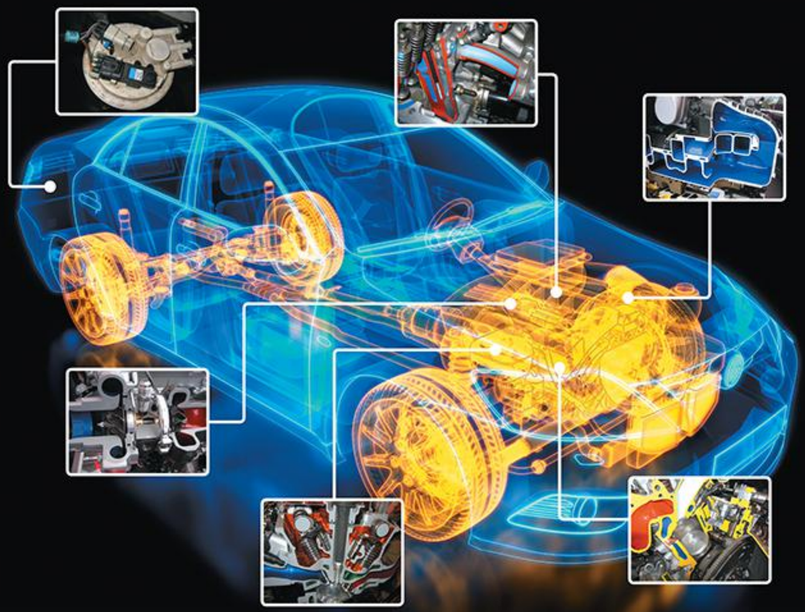
Advanced Engine Performance Diagnosis

JAMES D. HALDERMAN   CURT WARD



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ADVANCED ENGINE PERFORMANCE DIAGNOSIS

SEVENTH EDITION

James D. Halderman
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PREFACE

Advanced Engine Performance Diagnosis combines topics in engine performance (ASE A8) and the advanced engine performance (ASE L1) topics into one practical, comprehensive textbook that is easy for instructors to teach with, and an affordable option for students.

This hands-on introduction to the diagnosis and troubleshooting of automotive engine control systems serves students as a single source for information on digital storage, oscilloscopes, fuel injection and ignition system diagnoses, five-gas exhaust analysis, emission testing, and more.

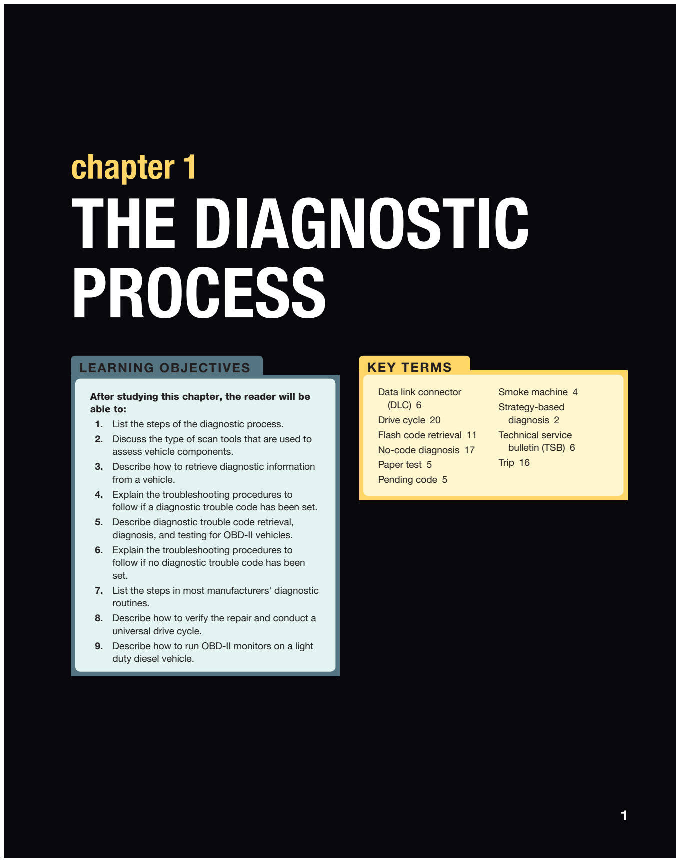
The book is formatted to appeal to today's technical trade students with a a technical, but easy-to-read and understand presentation that uses helpful real-world tips and visuals to bring concepts to life and guide students through the procedures they'll use on the job.

UPDATES TO THE SEVENTH EDITION

The following changes and updates have been made to the new seventh edition based on requests from instructors and reviewers from throughout North America:

- The content was reorganized to make it flow smoothly form beginning to the end.
- The chapters have been rewritten to be more concise.
- Over 75 new full color line drawings and photos have been added to the new edition to help bring the subject to life.
- Case studies have been added to many chapters that include the "three Cs" (Complaint, Cause, and Correction).
- Updated throughout and correlated to the latest ASE tasks.
- A new chapter title **Oscilloscopes and DSOs** (Chapter 4) has been greatly enhanced.
- The chapter **Valve and Variable Valve Timing Diagnosis** (Chapter 7) has been rewritten and updated to include Fiat-Chrysler Multiair systems and additional diagnosis procedures.
- Chapter 20, **Fuel Trim Diagnosis**, has been expanded and enhanced.
- The new Tier 3 emission standards have been added to Chapter 26 (**Vehicle Emissions Standards and Testing**).
- **Module Programming** (Chapter 28) has been added to the new edition.

IN-TEXT FEATURES



chapter 1

THE DIAGNOSTIC PROCESS

LEARNING OBJECTIVES

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

1. List the steps of the diagnostic process.
2. Discuss the type of scan tools that are used to assess vehicle components.
3. Describe how to retrieve diagnostic information from a vehicle.
4. Explain the troubleshooting procedures to follow if a diagnostic trouble code has been set.
5. Describe diagnostic trouble code retrieval, diagnosis, and testing for OBD-II vehicles.
6. Explain the troubleshooting procedures to follow if no diagnostic trouble code has been set.
7. List the steps in most manufacturers' diagnostic routines.
8. Describe how to verify the repair and conduct a universal drive cycle.
9. Describe how to run OBD-II monitors on a light duty diesel vehicle.

KEY TERMS

Data link connector (DLC) 6
Drive cycle 20
Flash code retrieval 11
No-code diagnosis 17
Paper test 5
Pending code 5
Smoke machine 4
Strategy-based diagnosis 2
Technical service bulletin (TSB) 6
Trip 16

1

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

TECH TIP

Smoke Machine Testing

Vacuum (air) leaks can cause a variety of driveability problems and are often difficult to locate. One good method is to use a machine that generates a stream of smoke. Connecting the outlet of the **smoke machine** to the hose that was removed from the vacuum brake booster allows smoke to enter the intake manifold. Any vacuum leaks will be spotted by observing smoke coming out of the leak. ● **SEE FIGURE 1–6**.

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

SAFETY TIP

Never Disconnect a Spark Plug Wire When the Engine Is Running!

Ignition systems produce a high-voltage pulse necessary to ignite a lean air–fuel mixture. If you disconnect a spark plug wire when the engine is running, this high-voltage spark could cause personal injury or damage to the ignition coil and/or ignition module.

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

CASE STUDY

The Chevrolet Pickup Truck Story

The owner of a Chevrolet pickup truck complained that the engine ran terribly. It would hesitate and surge, yet there were no diagnostic trouble codes (DTCs). After hours of troubleshooting, the technician discovered while talking to the owner that the problem started after the transmission had been repaired. However, the transmission shop said that the problem was an engine problem and not related to the transmission.

A thorough visual inspection revealed that the front and rear oxygen sensor connectors had been switched. The PCM was trying to compensate for an air–fuel mixture condition that did not exist. Reversing the O2S connectors restored proper operation of the truck.

Summary:

- **Complaint**—Vehicle owner complained that the pickup truck ran terribly.
- **Cause**—During a previous repair, the upstream and downstream oxygen sensor connectors were reversed.
- **Correction**—The connectors were moved to their correct locations which restored proper engine operation.

REAL WORLD FIXES present students with actual automotive service scenarios and show how these common (and sometimes uncommon) problems were diagnosed and repaired.

FREQUENTLY ASKED QUESTION

What Happens When the Engine Stops?

When the engine stops, the oil pressure drops to zero and a spring-loaded locking pin is used to keep the camshaft locked, preventing noise at engine start. When the engine starts, oil pressure releases the locking pin.

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

NOTE: A cam-within-a-cam is used on the 2008 + Viper V-10 OHV engine. This design allows the exhaust lobes to be moved up to 36° to improve idle quality and reduction of exhaust emissions.

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

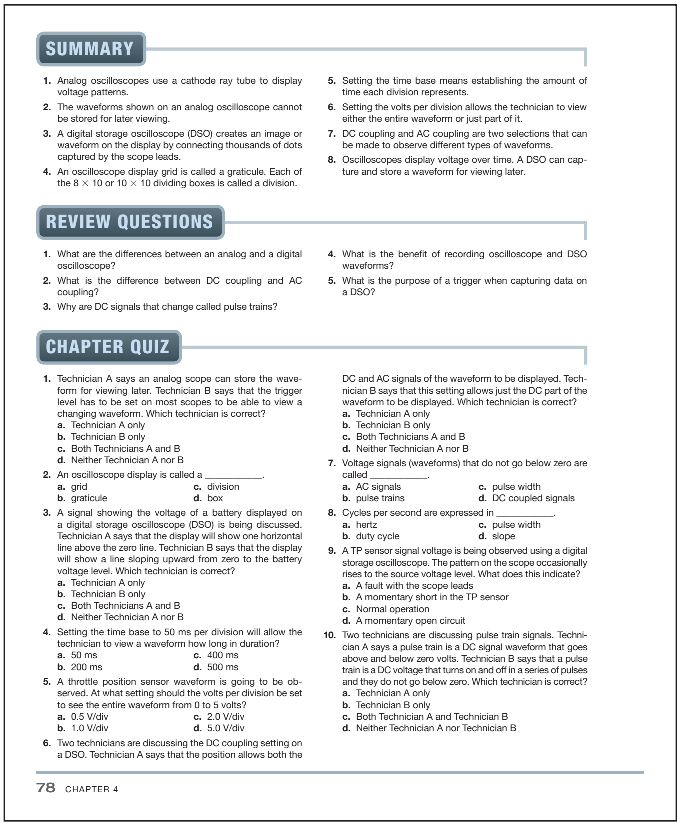
CAUTION: Do not use more than three squirts oil from a hand-operated oil squirt can. Too much oil can cause a hydrostatic lock, which can damage or break pistons or connecting rods or even crack a cylinder head.

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

WARNING

Check the coolant level in the radiator only when the radiator is cool. If the radiator is hot and the radiator cap is removed, the drop in pressure above the coolant will cause the coolant to boil immediately and as the coolant explosively expands upward and outward from the radiator opening, it can cause severe burns and personal injury.

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



SUMMARY

1. Analog oscilloscopes use a cathode ray tube to display voltage patterns.
2. The waveforms shown on an analog oscilloscope cannot be stored for later viewing.
3. A digital storage oscilloscope (DSO) creates an image or waveform on the display by connecting thousands of dots captured by the scope leads.
4. An oscilloscope display grid is called a graticule. Each of the 8 × 10 or 10 × 10 dividing boxes is called a division.
5. Setting the time base means establishing the amount of time each division represents.
6. Setting the volts per division allows the technician to view either the entire waveform or just part of it.
7. DC coupling and AC coupling are two selections that can be made to observe different types of waveforms.
8. Oscilloscopes display voltage over time. A DSO can capture and store a waveform for viewing later.

REVIEW QUESTIONS

1. What are the differences between an analog and a digital oscilloscope?
2. What is the difference between DC coupling and AC coupling?
3. Why are DC signals that change called pulse trains?
4. What is the benefit of recording oscilloscope and DSO waveforms?
5. What is the purpose of a trigger when capturing data on a DSO?

CHAPTER QUIZ

1. Technician A says an analog scope can store the waveform for viewing later. Technician B says that the trigger level has to be set on most scopes to be able to view a changing waveform. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
2. An oscilloscope display is called a ___________.
   a. grid
   b. graticule
   c. division
   d. box
3. A signal showing the voltage of a battery displayed on a digital storage oscilloscope (DSO) is being discussed. Technician A says that the display will show one horizontal line above the zero line. Technician B says that the display will show a line sloping upward from zero to the battery voltage level. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
4. Setting the time base to 50 ms per division will allow the technician to view a waveform how long in duration?
   a. 50 ms
   b. 200 ms
   c. 400 ms
   d. 500 ms
5. A throttle position sensor waveform is going to be observed. At what setting should the volts per division be set to see the entire waveform from 0 to 5 volts?
   a. 0.5 V/div
   b. 1.0 V/div
   c. 2.0 V/div
   d. 5.0 V/div
6. Two technicians are discussing the DC coupling setting on a DSO. Technician A says that the position allows both the DC and AC signals of the waveform to be displayed. Technician B says that this setting allows just the DC part of the waveform to be displayed. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Voltage signals (waveforms) that do not go below zero are called ___________.
   a. AC signals
   b. pulse trains
   c. pulse width
   d. DC coupled signals
8. Cycles per second are expressed in ___________.
   a. hertz
   b. duty cycle
   c. pulse width
   d. slope
9. A TP sensor signal voltage is being observed using a digital storage oscilloscope. The pattern on the scope occasionally rises to the source voltage level. What does this indicate?
   a. A fault with the scope leads
   b. A momentary short in the TP sensor
   c. Normal operation
   d. A momentary open circuit
10. Two technicians are discussing pulse train signals. Technician A says a pulse train is a DC signal waveform that goes above and below zero volts. Technician B says that a pulse train is a DC voltage that turns on and off in a series of pulses and they do not go below zero. Which technician is correct?
    a. Technician A only
    b. Technician B only
    c. Both Technician A and Technician B
    d. Neither Technician A nor Technician B

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

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

INSTRUCTOR RESOURCES

These resources are provided to help you teach your course, and can be found at pearsonhighered.com/automotive Search for this title there.

RESOURCES IN PRINT AND ONLINE

Advanced Engine Performance Diagnosis

NAME OF SUPPLEMENT	PRINT	ONLINE	AUDIENCE	DESCRIPTION
Instructor Resource Manual 0134985788		✔	Instructors	NEW! The Ultimate teaching aid: Chapter summaries, key terms, chapter learning objectives, lecture resources, discuss/demonstrate classroom activities, and answers to the in text review and quiz questions.
TestGen 0134985761		✔	Instructors	Test generation software and test bank for the text.
PowerPoint Presentation 0134985737		✔	Instructors	Slides include chapter learning objectives, lecture outline of the text, and graphics from the book.
Image Bank 0134985745		✔	Instructors	All of the images and graphs from the textbook to create customized lecture slides.
ASE Correlated Task Sheets – for instructors 0134985729		✔	Instructors	Downloadable ASE task sheets for easy customization and development of unique task sheets.
ASE Correlated Task Sheets – for Students 0134985796	✔		Students	Study activity manual that correlates ASE Automobile Standards to chapters and page numbers in the text. Available to students at a discounted price when packaged with the text.
VitalSource eBook 0133515214		✔	Students	An alternative to purchasing the print textbook, students can subscribe to the same content online and save up to 50% off the suggested list price of the print text. Visit **www.vitalsource.com**

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

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TECHNICAL AND CONTENT REVIEWERS

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Curt Ward

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JIM HALDERMAN brings a world of experience, knowledge, and talent to his work. His automotive service experience includes working as a flat-rate technician, a business owner, and a professor of automotive technology at a leading U.S. community college.

He has a Bachelor of Science degree from Ohio Northern University and a master's degree from Miami University in Oxford, Ohio. Jim also holds a U.S. patent for an electronic transmission control device. He is an ASE certified Master Automotive Technician and is also Advanced Engine Performance (L1) ASE certified. Jim is the author of many automotive textbooks, all published by Pearson Education. Jim has presented numerous technical seminars to national audiences, including the California Automotive Teachers (CAT) and the Illinois College Automotive Instructor Association (ICAIA). He is also a member and presenter at the North American Council of Automotive Teachers (NACAT). Jim was also named Regional Teacher of the Year by General Motors Corporation and a member of the advisory committee for the department of technology at Ohio Northern University. Jim and his wife, Michelle, live in Dayton, Ohio. They have two children. You can reach Jim at

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CURT WARD Prior to his years at Chrysler, he has worked as a technician, shop foreman, and service manager in the retail sector of the automotive industry for 13 years. During this time, Curt became a Chrysler Master Technician. Curt has an Associates of Applied Science in Automotive Service Technology from Southern Illinois University. He has a Bachelor of Fine Arts in Organizational Communications from North Central College. He earned his master's degree in Adult Education at the University of Phoenix.

Curt is an ASE Master Automotive Technician. Curt has presented technical seminars at numerous conferences around the country. He has presented for the Illinois College Automotive Instructor Association (ICAIA), the California Automotive Teachers (CAT), and the North American Council of Automotive Teachers (NACAT). Curt is an active member in the ICAIA and the NACAT. He has served as the secretary and president of the NACAT organization and was the conference host for the 2015 NACAT Conference. In 2015, Curt was named the NACAT MVP award winner for his outstanding contribution to the NACAT organization. Curt and his wife Tammy have five children and five grandchildren.

Together they enjoy traveling and exploring historical sites. In his spare time, Curt enjoys modeling 3-rail O-gauge railroads. You can reach Curt at: curt@curtward.net chapter 1

THE DIAGNOSTIC PROCESS

LEARNING OBJECTIVES

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

1. List the steps of the diagnostic process.
2. Discuss the type of scan tools that are used to assess vehicle components.
3. Describe how to retrieve diagnostic information from a vehicle.
4. Explain the troubleshooting procedures to follow if a diagnostic trouble code has been set.
5. Describe diagnostic trouble code retrieval, diagnosis, and testing for OBD-II vehicles.
6. Explain the troubleshooting procedures to follow if no diagnostic trouble code has been set.
7. List the steps in most manufacturers' diagnostic routines.
8. Describe how to verify the repair and conduct a universal drive cycle.
9. Describe how to run OBD-II monitors on a light duty diesel vehicle.

KEY TERMS

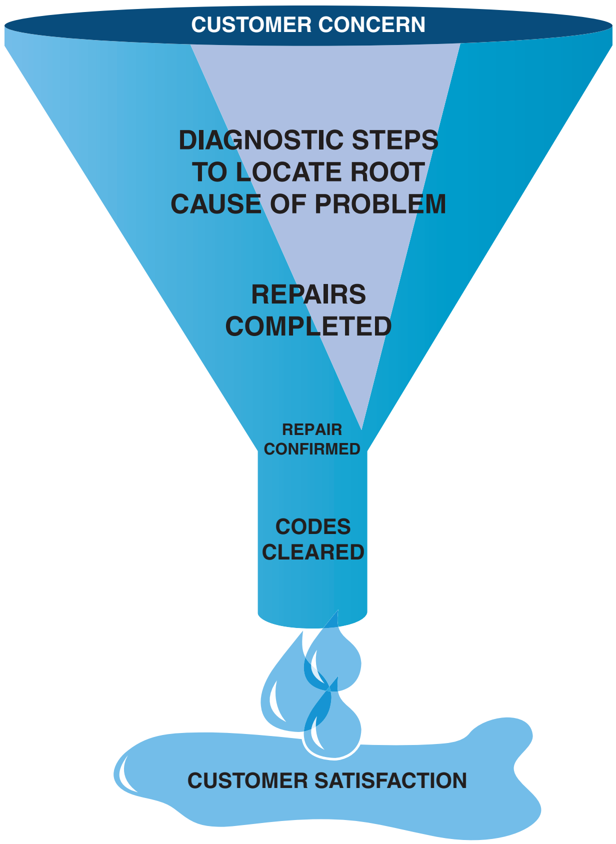


FIGURE 1–1 A funnel is one way to visualize the diagnostic process. The purpose is to narrow the possible causes of a concern until the root cause is determined and corrected.

THE EIGHT-STEP DIAGNOSTIC PROCEDURE

STRATEGY-BASED DIAGNOSIS Successful diagnose depends on using the same process for all problems and customer concerns to arrive at the root cause of the problem. The process is called **strategy-based diagnosis**.

Many different things can cause an engine performance problem or concern. The service technician has to narrow the possibilities to find the cause of the problem and correct it. A funnel is a way of visualizing a diagnostic procedure. ● **SEE FIGURE 1–1**. At the wide top are the symptoms of the problem; the funnel narrows as possible causes are eliminated until the root cause is found and corrected at the bottom of the funnel.

All problem diagnosis deals with symptoms that could be the result of many different causes. The wide range of possible solutions must be narrowed to the most likely and these must eventually be further narrowed to the actual cause. The following section describes eight steps the service technician can take to narrow the possibilities to one cause.

STEP 1 VERIFY THE PROBLEM (CONCERN) Before a minute is spent on diagnosis, be certain that a problem exists.

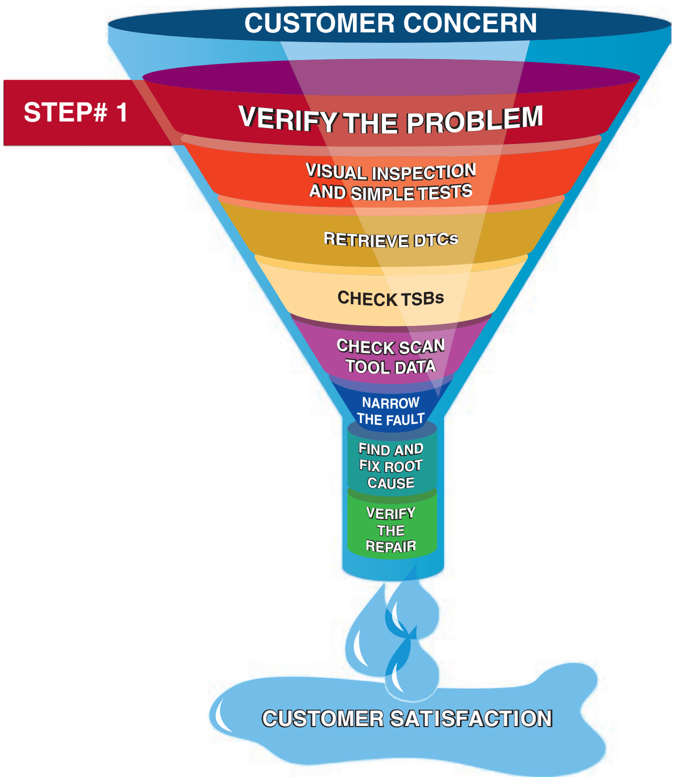


FIGURE 1–2 Step #1 is to verify the customer concern or problem. If the problem cannot be verified, then the repair cannot be verified.

If the problem cannot be verified, it cannot be solved or tested to verify that the repair was complete. ● **SEE FIGURE 1–2**.

The driver of the vehicle knows much about the vehicle and how it is driven. *Before* diagnosis, always ask the following questions:

- Is the malfunction indicator light (check engine) on?
- What was the temperature outside?
- Was the engine warm or cold?
- Was the problem during starting, acceleration, cruise, or some other condition?
- How far had the vehicle been driven?
- Were any dash warning lights on? If so, which one(s)? ● **SEE FIGURE 1–3**.
- Has there been any service or repair work performed on the vehicle lately?

NOTE: This last question is very important. Many engine performance faults are often the result of something being knocked loose or a hose falling off during repair work. Knowing that the vehicle was just serviced before the problem began may be an indicator as to where to look for the solution to a problem.

After the nature and scope of the problem are determined, the complaint should be verified before further diagnostic tests are performed. A sample form that customers could fill out with details of the problem is shown in ● **FIGURE 1–4**.

FIGURE 1–3 The amber dash warning symbols indicate that a fault has been detected. A red dash warning light indicates that a major fault has been detected requiring action by the driver as soon as possible.

NOTE: Because drivers differ, it is sometimes the best policy to take the customer on the test-drive to verify the concern.

STEP 2 PERFORM A THOROUGH VISUAL INSPECTION AND BASIC TESTS The visual inspection is the most important aspect of diagnosis! Most experts agree that between 10% and 30% of all engine performance problems can be found simply by performing a *thorough* visual inspection. The inspection should include the following:

- **Check for obvious problems (basics, basics, basics).**

  Fuel leaks

  Vacuum hoses that are disconnected or split

  Corroded connectors

  Unusual noises, smoke, or smell

  Check the air cleaner and air duct (squirrels and other small animals can build nests or store dog food in them). ● **SEE FIGURE 1–5**.

- **Check everything that does and does not work.** This step involves turning things on and observing that everything is working properly.
- **Look for evidence of previous repairs.** Any time work is performed on a vehicle, there is always a risk that something will be disturbed, knocked off, or left disconnected.
- **Check oil level and condition.** Another area for visual inspection is oil level and condition.

  Oil level. Oil should be to the proper level.

  Oil condition. Using a match or lighter, try to light the oil on the dipstick; if the oil flames up, gasoline is present

ENGINE PERFORMANCE DIAGNOSIS WORKSHEET

(To Be Filled Out By the Vehicle Owner)

Name: ______________________ Mileage: ______________ Date: ______________

Make: ______________ Model: ______________ Year: ______________ Engine: ______________

(Please Circle All That Apply in All Categories)	
Describe Problem:	
When Did the Problem First Occur?	• Just Started • Last Week • Last Month • Other ______________
List Previous Repairs in the Last 6 Months:	
Starting Problems	• Will Not Crank • Cranks, but Will Not Start • Starts, but Takes a Long Time
Engine Quits or Stalls	• Right after Starting • When Put into Gear • During Steady Speed Driving • Right after Vehicle Comes to a Stop • While Idling • During Acceleration • When Parking
Poor Idling Conditions	• Is Too Slow at All Times • Is Too Fast • Intermittently Too Fast or Too Slow • Is Rough or Uneven • Fluctuates Up and Down
Poor Running Conditions	• Runs Rough • Lacks Power • Bucks and Jerks • Poor Fuel Economy • Hesitates or Stumbles on Acceleration • Backfires • Misfires or Cuts Out • Engine Knocks, Pings, Rattles • Surges • Dieseling or Run-On
Automatic Transmission Problems	• Improper Shifting (Early/Late) • Changes Gear Incorrectly • Vehicle Does Not Move when in Gear • Jerks or Bucks
Usually Occurs	• Morning • Afternoon • Anytime
Engine Temperature	• Cold • Warm • Hot
Driving Conditions During Occurrence	• Short—Less Than 2 Miles • 2–10 Miles • Long—More Than 10 Miles • Stop and Go • While Turning • While Braking • At Gear Engagement • With A/C Operating • With Headlights On • During Acceleration • During Deceleration • Mostly Downhill • Mostly Uphill • Mostly Level • Mostly Curvy • Rough Road
Driving Habits	• Mostly City Driving • Highway • Park Vehicle Inside • Park Vehicle Outside **Drive Per Day:** • Less Than 10 Miles • 10–50 • More Than 50
Gasoline Used	**Fuel Octane:** • 87 • 89 • 91 • More Than 91 **Brand:** ______________
Temperature when Problem Occurs	• 32–55° F • Below Freezing (32° F) • Above 55° F
Check Engine Light/ Dash Warning Light	• Light on Sometimes • Light on Always • Light Never On
Smells	• "Hot" • Gasoline • Oil Burning • Electrical
Noises	• Rattle • Knock • Squeak • Other

FIGURE 1–4 A form that the customer should fill out if there is a driveability concern to help the service technician more quickly find the root cause.

FIGURE 1–5 This is what was found when removing an air filter from a vehicle that had a lack-of-power concern. Obviously the nuts were deposited by squirrels or some other animal, blocking a lot of the airflow into the engine.

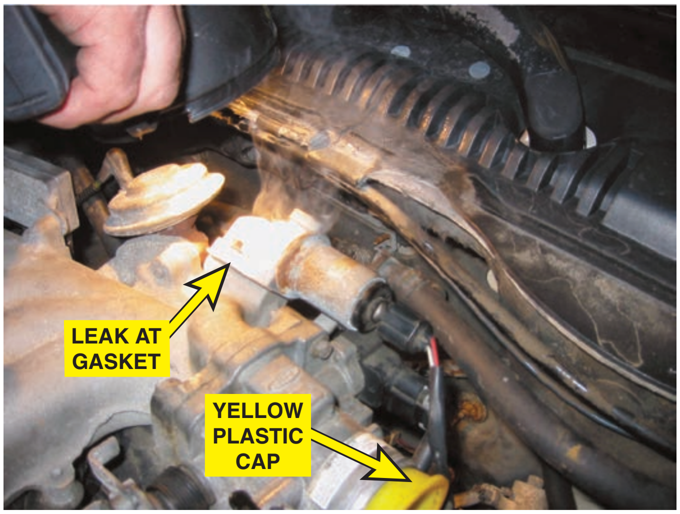


FIGURE 1–6 Using a bright light makes seeing where the smoke is coming from easier. In this case, smoke was added to the intake manifold with the inlet blocked with a yellow plastic cap and smoke was seen escaping past a gasket at the idle air control.

TECH TIP

"Original Equipment" Is Not a Four-Letter Word

To many service technicians, an original equipment (OE) part is considered to be only marginal and to get the really "good stuff" an aftermarket (renewal market) part has to be purchased. However, many problems can be traced to the use of an aftermarket part that has failed early in its service life. Technicians who work at dealerships usually begin their diagnosis with an aftermarket part identified during a visual inspection. It has been their experience that simply replacing the aftermarket part with the factory OE part often solves the problem.

OE parts are *required* to pass quality and durability standards and tests at a level not required of aftermarket parts. The technician should be aware that the presence of a new part does not necessarily mean that the part is good.

TECH TIP

Smoke Machine Testing

Vacuum (air) leaks can cause a variety of driveability problems and are often difficult to locate. One good method is to use a machine that generates a stream of smoke. Connecting the outlet of the **smoke machine** to the hose that was removed from the vacuum brake booster allows smoke to enter the intake manifold. Any vacuum leaks will be spotted by observing smoke coming out of the leak. **SEE FIGURE 1–6**.

in the engine oil. Drip some engine oil from the dipstick onto the hot exhaust manifold. If the oil bubbles or boils, coolant (water) is present in the oil. Check for grittiness by rubbing the oil between your fingers.

NOTE: Gasoline in the oil will cause the engine to run rich by drawing fuel through the positive crankcase ventilation (PCV) system.

- **Check coolant level and condition.** Many mechanical engine problems are caused by overheating. The proper operation of the cooling system is critical to the life of any engine.

NOTE: Check the coolant level in the radiator only if the radiator is cool. If the radiator is hot and the radiator cap is removed, the drop in pressure above the coolant will cause the coolant to boil immediately, which can cause severe burns because the coolant expands explosively upward and outward from the radiator opening.

- **Use the paper test.** even and steady exhaust flow at the tailpipe when running. For the **paper test,** hold a piece of paper (even a dollar bill works) or a 3-by-5-inch card within 1 inch (2.5 m) of the tailpipe with the engine running at idle. The paper should blow evenly away from the end of the tailpipe without "puffing" or being drawn inward toward the end of the tailpipe. If the paper is at times drawn *toward* the tailpipe, the valves in one or more cylinders could be burned. Other reasons why the paper might be drawn toward the tailpipe include the following:

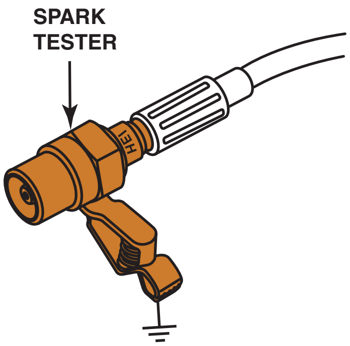


FIGURE 1–7 A spark tester connected to a spark plug wire or coil output. A typical spark tester will only fire if at least 25,000 volts are available from the coil, making a spark tester a very useful tool. Do not use one that just lights when a spark is present, because they do not require more than about 2,000 volts to light.

1. The engine could be misfiring because of a lean condition that could occur normally when the engine is cold.
2. Pulsing of the paper toward the tailpipe could also be caused by a hole in the exhaust system. If exhaust escapes through a hole in the exhaust system, air could be drawn—in the intervals between the exhaust puffs—from the tailpipe to the hole in the exhaust, causing the paper to be drawn toward the tailpipe.

- **Ensure adequate fuel level.** Make certain that the fuel tank is at least one-fourth to one-half full; if the fuel level is low, it is possible that any water or alcohol at the bottom of the fuel tank is more concentrated and can be drawn into the fuel system.
- **Check the battery voltage.** The voltage of the battery should be at least 12.4 volts and the charging voltage (engine running) should be 13.5 to 15.0 volts at 2000 RPM. Low battery voltage can cause a variety of problems, including reduced fuel economy and incorrect (usually too high) idle speed. Higher-than-normal battery voltage can also cause powertrain control module (PCM) problems and could cause damage to electronic modules.
- **Check the spark using a spark tester.** Remove one spark plug wire and attach the removed plug wire to the spark tester. Attach the grounding clip of the spark tester to a good clean engine ground, start or crank the engine, and observe the spark tester. ● **SEE FIGURE 1–7**. The spark at the spark tester should be steady and consistent. If an intermittent spark occurs, then this condition should be treated as a no-spark condition. If this test does not show satisfactory spark, carefully inspect and test all components of the primary and secondary ignition systems.

NOTE: Do not use a standard spark plug to check for proper ignition system voltage. An electronic ignition spark tester is designed to force the spark to jump about 0.75 inch (19 mm). This amount of gap requires between 25,000 and 30,000 volts (25 and 30 kV) at atmospheric pressure, which is enough voltage to ensure that a spark can occur under compression inside an engine.

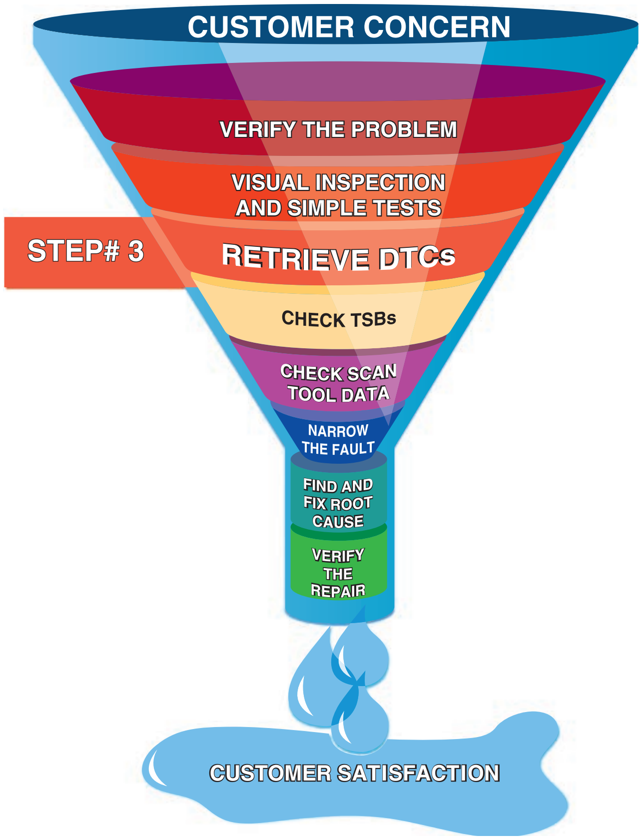


FIGURE 1–8 Step 3 in the diagnostic process is to retrieve any stored diagnostic trouble codes.

- **Check the fuel-pump pressure.** Checking the fuel-pump pressure is relatively easy on many port-fuel-injected engines. Often the cause of intermittent engine performance is due to a weak electric fuel pump or clogged fuel filter. Checking fuel-pump pressure early in the diagnostic process eliminates low fuel pressure as a possibility.

STEP 3 RETRIEVE THE DIAGNOSTIC TROUBLE CODES (DTCs) If a DTC is present in the computer memory, it may be signaled by illuminating a malfunction indicator lamp (MIL), commonly labeled "check engine" or "service engine soon." ● **SEE FIGURE 1–8**. Any code(s) that is displayed on a scan tool when the MIL is *not* on is called a **pending code.** Because the MIL is not on, this indicates that the fault has not repeated to cause the PCM to turn on the MIL. Although this pending code is helpful to the technician to know that a fault has, in the past, been detected, further testing will be needed to find the root cause of the problem. Check and record the freeze-frame information. This indicates when the DTC was set, and this not only will help the technician determine what may have caused the code to set but also helps to verify the repair by operating the vehicle under the same or similar conditions.

TECH TIP

Perform Both a Pre-Scan and a Post-Scan

Many experts advise shops to make a pre-scan of all the vehicle's computer modules as well as a scan after the vehicle has been repaired to be a part of their standard operation procedure (SOP). Not only is this good business practice, but it really helps communications with the customer about possible faults with the vehicle that may not be part of the original customer concern.

- **Pre-scan:** This involves accessing all of the modules in the vehicle and retrieving any or all of the stored diagnostic trouble codes (DTCs), including pending codes. Any stored DTCs are recorded on the work order, and if related to the customer concern, the customer may need to be notified to get their approval before proceeding with the repairs.
- **Post-scan:** After the vehicle has been repaired and before it is released to the customer, a total module scan is performed again to not only verify the repair but also to ensure that another DTC was not set during the repair process. The results of this post-scan should also be documented on the repair order so it becomes a part of the documentation for the vehicle history.

FIGURE 1–9 After checking for stored diagnostic trouble codes (DTCs), the wise technician checks service information for any technical service bulletins that may relate to the vehicle being serviced.

STEP 4 CHECK FOR TECHNICAL SERVICE BULLETINS (TSBS) Check for corrections or repair procedures in **technical service bulletins (TSBs)** that match the symptoms. ● **SEE FIGURE 1–9**. According to studies performed by automobile manufacturers, as many as 30% of vehicles can be repaired following the information, suggestions, or replacement parts found in a service bulletin. DTCs must be known before searching for service bulletins, because bulletins often include information on solving problems that involve a stored diagnostic trouble code.

STEP 5 LOOK CAREFULLY AT SCAN TOOL DATA Vehicle manufacturers have been giving the technician more and more data on a scan tool connected to the **data link connector (DLC)**. ● **SEE FIGURE 1–10**. Beginning technicians are often observed scrolling through scan data without a real clue about what they are looking for. When asked, they usually reply that they are looking for something unusual, as if the screen will flash a big message "LOOK HERE—THIS IS NOT CORRECT." That statement does not appear on scan tool displays. The best way to look at scan data is in a definite sequence and with specific, selected bits of data that can tell the most about the operation of the engine, such as the following:

- Engine coolant temperature (ECT) is the same as intake air temperature (IAT) after the vehicle sits for several hours.
- Idle air control (IAC) valve is being commanded to an acceptable range.
- Oxygen sensor (O2S) is operating properly:

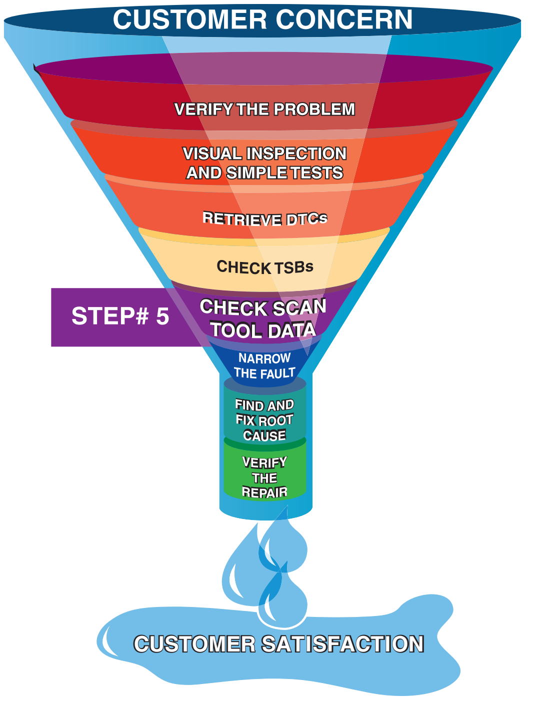


FIGURE 1–10 Looking carefully at the scan tool data is very helpful in locating the source of a problem.

1. Readings below 200 mV at times
2. Readings above 800 mV at times
3. Rapid transitions between rich and lean

STEP 6 NARROW THE PROBLEM TO A SYSTEM OR CYLINDER Narrowing the focus to a system or individual cylinder is the hardest part of the entire diagnostic process. For example:

- Perform a cylinder power balance test.
- If a weak cylinder is detected, perform a compression and a cylinder leakage test to determine the probable cause.

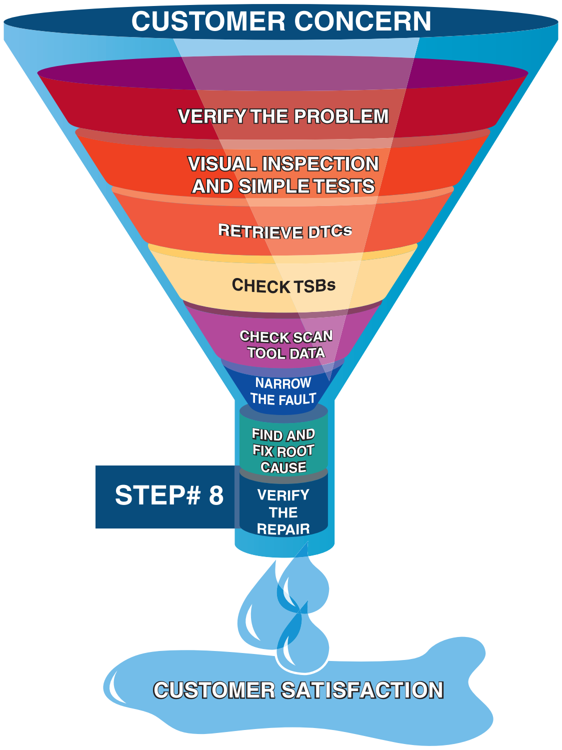


FIGURE 1–11 Step 8 is very important. Be sure that the customer's concern has been corrected.

STEP 7 REPAIR THE PROBLEM AND DETERMINE THE ROOT CAUSE

The repair or part replacement must be performed following vehicle manufacturer's recommendations and be certain that the root cause of the problem has been found. Also follow the manufacturer's recommended repair procedures and methods.

STEP 8 VERIFY THE REPAIR AND CLEAR ANY STORED DTCS

● **SEE FIGURE 1–11**.

- Test-drive to verify that the original problem (concern) is fixed.
- Verify that no additional problems have occurred during the repair process.
- Check for and then clear all diagnostic trouble codes. (This step ensures that the computer will not make any changes based on a stored DTC, but should not be performed if the vehicle is going to be tested for emissions because all of the monitors will need to be run and pass.)
- Return the vehicle to the customer and double check the following:

1. The vehicle is clean.
2. The radio is turned off.
3. The clock is set to the right time and the radio stations have been restored if the battery was disconnected during the repair procedure.

CASE STUDY

The Case of the No-Start Lexus

The owner of a Lexus IS250 had the car towed to a shop as a no-start. The technician discovered that the "check engine" light would not come on even with key on, engine off (KOEO). A scan tool would not communicate either. Checking the resources on www.iatn.net, the technician read of a similar case where the fuel pressure sensor was shorted, which disabled all serial data communications. The technician disconnected the fuel pressure sensor located on the backside of the engine and the communications were restored and the engine started. The fuel pressure sensor was replaced and the vehicle returned to the happy owner.

Summary:

- **Complaint**—The vehicle owner stated that the engine would not start.
- **Cause**—A shorted fuel pressure sensor was found as per a previous similar case.
- **Correction**—The fuel pressure sensor was replaced and this corrected the serial data fault that caused the no-start condition.

SCAN TOOLS

Scan tools are the workhorse for any diagnostic work on all vehicles. Scan tools can be divided into two basic groups:

1. **Factory scan tools.** These are the scan tools required by all dealers that sell and service the brand of vehicle. Examples of factory scan tools include:
   - **General Motors**—Tech 2 or GM MDI ● **SEE FIGURE 1–12**.
   - **Ford**—New Generation Star (NGS) and IDS (Integrated Diagnostic Software).

TECH TIP

One Test Is Worth 1,000 "Expert" Opinions

Whenever any vehicle has an engine performance or driveability concern, certain people always say:

"Sounds like it's a bad injector."
"I'll bet you it's a bad computer."
"I had a problem just like yours yesterday and it was a bad EGR valve."

Regardless of the skills and talents of those people, it is still more accurate to perform tests on the vehicle than to rely on feelings or opinions of others who have not even seen the vehicle. Even your own opinion should not sway your thinking. Follow a plan, perform tests, and the test results will lead to the root cause.

FIGURE 1–12 A TECH 2 scan tool is the factory scan tool used on General Motors vehicles.

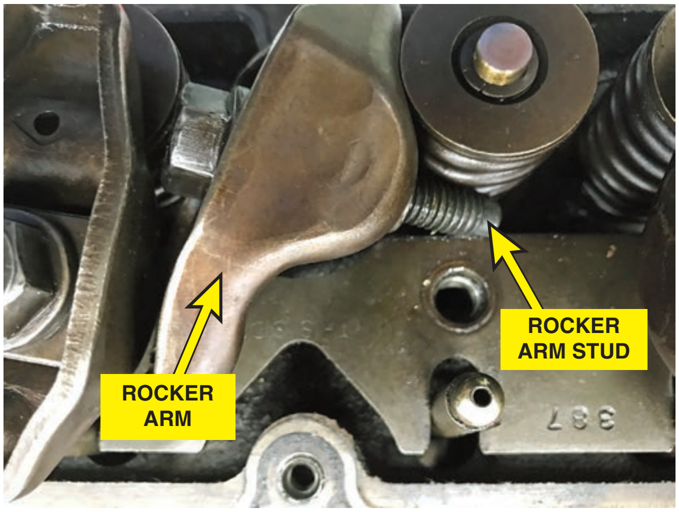


FIGURE 1–13 What the technician discovered after removing the valve cover was the root cause of the misfire.

The Case of the Rough-Running Impala

A customer with a Chevrolet Impala equipped with a 3.4 liter engine is complaining of a running-rough condition and the MIL is illuminated. The customer commented the condition first occurred after a hard acceleration.

The technician was able to verify the customer concern.

The technician retrieved the codes from the engine control module and found a P0306 and a P0300 to be present.

Using the graphic misfire counter on the scan tool, the technician was able to confirm that cylinder #6 was consistently misfiring.

The technician was able to confirm that both the injector and the ignition coil were operating normally.

A compression test of the cylinder #6 revealed compression readings below specifications. A cylinder leakage test of cylinder #six showed leakage percentage to be at an acceptable level.

The technician removed the valve cover to discover the bolt that held the #6 intake valve rocker arm had pulled out of the cylinder head. ● **SEE FIGURE 1–13**.

The technician was able to repair the bolt hole in the cylinder head with a thread repair kit and reinstall the rocker arm. The technician completed a drive cycle and confirmed the misfire condition was repaired.

Summary:

- **Complaint**—The owner complained of a running-rough condition and an illuminated MIL.
- **Cause**—Following the correct diagnostic procedure it was determined that the rocker arm bolt had pulled out of the cylinder head.
- **Correction**—The cylinder head was repaired and the rocker arm was reinstalled, which corrected the rough-running concern and turned off the MIL.

- **Chrysler**—DRB-III or Star Scan, wiTECH
- **Honda**—HDS or Master Tech
- **Toyota**—Master Tech or Tech Stream

All factory scan tools are designed to provide bidirectional capability, which allows the service technician the opportunity to operate components using the scan tool, thereby confirming that the component is able to work when commanded. Also, all factory scan tools are capable of displaying all factory parameters.

2. **Aftermarket scan tools.** These scan tools are designed to function on more than one brand of vehicle while many aftermarket scan tools can display most, if not all, of the parameters of the factory scan tool, there can be a difference when trying to troubleshoot some faults. Examples of aftermarket scan tools include:
   - **Snap-on** (various models including the MT2500 and Modis)
   - **OTC** (various models including Pegasus, Genisys, and Task Master)
   - **AutoEnginuity** and other programs that use a laptop or handheld computer for the display
3. **Global (generic) scan tools.** Scan tools that read and display just global data are capable of only displaying emission-related information. While global only data is helpful at times, generic scan tools are not usually considered to be suitable for use by professional service technicians. ● **SEE FIGURE 1–14**.

RETRIEVAL OF DIAGNOSTIC INFORMATION

To retrieve diagnostic information from the PCM, a scan tool is needed. If a factory or factory-level scan tool is used, then all of the data can be retrieved. If a global (generic)-only-type scan tool is used, only the emissions-related data can be retrieved. To retrieve diagnostic information from the PCM, use the following steps:

FIGURE 1–14 A Bluetooth adapter that plugs into the DLC and transmits global OBD II information to a smart phone that has a scan tool app installed.

STEP 1 Locate and gain access to the data link connector (DLC).

STEP 2 Connect the scan tool to the DLC and establish communication.

NOTE: If no communication is established, follow the vehicle manufacturer's specified instructions.

STEP 3 Follow the on-screen instructions of the scan tool to correctly identify the vehicle.

STEP 4 Observe the scan data, as well as any diagnostic trouble codes.

STEP 5 Follow vehicle manufacturer's instructions if any DTCs are stored. If no DTCs are stored, compare all sensor values with a factory-acceptable range chart to see if any sensor values are out of range.

Parameter Identification (PID)

Scan Tool Parameter	Units Displayed	Typical Data Value
Engine Idling/Radiator Hose Hot/Closed Throttle/ Park or Neutral/Closed Loop/Accessories Off/ Brake Pedal Released		
3X Crank Sensor	RPM	Varies
24X Crank Sensor	RPM	Varies
Actual EGR Position	Percent	0
BARO	kPa/Volts	65–110 kPa/ 3.5–4.5 Volts
CMP Sensor Signal Present	Yes/No	Yes
Commanded Fuel Pump	On/Off	On
Cycles of Misfire Data	Counts	0–99
Desired EGR Position	Percent	0
ECT	°C/°F	Varies
EGR Duty Cycle	Percent	0
Engine Run Time	Hr: Min: Sec	Varies
EVAP Canister Purge	Percent	Low and Varying
EVAP Fault History	No Fault/Excess Vacuum/Purge Valve Leak/ Small Leak/Weak Vacuum	No Fault
Fuel Tank Pressure	Inches of H_2O/ Volts	Varies
HO2S Sensor 1	Ready/Not Ready	Ready
HO2S Sensor 1	Millivolts	0–1,000 and Varying
HO2S Sensor 2	Millivolts	0–1,000 and Varying
HO2S X Counts	Counts	Varies
IAC Position	Counts	15–25 preferred
IAT	°C/°F	Varies
Knock Retard	Degrees	0
Long-term FT	Percent	0–10
MAF	Grams per second	3–7
MAF Frequency	Hz	1,200–3,000 (depends on altitude and engine load)
MAP	kPa/Volts	20–48 kPa/0.75–2 Volts (depends on altitude)
Misfire Current Cyl. 1–10	Counts	0
Misfire History Cyl. 1–10	Counts	0
Short-term FT	Percent	0–10
Start Up ECT	°C/°F	Varies
Start Up IAT	°C/°F	Varies
Total Misfire Current Count	Counts	0
Total Misfire Failures	Counts	0

Parameter Identification (PID)		
Scan Tool Parameter	Units Displayed	Typical Data Value
Total Misfire Passes	Counts	0
TP Angle	Percent	0
TP Sensor	Volts	0.20–0.74
Vehicle Speed	MPH/Km/h	0

Note: Viewing the PID screen on the scanner is useful in determining if a problem is occurring at the present time

FIGURE 1–15 Diagnostic trouble codes (DTCs) from Chrysler and Dodge vehicles can be retrieved by turning the ignition switch to on and then off three times.

TROUBLESHOOTING USING DIAGNOSTIC TROUBLE CODES

Pinning down causes of the actual problem can be accomplished by trying to set the opposite code. For example, if a code indicates an open throttle position (TP) sensor (high resistance), clear the code and create a shorted (low-resistance) condition. This can be accomplished by using a jumper wire and connecting the signal terminal to the 5-volt reference terminal. This should set a diagnostic trouble code.

- **If the opposite code sets,** this indicates that the wiring and connector for the sensor is okay and the sensor itself is defective (open).
- **If the same code sets,** this indicates that the wiring or electrical connection is open (has high resistance) and is the cause of the setting of the DTC.

METHODS FOR CLEARING DIAGNOSTIC TROUBLE CODES Clearing diagnostic trouble codes from a vehicle computer sometimes needs to be performed. There are three methods that can be used to clear stored diagnostic trouble codes.

CAUTION: Clearing diagnostic trouble codes (DTCs) also will clear all of the noncontinuous monitors.

- **Clearing codes—Method 1.** The preferred method of clearing codes is by using a scan tool. This is the method recommended by most vehicle manufacturers if the procedure can be performed on the vehicle. The computer of some vehicles cannot be cleared with a scan tool.
- **Clearing codes—Method 2.** If a scan tool is not available or a scan tool cannot be used on the vehicle being serviced, the power to the computer can be disconnected.
  1. Disconnect the fusible link (if so equipped) that feeds the computer.
  2. Disconnect the fuse or fuses that feed the computer.

  NOTE: The fuse may not be labeled as a computer fuse. For example, many Toyotas can be cleared by disconnecting the fuel-injection fuse. Some vehicles require that two fuses be disconnected to clear any stored codes.

- **Clearing codes—Method 3.** If the other two methods cannot be used, the negative battery cable can be disconnected to clear stored diagnostic trouble codes.

NOTE: Because of the adaptive learning capacity of the computer, a vehicle may fail an exhaust emissions test

TECH TIP

Do Not Lie to a Scan Tool!

Because computer calibration may vary from year to year, using the incorrect year for the vehicle while using a scan tool can cause the data retrieved to be incorrect or inaccurate.

TECH TIP

Quick and Easy Chrysler Code Retrieval

Most Chrysler-made vehicles (Dodge, Ram, and Chrysler) can display the diagnostic trouble code on the dash by turning the ignition switch on and then off and then on three times with the last time being on. This makes it easy for anyone to see if there are any stored trouble codes without having to use a scan tool. **SEE FIGURE 1–15**.

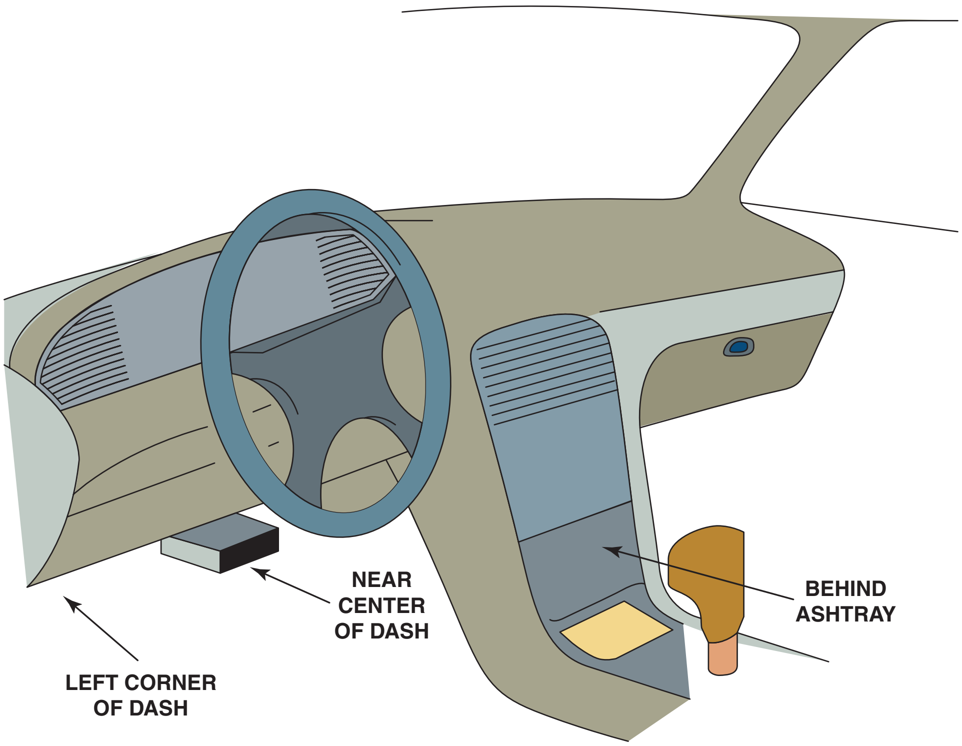


FIGURE 1–16 The data link connector (DLC) can be located in various locations.

if the vehicle is not driven enough to allow the computer to run all of the monitors.

CAUTION: By disconnecting the battery, the radio presets will be lost. They should be reset before returning the vehicle to the customer. If the radio has a security code, the code must be entered before the radio will function. Before disconnecting the battery, always check with the vehicle owner to be sure that the code is available.

DLC LOCATIONS

The data link connector (DLC) is a standardized 16-cavity connector where a scan tool can be connected to retrieve diagnostic information from the vehicle's computers.

The normal location is under the dash on the driver's side but it can be located within 12 inches (30 cm) of the center of the vehicle. It can be covered, but if it is, then the cover has to be able to be removed without the use of a tool, such as when it is located underneath the ash tray. ● **SEE FIGURE 1–16**.

OBD-II DIAGNOSIS

Starting with the 1996 model year, all vehicles sold in the United States must use the same type of 16-pin data link connector (DLC) and must monitor emission-related components. ● **SEE FIGURE 1–17**.

FIGURE 1–17 A typical OBD-II data link connector (DLC). The location varies with make and model and may even be covered, but a tool is not needed to gain access. Check service information for the exact location if needed.

RETRIEVING OBD-II CODES A scan tool is required to retrieve diagnostic trouble codes from most OBD-II vehicles. Every OBD-II scan tool will be able to read all generic Society of Automotive Engineers (SAE) DTCs from any vehicle.

Fuel and Air Metering System

P0100	Mass or Volume Airflow Circuit Problem
P0101	Mass or Volume Airflow Circuit Range or Performance Problem
P0102	Mass or Volume Airflow Circuit Low Input
P0103	Mass or Volume Airflow Circuit High Input
P0105	Manifold Absolute Pressure or Barometric Pressure Circuit Problem

P0106	Manifold Absolute Pressure or Barometric Pressure Circuit Range or Performance Problem
P0107	Manifold Absolute Pressure or Barometric Pressure Circuit Low Input
P0108	Manifold Absolute Pressure or Barometric Pressure Circuit High Input
P0110	Intake Air Temperature Circuit Problem
P0111	Intake Air Temperature Circuit Range or Performance Problem
P0112	Intake Air Temperature Circuit Low Input
P0113	Intake Air Temperature Circuit High Input
P0115	Engine Coolant Temperature Circuit Problem
P0116	Engine Coolant Temperature Circuit Range or Performance Problem
P0117	Engine Coolant Temperature Circuit Low Input
P0118	Engine Coolant Temperature Circuit High Input
P0120	Throttle Position Circuit Problem
P0121	Throttle Position Circuit Range or Performance Problem
P0122	Throttle Position Circuit Low Input
P0123	Throttle Position Circuit High Input
P0125	Excessive Time to Enter Closed-Loop Fuel Control
P0128	Coolant Temperature Below Thermostat Regulating Temperature
P0130	O2 Sensor Circuit Problem (Bank 1* Sensor 1)
P0131	O2 Sensor Circuit Low Voltage (Bank 1* Sensor 1)
P0132	O2 Sensor Circuit High Voltage (Bank 1* Sensor 1)
P0133	O2 Sensor Circuit Slow Response (Bank 1* Sensor 1)
P0134	O2 Sensor Circuit No Activity Detected (Bank 1* Sensor 1)
P0135	O2 Sensor Heater Circuit Problem (Bank 1* Sensor 1)
P0136	O2 Sensor Circuit Problem (Bank 1* Sensor 2)
P0137	O2 Sensor Circuit Low Voltage (Bank 1* Sensor 2)
P0138	O2 Sensor Circuit High Voltage (Bank 1* Sensor 2)
P0139	O2 Sensor Circuit Slow Response (Bank 1* Sensor 2)
P0140	O2 Sensor Circuit No Activity Detected (Bank 1* Sensor 2)
P0141	O2 Sensor Heater Circuit Problem (Bank 1* Sensor 2)
P0142	O2 Sensor Circuit Problem (Bank 1* Sensor 3)
P0143	O2 Sensor Circuit Low Voltage (Bank 1* Sensor 3)
P0144	O2 Sensor Circuit High Voltage (Bank 1* Sensor 3)
P0145	O2 Sensor Circuit Slow Response (Bank 1* Sensor 3)
P0146	O2 Sensor Circuit No Activity Detected (Bank 1* Sensor 3)
P0147	O2 Sensor Heater Circuit Problem (Bank 1* Sensor 3)
P0150	O2 Sensor Circuit Problem (Bank 2 Sensor 1)
P0151	O2 Sensor Circuit Low Voltage (Bank 2 Sensor 1)
P0152	O2 Sensor Circuit High Voltage (Bank 2 Sensor 1)
P0153	O2 Sensor Circuit Slow Response (Bank 2 Sensor 1)
P0154	O2 Sensor Circuit No Activity Detected (Bank 2 Sensor 1)
P0155	O2 Sensor Heater Circuit Problem (Bank 2 Sensor 1)
P0156	O2 Sensor Circuit Problem (Bank 2 Sensor 2)
P0157	O2 Sensor Circuit Low Voltage (Bank 2 Sensor 2)
P0158	O2 Sensor Circuit High Voltage (Bank 2 Sensor 2)
P0159	O2 Sensor Circuit Slow Response (Bank 2 Sensor 2)
P0160	O2 Sensor Circuit No Activity Detected (Bank 2 Sensor 2)
P0161	O2 Sensor Heater Circuit Problem (Bank 2 Sensor 2)
P0162	O2 Sensor Circuit Problem (Bank 2 Sensor 3)
P0163	O2 Sensor Circuit Low Voltage (Bank 2 Sensor 3)
P0164	O2 Sensor Circuit High Voltage (Bank 2 Sensor 3)
P0165	O2 Sensor Circuit Slow Response (Bank 2 Sensor 3)
P0166	O2 Sensor Circuit No Activity Detected (Bank 2 Sensor 3)
P0167	O2 Sensor Heater Circuit Problem (Bank 2 Sensor 3)
P0170	Fuel Trim Problem (Bank 1*)
P0171	System Too Lean (Bank 1*)
P0172	System Too Rich (Bank 1*)

(continued)

P0173 Fuel Trim Problem (Bank 2)
P0174 System Too Lean (Bank 2)
P0175 System Too Rich (Bank 2)
P0176 Fuel Composition Sensor Circuit Problem
P0177 Fuel Composition Sensor Circuit Range or Performance
P0178 Fuel Composition Sensor Circuit Low Input
P0179 Fuel Composition Sensor Circuit High Input
P0180 Fuel Temperature Sensor Problem
P0181 Fuel Temperature Sensor Circuit Range or Performance
P0182 Fuel Temperature Sensor Circuit Low Input
P0183 Fuel Temperature Sensor Circuit High Input

Fuel and Air Metering (Injector Circuit)

P0201 Injector Circuit Problem—Cylinder 1
P0202 Injector Circuit Problem—Cylinder 2
P0203 Injector Circuit Problem—Cylinder 3
P0204 Injector Circuit Problem—Cylinder 4
P0205 Injector Circuit Problem—Cylinder 5
P0206 Injector Circuit Problem—Cylinder 6
P0207 Injector Circuit Problem—Cylinder 7
P0208 Injector Circuit Problem—Cylinder 8
P0209 Injector Circuit Problem—Cylinder 9
P0210 Injector Circuit Problem—Cylinder 10
P0211 Injector Circuit Problem—Cylinder 11
P0212 Injector Circuit Problem—Cylinder 12
P0213 Cold Start Injector 1 Problem
P0214 Cold Start Injector 2 Problem

Ignition System or Misfire

P0300 Random Misfire Detected
P0301 Cylinder 1 Misfire Detected
P0302 Cylinder 2 Misfire Detected
P0303 Cylinder 3 Misfire Detected
P0304 Cylinder 4 Misfire Detected
P0305 Cylinder 5 Misfire Detected
P0306 Cylinder 6 Misfire Detected
P0307 Cylinder 7 Misfire Detected
P0308 Cylinder 8 Misfire Detected
P0309 Cylinder 9 Misfire Detected
P0310 Cylinder 10 Misfire Detected
P0311 Cylinder 11 Misfire Detected
P0312 Cylinder 12 Misfire Detected
P0320 Ignition or Distributor Engine Speed Input Circuit Problem
P0321 Ignition or Distributor Engine Speed Input Circuit Range or Performance
P0322 Ignition or Distributor Engine Speed Input Circuit No Signal
P0325 Knock Sensor 1 Circuit Problem
P0326 Knock Sensor 1 Circuit Range or Performance
P0327 Knock Sensor 1 Circuit Low Input
P0328 Knock Sensor 1 Circuit High Input
P0330 Knock Sensor 2 Circuit Problem
P0331 Knock Sensor 2 Circuit Range or Performance
P0332 Knock Sensor 2 Circuit Low Input
P0333 Knock Sensor 2 Circuit High Input
P0335 Crankshaft Position Sensor Circuit Problem
P0336 Crankshaft Position Sensor Circuit Range or Performance
P0337 Crankshaft Position Sensor Circuit Low Input
P0338 Crankshaft Position Sensor Circuit High Input

Auxiliary Emission Controls

P0400 Exhaust Gas Recirculation Flow Problem
P0401 Exhaust Gas Recirculation Flow Insufficient Detected
P0402 Exhaust Gas Recirculation Flow Excessive Detected
P0405 Air Conditioner Refrigerant Charge Loss
P0410 Secondary Air Injection System Problem
P0411 Secondary Air Injection System Insufficient Flow Detected
P0412 Secondary Air Injection System Switching Valve or Circuit Problem
P0413 Secondary Air Injection System Switching Valve or Circuit Open
P0414 Secondary Air Injection System Switching Valve or Circuit Shorted
P0420 Catalyst System Efficiency below Threshold (Bank 1*)
P0421 Warm Up Catalyst Efficiency below Threshold (Bank 1*)
P0422 Main Catalyst Efficiency below Threshold (Bank 1*)
P0423 Heated Catalyst Efficiency below Threshold (Bank 1*)
P0424 Heated Catalyst Temperature below Threshold (Bank 1*)
P0430 Catalyst System Efficiency below Threshold (Bank 2)
P0431 Warm Up Catalyst Efficiency below Threshold (Bank 2)

P0432 Main Catalyst Efficiency below Threshold (Bank 2)
P0433 Heated Catalyst Efficiency below Threshold (Bank 2)
P0434 Heated Catalyst Temperature below Threshold (Bank 2)
P0440 Evaporative Emission Control System Problem
P0441 Evaporative Emission Control System Insufficient Purge Flow
P0442 Evaporative Emission Control System Leak Detected
P0443 Evaporative Emission Control System Purge Control Valve Circuit Problem
P0444 Evaporative Emission Control System Purge Control Valve Circuit Open
P0445 Evaporative Emission Control System Purge Control Valve Circuit Shorted
P0446 Evaporative Emission Control System Vent Control Problem
P0447 Evaporative Emission Control System Vent Control Open
P0448 Evaporative Emission Control System Vent Control Shorted
P0450 Evaporative Emission Control System Pressure Sensor Problem
P0451 Evaporative Emission Control System Pressure Sensor Range or Performance
P0452 Evaporative Emission Control System Pressure Sensor Low Input
P0453 Evaporative Emission Control System Pressure Sensor High Input

Vehicle Speed Control and Idle Control

P0500 Vehicle Speed Sensor Problem
P0501 Vehicle Speed Sensor Range or Performance
P0502 Vehicle Speed Sensor Low Input
P0505 Idle Control System Problem
P0506 Idle Control System RPM Lower Than Expected
P0507 Idle Control System RPM Higher Than Expected
P0510 Closed Throttle Position Switch Problem

Computer Output Circuit

P0600 Serial Communication Link Problem
P0605 Internal Control Module (Module Identification Defined by J1979)

Transmission

P0703 Brake Switch Input Problem
P0705 Transmission Range Sensor Circuit Problem (PRNDL Input)
P0706 Transmission Range Sensor Circuit Range or Performance
P0707 Transmission Range Sensor Circuit Low Input
P0708 Transmission Range Sensor Circuit High Input
P0710 Transmission Fluid Temperature Sensor Problem
P0711 Transmission Fluid Temperature Sensor Range or Performance
P0712 Transmission Fluid Temperature Sensor Low Input
P0713 Transmission Fluid Temperature Sensor High Input
P0715 Input or Turbine Speed Sensor Circuit Problem
P0716 Input or Turbine Speed Sensor Circuit Range or Performance
P0717 Input or Turbine Speed Sensor Circuit No Signal
P0720 Output Speed Sensor Circuit Problem
P0721 Output Speed Sensor Circuit Range or Performance
P0722 Output Speed Sensor Circuit No Signal
P0725 Engine Speed Input Circuit Problem
P0726 Engine Speed Input Circuit Range or Performance
P0727 Engine Speed Input Circuit No Signal
P0730 Incorrect Gear Ratio
P0731 Gear 1 Incorrect Ratio
P0732 Gear 2 Incorrect Ratio
P0733 Gear 3 Incorrect Ratio
P0734 Gear 4 Incorrect Ratio
P0735 Gear 5 Incorrect Ratio
P0736 Reverse Incorrect Ratio
P0740 Torque Converter Clutch System Problem
P0741 Torque Converter Clutch System Performance or Stuck Off
P0742 Torque Converter Clutch System Stuck On
P0743 Torque Converter Clutch System Electrical
P0745 Pressure Control Solenoid Problem
P0746 Pressure Control Solenoid Performance or Stuck Off
P0747 Pressure Control Solenoid Stuck On
P0748 Pressure Control Solenoid Electrical
P0750 Shift Solenoid A Problem
P0751 Shift Solenoid A Performance or Stuck Off
P0752 Shift Solenoid A Stuck On
P0753 Shift Solenoid A Electrical

(continued)

P0755	Shift Solenoid B Problem
P0756	Shift Solenoid B Performance or Stuck Off
P0757	Shift Solenoid B Stuck On
P0758	Shift Solenoid B Electrical
P0760	Shift Solenoid C Problem
P0761	Shift Solenoid C Performance or Stuck Off
P0762	Shift Solenoid C Stuck On
P0763	Shift Solenoid C Electrical
P0765	Shift Solenoid D Problem
P0766	Shift Solenoid D Performance or Stuck Off
P0767	Shift Solenoid D Stuck On
P0768	Shift Solenoid D Electrical
P0770	Shift Solenoid E Problem
P0771	Shift Solenoid E Performance or Stuck Off
P0772	Shift Solenoid E Stuck On
P0773	Shift Solenoid E Electrical

* The side of the engine where number one cylinder is located.

OBD-II ACTIVE TESTS

The vehicle computer must run tests on the various emission-related components and turn on the malfunction indicator lamp (MIL) if faults are detected. OBD II is an *active* computer analysis system because it actually tests the operation of the oxygen sensors, exhaust gas recirculation system, and so forth whenever conditions permit. It is the purpose and function of the powertrain control module (PCM) to monitor these components and perform these active tests.

For example, the PCM may open the EGR valve momentarily to check its operation while the vehicle is decelerating. A change in the manifold absolute pressure (MAP) sensor signal will indicate to the computer that the exhaust gas is, in fact, being introduced into the engine. Because these tests are active and certain conditions must be present before these tests can be run, the computer uses its internal diagnostic program to keep track of all the various conditions and to schedule active tests so that they will not interfere with each other.

OBD-II DRIVE CYCLE The vehicle must be driven under a variety of operating conditions for all active tests to be performed. A **trip** is defined as an engine-operating drive cycle that contains the necessary conditions for a particular test to be performed. For example, for the EGR test to be performed, the engine has to be at normal operating temperature and decelerating for a minimum amount of time. Some tests are performed when the engine is cold, whereas others require that the vehicle be cruising at a steady highway speed.

TYPES OF OBD-II CODES Not all OBD-II diagnostic trouble codes are of the same importance for exhaust emissions. Each type of DTC has different requirements for it to set, and the computer will only turn on the MIL for emissions-related DTCs.

TYPE A CODES. A type A diagnostic trouble code is emission related and will cause the MIL to be turned on at the *first trip* if the computer has detected a problem. Engine misfire or a very rich or lean air–fuel ratio, for example, would cause a type A diagnostic trouble code. These codes alert the driver to an emissions problem that may cause damage to the catalytic converter.

TYPE B CODES. A type B code will be stored as a pending code in the PCM and the MIL will be turned on only after the second consecutive trip, alerting the driver to the fact that a diagnostic test was performed and failed.

NOTE: Type A and Type B codes are emission related and will cause the lighting of the malfunction indicator lamp, usually labeled "check engine" or "service engine soon."

TYPE C AND D CODES. Type C and type D codes are for use with non-emission-related diagnostic tests. They will cause the lighting of a "service" lamp (if the vehicle is so equipped).

OBD-II FREEZE-FRAME To assist the service technician, OBD II requires the computer to take a "snapshot" or freeze-frame of all data at the instant an emission-related DTC is set. A scan tool is required to retrieve this data. CARB and EPA regulations require that the controller store specific freeze-frame (engine-related) data when the first emission-related fault is detected. The data stored in freeze-frame can only be replaced by data from a trouble code with a higher priority such as a problem related to a fuel system or misfire monitor fault.

NOTE: Although OBD II requires that just one freeze-frame of data be stored, the instant an emission-related DTC is set, vehicle manufacturers usually provide expanded data about the DTC beyond that required. However, retrieving enhanced data usually requires the use of an enhanced or factory-level scan tool.

The freeze-frame has to contain data values that occurred at the time the code was set (these values are provided in standard units of measurement). Freeze-frame data are recorded during the first trip on a two-trip fault. As a result, OBD-II systems record the data present at the time an emission-related code is recorded and the MIL activated. These data can be accessed and displayed on a scan tool. Freeze-frame data are one frame or one instant in time. They are not updated (refreshed) if the same monitor test fails a second time.

REQUIRED FREEZE-FRAME DATA ITEMS.

- Code that triggered the freeze-frame
- A/F ratio, airflow rate, and calculated engine load
- Base fuel injector pulse width
- ECT, IAT, MAF, MAP, TP, and VS sensor data
- Engine speed and amount of ignition spark advance
- Open- or closed-loop status

- Short-term and long-term fuel trim values
- For misfire codes—identify the cylinder that misfired

NOTE: All freeze-frame data will be lost if the battery is disconnected, power to the PCM is removed, or the scan tool is used to erase or clear trouble codes.

DIAGNOSING INTERMITTENT MALFUNCTIONS Of all the different types of conditions that you will see, the hardest to accurately diagnose and repair are intermittent malfunctions. These conditions may be temperature related (only occur when the vehicle is hot or cold), or humidity related (only occur when it is raining). Regardless of the conditions that will cause the malfunction to occur, you must diagnose and correct the condition.

When dealing with an intermittent concern, you should determine the conditions when the malfunction occurs, and then try to duplicate those conditions. If a cause is not readily apparent to you, ask the customer when the symptom occurs. Ask if there are any conditions that seem to be related to, or cause the concern.

Another consideration when working on an OBD-II-equipped vehicle is whether a concern is intermittent, or if it only occurs when a specific diagnostic test is performed by the PCM. Since OBD-II systems conduct diagnostic tests only under very precise conditions, some tests may be run only once during an ignition cycle. Additionally, if the requirements needed to perform the test are not met, the test will not run during an ignition cycle. This type of onboard diagnostics could be mistaken as "intermittent" when, in fact, the tests are only infrequent (depending on how the vehicle is driven). Examples of this type of diagnostic test are HO2S heaters, evaporative canister purge, catalyst efficiency, and EGR flow. When diagnosing intermittent concerns on an OBD-II-equipped vehicle, a logical diagnostic strategy is essential. The use of stored freeze-frame information can also be very useful when diagnosing an intermittent malfunction if a code has been stored.

NO-CODE DIAGNOSIS

POSSIBLE CAUSES **No-code diagnosis** is what the service technician needs to perform when there is a customer concern but there are no stored diagnostic trouble codes (DTCs). This type of customer complaint often results in a potential long process to locate the root cause. There are many possible causes of a problem such as a hesitation, stalling of poor performance that will not cause a DTC to set. Some of the possible causes include:

- Alcohol (ethanol) in high concentrations in the fuel
- Contaminated fuel that has water or diesel fuel mixed with the fuel
- Clogged air intake systems due to an animal nest of road debris caught in the air intake system
- Partially clogged or restricted exhaust system
- Engine mechanical fault such as recessed valves into the cylinder head resulting in reduced valve lift, thereby reducing engine power.
- Incorrect oil level or viscosity
- Incorrectly timed timing belt or chain causing valve timing to off but not enough to cause a crank/cam correlation DTC to be set.

NO-CODE DIAGNOSTIC STRATEGY If there are no stored DTCs, diagnostic strategy the wise service technician follows includes the following steps:

STEP #1: After verifying the customer concern, check vehicle service history and perform a thorough visual inspection checking for the following:

- Evidence of a previous repair or recent body work that may be an indication of an accident (collision).
- Check the fuel for contamination or excessive alcohol content
- Check that all of the tire sizes are the same, because if they are not, this can cause a vibration that is often confused as being a misfire, especially in four-wheel-drive and all-wheel-drive vehicles.
- Check for evidence of previous service work if the vehicle history is not available that may include engine work such as a timing belt or water pump replacement.
- Check for technical service bulletins (TSBs) that relate to the customer's concern.

STEP #2: Check scan tool data and look at fuel trim numbers. A preferred fuel trim is less than 5% whereas anything less than 10% is considered to be acceptable. A diagnostic trouble code for a rich or lean air–fuel ratio is usually set when the fuel number exceeds 25%. Sometimes driveability issues can be experienced by the driver when the exhaust is lean but not lean enough to set a DTC.

STEP #3: Perform a test drive using a scan tool set to record the major high-authority sensors in movie mode. The high-authority sensors that should be selected include:

- MAP/MAF
- ECT/IAT
- TP sensor
- O_2 sensors

The TP and MAF sensor should track each other, and when shown using the graphing capability on the scan tool, they show a direct relationship to each other as the vehicle is accelerated. Any sensor that shows to be not responding during engine load test needs to be checked more thoroughly.

STEP #4: If the root cause has not been located, perform a five-gas analysis of the exhaust gases. See Chapter 26 for details regarding what the results may indicate.

STEP #5: Using all available resources, including vehicle manufacturer's recommended testing procedures, determine the root cause of the problem. After making the repair,

CASE STUDY

The Case of the No-Power Kia

A customer had a Kia Sorento towed to a shop because it would not accelerate and the engine would not increase in speed higher than 1000 RPM. No diagnostic trouble codes were found and no technical service bulletins were found that pertained to this condition either. The data display on the scan tool did not show anything out of range and a through visual inspection found that the engine appeared to well maintain without any obvious or visible faults. Then another technician in the shop told the technician working on the vehicle that the brake lights were on whenever the engine was running even though no one was in the vehicle. This led to a closer examination of the brake switch, and when it was moved the engine was then able to be accelerated normally. A replacement brake switch was installed and the problem of a lack of acceleration was solved, and after replacement, the vehicle performed normally. The customer was pleased that a simple and low-cost solution was found.

Summary:

- **Complaint**—The vehicle owner complained that the engine would not accelerate and the engine speed would not increase higher than 1000 RPM.
- **Cause**—A defective brake switch caused the PCM to sense that the brake was applied and limited engine speed.
- **Correction**—A replacement brake switch fixed the problem and allowed the vehicle to accelerate normally.

verify the repair by performing a test-drive under similar conditions that caused the customer concern to make sure that the cause has been successfully repaired.

DETERMINING ROOT CAUSE OF REPEATED COMPONENT FAILURES

THE FIVE WHYS Typically when a component or system fails multiple times, the root cause of the failure was not corrected. When diagnosing the root cause of repeated component or system failure, the wise technician asks why five times. For example, for a case where the PCM set repeated P0017 (CKP/CMP correlation) DTCs, the oil control valve was replaced and the DTC cleared. According to the repair forums, this was a common repair for this condition. The engine appeared to be operating correctly; however, the check engine light with the same code occurred again after a week? Why?

Why #1: The technician did not complete a thorough diagnosis, instead relying on a silver bullet in a repair forum. On the second attempt to repair the vehicle the technician followed the diagnostic procedure for the code. The resistance of the new oil control valve was found to be within specifications. The camshaft position (CMP) sensor was tested based on the advice from another technician. The sensor passed all the diagnostic tests and appeared to be generating a normal signal.

Why #2: If the oil control valve and the sensor are both good, why did the code reset? The technician checked all of the wiring and the electrical connectors and found them to be okay. Why was the problem still occurring?

Why #3: During a subsequent test drive, the code set again. This time the technician tested the crankshaft sensor and verified the condition of the timing belt. Each of the components tested normally.

Why #4: The technician thought that the recurring problem was related to the OCV because when these were replaced, it fixed the vehicle for some time. The technician then noticed the engine oil was low and very dirty. Why was this important?

Why #5: Understanding that clean oil was needed for the system to operate properly, the engine oil and filter were replaced making sure to use the oil recommended by the manufacturer and an oil filter that met original equipment specifications. The code was cleared and on subsequent test drives the failure did not reoccur.

On the second repair attempt the technician followed the diagnostic process to a logical end. No assumptions were made, but instead decisions were made based on the test results. In the end, the root cause of the problem was actually very simple and the repair was relatively inexpensive.

MULTIPLE COMPONENT FAILURE DIAGNOSIS If more than one component is found to be defective, the root cause has to be found. If the components are electrical, use a wiring diagram and check for the following:

- Do the components share a common ground connection? If so, this could be the most likely cause and the first place to check.

TECH TIP

The Brake Pedal Trick

If the vehicle manufacturer recommends that battery power be disconnected, first disconnect the negative battery cable and then depress the brake pedal. Because the brake lights are connected to battery power, depressing the brake pedal causes all of the capacitors in the electrical system and computer(s) to discharge through the brake lights.

- Do the components share the same power? If so, then this could be the source of common component failure.
- Are the components or wiring near a heat source such as the exhaust system or EGR system components? Heat can cause electrical issues and often cause issues with more than one component.
- Are the components or wiring near something that is moved such as a door, hood, or trunk (tailgate) opening? The movement can cause electrical issues and often cause issues with more than one component.
- Follow the diagnostic strategy to find and correct the root cause, then verify the repair has solved the customer concern before returning the vehicle.

MANUFACTURER'S DIAGNOSTIC ROUTINES

Each vehicle manufacturer has established their own diagnostic routines and they should be followed. Most include the following steps:

STEP 1 Retrieve diagnostic trouble codes.

STEP 2 Check for all technical service bulletins that could be related to the stored DTC.

STEP 3 If there are multiple DTCs, the diagnostic routine may include checking different components or systems instead of when only one DTC was stored.

STEP 4 Perform system checks.

STEP 5 Perform the necessary service or repair

STEP 6 Perform a road test matching the parameters recorded in the freeze-frame to check that the repair has corrected the malfunction.

STEP 7 Repeat the road test to cause the MIL to be extinguished.

NOTE: Do not clear codes (DTCs) unless instructed by the service information.

Following the vehicle manufacturer's specific diagnostic routines will ensure that the root cause is found and the repair verified. This is important for customer satisfaction.

VERIFYING THE REPAIR

PROCEDURE After the repair has been successfully completed, the vehicle should be driven under similar conditions that caused the original concern in order to verify that the problem has been corrected. To perform this test drive, it is helpful to have a copy of the freeze-frame parameters that were present when the DTC was set. By driving under similar conditions, the PCM may perform a test of the system and automatically extinguish the malfunction indicator light (MIL). This is the method preferred by many vehicle manufacturers.

TECH TIP

Drive the Light Out

If working on a vehicle that is subject to state emission testing, it is best to not clear codes. When diagnostic trouble codes are cleared, all of the monitors have to be rerun and this can be a time-consuming job. Instead of clearing the code, simply drive the vehicle until the PCM clears the code. This will likely take less time compared to trying to drive the vehicle under varying conditions to run all of the monitors.

OBD MONITORS FOR REPAIR VERIFICATION All 1996 and newer vehicles perform enhanced diagnostic checks of specific emission control components such as engine, transmission, fuel systems, and other emissions controls. Each diagnostic check communicates with the powertrain control module's (PCM) diagnostic executive to record the data in the *readiness monitor*. These diagnostic checks are generally performed while the vehicle is driven in a specific manner and are a great way to prove the repair was successful. If the diagnostic checks have been performed and passed, the PCM marks them as "ready." Technicians in a non-emissions test area are able to use the data to ensure the vehicle is repaired and that no other codes are set prior to returning the vehicle to the customer.

For technicians who work on vehicles in an emission test area this is an important step in the repair process. If diagnostic data has been erased during vehicle repairs or through battery disconnection, the PCM will flag the monitors as "incomplete" or "not ready." Vehicles are rejected from emission testing when these diagnostic checks are not completed. The number of monitors allowed to be not complete depends on the year of the vehicle and the emission testing area requirements.

The vehicle performs the self-diagnostic tests when the vehicle is driven, referred to as a "drive cycle." Therefore, after the repair is complete the vehicle will need to be driven through a drive cycle. If the check engine light does not turn off, then additional repair(s) may be required. If the repairs require the DTCs to be cleared or a battery disconnect (which also clears DTCs), then the vehicle needs to be driven to get the monitors to run and pass.

ROAD TEST (DRIVE CYCLE)

Use the freeze-frame data and test-drive the vehicle so that the vehicle is driven to match the conditions displayed on the freeze-frame. If the battery has been disconnected, then the vehicle may have to be driven under conditions that allow the PCM to conduct monitor tests. This drive pattern is called a **drive cycle.** The drive cycle is different for each vehicle manufacturer but a universal drive cycle may work in many cases. In many cases performing a universal drive cycle will reset most monitors in most vehicles.

UNIVERSAL DRIVE CYCLE

PRECONDITIONING: Phase I.

MIL must be off.

No DTCs present.

Fuel fill between 15% and 85%.

Cold start – Preferred = 8 – hour soak at 68°F to 86°F.

Alternative: ECT = IAT.

1. With the ignition off, connect scan tool.
2. Start engine and drive between 20 and 30 mph for 22 minutes, allowing speed to vary.
3. Stop and idle for 40 seconds, gradually accelerate to 55 mph.
4. Maintain 55 mph for 4 minutes using a steady throttle input.
5. Stop and idle for 30 seconds, then accelerate to 30 mph.
6. Maintain 30 mph for 12 minutes.
7. Repeat steps 4 and 5 four times.

Using scan tool, check readiness. If insufficient readiness set, continue to universal drive trace phase II.

Important: (Do not shut off engine between phases).

Phase II:

1. Vehicle at a stop and idle for 45 seconds, then accelerate to 30 mph.
2. Maintain 30 mph for 22 minutes.
3. Repeat steps 1 and 2 three times.
4. Bring vehicle to a stop and idle for 45 seconds, then accelerate to 35 mph.
5. Maintain speed between 30 and 35 mph for 4 minutes.
6. Bring vehicle to a stop and idle for 45 seconds, then accelerate to 30 mph.
7. Maintain 30 mph for 22 minutes.
8. Repeat steps 6 and 7 five times.
9. Using scan tool, check readiness.

DIESEL OBDII MONITOR READINESS

PRIOR TO START

- Fuel level greater than 25%.
- Coolant temperature below 140°F (60°C)
- Battery voltage must be between 11 and 16 volts. PTO is not engaged

TO RUN THE MONITORS

1. Allow the engine to idle for a minimum of two minutes and warm the engine to greater than 140 degrees. (Vehicle must be stationary and the accelerator must not be depressed during this time.)
2. Drive for 5 minutes at speeds above 25 mph and less than 45 mph (in-town driving).
3. Drive the vehicle at highway speeds and perform 10–15 zero fueling events (decelerate for 10 seconds with foot off of accelerator).
4. Drive the vehicle at highway speeds and perform 15–20 boost events (sudden depression of the accelerator pedal to provide turbocharger boost to the system).
5. Drive the vehicle at highway speeds in a steady state for 12–15 minutes.
6. Return to the shop and let vehicle idle for 30 seconds.
7. With the vehicle in park increase the engine speed to 1200–1300 RPM for 2–3 minutes (repeat 3–4 times).
8. Let idle for 30 seconds.
9. Shut off vehicle.
10. Cycle key back on and check readiness status.

SUMMARY

1. Funnel diagnostics—Visual approach to a diagnostic procedure:

   Step 1 Verify the problem (concern)

   Step 2 Perform a thorough visual inspection and basic tests

   Step 3 Retrieve the diagnostic trouble codes (DTCs)

   Step 4 Check for technical service bulletins (TSBs)

   Step 5 Look carefully at scan tool data

   Step 6 Narrow the problem to a system or cylinder

   Step 7 Repair the problem and determine the root cause

   Step 8 Verify the repair and check for any stored DTCs

2. A thorough visual inspection is important during the diagnosis and troubleshooting of any engine performance problem or electrical malfunction.
3. If the MIL is on, retrieve the DTC and follow the manufacturer's recommended procedure to find the root cause of the problem.
4. OBD-II vehicles use a 16-pin DLC and common DTCs.

REVIEW QUESTIONS

1. Why should TSBs be checked after retrieving diagnostic trouble codes?
2. Why does the customer concern need to verified?
3. What is the difference between an aftermarket scan tool and a factory-level scan tool?
4. What is the preferred method to use to clear DTCs?
5. What is the definition of a trip?

CHAPTER QUIZ

1. Technician A says that the first step in the diagnostic process is to verify the problem (concern). Technician B says the second step is to perform a thorough visual inspection. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
2. Which item is *not* important to know before starting the diagnosis of an engine performance problem?
   - **a.** List of previous repairs
   - **b.** The brand of engine oil used
   - **c.** The type of gasoline used
   - **d.** The temperature of the engine when the problem occurs
3. A generic (global)-type scan tool can retrieve ____________ data.
   - **a.** emissions-related
   - **b.** HVAC
   - **c.** ABS brake system
   - **d.** All of the above
4. The steps in a manufacturer-specific diagnostic routine are being discussed. Technician A says that after recording any DTCs, the codes should be erased. Technician B says to road test the vehicle twice to turn off the MIL. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both technicians are correct
   - **d.** Neither technician is correct
5. Technician A says that if the opposite DTC can be set, the problem is the component itself. Technician B says if the opposite DTC cannot be set, the problem is with the wiring or grounds. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
6. The preferred method to clear diagnostic trouble codes (DTCs) is to ____________.
   - **a.** disconnect the negative battery cable for 10 seconds
   - **b.** use a scan tool
   - **c.** remove the computer (PCM) power feed fuse
   - **d.** cycle the ignition key on and off 40 times
7. Which is the factory scan tool for Chrysler brand vehicles equipped with CAN?
   - **a.** wiTECH
   - **b.** Tech 2
   - **c.** NGS
   - **d.** Master Tech
8. What fault could occur that can cause a driveability issue and not set a diagnostic trouble code (DTC)?
   - **a.** Alcohol (ethanol) in high concentrations in the fuel
   - **b.** Contaminated fuel that has water or diesel fuel mixed with the fuel.
   - **c.** Clogged air intake systems due to an animal nest of road debris caught in the air intake system
   - **d.** Any of the above
9. Technician A says that knowing if there are any stored diagnostic trouble codes may be helpful when checking for related technical service bulletins. Technician B says that only a factory scan tool should be used to retrieve DTCs. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both Technicians A and B
   - **d.** Neither Technician A nor B
10. A drive cycle is designed to reset all the OBD-II monitors. Before starting the drive cycle the engine should be ____________.
    - **a.** fully warmed up (cooling fans cycled on and off two times)
    - **b.** have a full tank of fuel
    - **c.** cold (ECT = IAT)
    - **d.** operated at idle for two minutes

chapter 2

GASOLINE, ALTERNATIVE FUELS, AND DIESEL FUELS

LEARNING OBJECTIVES

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

1. Discuss the characteristics of gasoline, refining of gasoline, and volatility of gasoline.
2. Explain air–fuel ratios, normal and abnormal combustion, and octane rating.
3. Discuss gasoline additives, gasoline blending, and testing gasoline for alcohol content.
4. Discuss general gasoline recommendations.
5. Explain alternative fuel vehicles, and discuss the safety procedures when working with alternative fuels.
6. Discuss E85, methanol, and propane fuel.
7. Discuss compressed natural gas, liquefied natural gas, and P-series fuels.
8. Discuss synthetic fuels.
9. Compare diesel fuel, biodiesel, and E-diesel fuel.

KEY TERMS

AFV 33
Air–fuel ratio 25
Antiknock index (AKI) 27
API gravity 41
ASTM 23
B5 42
B20 42
Biodiesel 42
Biomass 35
Catalytic cracking 23
Cetane number 41
Cloud point 40
Coal to liquid (CTL) 39
Compressed natural gas (CNG) 35
Cracking 23
Detonation 26
Diesohol 43
Distillation 23
E10 28
E85 32
E-diesel 43
Ethanol 28
Ethyl alcohol 32
FFV 33
Fischer–Tropsch 38
Flex fuel 33
FTD 39
Fuel compensation sensor 33
Fungible 23
Gasoline 23
Grain alcohol 32
GTL 39
Hydrocracking 23
Liquefied petroleum gas (LPG) 35
LP gas 35
M85 35
Methanol 34
Methanol to gasoline (MTG) 40
NGV 35
Octane rating 26
Oxygenated fuels 28
Petrodiesel 42
Ping 26
PPO 43
Propane 35
Reid vapor pressure (RVP) 23
Spark knock 26
Stoichiometric 25
SVO 43
Syncrude 40
Syn-gas 35
UCO 43
ULSD 41
Underground coal gasification (UCG) 40
Variable fuel sensor 33
V-FFV 34
Volatility 23
WVO 43
WWFC 31

INTRODUCTION

Using the proper fuel is important for the proper operation of any engine. Although gasoline is the most commonly used fuel today, there are several alternative fuels that can be used in some vehicles. Diesel fuel contains much lower amounts of sulfur than before 2007 and this allows the introduction of many new clean burning diesel engines.

GASOLINE

Gasoline is a term used to describe a complex mixture of various hydrocarbons refined from crude petroleum oil for use as a fuel in engines. Gasoline and air burn in the cylinder of the engine and produce heat and pressure, which is transferred to rotary motion inside the engine and eventually powers the drive wheels of a vehicle. When the combustion process in the engine is perfect, all of the fuel and air are consumed and only carbon dioxide and water are produced.

REFINING

DISTILLATION In the late 1800s, crude was separated into different products by boiling in a process called **distillation**. Distillation works because crude oil is composed of hydrocarbons with a broad range of boiling points.

In a distillation column, the vapor of the lowest boiling hydrocarbons, propane and butane, rises to the top. The straight-run gasoline (also called naphtha), kerosene, and diesel fuel cuts are drawn off at successively lower positions in the column.

CRACKING **Cracking** is the process during which hydrocarbons with higher boiling points can be broken down (cracked) into lower boiling hydrocarbons by treating them to very high temperatures. This process, called *thermal cracking*, was used to increase gasoline production starting in 1913.

Today, instead of high heat, cracking is performed using a catalyst and is called **catalytic cracking**. A catalyst is a material that speeds up or otherwise facilitates a chemical reaction without undergoing a permanent chemical change itself. Catalytic cracking produces gasoline of higher quality than thermal cracking.

Hydrocracking is similar to catalytic cracking in that it uses a catalyst, but the catalyst is in a hydrogen atmosphere. Hydrocracking can break down hydrocarbons that are resistant to catalytic cracking alone and it is used to produce diesel fuel rather than gasoline.

Other types of refining processes include:

- Reforming
- Alkylation
- Isomerization
- Hydrotreating
- Desulfurization

● **SEE FIGURE 2–1**.

SHIPPING The gasoline is transported to regional storage facilities by tank railway car or by pipeline. In the pipeline method, all gasoline from many refiners is often sent through the same pipeline and can become mixed. All gasoline is said to be **fungible**, meaning that it is capable of being interchanged because each grade is created to specification so there is no reason to keep the different gasoline brands separated except for grade. Regular grade, midgrade, and premium grades are separated by using a device, called a *pig*, in the pipeline and sent to regional storage facilities. ● **SEE FIGURE 2–2**.

It is at these regional or local storage facilities where the additives and dye (if any) are added and then shipped by truck to individual gas stations.

VOLATILITY

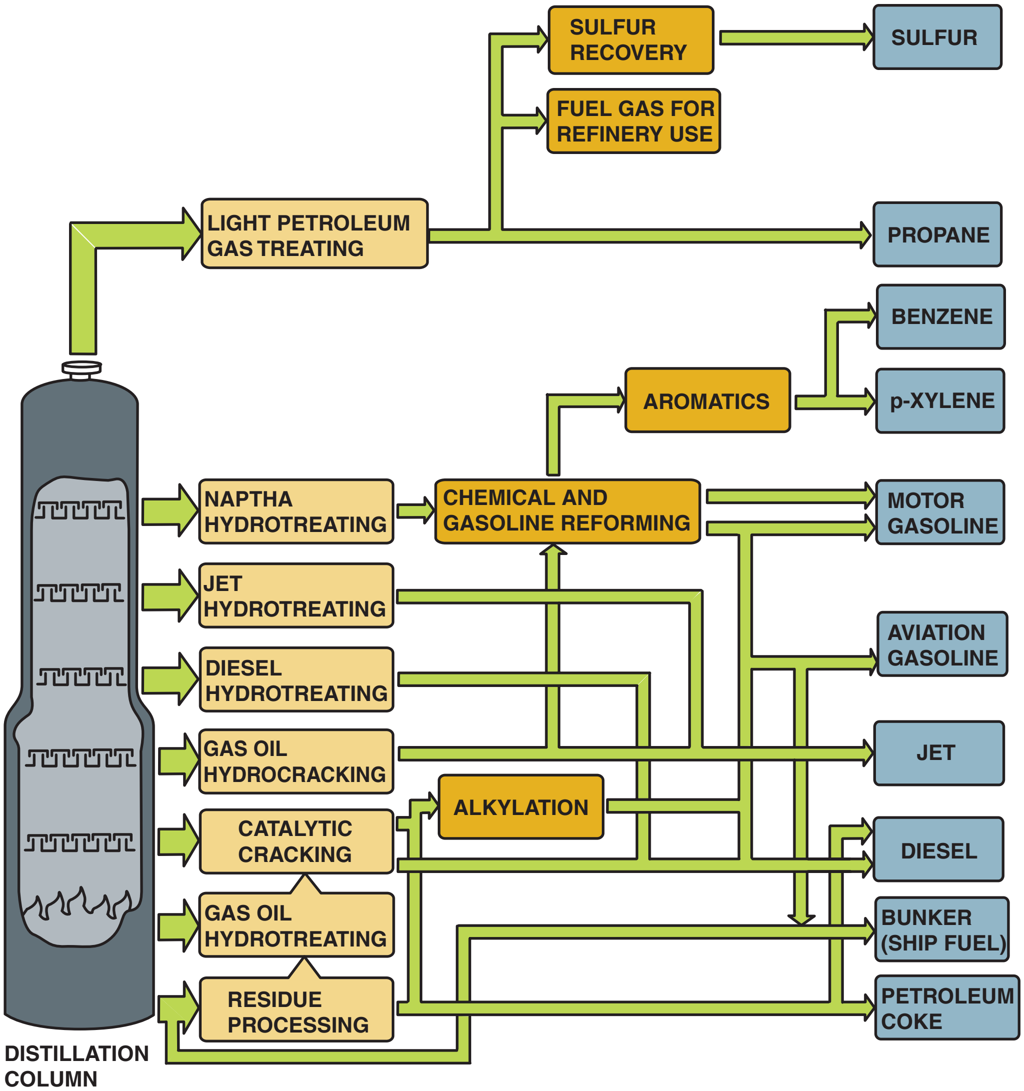
DEFINITION **Volatility** describes how easily the gasoline evaporates (forms a vapor). The definition of volatility assumes that the vapors will remain in the fuel tank or fuel line and will cause a certain pressure based on the temperature of the fuel.

REID VAPOR PRESSURE **Reid vapor pressure (RVP)** is the pressure of the vapor above the fuel when the fuel is at 100°F (38°C). Increased vapor pressure permits the engine to start in cold weather. Gasoline without air will not burn. Gasoline must be vaporized (mixed with air) to burn in an engine. ● **SEE FIGURE 2–3**.

SEASONAL BLENDING Cold temperatures reduce the normal vaporization of gasoline; therefore, winter-blended gasoline is specially formulated to vaporize at lower temperatures for proper starting and driveability at low ambient temperatures.

- **Winter blend.** The **American Society for Testing and Materials (ASTM)** standards for winter-blend gasoline allow volatility of up to 15 pounds per square inch (PSI) RVP.
- **Summer blend.** At warm ambient temperatures, gasoline vaporizes easily. However, the fuel system (fuel pump, fuel-injector nozzles, etc.) is designed to operate with liquid gasoline. The volatility of summer-grade gasoline should be about 7 PSI RVP. According to ASTM standards, the maximum RVP should be 10.5 PSI for summer-blend gasoline.

FIGURE 2–1 The crude oil refining process showing most of the major steps and processes.



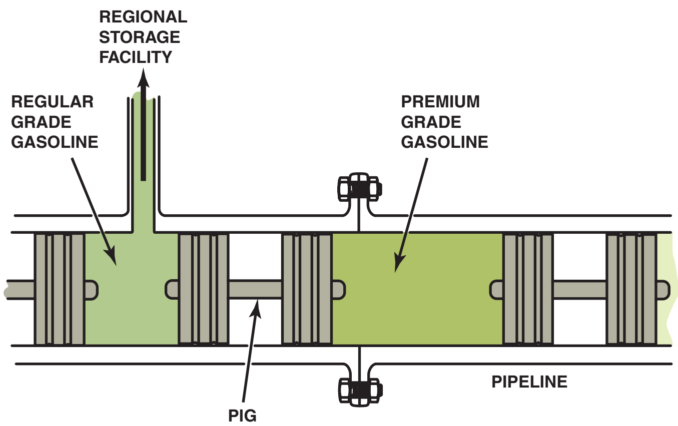


FIGURE 2–2 A pig is a plug-like device that is placed in a pipeline to separate two types or grades of fuel.

FIGURE 2–3 A gasoline testing kit, including an insulated container where water at 100°F is used to heat a container holding a small sample of gasoline. The reading on the pressure gauge is the Reid vapor pressure (RVP).

? FREQUENTLY ASKED QUESTION

Why Do I Get Lower Gas Mileage in the Winter?

Several factors cause the engine to use more fuel in the winter than in the summer.

- Gasoline that is blended for use in cold climates is designed for ease of starting and contains fewer heavy molecules, which contribute to fuel economy. The heat content of winter gasoline is lower than summer-blend gasoline.
- In cold temperatures, all lubricants are stiff, causing more resistance. These lubricants include the engine oil, as well as the transmission and differential gear lubricants.
- Heat from the engine is radiated into the outside air more rapidly when the temperature is cold, resulting in longer run time until the engine has reached normal operating temperature.
- Road conditions, such as ice and snow, can cause tire slippage or additional drag on the vehicle.

VOLATILITY-RELATED PROBLEMS If using winter-grade fuel during warm weather, the following may occur:

- Heat causes some fuel to evaporate, thereby causing bubbles.
- When the fuel is full of bubbles (sometimes called *vapor lock*), the engine is not being supplied with enough fuel and the engine runs lean. A lean engine will lead to the following:

1. Rough idle
2. Stalling
3. Hesitation on acceleration
4. Surging

If using summer-grade fuel in cold temperatures, then the engine will be hard to start (long cranking before starting) due to the lack of volatility to allow the engine to start easily.

AIR–FUEL RATIOS

DEFINITION The **air–fuel ratio** is the proportion by weight of air and gasoline that the injection system mixes as needed for engine combustion. Air–fuel ratios in which a gasoline engine can operate without stalling range from 8:1 to 18.5:1. ● **SEE FIGURE 2–4**.

The following ratios are usually stated by weight:

- 8 parts of air by weight combined with 1 part of gasoline by weight (8:1), which is the richest mixture that an engine can tolerate and still fire reliably

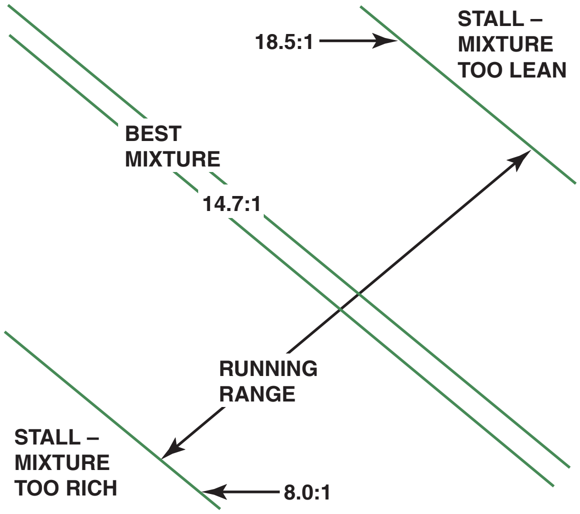


FIGURE 2–4 An engine will not run if the air–fuel mixture is either too rich or too lean.

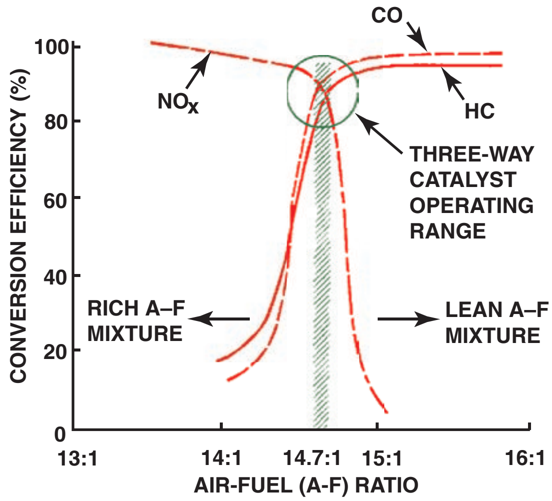


FIGURE 2–5 With a three-way catalytic converter, emission control is most efficient with an air–fuel ratio between 14.65:1 and 14.75:1.

- 18.5 parts of air mixed with 1 part of gasoline (18.5:1), which is the leanest practical ratio

Richer or leaner air–fuel ratios cause the engine to misfire badly or not run at all.

STOICHIOMETRIC AIR–FUEL RATIO The ideal mixture or ratio at which all of the fuel combines with all of the oxygen in the air and burns completely is called the **stoichiometric** ratio, a chemically perfect combination. In theory, this ratio for gasoline is an air–fuel mixture of 14.7:1. The stoichiometric ratio is a compromise between maximum power and maximum economy. ● **SEE FIGURE 2–5**.

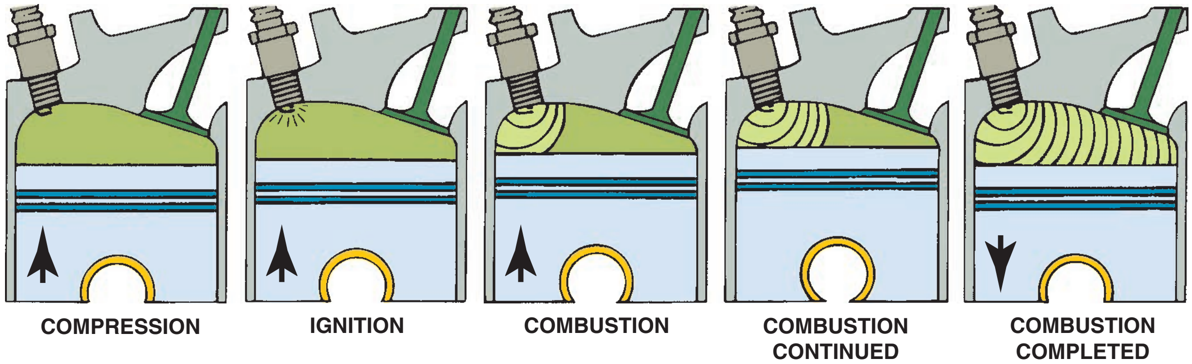


FIGURE 2–6 Normal combustion is a smooth, controlled burning of the air–fuel mixture.

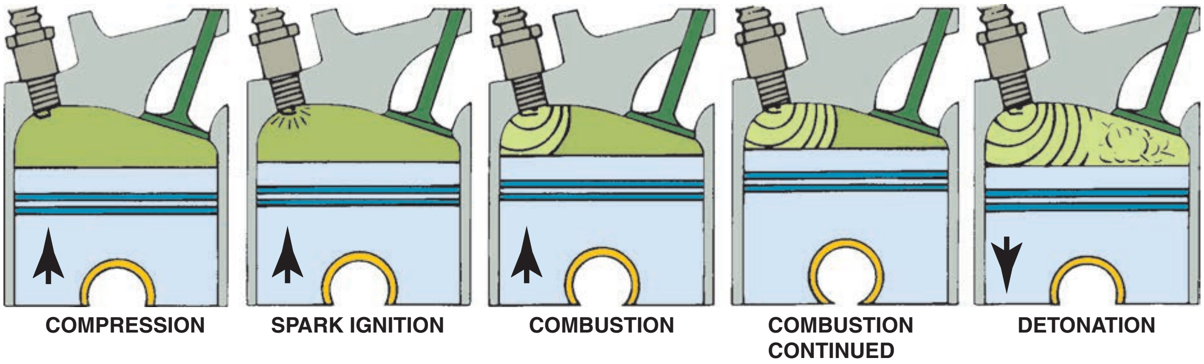


FIGURE 2–7 Detonation is a secondary ignition of the air–fuel mixture. It is also called spark knock or pinging.

NORMAL AND ABNORMAL COMBUSTION

TERMINOLOGY The **octane rating** of gasoline is the measure of its antiknock properties. **Spark knock** (also called **detonation** or **ping**) is a metallic noise an engine makes, usually during acceleration, resulting from abnormal or uncontrolled combustion inside the cylinder. Normal combustion occurs smoothly and progresses across the combustion chamber from the point of ignition.

● **SEE FIGURE 2–6**.

Normal flame-front combustion travels between 45 and 90 mph (72 and 145 km/h). The speed of the flame front depends on air–fuel ratio, combustion chamber design (determining amount of turbulence), and temperature.

ABNORMAL COMBUSTION During periods of abnormal combustion, called spark knock or detonation, the combustion speed increases by up to 10 times to near the speed of sound. The increased combustion speed also causes increased temperatures and pressures, which can damage pistons, gaskets, and cylinder heads. ● **SEE FIGURE 2–7**.

CONTROLLING SPARK KNOCK Spark knock was commonly heard in older engines especially when under load and in warm weather temperatures. Most engines built since the 1990s are equipped with a knock sensor that is used to signal the powertrain control module (PCM) to retard the ignition timing if knock is detected. Using the proper octane fuel helps to ensure that spark knock does not occur.

OCTANE RATING

RATING METHODS The two basic methods used to rate gasoline for antiknock properties (octane rating) include the *Research method* and the *Motor method.*

Each uses a model of the special *cooperative fuel research* (CFR) single-cylinder engine to test the octane of a fuel sample, and the two methods use different engine settings. The research method typically results in readings that are 6 to 10 points higher than those of the motor method. For example, a fuel with a research octane number (RON) of 93 might have a motor octane number (MON) of 85.

GASOLINE GRADES The octane rating posted on pumps in the United States is the average of the two methods and is referred to as R + M ÷ 2, meaning that, for the fuel used in the previous example, the rating posted on the pumps would be:

$$\frac{\textbf{RON} + \textbf{MON}}{\textbf{2}} = \frac{\textbf{93} + \textbf{85}}{\textbf{2}} = \textbf{89}$$

FIGURE 2–8 A pump showing regular with a pump octane of 87, plus rated at 89, and premium rated at 93. These ratings can vary with brand as well as in different parts of the country.

FIGURE 2–9 The posted octane rating in most high-altitude areas shows regular at 85 instead of the usual 87.

GRADES	OCTANE RATING
Regular	87
Midgrade (also called Plus)	89
Premium	91 or higher

CHART 2–1

The octane rating displayed on the fuel pumps can vary depending on climate.

This pump octane rating is often called the **antiknock index (AKI)**.

● **SEE FIGURE 2–8**.

● **SEE CHART 2–1** for the grades and octane ratings.

OCTANE EFFECTS OF ALTITUDE As the altitude increases, atmospheric pressure drops. The air is less dense because a pound of air takes more volume. The octane rating of fuel does not need to be as high because the engine cannot take in as much air. This process will reduce the combustion (compression) pressures inside the engine. In mountainous areas, gasoline (R + M) ÷ 2 octane ratings are two or more numbers lower than normal (according to the SAE, about one octane number lower per 1,000 ft (300 m) in altitude). ● **SEE FIGURE 2–9**.

A second reason for the lowered octane requirement of engines running at higher altitudes is the normal enrichment of the air–fuel ratio and lower engine vacuum with the decreased air density. Some problems, therefore, may occur when driving out of high-altitude areas into lower areas where the octane rating must be higher. Most electronic fuel injection systems can compensate for changes in altitude and modify air–fuel ratio and ignition timing for best operation.

FREQUENTLY ASKED QUESTION

What Grade of Gasoline Does the EPA Use When Testing Engines?

Due to the various grades and additives used in commercial fuel, the government (EPA) uses a liquid called indolene, which has a research method octane number of 96.5 and a motor method octane rating of 88, resulting in a (R + M) ÷ 2 rating of 92.25.

TECH TIP

Horsepower and Fuel Flow

To produce 1 hp, the engine must be supplied with 0.50 lb of fuel per hour (lb/hr). Fuel injectors are rated in pounds per hour. For example, a V-8 engine equipped with 25 lb/hr fuel injectors could produce 50 hp per cylinder (per injector) or 400 hp. Even if the cylinder head or block is modified to produce more horsepower, the limiting factor may be the injector flow rate.

The following are flow rates and resulting horsepower for a V-8 engine.

- 30 lb/hr: 60 hp per cylinder, or 480 hp
- 35 lb/hr: 70 hp per cylinder, or 560 hp
- 40 lb/hr: 80 hp per cylinder, or 640 hp

Of course, injector flow rate is only one of many variables that affect power output. Installing larger injectors without other major engine modifications could decrease engine output and drastically increase exhaust emissions.

Because the combustion burn rate slows at high altitude, the ignition (spark) timing can be advanced to improve power. The amount of timing advance can be about 1 degree per 1,000 ft over 5,000 ft. Therefore, if driving at 8,000 ft of altitude, the ignition timing can be advanced 3 degrees.

VOLATILITY EFFECTS OF ALTITUDE High altitude also allows fuel to evaporate more easily. The volatility of fuel should be reduced at higher altitudes to prevent vapor from forming in sections of the fuel system, which can cause driveability and stalling problems. The extra heat generated in climbing to higher altitudes plus the lower atmospheric pressure at higher altitudes combine to cause possible driveability problems as the vehicle goes to higher altitudes.

GASOLINE ADDITIVES

DYE Dye is usually added to gasoline at the distributor to help identify the grade and/or brand of fuel. Fuels are required to be colored using a fuel soluble dye in many countries. In the United States and Canada, diesel fuel used for off-road use and not taxed is required to be dyed red for identification. Gasoline sold for off-road use in Canada is dyed purple.

OXYGENATED FUEL ADDITIVES **Oxygenated fuels** contain oxygen in the molecule of the fuel itself. Examples of oxygenated fuels include:

- **Methyl tertiary butyl ether (MTBE).** This fuel is manufactured by means of the chemical reaction of methanol and isobutylene. Unlike methanol, MTBE does not increase the volatility of the fuel, and is not as sensitive to water as are other alcohols. The maximum allowable volume level, according to the EPA, is 15% but is currently being phased out due to health concerns, as well as MTBE contamination of drinking water if spilled from storage tanks.
- **Tertiary-amyl methyl ether (TAME).** This fuel contains an oxygen atom bonded to two carbon atoms, and is added to gasoline to provide oxygen to the fuel. It is slightly soluble in water, very soluble in ethers and alcohol, and soluble in most organic solvents including hydrocarbons.
- **Ethyl tertiary butyl ether (ETBE).** This fuel is derived from ethanol. The maximum allowable volume level is 17.2%. The use of ETBE is the cause of much of the odor from the exhaust of vehicles if using reformulated gasoline, as mandated for use in some parts of the country.
- **Ethanol.** Also called *ethyl alcohol,* **ethanol** is drinkable alcohol and is usually made from grain. Adding 10% ethanol (ethyl alcohol or grain alcohol) increases the (R + M) ÷ 2 octane rating by three points.

FIGURE 2–10 This fuel pump indicates that the gasoline is blended with 10% ethanol (ethyl alcohol) and can be used in any gasoline vehicle. E85 contains 85% ethanol and can only be used in vehicles specifically designed to use it.

The alcohol added to the base gasoline, however, also raises the volatility of the fuel about 0.5 PSI. Most automobile manufacturers permit up to 10% ethanol if driveability problems are not experienced.

The oxygen content of a 10% blend of ethanol in gasoline, called **E10**, is 3.5% oxygen by weight. ● **SEE FIGURE 2–10**.

GASOLINE BLENDING

Gasoline additives, such as ethanol and dyes, are usually added to the fuel at the distributor. Adding ethanol to gasoline is a way to add oxygen to the fuel itself. There are three basic methods used to blend ethanol with gasoline to create E10 (10% ethanol, 90% gasoline).

? FREQUENTLY ASKED QUESTION

What Is Meant by "Phase Separation"?

All alcohols absorb water, and the alcohol-water mixture can separate from the gasoline and sink to the bottom of the fuel tank. This process is called phase separation. To help avoid engine performance problems, try to keep at least a quarter tank of fuel at all times, especially during seasons when there is a wide temperature span between daytime highs and nighttime lows. These conditions can cause moisture to accumulate in the fuel tank as a result of condensation of the moisture in the air. Keeping the fuel tank full reduces the amount of air and moisture in the tank. ● **SEE FIGURE 2–11**.

FIGURE 2–11 A container with gasoline containing water and alcohol. Notice the separation line where the alcohol-water mixture separated from the gasoline and sank to the bottom.

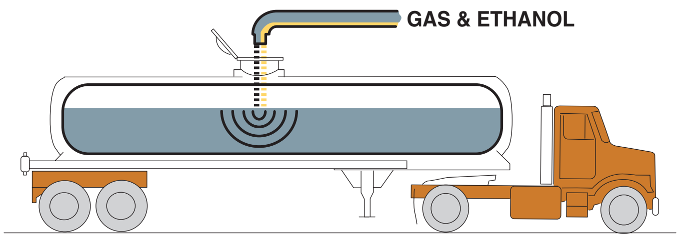


FIGURE 2–12 In-line blending is the most accurate method for blending ethanol with gasoline because computers are used to calculate the correct ratio.

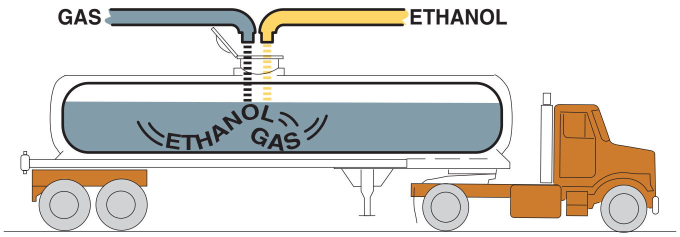


FIGURE 2–13 Sequential blending uses a computer to calculate the correct ratio as well as the prescribed order that the products are loaded.

1. **In-line blending.** Gasoline and ethanol are mixed in a storage tank or in the tank of a transport truck while it is being filled. Because the quantities of each can be accurately measured, this method is most likely to produce a well-mixed blend of ethanol and gasoline. ● **SEE FIGURE 2–12**.
2. **Sequential blending.** This method is usually performed at the wholesale terminal and involves adding a measured amount of ethanol to a tank truck followed by a measured amount of gasoline. ● **SEE FIGURE 2–13**.
3. **Splash blending.** This method can be done at the retail outlet or distributor and involves separate purchases of ethanol and gasoline. In a typical case, a distributor can purchase gasoline, and then drive to another supplier and purchase ethanol. The ethanol is then added (splashed) into the tank of gasoline. This method is the least accurate method of blending and can result in ethanol concentration for E10 that should be 10%, and ranges from 5% to over 20% in some cases. ● **SEE FIGURE 2–14**.

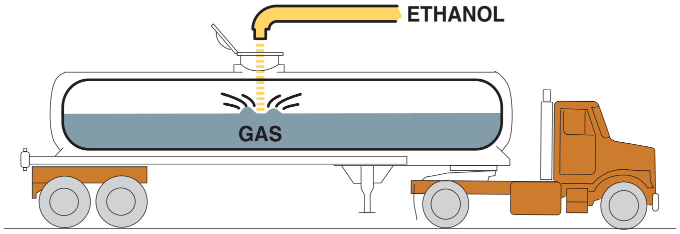


FIGURE 2–14 Splash blending occurs when the ethanol is added to a tanker with gasoline and is mixed as the truck travels to the retail outlet.

FREQUENTLY ASKED QUESTION

Is Water Heavier than Gasoline?

Yes. Water weighs about 8 lb per gallon, whereas gasoline weighs about 6 lb per gallon. The density as measured by specific gravity includes:

Water = 1.000 (the baseline for specific gravity)
Gasoline = 0.730 to 0.760

This means that any water that gets into the fuel tank will sink to the bottom.

TESTING GASOLINE FOR ALCOHOL CONTENT

Take the following steps when testing gasoline for alcohol content:

WARNING

Do not smoke or run the test around sources of ignition!

1. Pour suspect gasoline into a graduated cylinder.
2. Carefully fill the graduated cylinder to the 90 mL mark.
3. Add 10 mL of water to the graduated cylinder by counting the number of drops from an eyedropper.

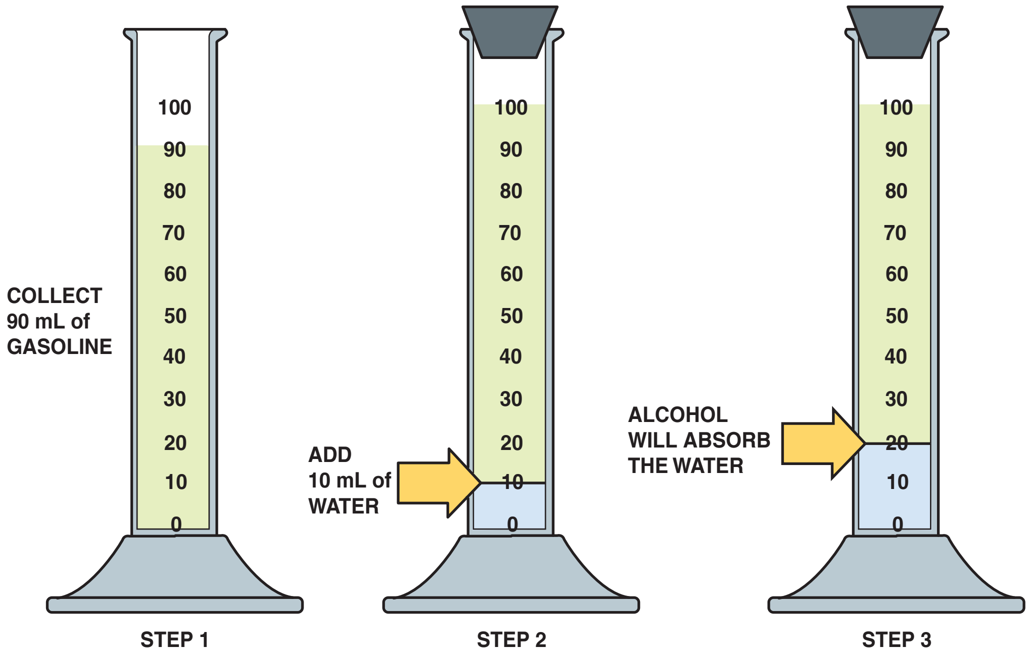


FIGURE 2–15 Checking gasoline for alcohol involves using a graduated cylinder and adding water to check if the alcohol absorbs the water.

4. Put the stopper in the cylinder and shake vigorously for one minute. Relieve built-up pressure by occasionally removing the stopper. Alcohol dissolves in water and will drop to the bottom of the cylinder.
5. Place the cylinder on a flat surface and let it stand for two minutes.
6. Take a reading near the bottom of the cylinder at the boundary between the two liquids.
7. For percentage of alcohol in gasoline, subtract 10 to get the percentage.

   For example,
   The reading is 20 mL: $20 - 10 = 10\%$ alcohol

If the increase in volume is 0.2% or less, it may be assumed that the test gasoline contains no alcohol. ● **SEE FIGURE 2–15**.

Alcohol content can also be checked using an electronic tester. See the photo sequence at the end of the chapter.

GENERAL GASOLINE RECOMMENDATIONS

The fuel used by an engine is a major expense in the operation cost of the vehicle. The proper operation of the engine depends on clean fuel of the proper octane rating and vapor pressure for the atmospheric conditions.

To help ensure proper engine operation and keep fuel costs to a minimum, follow these guidelines:

1. Purchase fuel from a busy station to help ensure that it is fresh and less likely to be contaminated with water or moisture.
2. Keep the fuel tank above one-quarter full, especially during seasons in which the temperature rises and falls by more than 20°F between daytime highs and nighttime lows. This helps to reduce condensed moisture in the fuel tank and could prevent gas line freeze-up in cold weather.

   NOTE: Gas line freeze-up occurs when the water in the gasoline freezes and forms an ice blockage in the fuel line.

3. Do not purchase fuel with a higher octane rating than is necessary. Try using premium high-octane fuel to check for operating differences. Most newer engines are equipped with a detonation (knock) sensor that signals the vehicle computer to retard the ignition timing when spark knock occurs. Therefore, an operating difference may not be noticeable to the driver when using a low-octane fuel, except for a decrease in power and fuel economy. In other words, the engine with a knock sensor will tend to operate knock free on regular fuel, even if premium, higher octane fuel is specified. Using premium fuel may result in more power and greater fuel economy. The increase in fuel economy, however, would have to be substantial to justify the increased cost of high-octane premium fuel. Some drivers find a good compromise by using midgrade (plus) fuel to benefit from the engine power and fuel economy gains without the cost of using premium fuel all the time.

FIGURE 2–16 Not all top-tier gas stations mention that they are top-tier like this station. For more information and the list of top-tier gasoline stations, visit *www.toptiergas.com*.

FREQUENTLY ASKED QUESTION

What Is "Top-Tier" Gasoline?

Top-tier gasoline has specific standards for quality, including enough detergent to keep all intake valves clean. Four automobile manufacturers (BMW, General Motors, Honda, and Toyota) developed the standards. Top-tier gasoline exceeds the quality standards developed by the **World Wide Fuel Charter (WWFC)** in 2002 by vehicle and engine manufacturers. The gasoline companies that agreed to make fuel that matches or exceeds the standards as a top-tier fuel include ChevronTexaco, Shell, and ConocoPhillips. ● **SEE FIGURE 2–16**.

4. Try to avoid using gasoline with alcohol in warm weather, even though many alcohol blends do not affect engine driveability. If warm-engine stumble, stalling, or rough idle occurs, change brands of gasoline.
5. Do not purchase fuel from a retail outlet when a tanker truck is filling the underground tanks. During the refilling procedure, dirt, rust, and water may be stirred up in the underground tanks. This undesirable material may be pumped into your vehicle's fuel tank.
6. Do not overfill the gas tank. After the nozzle clicks off, add just enough fuel to round up to the next dime. Adding additional gasoline will cause the excess to be drawn into the charcoal canister. This can lead to engine flooding and excessive exhaust emissions.

FIGURE 2–17 Many service stations have signs posted warning customers to place plastic fuel containers on the ground while filling. If placed in a trunk or pickup truck bed equipped with a plastic liner, static electricity could build up during fueling and discharge from the container to the metal nozzle, creating a spark and possible explosion. Some service stations have warning signs not to use cell phones while fueling to help avoid the possibility of an accidental spark creating a fire hazard.

TECH TIP

The Sniff Test

Problems can occur with stale gasoline from which the lighter parts of the gasoline have evaporated. Stale gasoline usually results in a no-start situation. If stale gasoline is suspected, sniff it. If it smells rancid, replace it with fresh gasoline.

NOTE: If storing a vehicle, boat, or lawnmower over the winter, put some gasoline stabilizer into the gasoline to reduce the evaporation and separation that can occur during storage. Gasoline stabilizer is frequently available at most automotive parts stores.

7. Be careful when filling gasoline containers. Always fill a gas can on the ground to help prevent the possibility of static electricity buildup during the refueling process. ● **SEE FIGURE 2–17**.

FREQUENTLY ASKED QUESTION

Why Should I Keep the Fuel Gauge above One-Quarter Tank?

The fuel pickup inside the fuel tank can help keep water from being drawn into the fuel system unless water is all that is left at the bottom of the tank. Over time, moisture in the air inside the fuel tank can condense, causing liquid water to drop to the bottom of the fuel tank. (Recall that water is heavier than gasoline–about 8 pound per gallon for water and about 6 pound per gallon for gasoline.) If alcohol-blended gasoline is used, the alcohol can absorb the water and the alcohol-water combination can be burned inside the engine. However, when water combines with alcohol, a separation layer occurs between the gasoline at the top of the tank and the alcohol-water combination at the bottom. When the fuel level is low, the fuel pump will draw from this concentrated level of alcohol and water. Because alcohol and water do not burn as well as pure gasoline, severe driveability problems can occur such as stalling, rough idle, hard starting, and missing.

TECH TIP

Do Not Overfill the Fuel Tank

Gasoline fuel tanks have an expansion volume area at the top. The volume of this expansion area is equal to 10% to 15% of the volume of the tank. This area is normally not filled with gasoline, but rather is designed to provide a place for the gasoline to expand into, if the vehicle is parked in the hot sun and the gasoline expands. This prevents raw gasoline from escaping from the fuel system. A small restriction is usually present to control the amount of air and vapors that can escape the tank and flow to the charcoal canister.

This volume area could be filled with gasoline if the fuel is slowly pumped into the tank. Since it can hold an extra 10% (2 gallons in a 20 gallon tank), some people deliberately try to fill the tank completely. When this expansion volume is filled, liquid fuel (rather than vapors) can be drawn into the charcoal canister. When the purge valve opens, liquid fuel can be drawn into the engine, causing an excessively rich air–fuel mixture. Not only can this liquid fuel harm vapor recovery parts, but overfilling the gas tank could also cause the vehicle to fail an exhaust emission test, particularly during an enhanced test when the tank could be purged while on the rollers.

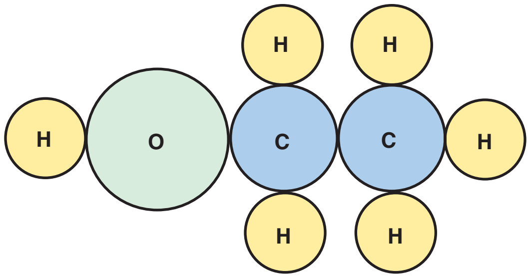


FIGURE 2–18 The ethanol molecule showing two carbon atoms, six hydrogen atoms, and one oxygen atom.

FIGURE 2–19 E85 has 85% ethanol mixed with 15% gasoline.

E85

WHAT IS E85? Vehicle manufacturers have available vehicles that are capable of operating on gasoline plus ethanol or a combination of gasoline and ethanol called **E85**, composed of 85% ethanol and 15% gasoline. Ethanol is also called **ethyl alcohol** or **grain alcohol**, because it is usually made from grain and is the type of alcohol found in alcoholic drinks such as beer, wine, and distilled spirits like whiskey. Ethanol is composed of two carbon atoms and six hydrogen atoms with one added oxygen atom. **SEE FIGURE 2–18**.

Pure ethanol has an octane rating of about 113. E85, which contains 35% oxygen by weight, has an octane rating of 100 to 105. This compares to a regular unleaded gasoline which has a rating of 87. **SEE FIGURE 2–19**.

NOTE: The octane rating of E85 depends on the exact percentage of ethanol used, which can vary from 81% to 85%. It also depends on the octane rating of the gasoline used to make E85.

HEAT ENERGY OF E85 E85 has less heat energy than gasoline.

TECH TIP

Purchase a Flex Fuel Vehicle

If purchasing a new or used vehicle, try to find a flex fuel vehicle. Even though you may not want to use E85, a flex fuel vehicle has a more robust fuel system than a conventional fuel system designed for gasoline or E10. The enhanced fuel system components and materials usually include:

- Stainless steel fuel rail
- Graphite commutator bars instead of copper in the fuel pump motor (ethanol can oxidize into acetic acid, which can corrode copper)
- Diamondlike carbon (DLC) corrosion-resistant fuel injectors
- Alcohol resistant O-rings and hoses

The cost of a flex fuel vehicle compared with the same vehicle designed to operate on gasoline is a no-cost or a low-cost option.

Gasoline: 114,000 BTUs per gallon

E85: 87,000 BTUs per gallon

This means that the fuel economy is reduced by 20% to 30% if E85 is used instead of gasoline.

Example: A Chevrolet Tahoe 5.3 liter V-8 with an automatic transmission has an EPA rating using gasoline of 15 mpg in the city and 20 mpg on the highway. If this same vehicle is fueled with E85, the EPA fuel economy rating drops to 11 mpg in the city and 15 mpg on the highway.

ALTERNATIVE FUEL VEHICLES

The 15% gasoline in the E85 blend helps the engine start, especially in cold weather. Vehicles equipped with this capability are commonly referred to as:

- **Alternative fuel vehicles (AFVs)**
- **Flex fuels**
- **Flexible fuel vehicles (FFVs)**

Using E85 in a flex fuel vehicle can result in a power increase of about 5%. For example, an engine rated at 200 hp using gasoline or E10 could produce 210 hp if using E85.

NOTE: E85 may test as containing less than 85% ethanol if tested because it is often blended according to outside temperature. A lower percentage of ethanol with a slightly higher percentage of gasoline helps engines start in cold climates.

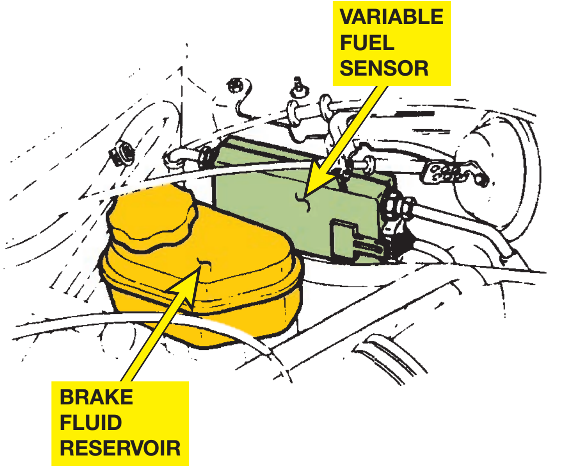


FIGURE 2–20 The location of the variable fuel sensor can vary, depending on the make and model of vehicle, but it is always in the fuel line between the fuel tank and the fuel injectors.

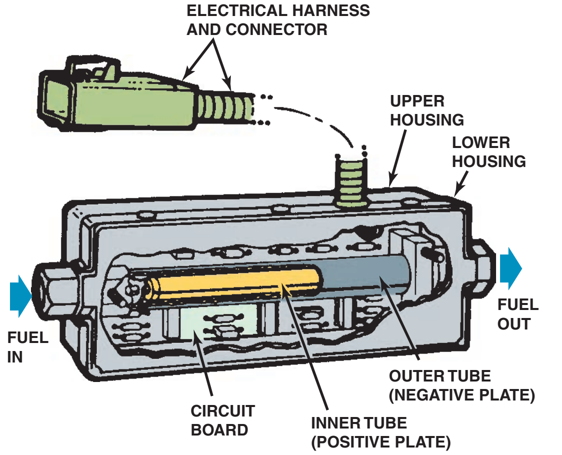


FIGURE 2–21 A cutaway view of a typical variable fuel sensor.

These vehicles are equipped with an electronic sensor in the fuel supply line that detects the presence and percentage of ethanol. The PCM then adjusts the fuel injector on-time and ignition timing to match the needs of the fuel being used.

E85 contains less heat energy, and therefore will use more fuel, but the benefits include a lower cost of the fuel and less environmental impact associated with using an oxygenated fuel.

General Motors, Ford, Chrysler, and Mazda are a few of the manufacturers offering E85 compatible vehicles. E85 vehicles use fuel system parts designed to withstand the additional alcohol content, modified driveability programs that adjust fuel delivery and timing to compensate for the various percentages of ethanol fuel, and a **fuel compensation sensor** that measures both the percentage of ethanol blend and the temperature of the fuel. This sensor is also called a **variable fuel sensor**. ● **SEE FIGURES 2–20 AND 2–21**.

E85 FUEL SYSTEM REQUIREMENTS Most E85 vehicles are very similar to non-E85 vehicles. Fuel system components may be redesigned to withstand the effects of higher

FIGURE 2–22 A flex fuel vehicle often has a yellow gas cap, which is labeled E85/gasoline.

FIGURE 2–23 This flexible fuel vehicle (FFV) vehicle emission control information (VECI) sticker located under the hood indicates that is can operate on either gasoline or ethanol.

concentrations of ethanol. In addition, since the stoichiometric point for ethanol is 9:1 instead of 14.7:1 as for gasoline, the air-fuel mixture has to be adjusted for the percentage of ethanol present in the fuel tank.

The benefits of E85 vehicles include:

- Reduced pollution
- Less CO_2 production
- Less dependence on imported oil

FLEX FUEL VEHICLE IDENTIFICATION Flexible fuel vehicles (FFVs) can be identified by:

- Emblems on the side, front, and/or rear of the vehicle
- Yellow fuel cap showing E85/gasoline (● **SEE FIGURE 2–22.**)
- Vehicle emission control information (VECI) label under the hood (● **SEE FIGURE 2–23.**)
- Vehicle identification number (VIN)

? FREQUENTLY ASKED QUESTION

How Does a Sensorless Flex Fuel System Work?

Many General Motors flex fuel vehicles do not use a fuel compensation sensor and instead use the oxygen sensor to detect the presence of the lean mixture and the extra oxygen in the fuel.

The powertrain control module (PCM) then adjusts the injector pulse width and the ignition timing to optimize engine operation to the use of E85. This type of vehicle is called a **virtual flexible fuel vehicle (V-FFV)**. It can operate on pure gasoline or blends up to 85% ethanol.

? FREQUENTLY ASKED QUESTION

How Long Can Oxygenated Fuel Be Stored before All of the Oxygen Escapes?

The oxygen in oxygenated fuels, such as E10 and E85, is not in a gaseous state like the CO_2 in soft drinks. The oxygen is part of the molecule of ethanol or other oxygenates and does not bubble out of the fuel. Oxygenated fuels, like any fuel, have a shelf life of about 90 days.

NOTE: For additional information on E85 and for the location of E85 stations in your area, go to www.e85fuel.com.

METHANOL

METHANOL TERMINOLOGY **Methanol**, also known as *methyl alcohol*, *wood alcohol*, or *methyl hydrate*, is a chemical compound formula that includes one carbon atom, four hydrogen atoms, and one oxygen atom. ● **SEE FIGURE 2–24.**

Methanol is a light, volatile, colorless, tasteless, flammable, poisonous liquid with a very faint odor. Methanol can be used in the following ways:

- As an antifreeze, a solvent, or a fuel
- To denature ethanol (to make undrinkable)

Methanol burns in air, forming CO_2 (carbon dioxide) and H_2O (water). A methanol flame is almost colorless. Methanol is often called wood alcohol because it was once produced chiefly as a by-product of the destructive distillation of wood. ● **SEE FIGURE 2–25.**

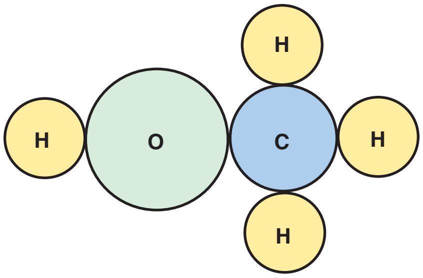


FIGURE 2–24 The molecular structure of methanol showing the one carbon atom, four hydrogen atoms, and one oxygen atom.

FIGURE 2–25 Sign on methanol pump shows that methyl alcohol is a poison and can cause skin irritation and other personal injury. Methanol is used in industry as well as being a fuel.

PRODUCTION OF METHANOL The biggest source of methanol in the United States is coal. Using a simple reaction between coal and steam, a gas mixture called **syn-gas** (synthesis gas) is formed. The components of this mixture are carbon monoxide and hydrogen, which, through an additional chemical reaction, are converted to methanol.

Natural gas can also be used to create methanol and is reformed or converted to synthesis gas, which is later made into methanol.

Biomass can be converted to synthesis gas by a process called partial oxidation, and later converted to methanol. Biomass is organic material, and includes:

- Urban wood wastes
- Primary mill residues
- Forest residues
- Agricultural residues
- Dedicated energy crops (e.g., sugarcane and sugar beets) that can be made into fuel

Electricity can be used to convert water into hydrogen, which is then reacted with carbon dioxide to produce methanol.

Methanol is toxic and can cause blindness and death. It can enter the body by ingestion, inhalation, or absorption through the skin. Dangerous doses will build up if a person is regularly exposed to fumes or handles liquid without skin protection. If methanol has been ingested, a doctor should be contacted immediately. The usual fatal dose is 4 fl oz (100 to 125 mL).

M85 Some flexible fuel vehicles are designed to operate on 85% methanol and 15% gasoline, called **M85**. Methanol is very corrosive and requires that the fuel system components be constructed of stainless steel and other alcohol-resistant rubber and plastic components. The heat content of M85 is about 60% of that of gasoline.

PROPANE

Propane is the most widely used of all the alternative fuels mainly because of its use in fleets, which utilize a central refueling station. Propane is normally a gas but is easily compressed into a liquid and stored in inexpensive containers. When sold as a fuel, it is also known as **liquefied petroleum gas (LPG)** or **LP gas**, because the propane is often mixed with about 10% of other gases, including:

- Butane
- Propylene
- Butylenes
- Mercaptan, to give the colorless and odorless propane a smell

Propane is nontoxic, but if inhaled can cause asphyxiation through lack of oxygen. Propane is heavier than air and lays near the floor if released into the atmosphere. Propane is commonly used in forklifts and other equipment located inside warehouses and factories, because the exhaust from the engine using propane is not harmful. Propane is a by-product of petroleum refining of natural gas. In order to liquefy the fuel, it is stored in strong tanks at about 300 PSI (2,000 kPa). The heating value of propane is less than that of gasoline; therefore, more is required, which reduces the fuel economy. ● **SEE FIGURE 2–26**.

COMPRESSED NATURAL GAS

CNG VEHICLE DESIGN Another alternative fuel that is often used in fleet vehicles is **compressed natural gas (CNG)**. Vehicles using this fuel are often referred to as **natural gas vehicles (NGVs)**. Look for the blue CNG label on vehicles designed to operate on compressed natural gas. ● **SEE FIGURE 2–27**.

FIGURE 2–26 Propane fuel storage tank in the trunk of a Ford taxi.

FIGURE 2–27 The blue sticker on the rear of this vehicle indicates that it is designed to use compressed natural gas. This Ford truck also has a sticker that allows it to be driven in the high occupancy vehicle (HOV) lane, even if there is just the driver, because it is a CNG vehicle.

Because natural gas must be compressed to 3,000 PSI (20,000 kPa) or more, the weight and cost of the storage container are major factors when it comes to preparing a vehicle to run on CNG. The tanks needed for CNG are typically constructed of 0.5 inch (3 mm) thick aluminum reinforced with fiberglass. ● **SEE FIGURE 2–28**.

The octane rating of CNG is about 130 and the cost per gallon is roughly half of the cost of gasoline. However, the heat value of CNG is also less, and therefore more is required to produce the same power; and the miles per gallon is less.

FIGURE 2–28 A CNG storage tank from a Honda Civic GX shown with the fixture used to support it while it is being removed or installed in the vehicle. Honda specifies that three technicians be used to remove or install the tank through the rear door of the vehicle due to the size and weight of the tank.

? FREQUENTLY ASKED QUESTION

What Is the Amount of CNG Equal to in Gasoline?

To achieve the amount of energy of 1 gallon of gasoline, 122 ft^3 of compressed natural gas (CNG) is needed. While the octane rating of CNG is much higher than gasoline (130 octane), using CNG instead of gasoline in the same engine would result in a 10%–20% reduction of power due to the lower heat energy that is released when CNG is burned in the engine.

CNG COMPOSITION

Compressed natural gas is a blend of the following:

- Methane
- Propane
- Ethane
- N-butane
- Carbon dioxide
- Nitrogen

Once it is processed, compressed natural gas is at least 93% methane. Natural gas is nontoxic, odorless, and colorless in its natural state. It is odorized during processing, using ethyl mercaptan (“skunk”), to allow for easy leak detection. Natural gas is lighter than air and will rise when released into the air. Since CNG is already a vapor, it does not need heat to vaporize before it will burn, which improves cold start-up and results