PREPARING FOR NATE CERTIFICATION EXAMS VOLUME 1

A Condensed, To-The-Point Approach To Passing A NATE Certification Exam

An E-Book By Jim Johnson

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Technical Training Associates
HC 70 Box 3172
Sahuarita, AZ 85629
(520) 625-6847
www.technicaltrainingassoc.com
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FORWARD

MYTHS, MISPERCEPTIONS AND REALITIES ABOUT CERTIFICATION

It’s been many years ago, but I’ll never forget it. A service industry was trying to get a technician certification program up and running. In the midst of all the brouh-ha-ha about it, the association that had developed the certification testing program made wonderful predictions of the tremendous success of their initiative. I, on the other hand (though I’m usually optimistic about things), had predicted that the program would fail miserably. I was right. The association that spent a huge amount of money, and invested a great deal of time and other resources in the development of the exams, wound up selling the program for $1 to a trade association in the same industry who thought they might make a go of it. They didn’t. The program died, and never came back to life.

Why was I so sure that it wouldn’t work? Actually, there were two key components to my reasoning. First and foremost, the only thing they had to offer were the exams themselves, (no recommended study materials or opportunity for preparation) and they expected technicians to show up with bells on to take them. They announced the date that they were going to launch the program, and later said that they had a large number of technicians who had committed to take the exams. When I heard the numbers they were bandying about, I said some things that most people didn't like to hear…that on that particular day that the exams were scheduled, although many people had committed to taking them, there would be more sick kids, broken-down vehicles, dying grandmothers, etc. than you could shake a stick at on that particular day…and that’s exactly what happened.

The bottom line was that the technicians, who were supposed to take the exams, were, like many people who work in the service and repair of equipment, good at what they did, and knowing what to do. What they didn’t have was a confidence that they knew why something should be done, or the fundamental theories of electricity, refrigeration, and mechanical concepts that applied to their work. Of course, they didn’t want to be portrayed as somebody who didn’t know what they were doing because they failed a written exam, so, in large numbers, they didn’t show up, even though they promised the would.

The second component to my reasoning is best explained by relating a conversation I had with a group of about 50 technicians (I was facilitating a training session at a national convention) in the midst of this certification initiative, and I asked them a question: “When are you going to get certified?”

Their answer was simple: “When customers start to ask for it.”
After getting that answer, I went directly to the trade association president and asked him when they were going to let the public know that they should be asking about a technician’s certifications before agreeing to book a service call. His response was, “When we have a large enough group of technicians who are certified.”

Hmmm….ever heard of the term “Catch-22”? It’s a term that has been used in the Air Force to describe the situation in which a pilot needs to be psychologically stable in order to be allowed to fly, but, the general opinion is that people have to be a little nuts to want to fly certain missions in the first place, so they can’t let him fly because he’s not nuts…or, maybe not nuts enough…or something like that. At any rate, the trade association was waiting until they had enough certified technicians before launching an advertising campaign to educate consumers about the benefits of having a certified technician do their repair work, and the people who were supposed to make up the group of available certified technicians were waiting until the consumers (who had no clue that they were supposed to ask) asked about technician certification. Like I said, Catch-22.

The bottom line with NATE certification is that neither of the two issues that caused the collapse of that technician certification initiative applies to its certification program. There are many opportunities (this e-book is one of them) for technicians to prepare for taking the certification exam, and NATE does offer the consumer the opportunity (via advertising and a Web site) to become educated on technician certification and the fact that they should be asking for it. So, no, NATE isn’t going to die. It will continue to grow. Consumers will be more aware about asking about it. Manufacturers will require dealers to have a given number of NATE certified technicians on board in order to sell and install their equipment, and NATE certification will become an issue relative to state licensing of contractors. That’s the reality of NATE certification.

On to some myths and misperceptions on the subject of certification….

If you were to ask anyone from the general public what they think when they see that a technician is certified, or that a business employs certified technicians, you would, with continued probing for information, likely hear from them that they believe some sort of government agency regulates the certification process of said technicians. And, of course, they would be wrong about 90% of the time. Sure, there are some specialty technician certifications that are overseen by some sort of “Big Brother” agency, be it a federal, state, county or city government, but they are not in the majority. For the most part (NATE included) the government doesn’t get involved in the requirements set down for certification testing. It’s left up to the industry (who better would know what the professionals working in a particular industry should know in order to be certified?) to determine what competencies must be demonstrated in order to be awarded certification.

Here’s one example…..AWS, the American Welding Society, has been certifying welders for decades. If you’re a welder and you want to get a job doing
pipe, structural, or any other type of welding, when you apply for the job there is always one question asked….‘Do you have your AWS cert?’

And there never has been so much as one bureaucrat involved in setting the standards for welder certification. AWS was born when a small group of professionals in the welding industry decided that a certification initiative was necessary, and welds are x-rayed to make sure they’re done properly before a welder can be certified in a given skill.

How about this one…? ASE, Automotive Service Excellence. Formerly known as NIASE, the National Institute for Automotive Service Excellence, this organization certifies technicians in specialty areas such as brakes or alignment, among other disciplines within the automotive service industry. And which government agency is that oversees the setting of standard for these certifications? None. Those ASE-Certified signs you see in independent garages and car dealers around the United States are the result of an industry, and only the industry, creating and implementing its own technician certification program. Again, though, from a consumer perspective, the underlying idea that somebody, somewhere in a conference room or office in Washington D.C. regulates what goes on with automotive technicians and their being certified, is likely what you could easily get people to accept.

But there’s a reality amid the consumer’s misperceptions about the term “Certified”. It gives them a feeling of confidence. That’s why some HVACR and major appliance service contractors have “Certified Technicians” painted on the side of their service vans even if it only means that the technicians who service equipment are EPA certified in refrigerant handling procedures. And, c’mon, anybody who works in the refrigeration industry knows that anybody who wants to study for a while about rules and regulations relative to Section 608 of the Clean Air Act, recall some specific dates when certain laws when into effect, and, OK, be able to answer a few questions about the fundamentals of a refrigeration system, can pass an EPA certification exam segment, by answering more than 17 out of 25 multiple-choice questions correctly. But that doesn’t change the fact that it makes consumers feel better about buying service from a company that lists their technicians as certified. They still do.

Beyond that perceived reality, though is another more “realistic” reality. NATE certification is a process that enhances a technician’s confidence and competence. The facts cannot be denied. A NATE certified technician experiences fewer callbacks. And in the end, that’s a win/win/win/win….a win for the consumers because they get quality work, a win for the HVACR sales and service organization because their expenses go down, a win for the technician because when expenses go down that means there are more resources that can be channeled into a technician’s earnings, and win for the HVACR industry because as the standards are raised, the industry itself has more credibility, which will attract the much-needed new blood that will allow it to grow and prosper….and that’s exactly what I want this book to help you do as you prepare for your NATE certification exams.
PART ONE

WHAT TECHNICIANS NEED TO KNOW ABOUT NATE

HVACR technical professionals please be advised: NATE is it. What do I mean by that? Well, it's pretty simple. Any industry goes through changes as time goes on, and one of the changes that the HVAC/R industry has gone through in the last decade relates to technician certification.

Other than the required EPA Refrigerant Handling Certification requirements, HVAC/R technician certification via a testing process has, historically, been somewhat limited. Since NATE (North American Technician Excellence) was incorporated in 1997 as a nonprofit testing and certification organization “for the purpose of recognizing and promoting technician excellence in the installation and service of heating and cooling equipment” though, the momentum of the program has been steady.

And now, as I said, NATE is it. It’s time for every HVAC/R technician, service manager, contractor and educator to recognize that fact, and consider technician certification as the norm rather than the exception. For my part in this effort, I’ll be presenting a series of articles that will assist technicians in achieving their goal of certification. Some of what you read in this e-book will be simple, straightforward information on how the testing process works and what it will take for technicians to successfully achieve their goals relative to certification, and some of it will appear to be quite opinionated—because it will be an opinion—mine, that is.

A Bit of History On HVAC/R Technician Certification

When looking back on the history of HVAC/R technician certification, one has to consider RSES (Refrigeration Service Engineers Society). Their organization, made up of members who are first and foremost technical professionals (sure, a member might also be a business owner, but membership in RSES is based on being a technician first) in refrigeration, air conditioning and heating, has offered a certification process for many years. Members have had the option to choose to achieve what is known as CM (Certified Member) status by successfully passing a test. At another level is a different test involving the CMS (Certified Member Specialist) status. The testing process has always been tough, as anything worthwhile is, and often, even technicians with a history of experience in HVAC/R, didn’t pass the first time around. But, those who persevered, more often than not, did pass with a second effort, and were awarded a CM or CMS member status. The certification process has always been on a voluntary basis, as it still is (to a certain degree—I’ll elaborate on that shortly) today in the HVAC/R industry.

If you’re a technician working in HVAC/R and you’re not a member or RSES, you should be. The investment of one hundred-bucks or so a year is a small one to consider in the scope a technical professional’s career, and what you gain from being a member, attending monthly chapter meetings and
participating in the education provided there (not just from the people who are scheduled to do the presentations, but from the others who attend) is immeasurable.

RSES and CARSES also regularly sponsor technician education seminars and workshops, and being a member allows you to attend at a lower fee than nonmembers. (CARSES, by the way, as I’ve been told, stands for California Arizona Refrigeration Service Engineers Society even though the regional organization also includes Nevada and Hawaii. If I haven’t got that quite right, somebody please get in touch with me and we’ll set the record straight.)

What’s that you say? You’re a technician who believes that if you’re going to be a member of RSES, your employer should pay for your dues for you? Well, everybody is entitled to an opinion, but that’s not mine. If an employer chooses not to assist in underwriting a technician’s professional development by either covering or splitting the expense of individual membership dues to an organization that will assist you in reaching career goals, then suck it up, pay your dues, join, and claim it as a deduction on your income taxes. But join. RSES, with their history of providing education for HVACR technicians can assist you in a variety of ways in achieving NATE certification.

Of course, NATE certification is voluntary, as most technician certification in the HVAC/R industry has always been. But that may be changing for some technicians. Some manufacturers (and I wholeheartedly agree with them) are requiring contractors to have a given number of NATE certified technicians on board in order to sell their equipment. And some states are considering a NATE requirement for those who want to get a contractor’s license.

Bravo on both counts as far as I’m concerned. The facts about NATE certification are measurable and undeniable. NATE certified technicians make fewer mistakes relative to the installation, diagnosis and troubleshooting of HVAC/R equipment. And that is a win-win-win.

First, it’s a win for technicians because they become more confident and competent in their craft. Second, it’s a win for HVAC/R customers—the bottom-line in any business—because they get better quality service. And, third, it’s a win for the HVAC/R industry. Raising the standards of the industry enhances our image in both the eyes of our customers and the young men and women who may consider HVAC/R as a career.

A Few Words on NATE Criticisms

At the risk of sounding like some Old Duck who longs for “the good old days” (really, I’m not), I want to make a point about technician certification program criticisms by discussing one of the first EPA certification testing sessions that took place in San Francisco in the early ’90s. When I attended that session and tested along with a couple hundred other technicians, I heard a lot of criticisms about the whole idea of EPA Refrigerant Handling Certification, that it was nothing but a farce, a way to wring money out of HVAC/R technicians. And, it’s likely that you can still find people today who express that opinion.
Believe me, I’ve heard it all, from “there’s not really a hole in the ozone” to “the space program dumps more chlorine on one launch that a thousand technicians do in a lifetime” to “volcanoes are responsible” to “rain washes the chlorine out of the atmosphere,” etc., and we finally made a rule during the training sessions we presented and the testing sessions we proctored: everybody was entitled to their opinion, whatever it was, but when it came to answering the questions and earning the certification, the EPA was right.

To put it simply: all right all ready, nothing’s perfect. So, now that we’ve established that, let’s move on.

There have been some criticisms in the past (and likely will still be some forever no matter what changes are made) about NATE test questions that are not relative to the real “nuts and bolts” of HVAC/R equipment servicing, and serve to prove nothing about a technician’s real competency. Well, that may be true to a certain degree, but it’s certainly not true of every question, or even the majority of questions on the various exams.

So, all right all ready, do you want to be right, or do you want to be happy? Consider this scenario: you’re crossing the street and you’re doing everything right. You wait for the walk sign, you look both ways, you stay in the crosswalk and you have plenty of time to get to the other side of the street, so you’re totally right. Then, a speeding car shows up out of nowhere and mows you down. You could, as you’re lying there and taking your last breath, point a finger at the driver of that car and you’d be right about the fact that he was totally in the wrong and you were totally in the right. But you’d still be dead.

So, do you want to be right, or do you want to be happy?

A NATE test packet always contains an evaluation that allows technicians to provide an opinion on the test itself, and make comments and offer suggestions for improvement. It’s through the process that some changes have been accomplished, and any future changes that are necessary will be made. Other criticisms that you may have heard about the NATE exam process is that the fees should be lower, and that the certification should not need to be renewed. Neither of these issues should even be raised. If you think the NATE testing fees are excessive, look into what other professionals pay for certification in their area of expertise. And on the issue of renewing the certification, c’mon…our industry, like any other industry that relies on technology, is ever changing. So recertification in an updated environment makes perfect sense.

The NATE Structure

First, you need to decide is what category of technician you are. The two types of certification are Installation Technician and Service Technician. Here’s NATE’s description of what an installation technician does:

“Primarily prepares the installation site (including removal of the existing HVAC/R equipment), fabricates connections, and assembles systems as specified in the installation instructions. The technician must be able to properly power up and set control positions to cycle equipment through primary heating,
cooling, and blower operation under on-site or off-site supervision of a service or senior technician. The installation technician takes specialized readings such as temperatures, refrigerant circuit pressure, and basic VOM electrical readings, with both operating and non-operating equipment, as may be required by others.”

And the NATE service technician responsibilities include the following:

“This technician must be able to accomplish the same tasks as an installation technician, as well as to independently power up and adjust control settings to cycle equipment through all designed-for sequences. A service technician must be able to acquire, evaluate, and interpret such readings as may be necessary to determine the adequacy and acceptability of system operation to meet specifications. This technician must be able to perform sufficient field diagnostic procedures as necessary to determine causes of inadequate performance and identify corrective actions as needed.”

Under the NATE certification system, a service technician is considered to often possess the same knowledge as an installation technician. This being the case, a technician who certifies under the Service category can order and pay separately for a wallet card and certificate for the Installation category when they accomplish the Specialty exams.

Before a technician is eligible to take a specialty exam, they must accomplish a core exam that covers safety, customer service, principles of heat transfer and total comfort, and fundamentals of electricity. The core exam consists of 50 multiple-choice questions.

In the specialties area, each exam consists of 100 multiple-choice questions, are focused on the following:

Air Conditioning
Air Distribution
Gas Heating
Heat Pumps
Oil Heating

In the case of both the core exam and the specialty exams, a technician must achieve a score of 70 or better to earn certification. A technician who accomplishes the heat pump certification exam is automatically certified in the air conditioning category. NATE’s approach to the structure of the exams is that they are designed to measure what 80 percent of technicians have an 80 percent probability of needing to know to do their job correctly.

And that’s our introduction to the NATE certification process, along with some of my opinions about it. Your opinions on NATE, and any information about experiences that you’ve had if you have participated in the certification process, are welcomed. In the next segment in this series, we’ll take a closer look at the concepts a technician needs to understand relative to the core exam. For more information on NATE, visit www.natex.org.
When a technician is pursuing NATE certification, the first step is to accomplish a core exam. Core exams in either the area of service or installation evaluate a technician's understanding of the fundamental concepts applied to HVAC/R equipment servicing (relative to refrigeration and electricity), as well as safety issues, an understanding of tools, and soft skills. All of which makes sense. After all, how can a technician perform effectively relative to comfort cooling, for example, without a firm understanding of the fundamentals of temperature and humidity measurement, how a refrigeration system works in conjunction with an airflow system, and how the basic sciences apply to the proper operation of a system? It's the same as building a house. Without the proper foundation, you won't have much of a building. And so it goes with demonstrating proficiency in heat pumps, gas heat equipment or airflow systems. (For a listing of the specific NATE categories of certification, see Part One)

Without the proper foundation of understanding, you can't be as effective as possible when troubleshooting and servicing comfort cooling, heating, or refrigeration systems. Some of the stuff a technician needs to know about core subjects is very straightforward, such as terms we should be familiar with when working in the HVAC/R industry. For example:

Sensible Heat: Heat that can be measured and felt.
Dry Bulb Thermometer: A temperature-measuring device used to measure sensible heat.
Latent Heat: Often referred to as “hidden heat”, it cannot be felt or measured, occurring during a phase change of a solid to a liquid, liquid to a vapor, or vice versa.
BTU: British Thermal Unit, the amount of heat it takes to raise the temperature of one pound of water one degree Fahrenheit.

Hmmm…seems pretty straightforward, doesn’t it? While the average person on the street would probably give you a puzzled look if you asked them to explain any of these simple terms, 99.9 percent of HVAC/R technicians would likely be able to recite the formal definitions we’ve listed here, as well as provide an explanation as to how they fit into the concept of heat transfer. And, beyond that “foundation” stuff, there’s the issue of actually paying the rent with that basic understanding.

What do I mean by “paying the rent”? Well (get ready, here comes an opinionated point-of-view), what I mean by that is that it’s nice to know stuff, but it isn’t worth much if you can’t find a way to pay the rent with it: put it into practical applications and accomplish some goal. In this case, the goal and the practical application are to be able to answer a test question relative to these fundamental terms. And I mean answer it. Not just by memorizing some information, then regurgitating at the appropriate time to choose A, B, C or D, but being able to
understand the concept so you can figure out what the correct answer would be to any question relative to that concept. For example, take a look at the drawing in 2-1.

![Figure 2-1](image)

First, note our thermometer illustrations that represent temperature. There are two showing 32-degrees and one showing zero. Note also that we’re using two of the specific terms we mentioned above, sensible and latent heat. We’ve also added the idea of change of state to make our point. And, it’s clear that our discussion on this concept is going to apply to the idea of removing heat from a given quantity of water and causing it to change in state from water to ice. Beginning at the left of our illustration, you could assign any temperature you wish, and you could also use any given quantity of water you want. For the sake of discussion, let’s say that we’ll be using one pound of water at 70-degrees F. With that understood (and recalling the definition of the term BTU) we could determine exactly how much heat would need to be removed in order to chill the water from 70 down to 32.

So, if our question was:

In the accompanying illustration, how many BTU’s of heat would be removed from one pound of water being chilled from 70-degrees F, down to 32-degrees F?

A. 40  
B. 32  
C. 38  
D. 70

What was your choice? How did you arrive at your answer? If you chose “C” you were correct. And, if you arrived at that answer by recalling that the definition of the BTU is “the amount of heat it takes to raise the
temperature of one pound of water one degree Fahrenheit", then applied that information to the concept of removing heat rather than adding, and then did some simple math—the difference between 70 and 32 is 38—then you answered the question by understanding a concept and being able to apply your ability to reason.

And what if you understood the concepts we’ve been discussing, and your question (refer to Figure 2-2) was:

![Figure 2-2](image)

The type of heat that must be added or removed to cause a change in the physical state of a substance is:

A. Specific Heat
B. Superheat
C. Latent Heat
D. Sensible Heat

Which answer would you choose? It’s “C” again, because the concept we’ve illustrated clearly shows that the change in the physical state of a substance (when water is in the process of becoming ice in this case), the type of heat being removed is latent heat. When you’re at the “beginning” of 32, your substance is a liquid. During 32, your substance changes in state from a liquid to a solid and you now have ice, once you reach the “end” of 32. Hence the definition of latent heat is “heat that brings about a change in state, but not a change in temperature”.

Now, referring again to Figure 2-2, on to your third question:

When one pound of ice is chilled down from 32 to zero degrees F, what type of heat is being removed?

A. Sensible Heat
B. Latent Heat
C. Superheat
D. Specific Heat
What did you choose this time? If you picked “A,” you were correct. Clearly, the latent heat process has been accomplished, and the numbers in our question illustrated a measurable drop in temperature, which means sensible heat—heat that can be measured—is the correct answer. By the way, did you notice that in this question, there was some information that didn’t really need to be there? The “one pound of ice” reference could be deleted from the question and it wouldn’t affect the answer. The concept that needed to be understood didn’t concern the amount of heat being removed, only the type of heat. Now, if the question read…

How many BTU’s of heat are removed when one pound of ice is chilled down from 32 to zero-degrees F?

A. 32  
B. 16  
C. 64  
D. 48  

…there’s another concept that needs to be understood, which is referred to as the specific heat capacity of a substance. In the case of water in the first question we presented the answer was straightforward because the specific heat capacity of water is 1. However, to get the answer correct about ice, you would have to understand the concept of the specific heat capacity of a substance changing in the event of a change in state. The specific heat capacity of ice is .5, which means that the correct answer to our question would be “B”, which we would arrive at by again doing simple math as we did in the first question.
PART THREE

MORE ON CORE EXAMS

In Part Two, we presented some very fundamental information on the concepts of heat transfer (thermodynamics, if you prefer). And we accomplished that by discussing first, some basic terms an HVAC/R technician needs to understand, then relating that information to concepts that need to be understood, not just from an academic perspective, but from a practical approach to understanding refrigeration systems...so as to be able to evaluate a system, determine whether or not it’s operating properly, and then accomplish a repair if it isn’t. That, in my opinion, is the underpinning of the NATE philosophy. The design and approach of an exam should allow a technician to demonstrate their understanding (and competency) relative to their craft—not just by remembering formal definitions through a rote process, by being able to apply the knowledge of those definitions and the concepts they represent to a given situation, then answer the question correctly. As an example of this process, consider the simplified drawing of a refrigeration system in Figure 3-1.
At this point, we don’t know the exact application of this refrigeration system—whether it’s comfort cooling, a walk-in cooler, a heat pump, or even an automobile air conditioner or a household refrigerator/freezer. And, at this point, we don’t care.

The idea we want to get across here is that the fundamentals are the fundamentals, no matter what the application. Every vapor compression system designed to accomplish the task of removing heat from a place where it’s not wanted to a place where we don’t give a darn (instructors, forgive me, I couldn’t resist tossing in my modified version of the formal definition of refrigeration there), has the components we’re showing here, and they have the same job to do no matter what the application.

The job of the compressor is to create a rise in pressure, the job of the metering device is, through a controlled restriction, to create a pressure drop, and the function of the two coils is to accomplish heat absorption and rejection. OK, that’s understood.

What’s also understood is that on the evaporator side, the air that is directed through the coil leaves at a temperature lower than it entered because the fundamental laws of thermodynamics are at work, and heat is absorbed out of the air by the refrigerant traveling through the tubing. And, the air that enters the condenser coil leaves at a warmer temperature than it entered because the heat in the refrigerant is being released, also because of a thermodynamic law. What are those two thermodynamic laws of heat transfer?

….. When a substance boils (evaporates) it absorbs heat.
….. When a substance condenses, it rejects heat.

OK, fine, now let’s move on to a series of questions, that a technician who has a complete understanding of the operation of a refrigeration system should be able to answer:

1) What is the condition of the refrigerant as it exits the compressor?

A) A hot, high-pressure vapor
B) A hot, low-pressure vapor
C) A hot, high-pressure liquid
D) A hot, low-pressure liquid

2) What is the condition of the refrigerant as it enters the metering device?

A) A cool, low-pressure liquid
B) A hot, low-pressure liquid
C) A hot, high-pressure liquid
D) A cool, high-pressure liquid
3) What is the condition of the refrigerant as it enters the condenser?

A) A hot, high-pressure vapor  
B) A hot, low-pressure vapor  
C) A hot, high-pressure liquid  
D) A hot, low-pressure liquid

4) What is the condition of the refrigerant as it enters the evaporator?

A) A cool, high-pressure liquid  
B) A cool, low-pressure liquid  
C) A cool, high-pressure vapor  
D) A cool, low-pressure vapor

5) What is the condition of the refrigerant as it enters the compressor?

A) A high-pressure vapor  
B) A superheated, low-pressure liquid  
C) A superheated, low-pressure vapor  
D) A hot, high-pressure vapor

6) What is the condition of the refrigerant as it exits the condenser?

A) A cool, low-pressure liquid  
B) A hot, low-pressure liquid  
C) A hot, high-pressure liquid  
D) A cool, high-pressure liquid

These are six simple questions, and answering them is even simpler than you might think.

What about question #1? The correct answer is “A” because the discharge line on a compressor, a component that is designed to create an increase in pressure, is, after all, under a high pressure, and a compressor in a vapor compression system is designed to pump vapor. All of which leads us to only one logical conclusion regarding the choices we were given in the question.

And, for an example of the simpler-than-you-might-think concept, skip question #2 and go to #3. Did you catch that when you went through the questions—the idea that it was basically the same question as far as the concept of fundamental refrigeration applies, but just asked differently? Entering the condenser is the same as exiting the compressor.

Now, go back to question #2 where you’ll note that the correct answer is “D.” Next, skip right on down to Question #4 where the correct answer is also “D.” Again, this is the same question asked in a different way. Exiting the condenser is the same as entering the metering device.

Moving on to questions, #4 and #5, what’s being asked here relates to an understanding of the change-of-state of the refrigerant as it travels through the
evaporator, and what happens in the suction line of a refrigeration system. The correct answer to #4 is “B” because of second fundamental thermodynamic law we mentioned earlier, and the condition of the refrigerant as it enters the compressor is a superheated, low-pressure vapor, so the correct answer to question #5 is “C.”

So, the two points we’ve made here are: a firm understanding of a concept will allow you to choose the right answer to a multiple-choice question; and test taking is a skill that can be learned, just like connecting gauges to a refrigeration system can be learned.
In order to pass a NATE core certification exam, a technician needs to be competent. That may sound like an oversimplification of the certification process, but it's not. Competency is the key. And a key to competency is a firm understanding of the fundamental principles of HVAC/R equipment servicing. In parts two and three, our focus was on the principles surrounding the four components found in any vapor compression system and how the refrigerant worked with those components to accomplish the process of heat transfer. In this segment, we'll continue stressing fundamental concepts, but this time with a focus on refrigerants themselves and the issue of oil compatibility.

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<tr>
<td>R-123</td>
<td>HCFC</td>
<td>Blue gray</td>
</tr>
<tr>
<td>R-124</td>
<td>HCFC</td>
<td>DOT green</td>
</tr>
<tr>
<td>R-125</td>
<td>HFC</td>
<td>Light brown</td>
</tr>
<tr>
<td>R-134a</td>
<td>HFC</td>
<td>Light brown</td>
</tr>
<tr>
<td>R-141b</td>
<td>HCFC</td>
<td>Sand</td>
</tr>
<tr>
<td>R-142b</td>
<td>HCFC</td>
<td>Slate gray</td>
</tr>
<tr>
<td>R-152a</td>
<td>HFC</td>
<td>Red</td>
</tr>
<tr>
<td>R-401a</td>
<td>HCFC</td>
<td>Coral</td>
</tr>
<tr>
<td>R-401b</td>
<td>HCFC</td>
<td>Warm orange</td>
</tr>
<tr>
<td>R-402a</td>
<td>HCFC</td>
<td>Whitish green</td>
</tr>
<tr>
<td>R-402b</td>
<td>HCFC</td>
<td>Mustard</td>
</tr>
<tr>
<td>R-403b</td>
<td>HCFC</td>
<td>Light purple</td>
</tr>
<tr>
<td>R-404a</td>
<td>HFC</td>
<td>Orange</td>
</tr>
<tr>
<td>R-406a</td>
<td>HCFC</td>
<td>Light gray</td>
</tr>
<tr>
<td>R-407a</td>
<td>HFC</td>
<td>Lime green</td>
</tr>
<tr>
<td>R-407c</td>
<td>HFC</td>
<td>Chocolate brown</td>
</tr>
<tr>
<td>R-408a</td>
<td>HCFC</td>
<td>Reddish purple</td>
</tr>
<tr>
<td>R-409a</td>
<td>HCFC</td>
<td>Medium brown</td>
</tr>
<tr>
<td>R-410a</td>
<td>HFC</td>
<td>Rose</td>
</tr>
<tr>
<td>R-500</td>
<td>CFC</td>
<td>Yellow</td>
</tr>
<tr>
<td>R-502</td>
<td>CFC</td>
<td>Orchid</td>
</tr>
<tr>
<td>R-503</td>
<td>CFC</td>
<td>Aquamarine</td>
</tr>
<tr>
<td>R-507</td>
<td>HFC</td>
<td>Teal</td>
</tr>
</tbody>
</table>

Figure 4-1
Refrigerant, sometimes referred to as the “fifth component” in a refrigeration system, has become a more complex issue, beginning with the Section 608 of The Clean Air Act of 1990, the EPA guideline that started technicians down the path of securing refrigerant handling certification and the phasing out of CFC and HCFC refrigerants. To illustrate, we’re showing you a partial list of refrigerants and the drum color code that represents them in Figure 4-1.

This list (which is only partial, by the way—there are refrigerants other than these is use today) makes a couple of points relative to a fundamental concept that a technician needs to understand, along with a couple of other things that need not be worried about from the perspective of achieving certification. For example, being able to recite this entire list of refrigerants, identifying the properties of each in regard to their specific type, and then matching each color code would not demonstrate competency. Understanding, what I like to refer to as, the “alphabet soup” of a chart like this does, however, demonstrate competency.

“CFC” for example, stands for chlorofluorocarbon, identifying refrigerants that consist of elements of chlorine, fluorine and carbon, and have been phased out of production. “HCFC” stands for hydrochlorofluorocarbon, and relates to refrigerants such as R-22, which contains elements of hydrogen, chlorine, fluorine and carbon, and “HFC” stands for hydrofluorocarbon, denoting refrigerants that don’t have any chlorine. And, when it comes to achieving certification, the concept of which types of refrigerants are commonly used in the HVAC/R industry today is what’s expected of a technician.

When it comes to color codes, it’s a safe bet that almost every technician with a reasonable amount of field experience could answer these questions:

The color code for a drum of R-22 is:
A) Rose  
B) White  
C) Light Green  
D) Yellow

The color code for a drum of R-410a is:
A) Rose  
B) White  
C) Light Green  
D) Yellow

Of course, the correct answer to question #1 is C, and for #2 it’s A. Our reason for focusing on those two refrigerants? Simply because they’re two of the most common ones found in comfort cooling systems today, which is why a technician would be expected to be able to differentiate between the two of them. And, of course, a technician demonstrating competency relative to these two refrigerants would be able to successfully answer questions about the main difference in the chemical makeup of them, the fact that while R-22 contains
chlorine, R-410a does not. That brings us to our next point in demonstrating competency: understanding oil compatibility.

Oils in refrigeration systems, of course, are there to provide lubrication for the compressor, but a major factor to understand about oil is the compatibility factor. Since refrigerant oil is entrained (a term that simply means that the oil is broken down into small particles so it can travel with the refrigerant through the system components, and also be able to make its way back to the compressor crankcase, the oil must be fully compatible with the refrigerant. Figure 4-2 illustrates this issue while giving us a few more “alphabet soup” issues to consider.

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Type</th>
<th>POE</th>
<th>AB</th>
<th>MO</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-11</td>
<td>CFC</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>R-12</td>
<td>CFC</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>R13</td>
<td>CFC</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>R-22</td>
<td>HCFC</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>R-23</td>
<td>HFC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-123</td>
<td>HCFC</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>R-124</td>
<td>HCFC</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-125</td>
<td>HFC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-134a</td>
<td>HFC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-401a</td>
<td>HCFC</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-401b</td>
<td>HCFC</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-402a</td>
<td>HCFC</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-402b</td>
<td>HCFC</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-403b</td>
<td>HCFC</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>R-404a</td>
<td>HFC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-407a</td>
<td>HFC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-407b</td>
<td>HFC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-407c</td>
<td>HFC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-410a</td>
<td>HFC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-500</td>
<td>CFC</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>R-502</td>
<td>CFC</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>R-503</td>
<td>CFC</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>R-507</td>
<td>HFC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4-2

MO: Mineral Oil, used in systems with CFC refrigerants and only slightly hygroscopic, meaning that it will attract and absorb some moisture only to a slight degree.

AB: Alkybenzene: oil that can be found used in systems employing HCFC’s as the refrigerant. One fundamental difference between this type of oil and MO, is that AB oil is highly hygroscopic, meaning that is it much more efficient at absorbing water.
POE: Polyol Ester: this synthetic oil is compatible with all refrigerants, and is commonly used with HFC refrigerants. It is also very hygroscopic.

And what are one of the competency issues relative to technicians and their understanding of POE oils? The hygroscopic issue, and what the result of poor service practices could be if a POE oil was subjected to moisture. When oil and water try to mix, hydrochloric and hydrofluoric acids are created, which attack the insulation of motor windings. And attacking the insulation of motor windings ultimately results in a premature compressor failure due to a burnout.

There are other terms and concepts relative to refrigerant oils that a technician pursuing certification needs to understand:

Viscosity—basically the thickness of an oil, which affects its ability to flow. Refrigerant oils are of high viscosity.

Chemical Stability—this is the ability of an oil to do its job (lubricate) in the refrigerant environment and still maintain its chemical properties.

Floc Point—this is a term that refers to the point at which wax in an oil will drop out from a mixture of oil and refrigerant.

Diacritic Strength—oil isn’t supposed to allow electrical current to flow, and this term explains the concept of the ability of an oil to resist conducting electricity. A refrigerant oil will have a high dialectric strength so as not to conduct electricity.

Miscibility—we mentioned that oil entrains (mixes) with refrigerant. This term is another way of describing the ability of an oil to mix with the refrigerant. In a low-temperature refrigeration system, it’s critical that an oil be able to remain mixed with the refrigerant at low temperatures and not separate, becoming trapped in the evaporator.

And, now, with our overview of the fundamentals relative to refrigerants and oils accomplished, we want wrap up this segment by presenting you with something that you won’t see on a NATE exam…a trick question. Here it is:

In Figure 4-3 there are two refrigerant drums, Drum A and Drum B. Both of these drums contain virgin R-22 and there are no condensibles in them. Both are sitting in the same ambient temperature. Drum A is filled to a level of 10 percent and Drum B is filled to its maximum level of 80 percent. Which drum will have the higher pressure?

A) Drum A
B) Drum B
The correct answer to this question is “none of the above.”

Both drums will have the same pressure. As long as there is an appreciable amount of liquid refrigerant in a drum, the vapor pressure will be the same whether that drum is only 10% full, or filled to its maximum. Understanding this concept and how it allows us to use a temperature/pressure chart to evaluate a refrigeration system whether it’s a 1 ½ ton unit or a 10-ton unit…think about it…. a temperature/pressure chart wouldn’t be workable if it had to deal with different volumes of refrigerant. Understanding this concept is just one more illustration of a technician’s competency.
In addition to having a firm understanding of the principles of refrigeration, a technician pursuing NATE certification also needs to know about HVAC/R electrical components and systems, and how to evaluate and troubleshoot those components and systems. And that knowledge begins with a firm understanding of the fundamentals. With that thought in mind, this segment will focus on eliminating the mysteries behind electricity. And we’ll begin with a question: do you believe in magnets? Your answer…certainly. Bill Nye the science guy, and others on learning TV shows have explained the principles of magnets; that there’s a North and South pole, and that there’s something known as “lines of force” surrounding a magnet. That’s why you can put two magnets down on a table, and depending on their positioning, either cause them to snap together (be attracted) or push apart (be repulsed). (See Figure 5-1)

![Figure 5-1](image)

A technician’s understanding of the concept of attraction or repulsion can be evaluated in the form of a question:

The law of electric charges states that:

A) Opposite charges attract
B) Like charges repel
C) Opposite charges repel
D) Both A and B

The correct answer to our question is “D” since opposite charges attract and like charges repel. This is one of the principles that several people from different countries (England, Italy, France, Germany and Scotland—their names have a lot to do with the terms we use related to electrical principles, and we’ll
get to them shortly) knew in their experiments related to electricity and its development. From an HVAC/R technician’s perspective, these experiments and illustrations of the fundamental concepts behind electricity relate to a term we use regularly: Alternating Current. The idea behind alternating current and magnets is the principle that is explains “when a conductor cuts the lines of force of a magnet, an energy is produced in the conductor. Two illustrations of this energy are shown in Figures 5-2 and 5-3.

![Figure 5-2](image)

In Figure 5-2 we’re showing the basic components of an electrical generating system. Conductors are positioned so that when shaft energy is applied to rotate the magnets, the conductor cuts the lines of force that Bill Nye and others explain so eloquently on their science shows.

![Figure 5-3](image)
The illustration in Figure 5-3 is a sine wave, which is a graphical representation of alternating current. When a conductor (X) is rotated through a magnetic field from A to B to C, then back from C to D, and finally to A again, it goes through what is termed a positive potential (A to C) then through a negative potential (C to A). The other concept that this illustration shows is that the rotating of a generator is accomplished in a given time frame, resulting in a cycle, or, if you prefer, the frequency of alternating current, which in the United States is 60 cycles per second.

And, now, on to those terms we mentioned.

Technicians use electrical terms every day related to HVAC/R electrical systems, and having a firm understanding of them is fundamental to achieving success, not only in pursuing NATE certification, but also in troubleshooting and service procedures. Here’s a simple question regarding electrical terms:

Electromotive Force is a term related to:

A) Amps  
B) Volts  
C) Watts  
D) Hertz

The correct answer is “B” since an Italian scientist by the name of Allessandro Volta was fundamental in the development of electricity. In the 1600s he experimented with generating energy through chemical means (batteries) and heat (2 dissimilar metals in a flame producing energy is what we refer to as a thermocouple). So the term volts, which is also referred to as EMF or Electromotive Force, is what we use today.

Another question…

Current flow is related to the term:

A) Amps  
B) Volts  
C) Watts  
D) Hertz

“A” is the correct answer to this one since Andre Ampere, a French scientist performed experiments related to measuring the electromagnetic field that surrounds a conductor when electricity travels through a conductor—every time we use a clamp-on meter to check the current draw of a motor we’re working with this principle.

Next question…
The phrase “cycles per second” relates to:

A) Amps
B) Volts
C) Watts
D) Hertz

“D” is our answer here, since Heinrich Rudolph Hertz of Germany was the scientist behind explaining concepts related to the frequency of alternating current. Hertz, of course, is abbreviated “Hz” on equipment tags.

And our last question…

Power in an electrical circuit relates to the term:

A) Amps
B) Volts
C) Watts
D) Hertz

Yeah, we know you this one. It is a dead giveaway through the process of elimination, and it’s the correct answer because of the experiments of James Watt of Scotland on things like work, force and horsepower.

So, are we saying that in order to get a passing score on a NATE core exam you’ll need to memorize the names of a bunch of guys who were in on the development of electricity a few hundred years ago? Probably not. However, what we are saying is what we’ve said throughout this series, which is that when a technician has a firm grip on the concepts related to the core subjects on NATE exams memorizing things isn’t the key to success, understanding things and using that knowledge to figure out the correct answer to a question is what it’s about.

Bonus question…

Part of the name of an English scientist involved in electrical experiments is used relative to the concept of:

A) Phase
B) Inductance
C) Capacitance
D) Delta and Wye

The answer to this question is “C” Capacitance. A measurement of capacitance is the microfarad, and an English scientist who experimented with fundamental electrical principles relative to conductors and magnetic fields was Michael Faraday.
PART SIX

ELECTRICAL PRINCIPLES CONTINUED

We’ll begin this segment with two very fundamental questions.

1) The rotor of a motor is:

A) An electromagnet
B) A permanent magnet
C) Stationary
D) None of the above

2) The stator of a motor is:

A) An electromagnet
B) A permanent magnet
C) Supported by bearings
D) All of the above

Two very simple, yet thought-provoking questions. And both answered easily by understanding some of the basic principles we discussed in Part Five of our series (magnetism is what it’s all about), and by keeping in mind the simple visual we’re showing in Figure 6-1.
In this illustration, we’re not only showing the very fundamental components that make up a standard alternating current motor, but also showing by positioning, the concept of electromagnetism and how it creates the mechanical energy that is the end result of operating said motor. Around the perimeter of the motor are the motor windings (the stator section, which is an electromagnet) and in the center is the rotor. The letter “C” representing the permanent magnet assembly that is the rotor, while the letter “A” represents the run winding, and the letter “B”—well, there’s really only one thing left here—the start winding.

So, by virtue of our simplified motor illustration, we’ve answered the two questions above: the correct answer for #1 is “B” and the correct answer for #2 is “A.”

And, in addition to answering the questions, our simple drawing furthers the understanding of the one of the fundamental electrical principles, that of the laws of attraction and repulsion related to magnets. Since the rotor is positioned with its magnets which have a North and South Pole, and the stator windings, when energized, will also have a North and South, then the rotor is bound to turn because of the principles of attraction and repulsion.

Also, with a start winding shown as having more turns than a run winding, we’re showing that the electromagnetic field of a start winding (remember, one of the laws of electricity is that whenever electricity travels through a wire there will be an electromagnetic field around the wire) will be stronger than that of the run winding.

Which means that if we had a system in which we energized both windings at the instant of start so as to create a very strong electromagnetic field that gets the rotor started moving from a dead stop, we would then be able to take the start winding out of the circuit and use only the run winding to keep the rotor moving. (Momentum plays a part in the rotation of a rotor.)

To take the start winding out after we’ve used it for its intended purpose, we could use a relay of some type, or a centrifugal switch built into the motor that is normally closed until the motor reaches about 75 percent of its running speed, causing the switch to open and break the start winding circuit. (See 6-2) As with the visual in Figure 6-1, this one, when understood, could be used as a basis for answering a question:

The start winding in the illustration is:

A) Wired in series with a switch
B) Wired to a common motor connection
C) Both A and B
D) None of the above
Even without the power supply illustrations of L1 on wire at the far left and L2 on the wire shown in the center of the drawing, along with the wire terminal connections (dots) identified from left to right as R, C and S, the correct answer to this question can be determined. Since this schematic shows a start winding that is taken out of the circuit after the motor starts operating, the winding has to be wired in series with a switch, and both windings are connected to a common terminal in the drawing, so the correct answer is “C.”

Of course, motors aren’t just fundamental. There are modifications in their operation and additional components that are used in conjunction with their starting and running processes. For example, Figure 6-3 gives us the background to answer another question.

A start capacitor is:

A) Wired in series with the start winding
B) Taken out of the circuit after start is accomplished
C) Provides a boost to help the motor start
D) All of the above.
Now, with our power supply identifiers in place along with our terminal connection designations and the style of our start winding circuit switch identified, it’s easy to understand that the correct answer here is “D.”

O.K, now we’re making things too easy, so we’ll go to another illustration and ask another question. (See Figure 6-4)

In this illustration, the capacitor is:

A) A run capacitor
B) A start capacitor
C) Wired in series with the run winding
D) Both A and C
At first blush, it might be easy to think, “Now wait a minute here, Jim, I can’t answer this question because there isn’t enough information.” But, the fact is, all the information you need is there. It’s, after all, a schematic, and schematic diagrams, even without the letters that are (sometimes) conveniently added to a manufacturer’s wiring diagram, this schematic tells a complete story via its symbols and structure.

First, there’s the fact that there is no switch shown. That in and of itself gives you the answer to the question. And then there’s the idea that you could add the same power supply and wiring terminal identifiers in exactly the same way we used in the previous diagram, though you certainly wouldn’t have to add them to get to the correct answer, which is “A.”

The symbols within the diagram are for a motor winding and a capacitor. The fact that there is no switch to take this capacitor out of the circuit means that it has to be a run capacitor and not a start capacitor. And, the diagram also shows a basic concept relative to run capacitors and motors when they are wired together to create a PSC (Permanent Split Capacitor) circuit, which is “the run
capacitor is wired in series with the start winding—a concept we’ll discuss in more
detail in the next segment.
In the last segment, we took a detailed look at the fundamentals of motor design and discussed the basic electromagnetic principles that allow a motor to do what it does—transfer electrical energy into mechanical energy. Of course, in the world of HVAC/R, that mechanical energy translates to airflow, either on the indoor or outdoor side of the cooling, heating or heat pump system, or to operating a compressor motor. And the most popular method of operating those air-handling and compressor motors is PSC, Permanent Split Capacitor. That brings us to our first question:

In a PSC motor, the run capacitor is:

A) Wired in series with the run winding  
B) Wired in series with the start winding  
C) Usually rated from 160 to 180 MFD  
D) A capacitor that requires discharging by shorting with a screwdriver

We thought this would be an interesting question to pose, since it brings up a couple of things that HVAC/R technicians need to have a fundamental understanding about relative to motor operation. First, there’s the obvious correct answer—B—regarding how a run cap is wired into a motor in order to make it operate more efficiently (more on how that really works shortly), and then there’s another issue have a general understanding about the average microfarad rating of different types of capacitors, as well as one test-taking skill point of interest we want to discuss.

First, the microfarad rating issue…

In the above question, C would never be considered as a possible answer because run capacitors in HVAC/R equipment will always have a much lower microfarad rating that 160 to 180. Often, a run capacitor servicing a compressor will have a rating of 35 MFD, while air handler motors will have even lower rated run capacitors, as little as 3 MFD, or maybe 5 to 7.5 MFD. Start capacitors, of course, are a different story, and may well have a rating of 160 to 180 MFD, but we’re discussing run capacitors here.

The other point of interest about this particular question relates to test-taking, one of the elements we are weaving in along with the technical side of this series on NATE certification. Often—note: we said often, not always—the longest answer to a question needs to be given strong consideration as being the correct one in a multiple-choice exam. And the question above is an example of being an exception to that rule. While D is the longest answer, having an overall understanding of run capacitors used today in HVAC/R equipment makes it an
answer not-to-be considered at all, even though it’s the longest one of the choices. The only correct answer to the question is, as we said, B.

So how would a technician, who, when sitting down to take a test, is likely, as they say “nervous as a long-tail cat in a room full of rocking chairs” not be misled by that longest answer test-taking adage and be able to focus in on the only correct answer for this question? One way would be to recall the concepts we’re showing in Figures 7-1 and 7-2.

In Figure 7-1, we’ve taken the fundamental motor that we showed you in last month’s segment and added a power supply. Simple enough, L1 and L2 are connected to the run winding of the motor. One way to think about this relative to a PSC motor operation, is that the current flow through the run winding is “unrestricted,” with nothing more than whatever switching contacts (such as those on a contactor) being wired in series with that winding, and allowing a complete circuit when closed. In Figure 7-2, on the other hand, we’ve added the PSC concept to the illustration.

The run capacitor is also shown as connected to the L1 side of the line, simply meaning that we are preparing for a parallel circuit to the start winding once we put power into the capacitor and then wire the other side of it to the start winding, then complete the circuit by connecting the other lead of the start winding to L2. This illustration demonstrates the statement “the run capacitor is wired in series with the start winding.”
It's common for new technicians to be just a little buzzed by that statement since it seems contradictory, due to the terms "run" relative to the capacitor and "start" relative to the motor winding. But, it's not a mix-up, nor is it a concept that is difficult to accept, providing there is a basic understanding of the concept of motor operation—meaning electromagnetism in the stator windings and the fact that the rotor is a permanent magnet.

In our illustrations, consider the idea that if the run winding "A" was the only winding energized, then the rotor "C" would only get a given number of...well...magnetic "slaps"—kind of like a paddle wheel on a riverboat would hit the water to propel the boat forward at a certain speed.

However, if the start winding was also energized at the same time, but with an electromagnetic field that is slightly out-of-sync with the timing of the run winding, there would be two distinct electromagnetic fields "slapping" the rotor around (just like adding more paddles to the paddle wheel of the boat to make it go faster and stronger through the water) more efficiently.

Another idea to keep in mind is to closely examine the P, the S and the C and what they stand for:

P = Permanent, obviously meaning that the capacitor is never taken out of the circuit.
S= Split, because what is being split is the phase—the timing—of the 60 Hertz alternating current.
C= Capacitor, simply because that’s the component being described.

And, as far as the incorrect D answer, an understanding that capacitors, while their job is to gather up a charge—kind of act like a storage bucket for electrons—they are also equipped with a bleed-off resistor, so they don’t need to be discharged by shorting a screwdriver across their terminals. This is true for start capacitors, which will be the subject of our next segment.
In this segment, we’re going to move on from one “alphabet soup” situation—the PSC discussion we presented in Part Seven—to another one. PSC, of course, stands for Permanent Split Capacitor, and what we’ll be referring to this time around is “CSR.” Often, when this is the reference point relative to the operation of a motor, it’s understood that it means “Capacitor Start, Capacitor Run”, and yes, sometimes manufacturers will use the terminology “CSCR” rather than just “CSR.”

By whatever letter-label, the concept is a straightforward one: a capacitor is used to provide a boost in order to get a motor that’s starting under a load rolling. And, once the start process has been accomplished, the start capacitor needs to be taken out of the circuit. Of course in HVAC/R, the application of a CSR circuit is related to the operation of a refrigeration system compressor, but sometimes the easiest way to understand the circuits and the components of this motor in operation is as something other than a compressor, perhaps something like an old centrifugal switch-type motor that is used on, say, an air compressor. (See Figure 8-1)
In this illustration, you can see the simplicity of using a start capacitor with a motor. Without any type of relay to consider, we can accept an idea in its simplest form: that a centrifugal switch on a motor will be in a closed position on starting, then open once the motor reaches about 75 percent of its running speed. Thinking about it from this perspective would point you in the right direction in answering the following question:

A start capacitor:

A) Is wired in series with the start winding of the motor  
B) Is taken out of the circuit after the motor has started  
C) Is wired in series with the run winding of the motor  
D) Both A and B

Following the simple rule of tracing a circuit from source to source, along with an understanding of symbols, leads you to the only possible correct answer to this one, which is “D.”

Following a circuit from L1, directly to the right and through the Starting Capacitor, then on through the Centrifugal Switch, to the start (“S”) motor connection, to the common (“C”) terminal on the motor, then on to the L2 connection proves undeniably that the start capacitor is wired in series with the start winding (almost too simple, isn’t it?), and that it will be taken out of the circuit once the motor is up and running.

What follows the understanding of fundamental theory relative to start capacitors and how they create a higher starting torque in a motor is, well, exactly how is it that they do what they do? The answer: Electron Flow. We’ve said before that the basic idea behind a capacitor is that it is “a storage bucket for electrons” and the illustration in Figure 8-2 drives that point home.

The function of a start capacitor is to allow the orderly introduction of electrons to enter (at the left), then store them up before releasing them in a batch, as shown at the right. When you consider the illustration in Figure 8-1 in which we noted that the capacitor was wired in series with the start winding, consider the idea that, when a far higher-than-normal current flow is allowed momentarily through that start winding, it creates a far stronger-than-normal electromagnetic field. And since motor starting and running is all about the electromagnetic field in the windings and the permanent magnet of the rotor, the
rotor can't help but be moved to rotate, even if there is a load bearding down against the mechanical segment of the motor.

And how is that this “storage bucket” can, in fact, “store” electrons? Figure 8-3 gives you the down-to-earth, nuts-and-bolts answer to that question.

[Figure 8-3: Paper and Foil plates]

It’s all about area. A wire is a wire, but a foil plate is a foil plate, and a start capacitor has a lot of foil plate area, surrounded by paper insulation. If you decided to take a saw and cut the top and bottom off of a start capacitor—caution: if you were to pursue this kind of experiment, remember that the electrolytic fluid in a start capacitor is acidic and dangerous—you would find what we’re showing here. You would also note that in comparing the thickness of the plates in a start capacitor to those of a run capacitor, the start cap plates would be heavier.

Run capacitor plates are much thinner since their “storing” isn’t related to providing more torque to get a motor going, but rather along the line of knocking the sequence of current alternation slightly out of sync in order to create two electromagnetic fields. (Refer to Part Seven for a review on the operation of a PSC motor)

Other factors to understand about start capacitors are their microfarad rating, voltage rating, bleed-off resistor, and pop-out holes. Figure 8-4 gives you a couple of views of a start capacitor, illustrating these concepts.
The purpose of the bleed-off resistor is to bleed off a charge. The pop out hole will let go before the case will explode in the event of a mis-wire or other electrical problem, and the microfarad rating information is important when replacing a failed capacitor.

All of which brings us to another sample question, one that should be simple to answer with an understanding of the fundamentals of capacitors. (See Figure 8-5)
Figure 8-5

Of the two capacitors illustrated here:

A) The one on the left could be found in a household refrigerator
B) The one on the right could be found in a 20-ton air conditioner compressor circuit
C) Both are start capacitors
D) Both are run capacitors

What do you think the correct answer is?

Consider solving this one via a process of elimination: One of them is a run capacitor and the other is a start capacitor, so C and D aren't correct, and a 20-ton compressor would employ a run capacitor much higher than 15 MFD, so the correct answer is “A”.
PART NINE

MORE ON CORE EXAMS: NAILING DOWN SOME ELECTRICAL FUNDAMENTAL PRINCIPLES

In our last few segments of this e-book, our focus has been on a kind of “nuts and bolts” approach to the fundamentals of electricity and how it applies to the operation of specific HVAC/R system components. And, no doubt, the practical application information is a lot more fun that some of the electrical theory that supports the concepts of things like motor operation, capacitors, coils, etc. But, a firm understanding of electrical concepts is also necessary. So, in this segment, we'll take a look at a couple of fundamental ideas relative to electrical circuits, among them, Ohm’s Law.

In the early 1800s, around the time Allessandro Volta of Italy was figuring out Volts, Andre Ampere of France was nailing down the concept of current, James Watt of Scotland was explaining power and Heinrich Hertz of Germany was giving us the term for “cycles per second,” a math professor/scientist by the name of Georg Ohm determined that he could, through either multiplication or division, find the unknown factor in an electrical circuit. If he knew the voltage and the current draw, he could find the resistance. If he knew the resistance and the current draw, he could find the voltage. And, if he knew the voltage and the resistance, he could find the current.

He explained the “law” he applied by assigning letters to the appropriate electrical factors:

E, for volts, because the formal term for volts is Electromotive Force.

I, for current, because current is “induced” in a circuit. (There have been theories presented that say that the "I" stands for “intensity” and that’s still up for debate, so you can apply whatever term floats your boat.)

R, for resistance, because…well, that one seem obvious.

Next, he explained the formulas that applied calculating the unknown factors:

E = IR…To calculate voltage, multiply the current by the resistance.

I = E/R…To calculate the current, divide the voltage by the resistance.

R = E/I…To calculate the resistance, divide the voltage by the current.

Hmmm…and you thought you really didn’t need to pay attention in Algebra 1 in junior high school because there wasn’t a lot of practical information you could use. Little did you know that part of being an HVAC/R technician is knowing how an algebraic formula can be used to find out what the resistance of a heating element is supposed to be.
As it is with understanding any formula, there are some simple rules that apply here. First, unlike basic arithmetic in which we would say “2 + 2 = 4,” the way a formula reads is actually “4 = 2 + 2.” The other simple rule that applies is that when two factors are positioned next to each other in the formula (E = IR), that means, “multiply,” in this case, multiply the current by the resistance. And the symbol for division is the other fundamental rule.

Now, with the rules understood, we’ll show the simplest tool there is to perform the Ohm’s Law calculations, the Ohm’s Law Memory Wheel. (See Figure 9-1)

![Figure 9-1](image)

The key to using this tool is simple: cover what you want to know.

As the gray shading shows, covering the appropriate factor leads you to the proper formula process. With the E covered, the I and R are next to each other (multiply). With the I covered, the E is over the R (divide). Likewise with covering the R, which shows the E over the I.

And now that we’ve given you the tools and information you need, you can answer a couple of questions relative to Ohm’s Law and electrical circuits. (Refer to the simplified diagram in Figure 9-2—E is at the left, R is at the right, and I is at the bottom of the diagram).

![Figure 9-2](image)
The voltage is 220, the resistance of the heating element is 10 Ohms. The current is:

A) 35 Amps  
B) 12 Amps  
C) 22 Amps  
D) 19 Amps

The current is 2 Amps, the resistance is 60 Ohms. The voltage is:

A) 220 Volts  
B) 240 Volts  
C) 277 Volts  
D) 120 Volts

These two questions relate to Ohm’s Law in its pure form, as it would apply to a resistive load, such as a heating element, and the correct answers are C and D, respectively. That brings us to the next issue relative to understanding HVAC/R circuits and components, calculating electrical power.

The formula for this process is: \( P = E \times I \), or Power is equal to the Voltage multiplied by the current, sometimes explained simply as Volts \( \times \) Amps = Watts. The reason behind this process is to know what the actual power consumption of a given component (such as a heating element) is, which means the cost of operation can be calculated. In our first question, for example, the current draw was calculated to be 22 amps and the voltage was listed as 220. When plugging these numbers into our electrical power formula, this is the result:

\[
220 \text{ Volts} \times 22 \text{ Amps} = 4840 \text{ Watts}
\]

Then, with applying the simple rule that there are 1,000 watts in a Kilowatt, we could calculate the correct KW rating of the element in question. 4840 Watts divided by 1,000 = 4.84 KW

And, if the cost of power was known, we could calculate the actual dollar amount spent to operate the heating element.

The power factor formula can also be used to find out the power consumption of a motor, however, since a motor isn’t a purely resistive load, but an electromagnetic one, we would have to add another factor into the formula, known as a power factor. A power factor is a number less than 1, expressed as a percentage. Actual power factors can vary, depending on the design of the motor.

In our example in Figure 9-3, we’re showing a motor that is operating on 230 VAC, and has a current draw of 25 Amps, and we have assigned a power factor of .70. So, here’s your question:
Figure 9-3

Using the formula \( P = I \times E \times PF \), the wattage of the motor would be:

A) 4025 Watts  
B) 2310 Watts  
C) 4650 Watts  
D) 3,000 Watts

When you apply the proper numbers to the formula above….

\[
230 \times 25 \times .70
\]

….the answer you arrive at will be the choice listed as “A”.
PART TEN

MOVING ON TO WIRING DIAGRAMS

So far in the electrical segments we’ve presented, we’ve covered the fundamental principles that technicians need to understand, along with some basic stuff about specific components—motors, relays, etc. In this segment, we’re moving on to wiring diagrams. And, as you would expect in this day and age, when we say wiring diagrams, we also mean printed circuit board control systems.

The steps to understanding current wiring diagrams are the same as they were when HVAC/R equipment was made of electromechanical systems.

Step one: understand that the schematic diagram is a “map” of the equipment’s electrical circuits and components, and that the intent of the diagram is to simplify and explain the overall operation of a system. To understand schematic diagrams and electronic control systems (and being able to answer questions about them), you must understand specific types of equipment, such as the gas furnace example shown in Figure 10-1.

To interpret this diagram, first locate the symbol for the transformer. It’s located at the center of our illustration and it forms the basis for the entire diagram. Once the symbol is presented, all that needs to be done is to add “tails” to it to form the overall pattern that allows for the addition of specific component symbols. For example, the four-speed blower motor identified as BLWM, the Hot Surface Igniter (HIS), and Induced Draft Motor (IDM).

And, when considering the blower motor circuit, you’ll note the normally open contacts shown as BLWR, and also the normally open and normally closed set shown as LO/HI. The idea to nail down here is that a schematic diagram, whether it is depicting an electronic or electromechanical control system, provides you with a line-by-line description of the switching contacts that are wired in series with the load they control. Consider the Hot Surface Igniter (HSI) and the HSIR contacts that, when closed, will provide a complete circuit to the HSI. Note also that the Induced Draft Motor (IDM) won’t operate until the contacts of IDR are closed and allowing a complete circuit though the load identified as IDM.

With the operating voltage (if you want, refer to it as the “high voltage”) segment of the schematic understood, you can move on to the control (or “low,” if you prefer) side of the diagram to clarify the basic schematic point-of-view, which is…whenever you see a set of contacts wired in series with an operating voltage load, there has to be some method on the control side of the system to cause a movement in those contacts.
NOTES:
1. COMMON SIDE (SEC-2 AND C) OF 24V AC TRANSFORMER CONNECTED TO GROUND THROUGH THIS MOUNTING SCREW.
2. IF ANY OF THE ORIGINAL EQUIPMENT WIRE IS REPLACED USE WIRE RATED FOR 105 C, OR EQUIVALENT.
3. INDUCER AND BLOWER MOTORS CONTAIN INTERNAL AUTO-RESET THERMAL OVERLOAD SWITCHES.
4. BLOWER MOTOR SPEED SELECTIONS ARE FOR AVERAGE CONDITIONS. SEE INSTALLATION INSTRUCTIONS FOR DETAILS ON OPTIMUM SPEED SELECTION.
5. USE COPPER WIRE ONLY BETWEEN THE DISCONNECT SWITCH AND THE FURNACE JUNCTION BOX.
When evaluating schematic diagrams, always look for this correlation between the operating and control sections. For example, consider again the BLWR contact points shown near the top of the illustration. Where else do you see the identifier BLWR? The answer, of course is on the control segment of the diagram, and it’s presented inside of a circle, which is “schematicspeak” for Coil. (Don’t bother to look up the term “schematicspeak.” We made it up.)

Taking this simple approach to schematic diagrams would mean you would be able to complete the following statement:

When the CPU provides a 24-volt circuit to the BLWR Coil:

A) The normally open BLWR contacts will close.
B) The normally closed BLWR contacts will open.
C) The blower motor should operate on medium-low speed.
D) Both A and C.

The correct answer is “D,” which is simply determined by examining the schematic from the control/operating correlation perspective. Certainly, when 24-volts is applied to the BLWR coil, the contacts close. Also shown on the operating side of the diagram is another set of contact points (in the LO/HI Fan Speed Relay) that are normally closed. And, since the statement didn’t address anything regarding energizing the LO/HI coil shown on the control side of the diagram, we know that the normally closed contacts will remain just that…closed, which means that there will be a complete circuit to the medium-low speed of the blower motor. And this brings us to rule #2 of understanding schematic diagrams and answering questions about them:

Step two: always trace a circuit from source to source.

Certainly, in the “good old days” of electromechanical stuff, this was easy because the diagram clearly showed the either open or closed contact points on both the operating load and the control circuitry. Well, it’s still not too complicated in the world of solid state control systems when you consider the idea that a printed circuit board or CPU (meaning microprocessor and control circuitry—Central Processing Unit, in this case) is really nothing more than an assembly into which power is introduced, and at the appropriate time, is allowed to provide a complete circuit to whatever coil it is supposed to be energizing at the moment.

Note that when locating the “C” on the control wiring connections at the bottom left of the diagram, you’ll see a connection for “one side of the line” to each of the coils shown just above the CPU. Note also that there is a direct connection from the “R” control wiring terminal connection to the CPU. OK...so it’s pretty simple. One side of the line “C” is wired directly to the control coils in this system. The “other side of the line” in the 24-volt power supply is wired into the CPU. And, at the appropriate time, on a call for heat, and once the
heating cycle is in process, the CPU will allow power to the BLWR coil, which, in turn, allows the complete circuit to the blower motor.
And now, the next step in evaluating wiring diagrams…

Step three: understand what the sequence of operation is supposed to be.
We’ll look further into this step in our next segment. In the meantime, consider the following:

If, when reading 120 VAC at the PR1 and PR2 terminal connections and 0 VAC at the SEC-1 and SEC-2, you have determined:

A) The control transformer has failed.
B) The ILK (Interlock Switch is open.
C) The CPU has failed.
D) A limit switch has opened.
PART ELEVEN

MORE ON USING WIRING DIAGRAMS TO EVALUATE EQUIPMENT OPERATION

(Note...Before we begin this segment, we want to mention that the correct answer to the last question posed at the end of Part Ten is “A”).

In our last segment we presented the first three steps relative to using schematic diagrams and the fundamentals (NATE core and specialty exam skills) of using them to troubleshoot HVACR equipment. To review, the steps we presented were:

1. Understand that the schematic is a “map” of the electrical system and that a technician’s task is to interpret that map and apply it to the actual, real-life, sitting-there-in-front-of-you “territory” (the equipment being evaluated).

2. Always trace a circuit from source to source.

3. Understand what the sequence of operation is supposed to be.

And, in this segment, we’ll move on to Step 4....Use your understanding of the first three steps in order to isolate, and if necessary, hopscotch.

The simplest way to explain isolating is to refer again to the last question we posed last month. The information regarding the test procedure was to simply test at terminals PR-1 and PR2 for a reading, then test directly after that at terminals SEC-1 and SEC-2. As we said, the answer to that question was “A”, that the control transformer had failed, a diagnosis we arrived at by isolating a component for testing. And when we isolate, we can consider step 4 as being the step in the process where a technician goes from understanding electrical troubleshooting to actually doing the work.

Here’s an example of isolating, and a simple question. (Refer to the diagram in Figure 11-1)

According to the diagram, the condenser fan motor:

A. Will run as soon as power is applied to L1 and L2.
B. Will only operate when the contactor coil is energized.
C. Operates in a parallel circuit with the compressor.
D. Both B and C.
Understanding isolating means that answer “A” can be written off immediately, because it’s clear from our diagram that a set of contact points must be closed before there is a complete circuit to the condenser fan motor. It’s also clear that “B” is true since the contact points of the contactor can only close when the coil of the contactor is energized. And, it’s also true that the condenser fan motor operates at the same time as the compressor, and also has the full voltage of the system delivered to it, which is what defines a parallel circuit. So, the correct answer has to be “D”. And, what answering this question correctly means from a practical standpoint is that, if the condenser fan motor was not operating, you would know where to check for the necessary applied voltage in order to
determine if the motor itself, or if the wiring harness to the motor was the source of the problem.

Isolating can also apply to simply being able to identify an electrical component and answer a question about it. (See Figure 11-2)

Figure 11-2
In the diagram, the switch that can provide a circuit to both the Indoor Fan Relay Coil and Control Relay Coil is:

A. A normally closed switch.
B. A close-on-temperature-rise switch.
C. A manually operated system switch.
D. A close-on-temperature-drop switch.

The correct answer here is “B” and it can be proven to be true by applying the four steps to understanding, interpreting, and isolating the circuit in question.

And, isolating, of course, often means being able to zero in on a certain component no matter how complex a diagram is, or what the specific engineering choice of design was applied in developing it. For example, the following question, relative to the diagram shown in Figure 11-2 would demonstrate a technician’s ability to isolate.

In this diagram, the crankcase heater would be energized:

A. Whenever power was applied to L1 and L2.
B. Whenever voltage can be measured at T1 and T2.
C. When the contactor contact points are closed.
D. When the contactor contact points are open.

When considering the 4 steps, along with an understanding of the fundamental principle that “energy will always follow the path of least resistance” isolating leads us to the correct answer here, which is “D”.

The term hopscotch can mean a variety of things, one of which is the ability to shift perspective back and forth between the control and operating sections of a schematic diagram. (Refer to Figure 11-3)

Relative to the operation of this heat pump, when the DFR coil is energized:

A. A circuit to a Heating Coil 1 would not be allowed if Outdoor Thermostat 1 was closed.
B. The Reversing Valve Solenoid will continue to be energized.
C. The Outdoor Fan Motor will not operate.
D. The Indoor Fan Motor will not operate.

We’ll provide the answer to this question in the next segment.
Figure 11-3
PART TWELVE

UNDERSTANDING COMPRESSOR MOTOR WINDINGS AND INSULATION

(Note...Before we begin this segment, want to mention that the correct answer to the last question posed in Part Eleven is “C”.)

In addition to having a good grip on the fundamentals of schematic diagrams, what the symbols really mean, and how to incorporate that information into a nuts and bolts approach to electrical systems, technicians also need to understand other electrical issues related to HVACR equipment servicing...such as compressor motor windings. When evaluating compressors from an electrical perspective, it's one thing to know when the windings are “good” or “bad”, but it's another issue to understand specific failures... and potential failures. First, to lay the ground work on the core issues related to compressor motor windings and applying those skills (and general understanding of motor fundamentals), we'll ask a question related to Figure 12-1.

When testing the motor shown here with an ohmmeter, assuming that it is not overheated:

A. The highest reading will be between terminals “C” and “R”
B. The highest reading will be between terminals “S” and “R”
C. The lowest reading will be between terminals “C” and “R”
D. Both B and C are correct answers

The thing to consider here is that this question, while it isn't asking for specific numbers, it is asking about a general understanding of the types of motors used in HVACR compressors. And, one of the general rules that apply relative to compressor motor windings is that the start winding will have a higher resistance that the run winding. Now, it may be significant difference in some cases, such as the start winding having a resistance of, say, 8 Ohms, and the run winding having
a resistance of only 2 Ohms. Or, it’s also possible that the difference between the two isn’t that great. Perhaps the start winding may be 2.5 Ohms and the run winding only .8 Ohms. Whatever the specifics are relative to the design of the compressor, it doesn’t change the fundamental rule that allows you to choose the correct answer to this question, which is “D”.

By the way, did you note the caveat in the question; the mention of the fact that it wasn’t overheated? When a technician has, as we said, a good grip on the fundamentals, that mention of the condition of the compressor temperature-wise is exactly what would be expected. Why? Because a good grip on the fundamentals means that the symbol inside the compressor identifying a temperature-sensing internal overload protective device could be a factor, so its condition (relative to the question) could be a consideration. But…what if the person writing the particular question didn’t even mention the internal overload? How would that change our approach to handling that question? To put it simply, it wouldn’t, because we would have an understanding of the normal position of that device (closed unless excessive temperature caused it to open), meaning, that if it wasn’t mentioned, we could safely assume that it is in its closed position and not a factor in the question.

With that understood, here’s our next question…. (Refer to Figure 12-2)

![Figure 12-2](image)

The condition of this compressor would be described as:

A. Good  
B. Open  
C. Shorted  
D. Grounded

Next question, referring to Figure 12-3.
The condition of this compressor would be described as:

A. Good  
B. Open  
C. Shorted  
D. Grounded

And, one more question, referring to Figure 12-4.

The condition of this compressor would be described as:

A. Good  
B. Open  
C. Shorted  
D. Grounded
OK...we’ve exaggerated the drawings a bit, but we did it to make a point. These three questions, with a firm understanding of the fundamentals of compressor motor windings from a nuts and bolts perspective, are simple to answer.... “B”, “C” and “D” respectively. Of course, what follows relative to applying a fundamental knowledge of the electrical characteristics of compressor motor windings, is the proper use of test instruments. In Figure 12-5, for example, we’re showing a particular make and model of digital multimeter. When this meter is set to check compressor motor windings, the reading in the display will default to “OL”, like many digital meters do when they are set to an Ohm’s setting and ready for use. So, if we were then applying this information to Figure 12-2 as....

![Digital Multimeter](image)

**Figure 12-5**

In this situation, a digital ohmmeter meter display, when testing between the “C” and “R” terminals, would show:

A. A lower resistance than the start winding  
B. The same resistance as the start winding  
C. The total resistance of both windings  
D. OL  
The answer to this question will appear in the next segment
PART THIRTEEN

MORE ON COMPRESSOR MOTOR WINDINGS AND INSULATION

(Note...before we begin this segment, we want to mention that the correct answer to the last question posed in Part Twelve is “D”.)

In the last segment we covered the fundamentals of testing motor windings with an ohmmeter to determine the electrical condition of a compressor. In this segment, we’ll take a look into the basics of motor winding insulation, another factor that technicians undertaking NATE certification need to know about. It’s common to hear comments such as “It’s a burnout”, or “The motor cooked”, or even “It overheated and burned out” about electrically failed compressors. And, certainly, if you were to conduct an autopsy on, say, a hermetic compressor by grinding off the weld and taking the top off, you may see the copper wiring of a motor winding that has been affected by severe heat. However, a factor to keep in mind about this kind of failure is that the root cause of the situation often isn’t related to the wire of the winding, but to the insulation of the winding.

On the surface, this might seem like an obvious point-of-view to consider when evaluating refrigeration system failures, but it’s important to have a good grasp of the subject since the wire of a winding is often not destroyed, but the insulation is almost always compromised in an electrical failure situation. Since the job of the insulation is to prevent the current that’s running through the wire from “leaking” to ground, or to a short-out situation, when the resistance of the insulation is compromised, that’s when you get this kind of failure. And the integrity of insulation can be tested when measured with a megohmmeter.

As with other electrical test equipment, there are a wide variety of megohmmeters available on the market. Older devices in this category include a type that uses a manual crank that, when turned, create the necessary high-voltage, direct current supply needed to test motor winding insulation. Newer devices can use batteries to accomplish the same task. Figure 13-1 shows you a typical design of a low-cost, basic megohmmeter that employs two leads, one for connection to an electrical terminal and the other for connection to ground. (When testing with a megohmmeter, always disconnect all electrical wiring from the compressor terminals.)

By comparison, measuring resistance of a motor winding (the wire itself) with an ohmmeter will often yield results a few ohms, or maybe even a fraction of an ohm in some situations. But a megohmmeter, as the term indicates, measures on a scale of millions of ohms (in many cases up to 1,000 megohms). And, in some cases, megohmmeters generate up to 1,000 volts when performing an insulation resistance measurement.

With some of the fundamentals of motor winding insulation evaluation understood, here’s a question for you to consider:
In general, what type of reading would you expect from a megohmmeter if the insulation of a winding was in excellent condition?

A. 20 to 60 Megohms  
B. 60 to 100 Megohms  
C. 100 to 150 Megohms

The correct answer to this question is “C” when you consider it from the perspective of “the more resistance to ground, the better”. The logic that follows, here, then, is that in general terms, a reading of 60 to 100 Megohms would indicate that there is some decline in resistance. And that a 20 to 60 Megohm reading would be an indicator of an impending failure of the insulation, possibly due to contaminated oil or moisture in the system.

However, keep in mind that the information we’re presenting here is, as we said in the question, “In general.” If you check with a particular manufacturer for specific information regarding the readings you should (or should not) get with a megohmmeter, you may get different information. For example, Copeland, recommends that when a 0.5 to 20 Megohm reading is shown on its installed and running compressors, it’s an indicator that the refrigeration system requires a
clean-up involving changing the compressor oil and replacing the filter-driers. Copeland also states that a reading of less than 0.5 Megohms indicates failing insulation requiring compressor replacement, while a reading of 20 to 50 Megohms indicates that the compressor winding insulation is OK.

Another factor to keep in mind about megohmmeter readings is that a lower-than-recommended reading doesn't always indicate failing insulation. Things like current leakage through electrical Fusite connections or terminal plates are other possibilities to be considered. Also, when using a megohmmeter to accomplish an insulation resistance test, keep in mind that a one-time reading, while it may give you a certain level of information, may not be all you need to do. In consideration of a regular preventive maintenance and inspection program, making an initial test, then setting that information as a benchmark, and then regularly testing again and again over time (making sure that the compressor operating temperature is the same since readings can vary with temperature change), will give you an accurate evaluation of the integrity of the motor winding insulation.
One of the goals of a technician certification process is to ensure that technicians working on equipment will be able to accomplish their tasks of evaluation and diagnosis with as few mistakes as possible. And, when it comes to measuring the technician's understanding of electrical systems, the ability to analyze a schematic diagram and use it as a troubleshooting tool is an integral element of that process. So, what we're going to accomplish in this NATE information segment is to review a simplified schematic diagram step-by-step. (See Figure 14-1).

In this illustration, we've simplified a typical diagram for a walk-in cooler that uses a remote condensing unit. In the process of simplifying it, we're showing
only the motors themselves with no special start devices or capacitors, and we’re showing a simplified control system that is electrical in nature. In many cases, pressure-sensing devices are used to control commercial refrigeration systems, and we’ll get to those in a subsequent segment…but first we’ll focus on the electrically-controlled system. Starting at the top of the diagram, we’ll explain the symbols and labeling.

1. First, in understanding any electrical system, the power source must be identified because that is the basis for tracing all electrical circuits, and ultimately accomplishing troubleshooting and diagnosis. The identifiers ―L1‖ and L2‖ represent the fact that this is a 240-volt single-phase power supply. We know it’s not a 120-volt system, which would have either shown ―L1‖ and “N” as the identifiers, or would have indicated the voltage as being 120 in the labeling.

2. ―CFM‖, shown in a circle represents the Condenser Fan Motor. In most cases, this type of motor is a PSC-type, meaning it uses a run capacitor wired in series with the start winding (yes, we said that right, it’s not a typo…we’ll get more into that detail later) in order to promote a more efficient operation. But, as we mentioned, we’re simplifying this diagram as much as possible to explain the fundamental components.

3. “COMP” which is shown directly below the condenser fan motor, is, of course, the system compressor. Since we have a bit more space with this symbol, we’re showing some of the actual electrical construction of a motor by representing the windings within the circle. Either type of symbol, lettering only inside a circle or schematic symbols, are standard industry practices for identifying components.

4. On the top line of our ladder diagram you’ll see the identifiers “C1” and “C2” which represent one segment of a contactor. These normally open contact points will only close when the other segment of the contactor (which we’ll discuss shortly) is energized. These are the types of contact points that will become blackened with a carbon build-up due to arcing. Often, inexperienced technicians note the pitting and discoloration and think that they need to file the contact points in order to promote a good connection when they close. And, when they take this approach to preventive maintenance, they wind up ruining a contactor. The contact points are coated with a silver or silver-oxide material that is designed to carry electrical current without sustaining damage. But, that doesn’t mean that the material won’t discolor. And, what the filing does is actually scrape off the thin silver surface, which shortens the life of a contactor. So the rule here is “don’t file the contact points, but if they’re damaged to the point where they’re pitted, the contactor needs to be replaced.”
5. The “EFM” is the evaporator fan motor located inside the walk-in cooler cabinet. Up till now, we’ve been describing components that are located on the roof or near the building on the ground, but with this symbol, we’ve moved into the cabinet. Like condenser fan motors, this one is also usually a PSC motor.

6. On the same line with the evaporator fan motor, and wired in series with it, you’ll note a set of normally open contact points, labeled “R1”. This represents one segment of a relay that is used to control the operation of the evaporator fan motor. Like the contactor, there’s another segment to this relay that we’ll discuss shortly. The relay itself is likely going to be located in a control box found on the side of the walk-in cabinet.

7. “CCH” is shown on the next line down on our ladder, and with this symbol we’ve moved back outside the building. This symbol and identifier represents a crankcase heater that is either attached to or integrated into the compressor. The purpose of this device, as its name indicates, is to keep the compressor crankcase warm. With the compressor sitting outside, refrigerant can migrate to the crankcase in lower ambient temperature situation when the compressor is cycled off. And if that were to happen, it would mean that there would be liquid refrigerant sitting in the compressor crankcase that, on start-up, which would cause the oil in the crankcase to foam. To prevent this bearing lubrication problem, the crankcase heater is used to keep the compressor temperature up, thereby preventing the migration of refrigerant.

8. “C3” is shown wired in series with the crankcase heater, and you’ll note that these are normally closed contact points. Another segment of the contactor, these contact points will remain closed until the contactor coil is energized. So, what we’ve identified so far in regard to our contactor is that two sets of contact points (C1 and C2) are normally open and one set (C3) is normally closed.

9. The transformer symbol is next. As the heart of the dual-voltage schematic diagram, one winding is shown connected to the L1 and L2 power supply, and a second winding is shown as being a power supply. That’s why we refer to it as a step-down transformer. While 240-volts is applied to the primary winding, 24-volts is being created to provide the control circuitry that involves the components shown in the lower segment of the diagram.

10. The letter “R” shown in a circle is next, and it represents the coil of the control relay, whose contact points are wired in series with the evaporator fan motor and shown on the upper segment of the diagram. There’s a correlation between the “R” shown in the circle below and the “R1” contact points. Even though these two identifiers are shown far apart, they represent one component....the evaporator fan relay. With 24-volts applied to the relay coil,
the contact points will close and the circuit to the evaporator fan motor will be complete.

11. The letter “C” is shown below on the next line and it represents the contactor coil. With the coil energized with the 24-volt control voltage in this electrical system, two things will happen. First, the normally closed contacts wired in series with the crankcase heater will open, and second, the normally open contact points will close, creating a complete circuit to both the compressor and condenser fan motor. Like our evaporator fan relay, even though the identifiers are shown far apart on the diagram, they represent one component.

12. Of course, what we described in 10 and 11 takes place due to the operation of the thermostat, which is also shown on the lower segment of our diagram. On a call for cooling the thermostat closes, completing the circuit to the coils, which turns off the crankcase heater while at the same time turning on the compressor, condenser fan motor and evaporator fan motor.
PART FIFTEEN

A CONTINUING LOOK AT THE ELECTRICAL SIDE OF REFRIGERATION EQUIPMENT

In our last segment, we walked through a simplified schematic diagram in a step-by-step process. The purpose of that exercise was to begin to lay a foundation for the development of testing, evaluating and, ultimately troubleshooting some common electrical components. To get us started, we’ll take a look at some fundamental relays and a contactor, all of which we’re showing in Figure 15-1.

In this illustration, we’re showing a picture of the components as they appear, as well as an electrical illustration of them so we can explain how they operate. First, let’s consider the relay shown at the left of the illustration. This is the simplest type of relay you’ll see on commercial equipment and it can be used for a variety of tasks such as operating a fan motor or controlling a circuit to a solenoid valve. We say it’s the simplest type of relay because it only contains one set of normally closed (N.C.) contacts and one set of normally open (N.O.) contacts. Which means that any circuit that is introduced at terminal #1, will leave either on terminal #2 or #3, depending on what is going on with the relay coil at the moment. The coil, which is often operated on a step-down voltage circuit
(although it may also be operated on line voltage) is shown without any terminal markings. In some cases this may be the case, while in other cases, a particular relay manufacturer may assign numbers to the coil connections also. Whatever the case, troubleshooting this type of relay is fundamentally nothing more than using an ohmmeter to check three things:

1. Resistance of the coil.
2. Continuity between 1 and 3 when there is no voltage applied to the coil.
3. Continuity between 1 and 2 when there is voltage applied to the coil.

We want to point out that we were very specific in using the terms “resistance” and “continuity.” While some technicians lump the two terms together under the same definition, they are two very different concepts. When checking a load…something that does work when electrical energy is applied to it…the term resistance applies. When checking a switch….something that does no work but either allows or interrupts current flow in a circuit…the term continuity applies.

Which means, that in a situation in which a technician finds a fan motor that isn’t running, and this type of relay is used to control its operation, some simple tests of the relay could identify or eliminate it as the source of the problem. (Testing, for example, at the coil terminals to see if voltage is being applied.) If so, the next step is to determine if the current that is entering on terminal #1 is leaving on terminal #2 (as it should be if the coil is energized). If the answer to the first question was yes (voltage applied to the coil) and the answer to the next question was no (current leaving on terminal #2), then we just found out that the reason the fan motor isn’t operating is because the control relay isn’t doing its job and allowing current flow through the fan motor circuit.

If we were to get a no (no voltage at the relay coil) result on our first check, we would have to find out why there was no voltage to the relay coil rather than why the relay switch contacts aren’t allowing current flow. You might, for example, find a set of timer contacts or a bimetal switch wired in series with the relay coil, so they could be the source of the problem. Or, in the case of using a step-down voltage for control, the transformer itself could be the reason the fan motor isn’t operating.

Another factor to consider relative to this type of relay is the N.C. set of contact points. They may be used to control the operation of a solenoid valve that redirects refrigerant flow in a hot gas defrost system, or to control a liquid line solenoid in a refrigeration system equipped with a pump-down feature. Whatever the use of the N.C. terminals, the troubleshooting procedure is the same as working with the N.O. contact points. If voltage is applied to the coil, then the switching contacts should change from their “at rest” position to the opposite position.
Moving on the relay shown in the center of our illustration…..

This relay could be used as a replacement for the first relay. After all, a set of contact points is a set of contact points, and a coil is a coil. It doesn’t matter whether or not you use all the contact connections in a given relay. So, if the coil voltage was a match between the two relays, you could use terminals #1 and #2 for a normally closed circuit and terminals #1 and #3 for a normally open circuit. While it’s true that we’ve reversed some numbers in comparing the two relays (in our first example, 1 to 3 is normally open while 1 to 2 is normally closed) that doesn’t matter as long as you understand what the relay is supposed to do and how it’s wired into the circuit from a schematic standpoint.

Often referred to as a 90-340 series relay with the last number being an 0, a 1 or a 2, this type of relay is popular with equipment manufacturers because it’s available in coil voltages of 24, 120 or 240. And, often, it’s used in exactly the same manner as the first relay, which means that often a lot of the terminals are not even used. And, another factor for you to consider relative to this type of relay is that there is no correlation whatsoever between the 1,2, 3 set of contact points and the 4,5,6 set. Which means that a manufacturer may decide to use that second set of contact points for an entirely different purpose. Actually, this type of relay could be used to control the operation of four loads, if two of them were to be operated when the coil of the relay was energized and two of them were to be operated when the coil of the relay was de-energized.

From a fundamental troubleshooting/service perspective, dealing with this type of relay, no matter how many loads it controls or how many terminals are not being used, it’s the same as for the first relay. The coil should show some resistance when checked with an ohmmeter (usually fairly low…around 12 to 20 ohms) and the contact points should show either continuity or infinity, depending on their Normal position and whether or not the coil is energized.

And, now on to the last component in our illustration, which is often considered to be the simplest of the three. A contactor functions in the same manner as a relay, using contact points and a coil, but there is no N.C./N.O. issue to consider. The contact points of a contactor, such as the one in our drawing, are always Normally Open, closing when the coil is energized.

One of the differences between a contactor and a relay is that while the contact points of the relay are not visible, the contact points of a contactor are. Which sometimes leads to problems…..

As we mentioned in the March issue, since the contact points of a contactor are exposed and a technician can actually see them make and break when the coil is energized, then de-energized, it’s tempting to want to “clean” the contact points because they look burnt. Well, they do look burnt, because, to a degree, they are. Whenever two contact points come together to carry current
across their surfaces, there will be some spark and arc, which will lead to a build-up on the contact surfaces. However, just because the contact points of a contactor look like they’re burnt, they shouldn’t be cleaned with a file or emery cloth.

The reason they shouldn’t is because cleaning them will remove the very thin silver coating on the contact point surface, and they will fail altogether very soon after they’ve been cleaned. The best way to evaluate a contactor that is being used to control the operation of a high-current draw load, such as compressor, is to do simple voltage drop test across the contact points. Check the voltage coming into the contactor at L1, L2, and if, applicable because you’re working on a three-phase unit, L3 (the Line side of the contactor) and one other line connections. Once you’ve read and recorded that voltage, move down to the Terminal side of the contactor and read voltage between any two of the connections. If the voltage drop is only a couple of volts, then the contactor is OK. If the voltage drop is excessive, (usually more than 5 volts) then the contactor should be replaced.

Another way to check a contactor is to disconnect the Line and Terminal wiring connections, then energize the coil with the appropriate voltage. If when checking from L1 to T1, L2 to T2 and L3 to T3, the reading on your ohmmeter is less than one-ohm resistance, the contactor is OK. If the resistance exceeds one ohm, the contactor should be replaced.
One of basic things taught in an HVACR training program is that any refrigeration system, no matter what the application, will have four basic components that accomplish the two things a system needs to do in order to function….change of state and maintain a pressure differential…..and of course, those four components are the compressor, condenser, evaporator and metering device. Beyond those basic four components, however, are other “refrigerant control devices” that assist the refrigeration system in its task of accomplishing the transfer of heat from a place where it’s not wanted to a place where it doesn’t matter, as efficiently as possible. We’ll begin with the suction line accumulator….refer to Figure 16-1.

In any refrigeration system application such as domestic refrigeration, package and split system comfort cooling systems, and commercial equipment such as walk-in’s and reach-in refrigerators and freezers, the compressor is designed to pump vapor, not liquid. And in a perfect world, that’s all that would
ever get into the suction line of the refrigeration system, causing the compressor to be protected from liquid slugging. However, there are such things as a dirty evaporator coil that would prevent the refrigerant from changing totally from a liquid to a vapor, a suction line accumulator can act, somewhat, to protect the compressor. While an accumulator can’t protect a grossly overcharged system, it is, in essence, a storage tank for refrigerant on the low-pressure side of the system.

Domestic refrigerator evaporators have them, and they appear as a segment of the evaporator. Room air conditioners also have them, and they will appear as a separate item in the piping of the suction line very near to the compressor. The room A/C accumulator appears more like those that you’ll find in commercial refrigeration systems, but there’s still another step up. As you can see in our illustration, in addition to the flow of refrigerant into the accumulator and an outlet at the top showing vapor flow to the compressor, there are a couple of additions to this particular example.

Note that there is what’s referred to as a heater coil wrapped around the body of the accumulator and that the condition of the refrigerant is this coil is identified as “Hot Gas.” The place where the “Hot Gas” comes from, of course, is from the condenser of the system. In commercial applications, manufacturers often allow a pass of the discharge line of the compressor to be fastened to the accumulator body. This heat exchanger (much like the heat exchanger that is made up of the capillary tube fastened to the suction line in a domestic refrigerator) ensures that any liquid refrigerant in the suction line will have some ‘work to do’ because of the heat being introduced, and completely change in state to a vapor. Another feature found on commercial equipment accumulators but not on domestic systems such as room A/C’s is the oil return line located at the bottom of the accumulator.

Remember, in any refrigeration system there is a certain amount of oil that travels with the refrigerant, and in commercial equipment, this is going to be a higher volume of oil than that found in a domestic equipment. Because of that, commercial refrigeration system suction accumulators are often equipped with an oil return line that allows easy flow of oil back into the crankcase of the compressor. Getting it directly into the crankcase is much more efficient than trying to get oil to flow into the suction side of the compressor, then be dealt with through the suction valves in a piston compressor or the rotary vane of a rotary-type compressor.

And now on to another accessory…..the receiver.

In some of the smaller refrigeration systems such as those in reach-in refrigerators or soda vending machines, the receiver will have an inlet at the top and an outlet at the bottom. In larger units, however, the receiver can appear differently because is uses a dip tube design, such as the one we’re showing in Figure 16-2.
In this illustration, we’re showing the receiver in a horizontal position, which is a common method of positioning by some manufacturers. In some cases, however, the receiver isn’t a horizontal type. Instead, it’s a vertical mount, such as we’re showing in Figure 16-3.

Whatever the position, the purpose of the receiver is to act as a storage tank on the high-pressure side of the system. In TXV systems, for example, we
have to put that extra refrigerant that we’re not using in a low heat load situation somewhere, and the somewhere is the receiver. Another use of the receiver on a commercial refrigeration system is to allow an automatic system pumpdown, or for a manual pumpdown of refrigerant during a service procedure. One other variable you might see relative to receivers in commercial equipment is that they may be equipped with a sight glass so you can check the liquid refrigerant level. And speaking of sight glasses, we’re showing a typical one in Figure 16-4.

Before blended refrigerants that have a tendency to show their bubble point in the liquid line of the refrigeration system, the general wisdom regarding this accessory was that you should never see any bubbles at all in it, and if you did, it meant that the refrigeration system was undercharged and “needed some gas.” Well, that’s not always true.

In a situation in which there is a high heat load on a system, you’ll likely see bubbles in the sight glass on an initial start-up and probably even for several minutes after that. Also, a restriction in the liquid line before the sight glass is sure to create bubbles. And, since a sight glass is often used in conjunction with a filter-drier on the liquid line (which can become restricted with contaminants) a restricted system is often misdiagnosed as a system undercharge, when in fact, the solution to the problem is to solve the restriction situation.

From a troubleshooting and service perspective, when a technician overcharges a system with a receiver to a certain extent, the only indication is a slightly higher-than-normal pressure on both the high and low pressure sides of the system. In severe overcharge situations, however, the entire receiver can be full of liquid. The bottom line on this situation is that if a technician understands the concepts of superheat and subcooling, they won’t be mislead by bubbles in the sight glass and jump to the conclusion that they have to add refrigerant.

Another situation in which bubbles can occur in the sight glass is in the event of a sudden change in heat load in the middle of a cycle. Placing a quantity of warm food product that need to be frozen or chilled into a walk-in or display
case is a good example of this situation. You also need to consider the possibility that there has been a change in a head pressure control system that could dump hot gas into the receiver to build head pressure up to a point where it’s supposed to be. One example of this would be a low ambient control system on a condenser fan motor. If the condensing unit is located outside in a cold temperature, the low ambient control would break the circuit to the condenser fan motor to ensure that the high side pressure would stay up where it’s supposed to, maintaining a proper differential between the high and low pressure sides of the system. (After all, if the high pressure and low-pressure side of a refrigeration system are too close together, then the refrigeration process won’t be accomplished.) At the beginning of this head pressure rise due to stopping the condenser fan motor, there may be bubbles in the sight glass.

And, of course another use for the sight glass is to check on the possibility that there is moisture in the system. Manufacturers use a variety of colors to determine if a system is wet or dry (green, yellow, etc...) so you need to check the color code on the sight glass itself to determine whether or not there is moisture in the system.

This can be difficult in older systems since the colors printed on the sight glass body tend to fade. In the event that you can’t determine whether or not there is moisture in the system, monitor the high side pressure closely. If, without the introduction of any heat load changes, the high side pressure tends to fluctuate, that would be an indicator of non-condensibles in a system. And, if there are non-condensibles (air) in a system, it means that there is also moisture present. This situation usually occurs due to improper service procedures in which the technician doesn’t take the time to purge the hoses on their gauge set before adding refrigerant (which they may not have needed to add in the first place, but that’s a story for another book), and the end result is the introduction of non-condensibles into the system along with the added refrigerant. In a situation like this, your only quality service solution is to recover the refrigerant, install a new filter-drier on the liquid line and also add a drier on the suction line, evacuate to a proper level using a micron gauge (another subject for a later segment) and re-charge the system.
PART SEVENTEEN

MORE ON REFRIGERATION SYSTEM “ACCESSORIES”

In our last segment we discussed some of the components that are known as accessories in refrigeration systems. In this segment, we’ll pick up where we left off with accumulators, receivers, and sight glasses. While from a strictly engineering perspective, these devices are referred to as “accessories” (because they’re not one of the ‘basic four’ components of a vapor compression heat transfer system) they can, from a practical standpoint, be considered necessary to the optimum performance of a refrigeration system.

FILTER-DRIERS....

While domestic refrigeration systems used in things like household refrigerators, drinking fountains and the like will more often that not have only a liquid line filter-drier, it’s more common to find a filter-drier on both the liquid line and suction line in HVACR systems. This is largely due to the fact that there are more sealed system repairs done in the commercial arena than there are in the domestic segment of the market….major repairs that are the result of a compressor burnout….which is the reason the suction line filter-drier shows up more often. As far as the basic construction of either one, Figure 17-1 shows you what they look like on the inside.

One thing you’ll note about this illustration is that it shows an arrow indicating the direction of flow through the drier assembly. This is a simple, yet very important point to remember about any filter-drier. When the refrigerant enters the assembly in the proper direction, it is allowed to free-flow through before being forced through a more dense material at the outlet side of the drier. If, however, the drier is installed backwards, the refrigerant hits the more dense
material first, and the result is a restriction of flow. Of course, if you restrict the flow of refrigerant in any way, then provide an area for free flow, what you’re simulating is a metering device of some sort, then a kind-of evaporator. Which means that a filter-drier that is installed backwards will be acting like a little evaporator….cool to the touch, or maybe even frosting a bit. 

(By the way, from a troubleshooting perspective, if a liquid line drier starts to fill up with moisture and debris, it will also be cool to the touch because it is restricting refrigerant flow, so keep that in mind too. The drier doesn’t just have to be installed backwards to show the “cool to the touch” restriction problem.)

And, now on to the suction line filter drier. In order for you to get an understanding of how it compares to a liquid line filter-drier, we’re showing both of them (our liquid line drier being a bi-flow type found in some heat pump refrigeration systems) in Figure 17-2.

![Figure 17-2](image)

The one on the left is the suction line drier, and you’ll note when you look closely that it has two service ports on it that allow you to connect your gauges. These aren’t just access ports that serve as nothing more than a convenient place to connect gauges. The two ports are there so you can check for pressure drop across the drier.

Here’s a simple way to consider suction line filter-driers…

Most often, a suction line filter-drier is installed on a system in the event of a major repair, such as a compressor burnout. The reason for the addition of the suction line drier is to filter the vapor refrigerant and catch an acid that may be remaining, along with any solids. When the repair is first accomplished, the flow through the drier should be without restriction. However, soon after the system has operated for a while, the suction line drier, depending on how much acid (and other contaminants) are in the system, can begin to clog up. How do you
know? By checking first on the inlet side of the drier for an operating pressure, then check on the outlet side of the drier. A rule-of-thumb to apply is if the pressure drop is less than 2 PSIG, then the flow through the drier is OK. If, however, you get a pressure drop of more than 2 PSIG, it's time to shut the system down and either isolate or recover the refrigerant, and install a new set of filter driers.

The reasoning behind this is that the suction line drier is doing exactly what you expect it to do – catch contaminants – and protect the new compressor. If the pressure drop becomes too great, however, the refrigerant flow to the new compressor will be compromised. Remember, in any vapor compression system that uses a piston compressor, the compressor depends on a free flow of cool refrigerant coming back down the suction line to help keep it cool. If that flow is restricted, then the overall temperature and discharge temperature of the compressor will be higher than normal, which could lead to a repeat compressor failure in the equipment.

MUFFLERS....

A muffler is another accessory you'll see on a variety of HVACR systems. Figure 17-3 shows you the type commonly found on commercial equipment.

![Figure 17-3](image)

Commonly found on the discharge line of the compressor, it serves the same purpose as the ones used on domestic systems...to reduce compressor noise. However, on commercial equipment, there's one more caveat to keep in mind. In some cases, if a system is large, it may have a muffler on the suction side of the compressor as well. Sometimes mistaken for a suction line filter-drier without access valves, it will be located fairly close to the compressor.
CRANKCASE HEATERS....

(Yeah, this is an electrical component, but it serves to ensure the proper operation of the refrigeration system.)

If you've had any experience with servicing heat pump systems in residential or light commercial applications, you've likely seen a crankcase heater. It's an accessory that is designed to keep a compressor crankcase warm in order to prevent the migration of liquid refrigerant into the compressor on an off cycle. So, what that means is that whenever the compressor is off, the crankcase heater should be on. Figure 17-4 shows you a situation in which a hermetic compressor is fitted with an external crankcase heater.

![Diagram of external crankcase heater](image)

Figure 17-4

Other situations in which you'll find an external crankcase heater (in both hermetic and semi-hermetic compressors) is when the condensing unit of the refrigeration system for the walk-in, ice machine, reach-in, or whatever, is located in a cold environment such as just outside the kitchen. Another factor to keep in mind about crankcase heaters is that they can be in the form of something other than an external mount. In some cases (such as newer equipment), the crankcase heater is an integral part of the compressor assembly. In a well that is built into the compressor, the crankcase heater is inserted and the wiring is the only thing showing exiting the compressor case. Which means that if you're
replacing a compressor with an external heater with one that has an internal heater, all you have to do is hook up the appropriate wiring so the new heater will operate in the same way the original one did.

And, when it comes to the wiring of a crankcase heater system, a transformer is sometimes used to control its operation. Figure 17-5 shows you a simplified schematic of a crankcase heater control system.

In this segmented diagram, we're showing the compressor, along with an accompanying outdoor fan motor, and we're controlling the operation of both components with a set of normally open contact points. On the secondary side of the step-down transformer symbol that makes up the body of the diagram itself, we're showing the symbol for a contactor coil, which is controlled by a simple switch. In most cases, this switch is a temperature-controlled device (like a simple thermostat on a refrigerator) that calls for cooling.

On a call for cooling the switch is closed, providing a 24-volt circuit to the contactor coil. When the coil is energized, the normally open contact points close and compressor and condenser fan motor operate. But, the real story behind this diagram is what happens when the temperature-operated switch in the system is satisfied and the compressor and condenser fan motor turn off. Another set of
contact points (shown as C3 on the diagram) are identified as being normally closed. And, you'll note that they are wired in series with a component identified as CCH, which will be energized in an off-cycle, but then de-energized when the compressor is operating.

This is the most common method of controlling the crankcase heater in a commercial refrigeration system. However, in some situations in newer equipment, there may be some reason the manufacturer has chosen to keep the crankcase heater on when the compressor is running below a certain operating temperature. In these cases, you'll likely find a thermistor and printed circuit board type of control system that tells the crankcase heater when to be on and off.
STILL MORE ON REFRIGERATION SYSTEM ACCESSORIES

We mentioned in the previous segment that some of the so-called “accessories” found in refrigeration systems are really necessary for optimum heat transfer. The fundamental components we discussed were filter-driers, mufflers, and crankcase heaters. In this segment we’ll take a detailed look at two of the many different control valves that technicians need to know about relative to the fundamental operation of refrigeration systems…the EPR Valve and CPR Valve….both are designed to control the refrigeration system pressures in the event of temperature changes.

First, the Evaporator Pressure Regulator Valve….

The EPR valve is located on the suction line of the refrigeration system and refrigerant flows into it from the evaporator, then on into the compressor. The basic idea behind the operation of the EPR valve is to modulate the flow of refrigerant, thereby maintaining the correct pressure in the evaporator. As you know, temperatures affect refrigeration pressures, and if the temperature of a coil goes too low, then the pressure of the system could also drop to a lower-than-desired level. Figure 18-1 shows you an illustration of the EPR valve.

One of the applications of an EPR valve is a chilled water system, which you won’t see much of in restaurant equipment, but it helps to know this so you can gain a full understanding of the operation of the device. In a chilled water system, the critical factor is to prevent freeze-up, so a drop in coil temperature below a certain level is a critical factor in the proper operation of the system. So, the EPR Valve, since it’s piped in series with the refrigerant flow from the evaporator, can sense a drop in pressure, then adjust to slow the flow of refrigerant, which in turn keeps the pressure in the evaporator up to a proper level. All of which, as we said, keeps the evaporator temperature correct.

In some cases, you may find an EPR valve referred to as a “hold-back” valve since that is what it really does.”holds back” the flow of refrigerant. The basic design of the valve is that it consists of a bellows that is regulated by a spring pressure (adjustable. In the event that the pressure in the evaporator drops below what it’s supposed to be, the spring pressure serves to control the position of a seat disk, allowing either an increase of decrease in refrigerant flow. This is often critical during a start-up of a refrigeration system. When there is a high heat load on a start-up, the valve will remain wide open to allow maximum refrigerant flow, then will modulate down slightly when necessary as the heat load drops, and it will maintain the lower rate of flow until the system cycles off. On a new cycle, the valve will again open wide to allow maximum flow.
If you find yourself working on a commercial refrigeration system that has multiple evaporator coils, it’s likely that you’ll see EPR Valves in use. Figure 18-2 gives you an illustration of this application.

Let’s say that you’re dealing with a combination walk-in cooler/freezer that has to maintain a 40-degree environment for things like vegetables in the fresh-food section, but in the freezer section, it needs to be near zero for ice cream, etc… In that situation, you will often find two different evaporator coils, one compressor, and one refrigerant being metered to both coils in order to accomplish the refrigeration process. Common sense tells us that in order to maintain these two very different cabinet temperatures, the coil temperatures will be different, which would result in different coil temperatures. And, this would be a problem for the refrigeration system overall because the refrigerant would have a tendency to migrate to the lower-pressure coil, starving the higher-pressure one. The solution is to use an EPR Valve on each of the coils in the system. (Our illustration shows four separate coils, but the same concept applies to only two coils.)
As you can see, no matter what the varying pressures would be on the individual coils, the suction line pressure leading back to the compressor is always going to be maintained at 15 PSIG. This would be the case no matter what the individual evaporator pressure would be, either above or below 15 PSIG.

When adjusting an EPR Valve, you need to know what the design temperature of the cabinet is supposed to be, then apply the rule of thumb that the actual coil temperature would be 15-degrees cooler than that number. For example, if you had a coil in a cabinet that was supposed to be 40-degrees, then the actual coil temperature would be 25-degrees. That would mean you could use a temperature/pressure chart to plot what the refrigerant pressure was supposed to be, put your gauges on the system while it was operating, then adjust the spring pressure in the valve until the evaporator coil pressure was correct. In most cases, this process is accomplished (and doesn’t need to be modified later) at the time the system is installed. The problem, though, is that sometimes, someone servicing a system may try adjusting it to solve a complaint.
of “not cooling enough”….when in reality the complaint is related to something simple like a dirty coil.

And, now, on to the CPR (Crankcase Pressure Regulator) Valve....

This valve, shown in Figure 18-3, looks very similar to the EPR valve.

Like an EPR Valve, it has a means to adjust a spring pressure and control the flow of refrigerant through an opening, and it also has an inlet and an outlet. Look closely, though at the indicators that show the path of refrigerant flow, and you can see that when it’s piped into a system, it can be identified as a CPR Valve. While both valves are located on the suction line of the refrigeration system, their inlet and outlet piping connections are reversed. And another tip-off that you’re looking at a CPR Valve rather than EPR Valve is that it’s going to be
located closer to the compressor. In the situation in which an EPR Valve is used, it is located much closer to the evaporator coil.

The function of a CPR Valve differs from an EPR in that its job is to protect the compressor in the event of what’s known as a hot pull-down. For example, if a customer loads a reach-in with a lot of hot product, then there will be a severe heat load on the system until that product is cooled down. In these situations, the refrigerant returning to the compressor will be much more dense than under normal operating conditions. And, since a refrigeration system compressor is a constant volume pump, it won’t know it is being overloaded, and the end result could be a higher-than-normal current draw. Figure 18-4 shows you an illustration of a hot pull-down and what the CPR Valve is designed to do.
In this situation, we're showing a box that is experiencing a higher-than-normal return air temperature, which is causing the low-side pressure to be higher than it should be. For example, if this was a low-temperature display case for frozen items, the return air temperature would likely be near 10-degrees, which wouldn’t have an effect on the pressure. However, with our high heat load, the low side pressure is way up, and could cause the compressor to run for an extended period of time at an amperage draw that could damage it. The answer is the CPR Valve.

With the valve adjusted to throttle the higher pressure in the suction line, the actual pressure of the refrigerant delivered to the compressor will be lower, and the end result will be a normal current draw, which means that in order to adjust a CPR Valve, you can use a clamp-on ammeter.

To begin either that adjustment process, or to check the operation of this valve during a preventative maintenance procedure, determine what the current draw of the compressor is supposed to be by checking the compressor tag or the equipment manufacturer’s equipment manual. Keep in mind that the compressor should not operate at a current draw of more than 10% of its rated capacity during a hot pull-down.

For example, if the rated current draw of the compressor was 20 amps, then you should not be exceeding 22 amps under a higher-than-normal heat load in the box. If you experience a current draw of more than 10%, adjust the valve until your ammeter shows a safe level.

Understanding this process and the operation of the CPR valve is an important factor in understanding the fundamental operation of a refrigeration system that employs one. In the event that a CPR Valve is not adjusted properly, the end result could be a compressor failure. In situations in which your customer tells you that they have had more than one compressor replacement in a piece of equipment employing a CPR valve, check to make sure that it is properly adjusted.
PART NINETEEN

EVALUATING REFRIGERATION SYSTEMS

Technicians pursuing NATE certification and accomplishing core exams, as well as other exam areas such as Air Conditioning, need to apply their understanding of the fundamentals of refrigeration systems we’ve been discussing in this series to the concept of sealed system evaluation (in addition to the concepts of air flow and electrical systems, of course) in order to achieve a passing score. For example:

1. Which of the following could be responsible for the suction pressure in a comfort cooling refrigeration system being lower than normal?
   
   A. A restriction in a filter-drier
   B. A dirty outdoor coil
   C. A system overcharge
   D. A high heat load on start-up

When you look at this question from the perspective of understanding the fundamentals of a refrigeration system layout, along with the basic operation of a system related to refrigerant pressure, you can see where answers B, C and D shouldn’t be considered the correct answer. All three of the conditions presented in these answers would contribute to a higher-than-normal pressure in the system, which means that the best answer to this question would be “A”.

This question is, of course, related to troubleshooting, which is related to the ability to evaluate effectively….which, can only be accomplished with an understanding of refrigerants, temperature/pressure relationships and normal operating characteristics. This process, as anybody who’s been in the business for quite a while can tell you, is more of a challenge today than it was a couple of decades ago when for HVACR techs, green was mostly it for comfort cooling except for rare occasions when yellow (R-500) was used by a manufacturer here and there, white (R-12) for certain refrigeration equipment (or, on rare occasions, for very old comfort cooling systems that were still operating), and orchid (R-502) if there was some servicing to be done on low-temp equipment such as an ice machine. Those days are gone.

The veritable plethora, as W.C. Fields would likely have opined, of color codes for virgin refrigerant drums is now beyond simple memory recall and on to double-checking a listing and the print on the drum…..what used to be just a “green drum” can be either “Light Green”, “DOT Green”, “Whitish Green”, or “Lime Green” depending on whether you’re working with R-22, R-124, R-402b, or R-407a. And, of course it’s not all CFC’s (Chlorofluorocarbons) and HCFC’s
Hydrochlorofluorocarbons) any more; there’s the new HFC’s (Hydrofluorocarbons) to replace the first two types that contain chlorine.

Another factor thrown into today’s technical mix is the difference between a single-compound refrigerant and those that are made from a combination of compounds, known as blends. The most familiar examples of single-compound refrigerants are R-12, R-22 and R-134a. The difference between the two can be seen in a comparison with temperature/pressure charts.

The single-compound refrigerant T/P chart illustrates the idea that a refrigerant of this type will boil at a set temperature at a given pressure. Blends, on the other hand, are subject to temperature glide, meaning the range of temperatures over a constant pressure that occur during the change of state, and the two terms that represent this situation are bubble point (a liquid temperature column) and dew point (a vapor temperature column). From a practical standpoint, these two temperatures are used to determine two factors in refrigeration systems: Dewpoint for superheat calculations and bubble point for subcooling because dew point is referred to as the point in the evaporator at which the refrigerant liquid has completely changed in state from a liquid to a vapor, and bubble point is the point in the condenser at which the refrigerant vapor has changed completely to a liquid.

One way in which manufacturers of refrigeration components and test equipment are helping technicians sort out the ever-expanding refrigerant situation is by offering up their own version of temperature/pressure (T/P) charts that list various refrigerants.

In the same way that technicians servicing simple capillary tube metering device systems understand that evaluating the refrigeration system in a refrigerator entails consideration of proper air flow through both the evaporator and condenser coil before assuming the poor performance is related directly to things like an undercharge, restriction, or inefficient compressor, Sporlan, for example, mentions factors such as coil icing, or poor air flow that need to be eliminated as possibilities before the refrigeration system itself can be blamed. Of course, since a TXV is a more complex metering device than a capillary tube, and the systems it is used on will often employ a variety of accessories to accomplish the refrigeration process, so there is a wider range of component failure possibilities and possible installation problems.

When considering evaluating a specific type of refrigeration system such as a comfort cooling application via “rules of thumb”...such as adding 30-degrees to the outdoor ambient in a standard efficiency, air-cooled condenser system or adding 20 degrees in the case of a high efficiency unit to calculate what the high side should be.... it’s best to understand that this method of determining system performance is best accomplished when operating conditions are what manufacturers would refer to as stable. For example, when checking a split system for proper refrigerant charge and operation, it’s best if the ambient is at
least 95-degrees, and the indoor temperature is near 75-degrees with a relative humidity of approximately 50 percent, and there is proper air flow through both the indoor and outdoor coils.

However, stable or “ideal” conditions don’t always exist. If the outdoor ambient isn’t high enough, steps would need to be taken in order to get as close as possible to stable conditions.

Assuming the ambient rather than actually checking the temperature of the air flow into the outdoor coil would lead a technician astray. The concept here is that if the outdoor ambient isn’t high enough for stable conditions, a technician could block the air flow over the outdoor coil to simulate the 95-degree ambient and add 30-degrees to 95 in order to calculate a 125-degree condensing temperature, which would convert to 278 PSIG on an R-22 T/P chart.

Beyond the rule-of-thumb approach, manufacturer’s charging charts and specific data can be used to evaluate refrigeration system performance.

Most charts of this type are structured with the diagonal lines, representing various wet-bulb temperature readings of the air entering the indoor coil and a listing of outdoor temperatures along the bottom, and one chart is used for a low pressure side evaluation, while a different chart is used for a high pressure side evaluation. A complete evaluation of a system using charging charts and data would include measuring suction and liquid line temperatures, and calculating superheat and subcooling.
PART TWENTY

CERTIFYING ON GAS FURNACES

Technicians who have already accomplished Core certification under NATE may consider certifying in the specialty of gas heating equipment. Under this heading, NATE offers a certification exam: Gas Furnaces, Residential/Light Commercial Service Technician. As with any NATE certification exam, there are the core elements to consider along with understanding the specifics of gas furnace operation from a fuel-burning, mechanical, and electrical perspective. For example, consider this question:

With the access door removed from a properly operating gas furnace (power supply remains connected), what voltage reading should a technician get when checking across the door interlock switch terminals with a voltmeter?

A. 0-volts
B. 24-volts
C. 120-volts
D. 230-volts

From a core and a specialty perspective, the fundamental rule of “voltage can be read across an open switch”, along with reading carefully….“a properly operating gas furnace…..” will point you in the right direction and ultimately provide the answer to this question. (See Figure 20-1)

In this diagram, we’ve identified the door interlock switch by understanding the idea of a schematic symbol and its identifying marker. The ILK switch shown at the top left of our diagram, wired directly to the L1 side of the line, is the access door switch mentioned in our question. You’ll also note that we’re showing one of the test points indicated in our question with a bright pink mark at one side of the switch, directly at the L1 connection. And that’s only one half of what needs to be understood relative to this question. The other half is related to the blue line, which is shown with a “beginning” point directly at the other terminal connection on the ILK. (Note the directional arrows on the blue line)

While our arrow indicators on the blue line in Figure One do not show a current flow in this situation (after all, nothing is operating here with the access door removed), they do, since our objective is to understand where, in essence, the second meter lead connected to the ILK terminal is actually reading, explain how to arrive at the correct answer. When you begin following the blue line at the ILK terminal connection, trace it on through the primary of the transformer, continuing on through our highlighted line, and ultimately ending up at the L2 connection to the furnace, you understand that the correct answer to our question is “C”.


NOTES:
1. COMMON SIDE (SEC-2 AND C) OF 24V AC TRANSFORMER CONNECTED TO GROUND THROUGH THIS MOUNTING SCREW.
2. IF ANY OF THE ORIGINAL EQUIPMENT WIRE IS REPLACED USE WIRE RATED FOR 105 C, OR EQUIVALENT.
3. INDUCER AND BLOWER MOTORS CONTAIN INTERNAL AUTO-RESET THERMAL OVERLOAD SWITCHES.
4. BLOWER MOTOR SPEED SELECTIONS ARE FOR AVERAGE CONDITIONS. SEE INSTALLATION INSTRUCTIONS FOR DETAILS ON OPTIMUM SPEED SELECTION.
5. USE COPPER WIRE ONLY BETWEEN THE DISCONNECT SWITCH AND THE FURNACE JUNCTION BOX.
And here’s a simplistic re-cap as to why it’s the correct answer:

1. One lead of the meter is connected to the L1 side of the power supply when touched to one terminal of the ILK.
2. The other lead of the meter, when connected to the other terminal of the ILK, actually reads all the way to the L2 side of the power supply.
3. The reason #2 is true is because this is not a situation in which there is current flow through the transforming winding. It’s only acting as a wire (OK, a very long wire, but still just a wire) in this case, simply providing an avenue through which the voltmeter can read a potential difference; the energy that is available to this circuit.

Of course the same fundamental rule we applied about voltage being read across and open switch, once it is understood, would be the basis for answering the following question:

With the access door removed from a properly operating gas furnace (power supply remains connected) and the door interlock held manually in a closed position, what voltage reading should a technician get when checking across the door interlock switch terminals with a voltmeter?

A. 0-volts
B. 24-volts
C. 120-volts
D. 230-volts

A similar question….we even have exactly the same choices….but a very different answer. In this case, with the door switch in a closed position, the correct answer is “A”. Figure 20-2 shows you why.

With the ILK closed, there is current flow from the L1 (Hot) through the switch and on to the PR-1 connection on the transformer. And, with this current flow now passing through the transformer winding, and the L2 (Neutral) connection to the PR-2 connection, the place to read voltage now would be directly at the two transformer connections. However, trying to get a voltage reading across the two terminals of the ILK in this situation would be the same as trying to get a voltage reading by simply touching both leads of a voltmeter to the L1 and PR-1 connections. It wouldn’t be there in the same way it wouldn’t if you were to bare two spots two inches apart on a current-carrying wire and then try to read voltage at those two points.

The two questions we’ve raised here also make a simple point relative to test-taking skills and understanding fundamental concepts. If you’re sitting there sweating bullets and passing an exam, and your nervousness is clouding your ability to think straight, consider that two of the answers in our choice list are so
far off the mark, they are immediately out of the running. First, "D"….in a gas furnace in a residential/light commercial application, we wouldn’t even consider 230-volts since all that equipment will operate on 115-volts, or 120-volts, however the manufacturer would choose to list the equipment voltage. The other answer "B" is another one not to be bothered with since it’s the secondary side of the transformer, which has nothing to do with equipment voltage, but with the control voltage instead.

![Figure 20-2](image)

With two of the answers eliminated as possibilities based on obvious facts, you will only have a 50/50 decision to consider. And with some of the pressure off, it will be easier to relax and recall the fundamental principle behind open and closed switch contacts.

Here’s one more question:

In the sequence of operation of the gas furnace shown in Figure 20-3, the IDM starts:

A. with a call for heat from the thermostat
B. when the burner flame is established
C. if the pressure switch proves
D. when a limit switch opens
Figure 20-3

We'll provide the answer to this question in our next segment.
PART TWENTY-ONE

MORE ON CERTIFYING ON GAS FURNACES

Note….the correct answer to the final question in Part 20 is “A”.

In our last segment, our focus was on some of the electrical fundamental processes technicians need to understand to be successful in becoming NATE certified on gas furnaces. In addition to the electrical side of gas furnace maintenance, troubleshooting and repair, technicians also need to know about the fundamental process of combustion systems related to servicing this type of equipment. To begin, we'll present a simple approach to the idea of combustion, that it is simply a process of chemical change, sometimes referred to as the “rapid oxidation of fuel.” Figure 21-1 shows a simplified illustration of the concept of oxidation.

![Figure 21-1](image)

What we're illustrating here is a universally understood concept that in order to get fuel to burn, we need oxygen. To have a complete understanding of combustion, though, a technician needs to recall the third element that is necessary for this process to be accomplished. For example, in the form of a question....

Which combination is necessary to accomplish the combustion process?

A. Fuel, Hydrogen and Ignition  
B. H2O, Fuel and Ignition  
C. Air, Fuel and Ignition  
D. Nitrogen, Oxygen and Fuel

....to which the correct answer is “C”, we are offering up information on the third component necessary, which is heat. Heat, of course, can be in the form of a glow coil or spark igniter, or in a pilot flame. Of course, it’s the oxygen in the air (air is 20.91% oxygen, leaving 79.09% of it to be nitrogen and other chemicals) that actually allows for combustion to be accomplished, and while the only real
answer to this question doesn’t have the term “oxygen” in its list, the commonly held understanding that oxygen is a part of air will lead you to the correct answer. (By the way….it’s also common to refer to the make-up of air as “about 21% oxygen and 79% nitrogen.) The reasoning behind the correct answer to this question is that the oxygen in the air is the only part of the air that is consumed.

Here are two other factors to consider regarding the idea of combustion actually being a process of chemical change:

1. The carbon in the fuel unites with the oxygen, forming carbon dioxide.
2. The hydrogen in the fuel unites with the oxygen, forming water vapor.

At least from the theory of perfect combustion that’s how it is. (See Figure 21-2)

![Figure 21-2](image)

In this illustration, we’re showing that the fuel (natural gas in this case) when combined with oxygen from the air (along with ignition) will result in a flame, which will result in carbon dioxide and water. This illustration also makes the case for being familiar with identifiers that are employed to explain the various chemicals in the combustion process.

An important point to remember from a nuts and bolts perspective about the combustion process is that we won’t be able to achieve that in the field, which means a technician needs to be familiar with carbon monoxide. Consider this question:
Carbon monoxide is identified by the symbol:

A. CO2
B. H2O
C. N2
D. CO

“C”, of course, represents carbon (a component of the fuel) and “O” represents oxygen (a component of air). And, since carbon monoxide is a product of the interaction between fuel and air in the combustion process, the correct answer to our question is D. Carbon Dioxide (choice A), on the other hand, is identified by the symbol CO2. The point we want to make here about these two similar symbols is that being in a hurry or feeling “under the gun” during a test could result in an incorrect choice.

In our next segment, we’ll continue our discussion on CO, and how understanding a proper air-to-fuel ratio can minimize its production. Speaking of fuel…..

LP gas manifold pressure should be:

A. 3.5 in. W.C.
B. 14 to 16 in. W.C.
C. 10 to 11 in. W.C.
D. 6 to 7 in. W.C.

We’ll provide the answer to the next segment.
PART TWENTY-TWO

PROPER AIR TO FUEL RATIO = GOOD COMBUSTION

Note….The correct answer to the final question in Part 21 is “C”.

In our last segment our discussion of combustion was about something we can’t actually achieve in the field when adjusting fuel pressure and air to a burner in order to have the correct balance relative to air-to-fuel ratio….perfect combustion. The best we can hope for is good combustion, and an understanding of this concept begins with identifying the types of air needed for the process to be as safe and efficient as possible. The first two types of air to identify are Primary Air and Secondary. Air (See Figure 22-1)

With an understanding of the process shown here, the answer to the following question…. 

The air that is mixed with the fuel before ignition is:

A. Secondary Air  
B. Primary Air  
C. Excess Air  
D. Dilution Air

….is easy to answer: “B”

In the scheme of air-to-fuel ratio, the bottom line in primary air is that it needs to be at the proper level for the combustion process to begin properly. If the level of primary air is too low relative to the fuel pressure, the flame will appear as lazy and yellow. If there is too much primary air, the flame will be noisy and unstable, even to the point of lifting off of the burner assembly. Secondary
air, on the other hand is necessary for the combustion process to be completed properly. It's a good practice to introduce more secondary air than is necessary into the burner chamber, which means that the term that applies is excess air. A burner that has enough primary air, but is starved for secondary air will not burn properly, and excessive carbon monoxide will be produced due to incomplete combustion.

Once the combustion process has been completed with an abundance of secondary air, dilution air introduced into the flue system is responsible for creating the proper amount of draft, allowing the by-products of combustion to exit the building via the vent system.

The other half of the air-to-fuel ratio requirements of combustion is the fuel being delivered at the proper pressure, regardless of the burner design, be it an atmospheric (natural draft) type as shown in Figure One, or a forced-draft burner. (See Figure 22-2)

![Figure 22-2](image)

Fuel pressure is critical and is measured in a fine increment known as the water column inch. The basis for this measurement is the early device used, known as a U-Tube Manometer. The basis behind the U-Tube (shown in Figure 22-3) is that when there is no fuel pressure applied at one opening, the water columns on both the left and right sides of the assembly will read zero. Applying fuel pressure as we’re showing in our illustration causes the water column on the right to move downward and the water column on the left to move upward.
By combining the number read on both columns and adding them together, you can measure the water column pressure applied. In our example, each column is showing 5 ½ inches, making our total pressure 11 inches of water column. For an understanding of how fine a measurement this is, see the chart in Figure 22-4.

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in. W.C.</td>
<td>0.578 oz/in²</td>
</tr>
<tr>
<td>11 in. W.C.</td>
<td>6.358 oz/in²</td>
</tr>
<tr>
<td>11 in. W.C.</td>
<td>0.397 psi</td>
</tr>
<tr>
<td>1 psi</td>
<td>27.720 in. W.C.</td>
</tr>
<tr>
<td>1 psi</td>
<td>2.036 in. Hg</td>
</tr>
<tr>
<td>1 in. Hg</td>
<td>0.491 psi</td>
</tr>
<tr>
<td>1 standard atm</td>
<td>14.696 psi</td>
</tr>
</tbody>
</table>

There are two readings that illustrate just how fine a measurement of pressure the water column inch is. The third on the list shows that 11 inches W.C. is equal to 0.397 PSI and the fourth listing breaks it down in another way, showing that 1 PSI is equal to 27.720 inches of water column. When you
consider that 1 PSI on a standard gauge reading is broken down into 27.720 increments in the water column measurement method, it illustrates how critical fuel pressure is to the proper operation of a burner.

For example, natural gas provided to the inlet side of the gas valve should be at a level of between 5” and 7”, while the manifold pressure (the level of fuel pressure delivered to the burner) should be at 3 ½” of water column for proper operation. In an LP fuel situation, equipment pressure should be 11” to 13” W.C. while manifold pressure can be required by some manufacturers to be 9” or 9 ½ ” in some cases, or 10”, 10 ½” or 11” in others, depending on particular equipment specifications.
PART TWENTY-THREE

ELECTRIC HEATING SYSTEMS

Beyond the NATE core exams for service and installation technicians that require a general knowledge of electrical principles and applied troubleshooting, other exams, such as Air Conditioning: Residential/Light Commercial Service Technician exams, will require technicians to have a fundamental understanding of electric heating systems and how to service and troubleshoot them. For example, consider this question: (Refer to Figure 23-1)

![Figure 23-1](image)

You are troubleshooting an electric furnace and find 242 volts measured across the heating element at points "A" and "B", and you subsequently measure no amperage when checking with a ammeter around the wire connected to L1. The problem with this system is:

A. There is an open fusible link or bimetal switch breaking the circuit to the element.
B. The element is shorted to ground.
C. The element is open
D. The sequencer contacts wired in series with this element have failed.

The correct answer (it’s “C”) to this interesting question, which refers to several of the other components found in electric heating systems....fusible links, bimetal switches and sequencers...is arrived at through a fundamental approach to understanding an electrical load performing work. In this case, our load (the element) is, in fact the recipient of the system’s applied voltage directly at its connections, but isn’t doing any of the work expected of it, which is providing heat. Which means that successfully answering this question can be approached
from the simple "If there is voltage applied to it, there should be current flow through it" philosophy of electrical troubleshooting.

The process of elimination is sometimes a successful approach to accomplishing exam questions, and a look at the other possibilities listed in this question in conjunction with a firm understanding of fundamental concepts is a good example of that. Choice "A" for example, can’t be correct since the direction in our sample question clearly stated the points at which voltage was measured, which is “downstream” from any protective devices that may be found in an electric heating equipment circuit. Likewise with choice “D”.

The current-carrying contacts in the device mentioned is this choice are wired “upstream” from the A and B points in our question, which means that if they were open, there would be no voltage read at the heating element connections. And choice “B” is out since a short to ground would have caused a fuse to blow, which means we wouldn’t have been able to measure the voltage described in the question.

Taking a detailed look the concept of the contacts and/or components wired in series with the heating element….Figure 23-2 is a simple illustration of a fusible link.

![Figure 23-2](image)

This is a one-time device, that, once open due to an over-current situation, will not re-set.

In Figure 23-3, we’re showing the fusible link in a different way, as a schematic symbol, along with the other two components in our scenario, the bimetal safety control and sequencer.
The sequencer, shown to the right of our illustration, employs a 24-volt heating segment (nothing is connected to our example since we’re focusing only on the operating voltage of this particular question and the individual, normally-open contacts in it are shown wired in series with not only the individual fusible links shown to the right of the heating elements, but also a bimetal protective switch. In the case of the bimetal, unlike the fusible link, it is an automatic re-set device that will close once the excessive temperature situation that caused it to open no longer exists.

One simple way to arrive at the correct answer to our question other than the process of elimination would be to picture the circuit. For example, consider the element shown at the bottom of our illustration, and decide that the A and B points described in our question as being the direct connection points of that element. Looking at it from this perspective clearly shows, not just explains from an academic approach, that if either the fusible link or the bimetal device were open, we would not be able to read the voltage that is supposed to be applied to the element upon a call for heat. This diagram also explains the correct answer to the following question….

1. Most safety controls are wired in:

   A. Series with the load.
   B. Parallel with the load.
   C. Parallel with other safety devices.
   D. Only the common leg of the power supply.

….which we’ll discuss in our next segment.
PART TWENTY-FOUR
MORE ON ELECTRIC HEATING SYSTEMS

Figure 24-1
No doubt, one of the challenges in successfully accomplishing a NATE exam, be it in the core area of testing or in a specific area such as heat pumps or air conditioning, is the ability to choose the correct answer to an electrical question.

As we demonstrated in Part 23, these questions often involve a diagram of some sort, and, in order to answer correctly, the technician must be able to interpret the schematic or pictorial presented. For example, the best answer to the final question from Part 23 is “A”, that safety controls are wired in series with a load. Since our focus of that particular question was on electric heating systems, the load in this case would be a heating element, and the safety controls we would consider would be the fusible link we discussed in Part 23, as well as a bi-metal switch that is also wired in series with a load. (See Figure 24-1)

Interpreting either this entire diagram, or any segment of it, involves the process of having a fundamental understanding of both symbols and the ability to trace and follow a particular circuit. In the case of the bi-metal switch mentioned above, take a look at the five heating elements shown in this diagram. Each of them is protected by both the safety control we discussed in our last segment… the fusible link shown at the left of each heating element… and the bi-metal switch shown at the right of each element. In this example, we’re showing that the key to answering that question correctly involves a fundamental understanding of the schematic symbols used. Inside the five-element box on the diagram, the standard symbol for a fuse is shown at the left, and at the right, the standard symbol that identifies some type of switch that reacts to temperature is shown. Also shown on this symbol is another important factor in interpreting diagrams and, in turn, being able to correctly answer the questions related to them. That concept is the N.O./N.C. factor on a schematic symbol.

N.O., of course, standing for Normally Open and N.C. standing for Normally Closed. In the perspective of schematic diagram interpretation, the term “normal” refers to the switch being “at rest” and not affected by any factor, such as temperature. In the case of our specific example, the bi-metal switches shown in series with each of the heating elements are normally closed, and will open upon a reaction to temperature, as we’re showing in Figure 24-2.

![Figure 24-2](image-url)
When positioned at a point near the heating element, this bi-metal will remain closed as long as there is sufficient air flow across the element. However, in the event of a reduction in air flow due to a clogged filter, ductwork problem, blocked registers, or any combination thereof, the bi-metal will react to the excessive temperature that is a result of that diminished air flow, and, reaching its limit, open and break the circuit to the heating element in its circuit….that is to say that the safety switch is wired in series with the load (heating element).

In addition to interpreting the schematic symbols on a diagram to answer a direct question on the method of operation, some questions, as we've mentioned before, relate to evaluating the system in the event of a malfunction. In the case of our schematic in Figure 24-1, the sequencer (there are five of them in our example…identified as SEQ1 through SEQ5) could be the focus of a question of this type. In the case of the sequencers in this diagram, a set of “M” contacts (Main) is shown wired in series with a heating element, and an “A” set (Auxiliary) is shown on the control side of the diagram. In sequencers 1 through 4, the “A” contacts are wired in series with the control segment of a subsequent sequencer in the electrical system. Focusing on the “M” set of sequencer #1, wired in series with the heating element shown in the bottom of the box, we could ask the following questions:

1. A technician is checking an electric furnace that isn't heating at all. Testing with a voltmeter at the M1 and M2 contacts of SEQ1, a reading of 240-volts is shown. This proves:

   A. That the sequencer contacts are open.
   B. That the heating element is not open.
   C. That the safety controls are closed.
   D. All of the above.

And, then, a follow-up question.....

2. In the question above, a voltmeter test proved several factors. A subsequent voltmeter test on the same equipment showed 24-volts at A1 and A2 of SEQ#1, and the same voltage reading at the heat segment of SEQ#1 These voltage readings prove:

   A. That the thermostat is calling for heat.
   B. That the A1 and A2 contacts of SEQ#1 are open.
   C. That the heating segment of SEQ#2 is not open.
   D. All of the above.

We'll have the answers to these questions in our next segment.
PART TWENTY-FIVE

ELECTRICAL TROUBLESHOOTING AND HEAT PUMPS

Note…before we get into the fundamentals of troubleshooting heat pump electrical systems, we’ll note that “D... All of the above” is the correct answer to both of the questions we posed in Part 24.

As we continue with our electrical troubleshooting focus and NATE certification testing…we’ve touched on gas and electric furnaces so far…in this segment we’ll lay the foundation for effective troubleshooting of heat pumps by dissecting a simplified version of a schematic diagram (see Figure 25-1) involving a heat pump with supplemental heat.

The key to success in accomplishing NATE questions related to electrical systems in heat pumps is to first simplify the diagram in a way that makes it much less intimidating when it appears on the page in front of you. The first step in that process is to go through the legend of the diagram, and gaining an overall understanding of the equipment circuits. In this particular diagram, and we’ll do that in the fashion of first identifying the loads on the diagram from the top down, then beginning again with the same process and identifying the switches.

LOADS ON THE DIAGRAM, MAIN SEGMENT:

1. COMP: 240 VAC Compressor, PSC Operation.
2. OFM: 240 VAC Outdoor Fan Motor, PSC Operation.
4. RVS: Reversing Valve Solenoid, 240 VAC Operation.
5. DFR: Defrost Relay Coil, 240 VAC Operation.
7. Main Transformer Primary, 240 VAC Operation.
8. CR: Control Relay Coil, 24 VAC Operation.
10. HC1: Heating Coil 1, 24 VAC Operation
11. IFR: Indoor Fan Relay Coil, 24 VAC Operation

LOADS ON THE DIAGRAM, SUPPLEMENTAL HEAT SEGMENT:

12. SH1: Strip Heater 1, 240 VAC Operation.
14. HC2: Heating Coil 2, 24 VAC Operation
15. SH2: Strip Heater 2, 240 VAC Operation.
SWITCHES ON THE DIAGRAM, MAIN SEGMENT:

1. C: Contactor Contacts, Normally Open, Carries 240 VAC.
2. CR: Control Relay Contacts, Normally Open, Carries 240 VAC.
3. DFE: Defrost Relay Contacts, Normally Closed, Carries 240 VAC.
4. IFR: Indoor Fan Relay Contacts: Normally Open, Carries 240 VAC.
5. RVR: Reversing Valve Relay Contacts, Normally Open, Carries 240 VAC.
6. DFR: Defrost Relay Contacts, Normally Closed, Carries 240 VAC.
7. AS: Air Switch, Normally Open, Carries 240 VAC.
8. CR: Control Relay Contacts, Normally Open, Carries 240 VAC.
9. Close-On-Temperature-Rise Switch (inside the thermostat, connected to “Y”), Carries 24 VAC.
10. RVR: Reversing Valve Relay Contacts, Normally Open, Carries 24 VAC.
11. Close-On-Temperature-Drop Switch (inside the thermostat, connected to “W1”), Carries 24 VAC.
12. Close-On-Temperature-Drop Switch (inside the thermostat, connected to “W2”), Carries 24 VAC.
13. DFR: Defrost Relay Contacts, Normally Open, Carries 24 VAC.
14. OTS1: Outdoor Thermostat 1, Normally Open, Carries 24 VAC.
15. Fan Switch (inside the thermostat, connected to “G”) carries 24 VAC.

SWITCHES ON THE DIAGRAM, SUPPLEMENTAL HEAT SEGMENT:

16. HC1: Heating Relay Contacts, Normally Open, Carries 24 VAC.
17. OTS2 Outdoor Thermostat 2, Normally Open, Carries 24 VAC.
18. HC2 Heating Relay Contacts, Normally Open, Carries 240 VAC.

Well… (or maybe we should say “whew”) that’s the detail on our diagram, along with the fundamental information that needs to be understood relative to the operating voltage of the loads and the voltage that the switch contacts wired in series with those loads carries….15 loads and 18 switches. Considering the switches from the perspective of the voltage they carry when closed is different than the idea of considering the concept of current flow through a complete circuit, but it can be an effective approach to gaining a full understanding of the circuits in the equipment, and ultimately, the sequence of operation. And, understanding those two concepts is a key to successful troubleshooting and being able to choose the correct answer to a question, such as…

The heat pump illustrated in the diagram is not operating at all in the heating mode with the thermostat set to call for heat. A meter test at the RVR coil shows 24-volts, and a meter test at the CR coil shows 0-volts. The reversing valve solenoid is energized. The component that needs replacing is:

A. The transformer.
B. The thermostat
C. The control relay
D. None of the above

In our next segment we’ll provide the answer to the above question and look at specific electrical circuits in heat pumps and how to trace them.
As we begin this segment we’ll point out that the answer to the question we posed in Part 25 is “D. None of the above.” And, we’ll provide some detail on why that answer is correct. Figure 26-1 shows the diagram we used in reference to our question.
As we reported in presenting this particular sample question, the
description of the problem was that the heat pump was not heating at all, and
that tests showed a 24-volt reading at the RVR coil, as well as 0-volts at the CR
coil. And, of the choices we offered for the correct answer to the situation (the
Transformer, the Thermostat, and the Control Relay, along with “None of the
above”), the first three were not possible choices in any way. First, a failed
transformer would prevent us from reading the 24-volts we described in the
question, second, a failed thermostat would never have allowed the 24-volt
reading to be available at the RVR coil, and third, you can't blame a relay coil for
not doing the job of changing the position of its contacts if 0-volts is applied to it
(the coil). So, with a simple understanding of the facts we just stated, the correct
answer to the question was obvious.

We also want to point out that when we presented this particular problem
and the question related to it, we first provided some fundamental information on
the process of analyzing this diagram, using a couple of terms again and again.
Those terms were "Operation" and "Carries". And, in the perspective of our
explanation, those terms related to whether or not we were describing a load
(Operation) or a switch (Carries). While there are many ways to express the idea
of a load being a component that does work when electrical energy is applied to
it, and a switch being a component that either makes or breaks a circuit,"Operation" and "Carries" were the two terms we selected in the detailed analysis
of the diagram.

When sitting for a NATE exam on heat pumps and reading a question, the
two terms we used may not be the ones used on a particular exam, but the
concept that needs to be understood about analyzing the diagram and being able
to arrive at the correct answer to the question is the same: the ability to interpret
the schematic symbols and the components (or segment of a component) that
they represent.

Another way to look at the concept of interpreting a schematic and
understanding the operation of the equipment is to consider it from the
perspective of what should (and would) be happening if the system was
operating properly. Whether it's the direct intent of the person composing the
question to look at it from this perspective or not, it is the overriding factor behind
the question. To illustrate our point, we'll take a second look at our diagram (see
Figure 26-2), and this time we'll show information on what would be happening if
this particular system was operating properly in the cooling mode.

On the control voltage segment of the diagram....the thermostat is set to a
point where it is calling for cooling and the fan switch is set in the AUTO position.
This is clearly indicated because the close-on-temperature-rise switch within the
thermostat is allowing a complete circuit to the CR coil, and the circuit to the IFR
coil is also complete with the fan switch in the position shown. (If the fan switch
was in the ON position, the circuit for the IFR coil wouldn't be as we're showing it
here. It would be directly to the secondary of the transformer via the “R” terminal only, not the thermostat’s temperature-sensing segment.)

![Diagram of electrical circuit]

Figure 26-2

On the operating voltage segment of the diagram, we can apply the idea of a sequence of events to describe what is shown in the form of complete circuit relative to the compressor. The CR contacts shown in series with the contactor (C) coil, close, which then allows the circuit to the contactor coil, and only after this circuit is complete will the C contacts at L1 an L2 close, allowing a circuit to the compressor. At the same instant that the circuit is being made to the contactor coil, there is also a complete circuit at the outdoor fan motor via a
second set of CR contacts, and the IFR contacts also provide the complete circuit to the indoor fan motor.

With an understanding of these circuits as we’ve described them, answering questions about either the normal operation of the equipment, or questions about it not operating properly, could be accomplished in a direct, process-of-elimination manner. In our next segment, we’ll examine these kinds of questions and explain how to arrive at the correct answers.
PART TWENTY SEVEN

HEAT PUMP ELECTRICAL CIRCUIT QUESTIONS

In this segment we’re going to get right to some questions regarding the evaluation of heat pump electrical circuits:

1. (Refer to the schematic in Figure 27-1) A customer calls to say that their residential heat pump is not cooling. You observe that the compressor and
outdoor fan motor are not operating, and the indoor fan motor is. You determine that the thermostat is set properly.

A. The transformer could be the source of the problem.
B. The contactor has failed.
C. The control relay could be the source of the problem.
D. The thermostat has failed.

Like many certification exam questions, this one can be answered correctly through a couple of techniques. One of which is the process of elimination. Take “A” for example. It couldn’t be correct since the information in the question established that the indoor fan motor was operating. Ditto for the thermostat…..the question clearly states that the thermostat is properly set. (Yes, somebody’s interpretation of the term “proper” could be that the fan is set in the ON position rather than AUTO, thus allowing the fan motor to operate without the benefit of a call for cooling, but it’s doubtful that the author of the question would have that idea in mind….one simple rule for success in certification testing is not to try to read too much into a question.)

With the most obvious answers out of the way…even if we didn’t take a close look at the schematic, but instead relied on common application of experience and overall understanding of the operation of any comfort cooling system…we can focus on the two choices that are left. And we can easily arrive at the only answer that makes sense by accomplishing the tracing of the appropriate circuits on our diagram. Could “B” be the correct answer?

Well, let’s find out. Begin tracing at L1 and follow through the normally-open “C” contacts, then continue on through the run winding and start winding and run capacitor, then finish the trace by going through the other normally-open “C” contacts, and back to L2.

Accomplishing this trace proves that the outdoor fan motor isn’t in the contactor two-pole switch circuit at all. Only the compressor would be affected if the contactor had failed. We’re no longer relying on that overall understanding of a comfort cooling system we mentioned above. Since this is a heat pump, and we understand that the outdoor fan motor will have to be controlled (operating) in the heating and cooling modes, but turned off in a defrost mode, it must be controlled independently of the compressor.

To confirm this, begin again at L1, then go through the “CR” contacts shown wired in series with the OFM, again following on through both the motor windings and the run capacitor before completing the trace by going back to L2. What’s that? You’re wondering about that normally-closed set of contacts labeled “DFR” (Defrost Relay)? Well, don’t. It’s like they in New York City………… fuggetaboudit. This component, even though it has a set of contacts wired in series with the outdoor fan motor, were not mentioned in any of the choices, so
it's not a factor. The only thing that is a factor is another trace, this time on the control voltage segment of the diagram.

With the thermostat set to call for cooling, there is a circuit to both the CR coil and IFR coil. And energizing the CR coil is supposed to close two sets of contacts immediately...those in series with the contactor coil and those in series with the outdoor fan motor, the two components that were identified in our question as not operating. To nail this down, trace from the “R” wire connected to the transformer to the cooling switch and control shown on the “Y” wire that leads to the CR coil. From the parallel connection on the Y wire, follow on down to the G switch set to AUTO and on to the IFR coil. Both circuit traces can be completed from the other connection of both coils to the other side of the transformer.

Next question....

2. A customer residing in an extremely cold climate reports that their heat pump is not providing enough heat. You determine that the refrigeration system is accomplishing heat transfer according to its capacity. Electrical checks at SH1 and SH2 show a reading of 240 VAC. An amp check of SH2 shows no current draw.

   A. The HC2 coil has failed.
   B. The OTS2 outdoor thermostat has failed.
   C. The SH2 element has failed.
   D. The field-installed supplemental heat kit transformer has failed.

We'll discuss the answer to this question in our next segment.
Before we continue with heat pump electrical systems and an overview on specific troubleshooting procedures, the answer to the question from Part 27 is "C: The SH2 element has failed."

This brings up the point we want to make relative to accomplishing a NATE certification on heat pump servicing. The ability to interpret a wiring diagram and choose the correct answer to a question is a skill that a technician needs to have, and the other factor to consider in the certification process is a general understanding of how electrical systems work in conjunction with heat pump air flow systems. For example, take a look at the illustration in Figure 28-1.
Here, we’re showing an air handler for a split system, but the concept we want to focus on could apply whether it was a roof-mounted package unit or a split system. Note that our squirrel-cage blower is located between the heat pump indoor coil (HP Coil) and the auxiliary heating elements, and that it draws air through the coil, then discharges it out through the top if the unit. That means that our indoor blower motor draws air, rather than forces it, through the indoor coil.

That being the case, any restriction such as that caused by a dirty filter, dirty coil, or, if the return is blocked in any way with, say a couch, cabinet, or other furniture, the unit isn’t going to be able to heat at full capacity, allowing the supplemental heat strips to do their job.

The point is to resist the temptation to jump to the conclusion that a complaint about lack of heating capacity is relate to a refrigeration system problem, or strictly and electrical problem, when the need for proper air flow must be considered. Consider this question:

A heat pump isn’t providing sufficient heat on a cold day. You should:

A. Check the refrigerant charge.
B. Test the supplemental heat elements for proper resistance.
C. Survey the overall installation to make sure there is proper air flow through the duct system.
D. Advise the customer that a heat pump doesn’t warm the air in the same way that a gas furnace does.

With an overall understanding of our discussion in the previous paragraph, the best answer to the question is certainly “C”.

Of course, air flow through the outdoor coil is also a consideration for the proper operation of a heat pump, and when we’re considering the heating mode, defrosting the coil when necessary is an issue. Heat pumps employ a variety of electronic control systems to accomplish this task, and one of those systems is shown in Figure 28-2.

On this control board, you find the ability to choose a variety of defrost times, and also test pins that force the device into a defrost mode. The pins in this example are located near the lower left of the assembly, and identified with the letters TST.
When you use these test pins to implement a defrost, all timing frequencies are accelerated by a factor of $1/256$, which means that 90 minutes is reduced to approximately 21 seconds. And, the specific procedure to test the operation of this type of control board in the event you find an iced-up outdoor coil is as follows:

1. Jump the test pins momentarily to initiate a defrost mode.
2. If the defrost mode doesn’t initiate, consider the defrost thermostat (DT) as the source of the problem.
3. Connect a jumper between the R and D terminals to take the DT out of the circuit, and jump the pins again. If a defrost mode is initiated this time, the defrost thermostat has failed.
4. If the defrost isn’t initiated when the DT is jumpered, check for 24-volts at terminals B and R. If you get a 0-volt reading with this test, check the field wiring.
5. If you get 24-volts with the previous test, check for 24-volts between B and Y. If you get a voltage reading with the two previous tests, but defrost cannot be initiated, the board has failed.
6. If the outdoor fan turns off when defrost is initiated, but the reversing valve isn’t energized, check for 24-volts at B and O. If you get a 0-volt reading here, the board has failed.
7. If the outdoor fan motor doesn’t turn off during defrost, the board has failed.
8. If the supplemental heat elements don’t come on during defrost, check for 24-volts at terminals B and X2. If you get a 0-volt reading, the board has failed. If you get 24-volts with this test, check the outdoor thermostat or the heating elements.

Now, consider this question:

A heat pump is not defrosting and the ambient temperature is 20-degrees. An ohmmeter test of the DT shows infinity. You should:

A. Replace the defrost thermostat.
B. Replace the control board.
C. Replace the indoor thermostat.
D. Replace the reversing valve solenoid.

We’ll provide the answer to this question in our next segment.
PART TWENTY-NINE

HEAT PUMP REFRIGERATION SYSTEM FUNDAMENTALS

Note...Before we begin our discussion on heat pump refrigeration systems, the answer to the electrical question from Part 28 is “A”....and, we’ll move right into our first refrigeration system question for this segment....

The tubing on a heat pump refrigeration system that would be identified as the common suction line would be:

A. Located between the evaporator and condenser.
B. Between the compressor and the reversing valve.
C. The entire tube length between the evaporator and compressor.
D. Between the compressor and the outdoor coil.

In considering this question, we’ll use as few words as possible while concentrating on three illustrations. Our reason for taking this approach?....the
way people learn and understand things. When we attempt to learn something, we have a tendency to think in pictures (whether we’re reading or listening) in an effort to understand. It always comes down to getting an internal picture in your mind about the thing you’re trying to figure out, so we’ll begin with Figure 29-1, which shows:

1. A heat pump refrigeration system in the cooling mode (because the discharge is to the outdoor coil).
2. Free-flow through the Outdoor Check Valve, forcing the refrigerant through the Indoor Capillary.
3. Suction from the indoor coil and looping into, then out of, the reversing valve.

And, Figure 29-2:

1. A heat pump refrigeration system in the heating mode (because the discharge is to the indoor coil).
2. Free-flow through the Indoor Check Valve, forcing the refrigerant through the Outdoor Capillary.
3. Suction from the outdoor coil and looping into, then out of, the reversing valve.

So, when you consider our question, and note the 3 simple facts that we derived from our illustrations.....go ahead, trace the path of refrigerant flow...it brings us to the conclusion that the correct answer is “B” regardless of which cycle the heat pump is operating in.

Figure 29-3

Are we saying that when you’re taking an exam and considering a specific question, you’ll likely conjure up some image in order to make sure of the correct answer? Yes, that’s the way our mind works. At some point in choosing A, B, C or D, you’ll recall either an illustration, or remember what you’ve seen in a field situation. To further illustrate our point, consider Figure 29-3 and the following question:
In the accompanying drawing, the common suction line is:

A. 1  
B. 2  
C. 3  
D. 4

We’ll provide the answer to this question in our next segment.
PART THIRTY

MORE ON HEAT PUMP REFRIGERATION SYSTEMS

*Note…the answer to the question from Part 29 is: “B”.*

Technicians who want to successfully accomplish a NATE certification exam on heat pumps need to know not only the fundamental concepts we discussed in the last segment of our series, they must also possess an understanding about the operation of specific components in the heat pump refrigeration system. Beyond the basics of:

1. Refrigerant absorbs heat when it changes in state from a liquid to a vapor.
2. Refrigerant rejects heat when it changes in state from a vapor to a liquid.
3. The compressor causes a rise in pressure.
4. The metering device causes a drop in pressure.

And:

5. The 4 things listed above represent the fact that the fundamental laws of thermodynamics and maintaining a pressure differential in a refrigeration system allow it to function according to its design.

They need to know which component in the system does what in order to allow the equipment to function, not just from an overview perspective, but what these components do to allow the system to work as efficiently as possible…and how to avoid the pitfall of misdiagnosis in the process of evaluating the performance of a heat pump. Take the reversing valve, for example. It’s likely the most misunderstood and most frequently blamed for abnormal system performance when it’s not the source of the problem. To make our point, we’ll consider two things: First, the illustration in Figure 30-1….

And, second, the question:

A customer reports that their heat pump is not heating enough. The technician should:

A. Replace the reversing valve after determining that the air coming out of the supply registers is not warm enough even though the compressor discharge line is very hot.
B. Increase the speed of the indoor fan motor.
C. Evaluate the performance of the refrigeration and air flow systems in order to arrive at a diagnosis.
D. Add refrigerant to the system.
As with many exam questions, some of the answers above are intended to evaluate a technician’s ability to not “jump the gun” and arrive at a conclusion that would do more harm than good. “D” and “A” fit into that category. There are also some questions that are just over-the-top silly (“B” for example) for anyone who has even a rudimentary understanding of the components in a heat pump, such as the design and operation of an indoor fan motor. Which means, obviously, that the correct answer is “C”. And, we want to point out that understanding a simple procedure relative to reversing valve performance evaluation would be the key to arriving at this correct answer.

Referring again to Figure 30-1, note the single tube connected to one side of the reversing valve body, identified as “Compressor discharge”. Now consider that since we are in the heating mode, the discharge will be to the indoor coil and suction will be from the outdoor coil. Understanding the process of using an accurate temperature measuring device such as a digital meter and a Type K thermocouple clamp, you would also understand why you could eliminate the “A” answer to this question. The two steps in this procedure are simple:
...Take a temperature reading of the discharge tube entering the reversing valve. 
...Take a temperature reading of the discharge tube exiting the reversing valve.

If the maximum temperature differential you read between the tube entering and the tube exiting is 2-degrees, then there’s nothing wrong with your reversing valve (no “sticking” or “leaking” as is often thought to be the case in heat pump performance complaints). You could also test the operation of the valve further by accurately measuring the temperature of the suction line connection from the outdoor coil, then measuring the suction vapor connection. Again, a two-degree differential would be acceptable and an indication that the reversing valve is OK.

![Diagram](image)

**Figure 30-2**

Now, here’s another question on the subject of heat pump reversing valves. (Refer to Figure 30-2)

In the system in this illustration:

A. The indoor coil is acting as a condenser.
B. The indoor coil is acting as an evaporator.
C. The outdoor coil is acting as an evaporator.
D. Both A and C.

The correct answer to this question is “D”
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