazards in the workplace. You will also gain insight regarding the impact of safety laws on your employer.

As you read this chapter, realize that the situations described can and do occur, sometimes often. Case histories presented throughout this book are true. Pay extra attention to the safety precautions detailed with each piece of equipment. Chemical safety is covered in this chapter as well.

GENERAL SHOP HEALTH AND SAFETY

When an accident occurs in an automotive shop, it is perhaps because safety considerations are not as obvious when repairing automobiles as they are in other trades like roofing or carpentry. This is sometimes the reason why people get hurt. Accidents are often caused by carelessness resulting from a lack of experience or knowledge. Often someone other than the one who has been injured causes the accident and suffers from the guilt of knowing the harm that he or she has caused.

In the event of an accident, inform your instructor or supervisor, who will know what procedures to follow to ensure your safety. Injured persons often suffer from shock. When an injury does not appear to be serious enough to call an ambulance, another person should be sent with the injured person to seek professional help. Every shop should have someone trained to handle emergencies. The American Red Cross offers thorough first-aid training.

General Personal Safety

A first-aid kit (**FIGURE 2.1**) contains items for treating some of the small cuts and abrasions that occur on a regular basis. Fires and accidents involving equipment like lifts and battery chargers happen occasionally in automotive shops. However, the most common injuries involve the back or the eyes. These are injuries that are largely preventable.

FIGURE 2.1 A first-aid kit.

Eye Protection

Eye injuries are one of the most common injuries in an automotive shop, so continual use of glasses is recommended. Eye protection is emphasized for your own good, so use common sense. Several types of eye protection are shown in **FIGURE 2.2**.

Safety glasses or a face shield must be worn when using equipment. Face shields are convenient because they can be stored with each piece of equipment. They are also easily adjustable to your head. Using a hydraulic press or pounding with a hammer can cause parts to explode, and rotating tools can throw pieces of metal or grit, causing eye injuries. Prescription safety glasses are an advantage because the user always wears them.

Wearing eye protection will prevent most eye injuries. Eye protection must be worn

- whenever working around moving parts and machinery.
- when blowing off parts with compressed air.
- when working on air conditioning. Refrigerant contained in the air-conditioning system will instantly freeze anything with which it comes into contact. If it gets into your eyes, blindness can result.

Additional cautions about skin and eye protection are covered throughout this book.

Eyewash

Most school shops are equipped with eyewash stations (**FIGURE 2.3**). Learn where the eyewash station is located in your shop. This is an important appliance to use when an unsafe liquid solution is accidentally splashed in your eyes. If this happens to you, remember to lift your eyelid while rinsing to be certain that no dangerous chemical remains trapped between your eyelid and your eyeball.

Back Safety

Protect your back when lifting. Following safe lifting procedures will prevent most back injuries. The normal tendency is to think that items are not that heavy, so you do not ask somebody for help. Be sure to get help when moving heavy items. If something is in an awkward position for lifting, leverage and

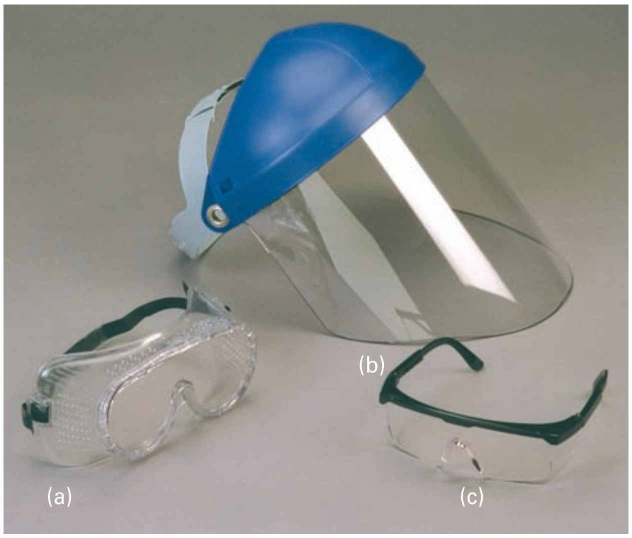


FIGURE 2.2 Eye protection. (a) goggles, (b) face shield, (c) safety glasses.

Photo courtesy of Tim Gilles.

FIGURE 2.3 An eyewash station is used when an unsafe liquid is accidentally splashed in your eyes.

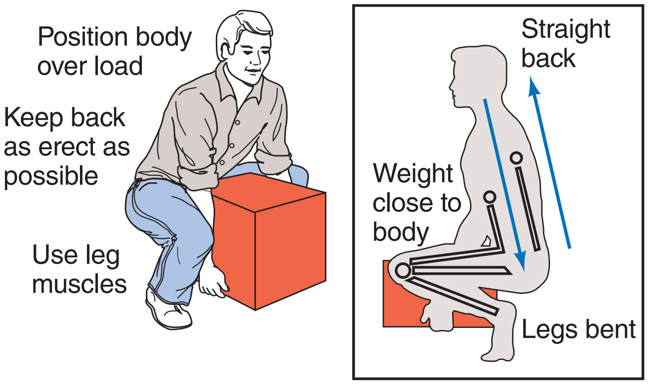


FIGURE 2.4 Lifting precautions.

the position your back is in can make it easier for an injury to occur. Before moving a heavy item, plan the route that the item will be carried and how you will set it down when you get there.

- If an item is too heavy to lift, use the appropriate equipment.
- Lift slowly.
- Do not jerk or twist your back. Shift your feet instead.
- Bend your knees and lift with your legs, not your back (**FIGURE 2.4**). Also, keep your lower back straight when lifting. Think about thrusting your stomach out.

Ear Protection

Damage to your hearing happens when you are exposed to loud noise over a period of time. A good rule of thumb is: if you feel any discomfort from noise, you are probably hurting your hearing. When loud machinery or air tools are used, ear protection should be worn.

> **CASE HISTORY**
>
> A machinist lifted a crankshaft out of the trunk of a car. As he reached forward and tugged the crankshaft up and out of the trunk, he felt a small pop in his lower back. The result was a herniated disc in his lower back, which is an injury that will affect him for the rest of his life.

> **NOTE**
>
> Your hearing will not recover once it has been damaged.

Clothing and Hair Protection

Clothing or hair that hangs out can get caught in moving machinery or under a creeper. Keep long hair tied back or tucked under a cap. Shirttails should be tucked in, or coveralls can be worn over the shirt.

Shoes or Boots

Leather shoes or boots offer much better protection than tennis shoes or sandals. Some soles are resistant to damage from petroleum products, and the tread can be designed to resist slipping. Boots and shoes that have the toe reinforced with steel inserts are widely available. An additional incentive is that safety footwear is often deductible from a technician's or machinist's income taxes.

SHOP CLEANLINESS

Good housekeeping practices are essential when cleaning engine parts and should be carried out throughout the rebuilding process and engine installation. A clean, orderly shop is vital for impressing on the public that your professional repair facility is thorough and competent. Of even more importance, however, is the health and safety of anyone in the shop area.

Shop Towels

A shop is cleaner if its technicians use shop towels when working. Greasy, oily tools and hands should be wiped clean, preventing the mess from being spread around the rest of the shop. Most shops have linen service for uniforms and shop towels. Shop towels are often dyed red so the linen company can tell when they have come into contact with battery acid, which leaves blue marks on red towels (**FIGURE 2.5**).

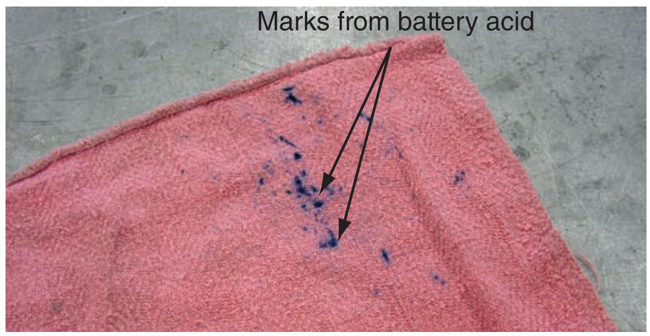


Photo courtesy of Tim Gilles.

FIGURE 2.5 This shop towel has been contaminated with battery acid. The repair shop will have to purchase it from the linen supplier.

SHOP TIP

You can save the shop some money by using a shop towel that has already been partly soiled but is not yet saturated.

SAFETY NOTE

Be very careful before wiping your hands, arms, or face with a shop towel. It is not uncommon for a shop towel to have metal chips hidden in its fibers (**FIGURE 2.6**).

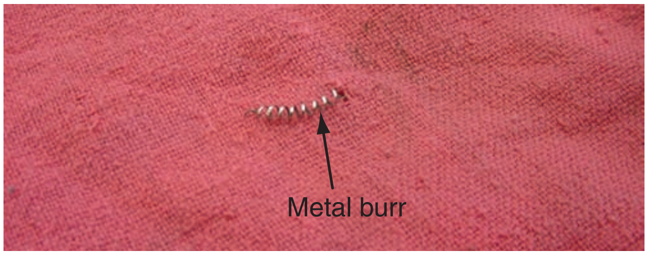


Photo courtesy of Tim Gilles.

FIGURE 2.6 Be careful when wiping your hands, arms, or face with a shop towel.

Photo courtesy of Tim Gilles.

FIGURE 2.7 When drying parts with compressed air, blow solvent back into the solvent tank.

Photo courtesy of Tim Gilles.

FIGURE 2.8 To avoid dripping solvent on the floor, carry wet parts in a drain pan.

Spills and Oil Leaks

Slippery floors are dangerous. To avoid the possibility of a dangerous slip and fall, immediately clean up slippery spills like coolant, solvents, glass beads, or steel shot. Preventing spills from occurring in the first place is best, but when spills do occur, they must be dealt with immediately.

- Cleaning up a mess will prevent it from spreading around the shop.
- Parts that are wet with solvent should be blown off *into* the solvent tank (**FIGURE 2.7**) or allowed to air dry before being moved.
- Wet parts can be carried from the solvent tank in a drain pan to prevent solvent from dripping onto the floor (**FIGURE 2.8**).
- An engine should be drained of oil and coolant before removing it from the vehicle. The oil filter holds oil, so it should be removed, too. The oil and filter will need to be disposed of properly in accordance with governmental requirements.

SHOP TIP

A spill often occurs when an engine block mounted on a stand is turned upside down during disassembly. There is usually some coolant remaining in the block. Position a drain pan under the engine before turning it upside down to catch a potential spill. After rinsing a block, it should be turned over and drained in the cleaning area before moving it into the shop.

Absorbing Spills

To prevent someone from slipping, clean oil spills immediately with **greasesweep** (**FIGURE 2.9**), an already soiled shop towel, or absorbent mats or pads.

Greasesweep is an absorbent material like rice hull ash or kitty litter. It is swept up and reused until it becomes too wet. In fact, it works better when slightly wet because the dust that results when using new greasesweep is avoided.

Greasesweep becomes a hazardous material after it is used to soak up used motor oil or spilled fuel. Bioremedial oil-absorbent products are newer materials sometimes used instead of greasesweep. These

Photo courtesy of Tim Gilles.

FIGURE 2.9 Cleaning an oil spill with greasesweep.

SHOP TIP

Coolant spills are best cleaned with a squeegee. Mixing water and coolant with oily greasesweep makes a muddy mess.

products have microbes that "eat" oil or fuel, converting them to harmless carbon dioxide (CO_2) and water. Concrete floors cleaned with this material are left clean and slip resistant. A major advantage to this method is that the need for hazardous disposal is reduced or eliminated.

Superabsorbent cloths are available from waste disposal companies for soaking up spills. The disposal company collects the soiled cloths for proper treatment. There are also nontoxic water-based degreasers.

FIRE PREVENTION

Some common sense is important when dealing with fires. If the fire is burning so dangerously that your personal safety is jeopardized, withdraw from the area immediately and call for help. But if you can safely remove the source of fuel to a fire, do so. This might include shutting off fuel to a fuel fire or disconnecting the electrical source from an electrical fire.

Fire Extinguishers

A fire extinguisher is a portable tank that contains water or foam, a chemical, or a gas (**FIGURE 2.10**). There are four kinds of fires, each calling for a different type of fire extinguisher (**FIGURE 2.11**).

- A Class A fire is one that can be put out with water. Such things as paper and wood make up these kinds of fires.
- A Class B fire is one in which there are flammable liquids such as grease, oil, gasoline, or paint.
- A Class C fire is electrical.
- A Class D fire involves a flammable metal such as magnesium or potassium.

Either CO_2 or a dry chemical fire extinguisher can be used on Class B and Class C fires.

SAFETY NOTE

Be sure to have a large enough fire extinguisher on hand. An engine compartment fire often requires a larger extinguisher, depending on how far the fire has progressed.

A popular fire extinguisher is the 2-A:10-B:C. You can find this information on the label. For car fires, fire officials recommend an extinguisher no smaller than this. An extinguisher with the number 1-A:5-B:C would be one-half as big.

The 1 is the size for the A (water) type of that extinguisher. The 5 is the size for Class B (flammable liquids) and C (electrical parts fires). This extinguisher does not work on Class D fires.

Locate and check the type of fire extinguisher(s) in your shop. They should not be located in a place where a fire is likely to start. For instance, do not

FIGURE 2.10 Fire extinguishers.

	Class of Fire	Typical Fuel Involved	Type of Extinguisher
Class A Fires (green)	**For Ordinary Combustibles** Put out a Class A fire by lowering its temperature or by coating the burning combustibles.	Wood Paper Cloth Rubber Plastics Rubbish Upholstery	Water*[1] Foam* Multipurpose dry chemical[4]
Class B Fires (red)	**For Flammable Liquids** Put out a Class B fire by smothering it. Use an extinguisher that gives a blanketing flame-interrupting effect; cover whole flaming liquid surface.	Gasoline Oil Grease Paint Lighter fluid	Foam* Carbon dioxide[5] Halogenated agent[6] Standard dry chemical[2] Purple K dry chemical[3] Multipurpose dry chemical[4]
Class C Fires (blue)	**For Electrical Equipment** Put out a Class C fire by shutting off power as quickly as possible and by always using a nonconducting extinguishing agent to prevent electric shock.	Motors Appliances Wiring Fuse boxes Switchboards	Carbon dioxide[5] Halogenated agent[6] Standard dry chemical[2] Purple K dry chemical[3] Multipurpose dry chemical[4]
Class D Fires (yellow)	**For Combustible Metals** Put out a Class D fire of metal chips, turnings, or shavings by smothering or coating with a specially designed extinguishing agent.	Aluminum Magnesium Potassium Sodium Titanium Zirconium	Dry powder extinguishers and agents only

*Cartridge-operated water, foam, and soda-acid types of extinguishers are no longer manufactured. These extinguishers should be removed from service when they become due for their next hydrostatic pressure test.

Notes:

(1) Freeze in low temperatures unless treated with antifreeze solution, usually weighs over 20 pounds, and is heavier than any other extinguisher mentioned.
(2) Also called ordinary or regular dry chemical. (solution bicarbonate)
(3) Has the greatest initial fire-stopping power of the extinguishers mentioned for class B fires. Be sure to clean residue immediately after using the extinguisher so sprayed surfaces will not be damaged. (potassium bicarbonate)
(4) The only extinguishers that fight A, B, and C class fires. However, they should not be used on fires in liquified fat or oil of appreciable depth. Be sure to clean residue immediately after using the extinguisher so sprayed surfaces will not be damaged. (ammonium phosphates)
(5) Use with caution in unventilated, confined spaces.
(6) May cause injury to the operator if the extinguishing agent (a gas) or the gases produced when the agent is applied to a fire is inhaled.

FIGURE 2.11 Guide to fire extinguisher selection.

mount a fire extinguisher right over the welding bench or next to the solvent tank. If a fire began in either of these places, you would not be able to get to the fire extinguisher.

A gauge on the top of the fire extinguisher tells whether it is fully charged or if the charge pressure has leaked off. Fire extinguishers in business establishments are routinely inspected by the local fire department.

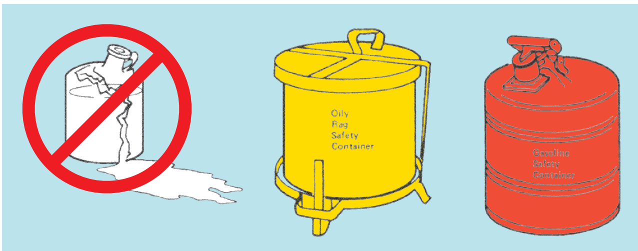


FIGURE 2.12 Keep combustibles in safety containers.

Flammable Materials

Greasesweep and shop towels soaked in oil or gasoline should be stored in covered metal containers (**FIGURE 2.12**). Keeping oil materials separated from air prevents them from self-igniting, a process called **spontaneous combustion**. Used greasesweep is kept in a flammable storage container because it is reused until it becomes saturated (wet). Flammable materials that are not in approved containers must be stored in a flammable storage cabinet (**FIGURE 2.13**).