CDC 3E151

Heating, Ventilation, Air Conditioning, and Refrigeration Journeyman

Volume 1. HVAC/R Fundamentals

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Material in this volume is reviewed annually for technical accuracy, adequacy, and currency. For SKT purposes the examinee should check the *Weighted Airman Promotion System Catalog* to determine the correct references to study.

THIS FIRST VOLUME of CDC 3E151, *Heating, Ventilation, Air Conditioning, and Refrigeration (HVAC/R) Journeyman*, introduces you to some HVAC/R specific concepts and fundamentals that are vital to this career field.

Unit one discusses the HVAC/R tools and test equipment. Topics include air conditioning, refrigeration, temperature, heating, electrical, air and hydronic tools.

Unit two talks about piping and tubing fundamentals. This unit will cover steel pipe and copper tubing applications that will give you a firm background on the skills. Also, valves, fittings and backflow prevention will be discussed.

Unit three covers brazing and soldering of the piping and tubing systems talked about in unit two. This skill has been important in this career field for a very long time now. The unit begins by covering the equipment required for soldering and brazing and then finishes by going over the procedures to accomplish those tasks.

Unit four discusses the physics of of HVAC/R Physics seems like a tough subject to cover but the concepts learned in this unit are the backbone of the career field. After learning the physics of the job, psychrometrics will be covered to give the student a better understanding of air and its relationships.

Unit five is about load calculations and equipment sizing.

This CDC has four additional volumes. Volume 2 covers air and hydronic systems, Volume 3 discusses electrical concepts, Volume 4 Heating Systems and Volume 5 Cooling Systems.

This coursemust be completed before you can obtain a 5-skill level in the 3E1X1 career field.

A glossary of abbreviations and acronyms is included at the end of this volume.

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This volume is valued at 15 hours and 5 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then do the unit review exercises.

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Unit 1. Specialized HVAC/R Tools and Test Equipment

IN THIS UNIT you are going to learn more about the tools that apply specifically to the heating, ventilation, air conditioning, and refrigeration (HVAC/R) career field. In technical school you learned about basic hand tools. This unit will cover that material again but will focus on the specific tools used when working on cooling, heating, electrical, air, and hydronic systems. It is vital to have a strong understanding of the tools we use in our Air Force specialty code (AFSC). Knowing which tool to select for a particular job and having a good foundation of how HVAC/R tools work will save you time and will lead to a safer work environment. We will not cover procedures on how to use these tools. Your on-the-job training (OJT) will cover procedures for using specific tools discussed in this unit. A recommended plan is to read the information in this unit and then have your supervisor go over the steps on how to use these tools. This is will give you the best approach to understanding how to use them.

001. Air conditioning/refrigeration specific tools

The HVAC/R career field is very vast. There are numerous tools you need to be familiar with for various applications. In this lesson, we cover tools that are specific to the air conditioning (cooling) and refrigeration side of our career field. We'll begin with refrigeration tools and then discuss vacuum equipment.

Refrigeration tools

There are numerous tools that you will use while dealing with refrigerant. The list below encompasses the important tools that we will cover.

- Leak detectors.
- Gauges.
- Compressor oil charging pump.
- Fin comb.
- Quick couples, low loss fittings, and adapter hoses.
- Schrader core remover.
- Refrigerant scales.
- Recovery devices.

Leak detectors

There are many methods and tools used to find refrigerant leaks. The "best" method is irrelevant. What is most important is that you know how and when to use each one. We'll take a more in-depth look at leak checking procedures in a later volume. The main focus now is on the tools themselves. The following table covers the six commonly used leak detector tools listed below.

- Visual indicators.
- Soapy bubbles.
- Halide leak detector.
- Electronic leak detector.
- Fluorescent leak detector.
- Ultrasonic leak detector.

Leak Detector Tools

Tool	Description
Visual indicator	Your first tool to use is your eyes! Look for oily residue around fittings and connections on the system.
Soapy bubbles	Soap bubbles are the oldest and the cheapest method of leak detection (fig. 1–1). This method uses a watery soap solution that you apply to pipe joints, fittings, or other suspect connections in the system. You can apply soap solution using a spray bottle or a dauber. If there is a leak present you can visually confirm it from the bubble formation.  **Figure 1–1. Soapy bubbles.**
Halide leak detector	You can use a halide torch to detect leaks in systems using halocarbon refrigerants. It detects the chlorine present in chlorofluorocarbon/hydrochlorofluorocarbon (CFC/HCFC) refrigerants. The halide torch consists of a copper element heated by a flame created by a propane torch. The air required to support the combustion of propane draws through a rubber tube connected to the base of the torch. After lighting the torch, the air fuel mixture heats the copper until it glows. The free end of the rubber tube is passed over suspect joints and fittings of the refrigeration system. If the faintly bluish flame turns green, this indicates a refrigerant leak. The intensity of the flame will vary depending on the size of the leak. The possibility of false readings is a major concern with this method of leak detection. This instrument is *not* effective in areas where a *high concentration* of refrigerant is present. The environment will play a role in this instrument's efficiency. Windy conditions make it difficult to suck in the refrigerant vapors. Sunlight can distort the actual color of the flame. Large leaks, even in well-ventilated areas, may cause false readings preventing detection of small leaks. **CAUTION:** The combustion of the halocarbon refrigerants produces highly toxic **phosgene gas.** *Only use this leak-detecting device in well-ventilated spaces.* You must never use halide torches in the presence of combustible vapors or an explosion may occur. Because some of the newer refrigerant blends may contain flammable components, the use of a halide torch may be dangerous. This is especially true if the leak is large.
Fluorescent leak detectors	This technique involves adding a bright color dye to the system charge through the low side service valve and then running the compressor to circulate it. A handheld ultraviolet (UV) light and the fluorescent dye are sold as a kit. Once the dye has spread through the system, any leaks will glow yellow-green under an ultraviolet lamp. The next step is to shine the UV light on the components of the system where a leak is likely to occur. There are usually no false indications with these kits; however, the UV lights only work on

Leak Detector Tools	
Tool	**Description**
	accessible systems. If part of the system is hidden from view, the lights cannot be used. Another drawback is small leaks could take a longer time to be detected. The fluorescent dye is a faster method of revealing larger leaks.
Ultrasonic leak detectors	Ultrasonic leak detectors are capable of detecting the sound of small leaks. • Large leaks make a hissing sound. • Smaller leaks make the same sound; however, the frequency is too high for our ears to detect. An ultrasonic leak detector amplifies the sound and converts it to a frequency range where you can hear the hissing of a leak on a set of headphones. Any turbulent gas will generate ultrasound when it leaks so it does not matter what refrigerant you are leak testing. Most ultrasonic detectors won’t hear background noise, but be aware of areas with a lot of pressure regulating valves and high velocity flow. These areas may produce hissing of the same frequency range used by the leak detector. In this case, you would need to shut down the system or use another type of instrument. You can use ultrasonic leak detectors along with soap bubbles. Combining both leak detection tools will help locate very small leaks. This technique requires you to detect that inaudible crackling sound made by refrigerant bursting the small bubbles in the solution.

Check the following areas when looking for leaks:

- Service valves.
- Pipe joints (bolted and brazed).
- Gaskets of semi-hermetic compressors.
- Seals around the wire connections (hermetic compressors).
- Expansion valves.
- Tubes (where they pass through sheet metal).
- Controls that appear stressed or worn.

Environmental Protection Agency (EPA) regulations dictate when you must repair leaks. Simple fixes such as tightening a fitting, without recovering the system charge, can stop a leak. Of course there are systems that require more complex repairs or leaks that require recovery of the entire charge. In either case, you must pinpoint the exact location of the leak.

Gauges

Gauges are an extremely important tool in HVAC/R. The can tell you water pressure, air pressures, refrigerant pressures, and even refrigerant temperatures. The gauge is the best means that you have to “see” inside of the system. We’ll cover the different gauges you need to be familiar with in the table below.

Gauges	
Type	**Description**
Manifold gauge assembly (MGA)	This is one of the most important tools you can have while working with refrigerants. The MGA comes with a manifold, compound gauge, valves, and hoses. Some have a four-way valve design that has separate valves for the vacuum, low pressure, high pressure and refrigerant cylinder connections. Look at figure 1–2: • The gauge on the *left* side is called a compound gauge and reads pressure above and below atmospheric pressure.

<table>
<tr><th colspan="2">Gauges</th></tr>
<tr><th>Type</th><th>Description</th></tr>
<tr><td></td><td>

- The gauge on the *right* is called the high-pressure (high-side) gauge.

Figure 1–2. Manifold gauge assembly.

MGAs also have temperature scales on them. Here is how it works.

Assume you have R-410a refrigerant. Look at figure 1–3 and go to the R-134a temperature scale. Now go to 35 degrees and follow the line to the black pressure readings. You can see that the pressure that corresponds with 35 degrees is about 31 pounds per square inch gauge (psig).

This shows you the pressure and its corresponding refrigerant temperature.

Note that the pressure was indicated in *psig, not* pounds per square inch absolute (psia).

An easy way to remember is that when using *gauges* for a reading you are using psi*g*.

Figure 1–3. Gauge.

The vacuum hose is $^3/_8$ inch on this gauge while the other hoses are ¼ inch. The larger size $^3/_8$ inch hose means fewer restrictions making it easier and quicker to pull a vacuum.

Finally, remember that *not all refrigerants are created equal*!

- Some, such as R-410a, operate at higher pressures than the commonly used R-22 and R-134a.
- Different MGAs will need to be used with R-410a due to its higher pressures.

</td></tr>
<tr><td>Pressure gauges</td><td>

A common type of gauge seen in our career field is one using a bourdon tube.

The bourdon tube is a steel tube attached to the needle through a linkage. When gas pressure fills the bourdon tube, the tube begins to straighten out. As the tube straightens, it moves the linkage and the needle pointer.

This is the type of gauge your MGAs and oxyacetylene equipment use.

Bourdon tubes are precision instruments that can be easily damaged.

Problems with a gauge are usually caused by a leaking or broken bourdon tube. This is indicated by a fluctuating gauge pressure or gas leaking from the gauge case. If

</td></tr>
</table>

Gauges	
Type	**Description**
	the cylinder valve is opened quickly and the regulator adjusting screw isn't released, the tube can be cracked. A sudden pressure increase can also crack the tube causing it to leak. A small leak in a bourdon tube can be repaired by silver brazing, but repairs of major damage to a regulator should be done by the manufacturer. Generally, it is more economical to replace the entire gauge instead of try to fix any major damage.

Other tools

In the table below we take a look at the other types of refrigeration tools that you need to be familiar with.

Other Tools	
Tool	**Description**
Compressor oil charging pump	Sometimes a system may need refrigerant oil added to it. The compressor oil charging pump is used for charging refrigeration compressors with oil while they are under pressure.
Fin comb	The fin comb is a very simple device but serves an important purpose. Sometimes the fins on an evaporator or condenser can get bent and flattened out. This is bad because it reduces heat transfer and heat transfer is what HVAC/R is all about! The fin comb is used to straighten out the fins. There are many different styles that are capable of straightening fins spaced at 8, 9, 10, 12, 14, and 15 inches.
Quick couples, low-loss fittings, and adapter hoses	These tools help reduce the amount of refrigerant lost while connecting and disconnecting gauges to a system. This is especially important when working on a critically charged system. • *Quick couples* (fig.1–4) trap refrigerant in the hoses when disconnected.  **Figure 1–4. Quick couple.** • *Low-loss fittings* connect to the end of refrigerant hoses. • *Adapter hoses* help to control the refrigerant loss. In figure 1–5, notice the hand valves that allow you to close the hoses off before removing them.  **Figure 1–5. Adapter hose.**

Other Tools	
Tool	**Description**
Schrader core remover and replacer	This tool allows you to replace Schrader cores without having to remove the refrigerant from the system. Removing the Schrader core makes it faster to pull a vacuum because there is less of a restriction caused by the core.
Recovery device	This device is used to pull refrigerant from a system.
Refrigerant scales	Refrigerant scales are used to weigh refrigerant tanks and are helpful while charging a unit (fig.1–6). There are analog and digital scales. The tank is simply put onto the scale and a reading produced with a needle and scale (analog) or digitally. Modern scales generally communicate wirelessly with a handheld remote.  **Figure 1–6. Refrigerant scale.**

Vacuum equipment

There will be times that you will need to pull a system into a vacuum. Pulling a vacuum is used to remove non-condensables and moisture from a system. A vacuum pump and vacuum gauges are used to accomplish this task.

Vacuum pump

The vacuum pump is just that, a pump. It pumps out moisture and non-condensable gas from the system and into the atmosphere. The vacuum pump is capable of reducing the atmosphere in a system down to a deep vacuum. In our career field, the vacuum pumps used are made with a rotary compressor. Vacuum pumps that are made with a two-stage rotary compressor can pull the lowest vacuums. Figure 1–7 is an example of a vacuum pump.

Figure 1–7. Vacuum pump.

Two-stage vacuum pumps are made up of two single-stage vacuum pumps in series. Almost all are the rotary style. The first stage vacuum pump will intake pressure from the system and exhaust it into the intake for the second stage of the vacuum pump. This design is what makes the two-stage vacuum pump more efficient than the single stage. Since the first stage is exhausting into the second stage, and not the atmosphere, there is less backpressure on the first stage, which makes it more efficient. The second stage is pulling in at a lower pressure which enables it to pull a lower vacuum.

The very low vacuum that is created boils the moisture and turns it into a vapor. Once the moisture is turned into a vapor, the vacuum pump pumps it out to the atmosphere.

Vacuum gauges or micron gauges

In the past, many HVAC/R mechanics normally relied on their manifold gauges while pulling vacuums on air conditioning and refrigeration appliances. The problem with this method is that the compound gauge gives readings in inches of mercury. These readings are not very accurate when low or deep vacuums are required. For these cases, the vacuum needs to be measured in microns. In order to measure microns, a micron gauge, also known as a vacuum gauge, is used. Micron gauge displays can be analog, digital, or light-emitting diode (LED). Figure 1–8 shows and example of a micron gauge. Some electronic vacuum gauges connect to the system's piping or to the manifold gauge connection.

Figure 1–8. Vacuum gauge.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

001. Air conditioning/refrigeration specific tools

1. What is most important when it comes to using leak detectors?

2. If there is a large refrigerant leak, what type of readings may be obtained if using a halide leak detector?

3. Where should a halide leak detector be used?

4. Since the fluorescent leak detector is good for finding larger leaks, what type of leaks could take longer to find?

5. When using an ultrasonic leak detector, why does the type of refrigerant in the system not matter?

6. What does combining the ultrasonic leak detector with soapy bubbles will allow you to locate?

7. What usually causes problems with a gauge?

8. When would a compressor oil pump be used?

9. Where does the first stage of a two-stage vacuum pump send its intake pressure?

10. What allows a two-stage vacuum pump to pull a lower vacuum than a single-stage vacuum pump?

11. Why should you *not use the manifold gauge assembly* when measuring a vacuum?

12. How can micron gauges be connected?

002. Temperature measuring tools

A thermometer is a simple tool but is vital to HVAC/R technicians like you since the job is all about temperatures. Even though this tool is simple it can be misused. In this lesson we'll cover the mercury, dial-indicator electronic, infrared, recording, and temperature leads. We'll group them into two categories: basic temperature measuring tools and advanced temperature measuring tools.

Basic temperature measuring tools

There are two basic tools in this category—the glass stem mercury thermometer and the dial-indicator type—discussed in the table below.

Basic Temperature Measuring Tools	
Type	**Description**
Glass stem mercury	This is the most basic type of thermometer. The mercury rises as the temperature rises and falls when the temperature falls (fig. 1–9).  **Figure 1–9. Glass stem thermometer.**

Basic Temperature Measuring Tools	
Type	**Description**
Dial-indicator	This another simple type of thermometer. There is a needle that moves back and forth and indicates what temperature is being sensed. The red handle in figure 1–10 has a hole in it that the long silver probe can be placed into. Don’t use your hand to hold the probe as this will affect the temperature reading. Think about it, your body temperature is 98.7 ºF. if you are holding the probe while it is trying to read 55 ºF supply air, the heat from your hand will be transferred to the probe and the dial indicator reading will be higher than what the real air temperature is. Using the handle will prevent this from occurring.  **Figure 1–10. Dial indicator.**

Advanced temperature measuring tools

There are five devices that we group as advanced temperature measuring tools: electronic, infrared, and recording thermometers, the temperature probe with multimeter, and superheat and supercooling thermometers. The following table presents the basic information you need to know about each type.

Advanced Temperature Measuring Tools	
Type	**Description**
Electronic	Electronic thermometers are often found in facilities and are used by the customer. Be careful when using this type. Its location could negatively affect the reading. The way it works is that it changes its resistance with changes in temperature. A computer or other circuit measures the resistance and changes it to a temperature. The temperature is then conveniently displayed for you to read.
Infrared	Infrared thermometers (figs. 1–11 and 1–12) are a quick and easy way of identifying temperatures. You simply point the “gun” at something and pull the trigger. A laser beam is emitted and the thermometer converts the reading to a temperature. You are given an instantaneous reading on an easily read display screen.

Advanced Temperature Measuring Tools	
Type	**Description**
	 **Figure 1–11. Infrared thermometer.**  **Figure 1–12. Infrared thermometer.** The easy use of this tool has led to it being misused and misunderstood. The beam emitted by the device *takes surface temperature only*. *This means there is no way for it to take air temperature.* Technicians often make the mistake of pointing it at a supply diffuser. This only gives the temperature of the diffuser—*not* the air coming out. While it will generally tell you that the air is cool, the number indicated cannot be understood as the actual, specific air temperature. Another issue is taking the reading from too far away. *The further away you are from the surface being read, the more inaccurate the reading will be.* Read the manufacturer's user manual for exact instructions on the effective distances for taking readings. Other factors such as the reflectivity of the surface being taken or any steam, dust or smoke that could be in the air will negatively affect the reading of this type of thermometer. **CAUTION:** The laser beam used by the gun could cause eye damage. Keep it away from eyes—yours and others!
Recording thermometers	There may be a need to record temperatures in a facility or room because customer comfort and equipment cooling is important. This type of thermometer performs this task by simply taking the temperature and recording it on a chart. These can be helpful to prove to customers that their facility or room is getting the proper temperatures. It can also be used to identify a troublesome area.

<table>
<tr><th colspan="2">Advanced Temperature Measuring Tools</th></tr>
<tr><th>Type</th><th>Description</th></tr>
<tr><td>Temperature probe with mulitmeter</td><td>There is an attachment that comes with many multimeters that allows the meter to take temperatures (fig. 1–13).
Simply plug the attachment into the meter with the proper polarity lined up, turn the meter switch to the temperature setting, and the meter will provide a temperature read out on the display.

Figure 1–13. Temperature probe attachment.</td></tr>
<tr><td>Superheat and subcooling thermometers</td><td>This type of tool will measure suction and liquid line temperature and calculate superheat and subcooling.
This tool normally comes with a pipe clamp that goes around the pipe to sense the temperatures.
• Pipe clamps use a thermocouple to convert to temperature to a digital display.
• Pipe clamps can be bought for refrigeration or air conditioning applications.
This tool is helpful for charging by superheat or subcooling and can also be used for troubleshooting.</td></tr>
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Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

002. Temperature measuring tools

1. What is the most basic type of thermometer?

2. Why should the probe on a dial type thermometer *not* be held while taking temperature readings?

3. How can the reading on an electronic thermometer be affected?

4. When would a recording-type thermometer be used?

5. On superheat/subcooling thermometers, how is the temperature converted to a digital display?

003. Heating specific tools and heating test equipment

Combustion analyzers offer you a look into how efficient the system is operating. They will be extremely useful to you as an HVAC/R journeyman. Because there are many manufacturers of combustion analyzers we will not cover the procedures for using them here. That will come as part of your OJT, which will focus on the specific tools used in the shop where you will be working. This lesson will provide a brief overview of the capabilities and features of combustion analyzers which we group into two categories: combustion analyzers and heating test equipment.

Combustion analyzers

As you can see in the following table, there are two basic types of combustion analyzers: digital and absorption.

Combustion Analyzers	
Type	**Description**
Digital	A digital flue gas analyzer measures flue gas content electronically. This type of analyzer can measure and display oxygen, carbon monoxide, oxides of nitrogen and sulfur dioxide, stack temperature, combustion efficiency, stack loss, and excess air. Each manufacturer offers different features, but most analyzers (fig. 1–14) will consist of the following: • A handheld device that allows the choice of fuel and navigation of the digital or full color display. • Sensors. • A probe that gets placed into the stack. • A probe handle to control the probe. • Batteries to power the device. Once the probe is placed is the stack, it will give you the readings that were previously mentioned. These tools must be properly maintained and cared for or they will provide erroneous readings.  **Figure 1–14. Digital combustion analyzer.**

Combustion Analyzers	
Type	**Description**
Absorption	The absorption-type analyzer is a simple, portable, chemical absorption analyzer. It consists of a container that holds a column of liquid that combines with the gas to be measured (either carbon dioxide [CO_2] or oxygen [O_2]). The top of the column has a plunger valve at the point where the gas enters. Along the side of the column is a scale used for measuring the quantity of gas absorbed by the liquid. A tube and hand bulb transfers flue gases from the boiler stack to the indicator unit, where it mixes with the liquid and raises the level of the column to read the percentage of gas on the scale. Purge the indicator by depressing the plunger valve and setting the zero mark on the percent scale even with the top of the fluid in the column. These tools must be probably maintained and cared for or they will provide erroneous readings.

Heating test equipment

There are five different devices that we group as heating test equipment. The table below provides the basic information you need to know about each type.

Heating Test Equipment	
Type	**Description**
Stack thermometer	The modern technician armed with a stack thermometer can take the temperature of a furnace or boiler just as a physician does a patient. Any abnormal reading tells a doctor that something is amiss and requires attention. The stack thermometer is used in the heating industry to determine the condition of our heating equipment "patients." Use it with our other combustion-testing instruments to diagnose and solve afflictions of the combustion process.
CO_2 indicator	The key to any successful burner examination is a CO_2 test of the flue gas contents. The CO_2 or carbon dioxide indicator draws up a sample of the combustion gases. If the CO_2 reading is low, it indicates that the fuel has not burned completely and you need to make adjustments. Though you use the CO_2 indicator with the other testing devices, a special slide-rule calculator that correlates stack temperature and percent of CO_2 is used to find combustion efficiency and stack loss of an oil heating installation.
Combustion efficiency slide rule	Two factors determine heat loss in the flue gases: percent CO_2 in the flue gases and stack temperature. The flue gas heat loss, in-turn, determines the combustion efficiency of the heating plant. The combustion efficiency-slide rule provides a rapid, simple means to determine combustion efficiency, stack loss from the results of the CO_2, and stack temperature tests. The slide rule has horizontal and vertical slide inserts used as indicated below. • Move the horizontal slide until the measured stack temperature appears in the window marked "stack temperature." • Next, move the vertical slide until the black arrow points to the measured percent CO_2. • Percent combustion efficiency and stack loss indicate in the cut out of the arrow on the vertical slide.
Smoke tester	The smoke tester and smoke scale will give you an accurate indication of the smoke content in the flue gases. Excessively smoky combustion recognizes an indication of wasteful, incomplete, and

Heating Test Equipment	
Type	**Description**
	inefficient oil burner operation. It goes hand in hand with soot formation. A soot buildup on the heating surfaces will not only mean waste—for example, $^1/_8$-inch soot may reduce heat absorption by as much as 10 percent—but can also cause many service difficulties. The objective of the smoke test is to measure the smoke content in the flue gases and then, with other combustion test results, adjust the burner to optimum operation. The smoke scale has 10 color-graded spots from zero (pure white) to nine (the darkest color).
Draft gauge	Correct draft is essential for efficient burner operation. While there is not a direct relation from draft to combustion efficiency, it does affect oil burner efficiency. • The intensity of draft determines the rate at which combustion gases pass through the boiler or furnace. • The intensity of draft also governs the amount of air supplied for combustion. Excessive draft can increase the stack temperature and reduce the percent CO_2 in the flue gases. A draft gauge will show you the amount of draft you have in your system. Each manufacturer's device has its own specific procedures so follow the instructions provided by the manufacturer. Basically, a tube is placed into a hole in the stack and you record the reading. Placement will also vary according to the manufacturer but generally the tube needs to be inserted *before* the draft regulator or draft diverter.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

003. Heating specific tools and heating test equipment

1. What part of the combustion analyzer gets placed into the stack?

2. What will happen if the digital combustion analyzer is *not* properly cared for?

3. In an absorption type analyzer, what combines with the gas being measured?

4. What are the special slide-rule calculator and CO_2 indicator used to determine?

5. When a rapid, simple means to determine combustion efficiency and stack is needed, what tool would you use?

6. How would a technician measure the smoke content in the flue gases?

7. How would a technician measure the draft in a system?

004. Electrical testing tools

When you work on electrical equipment, you often need to know something about the circuit that you cannot visually detect. We use electric meters to maintain, repair, and troubleshoot electrical circuits and equipment. Meters help you check for the proper voltage, current flow, and amount of resistance, and to see whether the wiring is defective.

However, the best and most expensive measuring instrument is useless unless you know what you are measuring and what each reading indicates. You must remember that the purpose of a meter is to measure quantities. When a meter is connected to a circuit, it must not change the condition of the circuit. In this lesson, we discuss common meters and special electrical testers including the digital multimeter and the clamp on ammeter.

Common meters

There are two common meters that you will use in your work: the digital multimeter and the clamp-on meter. Our discussion of these provides general information but does not cover specific operating procedures which may vary depending on the manufacturer and model. Operating procedures will be covered as part of your OJT and focus on the specific type used in the shop you will work in.

Digital multimeter

The digital multimeter (fig. 1–15) is just what the name says it is—it is digital and it is a meter with multiple functions. Figure 1–16 shows you the meter outside of its casing. The display is in a digital format. It is important to look at the format of the display to see if you are reading what you intend. Multimeters have many settings such as: temperature, capacitance, frequency, ohms, amperes and voltage, alternating or direct current. More advanced and expensive versions allow you to share information from your readings wirelessly via an app. These more expensive models can also have a graphing function. Like any tool, functions vary by manufacturer, and your supervisor will teach you the ins and outs of the specific meters used in your shop.

Figure 1–15. Digital multimeter.

Figure 1–16. Multimeter out of case.

When any meter is not in use, it needs to be turned OFF! If you don’t turn the meter off, the battery will quickly die. Also, care must be taken to prevent heavy objects from falling on the meter. Even though modern meters are fairly rugged, avoid dropping the meter because it could damage the electronics that are inside.

Any meter is a delicate electronic piece of equipment that you depend upon. Most meters do not get the respect they deserve. Typically they are thrown into the back of the service truck along with anything from pipe wrenches to compressors. *Do not do this!* When you subject a meter to falling heavy objects, vibrations, large temperature swings, water, dirt, and other contaminates, the meter may still "work," but would you bet your life on it? Make sure your meter is in good condition. Check the case, display, battery, and leads for problems. Make sure no wires are exposed on the leads. Bare leads will shock you if you touch them. A meter should be bench tested before each use to determine that it will work within safe parameters. A simple method is to read a good 115 volts, alternating current (VAC) wall outlet and see if the meter reads 115 VAC. If it is near the right reading, it is calibrated correctly. If it is far from the predicted voltage, check the outlet against another meter. Replace the meter or leads if they are defective.

Clamp-on meter

An ammeter is a device that measures amperes in a live circuit. Two types of ammeters that you may come across are the in-line and clamp-on style meters. The clamp-on style is probably the most popular used in shops today, so we will focus on it.

A clamp-on ammeter is often referred to simply as a clamp on and can be digital or analog (fig. 1–17). A digital ammeter usually has an auto range function and is the type used in most shops. Analog meters are becoming a tool of the past in the HVAC/R career field.

Figure 1–17. Clamp on ammeter.

A clamp-on ammeter uses the electromagnetic field generated around a conductor when current flows through that conductor. The meter converts the electromagnetic field to a display for you to read. Clamp the meter on a *single* conductor carrying current. Choosing more than one current carrying conductor will give you incorrect readings. Figure 1–18 shows you the the proper way to take an ampere reading. This is extremely important to remember because many young technicians will put the clamp around multiple conductors and become confused as to what is really happening electrically in the system. Some common readings taken are amp draws on loads such as compressors and motors. (See fig. 1–19 for an example of the clamp-on ammeter taking a reading.) The term *amp draw* is a common way of describing taking a reading on a conductor to determine how many amps are flowing through that conductor.

Figure 1–18. Proper way to take ampere reading.

Figure 1–19. Ampere reading.

Much like the digital multimeter, some clamp ons have numerous functions. Features included are wireless readings and longer cords or clamps that can fit into tight spaces. You may wonder why you would need wireless settings on a meter. This feature enables you to place the clamp on around a conductor and operate controls or observe other parts of the system running on the other side of the mechanical room and still be able to read the amps flowing through the conductor.

Special electrical testers

Sometimes you will need to use more specialized equipment than the two basic meters discussed above. Here we provide information that will help you differientiate between the common meters and the more unique electrical test equipment.

Special Electrical Testers	
Type	**Description**
Megohmmeter	We use the megohmmeter for measuring the resistance of insulating material. As its name indicates, the megohmmeter gives resistance readings directly in millions of ohms. One megohm equals 1 million ohms. We use the megohmmeter primarily to indicate the insulation resistance of cables, motor and generator windings, transformer windings, and circuits. Since a megohmmeter has its own power source, like an ohmmeter, *never use it on a live circuit.* To do so will more than likely ruin the meter.
Electrical tester	This tool is a non-contact-type tester. Voltage can be detected in an outlet or in a wire without making contact. Common models have a green light that comes on when voltage is present. This tool is used when a quick-voltage check is desired. Use a volt meter to determine the actual voltage that is present.
Capacitance checker	This device is used to test capacitors. Most manufacturers have a very wide range of microfarads the device can test. This is a simple device that quickly connects to a capacitor and gives a display that informs the user whether a capacitor is good or bad. This test can be performed on alternating current (AC) or direct current (DC) capacitors. Some older meters do not have a capacitance function, so it is important to know how to use this tool.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

004. Electrical testing tools

1. What will happen if you do not turn off the meter when it is not in use?

2. Why should you avoid dropping digital meters?

3. Why must you ensure no wires are exposed on your meter’s leads?

4. If a meter is defective, what must be done?

5. When could the wireless feature on a clamp on meter be used?

6. When would a megohmmeter be used?

7. When would a green light appear on a voltage tester?

8. When would an electrical tester be used?

9. When would a capacitance checker be used?

005. Air and hydronic measurement tools

In HVAC/R, air is used as a medium to transfer heat from one place to another. Therefore, as a technician it is vital for you to know what tools to use to measure air in an HVAC/R system. The same goes for hydronics. Hydronics—think water—also transfers heat. This means the tools used to measure hydronics are extremely important. The measurements you obtain from these readings will assist you in performing operational tests, troubleshooting, and balancing.

Revolutions per minute instruments

Revolutions per minute (rpm) instruments, commonly called tachometers, are used to measure the rpms of fans, pumps, and motors to determine if they are running at the right speed. Basically, a tachometer reads the the rpm of a spinning object. Every fan has a recommended maximum operating speed that must *not be exceeded*. When taking readings on equipment, you MUST know what rpms the equipment is designed to operate at and compare it to the reading on the instrument. If you don't know the rating on the equipment, then you won't be able to determine what your reading means.

The most common types of rpm instruments (tachometers) used are listed below. While there are many types of tachometers available, we limit our discussion to the following types in the table below.

- Direct-contact, manually timed revolution counters.
- Direct-contact, automatically timed chronometric tachometers.
- Non-contact, Photo tachometers.
- Non-contact, stroboscopes.

RPM Instruments	
Type	**Description**
Direct-contact manually timed revolution counters	Direct-contact, manually timed revolution counters are small and inexpensive rpm reading instruments (fig. 1–20). Easily carried in your pocket, they are available at any time. The recommended maximum speed is 1,000 rpm for constant service; however, for intermittent service, as in balancing, 2,500 rpm is acceptable.

RPM Instruments	
Type	**Description**
	 **Figure 1–20. Direct-contact, manually timed revolution counter.** You must take timed readings with a watch that has a second hand or with a stopwatch. Apply the rubber tip of the revolution counter to the end of the rotating shaft. When you push the plunger in, a clutch engages a mechanical counter. The counter can turn in either direction—clockwise or counterclockwise. Remember there is an inherent safety risk when taking readings directly because the instrument is placed on a moving object. If you aren't cautious you run the risk of injuring yourself.
Direct-contact automatically timed chronometric tachometers	Probably the most practical and accurate of the direct-contact-type tachometers is the automatically timed chronometric counter. It incorporates a combination revolution counter and precision stopwatch in one unit. It is self-timing and self-zeroing. Simply press and release the operating button. The counter zeros itself, counts for 6 seconds, automatically stops, computes, and locks in the rpm for a 1-minute period. Again, remember there is an inherent safety risk when taking readings directly because the instrument is placed on a moving object.
Non-contact photo tachometer	This type tachometer reads rpms directly and instantly. As stated previously, a tachometer measures the rpm of a spinning object. The photo tachometer is no different in this aspect. The difference from the contact types is the photo tachometer does not require contact with the shaft or pulley like mechanical-contact tachometers. Therefore, it is less likey injury will occur due to moving parts (fig. 1–21). Where space conditions are such that you cannot reach the end of the shaft, you can direct the photo tachometer's light beam toward the shaft or pulley from any available vantage point. No connections or wires are needed, as the photo tachometer has a self-contained power source of throwaway batteries.  **Figure 1–21. Non-contact photo tachometer.**

RPM Instruments	
Type	**Description**
Non-contact stroboscope	This device operates by flashing a light on and off at a known frequency. When the object appears to be standing still, the rpm of the equipment matches the frequency and the reading will be displayed for the technician. No contact is needed between the stroboscope and the object being measured.

Pressure reading instruments

You use the pressure reading instruments for reading air velocities in ducts; pressure drops across components; fan inlet and discharge pressures; pressures in ducts, plenums, spaces, outside; draft in flue or chimney. These readings are taken with the following instruments:

- Inclined liquid manometer.
- Inclined-vertical liquid manometer.
- Pitot tube.
- Magnehelic pressure gauges.
- U-Tube manometer.
- Digital manometer.

Pressure Reading Instruments	
Type	**Description**
Inclined liquid manometer	This pressure measurement device is simple in construction and very easy to use. It can be used at pressures above and below atmospheric pressure and can be used for pressure differential measurements. Some locations you may use this to take readings are in ducts, fan inlets and outlets, and to read pressure drops across system components. The precision, accuracy, and range of this tool varies by manufacturer. One disadvantage is the time it takes to set these up because they have to be releveled every time they are moved. The red liquid in the manometer is called red gauge oil. The inclined manometer is used to measure low pressures usually in inches of water column. The inclined manometer is not used alone and requires a pitot tube (discussed below). The pitot tube allows system air to enter on one or both sides of the inclined manometer. Static and total pressures can be taken individually by connecting only one tube. If both tubes are connected then the inclined manometer will give the difference between the static and total presures, otherwise known as the *velocity pressure*. Use your OJT and manufacturer's manual for more information on when and how to use this tool.
Inclined-vertical liquid manometer	This tool operates on the same principle as the inclined manometer and is also used with the red gauge oil and pitot tube. It is commonly used for higher pressure readings than the inclined manometer. The reading is usually given in inches of water column. One disadvantage is the time it takes to set it up because is has to be releveled every time it is moved.
Pitot tube	Use the pitot tube with manometers to sense both total and static pressure in ducts and plenums. Insert it into the airstream parallel to and facing the airflow. Pitot tubes are double-wall tubes that are constructed of stainless steel. The inner tube senses total pressure, and the outer tube sense the static pressure. The total pressure enters the center of the tip of the leg facing the airstream and comes out of the center of the bottom. When you insert the pitot tube into the airstream, static

Pressure Reading Instruments	
Type	**Description**
	pressure enters through a ring of small holes around the main leg, travels through the outer tube, and leaves the short leg near the bottom. You can read static and total pressures separately with a single hookup to either the static or the total pressure legs at the bottom of the tube. Velocity pressure readings are made with the pitot tube by hooking up, simultaneously, to both the static pressure legs and to both sides of the manometer at the same time. • Hook up the static pressure leg, which is normally the lower pressure, to the right side of a liquid manometer. • Hook up the total pressure, which is the greater pressure, to the left side of the manometer. The two forces internally subtract themselves in the gauges and result in a velocity pressure reading.
Magnehelic pressure gauges	The inclined and vertical draft gauges are excellent and highly accurate instruments for velocity pressure readings. However, they take a relatively long time to set up, they have to be releveled each time they are moved, and they can be knocked over accidentally. Consequently, they are not very practical for the many static pressure readings that you must make in balancing. To overcome these problems, a series of direct-reading air pressure gauges were developed. Called magnehelic gauges, they are extremely portable, quick to set up, and far handier than the liquid gauges. Like the liquid gauges, we use them with pitot tubes, straight tubes, static sensors, rubber tubes, and so on, releveled. The magnehelic is a dry-type manometer that uses an internal bellow, which is connected to the scale needle for sensing pressure. The scale is usually in inches of mercury, inches of water column, or pounds per square inch (psi). The magnehelic gauge has many uses in the balancing, servicing, and maintenance of air distribution systems. You can use it for reading • Pressure drops across filters, coils, and dampers, duct runs in balancing, and troubleshooting. • Fan inlet and discharge pressures. • Pressures at the inlet of constant-volume and variable-air-volume (VAV) terminal boxes. • Orifice valves in induction units. • Pressure differential or velocity at flow or pressure measuring stations. The magnehelic gauge needs more frequent calibration because it is a mechanical instrument and is sensitive to physical abuse, dirt, dust, corrosive gases, and fluids.
U-tube manometer	U-tube manometers are inexpensive liquid instruments for measuring positive, negative, or differential pressures with great precision in inches of water column. Since it uses water instead of oil of a different density, the U-tube gives you the full scale measurement of inches of water column. Balancers usually use flexible-plastic U-tubes with magnets for easy portability and mounting on metal surfaces. Use U-tube gauges for reading air pressure drops across system components, natural gas pressures in gas piping for heating equipment, and pressure drops across hydronic system components.
Digital manometers	Digital manometers are microprocessor-based instruments that are convenient, portable sized for ease of use in the field, panel use or stand alone mounting styles. Instead of using a liquid (like in the U-tube manometer), the digital manometer comes equipped with dual ports installed with sensors that take pressure measurements.

Velocity reading instruments

There are three basic types of velocity reading instruments you will use on the job: anemometers, velometers, and flow hoods. The following table provides some basic information about each one.

Velocity Reading Instruments	
Type	**Description**
Anemometers	Your shop may have an old manual anemometer that requires you to time each measurement with a separate watch. Those devices will not be discussed here. There are newer digital anemometers in use in many shops (fig. 1–22).  **Figure 1–22. Anemometer.** The operation is simple. The tool consists of a fan wheel that is placed in an airstream. As the air pushes against the fan wheel, a number is displayed on a screen. There are many units of measure velocity could be given but the number an HVAC/R technician should be most concerned with is feet per minute. In addition to measuring air velocity, some anemometers can measure temperature, relative humidity, dew point, and cubic feet per minute (fpm). Accuracy at filters, louvers, and coils is very rough due to the uncertainty of the Ak (correction factor) area. Correction factors can be found in the manufacturer's literature. The degree of accuracy in an anemometer also varies with the speed of the air flowing through it. Manufacturers provide correction factor charts for adding or subtracting fpm from the actual reading.
Velometers	The velometer is an instantaneous, direct-reading, air-balancing instrument that reads air velocities in fpm and pressures in inches of water column. The velometer excels in reading supply-air velocities at ceiling diffusers. Its versatility also includes reading exhaust velocities at grilles, hoods, and duct openings; air currents in open spaces; velocities at filters, coils, and louvers; pitot-tube traverses; and static pressure. The internal sensor is made so that the instrument can be held in either a horizontal or a vertical position. The instrument doesn't require correction factors for different density air. It operates on the pitot-tube principle where pressure is applied on a vane that travels in a circular tunnel. Two hoses are used with the newer models.
Flow hoods	A flow hood or capture box completely surrounds and covers a diffuser or grille and forces all the air to flow from the diffuser or grille to be measured. The airflow is measured directly in cubic feet per minute (cfm) with one reading in a few seconds (fig. 1–23).

<table>
<tr><th colspan="2">Velocity Reading Instruments</th></tr>
<tr><th>Type</th><th>Description</th></tr>
<tr><td></td><td>


Figure 1–23. Flow hood.

Flow hoods save the time and hassle involved with Aks and multiple velocity calculations.

They avoid the potentially erroneous readings of diffusers due to jet velocities and misdirected airflow from dampers behind grilles.

Flow hoods are especially practical in existing buildings where the manufacturers or Ak factors of the outlets are not known, in wide open areas, and where there are a multitude of ceiling diffusers and grilles. They handle air-light troffers and linear and perforated diffusers well.

Do *not* use them where the ductwork and outlets are exposed or where there are no ceilings or walls.

The designer of a flow hood must take the back pressure on the diffuser that is created by the flow hood into consideration and compensate for it in the design of a proper flow hood.

The flow hood consists of a nylon cloth top, aluminum bottom housing with an averaging manifold to sense the total and static pressure at 16 traverse points, a specially adapted velometer, and a range selector.

Five standard top sizes are assembled from interchangeable frame members:

- 24 by 24 inches.
- 25 by 47 inches.
- 13 by 47 inches.
- 13 by 60 inches.
- 36 by 36 inches.
</td></tr>
</table>

This concludes the discussion on velocity reading instruments.

Hydronic flow measurement tools

We can measure flow in a hydronic system in a number of different ways:

- With a flow measuring meter.
- By reading the pressure drop across a system component and relating it to the manufacturer's published flow-pressure data.
- By reading the air temperature change across the component and again relating it to the manufacturer's flow data.

Reading the flow directly is the most accurate and positive technique. The instruments covered in this unit deal with flow measurement. Pressure drop and temperature readings are less reliable and are subject to other variables.

There are a number of different types of flowmeters available that are manufactured specifically for flow measurement:

- Orifice-plate flowmeter.
- Venturi flowmeter.
- Circuit testers.
- Pitot-tube flowmeter.

<table>
<tr><th colspan="2">Hydronic Flow Measurement Tools</th></tr>
<tr><th>Type</th><th>Description</th></tr>
<tr><td>Orifice-plate flowmeters</td><td>
Sharp-edge orifice plates have a high degree of accuracy and are relatively low cost.

The temporary pressure drop across the orifice-plate opening, in inches of water, is correlated against the flow in gallons per minute (gpm) by the manufacturer in the laboratory (fig. 1–24).

The manufacturer prepares calibration curves for the equipment and furnishes them with the orifice plate. Normally, you can measure the orifice at maximum flow with a 100-inch differential pressure gauge.

Install the orifice plate within a straight length of pipe upstream and downstream of the plate. Determine the length of the pipe by the size of the orifice, according to the manufacturer’s instructions.

The orifice plate is used with a dial-type differential pressure gauge. The technician hooks up the gauge to the orifice plate, notes the pressure drop, and reads the gpm off the calibration curve based on the pressure drop.

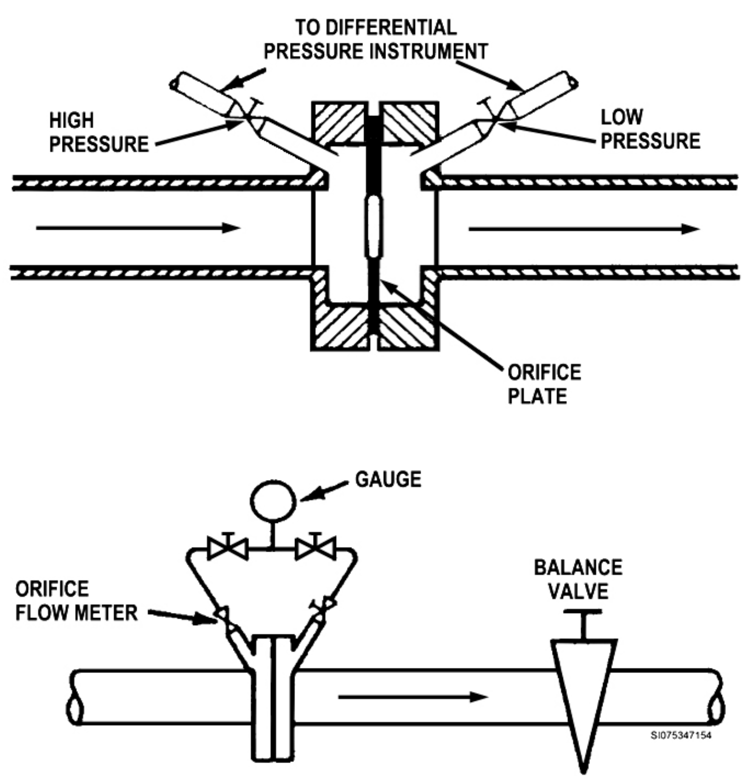
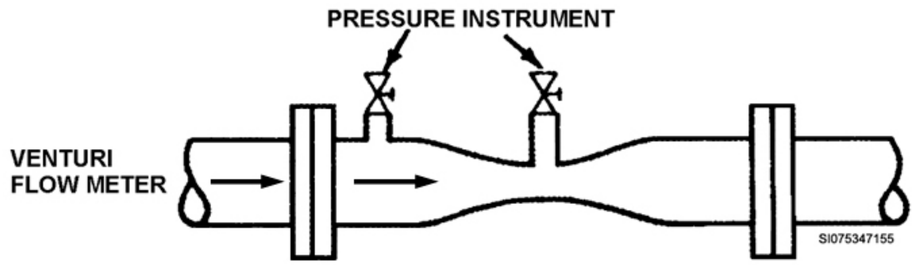
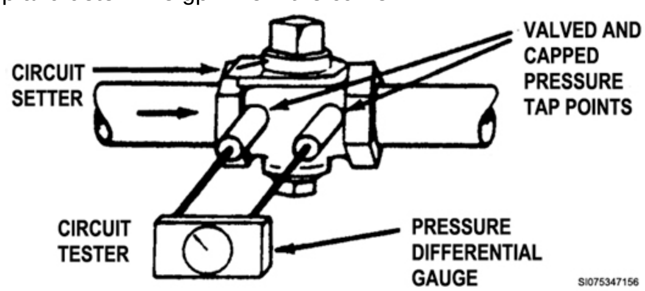


Figure 1–24. Orifice-plate flowmeter.
</td></tr>
</table>

Hydronic Flow Measurement Tools	
Type	**Description**
Venturi flowmeters	The venturi flowmeter (fig. 1–25) measures flow in a similar way as the orifice plate. The narrow neck of the venturi causes a pressure drop, and like the orifice plate, the manufacturer develops a calibration curve of pressure drop in inches of water versus gpm flow and provides it along with the meter. You must install appropriate lengths of straight pipe on either side of the meter also.  **Figure 1–25. Venturi flowmeter.**
Circuit testers	A circuit tester (fig. 1–26) is a variable-orifice flowmeter that combines a flowmeter and a balance valve into one unit. In addition to its functioning as a balancing flowmeter, it also serves as a shutoff valve. Readings are in feet of water rather than inches; consequently, a foot-reading differential is required. The procedure, again, is the same as with the orifice plate and venturi: read the pressure drop and determine gpm from the curve.  **Figure 1–26. Circuit tester.**
Pitot-tube flowmeter	The pitot-tube flowmeter is used to determine the velocity of fluid by measuring the difference in static and dynamic pressure between two points in a pipe. It is used to measure the local velocity at a given point in the flow stream and not the average velocity in the pipe or unit. Pitot tube flowmeters are very common in measuring fluids in hydronic systems and have very low pressure loss.

Summary

We covered the specific tools used when working on cooling, heating, electrical, air, and hydronic systems. It is vital to have a strong understanding of all of these tools. Knowing which tool to select for a particular job and having a good foundation of how HVAC/R tools work will save you time and will lead to a safer work environment. Procedures on how to use these tools was not covered here since they are covered in your OJT, which focuses on the specific tools used in the shop you will be working in. With the knowledge gained here you should be ready for the next unit.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

005. Air and hydronic measurement tools

1. What may result if you do *not* exercise caution when using direct-contact manually timed revolution counters?

2. Why is the direct-contact, automatically timed chronometric tachometer the most practical?

3. Why is injury not as much of a concern with the non-contact photo tachometer?

4. Why are no connections or wires needed with the non-contact photo tachometer?

5. When can the inclined liquid manometer be used?

6. If both tubes are connected then the inclined manometer will give what pressure?

7. Why does the inclined vertical manometer take so long to set up?

8. When air enters the inner tube of the pitot tube, what pressure will be read?

9. Why were magnehelic pressure gauges developed?

10. How does the U-tube manometer give you full scale measurement of inches of water column?

11. What happens when air pushes against the fan wheel on an anemometer?

12. Why is the accuracy at filters, louvers, and coils very rough?

13. Why can the velometer be held in the horizontal or vertical position?

14. How is all of the air forced to flow through the diffuser or grille to be measured by the flow hood?

15. When are flow hoods especially practical?

16. Why are pressure drop and temperature reading less reliable?

17. What causes the pressures drop in an orifice-plate flowmeter?

18. What causes the pressure drop in a venturi flowmeter?

Answers to Self-Test Questions

001

1. Knowing how and when to use each one.
2. False readings and prevents detection of small leaks.
3. In well-ventilated spaces.
4. Small leaks.
5. Because any turbulent gas will generate ultrasound when it leaks.
6. Very small leaks.
7. Leaking or broken bourdon tube.
8. For charging refrigeration compressors with oil while they are under pressure.
9. Exhausts it to the intake of the second stage.
10. The second stage pulling in at a lower pressure.
11. The gauge assembly reads inches of mercury and is not accurate when pulling deep vacuums.
12. To the system’s piping or the MGA connection.

002

1. Glass stem mercury type.
2. This will affect the temperature reading.
3. Location.
4. To prove to a customer that a facility or room is getting the proper temperatures. Also, it could be used to identify a troublesome area
5. By a thermocouple.

003

1. Probe.
2. Erroneous readings.
3. Column of liquid.
4. Combustion efficiency and stack loss of an oil heating installation.

5. Combustion efficiency slide rule
6. A smoke tester.
7. With a draft gauge.

004

1. It will die sooner.
2. Because you may damage the electronics on the inside.
3. Bare leads can shock you if you touch them.
4. Replace it.
5. To place the clamp on around a conductor and operate controls or observe other parts of the system running on the other side of the mechanical room and still be able to read the amps flowing through the conductor.
6. To measure the resistance of insulating material.
7. When voltage is present.
8. Because a quick voltage check is desired.
9. To test a capacitor.

005

1. Injury.
2. Because it is automatic and more accurate.
3. There is no contact being made with any moving parts.
4. The tool has a self-contained power source of throwaway batteries.
5. At pressures above and below atmospheric pressure and can be used for pressure differential measurements.
6. Velocity pressure
7. Because it has to be releveled every time it is moved.
8. Total pressure.
9. To overcome the disadvantages of the inclined and inclined vertical manometers.
10. Uses water instead of oil of a different density
11. A number (usually fpm) is displayed on a screen.
12. Due to the uncertainty of the Ak (correction factor) area.
13. The internal sensor was designed for this use.
14. The flow hood or capture box completely surrounds and covers a diffuser or grille.
15. In existing buildings where the manufacturer’s or Ak factors of the outlets are not known, in wide open areas, and where there are a multitude of ceiling diffusers and grilles.
16. Because they are subject to other variables.
17. Orifice plate.
18. Venturi.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (001) When using a halide leak detector, the bluish flame turning green indicates
   a. a refrigerant leak.
   b. the system is leak free.
   c. the system is low on oil.
   d. the system is low on oil and leak free.

2. (001) On a manifold gauge assembly, the vacuum hose is $^3/_8$ inch and the other hoses are ¼ inch because larger sizes allow for
   a. more restrictions which will ensure a better vacuum.
   b. fewer restrictions but a vacuum may not be achieved.
   c. more restrictions which makes it easier and quicker to pull a vacuum.
   d. fewer restrictions which makes it easier and quicker to pull a vacuum.

3. (001) Why should the manifold gauge assembly *not* be used when measuring a vacuum?
   a. The manifold gauge assembly will not allow a vacuum to be pulled.
   b. The gauge assembly reads inches of fuel and is not accurate when pulling deep vacuums.
   c. The gauge assembly reads inches of mercury and is not accurate when pulling deep vacuums.
   d. The gauge assembly reads inches of water column and is not accurate when pulling deep vacuums.

4. (002) While taking a reading with an infrared thermometer, what happens as you get *further from the object being measured*?
   a. The object will heat up.
   b. The reading becomes more accurate.
   c. The screen will eventually turn blank.
   d. The reading becomes more inaccurate.

5. (003) What part of the *combustion analyzer* gets placed into the stack?
   a. The probe.
   b. The entire analyzer.
   c. Half of the analyzer.
   d. The handle and probe.

6. (003) What transfers *flue gases* from the boiler stack to the indicator unit?
   a. Pump.
   b. The burner.
   c. A tube and hand bulb.
   d. Suction from a vacuum.

7. (003) The special slide-rule calculator and CO_2 indicator are used to determine
   a. oil pressure.
   b. stack temperature.
   c. oil and gas pressure efficiency.
   d. combustion efficiency and stack loss.

8. (004) What will occur if you choose more than one conductor to measure when using a clamp on meter?
   a. Incorrect readings.
   b. The correct reading will be taken.
   c. The entire systems amperage will be read.
   d. The amperage of the entire component will be read.

9. (004) A megohmmeter should *never be used on a live circuit* because
   a. it has its own power source that will start the compressor.
   b. it has its own power source and it will ruin the meter.
   c. its power source with melt the wires in the system.
   d. the voltage reading will be incorrect.

10. (004) A *capacitance checker* is used to test
    a. the capacitance of a resistor.
    b. the voltage of a capacitor.
    c. a capacitor's ohms.
    d. a capacitor.

11. (005) A *photo tachometer* is used to read the
    a. revolutions per minute (RPM) of a spinning motor shaft.
    b. cubic feet per minute (CFM) of air flow.
    c. feet per minute (FPM) of air flow.
    d. CFM of a spinning motor shaft.

12. (005) When using the *stroboscope*, the frequency and reading is displayed for the technician when the object appears to be
    a. standing still and the rpm of the equipment matches.
    b. speeding up and the rpm of the equipment matches.
    c. slowing down and the rpm of the equipment rises.
    d. standing still and the rpm of the equipment rises.

13. (005) What pressure will be given if *both tubes are connected* to the *inclined manometer*?
    a. Velocity pressure.
    b. Burner pressure.
    c. Static pressure.
    d. Total pressure.

14. (005) Magnehelic pressure gauges were developed to
    a. overcome the disadvantages of the inclined and inclined vertical manometers.
    b. establish an industry standard for air measuring.
    c. eliminate the need to level equipment.
    d. eliminate red gauge oil.

15. (005) Why does the *magnehelic gauge* need more frequent calibration?
    a. Because it has a poor design.
    b. This feature makes in more accurate.
    c. Like all gauges it needs calibration for each use.
    d. Because it is a mechanical instrument and is sensitive to physical abuse, dirt, dust, corrosive gases, and fluids.

16. (005) Why is the accuracy at filters, louvers, and coils very rough?
    a. Due to the limited reach of the probe.
    b. Because the probe is *not* placed into the stack.
    c. Due to the uncertainty of the Ak (correction factor) area.
    d. Because the entire analyzer with probe must be placed into the stack.

17. (005) In order to be measured by the flow hood, how is all of the air forced to flow through the diffuser or grille?
    a. A flow hood or capture box completely surrounds and covers a diffuser or grille.
    b. A flow hood will be combined with other tools to capture all of the air.
    c. The diffusers are modified.
    d. A diffuser adjuster is used.

18. (005) When are *flow hoods* especially practical?
    a. When a journeyman is using them.
    b. When performing a hydronic balancing test in a new building.
    c. In brand new buildings where the blueprints are readily available.
    d. In existing buildings where the manufacturers or Ak factors of the outlets are not known.

19. (005) If you need a tool that functions as a *balancing flowmeter* you should select
    a. a venturi flowmeter.
    b. an orifice plate.
    c. a circuit tester.
    d. a flow hood.

Please read the unit menu for unit 2 and continue ➔

Student Notes

Unit 2. HVAC/R Piping and Tubing Fundamentals

THIS UNIT covers many different (but related) subjects; the information will be very useful in your work. We begin with a look at the steel piping and copper tubing lines used to transfer and control the liquids and gases used within heating ventilation, air-conditioning, and refrigeration (HVAC/R) systems. You will learn that these pipes and tubes not only must withstand high pressures but also are subject to pressures as low as a vacuum as well.

In addition to piping and tubing, automatic or manual control of the equipment is necessary. Many types of valves are used to make this possible. We'll cover the valves that are used to enable a certain amount of control—either automatic or manual. We'll end the unit with a discussion of backflow prevention concepts.

2–1. Steel Piping Applications

Part of your duties as an HVAC/R mechanic is to maintain environmental systems. To do this, you must be able to quickly and efficiently install or repair the heating and cooling lines associated with these systems. In order to accomplish these tasks, you must know how the systems are put together. In this section we'll first cover steel pipes and fittings. Then we'll turn our attention to the techniques used in pipe preparation. We conclude the section by discussing pipe fabrication methods.

006. Pipe and fittings

For all practical purposes, a pipe is a hollow cylinder that can be joined or coupled and used to transport or convey liquids or gases. When used in a HVAC/R system, it becomes a little more complicated and some important factors come into play. They include sizes and types.

Size

The pipes used in HVAC/R installations are manufactured for different pressures and are available in various rated sizes. The sizes of pipe can be as small as $^1/_8$ inch and as large as 24 inches. The size of a pipe is referred to as "*nominal*." Nominal is a theoretical size that may vary from the actual. In other words, the actual pipe size might be in decimals (1.315"), but to help reduce confusion it is sized as 1" nominal.

Steel pipe basically comes in two grades (fig. 2–1):

- Standard, or schedule 40.

- Extra strong (or heavy), or schedule 80.

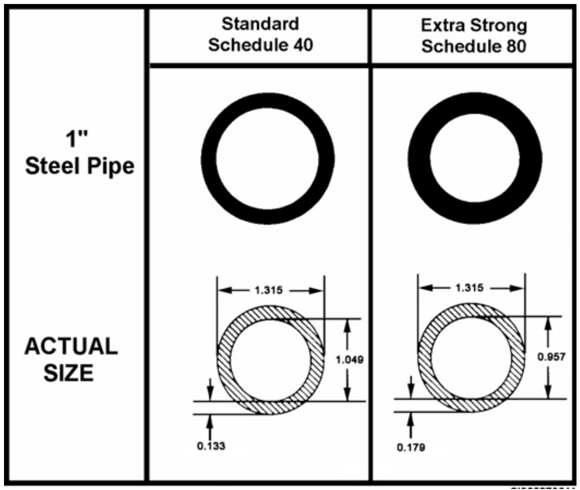


Figure 2–1. Grades of steep pipe.

These grades represent the wall thickness of a given diameter of pipe.

The inside diameter (ID) becomes smaller as the wall thickness increases. In the table below, the two pipe grades are illustrated by showing the actual sizes of a 1-inch (nominal) pipe. When pipe is needed for a high pressure it requires extra strong pipe (1” schedule 80 can be used up to 642 psig at 400 °F).This grade reduces the ID because the wall is thicker.

The diameters given for pipes are far from the actual outside diameters (OD), especially in the small sizes. For example, a pipe known as ¼ inch (rated size) has an OD of 0.54 inch and an ID of 0.364 inch. The following table illustrates the comparison of nominal and the true OD of various sizes of pipe.

Steel Pipe Sizes									
Pipe Sizes (nominal)	**½”**	**¾”**	**1”**	**1 ¼”**	**1 ½”**	**2”**	**2 ½”**	**3”**	**6”**
OD	= .54”	= 1.05”	1.315”	= 1.66”	= 1.9”	= 2.375”	= 2.875”	= 3.5”	= 6.625”

Types

Here we focus our attention on steel and iron pipes. There are other less common materials that are being increasingly used including:

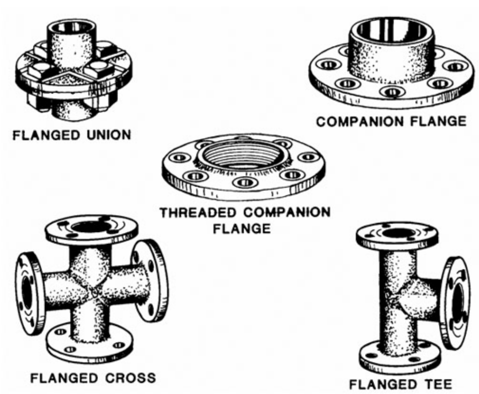
- Iron and steel alloys.
- Galvanized.
- Copper alloys.
- Nickel.
- Nickel alloys.
- Nonmetallic pipe.

Steel pipe can be seam-welded or produced without a seam. In addition, it comes either in black or galvanized. Galvanized pipe is coated with zinc, and is mostly used for domestic water applications. HVAC/R technicians primarily deal with black iron piping.

When you’re selecting piping materials, be sure you make reference to all applicable codes and dimensional standards, as well as to the material specifications that cover service requirements. These consider such effects as corrosion, scale, thermal or mechanical fatigue, and metallurgical instability at high temperatures and pressures.

Pipe fittings and their functions

Fittings are used to join two or more lines together or to connect one or more lines to a unit. Although all fittings have the same purpose, they may differ in composition, type, size, and shape. Three of the most common types used on HVAC/R systems are thread, flange, and welded. Thread and flanges are mostly used on steel pipe.

Pipe Fittings	
Type	**Description**
Thread fittings	Pipe fittings are fabricated in malleable iron for use with steel pipe and black iron pipe. There are many different types of pipe fittings. Pipe fittings are measured by ID, *not* by the OD of the pipe. For example, a ½" fitting will accommodate a ½" pipe, although the ID of the *fitting* may be around ¾". Threading is the main method for joining small diameter pipe. American Society of Mechanical Engineers (ASME) Standard B31.5, Refrigeration Piping, limits the threading for various refrigerants and pipe sizes. This publication states that *pipe with a wall thickness less than standard weight should not be threaded*.
Flange fittings	Illustrations of examples of threaded flanges are shown in figure 2–2. These fittings can be used for large pipe and all piping materials. They're commonly used to connect to equipment or valves. Also, they are installed wherever it may be necessary to open the joint to permit service or replacement of components. • For steel pipe, flanges are available in pressure rating to 2,500 psig. • For threaded pipe, thread-on flanges are available.  **Figure 2–2.Thread flanges.**

007. Pipe preparation

When you're preparing pipe for fabrication, you usually perform these three tasks:

1. Measure the pipe.
2. Cut the pipe.
3. Thread the pipe.

If you perform these tasks correctly, you'll ensure there will be a minimum of improper or defective connections. This will also ensure there is minimum leakage and loss of fluids. Systems that leak waste Air Force funds. For example, in a chilled water system, the chiller uses energy to chill the warm water. If there is a leak in the chilled water supply then the energy used to create the chilled water is wasted and now more water will have to be brought into the system which also costs money.

These actions will enhance the ability of HVAC/R systems to safely and properly perform their required function.

Measuring pipe

There are several different methods of measuring pipe including:

- End-to-center.
- End-to-end.
- Center-to-center.

The different views shown on figure 2–3 illustrate these methods.

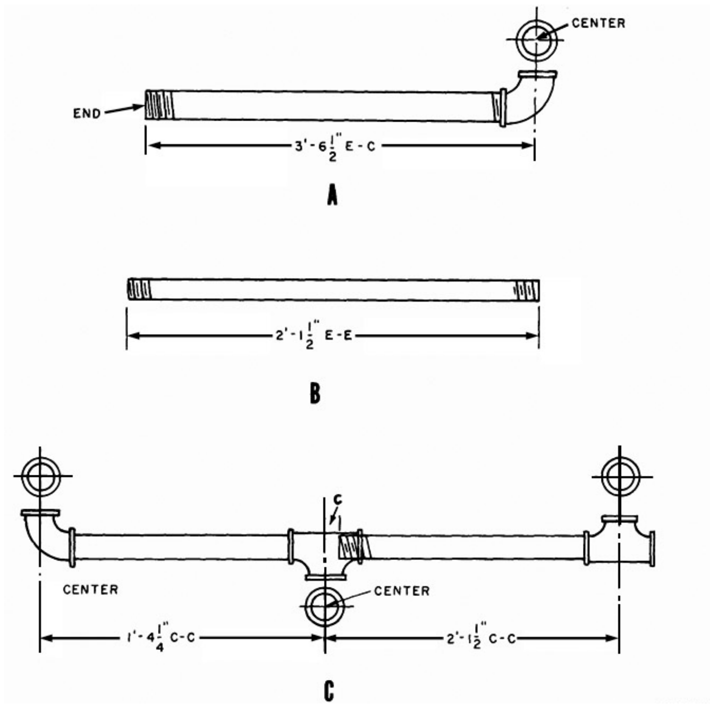


Figure 2–3. Center-to-center measurement.

Measuring Pipe	
Method	**Description**
End-to-center	An end-to-center measurement is taken from the center of an elbow or tee screwed on one end to the opposite end of the pipe (fig. 2–3, view A). This measurement is made by first tightening an elbow on the threaded end of a pipe. After this place the end of your rule exactly in the center of the fitting. Next, measure along the pipe and mark at the proper length.
End-to-end	Figure 2–3, view B illustrates end-to-end measurement. This is the measurement of the pipe *without any fittings*.
Center-to-center	Most pipe drawings are shown as center-to-center measurements (fig. 2–3, view C). As you can see, a center-to-center measurement is the distance between the centers of two fittings in a line of pipe. To make a center-to-center measurement: • First, put a fitting on the end of the pipe (fig. 2–3, view A).

Measuring Pipe	
Method	**Description**
	• Next, measure from the center of the fitting and mark the pipe as you did in the end-to-center measurement. • Finally, place the center of the tee on the mark and make a new mark allowing for the pipe to screw into the tee (fig. 2–3, view C).

Power cutting, reaming and threading

When working in HVAC/R, you'll frequently need to cut, ream, and thread pipe. Most often this is accomplished with a power threading machine. Most HVAC/R shops have access to a power threading machine, which is a big time saver when working on a project. Knowing how to use the power threading machine will save wear and tear on it as well as keep you safe. This lesson focuses on the steps involved in cutting, reaming, and threading using the power threading machine.

Cutting pipe

To cut pipe with these machines, follow the procedure in the table below.

Cutting Pipe	
Step	**Action**
1	Check the inside surface of the chuck to make sure that it is clean and free of pipe chips and flakes.
2	Insert the pipe into the chuck so that it protrudes about 8 inches beyond the face of the chuck.
3	Adjust the pipe rest to carry the weight of the pipe that extends beyond the end of the machine. This may require a pipe stand.
4	Tighten the chuck onto the pipe.
5	Advance the pipe dies and pipe cutter until the wheel of the cutter is directly in line with the mark on the pipe.
6	When the cutter is lined up with the mark, turn on the machine and apply pressure to the cutter wheel as the pipe rotates.
7	Rotate the handle one-quarter turn for each full revolution of the pipe. Do this until the pipe has been cut completely through
8	After you've cut the desired amount from the rest of the pipe, withdraw the pipe dies and cutter from the pipe.

Reaming pipe

Your next operation after cutting the pipe is to ream it to remove the burr caused by the cutter. To do this, follow the steps below.

Reaming Pipe	
Step	**Action**
1	Put the reamer into place.
2	Move the reamer toward the protruding pipe until it enters and touches the pipe.
3	Turn on the machine and apply pressure to the reamer until the pipe has been reamed properly.
4	Withdraw the reamer from the pipe.

Threading pipe

Before you thread a piece of pipe on a power-driven threading machine, check the pipe chuck jaw teeth to ensure they're clean and free of pipe chips or flakes. If they need to be cleaned, use a stiff wire brush to remove the dirt and chips. When the teeth of the chuck have been cleaned, follow the preparation steps in the table below before threading pipe.

Threading Pipe: Preparation Steps	
Step	**Action**
1	Open the chuck to receive the piece of pipe.
2	Insert the proper size die into the slots of the carriage.
3	Insert the die-holder pins.
4	Check to ensure all the teeth on the pipe dies are clean and not chipped.
5	Move the die-releasing handle up and down to ensure the segments in the dies open all of the way and come down the proper distance.
6	Take a short nipple and screw it into the die segments by hand to see that the segments are properly aligned. If you prefer, you can check the alignment of the segments by putting the nipple into the chuck, starting the machine, and running the dies onto the nipple. When the segments have been run the proper distance, release them by lifting the die-release lever. Back off the die and shut off the motor, stopping the chuck. After the chuck has stopped, open it and remove the nipple; then check it with a standard female-tapped fitting. You should be able to screw the nipple into the fitting by hand about 3 to 3½ turns. • If the nipple screws in more than 3 turns, the segments have been set too deep. • However, if the nipple screws in only about 2 turns, the segments are worn out or are improperly set (too shallow).

After the chuck and dies have been properly cleaned and set, you're ready to start threading the pipe. To do this, use the steps in the following table.

Threading Pipe	
Step	**Action**
1	Make sure that the release lever is in the closed position.
2	Move the dies up to the end of the pipe.
3	Before you apply pressure on the dies, be sure you have the oil running to help start the segments on the pipe. **NOTE:** If there is no oil, you will damage the dies.
4	Apply pressure until at least two threads are started. After this the die will continue to thread itself.
5	Allow the machine to operate until the end of the pipe comes through the die teeth about two full threads, and then release the segments by lifting up on the release lever.
6	Back off the diestock until it's clear of the pipe in the chuck.
7	Remove the threaded pipe from the machine.

008. Pipe fabrication

In this lesson, we'll look at two important factors of pipe fabrication. The first will be the assembly of threaded joints. You will be asked to connect piping systems to allow for the proper operation

HVAC/R systems like boilers and chillers. You must know how to assemble threaded joints in order to accomplish this task. Finally, pipe expansion and its flexibility will be covered.

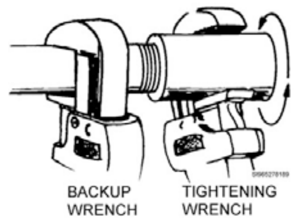
Assembly of threaded joints

Fittings are generally screwed to one end of the pipe while it's still in the vise after cutting, reaming, and threading. It is easier to assemble pipe while it is still in the vise versus trying to put it together at the job site. The assembled pipe and fittings are then screwed into the proper place in the system. The following table describes how to make up leak-proof joints while the pipe is in a vise.

Making Leak-Proof Joint With Pipe in a Vise	
Step	**Action**
1	Clean the threads of the fitting and pipe with a wire brush.
2	Apply a small amount of pipe joint compound (pipe dope) or Teflon tape to the male threads. There are several reasons for using pipe joint compounds. • They may be used as a lubricant, a sealing agent, a corrosive protective agent, or an anti-seize compound. • Anti-seize compound is used in case the joints must later be disassembled.
3	Screw the fitting hand tight on the pipe in a clockwise direction.
4	Select a pipe wrench from the following pipe sizes: • 8” wrench for ⅛ to ¼” pipe. • 10” wrench for ⅜ to ½” pipe. • 14” wrench for ¾ to 1” pipe. • 18” wrench for 1¼ to 1½” pipe. • 24” wrench for up to 2” pipe.
5	Tighten with the correct-sized pipe wrench about two more turns.

To tighten a fitting, such as a coupling without the use of a vise, follow the procedures in the table below.

Tighten Fitting Without Using a Vise	
Step	**Action**
1	Clean the pipe and fitting threads with a wire brush.
2	Apply pipe dope to the male threads.
3	Screw the coupling on the pipe hand-tight.
4	Select two wrenches. One of these is called a *backup wrench*; it holds the pipe or fitting in place so that it doesn't turn. This wrench takes the place of the vise.
5	Tighten the coupling on the pipe.
6	Screw in the remaining piece of pipe by hand.
7	Tighten the remaining piece of pipe using the pipe wrenches. The placement of the wrenches is illustrated in fig. 2–4.

Tighten Fitting Without Using a Vise	
Step	**Action**
	 **Figure 2–4. Tightening with wrenches.**

Pipe expansion and flexibility

A temperature change causes dimensional changes in all materials. For piping systems, this results in expansion and contraction. This expansion and contraction must be allowed to occur in response to thermal changes. Designing pipe bends and loops or supplemental devices such as expansion joints into the system can attain ample flexibility.

The table in figure 2–5 shows the coefficients of expansion for the piping materials most commonly used in HVAC/R systems. Notice how as the pressure and temperature go up, so does the linear thermal expansion. For example, consider a pressure of 232.6 psig and a temperature of 480 ºF. The linear thermal expansion, which basically means “how much the pipe expands due to heat,” for carbon steel is 3.97 inches per 100 ft. In contrast, the same carbon steel at 2.5 psig and 220 ºF is 1.69 inches per 100 ft. Remember the fact that this is only 100 ft., so for a building with 500 feet of carbon steel pipe at 232.6 psig and a temperature of 480 ºF, the total linear thermal expansion would be 19.85 inches.

			Linear Thermal Expansion in./100ft		
	Saturated steam pressure psig	Temperature °F	Carbon steel	Type 304 stainless steel	Copper
		-30	-0.19	-0.30	-0.32
		-20	-0.12	-0.20	-0.21
		-10	-0.06	-0.10	-0.11
		0	0	0	0
		10	0.08	0.11	0.12
		20	0.15	0.22	0.24
	-14.6	32	0.24	0.36	0.37
	-14.6	40	0.30	0.45	0.45
	-14.5	50	0.38	0.56	0.57
	-14.4	60	0.46	0.67	0.68
VACUUM	-14.3	70	0.53	0.78	0.79
	-14.2	80	0.61	0.90	0.90
	-14.0	90	0.68	1.01	1.02
	-13.7	100	0.76	1.12	1.13
	-13.0	120.	0.91	1.35	1.37
	-11.8	140	1.06	1.57	1.59
	-10.0	160	1.22	1.79	1.80
	-7.2	180	1.37	2.02	2.05
	-3.2	200	1.52	2.24	2.30
	0	212	1.62	2.38	2.43
	2.5	220	1.69	2.48	2.52
	10.3	240	1.85	2.71	2.76
	20.7	260	2.02	2.94	2.99
	34.6	280	2.18	3.17	3.22
	52.3	300	2.35	3.40	3.46
	75.0	320	2.53	3.64	3.70
	103.3	340	2.70	3.88	3.94
	138.3	360	2.88	4.11	4.18
	181.1	380	3.05	4.35	4.42
	232.6	480	3.97	5.56	5.65
	294.1	420	3.41	4.83	4.91
	366.9	440	3.60	5.07	5.15
	452.2	460	3.78	5.32	5.41
	551.4	480	3.97	5.56	5.65

Figure 2–5. Coefficients of expansion.

For systems operating at high temperatures, such as steam and hot water, the rate of expansion is higher, and significant movements can occur in short runs of piping. Even though rates of expansion may be low for systems operating in the range of 40 to 100 °F (5 to 40 °C), such as chilled and condenser water, they can cause large movements in long runs of piping. These movements commonly occur in distribution systems and high-rise buildings. Therefore, in addition to design requirements for pressure, weight, and other loads, piping systems must accommodate thermal and other movements to prevent the following problems:

- Failure of pipe and supports from over-stress and fatigue.
- Leakage of joints.
- Detrimental forces and stresses in connected equipment.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

006. Pipe and fittings

1. What type of pipe should be selected when pipe is needed for a high pressure application?

2. When should pipe *not* be threaded?

3. When would flanges be installed?

007. Pipe preparation

1. What is the next step after you place the end of your rule exactly in the center of the fitting?

2. What is the *first step* in making a *center-to-center* measurement?

3. After you check the inside surface of the chuck to make sure that it is clean and free of pipe chips and flakes, what is the *next step*?

4. What is the next step after the cutter is lined up with the mark?

5. What must be done *before* you thread a piece of pipe on a power-driven threading machine?

6. What should be done *after* you insert the die-holder pins?

7. When are you ready to start threading the pipe?

8. What is the *first step* of threading pipe?

008. Pipe fabrication

1. After you clean the threads of the fitting with a wire brush, what is the *next step*?

2. What do you do *immediately after* you screw the fitting hand tight on the pipe in a clockwise direction?

3. Without using a vise, what action do you take *after* you screw the coupling on the pipe hand-tight?

2–2. Copper Tubing Applications

Part of your job as an Air Force HVAC/R specialist is working with copper piping. Working with copper is enjoyable because it's lightweight and easily installed. Joints are easily made and are as permanent as the tubing itself. Another advantage of copper is its lack of resistance to flow. Because of this, copper can be used anywhere pipe can be used (*except* in gas systems). In this section, we'll first look at the different types of tubing and fittings. Then we'll cover tubing preparation and fabrication.

009. Tubing and fittings

There are many types of tubing that you will encounter when installing HVAC/R systems. Each type of tubing has its own specific characteristic that determines how and when it will be used. Then, in order to connect your tubing, you'll have to know the many different types of fittings that can be used to make your installation job easier or neater.

Characteristics of tubing

Copper tubing may be hard drawn or annealed. Hard-drawn tubing is called copper pipe and comes in 20-foot lengths. Annealed tubing is soft-tempered and comes in rolls. One of the most confusing things about copper tubing is how it's sized. Here is how it is broken down:

- *Plumbing applications* such as waste water or domestic water use tubing sized according to plumbing tubing (ID).
- *Refrigeration components* use tubing sized for air conditioning (OD).
- *Heating installations* - Primarily your heating applications require copper pipe or tubing designed for water use. Basically, you will be using the same pipe/tubing as the plumber, ID.

When you're deciding upon the type of tubing material required for an application, you also need to determine the size. The following table shows a comparison of the diameters between air conditioning (OD) and plumbing tubing (ID):

Copper Tubing Sizes	
Air Conditioning	**Plumbing (nominal)**
¼” OD =	$^{1}/_{8}$” ID
$^{5}/_{16}$” OD =	$^{3}/_{16}$” ID
$^{3}/_{8}$” OD =	¼” ID
½” OD =	$^{3}/_{8}$” ID
$^{5}/_{8}$” OD =	½” ID
¾” OD =	$^{5}/_{8}$” ID
$^{7}/_{8}$” OD =	¾” ID

Normally OD tubing is $^{1}/_{8}$ inch bigger than plumbing tubing. For example, a piece of $^{7}/_{8}$ inch OD tubing will equal ¾ ID in plumbing. This information will become valuable when you’re confronted with plumbing size verses an air conditioning/refrigeration tubing size.

Types of copper tubing

Copper and copper alloy material is used a lot in the HVAC/R areas. (*Alloy* basically means one or more than one type of metal is combined with another.) This is due to its inherent resistance to corrosion and ease of installation. Even though there are other types of copper tubing, you will mostly work with three main types of copper:

- K copper.
- L copper.
- Air conditioning refrigeration (ACR) copper.

Copper Tubing	
Type	**Description**
K copper	A green-colored band and a stencil on the surface identify a pipe as type K. This type of copper can be used with brazed joints for high pressure-temperature applications and can be directly buried in the ground. Type K is available in a variety of sizes ranging from ¼ inch to 12 inches in diameter and has the thickest wall of the three types being discussed. This type is mostly purchased in lengths of 10 to 20 feet hard drawn but can be annealed (soft) temper.
L copper	A blue-colored band and a stencil on the surface identify a pipe as type L. This type of copper is also available in hard and soft temper. It’s used for recirculating water, refrigerant, and potable water inside buildings. Type L is available in ¼ inch to 12 inches in diameter. Type L copper can also be purchased in standard lengths of 10 to 20 feet hard drawn, or coils 25 to 100 feet annealed.
ACR copper	ACR tubing should be used on ACR systems. When you purchase ACR tubing, there will be plugs inserted into the ends of the tubing. These plugs are saying that the tubing has been dried and then charged with nitrogen from the factory. The purpose behind sealing the tubing is to reduce the possibility of oxidation within the tube.

One of the main reasons for several types of classification is due to the differences in wall thickness, but all types will have the same OD for corresponding sizes. This wall thickness also determines how the tubing can be used.

As previously mentioned, copper can be either hard drawn or soft temper. Soft temper is commonly used for applications where the number of joints is kept to a minimum (i.e., radiant heating panels in slabs, fuel lines, and lines below grade). In exposed locations, hard-drawn copper generally is used.

Types of specialty tubing

With the emphasis on energy efficiency, its ease of handling and high-heat conductivity makes copper tubing highly desirable for use in the HVAC/R installations. However manufacturers are using alternative methods such as aluminum tubing. Some of the specialty tubing you may encounter is described in the following table.

Specialty Tubing	
Type	**Description**
Aluminum tubing	Aluminum tubing is being used because it is lightweight and has a high-heat conductivity rating. Aluminum tubing is widely used in the manufacture of evaporators for domestic refrigerators. This type of tubing is also used for many pilot lines for gas-burning equipment.
Steel tubing	In some installations, thin-wall steel tubing is being used for refrigeration and air-conditioning work. Steel tubing can be connected to the system by using a flare joint or silver brazed joint.
Stainless steel tubing	Stainless steel tubing is required in milk-handling systems, ice cream manufacture, and in food processing. Stainless steel tubing is available in the common refrigeration tube sizes. It’s strong, resistant to corrosion, and can be connected to the system by either brazing or a flare connection.
Plastic tubing	Polyethylene tubing isn’t generally used in the refrigeration cycle; however, it’s often used in cold waterlines, evaporative coolers, and waterlines in evaporative and water-cooled condensers. Plastic tubing is also used for connecting pneumatic controls on HVAC/R systems.

Types of fittings

Except for steel pipe, copper pipe or tubing can be considered one of the most widely used material in the HVAC/R arena. There have been numerous fittings developed over the years to help you install your HVAC/R systems properly. The fittings we’ll discuss are primarily used with copper tubing. Fittings allow you to reduce, turn, and adapt to other line sizes, or just connect one line to another. The types of connection fittings include:

- Flare.
- Soldered.
- Adapters.
- Compression.

Fitting Types	
Type	**Description**
Flare	You can use a flare fitting when an item like a filter drier needs to be readily replaced. You can continuously tighten and untighten a flare fitting with little problem of leakage. These types of fittings are made of brass and connect tubing in all the usual methods using a tee, elbow, or some type of an adapter.

<table>
<tr><th colspan="2">Fitting Types</th></tr>
<tr><th>Type</th><th>Description</th></tr>
<tr><td></td><td>Then there is the union flare fitting that connects two tubing sections together of the same size (e.g., ¼” to ¼” OD) using flare nuts.</td></tr>
<tr><td>Soldered or brazed</td><td>Soldered and brazed fittings require more preparation or work to install but can last for years.

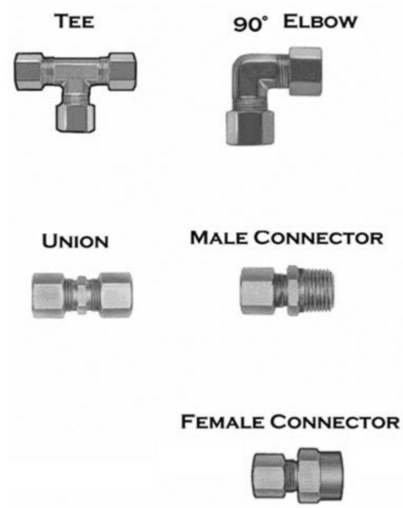
A filter drier could also be used with soldered or brazed fittings.

Soldered fittings are sometimes referred to as sweat fittings.

Refer to figure 2–6. The types include:
Couplings.
Tees.
Elbows.
Reducers.


Figure 2–6. Soldered fittings.</td></tr>
<tr><td>Adapters</td><td>At times, you may be required to make connections between steel pipe and copper pipe.

Use adapters for this purpose.</td></tr>
</table>

Fitting Types	
Type	**Description**
	One end of an adapter has standard pipe threads that are either male pipe threads or female pipe threads that will connect to steel or copper pipe.
Compression	A common type of compression fitting is shown in figure 2–7. These are easily connected, but aren't good for reuse in most cases and they don't take excess vibration very well. They also come in many different styles such as mentioned earlier for flare fittings. One example is a 90-degree elbow that has male National Pipe Thread (NPT) on one end and a compression fitting on the other (called a *male elbow*).  **Figure 2–7. Compression fittings.**

There will be times when you may have to order a particular size or type of fitting. All fittings have a standard classification that determines if they're sweat, male NPT, female NPT, and so forth. This chart shows some the common classifications.

C = Female solder (sweat)
Ftg. = Male solder (sweat)
F = Female NPT
M = Male NPT

Let's say you need to order a copper coupling that's female sweat on one end, and male sweat on the other end. In this case, you'd classify the coupling as C × ftg. Then a female sweat to female sweat would be C × C; as such, it would be called a coupling.

010. Tubing preparation

Successful preparation of copper tubing involves several steps including:

- Measuring.
- Cutting.
- Bending.

Measuring

Your first step in preparation of copper tubing is to make the necessary measurements for a particular installation. You can use the same procedures we used to measure threaded pipe. When you've determined the length, you're ready to cut the tubing.

Cutting

The second step in preparation is to cut the tubing. The two methods you can use to cut the tubing include the tube cutter and the hacksaw.

Tube cutter

The tube cutter for copper is similar to the pipe cutter for iron pipe but is usually smaller. To cut tubing with a cutter, follow these steps.

Cutting Tubing Using a Cutter	
Step	**Action**
1	Mark the tubing where it's to be cut. Use a pencil, pen, or marker to mark the tubing.
2	Install the cutter on the tube. Make sure the cutter wheel is over the mark.
3	Next, turn the tube-cutter adjustment knob clockwise until it makes contact with the tubing.
4	Now revolve the cutter around the tubing turning the adjustment knob slightly after each revolution. Continue this process until the tubing is cut through and the pieces separate.
5	After the tubing has been cut with a tube cutter, use the tube reamer on the cutter to remove the burr inside the tube. Place the point of the reamer into the end of the tubing and turn the reamer alternately in opposite directions until the burr is removed. Do *not* use tubing that has *not* been reamed because the burrs restrict flow through the pipe.

Hacksaw

Select a hacksaw blade with fine teeth to do the cutting. Be sure you cut the tubing square. The number of teeth per inch on the blade determines what type of work the blade will be used for. For example, 14 teeth per inch are used for soft metals; 24 inch for general work; and 32 teeth per inch for thin metal, tubing, or hard metal. Basically, the thinner or harder metal requires a blade with more teeth per inch. The blade must be placed in the right direction. To cut tubing with a hacksaw, follow the steps below.

Cutting Tubing Using a Hacksaw	
Step	**Action**
1	Select the 32 teeth per inch hacksaw blade.
2	Move the saw back and forth slowly with very little pressure.
3	Clean the edge of the cut with a file or pipe reamer.
4	Fine tune the edge with emery cloth.

Bending copper tubing

Most of the copper you'll use is soft enough to be formed into bends that are necessary to change the direction of a line. You may bend copper tubing by hand, but the slightest excess pressure at a particular point will flatten or kink the tubing and render it useless.

Anneal (soften) the portions of hard-tempered tubing by heating the portion of the tubing to be bent. Use a torch to heat the portion of tubing to be bent to a dull red color. Then cool it with rags soaked in water. After annealing, you can hand-bend the tubing. Be careful you don't make sharp bends or the tubing will partially collapse, flatten, or kink. If at all possible, use a tube bender for this operation. You'll have the option of using two basic types of tube benders:

- Bending springs.
- Lever type.

Bending spring

On occasions where the job doesn't require a high degree of accuracy, you can use a tube-bending spring (fig. 2–8) to bend tubing by hand. These springs come in all sizes for different diameters and are made for both internal and external use.

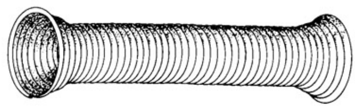


Figure 2–8. Bending spring.

When using the external spring, make all necessary bends *before* you make any flares or swages. The internal spring is for use near the ends of copper or flared tubing. It is best to use the external spring in the middle of long lengths of tubing. To bend copper tubing using an external flexible bending spring, first place the correct size of flexible bending spring over the copper tube; then gradually form the copper with your thumbs while you hold it against a table or solid flat surface.

Lever-type bender

A lever-type bender (fig. 2–9) is used to make bends in tubing when a high degree of accuracy is required. Often you have to make installations in close areas such as in closets and under staircases or foundations, and you have to make bends at specific angles in order for the tubing to connect the units. Not only does the lever-type bender provide an accurate means of fabricating bends, but it also helps to make a neat installation. Although the lever-type bender is light in weight, it's strong and durable.

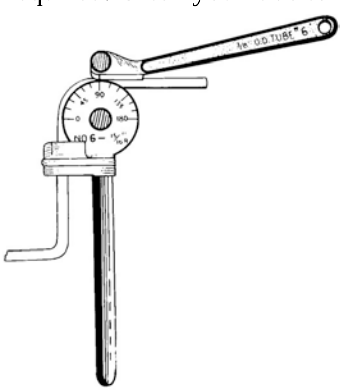


Figure 2–9. Lever-type bender.

There are two parts to the lever type tube bender—the body and the lever. The body has numbers that represent the amount of bend that is needed (fig. 2–9). The lever has markings of *L* and *R* to show the starting points and the number zero. To bend tubing with the lever-type bender, follow the steps in the table below.

For this example, the requirements are *a 90-degree angle with the center of the bend at 8 inches*.

Bending Tubing Using Lever-Type Bender	
Step	**Action**
1	Measure the pipe and determine the degree of bend. Measure 8 inches from one end (A) of the tubing to where you want the center of the bend (B) to be.
2	Now mark your measurement.
3	Insert the tubing with the end that you measured from (A) sticking out the left side of the bender.
4	Line your mark up with L on the lever. The reason the L is used is because you are sticking the measured portion out the left side.
5	Now ensure the "0" and "0" line up before you start to bend.
6	Now grab the handle of the lever and the handle of the body and pull them together until the "0" on the lever lines up with the 90 degrees on the body (fig. 2–10).
7	Pull the handles back and remove the tubing.

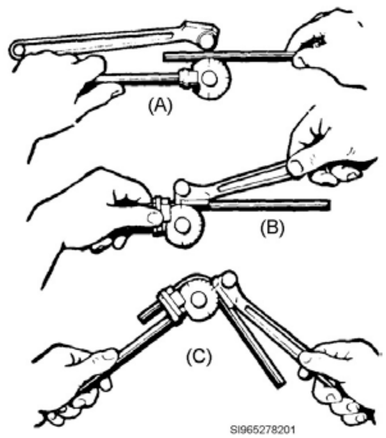


Figure 2–10. Tube bending.

The procedure above can be repeated for any of the degrees listed on the body. It can also be accomplished sticking the measured end out of the right side. If it is placed out of the right side, line your mark up with the R. In short, the letter L or R will depend on the direction the measured end of pipe is coming out of the bender. Practice this with your supervisor present. The only way to become proficient at this task is repetition, repetition, and repetition.

011. Tubing fabrication

There are several ways of fabricating tubing. Mostly this consists of making the proper connections or joints. We'll discuss the most common methods in this lesson which are:

- Flaring.
- Compression fittings.
- Soldering.
- Brazing.

Flaring copper tubing

One easy and satisfactory method of joining copper tubing is to flare the ends of the tubing and use a flare fitting. An advantage of this type of connection is that it's easily disassembled to make repairs. In previous versions of this course only single flare procedures were covered. Now we're taking it to the next level by including the double flare procedures.

Single flare procedures

When you make a flare on copper tubing, take every precaution to produce an airtight and watertight joint. Before you make the flare on the tubing, slip the flare nut on the tubing and insert the end of the tubing into the correct-sized hole in the flaring block. Follow the steps in the table below to complete your single flare.

Making a Single Flare on Copper Tubing	
Step	**Action**
1	First, measure and cut the tubing to the proper length with a tube cutter or hacksaw.
2	Remove the burr within the pipe by reaming it.
3	Clean the surface to be flared with emery cloth or steel wool. Remove any residual matter from the tubing.
4	Insert tubing in the flaring block so that the end to be flared extends above the surface approximately $^{1}/_{16}$ inch.

Making a Single Flare on Copper Tubing	
Step	**Action**
5	Tighten the block's clamp so the tube will not move while you flare.
6	Place refrigerant oil on the flaring cone.
7	Place the male end of flaring adapter inside the tubing.
8	Place the yoke onto the block and begin to turn the handle clockwise until the flaring adapter is tightly pressed against the block. Turn the handle clockwise ½ of a turn and then backwards ¼ of a turn. Repeat until you fully form the flare. *Do not overtighten!* This weakens the flare.
9	Turn counterclockwise until you can remove the yoke.
10	Unscrew the clamp handle and open the block.
11	Remove your finished tubing.
12	Put all pieces back into the flaring kit.

A completed flare should fill 75 percent of the flare seat inside the flare nut. The completed flare should not be large enough to come into contact with the threads inside the flare nut because copper particles taken from the flare may prevent a leak-proof connection.

Double flare procedures

Double flares can be accomplished with an adapter or a punch. The procedure we'll cover uses an adapter. Double flares are stronger than single flares and will rarely cause an issue if they are properly fabricated. Double flares should on be used on tubing that is $^{5}/_{16}$ inch and larger. This is because it is more difficult to make double flares on smaller tubing.

Before you make the flare on the tubing, slip the flare nut on the tubing and insert the end of the tubing into the correct-sized hole in the flaring block. Follow the steps in the table below to complete a double flare.

Making a Double Flare on Tubing	
Step	**Action**
1	Insert tubing in the flaring block so that the end to be flared extends above the surface of the block. Set the flaring adapter on the block so you can use it to see how far the tubing should extend. It should extend so the tube is even with the wide part of the adapter.
2	Tighten the block's clamp so the tube will not move while you flare.
3	Place refrigerant oil on the male end of the adapter.
4	Place the male end of flaring adapter inside the tubing.
5	Place the yoke onto the block and begin to turn the handle clockwise until the flaring adapter is tightly pressed against the block.
6	Turn the handle counterclockwise to back up the flaring cone far enough to remove the adapter.
7	Remove the flaring adapter from the tubing.
8	Turn the handle clockwise ¾ of a turn and then backwards ¼ of a turn. Repeat until you fully form the flare. *Do not overtighten!* This weakens the flare.

Making a Double Flare on Tubing	
Step	**Action**
9	Turn counterclockwise until you can remove the yoke.
10	Unscrew the clamp handle and open the block.
11	Remove your finished tubing.
12	Put all pieces back into the flaring kit.

Joint assembly

After the tubing has been properly flared, assembly of the joint is simple. To make the joint, it requires a fitting that's threaded and formed on both ends to receive the flare of the tubing. Some fittings are designed with only one end to receive the flare; others have a regular tapered pipe thread to fit the threads in casting or pipe. When the proper fitting is obtained,

1. Place the flare against the fitting.
2. Slip the flare nut against the flare.
3. Screw it on the fitting.

This operation squeezes the flare of the pipe between the fitting and flare nut making a watertight and airtight joint. When you properly tighten these joints with two wrenches, they'll withstand a pressure of 3,000 psi.

To prevent twisting the tubing, always use two flare nut wrenches when tightening or loosening these fittings. It isn't necessary to use a great deal of pressure when tightening these connections. This is because copper and brass fittings are soft, and the metals contain a certain amount of lubricant of their own which seals them together with a minimum amount of pressure.

Connect tubing using a ferrule (compression) fitting

The compression fittings have these three parts:

- Fitting.
- Nut.
- Brass ferrule (compression) sleeve.

To make this type of joint, follow the steps in the table below.

Connecting Tubing Using a Ferrule Fitting	
Step	**Action**
1	Cut the copper tubing to the correct length.
2	Ream the inside of the tubing to remove the burr.
3	Slip the nut on the tubing first.
4	Slip the ferrule on the tubing.
5	Slide the end of the tubing into the fitting, and slide the ferrule up against the fitting.
6	Screw the nut onto the fitting. Use either open-end or adjustable-jaw wrenches to finish tightening the nut on the fitting.

Tightening the nut squeezes the ferrule onto the tubing and against the fitting. This makes a watertight and airtight seal. Like flared joints, use two wrenches when assembling ferrule joints to protect the tubing from damage and prevent leaks. Take care not to tighten too much because the ferrule can be damaged and the fitting will leak. Do not use any type of thread sealers on compression fittings as they may cause the fitting to leak.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

009. Tubing and fittings

1. Where is aluminum tubing mostly used?

2. When would stainless steel tubing be used?

3. When installing a filter drier, what type of fitting(s) would be used?

4. When would an adapter be used?

010. Tubing preparation

1. What is the *first* step in preparation of copper tubing?

2. What is the *first* step in cutting tubing with a tube cutter?

3. What is done *immediately after* the tubing has been cut with a tube cutter?

4. What task can you perform after annealing?

5. When using an external spring what must you do before making any flare swagings?

6. What is the *first* step to bend copper tubing using an external flexible bending spring?

7. What is the *first* step of bending tube with a lever-type bender?

8. What is the *fifth* step of bending tube with a lever-type bender?

011. Tubing fabrication

1. What is the *second* step in the single flare procedure?

2. What is the next step after you insert tubing in the flaring block so that the end to be flared extends above the surface approximately $^{1}/_{16}$ inch?

3. What is the next step after you tighten the block's clamp so the tube will not move while you flare?

4. What is the next step after placing the male end of flaring adapter inside tubing?

5. What is the *second* step of assembling a joint?

6. On compression fittings, what is done after you ream the inside of the tubing to remove the burr?

7. What is the next step after slipping the nut on the tubing?

2–3. Valves

Valves are used throughout HVAC/R piping systems. Generally valves are used to control the flow of liquids or gases into, through, and out of an HVAC/R system. The type of valve used is important for the proper operation of the system. In this section we cover the characteristics of manual valves.

012. Valve basics

In the HVAC/R career field there are many types of valves used on the different systems. In this lesson, we'll only look at the major valves that are found on all systems. Individual valves relating to special pieces of equipment are covered in the appropriate section.

Every HVAC/R piping system must have some means of controlling the amount and direction of the flow of liquid or gas through the lines. This flow control is accomplished by using valves. The valves you'll encounter are made of bronze, brass, iron, or steel. In order to understand (or if ordering) these valves, you should be able to identify their size, markings, actual dimensions, and pressure ratings. Normally these valves are manufactured with certain exterior markings:

- Size-stamped on body side to reflect thread size (normally a nominal size).
- Body markings:

- o WOG—Water, oil, or gas.
- o WSP—Working steam pressure.
- o Arrow—To show flow direction.

In addition to these markings, there are two safety precautions you must heed:

- Unmarked brass valves can be used for a *maximum* of 125 psi or 450 °F temperature.
- All valves should conform to the requirements of the American National Standards.

Types of valves

Many different types of valves are used to control the flow of liquids and gases. The basic valve types are divided into three general groups:

- Stop valves.
- Check valves.
- Combination stop-check valves.

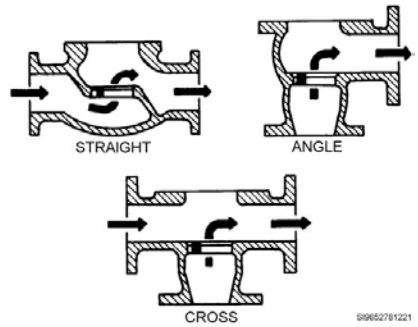
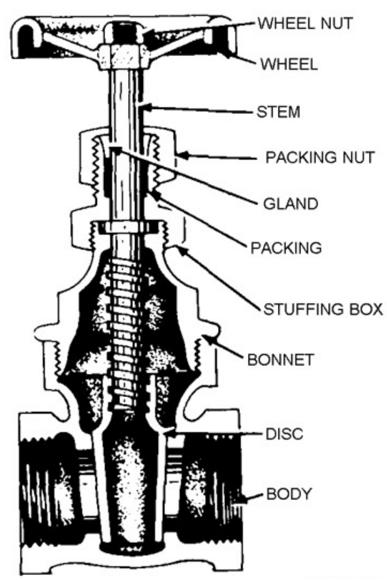
Stop valves

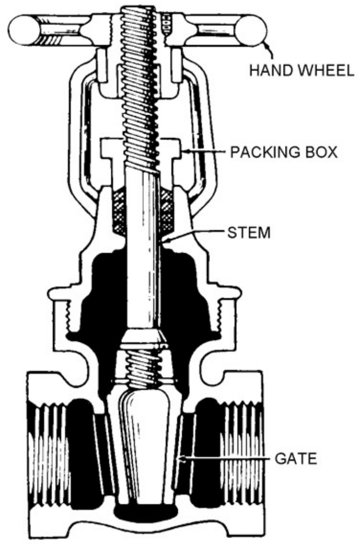
Stop valves are used to shut off—or in some cases to partially shut off—the flow of fluid. Stop valves are controlled by the movement of a valve stem. These valves include:

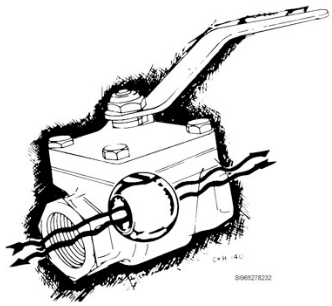
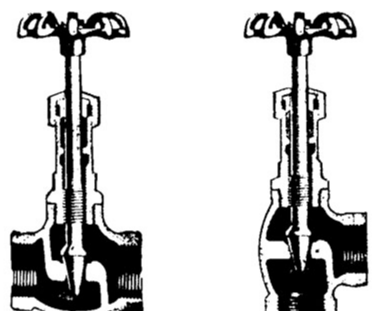
- Globe.
- Gate.
- Plug.
- Ball.
- Needle.

The following table provides additional information about each type of stop valve.

Stop Valves	
Type	**Description**
Globe	Globe valves are used in steam, air, oil, and water lines. They are one of the most common types of stop valves. Globe valves get their name from the globular shape of their bodies. Keep in mind that other types of valves may also have globe-shaped bodies; when you see a valve with a globe-shaped body, do not immediately jump to the conclusion that it's actually a globe valve. The internal structure of the valve, rather than the external shape, is what distinguishes one type of valve from another. • In a globe-type valve, the disc is attached to the valve stem. • The disc seats against a seating ring or a seating surface and, thus, shuts off the flow of fluid. • When the disc is moved off the seating surface, fluid can pass through the valve. • The valve is opened and closed by turning the handwheel clockwise to close and counterclockwise to open. The globe valve has one advantage over some valves in that it can be partially opened as well as fully opened or fully closed. Globe valve inlet and outlet openings are arranged in several ways to suit varying requirements of flow. Figure 2–11 shows three common types of globe valve bodies.

Stop Valves	
Type	**Description**
	 **Figure 2–11. Globe valve openings.** • In the *straight type*, the fluid inlet and outlet openings are in line with each other. • In the *angle type*, the inlet and outlet openings are at an angle to each other. An angle-type globe valve is commonly used where a valve is needed at a 90-degree turn in a line. • The *cross type* of globe valve has three openings rather than two; it's frequently used in connection with bypass piping.
Gate	Another valve used widely on HVAC/R systems is a gate valve. Basically, gate valves consist of the same items as a globe valve—a handwheel, a stem, a sliding disc, and a valve body. Gate valves can have *nonrising* or *rising* stems. • *Nonrising stems* are valves on which the stem is threaded on the lower end and the disc is threaded on the inside so that the disc travels up the stem when the valve is opened (fig. 2–12). • *Rising stems* are valves on which both the disc and the stem move upward when the valve is opened (fig. 2–13). These valves are designed with different shaped discs for different purposes.  **Figure 2–12. Non-rising stem.**

Stop Valves	
Type	**Description**
	 **Figure 2–13. Rising stem.** Gate valves are used for services requiring infrequent valve operation and where the valve disc is kept either fully opened or fully closed. When fully opened, the seating design permits the fluid to move through the valve in a straight line with a minimum restriction of flow and a minimum loss of pressure at the valve. This type of valve is not suitable for throttling flow (where the valve is kept only partially opened) since the velocity of flow against the partly opened valve may cause vibration and damage to the disc and seating surface. In order to prevent binding of some gate valves, they should be backed off ¼ turn to ½ turn from the fully closed position.
Plug	The body of a plug valve is shaped in such a way that it holds a cylindrical or tapered plug. Holes or slots in the body line up with the pipe in which the valve is installed. A solid cylindrical plug (or in some cases a plug shaped like a pyramid) fits snugly into the hollow of the body. A passageway is bored through the plug. The plug is attached to a handle allowing the plug to be turned within the body. • When the valve is in the OPEN position, the passage in the plug lines up with the inlet and outlet ports of the body, thus allowing fluid to flow through the valve. • When the plug is turned in the body (CLOSED), the solid part of the plug blocks the ports and thus prevents the flow of fluid.
Ball	A ball valve (fig. 2–14) is very similar to a plug valve except that the ball valve has a round ball with a hole through it to allow for flow through the valve. A handle is connected to the ball. • When the hole in the ball is in line with the inlet and outlet of the valve, the valve is *open*. • When you rotate the handle 90 degrees, the valve is *closed*.

Stop Valves	
Type	**Description**
	 **Figure 2–14. Ball valve.**
Needle	Needle valves (fig. 2–15) are stop valves used for making fine adjustments in the amount of fluid allowed to pass through an opening. You can recognize a needle valve by the long, tapering, needle-like point on the end of the valve stem. This “needle” acts as a disc. The longer part of the needle is smaller than the opening in the valve seat, and therefore, passes through it before the needle seats. This arrangement permits a very gradual increase or decrease in the size of the opening, and thus allows more precise control of flow than could be obtained with an ordinary globe valve.  **Figure 2–15. Needle valve.**

Check valves

Check valves are designed to permit the flow of fluid or gases in *only one direction*. The valves are controlled by the movement of the fluid itself. An illustration of the external appearance of a check valve is shown on figure 2–16. As we stated earlier, you can use a check valve when it’s necessary to control the flow of fluids or gases in one direction only. The flow of liquid or gas in the proper direction keeps the valve open, and the reversal of flow closes it automatically.

Figure 2–16. Check valve.

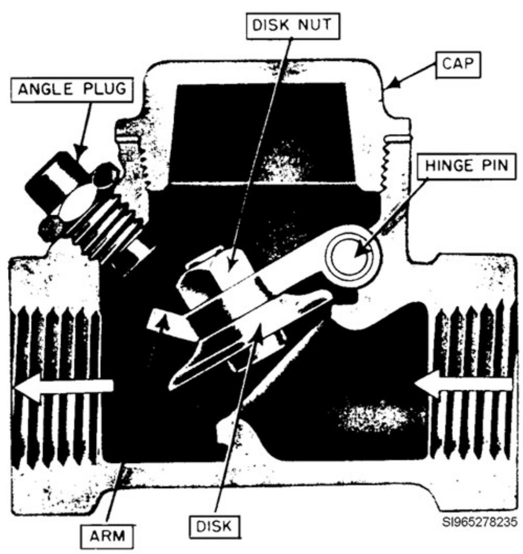
These valves have several variations that make them suitable for specific HVAC/R installations. For example, you can use check valves on boiler feedwater lines to prevent boiler water from backing up in the feedwater lines, or anywhere on a HVAC/R system where free-flow is needed in one direction only. They come in bronze, cast iron, ductile, and alloy iron check valves.

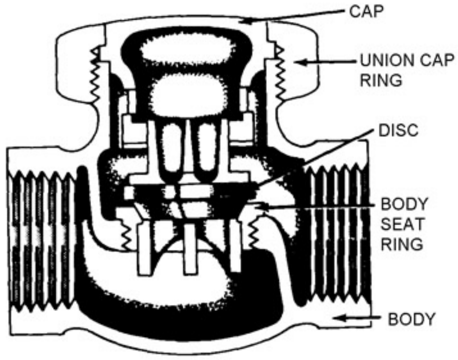
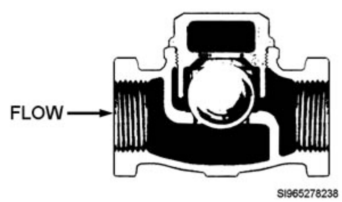
> **NOTE:** For installation purposes, check valves are marked with an arrow that indicates the inlet opening or direction of flow.

There are three basic types of check valves:

- Swing check.
- Lift check.
- Ball check.

The table below provides more information about each of these check valves.

Check Valves	
Type	**Description**
Swing-check	A cross-sectional view of a swing-check valve is shown on figure 2–17. As you can see, the valve contains a hinged disk which seats against a machined seat in the tilted bridge wall opening of the valve body. The disk swings freely on its hinge pin in an arc from a fully closed position to one parallel with the flow. The fluid or gas in the pipeline enters below the disk. Line pressure overcomes the weight of the disk and raises it to allow a continuous flow. If the flow is reversed, pressure is exerted against the disk, forcing it to close and to stop the flow. A swing check is usually installed in the same system as a gate valve; it can be installed either vertically or horizontally.  **Figure 2–17. Swing check valve.**
Lift-check	A cross-sectional view of a lift-check valve is shown on figure 2–18. This valve contains a disc that seats on a horizontal bridge wall in the valve body. The disc moves up to open and is raised from its seat by the pressure of the fluid flow. To ensure proper seating and rising, the disc has short guides, which are usually above and below the disc. The valve is closed by backflow, or by gravity when there’s no flow.

Check Valves	
Type	**Description**
	A lift check is usually installed in the same system as a globe valve. *This valve must be installed in a horizontal line.*  **Figure 2–18. Lift check valve.**
Ball-check	A ball-check valve is recommended for use in steam, water, oil, and gas systems. There are two types of ball-check valves: • Vertical. • Horizontal. As the name implies, the *vertical* type valve must be mounted in the vertical position. A cut-away view of the horizontal type ball-check valve is shown on figure 2–19. As the name implies, the *horizontal* ball-check valve must be mounted in the horizontal position. The direction of flow is from below the ball. The flow lifts the ball, opening the valve. If the flow is reversed or stopped, the ball will shut off the flow.  **Figure 2–19. Horizontal ball check valve.**

Combination stop-check valves

Combination stop-check valves function either as stop valves or as check valves depending upon the position of the valve stem. An example of this is a non-return steam valve.

In addition to the basic types of valves (stop and check) and the combination valves, you'll see many special valves that serve special purposes and can't really be classified as either stop or check valves.

013. Miscellaneous valves

You will work with valves on nearly every job you perform as an HVAC/R technician. It is important that you know about the valves discussed in this lesson so that you can be more efficient on the job site. We'll cover pressure, mixing, balancing, pressure reducing, and service valves.

Pressure valves

Pressure valves are designed to open automatically when the pressure in a line or vessel becomes too high. They can be used on liquids or gases. There are several types of pressure valves, but most of them look alike and operate the same. Most pressure valves have a disc or ball that acts against a coil spring. The spring pushes downward against the disc or ball and keeps the valve closed. When the pressure in the line or vessel is great enough to overcome the spring pressure, the disc or ball is forced upward, and the valve opens. After the pressure has been reduced (because of the escape of the liquid or gas through the pressure valve), the spring exerts enough force to close the valve again. Pressure valves must close tightly to avoid damage to the valve and seat.

There are three types of pressure valves used in the HVAC/R career field:

- Safety valve.
- Relief valve.
- Safety relief valve.

It's important you know the difference between these valves. The definitions provided by The American Society of Mechanical Engineers (ASME) are used in the table below

Pressure Valves	
Type	**Definition**
Safety	An automatic pressure-relieving device actuated by the static pressure upstream of the valve and characterized by full opening pop action. It's used for gas or vapor service.
Relief	An automatic pressure-relieving device actuated by the static pressure upstream of the valve, which opens further with the increase in pressure over the opening pressure. It's used primarily for liquid service.
Safety relief	An automatic pressure-actuated relieving device suitable for use either as a safety valve or relief valve, depending on application.

Mixing valves

This valve mixes hot water from one inlet with cooler water from another. After being mixed, the water leaving is the desired temperature. The valve opens and closes internally to adjust the leaving water temperature. There are two types of mixing valves—thermostatic and motorized. *Thermostatic* mixing valves have a sensing element that senses the temperature of the water and then adjusts the valve. For example, if the leaving water set point is 75 ºF and the temperature starts to rise, the valve will throttle back the hot water and "open up" the cold water. This will prevent the water temperature from rising. The *motorized* valve will accomplish the same task but it uses an electronic sensor instead of a thermostatic one. The electronic sensor monitors the temperature and a motorized valve opens and closes the hot and cold water.

Balancing valves

Balancing valves ensure the proper amount of water is supplied to each terminal unit. If a terminal unit is not receiving its designed water flow, then heat transfer will be negatively affected. You can adjust balancing valves to ensure proper flow to each terminal unit.

Pressure-reducing valves

The pressure inside of a hydronic system must stay within its design parameters. The pressure-reducing valve is installed in boiler make-up lines to ensure the pressure doesn't rise above the system's operating pressure. The city water pressure coming into a building is much higher than required for the system. The pressure-reducing valve reduces the city water pressure to the operating pressure of the system.

Service valves

These valves are installed in air conditioning and refrigeration systems to allow the technician access to perform tasks such as taking pressure readings, pumping down, compressor removal, recovering refrigerant, and charging the system (fig. 2–20). The service valve should be opened and closed with a service valve wrench unless the service valve was designed with a hand wheel. There are four positions the service valve can be in. Sometimes, less experienced technicians can confuse these positions. Each position is described separately in the table below for your convenience.

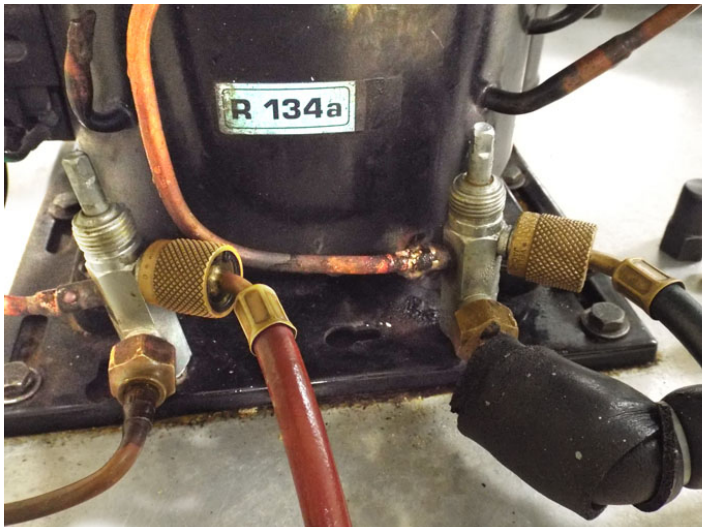


Figure 2–20. Service valves.

Service Valve Positions	
Position	**Description**
Back seated	This means the valve is backed all the way out. If the valve is turned counterclockwise all of the way, it is back seated. This is the position the valve should be in while the system operates. If the valve is back seated, then no pressure will be read on the gauges because the service port will be closed off from the system.
Front seated	This means the valve is turned all the way inward. If the valve is turned clockwise all of the way, it is front seated. This position will block the flow of refrigerant in the system. If the valve is front seated, it will allow a passage from part of the system and the service port.
Mid-position	This means the valve is somewhere in between the front and back seated positions. If the valve is back seated then turning the valve clockwise two complete rotations will put it in the mid-position. This position will allow refrigerant to continue its flow in the system and it will allow a connection between the rest of the system and the service port. When the valve is in the mid-position you will be able to read pressure on your gauges while the system is in operation.
Cracked position	This is much like the mid-position except the valve is only turned $^{1}/_{16}$ to $^{1}/_{8}$ of a turn clockwise. Cracking the valve will prevent a pressure rush which could damage your gauges. Crack a service valve before you fully open it to prevent this rush.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

012. Valves

1. Why does the *globe valve* have an advantage over some other valves?

2. When would a *gate valve* be used?

3. Why is the gate valve *not* suitable for throttling flow?

4. What should you do to prevent binding of a gate valve?

5. What position is the ball valve in when the handle is rotated 90 degrees?

6. Why does the *needle valve* arrangement permit a very gradual increase or decrease in the size of the opening?

7. If pressure is reversed, what will happen to the *check valve*?

8. What causes the ball to lift in a *lift check valve*?

013. Pressure regulating and miscellaneous valves

1. After the pressure has been reduced (because of the escape of the liquid or gas through the pressure valve), what causes enough force to close the valve again?

2. What does the *mixing valve* do when the leaving water temperature rises above set point?

3. What will happen if a terminal unit is *not receiving* its designed water flow?

4. Why is the *pressure reducing valve* installed in boiler make up lines?

5. If the valve is turned *counterclockwise* all the way, what position is it in?

6. If the valve is turned *clockwise* all the way, what position is it in?

7. When the *service valve* is front seated, what will happen to the refrigerant flow in the system?

8. What is the difference between the mid- and cracked position?

2–4. Backflow Prevention

As an HVAC/R technician you are not only be responsible for HVAC/R systems, but you are concerned with protecting drinkable (potable) water supplies. Essentially in this section you'll learn how to prevent the back-flow of toxic or nontoxic water into a potable (drinking) water system. This contamination is often caused by human error or faulty equipment. Whichever the cause, you must be able to identify the possible source of contamination and take the appropriate corrective action. In most cases, the appropriate corrective action is to notify the utility systems personnel. In the following lessons we'll cover the possible causes of contamination of potable water, the degree of hazards, and the devices used to prevent this action.

014. Backflow concepts

In the past, the backflow of toxic (antifreeze or sewage) or nontoxic (steam) water into a potable (drinking) water system was a safety hazard that was often overlooked. Perhaps you've innocently caused cross-contamination of a system and weren't even aware of your actions. In this lesson we look at the different types of backflow, cross connections, and the hazard levels associated with backflow.

Backflow

Backflow is defined as:

> the flow of water or other liquids, mixtures, or substances into the distributing pipes of a potable supply of water from any sources other than its intended source.

There are two types of backflow—backsiphonage and backpressure. They are defined in the table below.

Backflow	
Type	**Description**
Backsiphonage	Backsiphonage is the flowing back of used, contaminated, or polluted water from a plumbing fixture or vessel into a water supply pipe due to a negative pressure in such pipe. An example of this negative pressure is a person drinking a soda with a straw. The person "draws" on the straw and the soda flows up the straw and into the mouth. What the person is actually doing is creating a negative pressure in his mouth and the atmospheric pressure (14.7 psi at sea level) is pushing down on the surface of the soda and forcing the soda up the straw and into the mouth.
Backpressure	Backpressure is caused by an increased pressure above the supply pressure.

Backflow	
Type	**Description**
	This may be due to pumps, boilers, gravity, or other sources of pressure. An example of this is a steam heating system with the make-up water line piped directly into the boiler. The higher pressure in the boiler could force the chemically treated boiler water back through the make-up water line and into the potable water system.

Cross-connection

A cross-connection is:

> any connection or arrangement (physical or otherwise) between a potable water supply system and any plumbing fixture or any tank, receptacle, equipment, or device, through which it may be possible for non-potable, used, unclean, polluted and contaminated water, or other substances, to enter into any part of such potable water system under any condition.

The two types of cross-connections—indirect (potential) and direct (actual)—are described in the following table.

Cross-Connection	
Type	**Description**
Direct (actual)	This type of cross-connection is a direct link between the potable and non-potable water lines. The piping connected by the utilities specialist during construction of the water system makes this type of cross-connection a direct connection.
Indirect (potential)	This type of cross-connection is also a link between the potable and non-potable water lines. What makes this type cross-connection a potential one? The conditions have to be just right for backflow condition to occur. An example is a hose attached to the end of a faucet extending the end of the water line past the overflow rim, thus creating a cross-connection. The water pressure on the supply side of the faucet would have to create a vacuum, which would cause the wastewater to be "sucked" into the supply line, making the potable water polluted. This vacuum could occur due to a water break.

Degree of hazard

Before you're tasked to install a backflow preventer, it's essential you know the degree of hazard. Only then can you decide on the type of backflow preventer to use. Again, this is primarily a utilities personnel job, but as an HVAC/R technician you may be tasked to choose the type of backflow device. The degree of hazard is determined by the director of base medical services, who assigns it to one of three classes described in the following table.

Degrees of Hazard		
Class	**Hazard Level**	**Description**
I	Low	The backflow of a Class I substance into a potable water supply would cause a minor change in the water quality. Examples are taste, odor, or color. To qualify for a Class I rating, the foreign substance must be *nontoxic* and *nonbacterial* with *no significant health effect*.
II	Moderate	The backflow of a Class II substance into a potable water supply would

Degrees of Hazard		
Class	**Hazard Level**	**Description**
		significantly change the water quality. The foreign substance must be *nontoxic to humans*.
III	High	The backflow of a Class III substance into a potable water supply could cause illness or death if consumed by humans. The foreign substance may be *toxic to humans* either from a chemical, bacteriological, or radiological standpoint.

015. Backflow prevention devices

Now that you have an understanding of what backflow is and the issues it can cause, let's focus on devices that can prevent backflow. Again, more than likely this will not be your primary job but it is vital that you know how these devices operate. Your knowledge will help prevent backflow into important potable water sources.

There are five types of backflow prevention devices:

- Air gap.
- Atmospheric-type vacuum breaker.
- Pressure-type vacuum breaker.
- Double check valve.
- Reduced pressure backflow preventer.

NOTE: Check with the utility personnel for proper installation procedures before you use a backflow prevention device on an HVAC/R system.

Air gap

An *air gap* is the physical separation of the potable and non-potable system by an air space (fig. 2–21). Use an air gap whenever possible. To work properly, the vertical space between the supply line and the flood-level rim must be at least *two times the inside diameter of the supply pipe*. In addition, it cannot be less than 1 inch and need not be more than 12 inches. This means that if the supply pipe is 2 inches in diameter, then the air gap must be at least 4 inches wide. An air gap is used on an open or non-pressure-receiving vessel. This device protects only against backsiphonage and *not* backpressure. It can be used on all three hazard classes.

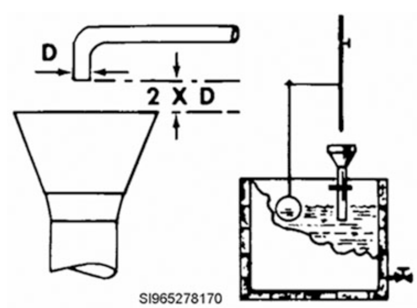


Figure 2–21. Air gap.

Atmospheric-type vacuum breaker

A cutaway illustration of an atmospheric-type vacuum breaker is shown on figure 2–22. This type of breaker is designed to prevent backsiphonage of Class I substances into a potable water supply. As you can see, this device has a moving disc float in the body which stops water from spilling from the device during flow. When the flow stops, the disc float drops down to provide a vent to the atmosphere. This prevents a vacuum from occurring on the discharge line by allowing air to enter the line. The atmospheric-type vacuum breaker must be installed on the *discharge side of the last control valve and above the highest usage point*. It cannot be used under continuous pressure or be subjected to backpressure. *Continuous pressure* is a term applied to an installation in which the pressure is supplied continuously to a backflow prevention device for a period over 12 hours.

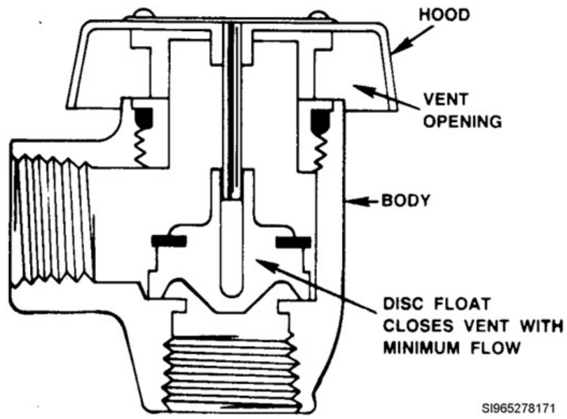


Figure 2–22. Atmospheric-type vacuum breaker.

Pressure-type vacuum breaker

A cutaway illustration of a pressure-type vacuum breaker is shown on figure 2–23. This device is designed to prevent backsiphonage of Class I substances into a potable water supply. It may be used under continuous pressure, but must *not* be subjected to backpressure. As you can see, this device has a moving, spring-loaded disc float and check valve in the body. A gate valve is on both the inlet and the outlet of the body. The body is also equipped with two cocks. When the supply line pressure drops to 1 psi or below, the spring-loaded disc float opens the atmospheric vent. At the same time, the spring-loaded check valve closes the inlet. This keeps a vacuum from occurring on the discharge line; thus, there's no backsiphonage.

During the normal operation of the pressure-type vacuum breaker, the flow of water through the device pushes the check valve open. The flow also lifts the disc float, which closes the atmospheric vent thus preventing leakage. It must be *installed above the overflow level* of the system being supplied.

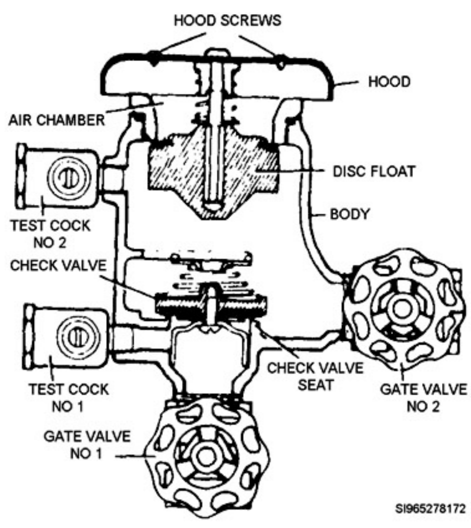


Figure 2–23. Pressure-type vacuum breaker.

Double check valve

A cut-away illustration of the double check valve is shown on figure 2–24. This device is used in direct connection-type systems to prevent the backflow of Class I and II substances into the potable water supply. The double check valve can be used in continuous pressure systems that are subject to backpressure or backsiphonage. As you can see on figure 2–24, this device has two independently operating, spring-loaded check valves in the body. In addition, there is a gate valve on both the inlet and the outlet of the body. The double check valve is also equipped with four cocks. The spring-loaded check valves close tightly when the water pressure flowing through the device drops below 1 psi or when the flow reverses. Failure of one check valve to close, does not affect the operation of the other check valve, which will still close tightly.

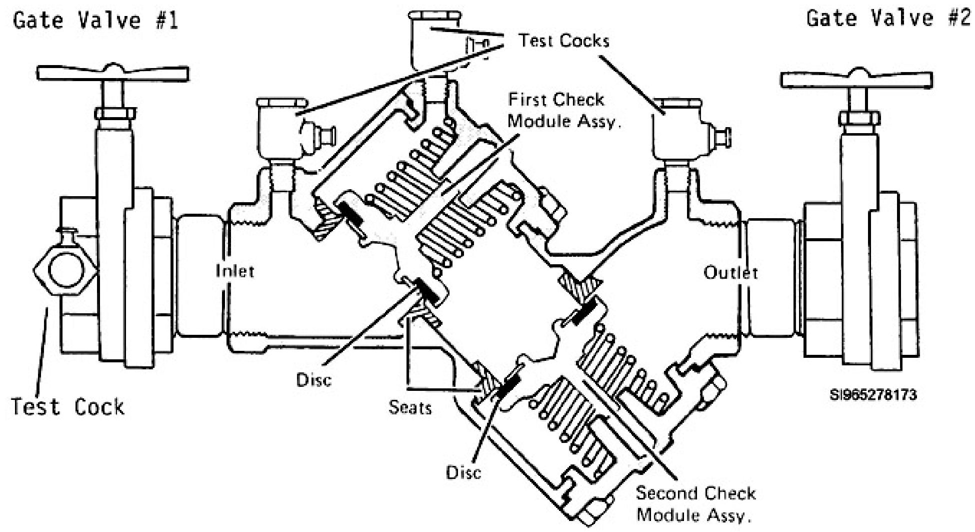


Figure 2–24. Double check valve.

Reduced pressure backflow preventer

An illustration of the reduced pressure backflow preventer is shown in figure 2–25. This type of backflow preventer may be used on all direct connection-type systems. It's designed to prevent the backflow of all three classes of substances into the potable water supply.

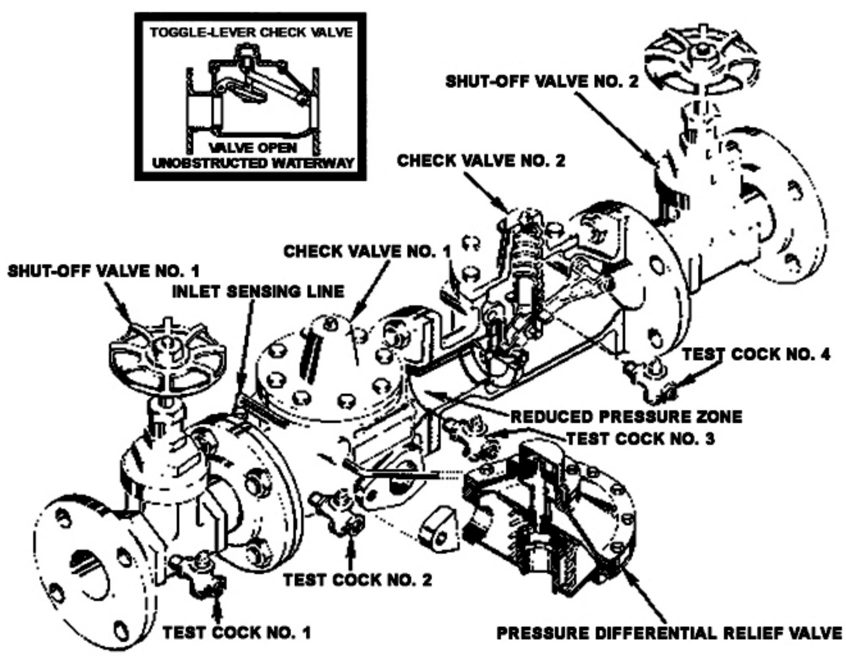


Figure 2–25. Reduced pressure backflow preventer.

The reduced pressure backflow preventer is used in continuous pressure systems that are subject to backpressure or backsiphonage. Shutoff valves are located at both the inlet and the outlet of the body along with four cocks. The valve is also equipped with two independently operating spring-loaded check valves, which are located in the body. A pressure differential relief valve is located in a reduced pressure zone between the two check valves. During normal operation, both check valves are open and the relief valve is closed. The first check valve reduces the supply-line pressure to a predetermined amount. This is so that during normal flow, and at cessation of normal flow, the pressure between the two check valves is lower than the supply-line pressure. Both check valves close, and the relief valve stays closed when backpressure occurs. If either check valve fails to close during backpressure, the relief valve will open discharging water out of the zone. The relief valve stays open until the pressure in the zone drops below the supply-line pressure. In the event of backsiphonage, both check valves close and the relief valve opens, fully discharging the water in the zone.

Summary

This unit discussed some of the important ideas that you will need to know while you are working in your new career. Safety in the workplace is important. Working around heavy, rotating machinery is dangerous. Being aware of your surroundings and knowing how to identify and correct hazards will keep you in one piece and ready for a full life after your job is done. Some other hazards such as cross-connections of potable water supplies can be problems too. As an HVAC/R journeyman, you may not work on a lot of water supplies, but you will be using them to connect your chillers and boilers for water. Knowing about the hazards involved will keep other people protected against contaminates in these systems. A lot of common sense goes a long way. Use your new smarts and keep safe!

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

014. Backflow concepts

1. Besides backflow, what causes the flow back of contaminated water from a vessel into a water supply pipe?

2. What causes an increased pressure *above the supply pressure*?

3. When the conditions have to be just right for backflow condition to occur, what type of connection do you have?

4. What may cause a minor change in taste or odor of water?

5. What may cause a radiological change in a water supply?

015. Backflow prevention devices

1. When should the air gap be used?

2. On an atmospheric-type vacuum breaker, what prevents a vacuum from occurring on the discharge line by allowing air to enter the line?

3. During the normal operation of the pressure-type vacuum breaker, what pushes open the check valve?

4. On a reduced-pressure backflow prevent, what will happen if either check valve fails to close during backpressure?

5. The relief valve stays open until what occurs?

Answers to Self-Test Questions

006

1. Extra strong pipe.
2. When the wall thickness is less than standard weight.
3. Wherever it may be necessary to open the joint to permit service or replacement of components.

007

1. Measure along the pipe and mark at the proper length.
2. Put a fitting on the end of pipe.
3. Insert the pipe into the chuck so that it protrudes about 8 inches beyond the face of the chuck.
4. Turn on the machine and apply pressure to the cutter wheel as the pipe rotates.
5. Check the pipe chuck jaw teeth to ensure they're clean and free of pipe chips or flakes.
6. Check to ensure all the teeth on the pipe dies are clean and not chipped.
7. After the chuck and dies have been properly cleaned and set.
8. Make sure that the release lever is in the closed position

008

1. Apply a small amount of pipe joint compound (pipe dope) or Teflon tape to the male threads.
2. Tighten with the correct-sized pipe wrench about two more turns.
3. Select two wrenches.

009

1. In the manufacture of evaporators for domestic refrigerators.
2. With milk-handling systems, ice cream manufacture, and in food processing.
3. Flare or sweat.
4. To connect iron pipe to copper for a straight run.

010

1. Make the necessary measurements for a particular installation.
2. Mark the tubing where it's to be cut.
3. Use the tube reamer on the cutter to remove the burr inside the tube.

4. Hand-bend the tubing
5. Make all necessary bends
6. Place the correct size of flexible bending spring over the copper tube
7. Measure the pipe and determine the degree of bend.
8. Ensure the “0” and “0” line up before you start to bend

011

1. Remove the burr within the pipe by reaming it.
2. Tighten the block’s clamp so the tube will not move while you flare.
3. Place refrigerant oil on the male end of the adapter.
4. Place the yoke onto the block and begin to turn handle clockwise until the flaring adapter is tightly pressed against the block.
5. Slip the flare nut against the flare.
6. Slip the nut on the tubing.
7. Slip the ferrule on the tubing.

012

1. It can be partially opened as well as fully opened or fully closed.
2. For services requiring infrequent valve operation and where the valve disc is kept either fully opened or fully closed.
3. Because the velocity of flow against the partly opened valve may cause vibration and damage to the disc and seating surface.
4. It should be backed off one-quarter turn to one-half turn from the fully closed position.
5. Closed.
6. Because it allows more precise control of flow than could be obtained with an ordinary globe valve.
7. It will close.
8. Flow coming from beneath the ball.

013

1. The spring.
2. It will throttle back the hot water and “open up” the cold water.
3. Then heat transfer will be negatively affected.
4. To ensure the pressure doesn’t rise above the system’s operating pressure.
5. It is back seated.
6. It is front seated.
7. The flow of refrigerant in the system will be blocked.
8. The cracked position is much like the mid-position except the valve is only turned $^{1}/_{16}$ to $^{1}/_{8}$ of a turn clockwise.

014

1. Negative pressure in the pipe.
2. Pumps, boilers, gravity, or other sources of pressure
3. Indirect or potential.
4. Class I, low degree of hazard
5. Class III, high degree of hazard

015

1. Whenever possible.
2. Disc float drops down to provide a vent to the atmosphere.
3. The flow of water through the device.

4. The relief valve will open discharging water out of the zone.
5. Zone pressure drops below the supply-line pressure.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

20. (006) When pipe is needed for a *high pressure application* you should select
    a. standard strong pipe.
    b. extra strong pipe.
    c. extra thin pipe.
    d. standard pipe.

21. (006) Pipe should *not* be threaded when it is
    a. not heavy enough to withstand it.
    b. ½ the wall thickness of the steel weight.
    c. a wall thickness *less* than standard weight.
    d. a wall thickness *more* than standard weight.

22. (006) When would *flanges* be installed?
    a. To install flare fittings.
    b. For permanent installs.
    c. With extra strong weighted metal.
    d. Wherever it may be necessary to open the joint for service or replacement of components.

23. (007) What must be done *before* you apply pressure on the dies?
    a. Be sure the pipe is threaded.
    b. Remove the threaded pipe from the machine.
    c. Back off the diestock until it is clear of the pipe in the chuck.
    d. Be sure you have the oil running to help start the segments on the pipe.

24. (007) How are the *die segments* released?
    a. Release lever.
    b. Return lever.
    c. Supply lever.
    d. Oil lever.

25. (008) After you clean the threads of the fitting with a wire brush, what is the *next step*?
    a. Remove the threads.
    b. Clean the threads with a detergent.
    c. Clean the male threads with pipe joint compound.
    d. Apply a small amount of pipe joint compound to the male threads.

26. (008) After you screw the fitting hand tight on the pipe in a clockwise direction you immediately
    a. tighten with the correct-sized pipe wrench about 2 more turns.
    b. tighten with the correct-sized pipe wrench about 5 more turns.
    c. tighten with any sized pipe wrench about 3 more turns.
    d. select a pipe wrench size.

27. (008) After you screw the coupling on the pipe hand-tight without using a vise, the next step is to?
    a. select one wrench of the proper size.
    b. apply pipe dope to the male threads.
    c. clean the pipe and fitting threads.
    d. select two wrenches.

28. (009) Aluminum tubing is mostly used in
    a. gas lines.
    b. burner feed lines.
    c. air conditioning applications.
    d. the manufacture of evaporators for domestic refrigerators.

29. (009) Stainless steel tubing is used
    a. in domestic refrigerators.
    b. in all oil burning equipment.
    c. in air conditioning applications.
    d. with milk-handling systems, ice cream manufacture, and in food processing.

30. (009) If you are required to make *connections between steel pipe and copper pipe*, which fitting would you choose?
    a. A tee.
    b. An elbow.
    c. An adapter.
    d. Tees and elbows.

31. (010) What is done *immediately after* the tubing has been cut with a tube cutter?
    a. Thread the tubing.
    b. Install the copper into the system.
    c. Measure the length needed for the installation.
    d. Use the tube reamer on the cutter to remove the burr inside the tube.

32. (010) The *first step* in cutting tubing with a hacksaw is to select which hacksaw blade
    a. 5 teeth per inch.
    b. 8 teeth per inch.
    c. 30 teeth per inch.
    d. 32 teeth per inch.

33. (011) After slipping the nut on the tubing the *next step* is to
    a. place anchors on pipe every 20 feet.
    b. design pipe bends or loops into the system.
    c. use special design elbows and tees on system.
    d. insert the end of the tubing into the correct-sized hole in the flaring block.

34. (011) When fabricating a single flare, the *next step after* you tighten the block’s clamp is to
    a. insert tubing in the flaring block.
    b. put all pieces back into the flaring kit.
    c. place refrigerant oil on the flaring cone.
    d. unscrew the clamp handle and open the block.

35. (012) The gate valve is *not* suitable for throttling flow because
    a. the velocity of flow against the partly opened valve may cause vibration and damage.
    b. the vibrations it causes could create incorrect pressure readings.
    c. its design will only allow it to be opened 100%.
    d. it has similar characteristics of the check valve.

36. (013) What does the *mixing valve* do when the leaving water temperature *rises above set point*?
    a. Closes off all discharge.
    b. Opens the hot water up more.
    c. Mixes refrigerant to keep the temperature down.
    d. It will throttle back the hot water and “open up” the cold water.

37. (013) What position should the *service valve* be in during *normal* operation?
    a. Cracked.
    b. Back seated.
    c. Front seated.
    d. Mid position.

38. (013) Cracking a *service valve* will
    a. isolate the compressor.
    b. prevent a pressure rush.
    c. isolate the high and low side of the system.
    d. prevent pressure readings from being taken.

39. (014) What type of *cross connection* exists if the spout on a sink faucet extends *below* the overflow rim?
    a. Inlet.
    b. Direct.
    c. Outlet.
    d. Indirect.

40. (014) What hazard may cause a *significant change* in water quality?
    a. Class I.
    b. Class II.
    c. Class III.
    d. Class IV.

41. (015) When should the *air gap* be used?
    a. To protect against backpressure.
    b. For Class I hazards *only*.
    c. Whenever possible.
    d. Never.

Please read the unit menu for unit 3 and continue ➔

Unit 3. Oxyacetylene Equipment Familiarization and Utilization

OXYACETYLENE AND ACETYLENE soldering and brazing includes several processes in which metal parts are joined together. In this unit, we'll discuss several of these methods. However, before we cover the various operations, we'll acquaint you with using and operating the required equipment. As we go through the lessons, we'll cover these areas: assembling, operating, closing down, disassembling, and testing for leaks. The lessons in the first section, Oxyacetylene Equipment, focus on the actual equipment you will be using in your job. As its title states, the second section, Brazing and Soldering, has lessons that cover using the equipment covered in earlier lessons for brazing and soldering.

3–1. Oxyacetylene Equipment

In order to properly and safely use oxyacetylene equipment, you need to know the parts of this equipment. In addition, you must be able to correctly assemble the equipment and follow the procedures for taking care of it. We'll cover all of these items in this section. As you can see from the contents above, there are two lessons in this section. The first covers acetylene equipment and the second covers oxyacetylene equipment.

016. Acetylene equipment

The focus of this lesson is on equipment used for acetylene soldering and brazing. We'll look at the characteristics of the acetylene gas, the associated equipment, and its basic operation.

Acetylene

Acetylene is the fuel gas of the oxyacetylene flame. It's made by dissolving calcium carbide in water. Acetylene isn't an ordinary gas; instead, it has its own peculiar characteristics. Its composition is about 93 percent carbon and about 7 percent hydrogen. When in the presence of pure oxygen, acetylene burns at a temperature of 6,300 °F. Acetylene not only develops a large amount of heat but also releases the heat units so rapidly that the flame's highest temperature is produced almost instantly.

Acetylene characteristics

When working around acetylene, you'll need to consider these important properties:

- Acetylene is unstable at pressures greater than 15 psi, and may split up or disassociate.
- Unstable pressures can result in an explosion when acetylene's (split up or decomposed) gas molecules produce heat.
- Above pressures of 29.4 psi, acetylene becomes self-explosive and the slightest shock could cause spontaneous combustion. However, because acetylene is dissolved in acetone it can be compressed into cylinders at pressures up to 250 psi.
- Mixtures of acetylene and air containing from 2 to 80 percent acetylene by volume will explode when ignited.

To completely consume one part of acetylene requires 1½ parts of oxygen. However, because a portion of the oxygen is derived from the air surrounding the flame, not all of the oxygen has to be supplied by the oxyacetylene torch. The torch is designed to supply oxygen in a 1 to 1 ratio: 1 part oxygen to each part of acetylene that passes through it.

Acetylene cylinder and valve

Figure 3–1 shows an acetylene cylinder. These cylinders are designed to store acetylene under pressure—up to 250 psi. The cylinder is made of welded or brazed steel and is filled with a substance that has a porosity of 75 to 80 percent. This cylinder is then filled with acetone to 40 percent of its liquid volume. This allows space for expansion which occurs as the acetone absorbs the acetylene to stabilize it under pressure.

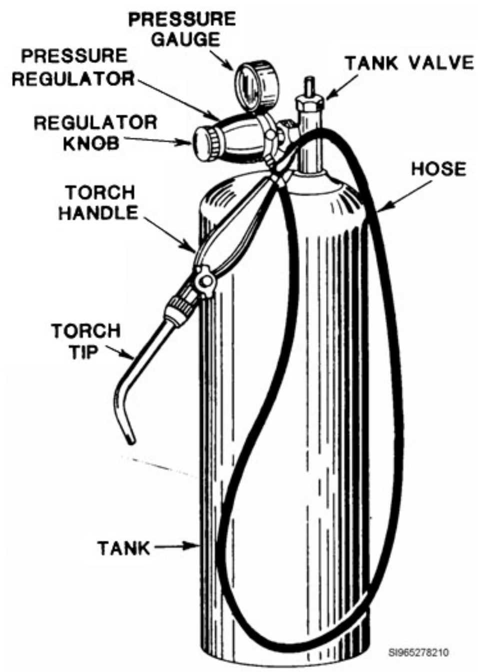


Figure 3–1. Acetylene cylinder.

The cylinder is equipped with a cylinder valve and a protective cap. As a safety factor, the valve has *left-hand threads* to prevent an improper connection. Another safety measure is the use of safety plugs which can release the gas if the cylinder is overheated. These plugs are designed to melt between 212 and 220 °F and are small enough to keep the escaping gas from burning back into the cylinder. All acetylene cylinders are yellow colored and they *must be stored upright* to prevent the acetone from escaping.

Propane/butane torch

The propane or butane torch is small, highly mobile, and provides temperatures high enough for soldering. This equipment allows you to make quick solder joints on low-pressure connections. It is very popular among technicians since it is highly portable. It is often used for tasks when an acetylene system is not suitable. We'll cover the parts of the torch and how to operate it in the following tables.

Propane/Butane Torch Assembly	
Part	**Description**
Torch	The torch is the same concept as the other rigs. Gas will come out of it and it needs to be lit.
Hose	Not all assemblies will have a hose. If there is a hose, take care not to damage it or cause leaks.

Propane/Butane Torch Assembly	
Part	**Description**
	If a leak occurs it could cause a fire.
Can	The propane/butane can is about 12 inches tall and very portable compared to normal acetylene and oxyacetylene kits. Treat the propane/butane with respect. Do not leave it in hot locations or directly in the sun.
Ignitor	A normal spark ignitor is used to light the torch. Do *not* use a cigarette lighter because you may get burned.
Valve	The valve is a simple knob that allows more or less gas through depending on how far it is open. Be careful not to let this valve break or you may lose all of your gas.

Operating the propane/butane torch is simple and following the steps in the table below will ensure safe operation.

Propane/Butane Torch Operation	
Step	**Action**
1	Attach the torch assembly to the can of propane or butane.
2	Open the valve.
3	Light the torch with the ignitor.
4	Solder your joint.
5	Turn the valve off.
6	Store the assembly in a safe and cool place.

017. Oxyacetyelene equipment

Oxyacetyelene equipment adds the oxygen element to the soldering and brazing equation. Oxygen allows the flame to reach hotter temperatures and provides the technician with a greater range of skills. We'll first discuss the parts of the oxyacetylene equipment and then follow with its operation.

Oxyacetylene assembly

There are several components that are combined to make a complete oxyacetylene assembly. These include the oxygen gas, the cylinder and valve, and the actual working parts. We'll take a look at each of these in the following paragraphs.

Oxygen

Oxygen is a colorless, tasteless, and odorless gas that's slightly heavier than air. It won't burn, but it does support combustion very actively, more so than air. This characteristic of oxygen makes it desirable to use with acetylene for welding, brazing, and silver soldering.

Oxygen cylinder and valve

Figure 3–2 shows an oxygen cylinder and a cutaway view of the valve. The cylinder is made of seamless steel and is designed to contain oxygen at a pressure of up to 2,000 pounds per square inch (psi). The container is colored green and is equipped with a safety cap to protect the valve.

The valve is equipped with a bursting disc designed to release pressure increases due to heat. The valve comes with *right-hand threads* to keep you from confusing the oxygen connection with the acetylene connections.

> **CAUTION:** Take care when you're handling oxygen cylinders. The extreme pressure in an oxygen cylinder makes it a potential missile should the valve be broken off or the tank pierced.

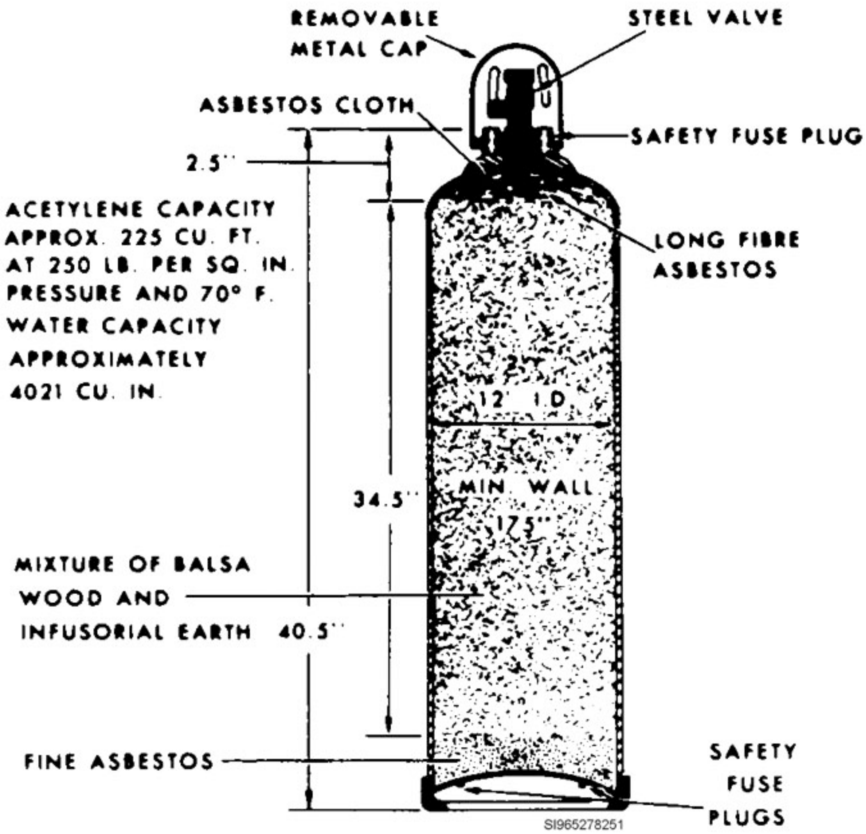


Figure 3–2. Oxygen cylinder and valve.

Parts

In addition to the cylinder and valve mentioned above, there are other items that make up an oxyacetylene outfit. These include regulators, hoses, the torch, torch tips, torch wrenches, and safety equipment. These are described in the following table.

Oxyacetylene Components	
Component	**Description**
Regulators	The regulators, or reducing valves, are mechanical devices that reduce the high pressure of gases as they flow from the cylinders. • *Single-stage* regulators reduce the high pressure of gases as they flow from the cylinders to the working pressure needed at the torch in one step (stage). • The *two-stage regulator* (fig. 3–3) reduces the pressure in two steps.
Hoses	Hoses take the gases at working pressure from the regulators to the torch's needle valves. • The *oxygen hose* is always green or black. • The *acetylene hose* is always red or maroon.

<table>
<tr><th colspan="2">Oxyacetylene Components</th></tr>
<tr><th>Component</th><th>Description</th></tr>
<tr><td></td><td>


Figure 3–3. Two-stage regulator and hoses.
</td></tr>
<tr><td>Torch</td><td>
Figure 3–4 is a cutaway illustration of an oxyacetylene torch.

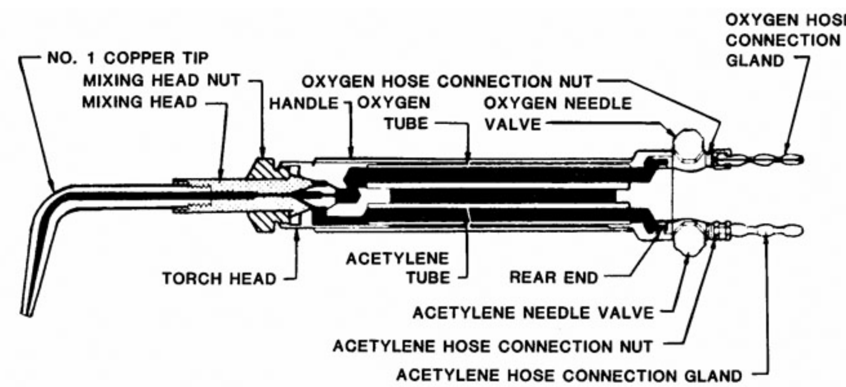


Figure 3–4. Torch cutaway.

Figure 3–5 shows the torch assembly.

The gases flow from the hoses, through the needle valves, then to their respective tubes, and to the mixing head.

The gases combine in the mixing head and flow forward through the tip to produce a flame.

Figure 3–5. Torch assembly.
</td></tr>
<tr><td>Torch tips</td><td>
There are many types and sizes of torch tips; however, they all serve the same purpose.

The torch tip directs the flow of the oxyacetylene mixture so that the flame can be controlled.
</td></tr>
<tr><td>Torch wrenches</td><td>
Special torch wrenches are designed for use with an oxyacetylene outfit.

A torch wrench has slots or holes the correct size to tighten all connections.
</td></tr>
</table>

Oxyacetylene Components	
Component	**Description**
Safety equipment	The welding goggles, flint lighter, and fire extinguisher are all safety equipment used with the oxyacetylene outfit. This equipment is designed to protect the operator from injury and to prevent damage to property.

Tank storage and leak testing

Tank storage and leak testing are life saving topics. If any one of these concepts is ignored it could lead to a dangerous situation. Cylinder storage and its requirements will be covered first and then procedures for leak testing will be done.

Cylinder storage

Both oxygen and acetylene cylinders are stored according to Air Force Joint Manual (AFJMAN) 23–209, *Storage and Handling of Hazardous Materials*, which also refers to Defense Logistics Agency Instruction (DLAI) 4145.11, *Storage and Handling of Hazardous Materials*.

Some basic rules for storing include:

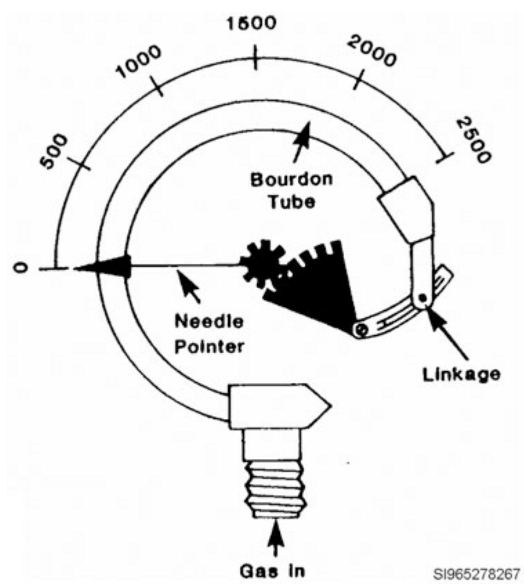
- Keeping oxygen cylinders away from oil or grease. Oil or grease mixed under pressure with oxygen may explode.
- Do not drop cylinders or handle them roughly.
- Store cylinders in a cool, dry, well-ventilated building (storage temperature should *not exceed* 125 °F measured at surface of cylinder).
- Store oxygen and acetylene cylinders in an upright, secured position.
- Separate full and empty cylinders (label/tag a full cylinder with its correct stock number, and label/tag empty cylinder with its correct stock number).
- Provide support for cylinders to prevent them from falling (secure cylinders in a storage facility by using steel framing, supports etc.).
- Separate flammable gas cylinders from other gases that support combustion while in storage (must be at least 50 feet away from—in separate shed, or use an approved firewall or barrier).

Remember these are just few of the basic requirements. You also need to be familiar with the rules or requirements of your specific work location (your unit or base).

Leak testing

Before you put any oxyacetylene outfit into use, you should thoroughly check it for gas leaks. The testing of the outfit is a very simple but important task. All that's required is a can or jar of soapy water, a small paintbrush or acid brush, and a bucket of clear water. Let's say you have the outfit assembled and adjusted to a working pressure. You're now ready to test by brushing soapy water onto all the connections listed. A leak will be indicated by bubbles.

The specific components to be tested are discussed in the following table.

Components to Leak Test	
Component	**Description**
Regulators	The primary problem with regulators is gas leakage between the regulator seat and the nozzle. A leak can be detected by observing a gradual pressure rise on the working pressure gauge after the cylinder or manifold valve is opened. This is known as a “creeping regulator” and is caused by a worn or cracked seat or by dirt particles lodged between the seat and the nozzle. A leaking regulator should be replaced by a good one, and the faulty one should be sent out for repair.
Gauges	Problems with a gauge are usually caused by a leaking or broken bourdon tube. This is indicated by fluctuating gauge pressure or gas leaking from the gauge case. Figure 3–14 illustrates how a bourdon tube works in a pressure gauge. The bourdon tube is a steel tube attached to the needle through a linkage. When gas pressure fills the bourdon tube, the tube begins to straighten out. As the tube straightens, it moves the linkage and the needle pointer. Bourdon tubes (fig. 3–6) are precision instruments that can be easily damaged. If the cylinder valve is opened quickly and the regulator adjusting screw isn’t released, the tube can be cracked. A sudden pressure increase can also crack the tube causing it to leak. A leak in the bourdon tube is indicated by a gas leak from the gauge case. A small leak in a bourdon tube can be repaired by silver brazing, but repairs of major damage to a regulator should be done by the manufacturer.  **Figure 3–6. Bourdon tube.**

<table>
<tr><th colspan="2">Components to Leak Test</th></tr>
<tr><th>Component</th><th>Description</th></tr>
<tr><td>Torches</td><td>The three primary causes of torch trouble are as follows:

Leaking needle valves.
Leaks in the mixing head seat.
Clogged torch tubes.

<table>
<tr><th colspan="2">Torch Trouble Areas</th></tr>
<tr><th>Trouble</th><th>Description</th></tr>
<tr><td>Leaking needle valves</td><td>When the gas continues to flow after the valve is closed, you’ll know the needle valve is leaking.

This condition is caused by a worn or bent valve stem, a damaged valve seat, or loose packing around the needle valve.

Repair needle valve leaks around the seat by tightening the packing gland nut.

If the leak is in the seat, remove the needle valve with a wrench and clean it. If it’s worn or pitted, replace it with a new one.

If the valve seat is scored, pitted, or otherwise damaged, the torch should be returned to the manufacturer for repair.</td></tr>
<tr><td>Leaks in the mixing head seat</td><td>A leak in the mixing head seat allows the gases to escape and, unless you correct the trouble immediately, flashback is the dangerous result.

Leaking mixing head seats should be removed and cleaned.

If the seats are damaged, the torch should be returned to the manufacturer for repair.</td></tr>
<tr><td>Clogged torch tubes</td><td>Clean clogged torch tubes by removing the hoses and mixing head, and by blowing out each tube with 20 to 30 pounds of oxygen pressure.</td></tr>
</table>
</td></tr>
<tr><td>Hoses</td><td>Check the welding hose at regular intervals for leaks, worn spots, and loose connections.

Test all the hoses by submerging them in a bucket of clear water while they’re pressurized.

Since worn or leaking hoses are dangerous and wasteful, they should be repaired or replaced immediately.</td></tr>
</table>

Repairing hose leaks

Repair hose leaks by removing the damaged section and inserting a hose splice. The proper splice is illustrated in figure 3–7.

> **NOTE:** Do ***not*** (by way of shortcut or for other reasons) put a piece of copper tubing in place of a brass hose splice. You may want to ask the question: Why not? When copper and acetylene are placed together, they form copper acetylene, an unstable compound that explodes violently at the slightest shock. In short, ***do not use copper with acetylene***.

Repair hoses leaking at the regulator or torch connection by cutting off 1 or 2 inches of hose and replacing the connections.

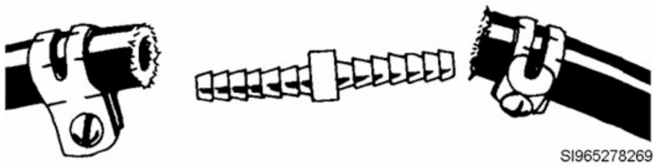


Figure 3–7. Splice.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

016. Acetylene equipment

1. How does an acetylene flame reach its highest temperature almost immediately?

2. When does acetylene become unstable?

3. When does acetylene become self-explosive?

4. Why is it *not* necessary to supply all 1 ½ parts of oxygen for acetylene use?

5. Why is the substance in an acetylene cylinder filled with acetone to 40 percent of its liquid volume?

6. Why are the threads on the acetylene cylinder *left handed*?

7. Why must care be taken to prevent hose damage?

8. Why should you *not* use a cigarette lighter to light the *propane torch*?

9. What is the *first step* in operating the propane torch?

10. What is the *last step* in operating the propane torch?

017. Oxyacetylene equipment

1. Why are the oxygen valve threads *right handed*?

2. Where are the gases from the oxygen and acetylene cylinders mixed?

3. How is the flame controlled?

4. Why should oxygen cylinders be kept away from oil and grease?

5. How can a *regulator leak* be detected?

6. In a bourdon gauge, what happens as the tube straightens out?

7. What is the needle valve status when the gas continues to flow after the valve is closed?

8. What could occur if you *do not immediately correct a leaking mixing head*?

9. What could occur *if copper is used to replace a brass hose splice*?

10. How can you test hoses for leaks?

3–2. Brazing and Soldering

The lessons in the preceding section introduced you to the equipment used with acetylene and oxyacetelyne. This section builds on the knowledge you gained and focuses on using that equipment in the brazing and soldering process. We'll cover brazing in the first lesson in this section and conclude the section, and the unit, with a lesson on soldering.

018. Brazing

Brazing will produce stronger connection than soldering. It is also used for higher pressure applications that soldering cannot be used for. Our discussion on brazing begins with assembly and operation and ends with shut down and disassembly procedures. Pay attention to each step in these procedures as they are all equally important.

Assembly procedures

Portable equipment is assembled by first placing the acetylene and oxygen cylinders on the cart and securing them. Next, remove the cylinder valve protective caps. Then open (“crack”) each cylinder valve slightly then quickly close it. This will blow out any dirt that may be lodged in the outlet nipple.

Next, attach the two-stage regulators to their respective cylinders. Complete this step by tightening the union nut with the torch wrench.

Now you’re ready to attach the hoses to the tanks. Attach the red acetylene hose to the acetylene regulator outlet (left-hand threads). Attach the green oxygen hose to the oxygen regulator outlet (right-hand threads). Screw the nuts tightly with the torch wrench. Make sure the regulator adjusting screws are backed out by turning them counterclockwise until they’re loose.

> **NOTE:** Never open cylinder valves before releasing the regulator adjusting screws. You could damage the regulator if the adjusting screws aren’t released.

Open the acetylene cylinder valve slowly, about $^1/_4$ to $^1/_2$ turn.

> **CAUTION:** ***NEVER*** open the acetylene valve more than 1½ turn. This limited amount allows you to quickly close the valve in case of an emergency.

If the acetylene cylinder valve is *not* equipped with a hand wheel, ensure that a wrench of the proper size remains attached to the cylinder valve stem. This will allow you to quickly turn off the acetylene cylinder in case of an emergency.

Next, open the oxygen valve slowly at first, then fully open. Read the high-pressure gauges to check the pressure of each cylinder. Open each regulator by turning the adjusting screw clockwise. Blow out the hoses one at a time.

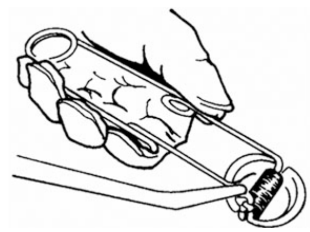
After you’ve blown out the hoses, release the adjusting screws. Install flashback arrestors between the hoses and the torch. These are normally installed on the oxygen and acetylene torch gland nuts. They’re designed to keep a flashback from burning back into the oxygen or acetylene hoses. After installing the flashback arrestors, connect the hoses to them. The red hose connects to the acetylene flashback arrestor with the left-hand threads, and the green hose connects to the oxygen flashback arrestor with the right-hand threads. Another way to tell the oxygen from the acetylene connection is to look for the notch on the connection fitting. The acetylene connection fitting has a notch in the middle of the fitting while the oxygen fitting does not. Select the torch tip. After you’ve selected the proper tip, attach it to the torch. Tighten the tip moderately. At this point your equipment assembly is complete and ready for operation.

Lighting the torch

Before you light an oxyacetylene torch, you must adjust the regulators for the right working pressure of the gases. To do this, first open the torch’s acetylene valve, adjust the regulator for the required pressure, and then close the torch’s acetylene valve. Adjust the oxygen working pressure in the same way.

Now you’re ready to light the torch. To light the torch for brazing, follow the steps in the table below.

Lighting Oxyacetylene Torch for Brazing	
Step	**Action**
1	First open only the acetylene torch valve. Hold the torch so the flame is directed *away from* the cylinders, the hose, any flammable material, and yourself.
2	Strike the flint lighter in front of the tip, keeping your hand at one side (fig. 3–8). Push the arm of the lighter with the flint across the rough surface to make a spark. This lights the

Lighting Oxyacetylene Torch for Brazing	
Step	**Action**
	flame. The pure acetylene flame is long and bushy and has a yellowish color. Since the oxygen valve is closed at this point, the acetylene burns in combination with the oxygen in the air. Because there isn't enough oxygen in the air to burn the acetylene completely, the flame is smoky. In fact, it produces soot of fine, unburned carbon. *The pure acetylene flame is unsuitable for brazing.*  **Figure 3–8. Flint lighter.**
3	Open the oxygen valve. When you do, the flame shortens and the mixed gases burn in contact with the tip face. The flame will change to a bluish-white and form a bright inner cone surrounded by an outer envelope. The inner cone develops the high temperature needed for brazing.

Adjusting the flame

Three distinct flames can be obtained with the oxyacetylene outfit: neutral, reducing or carburizing, and oxidizing. They're illustrated on figure 3–9 and discussed in the following table.

Adjusting the Flame	
Type	**Description**
Neutral flame	There are two clearly defined cones in a neutral flame. These are the inner cone and the central cone. The *inner cone* is luminous and bluish white. Around this cone is a colorless area surrounded by a large flame envelope or sheath, which is faintly luminous and has a light bluish tint (fig. 3–9). The neutral flame is produced by a mixture of approximately one part of oxygen and one part of acetylene supplied from the torch. To adjust the torch for a neutral flame, open the torch oxygen valve slowly until the feather at the end of the central cone disappears. The temperature at the tip of the inner cone is approximately 5,850 °F.
Reducing or carburizing flame	The reducing or carburizing flame (fig. 3–9) is produced by slightly more than one part acetylene to one part oxygen. To get this flame, adjust the welding flame to neutral and then open the acetylene torch valve slightly to produce a white streamer or "feather" of acetylene at the end of the inner cone. You can recognize the reducing or carburizing flame by the presence of these three distinct flame cones: • The clearly defined, intense, white *central cone*. • A white feather or intermediate *reducing cone*, indicating the amount of excess acetylene. • The light orange to bluish *outer flame envelope*. The flame has a temperature of approximately 5,700 °F at the tip of the central cone.

Adjusting the Flame	
Type	**Description**
Oxidizing flame	The oxidizing flame (fig. 3–9) is produced by slightly more than one part of oxygen mixed with one part of acetylene. To get this type of flame, adjust the torch first to the neutral flame. Then, increase the flow of oxygen by opening the oxygen torch valve. You can identify the oxidizing flame by the following three factors: • Short, pointed *central cone*. • A white or colorless *middle cone*. • A somewhat shorter *outer flame envelope*. You'll also hear a distinct hissing sound. This flame has a temperature of approximately 6,300 °F.

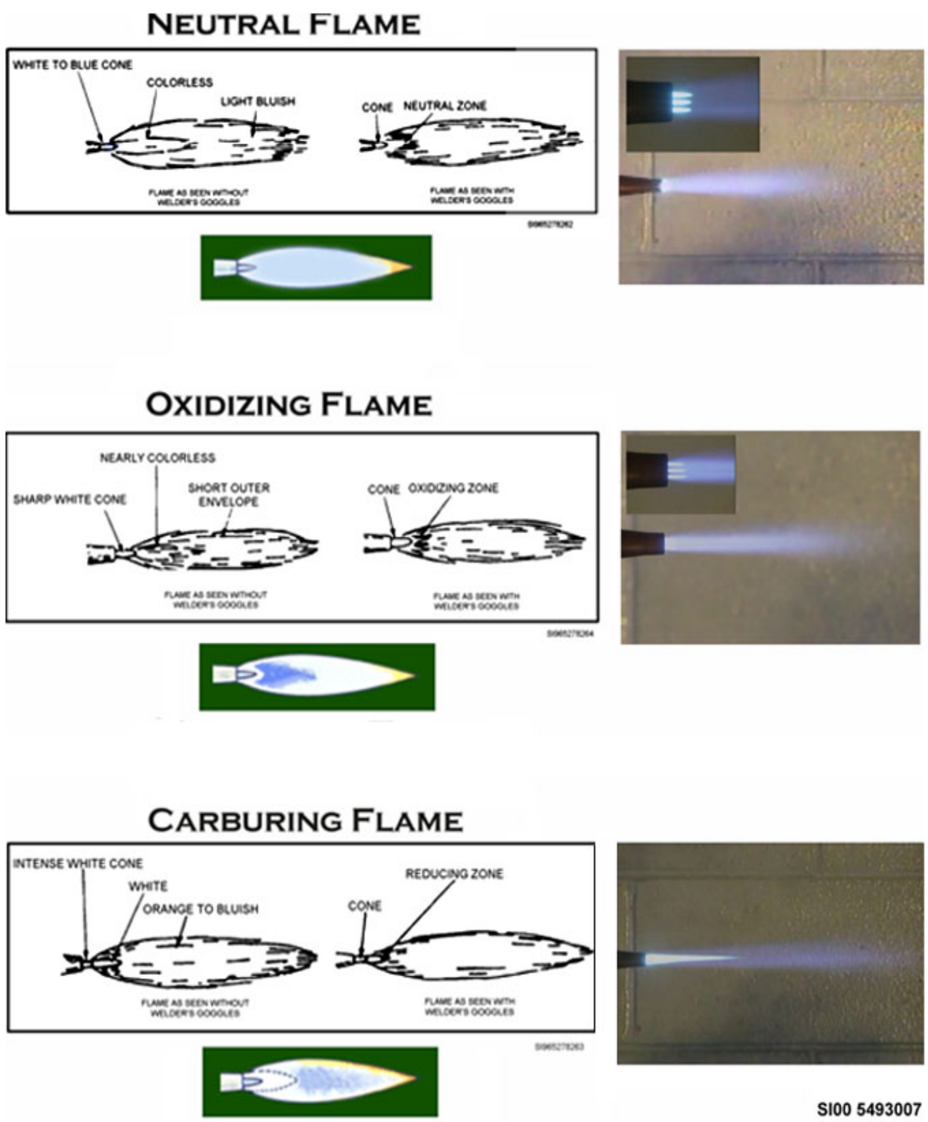


Figure 3–9. Flame types.

Shutdown and disassembly

Shutdown and disassembly is a very simple but important task. If these steps are not followed properly you could injure yourself and others. There is also the possibility of damaging the equipment and Air Force facilities. After your joint is finished, ensure the job is done by being thorough and shutting down and disassembling the rig.

There are two procedures for shutting down oxyacetylene equipment: normal and emergency. We'll cover each of these procedures below.

Normal shutdown

When you are using the normal method of shutdown, follow the steps in the following table.

Normal Oxyacetylene Shutdown	
Step	**Action**
1	Close the torch acetylene valve.
2	Close the torch oxygen valve.
3	Close both cylinder valves.
4	Open the torch valves one at a time (acetylene first) and bleed the regulators.
5	Close the torch valves.
6	Turn the regulator-adjusting screws counterclockwise to relieve the pressure of the diaphragm.
7	Hang the torch and hose up properly to prevent kinking the hose or damaging the torch.

Emergency shutdown

An emergency shutdown may be necessary due to a flashback or for other reasons. A *flashback* is the burning of gas inside the torch and is indicated by a high-pitched whistle. It can burn all the way back to the cylinder if it isn't stopped. Flashback arrestors are installed between the torch and hoses to keep flashbacks from getting from the torch to the hoses. However the flashback arrestors aren't foolproof—*always shut down the equipment if a flashback occurs!*

If the flashback reaches the cylinder, the cylinder may explode. It's always dangerous; and the farther back it burns, the more the equipment is damaged.

To close down because of an emergency:

- **Always** shut off the **acetylene torch valve** **first**.
- Then shut off the acetylene cylinder valve.

Disassembling an oxyacetylene outfit

When you're ready to disassemble a welding outfit, you'll use a procedure that's the exact opposite of assembly. You can use a checklist like the one in the following table.

Oxyacetylene Disassembly Checklist	
Item	**Description**
1	Be sure the gas supply is off.
2	Bleed the regulators.
3	Remove the torch tip.
4	Disconnect the hoses from the torch.
5	Disconnect the hoses from the regulators.
6	Disconnect the regulator from the cylinder or manifold line.

Oxyacetylene Disassembly Checklist	
Item	**Description**
7	Replace the cylinder valve safety cap or line protective nuts.
8	Always use the right tool such as a torch wrench to assemble and disassemble a welding or cutting rig. A torch wrench will prevent rounding of the corners on connecting and union nuts.

019. Soldering

It is important to remember that *soldering is not brazing*. Soldering is accomplished at lower temperatures and the joints formed are not as strong as those formed by brazing. Having said that, soldering is a task that you will perform quite often in this career field. Soldering procedures and some soldering tips are the subject of this lesson.

After you measure, cut, and set up your work as needed you can begin soldering.

Concept

Soldering is a process of joining two metals together. This is accomplished at a temperature under 840 °F. The two metals are connected by a filler metal that melts and creates an adhesion for the two metals.

The filler metal, known as the solder, is usually provided in a roll and is made of soft metals such as tin, lead, and silver. These metals are used because they have low melting points. Because there are many different types of solder, we aren't able to discuss them here. The basic principle is to select the solder suitable for the pressure and temperature of the line you will be soldering.

An important thing to remember when soldering is to keep the copper clean. Flux in the form of a powder, paste, or liquid can be used to assist in keeping the connection clean. This flux keeps oxidation from occurring.

The process of soldering is often referred to as "soft soldering" or "sweating." Either term is acceptable, but remember, the person you are talking to may not know all of the terminology.

Procedures

The procedures in the table below need to be followed to create a tight and leak-proof joint. Master these procedures so you can become the go-to person in the shop when a soldering job needs to be accomplished.

Soldering Procedure	
Step	**Action**
1	Ream the inside of the tubing to remove burrs which cause restrictions.
2	Make sure all connections are clean and dry.
3	Clean the exterior of the tubing with something abrasive like emery cloth.
4	Apply a thin layer of flux to the outside of the tubing. *Do not apply flux inside the tubing.*
5	Place the tubing and fittings together. Ensure dirt does not get on fittings or stuck in the flux.
6	Heat the tubing by placing the inner cone to touch tubing. The torch tip should be a few inches away.
7	Move the flame around in a figure eight motion all around the fitting.

Soldering Procedure	
Step	**Action**
	If you hold the torch in one place too long you could burn the metal.
8	When you think the metal is at the solder's melting point, place the flame at the center of the fitting.
9	Touch the solder to the bottom of the joint. • If it melts, then feed the solder around the joint. • If it doesn't melt then remove the solder.
10	Stop feeding solder once a ring of solder is visible around the fitting. This should not take very long because of the capillary action pulling the solder around the joint.
11	Shut off the torch handle.
12	Immediately wipe the joint with a damp rag or with the flux brush to clean the joint and make it look sharp.

Shutdown

Performing a proper shutdown is important for safety and the life of the equipment. The following table covers shutting down after soldering.

After Soldering Shutdown	
Step	**Action**
1	Close the torch's acetylene valve.
2	Open the torch valve to bleed the regulator. This is done to take pressure off the regulator and valve.
3	Close the torch valve.
4	Turn the regulator-adjusting screws counterclockwise to relieve the pressure on the diaphragm.
5	Hang the torch and hose up properly to prevent kinking the hose or damaging the torch.
6	Place the tank upright and secured in your work vehicle.
7	Upon return to the shop remove the assembly and place in designated location. Do not leave tank in the work vehicle.

There it is! It's simple but important. Study these procedures and make sure you follow every single one of them.

Soldering tips

Often technicians will not be able make a solder connection even if they have done it multiple times before. Sometimes they lose focus during the swaging process or don't pay attention to the solder they choose. The following information, though short, is very important to becoming and staying great at the task of soldering.

Temperatures

A common problem during soldering is the solder not staying in the joint. This can be caused by the melting point and flow points being too close together. A solution is to use a silver type solder that has a greater difference between its melting and flow points.

Another issue is with 95/5 solder. *This solder should never be used on the discharge line of a refrigerant system.* This solder will become weak and leak due to the amount of vibrations on the high side. Use a solder with silver content and low temperature melting point to prevent this problem.

Connections

Another issue that occurs is poor connections caused by dirt or bad workmanship. If the technician does not take the time to clean the connection then the dirt and other matter will oxidize due to the high temperatures involved in the soldering process. Ensure the connection is cleaned with a rag to remove larger particles of dirt and then smooth it out to a shine with emery cloth.

Another issue with connections is bad worksmanship when fabricating the swage. The swage could become damaged during the swaging process. Also, the swage could be disproportionate. If this occurs, the solder may not completely fill into the connection. Ensure all swages are made properly and are are square.

Reversing valve

Use a tip with multiple flames to install or remove a four way reversing valve. The multiple flames make it quicker and easier to perform this task. Do not forget to install a heat sink to take the heat away from the inside of the valve. If the valve gets too much heat, the interior parts will melt and ruin the valve.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

018. Assembly and operation

1. Why is each cylinder valve cracked?

2. Why should you *never open cylinder valves before releasing the regulator adjusting screws*?

3. Why should you *never* open the acetylene valve more than 1½ turns?

4. What must be done *before* you use an oxyacetelene torch?

5. What is the *first step* in lighting the torch for *brazing*?

6. During shutdown, why should you turn the regulator-adjusting screws *counterclockwise*?

7. How is flashback indicated?

8. What is the *first step* in disassembling an oxyacetylene outfit?

9. What will using a torch wrench help prevent?

019. Soldering procedures

1. Why are soft metals used for soldering?

2. What does the flux help prevent?

3. What is the *next step* after you think the metal is at the solder's melting point and you place the flame at the center of the fitting?

4. What is the *first step* when shutting down the acetylene equipment?

5. How do you relieve pressure off of the diagphram?

6. What is a cause of solder not staying on a joint?

7. Why should 95/5 solder *never* be used on the discharge line of a refrigerant system?

8. What makes soldering a reversing valve in quicker?

Answers to Self-Test Questions

016

1. By releasing its heat unit very quickly.
2. 15 psi.
3. 29.4 psi.
4. Because a portion of the oxygen is derived from the air surrounding the flame.
5. This allows space for expansion as the acetone absorbs the acetylene to stabilize it under pressure.
6. A safety factor to prevent incorrect connections.

7. To prevent a possible fire.
8. Because you may get burned.
9. Attach the torch assembly to the can of propane or butane.
10. Store the assembly in a safe and cool place.

017

1. Keep you from confusing the oxygen connection with the acetylene connections.
2. In the mixing head.
3. The torch tip directs the flow of the oxyacetylene mixture.
4. Oil or grease mixed under pressure with oxygen may explode.
5. By observing a gradual pressure rise on the working pressure gauge after the cylinder or manifold valve is opened.
6. It moves the linkage and the needle pointer.
7. Leaking.
8. Flashback.
9. Copper acetylene is formed and it explodes violently at the slightest shock.
10. By submerging them in a bucket of clear water while they're pressurized.

018

1. To blow out any dirt that may be lodged in the outlet nipple.
2. You could damage the regulator if the adjusting screws aren't released.
3. It allows you to quickly close the valve in case of an emergency.
4. Adjust the regulators for the right working pressure of the gases.
5. Open only the acetylene torch valve.
6. To relieve the pressure of the diaphragm.
7. By a high pitched whistle.
8. Be sure the gas supply is off.
9. Rounding the corners on connecting and union nuts.

019

1. Because they have low melting points.
2. Oxidation.
3. Touch the solder to the bottom of the joint.
4. Close the torch acetylene valve.
5. Turn the regulator-adjusting screws counterclockwise.
6. The melting point and flow points are too close together.
7. It will become weak and leak.
8. The multiple flames.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

42. (016) To completely burn acetylene, it is *not* necessary to supply *all* 1½ parts of oxygen because
    a. a portion of the acetone is derived from the air surrounding the flame.
    b. a portion of the oxygen is derived from the air surrounding the flame.
    c. oxygen does *not* mix with acetylene outside of the tank.
    d. oxygen is pulled from inside the acetylene tank.

43. (016) When will the *safety plugs* in *acetylene* cylinders melt?
    a. 202 to 222 °F.
    b. 210 to 220 °F.
    c. 212 to 220 °F.
    d. 225 to 235 °F.

44. (016) Care must be taken to prevent propane/butane torch hose damage to
    a. prevent complete combustion.
    b. keep the customer satisfied.
    c. ensure a better connection.
    d. prevent a possible fire.

45. (016) What is the *last step* in operating the propane/butane torch?
    a. Attach the torch assembly to the can of propane or butane.
    b. Store the assembly in a safe and cool place.
    c. Turn the valve off.
    d. Solder the joint.

46. (017) Oxygen valve threads are *right handed* to
    a. prevent external combustion.
    b. prevent internal combustion.
    c. keep you from confusing the oxygen connection with the acetone connections.
    d. keep you from confusing the oxygen connection with the acetylene connections.

47. (017) The gases from the oxygen and acetylene cylinders are mixed in the
    a. tanks.
    b. torch tip.
    c. mixing head.
    d. torch tip and in the tanks.

48. (017) How can a *regulator leak* be detected?
    a. A hissing sound coming from the tank valve.
    b. The tank valve will be stuck in the closed position.
    c. A gradual pressure rise on the working pressure gauge *after* the cylinder or manifold valve is opened.
    d. A gradual pressure rise on the working pressure gauge *before* the cylinder or manifold valve is opened.

49. (017) What could occur if *copper* is used to replace a brass hose splice?
    a. Copper acetylene is formed which explodes violently.
    b. Solder acetylene is formed which explodes violently.
    c. Soldering efficiency will increase by 25 percent.
    d. Brazing efficiency will increase by 25 percent.

50. (018) Each acetylene and oxygen cylinder valve is cracked to
    a. blow out any dirt that may be lodged in the outlet nipple.
    b. blow out any dirt that may be lodged in the mixing head.
    c. blow out any dirt that may be lodged in the hoses.
    d. help make soldering easier.

51. (018) What is the *first step* in disassembling an oxyacetylene outfit?
    a. Bleed the regulators.
    b. Remove the torch tip.
    c. Disconnect the regulator.
    d. Be sure the gas supply is off.

52. (018) Using a torch wrench helps prevent
    a. rounding the torch tips.
    b. random pressure increases.
    c. random pressure decreases.
    d. rounding of corners on connecting and union nuts.

53. (019) Soft metals are used for soldering because
    a. they have low melting points.
    b. they have higher melting points.
    c. the softer metal is not as abrasive.
    d. they are less harmful to the environment.

54. (019) What is the *next step* after you think the metal is at the solder's melting point and you place the flame at the center of the fitting?
    a. Move the flame around.
    b. Shut off the torch handle.
    c. Ensure connections are dry.
    d. Touch the solder to the bottom of the joint.

55. (019) What is a cause for solder *not staying on a joint*?
    a. The pour point is too low.
    b. The melting point is the same as the pour point.
    c. The melting point and flow points are too far apart.
    d. The melting point and flow points are too close together.

56. (019) Why should 95/5 solder *never* be used on the discharge line of a refrigerant system?
    a. It will become weak and leak.
    b. It will cause a restriction in the line.
    c. It was designed for aluminum tubing only.
    d. It will cause the refrigerant temperature to be higher.

Please read the unit menu for unit 4 and continue ➔

Student Notes

Unit 4. Heating, Ventilation, Air Conditioning, and Refrigeration Physics

PHYSICS IS A SCIENCE that deals with matter and energy. In the field of heating, ventilating, air conditioning, and /refrigeration (HVAC/R), you are concerned with matter and energy interactions as applied to mechanics, heat, electricity, magnetism, and radiation. What does this mean? In HVAC/R, knowing certain science concepts is crucial to your becoming a better technician. You may wonder why having an understanding of matter is important to you fixing air conditioners. The simple answer is the more you know about the process the better you become. It is as simple as that. You need to have a thorough understanding of the physics of HVAC/R so you have a better grasp of what is happening in an HVAC/R system.

4–1. HVAC/R Physics

Heat is a necessity of life. It is as necessary as food, clothing, and shelter. Even when you have shelter, you still need heat for comfort. The absence (or the reduction) of heat is also a necessity—for the preservation of food and for comfort.

020. Energy and heat: measurement, calculations, and transfer

In your job, you are concerned with removing, producing, and controlling heat. Since heat is energy, and energy is in all matter, you need to understand the relationship of heat, energy, and matter.

Energy

Energy is the capacity to produce an effect or to do work, and you can neither create nor destroy it, but you can convert it from one form to another. Energy comes in many forms, such as thermal, mechanical, electrical, chemical, and light. Further, it can be broken down into potential and kinetic. *Potential* energy is stored energy. For example, if a man holds a ball out in front of him, the ball has potential energy. It will stay as potential energy until a force acts upon it. *Kinetic* energy is energy doing work. If the man drops the ball, it will fall.

The ball first possessed potential energy and then kinetic energy. Once the man dropped the ball, the energy was transferred. The potential energy did not disappear but was transferred to kinetic energy (the ball moving). This is an important law in the HVAC/R field because we are constantly converting one form of energy to another.

For an HVAC/R specific example, consider water sitting at a closed valve. This is potential energy and requires an action to be converted to kinetic energy. When a technician or an automated control opens the valve and allows the water to flow, the water's potential energy is converted into kinetic energy.

How does potential and kinetic energy apply to everyday work? Using the water example, you must know that the valve has kinetic energy (the flow of water) capability. You need the water to flow; if the valve is closed when it is supposed to be open, then there is no water flow and thus no kinetic energy. This is a direct application of the concepts of energy to HVAC/R troubleshooting.

Another example of energy conversion is how you can convert the various forms of energy from one form to another. For example, gas and oil have chemical energy because they combine with atmospheric oxygen and produce heat as they burn.

Laws of thermodynamics

Thermodynamics is the science of heat energy and its transformation to and from other forms of energy. Using the proper equation, you can calculate the amount of energy obtained upon conversion to another form of energy. However, in HVAC work, not all the “converted” energy is totally converted. You can measure this difference as the efficiency of the transfer process.

Laws of Thermodynamics	
First law	Energy can neither be created nor destroyed (the net increase in the energy content of a particular system in a given period is equal to the energy content of the material leaving the system plus the heat added to the system).
Second law	It is impossible for a self-acting machine, unaided by any external agency, to convey heat from a body of lower temperature to one of a higher temperature (heat flow always occurs from the higher temperature level to the lower temperature level).

Defining heat

Heat is a form of energy produced by the activity of atoms and molecules within the structure of a substance. Since the activity varies within different substances and within the same substance at different times, the amount of heat energy given up or absorbed varies greatly. If activity is rapid, a substance may generate large amounts of heat. With the increased activity, combustion can occur that changes the composition of the original material. For example, you can make molecules of oil move rapidly. The hot oil, without changing form, is a source of heat to warm another substance. If the oil is heated even more, it reaches a temperature where the oil molecules move so fast that the oil breaks down. It combines with gases from the surrounding air to form other substances. Large amounts of heat energy release and the oil ignites.

Cold

Cold is term that really means there is an absence of heat. If a refrigeration system has cooled its space to 28 °F there is still heat in the air but no one would ever call 28 °F warm or hot. They probably wouldn’t even consider that 28 °F air contains heat but it does.

Both quantity and intensity are expressions of heat. Thermometers measure the intensity of heat, expressed in degrees. Measurements and calculations provide you with the quantity of heat.

Heat and temperature

A thermometer measures the *intensity* of heat called *temperature.* Heat and temperature have a *direct relationship*, but they are different. Temperature will not give you the amount of heat energy in a substance. For example, a burning match develops a much higher temperature (intensity) than a radiator, but the match does not give off enough heat to warm a room. In addition, 10 pounds of water at 80 °F melts more ice in a given length of time than one pound of water at 100 °F. There is more total heat energy in the 10 pounds of water even though the temperature is less. The terms heat and temperature should be used with care.

Heat measurement and calculations

Both quantity and intensity are expressions of heat. Thermometers measure the intensity of heat, expressed in degrees. Calculations provide you with the quantity of heat.

Temperature measurement and conversion

Temperature measurements can be made by using a thermometer calibrated in degrees Fahrenheit (°F) or degrees centigrade (°C), also known as Celsius. The Fahrenheit thermometer has been the standard used most in English-speaking countries for years. Recently, these countries have been introducing the Celsius standard. Thermometers measure the degree of sensible heat of different bodies. The thermometer can make a comparison only between the temperature of a body and some definitely known temperature, such as the melting point of ice or the boiling point of water. It also shows the markings of the freezing and boiling points of pure water at sea level. The range of the Fahrenheit thermometer between the freezing point and the boiling point is 180 °F (32 to 212 °F). On the Celsius thermometer, the range is 100 °C (0 to 100 °C) from the freezing point to the boiling point. These temperature scales are shown in figure 4–1.

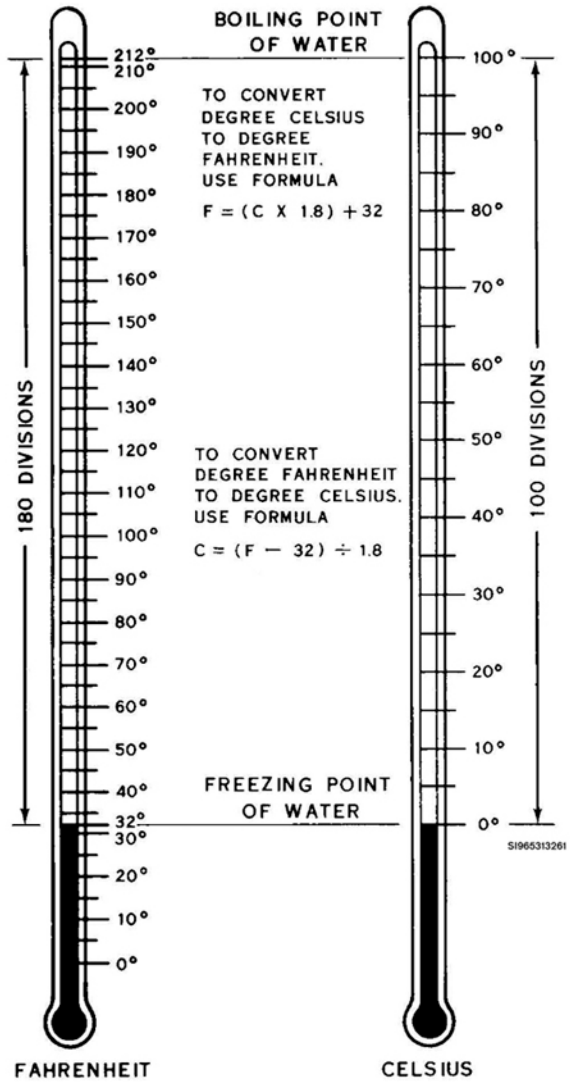


Figure 4–1. Fahrenheit and Celsius Scale.

Converting Fahrenheit and Celsius Temperatures	
Conversion	**Procedure**
Fahrenheit to Celsius	Subtract 32 from the Fahrenheit temperature reading. Divide the remainder by 1.8.
Celsius to Fahrenheit	Multiply the Celsius temperature reading by 1.8. Add 32.

Another way to convert temperatures is by using the fraction $^5/_9$ to convert Fahrenheit to Celsius, or $^9/_5$ to convert Celsius to Fahrenheit. Ask your trainer to explain this method if you are not familiar with it.

Sensible and latent heat

The terms "sensible heat" and "latent heat" often indicate the effect the flow of heat has on a substance. The flow of heat from one substance to another normally is a temperature change reflected in each substance—the hotter substance becomes cooler; the cooler substance becomes hotter. However, a substance that is changing from one physical state (solid, liquid, or gas) to another does *not* reflect temperature change. The addition or removal of sensible heat to a substance reflects a rising temperature change.

Latent heat has been added or removed from a substance when the flow of heat is not reflected in a temperature change, but is reflected in the changing physical state of a substance.

Does anything bother you in this last paragraph? It should. Here we are talking about adding and removing heat—we mean that we are providing sensible and latent heat—as though we had two different kinds of heat to consider. This is common (if inaccurate) engineering language. So keep these points clearly in mind:

- Heat is the flow of thermal energy.
- "Adding and removing heat" means that we are providing temperature differentials so that thermal energy can flow from one substance to another.
- Sensible heat and latent heat are two different kinds of *effects* produced by heat, *not* two different kinds of heat.

The three physical states of matter are (1) solid, (2) liquid, and (3) gas (or vapor). The physical state of a substance relates closely to the distance between molecules. The molecules are closest together in solids, farther apart in liquids, and farthest apart in gases. When the flow of heat to a substance is *not* reflected in a temperature change, we know that the energy is being used to increase the distance between the molecules of the substance. This changes it from a solid to a liquid or from a liquid to a gas. The energy is *not* lost; it is stored in the substance as internal energy. The energy price is "repaid" when the substance changes back from gas to liquid or from liquid to solid, since heat flows from the substance during these changes of state.

If we start with 1 pound of ice at 0 °F, we must add 16 British Thermal Units (Btus) to raise the temperature of the ice to 32 °F. We call this adding *sensible heat.* To change the pound of ice at 32 °F to a pound of water at 32 °F, we must add 144 Btus (the *latent heat of fusion*). There is no change in temperature while the ice is melting. After all the ice has melted, the temperature of the water rises as you apply additional heat. If we add 180 Btus—that is, one Btu for each degree of temperature between 32 °F and 212 °F—the temperature of the water rises to the boiling point. To change the pound of water at 212 °F to a pound of steam at 212 °F, we must add 970 Btus (the *latent heat of vaporization*). After the water is converted to steam, adding more heat increases the temperature of the steam. If we add about 44 Btus to the pound of steam at 212 °F, we can superheat it to 300 °F.

The same relationships apply when removing heat. Removing 44 Btus from the pound of steam at 300 °F causes the temperature to drop to 212 °F. As the pound of steam at 212 °F changes to a pound of water at 212 °F, it releases 970 Btus. When a substance is changing from a gas or vapor to a liquid, we use the term "*latent heat of condensation*" for the heat given off. *Note that the latent heat of condensation is the same as the latent heat of vaporization.* Removing another 180 Btus of sensible heat lowers the temperature of the pound of water from 212 to 32 °F. As the pound of water at 32 °F changes to a pound of ice at 32 °F, it releases 144 Btus without any accompanying change in temperature. Further removal of heat causes the temperature of the ice to decrease. To determine Btus when water is stated in gallons, multiply gallons by 8.3 to find the pounds. To determine Btus when water is stated in cubic feet, multiply cubic feet by 62.5 to find the pounds.

Specific heat capacity

Specific heat capacity is the amount of heat added or released to change the temperature of one pound of the substance 1 °F. The size and state of the substance affects the specific heat capacity of that substance.

British thermal unit

The unit of measurement for a given quantity of heat is the British thermal unit, commonly known and abbreviated as Btu. One Btu is the amount of heat needed to change the temperature of 1 pound of pure water 1 °F at sea level. At sea level, if you add 1 Btu to 1 pound of pure water at 50 °F, the temperature rises to 51 °F.

It is easy to see that it takes far more Btus to heat a swimming pool from 94 to 95 °F than it does to heat a cup of coffee the same one degree. By using the Btu per hour (Btuh), you can find the amount of heat transferred in a given amount of time. Using weight for mass, you can establish the heat in a substance used as heat source, such as Btu per pound of coal or Btu per pound of air.

Enthalpy

This is the total amount of heat in a substance. This term takes into account the mass of an object (m), its specific heat (c) and the difference between its measured temperature and its reference temperature. That may sound like a lot but break it down simpler:

- How big is the object?
- What is its specific heat?
- What was the temperature measured?
- What is the reference temperature?

Here is the formula, H = m x c x ΔT, and an example using: *Water with a specific heat of 1*.

Determine Total Heat Content of Water	
Factor	**Quantity**
Mass (m)	10 lbs
Specific heat (c)	1
Temperature measured	50
Temperature referenced	10
ΔT	(50 - 10) = 40

From the table above, substitute in the formula:

$$H = 10 \text{ x } 1 \text{ x } (50 - 10) = \text{Btus}$$

$$H = 10 \text{ x } 1 \text{ x } 40 = 400 \text{ Btus}$$

Therefore, the total heat content of that water is 400 Btus.

Methods of transferring heat

Heat transfer is what we do as HVAC/R technicians. In cooling, heat is taken from inside the space and transferred someplace less objectionable, like outside. In heating, we can take heat from outside and transfer it inside or we create the heat and move it with air. Heat is in all matter that has a temperature above absolute zero. Absolute zero is a hypothetical temperature of about –460 °F where no thermal energy exists. Heat transfer can occur anywhere above absolute zero. Heat transfer can be from one place or object to another by conduction, convection, or radiation. Following the second law of thermodynamics, heat flows from the warmer to the colder substance, with a rise in temperature in the colder substance. This direction of flow occurs in all transfers of heat, whether or not there is combustion.

Conduction

Conduction is the flow of heat through a substance or the flow of heat from one body to another when the bodies are in direct physical contact with one another. The ability of various materials to conduct heat differs greatly. The best conductors are metals, such as aluminum and copper, but glass also is a good conductor of heat. Poor conductors, such as wood, mineral wood, air cork, and so forth, are called *insulators*.

Insulators slow conduction heat transfer, but cannot stop it. Glass, which is a good conductor, becomes an insulator when used as fibrous glass because of the small isolated pockets of trapped air (a good insulator).

Convection

Most heat transfer in the HVAC industry is by convection. Convection is the transfer of heat by movement of a fluid, such as air or water, over a substance. The heat flow can be either to or from the substance or object. For example, transfer of heat from the pipes to the air heats air flowing over a bank of hot pipes. If the pipes were cold and the air is warm, the air is cooled by transfer of heat to the colder pipes. Natural convection occurs when cool air surrounds a hot object, becomes heated, and then rises and allows more cool air to move in and contact the hot object. In a like manner, chilled air falls, allowing warmer surrounding air to contact the cold object, reversing the above process.

When a fan propels air across a hot or cold surface, heat transfer generally increases with an increase in air velocity. Forced convection (air moved across the surface by a fan) is a more efficient method of heat transfer that produces a greater volume of transferred heat.

The conditions that affect the transfer surfaces of HVAC equipment and reduce the output of the unit include dirt, fouling, corrosion, condensables, and freezing. You can prevent most of these conditions through good maintenance.

Radiation

Radiation is a form of energy transfer like that of light waves and radio waves. The transfer occurs without heating the space *between* the two substances. For example, a person can feel energy waves from the sun until a heavy cloud layer passes in front of it. The person feels the change immediately because the air in the space between was not heated directly by the sun's rays. Heat from an outdoor campfire and an infrared heater are examples of radiant heat. Figure 4–2 shows an example of a radiant heater. You will readily feel this heat, even when the air temperature is cold, but only on the side facing the fire or heater.

Figure 4–2. Radiant heater.

Dense or solid substances like masonry walls block or retard radiant heat (as from the sun), but ordinary window glass is transparent to both light and solar radiation. The walls and roof of a house that block the passage of radiant heat to the inside are themselves heated by the radiant heat rays.

When heat waves strike an object, some reflect, some may pass through, and the object absorbs the rest. Polished metals are the best reflectors of heat, but they are poor absorbers of heat. Rough metal absorbs heat more readily than a highly polished metal. It also loses heat faster by radiation. The color of a substance also affects its absorbing power. A black surface absorbs heat faster than a white one. That is why light-colored clothes are cooler in the summer than dark-colored ones.

021. Basics of fluid flow

When mentioning the word *fluid*, most people think of water or some other liquid. However, a fluid also can be a gas or vapor. When used with environmental systems, the word *fluid* means air (from the atmosphere), water (or a heat transfer fluid), steam, refrigerants, and, occasionally, a few other gases.

Fluid properties

The basic categories of fluid properties are state, weight or density, volume as specific volume, vapor pressure, specific heat, and heat content. We'll look at each of these in the following paragraphs.

State

The state of a fluid refers to its form—liquid or gas.

- *Liquids* used in environmental systems are water, thermal fluids, such as ethylene glycol solutions, and refrigerants in the liquid state.
- *Gases* consist of steam, evaporated refrigerants, and the air-water vapor mixture in the atmosphere.

Some substances, including commonly used refrigerants, may exist in any of three states. An example is water, which may be solid (ice), liquid (water), or gas (steam or water vapor).

Weight, density, and specific volume relationships

The *weight* of a substance is the amount of force it exerts under pull by the earth's gravitational field; measured in pounds in the United States.

The *density* of a substance relates to the nearness and the number of particles or molecules of the substance in a given volume. Because it is easier to walk in still air than in still water, you can assume the density of air is less than that of water. Density is referred to in terms of units of weight per unit of fixed volume, and when used in environmental systems, in terms of pounds per cubic feet.

Specific volume is the reciprocal of density; used to find the cubic feet of volume if we know what the weight in pounds is.

Temperature and pressure affects both density and specific volume. These are explained later.

Vapor pressure

Vapor pressure denotes the lowest absolute pressure at which a given liquid at a given temperature remains liquid instead of changing into a gas. The vapor pressure of a fluid can limit the suction lift of a hydronic pump. For example, if the pressure in a pump system is not equal to or greater than the vapor pressure of the liquid, the liquid flashes into a gas. For the same reason, we must maintain pressure on the suction side of a pump when handling hot water or volatile liquids, such as gasoline. Without sufficient pressure, the liquid flashes into a gas and cannot be pumped.

Many process applications use pressurized vessels on the suction side of the pump to overcome the vapor pressure of some liquids. The amount of pressure needed depends on the liquid and the liquid's temperature. In most cases, the higher the temperature, the higher the vapor pressure. We measure vapor pressure in pounds per square inch absolute (psia).

Specific heat

Specific heat is the amount of heat energy in Btus needed to raise the temperature of 1 pound of a substance 1 °F. Using specific heat values in simple equations lets you calculate the gallons per minute or cubic feet per minute in a system if you know the Btus per hour and the temperature difference. The table below shows standard temperature, pressure, density, specific volume, and specific heat of dry air and of water.

	Temperature	Atmospheric pressure	Density	Specific volume	Specific heat
Dry air	70 °F	29.92 inches mercury (in. Hg.)	0.075 pounds per cubic foot	13.33 cubic feet per pound	1 Btu/lb. °F
Water	68 °F	29.92 inches mercury (14.7 psi in. Hg.)	62.4 pounds per cubic foot	0.016 cubic feet per pound	.24 Btu/lb. °F

Enthalpy (total heat)

Earlier we stated that heat is a form of energy produced by the activity of atoms and molecules within the structure of a substance. The amount of heat energy in that substance at any one time depends on the molecular motion at the time. The quantity of heat energy within the substance is “enthalpy” or “total heat.”

At any given time, a substance has only one value of enthalpy and a related specific temperature value on the thermometer.

- If enthalpy increases, temperature increases.
- If temperature decreases, enthalpy decreases.

The ability to increase or decrease enthalpy and temperature together is the basis for heat transfer in environmental systems, and only *differences* in enthalpy and temperature are normally of importance.

Fluid static

The term “static,” as used here, means “at rest” or “not moving.” Although the static condition continues to exist when pumping a fluid through a system, the concept is easier to discuss as if the pumps (or fans) were not operating. For example, on an air system, static measurements can be taken while the fan is moving air. This seems confusing because static means “at rest” but it remember it is easier to discuss if considered at rest.

Standard atmospheric pressure

Weight, as just discussed, is the gravitational force that a substance exerts. The United States measures weight in pounds, while most of the world measures weight in grams or kilograms. At standard conditions, a cubic foot of water weighs 62.4 pounds and a cubic foot of air 0.075 pounds. Both of these also happen to be the densities of the substances. However, mercury weighs 849 pounds per cubic foot. A one-foot-high column of each of the three substances exerts the above named force (weight) in pounds over a one square foot area. There are 144 square inches in a square foot. To find the force in pounds per square inch (psi), divide each one-foot column weight by 144:

Air	$\frac{0.0075 \text{ lb./ft.2}}{144 \text{ in.}^2/\text{ft}} = .00052 \text{ psi}$
Water	$\frac{62.4 \text{ lb./ft}^2}{144 \text{ in.}^2/\text{ft.}^2} = .433 \text{ psi}$
Mercury	$\frac{848.4 \text{ lb./ft.}^2}{144 \text{ in.}^2/\text{ft.}^2} = 5.8 \text{ psi}$

These values are the “static heads” for these substances for a height of 1 foot, or 12 inches.

You can find the atmospheric pressure in psi at standard conditions using the value of 5.894 psi for 12 inches of mercury (12 in. Hg.):

$$\text{Standard conditions} = (29.92 \text{ in. Hg.}) \bullet \frac{5.894 \text{ psi}}{12 \text{ in. Hg.}} = 14.696 \text{ psi}$$

The value of 14.696 psi is the actual weight of a column of air of the earth's atmosphere pressing on one square inch at standard conditions. Therefore, 70 °F air at sea level with a barometric pressure of 29.92 in. Hg. exerts a pressure of 14.696 psi. This is *standard atmospheric pressure*. As the altitude above sea level is increased, the atmospheric pressure decreases.Think about it, the higher up you are there is less atmosphere pushing on you.

It takes longer for water to boil in the mountains than it does at sea level. Why? Since it is not possible to raise the temperature of boiling water above the saturation temperature for that pressure, the amount of internal energy available is much less at high altitudes than at sea level. By the logic, you can see that water boils faster in a pressure cooker than in an open pot.

Absolute pressure

Atmospheric pressure is the pressure in a system when the pressure gauge reads zero. *Absolute pressure* of a system is gauge pressure (whatever the gauge reads) in pounds per square inch plus the atmospheric pressure of 14.696 psi (14.7 psi in environmental system work); the symbol is *psia* (pounds per square inch absolute).

- *When using psi in HVAC system work, never assume that the pressure stated is gauge pressure.*
- Always verify between *psia* and *psig*.

Vacuum

"Emptiness of space," "negative pressure," "a state of isolation," and "a vacant space" all express the concept of vacuum. A vacuum is important in the HVAC field because it lowers the boiling and condensing point. These points are lower than at atmospheric pressure.

In theory, there are two classifications of vacuum—perfect and partial.

- A *perfect vacuum* would be a space completely void of any pressure. A perfect vacuum has never been achieved.
- A *partial vacuum* is a space with a gas content less than atmospheric pressure (14.7 psi) and above a perfect vacuum (0 psia).

Static head

From the earlier discussion, we can conclude that *static head is the pressure developed by the weight of a fluid at rest in a system.* Regardless of the pressure at the bottom of a one-foot-high column of air, water, or mercury, the pressure at the top of the column in each case is zero since there is no fluid above that point to exert pressure. Since water and mercury are comparatively incompressible, the density does not vary whether the height of the column is 1 foot or 10,000 feet. Because air is a compressible fluid, the density of air reduces as height or elevation increases. Charts are available to find density correction factors for heights above sea level and temperatures different from standard conditions.

The pressure at any point between the top and the bottom of a water system without flow is the static head at that point (fig. 4–3). If the pressure releases and the fluid is allowed to flow, energy is available at these points to do work.

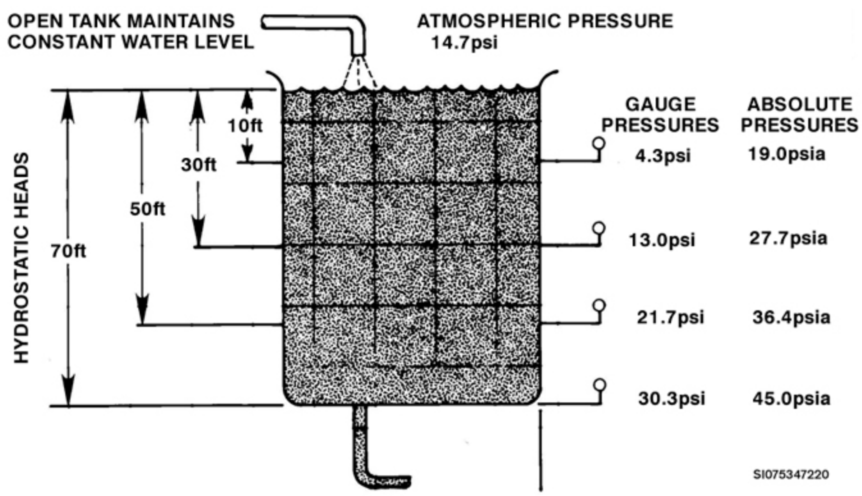


Figure 4–3. Static head.

Fluid dynamics

In fluid mechanics, the term *dynamics* describes the condition of motion of fluid in a system. In environmental systems, *dynamics* refers to a system *in operation* with fluids flowing as opposed to the static condition of the system when shut down and fluids are at rest.

Potential energy is the ability to do work. Water behind a dam has the ability to do work because of the difference in static heads between the high water level behind the dam and the low water level below the foot of the dam. However, until there is flow, there is no work and the stored energy is all *potential*. If the water behind the dam is allowed to flow through a gate in the dam, the potential (at rest) energy is transformed into kinetic energy (of motion), and work is done.

If the moving water rotates a turbine connected to a generator that produces electricity, then the kinetic energy produces useful work. Energy in motion does *not* automatically mean that the work has a useful purpose.

Velocity

Velocity of a fluid related to the cross-sectional area of the pipe or duct through which it is flowing and the volume of the fluid within the pipe or duct. The common units of measurement for velocity are feet per second (fps or ft/sec) and feet per minute (fpm or ft/min).

- In the case of fluid flow, velocity is linear (that is, in a straight line) even though the line may change direction.
- In rotating velocities, as with rotating machinery (e.g., motors, fans, and pumps), velocity is translated into convenient rotational units, such as revolutions per minute (rpm).

The particles or molecules of a fluid are somewhat independent and may move at different velocities relative to each other. Because of this, velocities measured at different points in the same cross-section of a pipe or ducts are not the same, since molecules may slip against each other.

Friction is responsible for the different velocities of a fluid in a cross-section of pipe. Friction at the unmoving wall of a pipe or duct reduces the velocity of the fluid to near zero. The first layer of fluid molecules slows the next layer; the third layer is slowed by the second, and so on until the single center group or layers reach the highest velocity. Without friction, all particles would move independently but at the same speed. The *calculated velocity of the fluid* in the pipe is an *average* rather than a value that represents the speed of the fluid at any one point in the cross section.

Flow

The diagram in figure 4–4 shows the phenomenon known as *laminar flow*. Velocity lines are straight to illustrate the point. This condition exists under special conditions, depending on viscosity, friction, velocity, and other factors that, when combined, result in a value known as *Reynold's number*. When the Reynold's number is low enough, laminar flow occurs and all particles flow in a straight line.

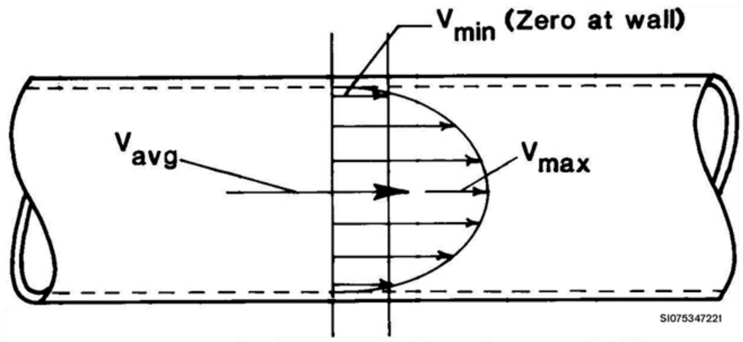


Figure 4–4. Laminar flow.

To observe this condition, shake a bottle of syrup and watch the entrained air bubbles as you pour the syrup, without allowing the neck of the bottle to fill with syrup. The bubbles flow in layers—top layer bubbles flow faster than the lower ones.

When you increase the velocity to or above a critical value of Reynold's number (approximately 2000 to 3000) the situation becomes more complicated. Molecules tumble about in a random manner, but they constantly move forward in the direction of flow. This condition is called *turbulent flow*.

Laminar flow produces less friction loss, but velocities are impracticably low. *Stratification*—a special case of laminar flow—is the result of differences of fluid density. Stratification can raise havoc in air systems. Laminar flow generates considerably less system noise. Heat transfer is extremely poor because of laminar flow.

Conversely, turbulent flow produces higher friction losses, higher velocities, reduced chance of stratification by mixing, more noise, and excellent heat transfer. In general, turbulent flow is easier to produce and more desirable for system operation, but it is not desirable when a technician is trying to take readings to use in balancing the system. Proper design of the system helps to eliminate the disadvantages.

Whether flow is laminar or turbulent, the resulting overall velocity assumes a positive direction away from the pumping devices. The result is flow of the fluid in a single direction, no matter how complex the path. No system could operate without this result. For simplicity, *a single arrow in the direction of flow indicates the velocity average*.

The discussion above has shown that *friction* resists the flow of fluid, a natural resistance caused by a substance moving at a different rate than the substance with which it is in contact. One substance may be stationary and the other moving, or both may be moving at different velocities.

In many cases, friction is necessary and useful. For example, if there were no friction, walking would be impossible. In oversimplified terms, without friction, we could not stop anything moving by conventional means. In many cases, however, friction is an expensive disadvantage.

If it were possible to start the fluids flowing in a system and then eliminate friction, it would be possible to eliminate all power consuming pumping equipment in closed systems, since the only purpose served by this equipment is to overcome the friction losses resulting from the flow that the pumping equipment produces.

Flow produces velocity, velocity produces molecular contact, and the molecular contact results in friction—a force in the opposite direction of flow. Conversely, there must be a force in the direction of flow, causing the flow. Fortunately, it is possible to produce forces in the direction of flow greater than frictional resistance; otherwise, fluids could not flow at all.

Pressure

Pressure is the force needed to overcome the friction and dynamic losses of a system. A pumping device produces pressure. In environmental or HVAC systems, the pumping device may be a circulating pump or fan. The only purpose of the pumping device is to produce pressure great enough to overcome the system's resistance to the flow of the fluid. The pressure produced is indicated by the pressure difference from the pump or fan discharge. This is exactly equal to the system resistance to flow and, in the case of water, the elevation differences for fluid you are pumping. Thus, a measurement of the difference between the inlet and discharge pressures of a pressure device of any kind is a measurement of the system resistance at a particular flow rate.

System pressure

It is now possible to summarize the forces in a system that produce and resist flow.

Forces in Systems that Produce and Resist Flow	
TP	Total pressure Determines how much energy is in the fluid at any point in the system.
SP	Static pressure Pressure exerted equally in all directions in the system at any point. It is a measure of the potential energy available to produce flow and to maintain that flow against the resistance.
Vp	Velocity pressure At any point in the system this is a measure of kinetic energy resulting from the flow of fluid. Velocity pressure and velocity are directly related, or proportional, allowing the system airflow capacity to be calculated. *The pressure is exerted in the direction of flow only*.

The equation below defines the relationship between the three pressures at a specific point in a system:

$$TP = SP + Vp$$

If there is no fluid flow in the system ($Vp = 0$), then $TP = SP$, or the system pressure at any point is equal to the static pressure at that point.

Static pressure and static head are *not* the same pressures, but you can add them together. As stated before, static head is not a factor in air systems, but it is a significant pressure in hydronic systems.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

020. Energy and heat: measurement, calculations, and transfer

1. Potential energy will remain potential energy until what occurs?

2. Water sitting at a valve is potential energy until what happens?

3. What may rapid activity cause a substance to generate?

4. Which has more total heat energy and melts more ice: 10 pounds of water at 80 °F or a pound of water at 100 °F?

5. When the flow of heat is *not* reflected in a temperature change, what type of heat change is taking place?

6. Sensible heat and latent heat are *not* different kinds of heat, instead, they are considered what?

7. When the flow of heat to a substance is *not* reflected in a temperature change, we know that the energy is being used to do what?

8. If we add about 44 Btus to the pound of steam at 212 °F, what can we superheat it to?

9. When does glass become a good insulator?

10. If the pipes were cold and the air is warm, how is the air cooled?

11. When a fan propels air across a hot or cold surface, what generally increases heat transfer?

12. What could affect the transfer surfaces of HVAC equipment and reduce the output of the unit?

021. Basics of fluid flow

1. When used with environmental systems, what does the word *fluid* mean?

2. If enthalpy increases then what will happen to the temperature?

3. What happens to atmospheric pressure as the *altitude above sea level is increased*?

4. What is the pressure developed by the weight of a fluid at rest in a system called?

5. Because air is a compressible fluid, what is the effect on the density of air as height or elevation increases?

6. When heights above sea level and temperatures are different from standard conditions, how can you find density correction factors?

7. What reduces the velocity of the fluid at the unmoving wall of a pipe or duct to near zero?

8. How does *friction* resist the flow of fluid?

9. We could not stop anything moving by conventional means without what?

4–2. Psychrometrics

Whatever affects air affects the systems and the air in which people live. To work intelligently with this important fluid, a person must understand the language of psychrometrics and be able to use psychrometric charts and tables as tools to change existing conditions to desired or required conditions. So what is psychrometrics? Simply stated it is the study of the air and water vapor mixture. We'll begin by discussing the air-vapor relationship. Then we'll focus on the psychometric chart and processes.

022. Air-vapor relationship

To begin our discussion of the air-vapor relationship, we need some basic information about the properties of air. Once we know them, then we can turn our attention to other factors of the air-vapor relationship including volume/temperature, volume/pressure changes, combination changes, and steam.

Properties of air

Air is a mixture of two basic gases: nitrogen and oxygen. Nitrogen accounts for about three-fourths of air's weight by volume, and oxygen accounts for the remaining one-fourth. There are, of course, traces of a few other gases in the atmosphere, but they do not usually appear in volumes great enough to be important factors. One remaining element is in air—water vapor. The amount of water vapor in the air influences equipment cooling and human comfort. This atmospheric moisture is referred to as *humidity*.

Air neither absorbs nor dissolves water. The mixture is a simple physical one, just as sand and water are when mixed. The temperature of the water vapor is always the same as that of the surrounding air. When the air contains all the water it can hold, it is termed "saturated air."The amount of moisture present at the saturation point varies with the temperature of the air. Thus, the higher the air temperature, the more moisture the air can hold.

Volume/temperature relationship

As you know, the weight of air at standard conditions is 0.075 pounds per cubic foot. Almost all substances expand with an increase in temperature; atmospheric air is no exception. If the pressure of air in a closed container is constant, the air expands in volume at a definite rate with an increase in temperature. Based on the volume of air at 0 °F, experiments show that, with each degree of temperature rise or drop, volume changes by 1.460th.

If air did not solidify before it reached –460 °F (–273 °C), it could be assumed that it would disappear. Early scientists noted this phenomenon and identified these temperatures as absolute zero.

Gay-Lussac's law is basic to understanding this volume/temperature relationship. By the terms of Gay-Lussac's law:

> The volume of a given weight of gas varies directly with the absolute temperature when the pressure remains constant.

Volume/pressure changes

The *volume of a given gas varies with changes in pressure*. This also applies to air or superheated steam (moisture in atmospheric air is in the form of superheated steam at a very low pressure). This can be demonstrated by placing a given weight of air at atmospheric pressure (14.7 psi) in a cylinder with a piston (fig. 4–5). At the point when the air volume is half of the original volume, the gauge pressure increases from 0 to 14.7 pounds per square inch (psi), or 29.4 psia. From experiments like this, Boyle's law was developed.

Boyle's law states that:

> The volume of a gas varies inversely with absolute pressure when temperature remains constant.

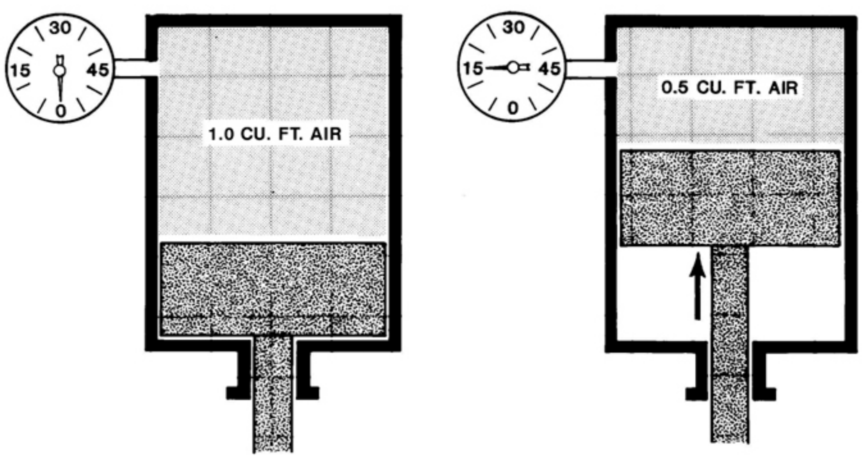


Figure 4–5. Air in a cylinder with a piston.

Combination changes

In addition to the volume/temperature and volume/pressure relationships governed by Gay-Lussac's and Boyle's laws, there are other principles that are applied to combination changes. The important ones are Charles' and Dalton's laws.

According to *Charles' law:*

> Absolute pressure varies directly with absolute temperature when volume remains constant.

This means that if you keep the pressure of a gas constant, its volume varies directly with its temperature, and if you keep volume constant, pressure varies directly with temperature (fig. 4–6).

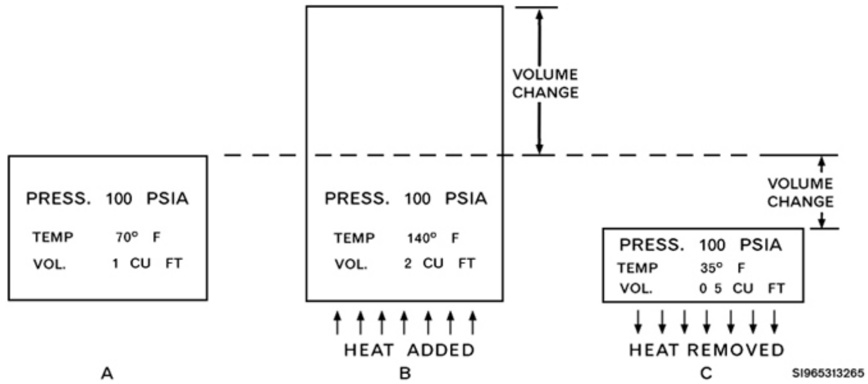


Figure 4–6. Charles law.

According to *Dalton's law:*

> The total pressure of a mixture of gases equals the partial pressures of the individual gases.

This means that if an air cylinder has 20 psi of nitrogen gas, 15 psi of oxygen gas, and 15 psi of carbon dioxide gas, the total gas pressure is 50 psi (the sum of the partial pressures of all of the gases present).

Steam

In standard atmospheric conditions, water (in an open vessel) boils into steam at 212 °F. In a closed vessel, the boiling temperature of water changes upward or downward depending on the pressure above the liquid. Under a vacuum of 29.7 inches of Mercury (in. Hg.) (0.12 psia), water boils at 40 °F; at 53 psig (67 psia), it will not boil until reaching 300 °F.

Other physical properties change with variations in pressure, including latent heat of vaporization and specific volume.

When steam passes through a coil (fig. 4–7), the addition of more heat *superheats* the steam above the temperature at which it originally evaporated. Steam at the same temperature as the boiling water is called *saturated steam*.

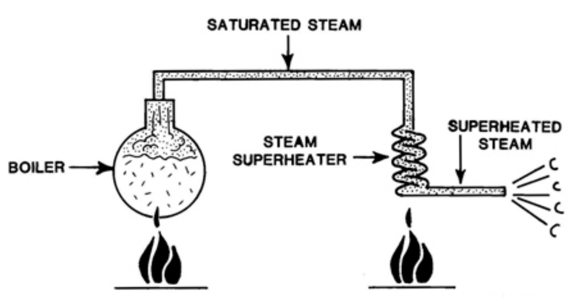


Figure 4–7. Superheat.

It is impossible to superheat steam in the presence of boiling water because the added heat only evaporates more water until all the water has boiled to steam.

When superheated steam is cooled to the boiling point corresponding to its temperature, it starts to condense into a liquid. For example, the boiling or condensing point of steam at 0.256 psia is 60 °F. If the steam encounters a 60 °F surface, beads of moisture soon collect on the surface from the steam condensing.

Ordinarily, steam condenses under constant pressure conditions. However, when steam condenses in a vessel or contained space—unless supplied with additional steam at a rate equal to or greater than the condensed amount—the pressure in the space falls because the liquid occupies far less space than steam. The data in the steam tables also show that the condensing temperature is lower at lower pressures, so both the temperature and pressure continue to fall unless more heat is supplied by more steam.

If we mix superheated steam at 70 °F and 0.18 psia with 70 °F dry air, and then cool the mixture to 50 °F, the steam begins to condense and appear as moisture on nearby surfaces. In HVAC, the point at which condensation occurs is the *dew point*.

023. Psychrometric chart and processes

The psychrometric chart is the tool used to analyze the relationship of the properties of the air (fig. 4–8). You should master at least the meaning of the chart to understand conditioned air. The scientifically formulated series of lines and curves illustrate the “whole picture” relationships of the properties of the air on the psychrometric chart.

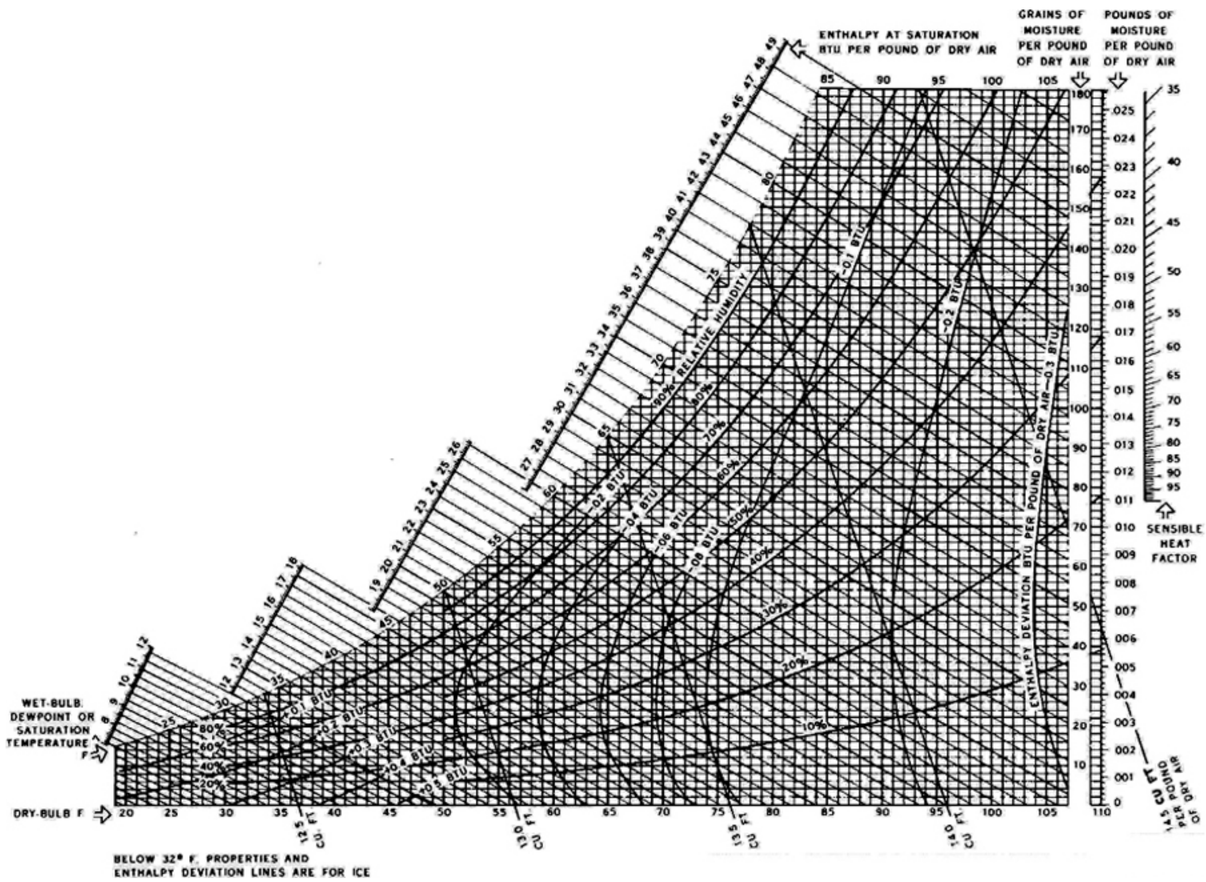


Figure 4–8. Psychrometric chart.

Terms related to psychrometrics

To understand and interpret the psychrometric chart you need to understand the terms related to psychrometrics. The essential ones are described in the following table.

Psychrometrics Terms	
Term	**Description**
Dry-bulb (DB) temperature	In air conditioning, air temperature is more accurate when listed as DB temperature. We take this temperature with the sensitive element of the thermometer in a dry

Psychrometrics Terms	
Term	**Description**
	condition. Unless otherwise specified, *all air temperatures are DB temperatures*.
Wet-bulb (WB) temperature	WB temperature is the temperature at which air stops cooling by the process of evaporation. A WB thermometer, part of a sling psychrometer, is an ordinary thermometer with a cloth sleeve placed around its bulb and then made wet with water (distilled water is preferred). The cloth sleeve should be clean, free from oil, and thoroughly wet with clean, fresh water. The high velocity current of air evaporates the water in the cloth sleeve. The evaporation withdraws heat from the thermometer bulb, thus lowering the temperature measured in °F. We call the difference between DB and the WB temperatures the *wet-bulb depression.* If the air is saturated, evaporation cannot take place, and the wet-bulb temperature is the same as the dry-bulb temperature. Complete saturation is not usual, and a wet-bulb depression is normally to be expected. The WB thermometer shows the total heat of the air measured. If air at several different times or places is measured and the wet-bulb temperatures stay the same, the total heat is the same, though their sensible heats and respective latent heats might vary greatly.
Dew point (DP) temperature	The DP depends on the amount of water vapor in the air. If air at a certain temperature is not saturated—if it does not hold the full quantity of water vapor that it can hold at that temperature—and the temperature of the air then falls, a point is reached at which the air is saturated for the new lower temperature, and condensation of the moisture begins. This point is the DP temperature of the air for the quantity of water vapor present.
Relative humidity (RH)	RH is the ratio of the amount of moisture in the air compared to what it could hold at the same temperature. It is a percentage expression of the grains of moisture in the air.
Grains of moisture (GM) and pounds of moisture (PM)	You see both GM and PM. By GM or PM, we mean the unit of measurement expressing the actual amount of moisture in 1 pound of dry air. This measurement is in grains or pounds, mixed with 1 pound of dry air. Seventy grains equals 0.010 pounds per pound of dry air. The weight of the water vapor that mixes with 1 pound of dry air is the *humidity ratio* or *specific humidity*.

Now that we have defined the terms, we need to take a look at the relationship between the different types of temperatures discussed in the preceding table.

Relation of DB, WB, and DP temperatures

The relationships between the three temperatures are as follows:

- When the air is moist but is not saturated, the DP temperature is lower than the DB temperature; WB temperature lies in between.
- As the amount of moisture in the air increases, the difference between the temperatures decreases.
- When air is saturated, all three temperatures are the same.

Psychrometric chart scales

Once we have both the DB temperature and the WB temperature, we can then start the plotting procedure. The psychrometric chart has lines and curves that have corresponding scales plotted and read at intersecting points. Figure 4–9 identifies the lines and scales; then the later figures that accompany the terms point out the names of the lines corresponding to each set of scales. There are five sets of scales used on the psychrometric chart. Some of the readings are scale differential readings. The following table describes the different scales used on psychrometric charts.

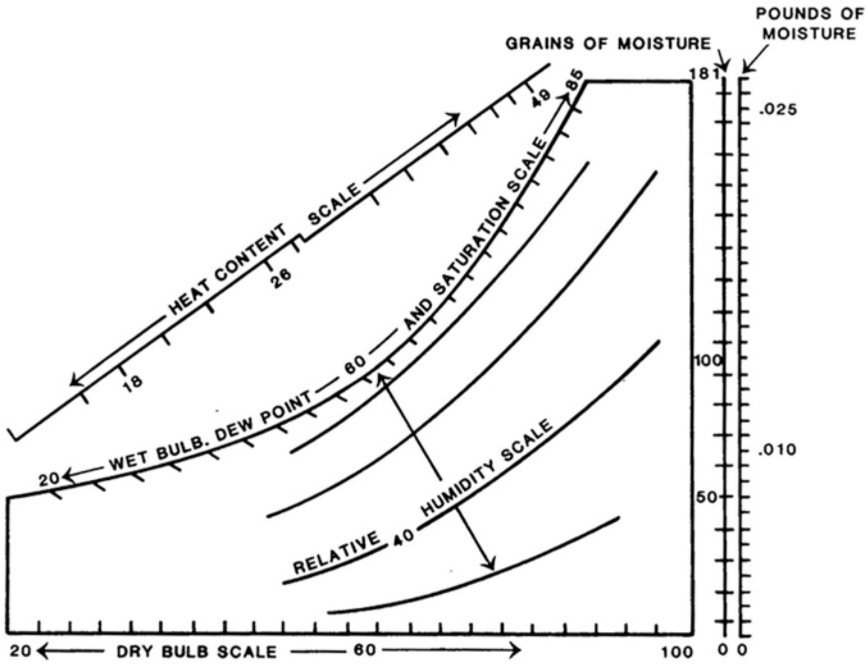


Figure 4–9. Psychrometric chart scales.

Psychrometric Chart Scales	
Scale	**Description**
DB temperature	DB plots appear on the vertical lines of the chart that correspond to the DB scale located along the bottom of the graph. You plot DB temperature by locating the indicated condition on the scale and drawing a vertical line corresponding to the temperature value, as shown by the heavy line in figure 4–10. The figure is a representative sketch of the DB temperature part of a psychrometric chart. A complete psychrometric chart has a vertical line for each degree of temperature. Usually, we number every fifth line with its corresponding temperature. The common range for a psychrometric chart is from about 20 to 105 °F. This type of arrangement makes it simple to plot any DB temperature on the chart to the nearest degree.

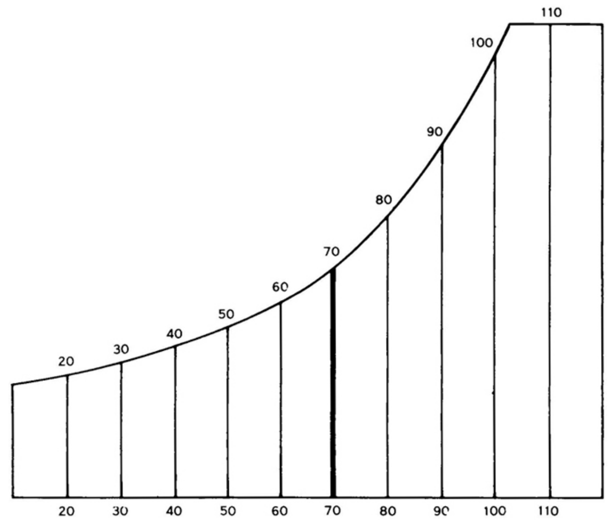
<table>
<tr><th colspan="2">Psychrometric Chart Scales</th></tr>
<tr><th>Scale</th><th>Description</th></tr>
<tr><td></td><td>


Figure 4–10. Dry bulb.
</td></tr>
<tr><td>WB temperature</td><td>
You notice the slope of the psychrometric chart changes to smaller increments as the temperature drops in intensity.

You plot WB temperature from the temperature values given on the saturation or WB scale.

To plot a WB temperature, start with the corresponding temperature reading on the WB scale. Plot the WB temperature on the diagonal line that extends to the right and downward from the WB scale.

The heavy line in figure 4–11 shows a WB plot.

It is not necessary to extend the WB line past its intersection with a previously plotted DB line

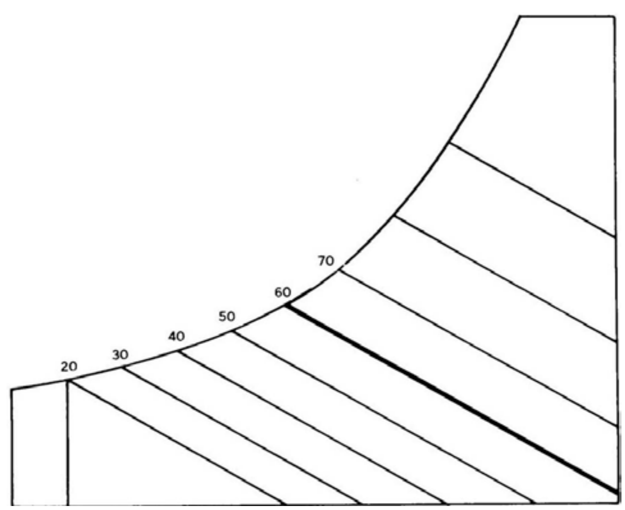


Figure 4–11. Wet bulb.
</td></tr>
<tr><td>RH</td><td>
We read relative humidity at the point of intersection of the DB and WB lines (fig. 4–12).

The DB and WB lines are the long curved lines between the zero humidity ratio line at the bottom and the curved saturation line above.
</td></tr>
</table>

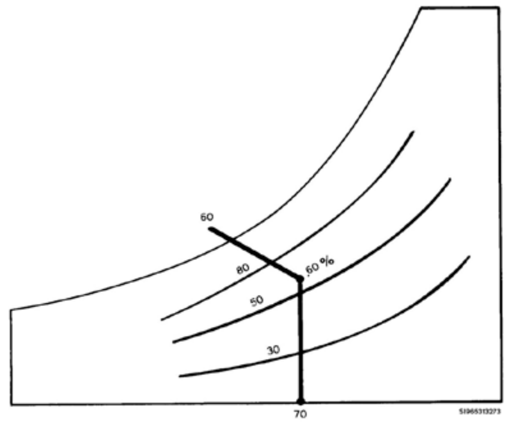
<table>
<tr><th colspan="2">Psychrometric Chart Scales</th></tr>
<tr><th>Scale</th><th>Description</th></tr>
<tr><td></td><td>

Figure 4–12. Relative humidity.</td></tr>
<tr><td>DP</td><td>You plot DP on the horizontal line of the psychrometric chart that extends from the point of percent RH to the saturation curve.

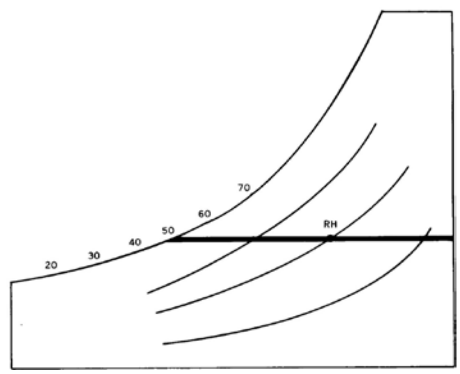
We read the value at the point of intersection with the curve (fig. 4–13).


Figure 4–13. Dew point.</td></tr>
<tr><td>Heat content</td><td>Heat content, enthalpy, and total heat are measures of the Btus in 1 pound of dry air.

To plot heat content, extend the WB line through the saturation curve to the heat-content or enthalpy scale, located to the left of the saturation scale.

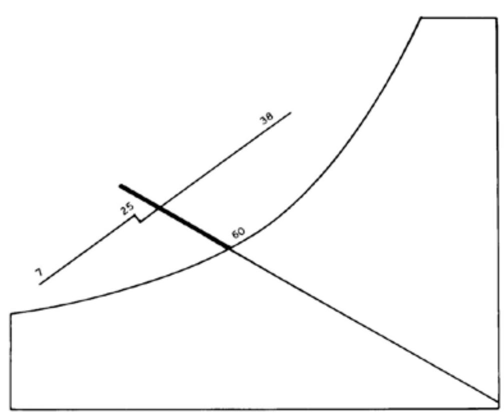
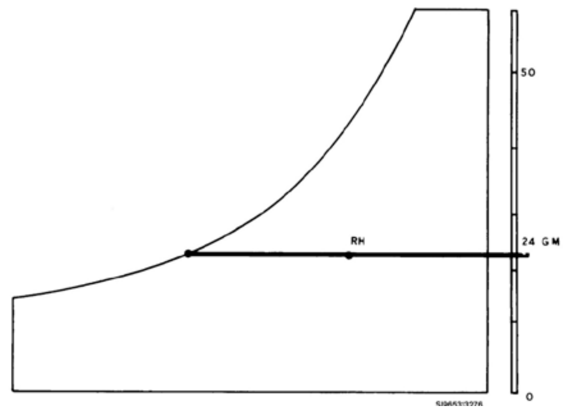
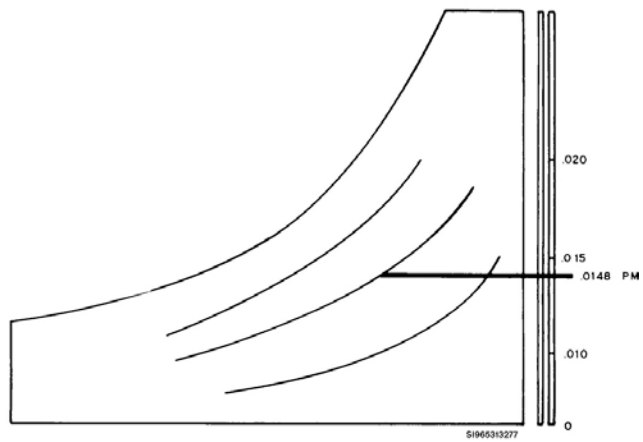
Read the Btu value at the point the extended WB line intersects the heat-content scale (fig. 4–14).


Figure 4–14. Heat content.</td></tr>
</table>

Psychrometric Chart Scales	
Scale	**Description**
GM	To plot GM per pound, draw a horizontal line from the point of percent RH to the GM scale and read the intersecting value on the chart (fig. 4–15).  **Figure 4–15. Grains of moisture.**
PM	To determine PM, draw a horizontal line from the GM plot to the PM scale and reading the corresponding value at the point of intersection with the scale (fig. 4–16).  **Figure 4–16. Pounds of moisture.**

Sensible heat and enthalpy changes

Sensible heat, by definition, indicates only DB temperature changes of an air-vapor mixture.

Example:

Find the amount of sensible heat to raise the temperature of one pound of standard air from 70 °F to 105 °F.

Solution:

Using the psychrometric chart, find the enthalpy values of the two temperatures (reading diagonal upward to the left) from the 0 percent humidity line or bottom line of the chart and take the difference:

Enthalpy of dry air at 105 °F	=	25.4 Btus/lb
Enthalpy of the air at 70 °F	=	16.9 Btus/lb
Difference	=	8.5 Btus/lb

A horizontal straight line on the psychrometric chart represents a sensible heat change to the air-vapor mixture in any heating system. Conversely, any cooling system that uses a dry coil that does not dehumidify, or where the surface of the cooling coil does not fall below the dew point, also creates a horizontal straight line on the psychrometric chart.

Assume that you heat air at 70 °F and 20% RH to 105 °F. We indicate this process in figure 4–17. Conditions other than those mentioned here have been determined from the psychrometric chart.

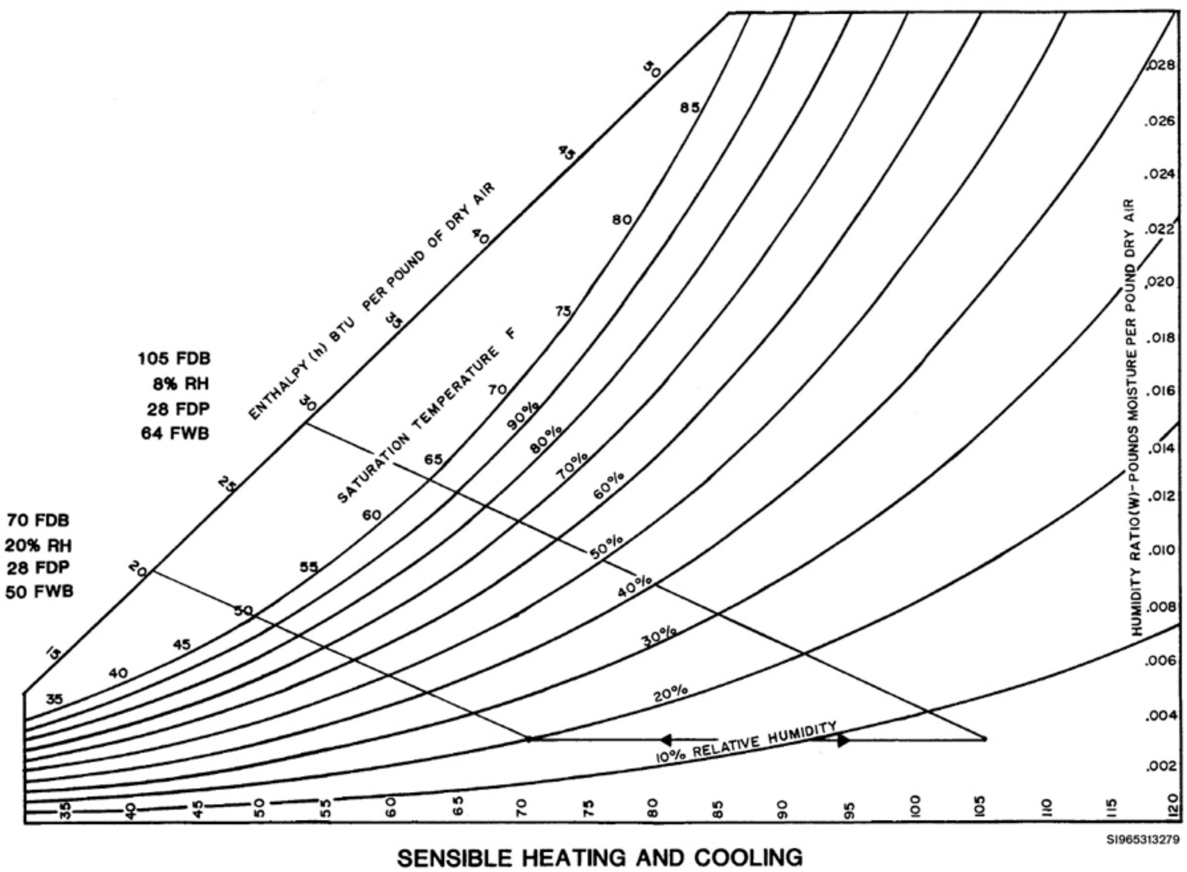


Figure 4–17. Process.

By considering the values, we can see that the DP has not changed and the total moisture content in grains per pound has not changed. The DB temperature has gone up, the heat content has gone up, the WB temperature has gone up, and the ability of the air to absorb moisture has gone up, as indicated by the decrease in RH. The example is theoretical because moisture from people, cooking, infiltration and other sources contribute to the moisture in the air. However, this is the design diagram for heating without deliberate humidification.

Now let us consider the process of cooling and ignore the extra moisture sources noted above. In ideal conditions, air gives up its heat along the same line to maintain the occupied spaces at the given 70 °F DB and 20% RH. A cooling coil, selected to cool air from 105 °F DB and 28 °F DP produces conditions along the same line as long as the coil surface temperature is above 28 °F. In most systems, this would be impractical, if not impossible, since frost would immediately cover the coil.

Latent heat changes

The latent heat process change involves a change of state of a fluid. In the case of air, this change means the addition or removal of moisture. The DB temperature does not change during this addition or removal of moisture. Therefore, a vertical line on the psychrometric chart between any two points at a constant DB temperature represents a change in latent heat. We see this process on the chart in figure 4–18.

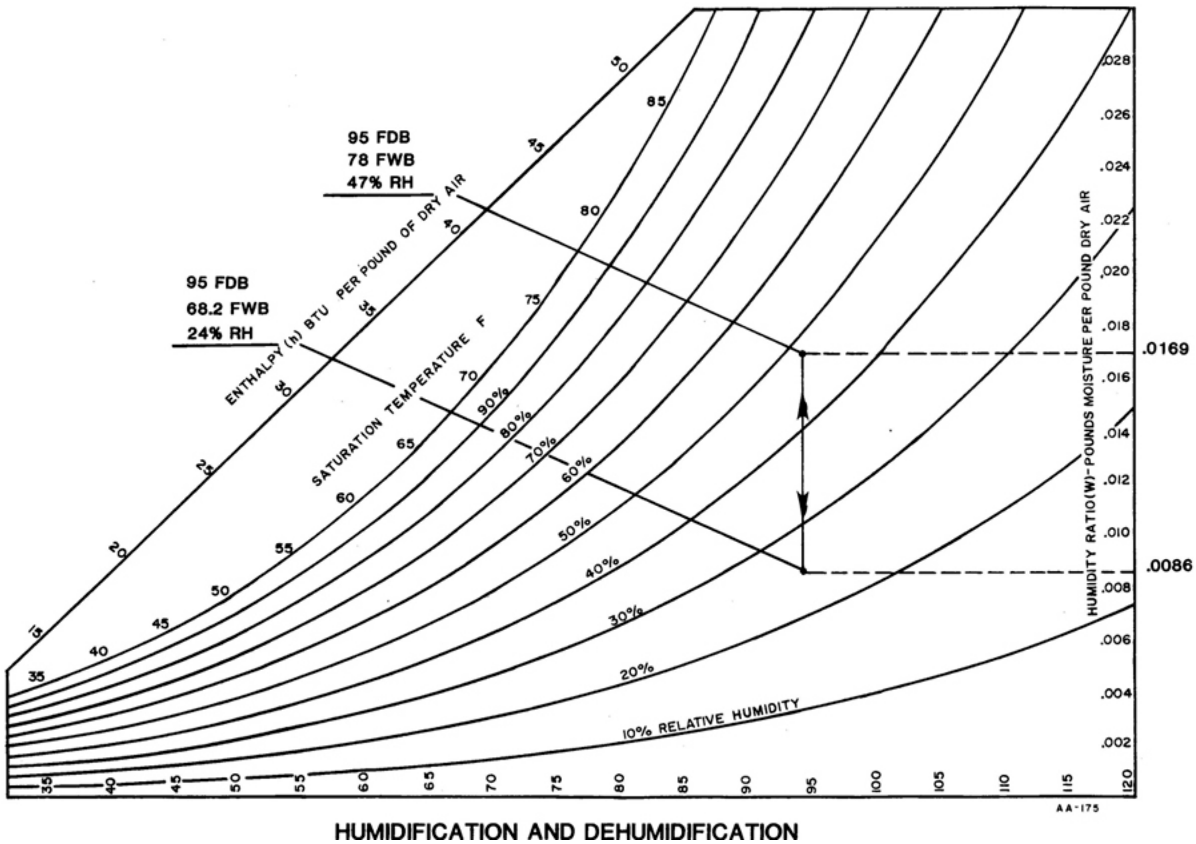


Figure 4–18. Latent heat change.

Air humidification or dehumidification is the addition or subtraction of moisture from the air. Each of these conditions is a change of state from liquid to gas or from gas to liquid, and each occurs at a constant DB temperature, but at a varying WB temperature. Note that this is the same process used for the addition or subtraction of latent heat, and it uses the same vertical line on the chart in figure 4–18 at a constant DB temperature. Humidification and dehumidification are both latent heat processes, and we can see both on the same chart.

In this example, the only constant value is the DB temperature; all other properties increase for humidification and decrease for dehumidification. Note that this process is essentially an illustration and normally cannot be reproduced in environmental systems. We discuss this process with the DB temperature constant to make the concept easier to understand.

Combination changes

Combination sensible heat and/or latent heat changes are common in most HVAC systems. The addition or subtraction of latent and sensible heat appears as a combination process with all changes occurring simultaneously. The result is neither a horizontal nor a vertical line but a slanted one tilted in the direction dictated by the process.

Refer to figure 4–19, and consider the general rules in the table below based on the two end points of the process, the first being the initial condition of the air, and the second being the final condition after the process or a portion of the air treatment has been completed. On the chart, all processes have the same initial point and the arrow point indicates each arbitrary final point.

Combination Changes Plotted on Chart	
Process	**Representation**
Sensible heating	A horizontal line from left to right.
Sensible cooling	A horizontal line from right to left.
Humidification	A vertical line upward.
Dehumidification	A vertical line downward.
Heating humidification	A line sloping upward to the right.
Cooling dehumidification	A line sloping downward to the left.
Evaporative cooling	A line sloping upward to the left.
Chemical dehydration or dehumidification	A line sloping downward to the right.

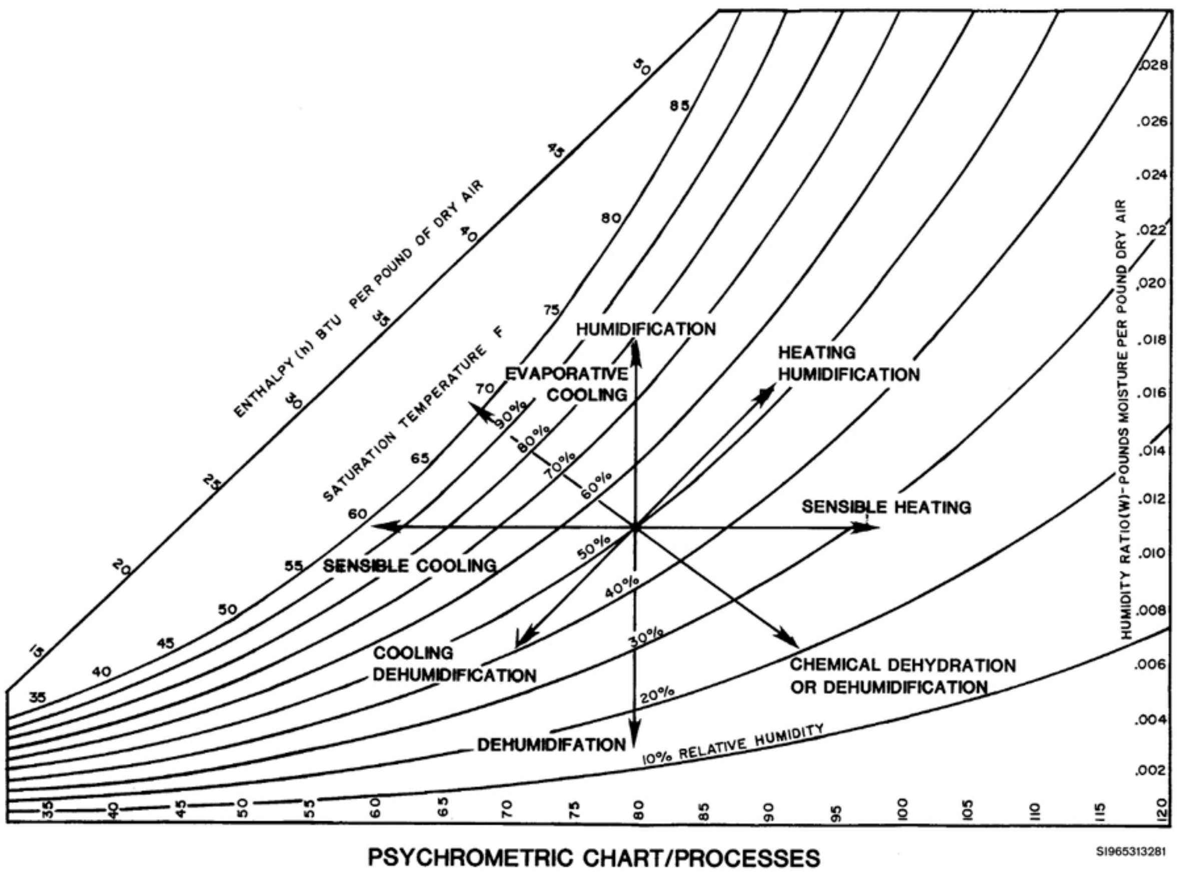


Figure 4–19. Combination changes.

Evaporative cooling (air washer) and moisture injection (steam)

Air washers, sprays, pan humidifiers, or steam jets can humidify air. An air washer is a chamber containing a system of water sprays through which the air passes. Sprayed coil is similar, but you need upstream filters. The sprays also help to clean the air, remove undesirable gases, such as hydrogen sulfide, and keep the coil face clean. When the coil is a cooling coil, the sprays increase the cooling capacity by reducing the entering air temperature before it reaches the coil. When balancing a system with a sprayed coil unit, the sprays should be operating as they add resistance to the system airflow. When you operate a system designed to operate with sprays without them, the airflow is higher. The heat extracted by the cooling coil, per pound of airflow, also is less without the sprays.

If the spray water is warmer than the dew point of the entering air, the sprays add moisture or humidity to the air. If the spray water is colder than the dew point of the entering air, the sprays dehumidify the air. You perform the latter with a spray washer in which the sprays are supplied with chilled water rather than with recirculated water. Refer to figure 4–20 for a graphical representation of this process.

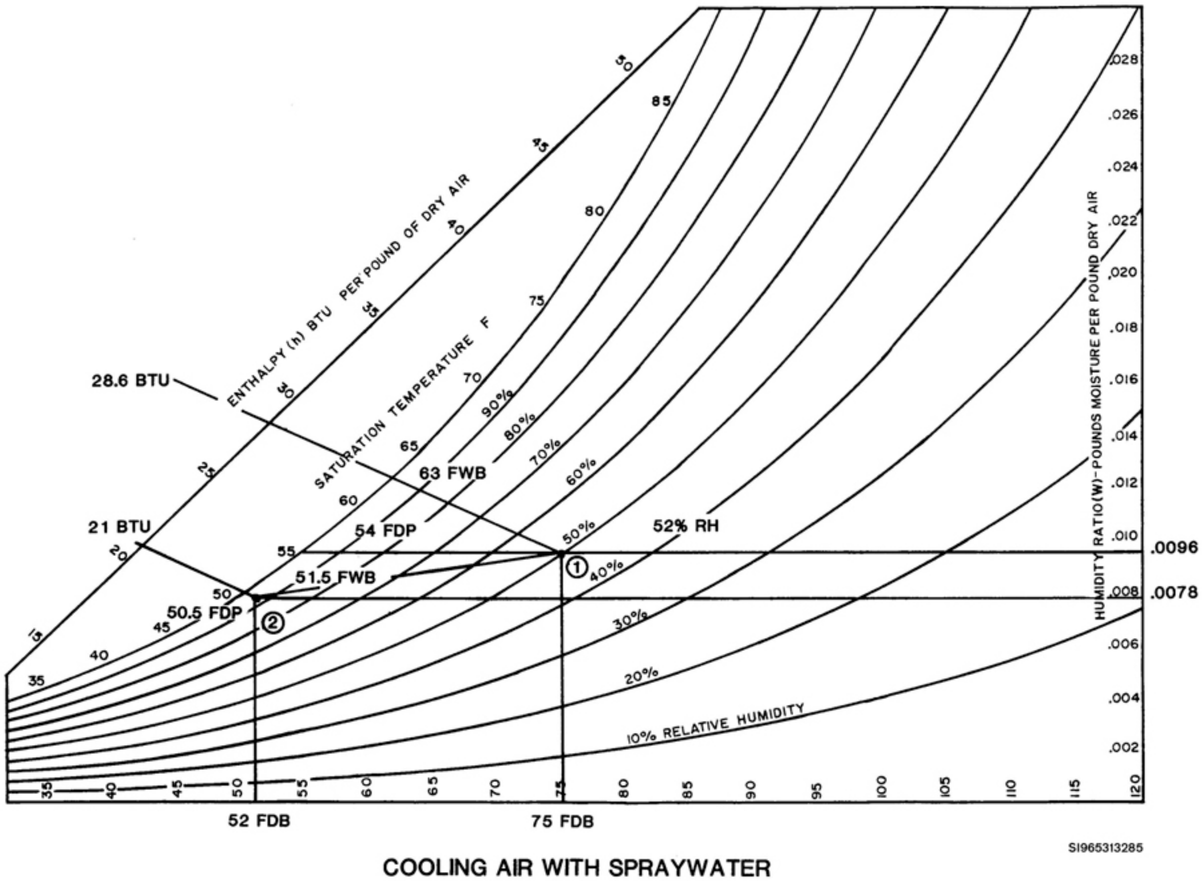


Figure 4–20. Evaporative cooling.

Recirculating spray water with an inactive cooling coil has the same effect as an air washer. The spray nozzles break up the water into fine droplets so that the air comes into very close contact with the water. The result is that air of any relative humidity as it enters the sprays leaves very nearly saturated. You have not added or removed any heat from either the water or the air. The process is the same as occurs with the WB thermometer. The total heat remains the same. This process is called *adiabatic saturation* (fig. 4–21) indicating that the air has become saturated with moisture without any change in its total heat. (Any process in which there is no change of heat is an adiabatic process.) Like the WB thermometer, the DB temperature of the air is lowered in the process.

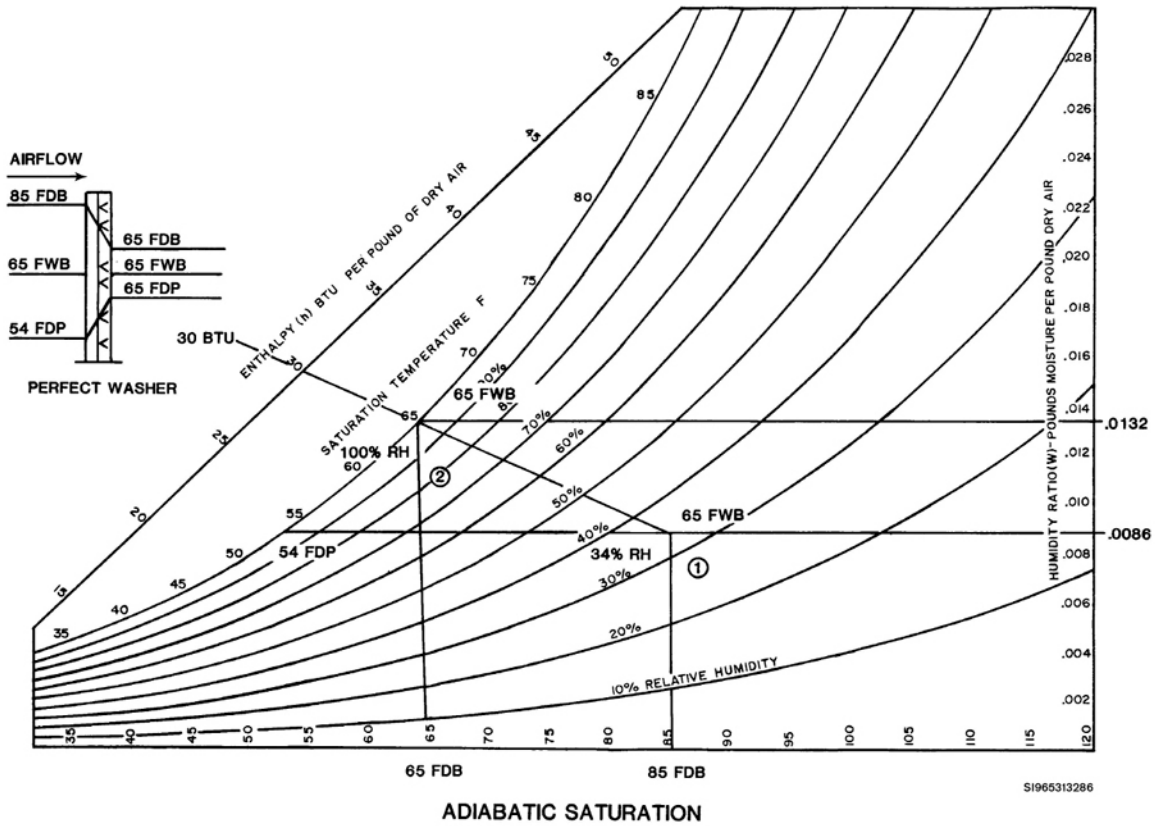


Figure 4–21. Adiabatic saturation.

The efficiency of an air washer is the ratio of the actual drop in DB to the maximum theoretical drop in DB temperature that could take place if the air washer were 100 percent efficient and the air emerged saturated. In such a case, the final DB temperature of the air would be equal to its initial WB temperature. The efficiency of actual air washers varies with the design, the quantity, and pressure of the spray water and other factors.

This is the type of process used in evaporative coolers, and the success of such an application depends on having an air source that has very little moisture or low RH. Even though the first DB temperature could be uncomfortably high, the WB temperature must be low enough to allow the DB temperature, after approaching adiabatic saturation, to become low enough to cool the room or space effectively.

Some air conditioning systems are designed to maintain room RH within a narrow range while heating using a spray washer or sprayed coil equipped with a heat exchanger to heat the spray water (fig. 4–22). The process is *not* adiabatic because the heat added to the water also added to the air. With heated water, the air leaves near or at saturation, depending on the efficiency of the sprays in making contact with the air. The temperature of the leaving air tends to approach the temperature of the spray water.

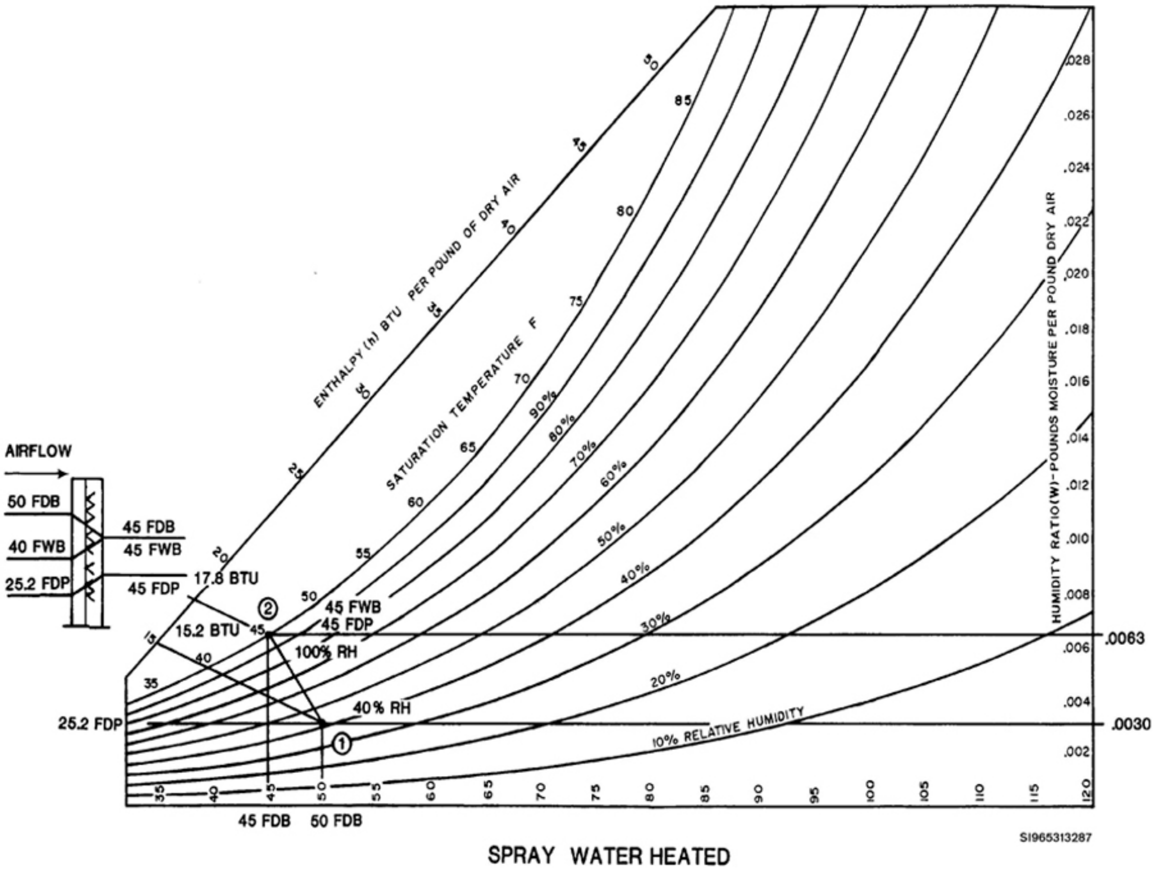


Figure 4–22. Spray washer.

Air stream mixtures

Mixtures of two or more airstreams are a common requirement of environmental systems. The mixing of outside and return air on the entering side of the air cooling and/or heating equipment is a common way to introduce the outside ventilation air or economizer (free cooling) air to the system. Outside air can be one of the greatest loads on a heating or cooling system.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

022. Air-vapor relationship

1. When the air temperature rises what happens to the amount of moisture it can hold?

2. If the pressure remains constant and the volume increases what will happen to the *absolute temperature*?

3. If temperature remains constant and the volume of a gas decreases, what will happen to the *absolute pressure*?

4. In a closed vessel with water, if the pressure decreases what affect will it have on the boiling temperature of the water?

5. When steam passes through a coil what does the addition of more heat cause?

6. When steam condenses in a vessel or contained space, unless supplied with additional steam at a rate equal to or greater than the condensed amount, what happens to the pressure in the space?

023. Psychrometric chart and processes

1. If air at several different times or places is measured and the WB temperatures stay the same, what affect does it have on the total heat?

2. When the coil is a cooling coil, how do the sprays increase the cooling capacity?

3. When balancing a system with a sprayed coil unit, how should the sprays be operating?

4. If the spray water is warmer than the dew point of the entering air, what will the sprays do to the air?

5. While heating some systems use a spray washer equipped with a heat exchanger to heat the spray water. Why is this process *not* considered adiabatic?

Answers to Self-Test Questions

020

1. A force acts upon it.
2. A technician or an automated control opens the valve and allows the water to flow thus turning it into kinetic energy.
3. Large amounts of heat.
4. 10 pounds of water at 80 °F.
5. Latent heat.
6. Effects of heat.
7. Increase the distance between the molecules of the substance.
8. 300 °F.
9. When used as fibrous glass because of the small isolated pockets of trapped air.

10. By the transfer of heat to the colder pipes.
11. Increase in air velocity.
12. Dirt, fouling, corrosion, condensables, and freezing.

021

1. Air (from the atmosphere), water (or a heat transfer fluid), steam, refrigerants, and, occasionally, a few other gases.
2. It will increase.
3. Decreases.
4. Static head.
5. Decreases.
6. Consult appropriate charts.
7. Friction.
8. There is a natural resistance caused by a substance moving at a different rate than the substance with which it is in contact.
9. Friction.

022

1. The amount is increased.
2. It will go up.
3. Pressure will increase.
4. Boiling temperature will decrease.
5. Superheats the steam above the temperature at which it originally evaporated.
6. The pressure in the space falls because the liquid occupies far less space than steam.

023

1. Total heat stays the same.
2. By reducing the entering air temperature before it reaches the coil.
3. Operating as normal because they add resistance to the system airflow.
4. Add moisture or humidity.
5. Because the heat added to the water is also added to the air.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

57. (020) How is energy used in the HVAC/R career field?
    a. It is destroyed.
    b. It is converted.
    c. It is left alone.
    d. It is created.

58. (020) Water sitting at a valve will be potential energy until
    a. the static pressure is equal on both sides of the valve.
    b. velocity pressure is released and static pressure is added.
    c. a technician opens the valve and allows the water to flow.
    d. an automated control closes the valve and allows the water to flow.

59. (020) When the flow of heat is *not* reflected in a temperature change, what type of heat change is taking place?
    a. Latent heat.
    b. Sensible heat.
    c. Residual heat.
    d. Latent and sensible heat.

60. (020) Molecules *closest together* when an object is
    a. not very dense.
    b. a liquid.
    c. a solid.
    d. a gas.

61. (020) If pipes are warm and the air is cool, how will the air be warmed?
    a. The transfer of heat to the cooler air.
    b. The transfer of heat to the warmer air.
    c. Heat transfer will not occur in this situation.
    d. The transfer of heat from the air to the warmer pipes.

62. (020) When a fan propels air across a hot or cold surface, what generally *increases heat transfer*?
    a. Shutting off the fan.
    b. A decrease in velocity.
    c. The fan slowing down.
    d. An increase in velocity.

63. (021) When are static measurements taken on an air system?
    a. Static measurements are not taken in air systems.
    b. After the filter drier is removed.
    c. While the fan is moving air.
    d. While the fan is off.

64. (021) Velocities measured at different points in the same cross-section of a pipe or ducts are *not* the same because
    a. velocity is constant throughout the system.
    b. molecules may slip against each other.
    c. there is no friction present.
    d. static pressure increases.

65. (021) If there is *no fluid flow in the system*, then TP = SP, or
    a. system pressure at any point is equal to the static pressure at that point.
    b. velocity pressure will be greater than 5 inches of water column.
    c. velocity pressure would be greater than static pressure.
    d. total pressure will be greater than static pressure.

66. (022) In a *closed system with constant pressure*, if the *temperature increases* the
    a. volume will decrease.
    b. volume will increase.
    c. volume will stay constant.
    d. temperature will eventually drop.

67. (022) Why is it impossible to superheat steam in the presence of boiling water?
    a. Steam will never be superheated in HVAC/R.
    b. Boiler stack temperatures will not allow this to happen.
    c. All the added heat only evaporates more water until all the water has boiled to steam.
    d. All of the added heat condenses into more water until all the steam is turned to water.

68. (023) What will the dry-bulb, wet-bulb, and dew point temperatures be when *air is saturated*?
    a. The dew point will be higher than the dry bulb.
    b. The wet bulb will be higher.
    c. The dry bulb will be higher.
    d. They will all be the same.

69. (023) If the spray water is colder than the dew point of the entering air, the sprays will
    a. cleanse the air.
    b. humidify the air.
    c. dehumidify the air.
    d. humidify and dehumidify the air.

Please read the unit menu for unit 5 and continue ➔

Unit 5. Load Calculations

IN THIS FINAL UNIT, we turn our attention to load calculations which are a very vital part of HVAC/R operations. The information discussed here will draw upon much of the material preceeding it in this volume. Like some other material in the volume, the information in this unit is not designed to make you an expert in load calculations; rather it is designed to familiarize you with the basics and provide the knowledge on how to proceed when you need to make these types of calculations. We'll discuss heat load requirements first and conclude with determining system requirements.

5–1. Heat Load Requirements

A heat load calculation is more than likely not a task you, as an Air Force HVAC/R technician, will perform everyday. Although you may not do it frequently, it is important that you understand the process and the reasons it is done. There are several different reasons for performing heat load calculations. One reason is sizing an air conditioning system when installing a new unit on a new building. Another reason is the possibility that an improperly sized unit is the suspected cause in a building on base that consistently has trouble. From these examples you can see that heat load calculations can be used for different purposes from new installs to advanced troubleshooting—tasks that are not necessarily performed everyday. However, when the time comes and you need to perform this task, you must be ready and knowledgable. The core concepts discussed in the lessons in this section will give you a strong background when called upon to make this calculation.

024. Heat load basics

Before calculating a heat load, you need a thorough understanding of heat transfer in and out of a building. Also, you must have a solid understanding of building construction features and design. We'll cover these topics in this lesson.

Heat transfer

Remember, heat always travels from hot to cold or a warmer object to a cooler object. When a cold energy drink is sitting on a desk in an office at normal room temperatures, the energy drink is gaining heat from the surrounding air. At the same time, the surrounding air is losing some of its heat to the energy drink. This same concept is true for a building and applies during heat load calculations.

The design, construction materials, and location of a building are factors that affect heat transfer. Let's use our energy drink example again. If the drink is placed outdoors on a 110 °F day, the heat transfer from the outdoor air to the drink will speed up. Again, this concept applies to a facility. The hotter the day, the faster heat will transfer indoors.

If you insulate that energy drink with a coozie, the heat transfer process will be slowed. This is the same as insulating a building. In a building with no insulation, heat transfers in or out very quickly.

Cooling season

During the cooling season, the heat load concern is dealing with heat gain. Imagine a 100 °F day outside and the inside of the facility is 70 °F. The heat will travel from the hot outside environment to the cool inside. The heat that is transferred indoors must be cooled, which is why we use cooling equipment such as split systems and chillers.

Heating season

During the heating season, the primary concern for heat loads is dealing with heat loss. Just think about a situation where it is 20 °F outside and 75 °F inside a building. Since heat travels from hot to cold, the heat inside the building will travel to the outdoors causing a loss of heat. To maintain the internal temperature, all of the heat lost must be replaced. We use heating equipment such as furnaces and boilers to accomplish this.

Sensible heat

Sensible heat is defined as the heat added or removed from a substance causing a *change in temperature without a change in state*. Sensible heat is considered to be the actual temperature of the air. It is the heat that can be felt and is measured with a normal thermometer. It is expressed in degrees Fahrenheit (°F) in standard units or degrees Celsius (°C) in metric units.

Latent heat

Latent heat is heat added or removed from a substance causing a *change in state but no change in temperature*. Latent heat can be measured by determining the amount of moisture in the air. During load calculation, the amount of moisture in the air can be expressed in percent relative humidity (RH) or grains of moisture (GM). As stated before, the cooling coil will remove moisture before it cools the air, so equipment must be able to handle both a latent heat load (changing the state of the moisture in the air back to a liquid form) and then cool the air (a sensible heat change).

Heat exposure

Heat exposure is the process in which sensible heat from outside a facility soaks through the walls, roofs, windows, doors, and floors of a facility and reaches the cooler inside. Heat transfer through a wall that separates spaces with different temperatures typically depends on three things: the area of the wall, the temperature difference of the two spaces, and the heat-conducting properties of the wall itself.

Every type of material used in construction has a rating from the manufacturer indicating how much exposure the specific material will allow through it. This heat conductivity rating may not be specifically stated or may be hard to find. However, it can also be calculated from the data provided by the manufacturer.

Heat conductivity ratings are actually expressed as values, and there are several commonly used ones. Technicians need to know how to work with all types of values in order to successfully calculate window, door, wall, and roof heat transfer rates. We'll explain this later.

As mentioned before, exposure is heat coming into the conditioned space from the outside. Exposure adds only sensible heat and it enters the space because of the natural properties of heat. Heat wants to travel from the hotter to the cooler space. Simply stated, the difference between indoor and outdoor temperatures causes heat transfer into a facility.

Exposure is prevented by insulating the conditioned space from the outdoors. When heat exposure has been determined as too much for certain features, you can use layers of material, materials with different heat resistance values, and insulating construction features (like windows and doors) to reduce exposure. Be aware that while exposure can be reduced, it can never be completely eliminated.

Given enough information, heat gained from exposure can be calculated relatively accurately. First, gather as much accurate information about the building as possible. The quantity and accuracy of the information affects the exposure measurement. We'll explore this in detail later in the lesson, but keep in mind that not every variable can be measured and calculated; there is *always a margin of error*.

Heat infiltration

No facility should be completely sealed, and air should be constantly entering the facility. Traditionally, air enters through cracks and openings at will. Heat infiltration is the uncontrolled entry of sensible and latent heat in air seeping into the facility around construction features such as windows, doors, and other openings. Heat can infiltrate around receptacles, light switches, light fixtures, duct registers, and even baseboards and door casings. Heat is also purposefully drawn into larger facilities from outdoors (called outside air or OA) by the duct system to improve air quality. While infiltration can also be calculated, it is relatively less accurate than heat exposure estimates. Heat infiltration should *not* (and practically cannot) be completely eliminated. For health and comfort reasons, some amount of fresh outside air must be allowed to enter the facility. Modern facilities attempt to control the infiltration of outside air by drawing it in through the HVAC/R system. When compared to older, traditional structures, modern facilities have much less uncontrolled infiltration through cracks and spaces.

Both sensible and latent heat is added to the facility by infiltration. Infiltrated air comes through openings or seeps into the facility from the outdoors and typically brings moisture and contaminates with it. Moisture typically gets into the facility through the attic or basement, but can also enter through cracks and spaces around the windows, doors, and other pass-through-the-wall features.

Heat generation

Equipment and people also release heat within the conditioned space. This process—called *heat generation*—can greatly affect the heat load of a facility. Refrigerators, microwaves, computers, monitors, equipment, televisions, lights, and even human bodies are all heat generators. The sources must be determined and calculated to ensure the HVAC system is properly sized.

Generated heat can be sensible, latent, or both. Unlike heat exposure, generated heat is variable and hard to calculate. This is because many heat-generating sources do not generate a steady amount of heat. For example, an oven generates heat in a house but only does so for an hour or two at a time, anywhere from every day to only a few days a week. Occupants have different body types and activity levels (all generating varying amounts of sensible and latent heat) and occupy the facility anywhere from an hour or less to 14 or more hours. These variables mean that frequency and duration of heat generation are very subjective and, therefore, are often estimated for calculation purposes.

The following table describes some of the heat-generation sources.

Heat Generation Sources	
Type	**Description**
Heat from equipment (latent and sensible)	Heat comes from more than just the sun. Every appliance, computer, television, and light fixture in a facility generates heat. Most heat from equipment is sensible, but many also generate latent heat. Some examples of latent heat-generating equipment are coffee pots, microwaves, or hot-tubs. Since this equipment is not always operated on a continuous basis, the operating frequency and duration of each device should be considered. An average of 1200 Btuh is usually used to represent the entire heat generation from equipment. In an actual calculation, further investigation and calculations would need to be performed.
Heat from people (latent and sensible)	The human body also generates sensible and latent heat. Many variables can be used in a detailed heat gain calculation for an individual. Detailed calculations can even give Btuh rates for different times of year, for males and females of different ages and weights, types of clothing worn, activity performed, etc.

Heat Generation Sources	
Type	**Description**
	For most practical applications a set of pre-determined averages is used. • On average, a person at rest will generate 300 Btuh of sensible heat. • That same person will produce about 230 Btuh of latent heat. The total number of personnel in the facility should be considered. Facilities with large fluctuating populations or populations that are at widely different levels of activity may prove to be more difficult to calculate and maintain. For example, consider a gym. In a gym, 300 Btuh would likely be an underestimate because of the increased amount of body heat and moisture generated by people working out. A multipurpose facility like a shop with offices would have people both at work and at rest, as well as computers and other equipment, all affecting the heat estimation.

Solar loading

Solar loading is the amount of heat that comes directly from the sun passing through the glass of windows and skylights. Solar loading changes depending on such factors as time of day, shade from trees, the eaves of the facility, and more. The solar load typically must be averaged throughout the day and can be different for different rooms. The amount of shade on the window from the eaves of the facility and from other outside factors (trees, other facilities, etc.) should also be considered. Solar loading works like a large boiler slowly heating up a room. Once the room is warm, it takes time for the room to cool down unless something removes it. An A/C unit trying to remove that heat will have a significant load, especially in mid-afternoon. The use of draperies, Venetian blinds, or pull-shades can greatly reduce solar loading.

Direct sunlight on a surface receives radiant heat from the sun. The sun's position in the sky changes not just throughout the day but also throughout the year. The global latitude and the facing direction of a facility determine the amount of solar loading. East-facing construction features get peak intensity during morning in July and August, and west-facing features and roofs get peak intensity during late afternoon during those same months. South-facing features get peak intensity during early afternoon in September and October. In North America and all locations above the equator, north facing features are never subject to solar exposure. In these areas, heat gain on north-facing features is limited only to the temperature of the air in contact with them.

025. Load calculation procedures

This lesson covers heat load calculation procedures. This process is not one that is quickly mastered since it includes engineering concepts and requires HVAC/R experience. To give you an idea of the detail involved, the Air Conditioning Contractors of America (ACCA) Manual J that covers this topic is over 500 pages long. For this reason we'll only cover the basic procedures as an introduction to heat load calculation procedures. This is not a comphrehensive lesson intended to make you an expert. The information is presented as a series of steps from information gathering to the final review of your work.

Step 1: Gather basic information

The first step is gathering information about your project. Place the information on a worksheet for quick reference later. These worksheets are usually available free online or from your squadron's purchase of a printed manual or computer software. You should not attempt a load calculation without a manual and/or worksheets, whether printed or computerized.

Items that need to go on the worksheet include the project name, your location (e.g., Portsmouth, Pease AFB, NH), latitude, elevation, and outdoor design conditions. Outdoor design conditions consist of the temperatures and humidities applicable to your local area. This information can be found in load calculation manuals.

Once you have the basic information entered on your worksheet, you're ready for the next step.

Step 2: Gather building information

You need to measure construction features and inspect construction materials before making any calculations. Start by gathering data from the engineering assistants or engineers in your squadron. This is usally achieved by acquiring prints and as-builts. Next, perform a walk-through of the facility to get an idea of size and scope. Determine how to best label the sides of the facility for reference purposes.

During the site visit and review of the prints you need to enter the information on a worksheet. Again, the worksheet can be acquired from a manual but the descriptions of construction materials and features will require additional learning on your part.

Gather and record information such as the construction materials and features for exposed walls, floor and ceiling areas, windows and all glass doors, skylights, doors (metal and wood), above and below grade walls, and partition walls.

When you have entered the required information on your worksheet, you can proceed to the process of calculating loads.

Step 3: Calculate sensible loads in btuh

At this point you need to determine the sensible loads imposed by all of the building features listed in step 2. In short, the heat transfer multiplier (HTM) of a specific construction feature is multiplied by the area of that feature to obtain the total Btuh being transferred through that one feature. This gives you the HTM number. Once you have the HTM, the calculation is completed by substituting the values in the equation below:

HTM x Area = Btuh

For the following example, you use a manual to find the HTM for a 4 x 4 window. In this example, the HTM for the 4 x 4 window is 15. Next, you calculate the the total Btuh using the formula above.

Calculate Total Btuh

Operation	Formula	Substitution
Determine HTM for window		15
Next find the area of the window	Length x Width	4 x 4 = 16
Next, multiply the area by the HTM	Area x HTM	16 x 15 =
Result		**240 Btuh**

The result is 240 btuh. But what does this mean? This means 240 Btus of sensible heat are being transferred through that window *every hour*.

Let's take a closer look at the HTM. HTMs quantify the amount of heat that flows through 1 square foot of a construction feature at a given outdoor-to-indoor temperature difference. HTMs are given in Btuh. For example, if the HTM value for a door is 23, the "23" means the door transfers 23 Btuh through 1 square foot of its surface. To find the total heat gain, the HTM must be multiplied by the amount of surface area of the particular construction feature. The HTMs help bring all construction materials and construction features to the same playing field.

NOTE: This course will *not* cover how to use a manual to find HTMs.

Remember that the heat transfer in Btuh needs to be calculated for these features—exposed walls, floor and ceiling areas, windows and all glass doors and skylights, doors (metal and wood), above and below grade walls, and partition walls. In order to complete step 3, add the Btuh of each feature together to get the total sensible head load for all of these features.

Calculations for sensible heat infiltration, generation, duct run, ventilation, and blower heat gains also need to be calculated. Unfortunately these concepts are too advanced for this course and will not be covered here. The main thing you need to know about these items is that they do *affect the heat load on a facility*.

When you have calculated the sensible loads, you next step is to calculate latent heat gain.

Step 4: Calculate latent heat gain

A unit cannot be sized based on sensible heat alone. Areas like Korea, Guam, and the Southeast United States are very humid locations. If you only account for sensible heat, you could be ignoring a large portion of the *total heat load*. Considerations for latent heat loads include infiltration, occupants, plants, duct, and ventilation systems.

When you have the information and have calculated the latent heat gain you are ready for the next step.

Step 5: Add sensible and latent loads

This step is simple in comparison to some of the preceding ones. Once you have calculated all sensible and latent loads, add them together. This gives you the total heat load for the facility.

At this point your task is almost complete and the next step is one of the most important.

Step 6. Review and trust your work

This may not seem like a step like some of the previous ones but it is absolutely crucial. There are many mearsurements, numbers, and figures that comprise a heat load calculation. Some of these calculations are borderline engineering work! In any endeavor, accuracy is important and it is no less so than in calculating heat loads. Always review your worksheets and calculations for accuracy. Finally, if you took your time to ensure accuracy during the process and then review it in the end, then trust your work. Don't second guess yourself. Believe in and stand by your work!

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

024. Heat load basics

1. In order to calculate a heat load, what is necessary?

2. If a cold object is placed in the hot outdoors, what will happen next?

3. After determining heat exposure is too much for certain features, what can you do?

4. What is the *first step* when calculating heat exposure?

5. When is solar loading *averaged*?

025. Load calculation procedures

1. How many general steps are there in heat load calculations?

2. What is the next step in heat load calculations after gathering basic information?

3. Given an HTM of 19 and an area of 18, calculate the Btuh.

4. Given a 4 x 6 window and an HTM of 28, calculate the Btuh.

5. What step is accomplished after calculating sensible loads in Btuh?

6. What is the fifth step of heat load calculations?

7. What step is performed after all sensible and latent heat loads have been found?

5–2. Determine System Requirements

After you perform the load calculation you will need to determine the system requirements. It is absolutely crucial to ensure the proper requirements are selected. If the proper system is selected then trouble calls will be reduced and the system will run efficiently. The procedures and requirements will be covered in this section's lessons. The first lesson described the procedures for determining system requirements, and the final lesson covers special system requirements.

026. System requirements procedures

Like some other activities discussed in this volume, there are procedures that need to be followed to ensure that a task is accomplished correctly. Following some established steps also helps you organize any project and ensures that you have the information required for a successful conclusion. As you will see, this lesson takes a look at the steps to follow in the system's requirement process. So let's begin with the first step.

Step 1: Selecting the correct equipment

Just knowing the sensible and latent equipment sizing loads is not the end of your work. You must select the proper equipment based on your calculations.

Begin by obtaining the equipment performance data from the prospective manufacturer. Each manufacturer's data sheets should list the features and specifications of its equipment. These spec sheets are typically available from the local distributor, but may often be found more easily on the internet. Once you have the sheets, you must determine specific features.

The first place to starts is to verifty that the condensing unit operating temperature is compatible with the outdoor design temperature. The outdoor temperature at design on most equipment is 95 °F, but some manufacturers provide equipment that is designed for other temperatures. Next, verify that the indoor fan provides adequate cubic feet per minute for the facility. Finally, verify that the indoor coil can perform correctly given the entering wet-bulb (WB) and dry-bulb (DB) temperatures.

Since equipment must be able to handle both the sensible and latent heat, ensure that the incoming WB and DB temperatures are within the equipment's operating range. Do this by comparing the sensible and latent Btuh ratings gathered earlier. Air conditioning/refrigeration (AC/R) equipment is sized in cooling tons which derives from refrigeration's roots.

Refrigeration was originally conceived in relation to ice required for use in the original refrigerators (then called ice boxes). The latent heat of fusion for ice (the amount of Btus that must be removed from water at 32 °F to make ice at 32 °F) is 144 Btu/lb. The requirement for making one ton (2,000 lbs) of ice is calculated by multiplying the quantity (2,000 lbs) by the latent heat of fusion (144 Btu/lb). The calculation and results are:

2,000 lbs x 144 Btu/lb = 288,000 Btus.

As a production statistic tool, 288,000 BTUs are required to make one ton of ice per day. To determine the Btus per hour, divide the 288,000 Btu total by 24 (number of hours in a day). The result: 12,000 Btuh—the amount required per hour to make one ton of ice in one day.

To convert Btuh to Cooling Tons, divide the Btuh by 12,000 (one ton of cooling):

$$\textit{Cooling Tonnage} = \textit{Btuh} \div 12{,}000$$

When you know the cooling ton requirements, then you can proceed with equipment selection.

If the equipment will be used for cooling only, select a unit with a capacity *not less than the latent or sensible heat loads* (*whichever is lowest*). The unit should also *never be more than 115 percent of the sensible heat load*.

To determine the over sizing limit, take the total sensible load size (in tons) and add 115 percent. The simple way to do this is to multiply the total sensible load size by 1.15.

If a heat pump will be installed, it should also not be sized less than the sensible or latent heat loads (whichever is lowest). Heat pumps, however, have an upper limit of 125 percent of the sensible heat load. This will make a heat pump unit slightly larger than a comparable cooling-only unit. This compensates for capacity differences during heating operation and actually produces lower overall operating costs. The same calculation can be made using the procedures listed for cooling-only units, but using the 12 percent (total sensible load x 1.25) value, or adding 25 percent.

Obviously other features such as supply voltage, equipment size and weight, control features, noise levels, and so forth, will also need to be determined.

Now that you know the capacity needed, you can move forward and order the unit.

Step 2: Order the unit

Take all of your data, review the manufacturer's data you have, and place the unit on order. Company brand is an example of certain leadership preferences that you may need to account for. Some bases prefer certain brands for varying reasons while some are preferred because they have worked well for them in the past. Recognize that base contracting may become involved to ensure that certain companies or brands are not being given preferential treatment by the government. If there are specific requirements that must be met and the vendor selection is limited, work with base contracting to resolve any issues.

Step 3: Install and monitor operation

Obviously when the unit arrives at your shop your next step is to install it. But your job is *not* done once the unit is installed and operating. You'll need to spend the next few weeks or months monitoring its performance and making sure the customer is satisfied with your work. This helps build rapport and trust for future projects. When your customers are happy, they are more likely to remember you and trust you the next time you are needed. Customer satisfaction and rapport is crucial for the HVAC shop as well as the squadron's appearance and reputation.

At this point, the most difficult and time-consuming aspects of your project are complete. Now is the time to capitalize on your efforts for future projects.

Step 4: Save all data and work

Saving and storing all data and work from the project is next. There are numerous ways to do this. The engineering assistant shop could save your work for you; it can be saved on a shared drive used by your shop; or the papers could be saved in the shop library. This will make the information available should there be problems later and the information may be useful for future projects. Check with your supervisor to determine the preferred method in your shop.

027. Special system requirements

There are many advantages to having a properly sized air conditioning system. One advantage is they will simply do what they are supposed to do in the most economical and efficient way, benefitting both the customer and the Air Force. Some of the advantages of a properly sized unit are: saves costs during installation, operation, and maintenance and service; saves energy by using just the right amount to cool the space; and it keeps customers happy and productive. There are two potential troublesome concepts that you need to be aware of—undersized and oversized units.

Undersized units

Cooling equipment that cannot keep up with the load of the facility is considered undersized. The most noticeable problem of undersized units is long operation cycles. Even on mild days, the equipment operates almost non-stop and cannot properly satisfy the conditioned space. It has been calculated that a normal unit will operate for a total of 3 or 4 hours a day for a few days a month on above average days. In some cases, it can seem as if the refrigeration system is undercharged, even freezing the coil. Undersizing causes the unit to operate more frequently than it should, reduces the lifespan of the equipment, and increases energy costs.

Oversized units

Through calculations and planning, designers will determine the proper size of an air conditioning unit to satisfy the requirements of a facility. Facility designers often increase a unit's overall tonnage by about 10 percent. If another designer (performing a renovation, for instance) or builder increases the tonnage of that system without knowing what the facility's design size was, the equipment installed may be too large.

An oversized unit has more capacity than needed to handle the facility's requirements. There are many problems that are caused by oversizing. One problem, caused by a unit that is too large, is called *short-cycling* (the unit starting and stopping frequently). Short-cycling does not allow enough time for the moisture to be pulled out of the air because the coil does not have time to get below dew point before the compressor shuts off again. This means the system will satisfy because it reached its temperature set point even though there was not enough time for the humidity to get pulled out. All of this cycling costs money; energy costs escalate after an average of 4 or 5 cycle times an hour. Oversized units also have increased installation costs; the price of the unit will be higher. Also, the wire size and the rest of the electrical circuit must be upgraded to safely carry the higher amp draw of a larger unit. These upgrades require man-hours and down time, another waste of money on installation costs.

A grossly oversized unit will bring a flood of service calls. Many HVAC/R technicians have been victims of this with newly built facilities. The short-cycling unit will not run long enough to keep comfortable humidity levels in check and the building will not cool as it should. This can lead to unhappy customers who will feel warm and clammy.

Steps to prevent improperly sized units

The steps outlined in the following table will help you with planning and troubleshooting. They will also help avoid undersizing/oversizing issues.

Preventing Improperly Sized Units	
Step	**Action**
1	***Calculate latent heat, accurately*** When sizing a unit, always take the humidity level in the conditioned space into account. In cooling, the moisture loads of the equipment should be able to handle the facility. The refrigeration effect of a coil will always work to remove the moisture from the air before it begins to cool it, so the system must be able to perform both. Only after the latent heat is removed will the unit be able to remove the sensible heat (the heat that can be felt).
2	***Ensure condensers are of proper design*** Condensers on cooling equipment are, for the most part, designed for maximum outside air temperature of 95 °F (105 °F for use in extremely hot locations). Once the condenser inlet temperature of 95 °F is surpassed, the unit begins to lose efficiency.
3	***Recheck intial design*** Sizing problems result from many different factors. Some units are doomed from the start because of poor initial design. Design flaws could stem from calculation errors or from lack of communication. The designer plans for an office area, but no one has told the designer that the office will be filled with computer equipment that creates a larger heat load. This highlights the need for HVAC/R technicians to be involved in the planning and construction phase of all designs.
4	***Check current facility use*** Facility use changes could become a problem depending on the amount of load change in the facility. For example, a flight simulator building has been renovated into office space, but the project did not call for changing out the three existing 100-ton centrifugal chillers. This results in a drastic change in the heat load. This means that two of the chillers will never run unless manually switched over. There is also the possibility of oil collecting in the evaporator due to low load conditions. This situation could turn into a costly mistake if not promptly identified. Self-help modifications that are not routed through the HVAC/R section typically result in problems. Often when walls or false ceilings are built to convert a wide open space into office space, duct or air registers are not considered. After the occupants move into this facility, the “A/C inop” calls start to roll in. Even simple office changes can spur a drastic load change. You’ll also find that occupants move furniture and put a computer monitor, copier, refrigerator, or coffee pot near or directly under a thermostat. The placement of such a heat source ‘fakes’ a load, keeping the room cold because the thermostat thinks that the room is hot. Even seemingly positive changes can make a negative impact on heat load. Upgraded windows, insulation, roofs, and siding can make a big difference in the heat load. A heat load calculation shows that the upgrades have dramatically changed the equipment requirement.

Preventing Improperly Sized Units	
Step	**Action**
	For example, a resident decides to upgrade to spray-on polyurethane foam insulation in an old house. The old indoor unit in these houses did not have fresh air make up, counting on the walls to 'breathe.' Now that the foam has been sprayed, the house will become almost completely air tight. Soon, the occupants may find a mildew problem, and wonder why the children are always sick. Following the insulation upgrade, there should have been a simple outside air damper and ductwork installed to compensate for this change. Although the fix for this problem is simple, if it is not identified it may not be recognized for many years, if ever.

Summary

In this unit, you learned about heat loads and cooling loads. You learned that you need to take values given by the manufacturers of various different building materials and convert them into btuh. By performing all necessary steps, you know the basic procedures for calculating heat loads. Then, armed with that information you can determine a unit size by comparing the needs of the facility and the limits of the equipment. You can also determine upgrades or changes to the facility or equipment.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

026. System requirements procedure

1. How do you begin to select the correct equipment?

2. After selecting the correct equipment, what is the next step?

3. After the unit is ordered, what is the next step?

4. After the unit is installed, what should be done next?

5. What is the final step in the determining system requirements process?

027. Special system requirements

1. What is the *first* step in ensuring a system isn't over or under sized?

2. What is the *second* step to ensure a system isn't over or undersized?

3. After ensuring the condensers are of the proper design, what is the *next* step?

4. What is the *final* step when determining finding mistakes with sizing?

Answers to Self-Test Questions

024

1. A thorough understanding of heat transfer in and out of a building.
2. Heat transfer.
3. Use layers of material, materials with different heat resistance values, and insulating construction features to reduce heat exposure effects.
4. Gather as much accurate information about the building as possible.
5. Throughout the day.

025

1. 6.
2. Gather building information.
3. 342 Btuh.
4. 672 Btuh.
5. Calculate latent heat gain.
6. Add sensible and latent loads.
7. Review your work.

026

1. By obtaining the equipment performance data from the prospective manufacturer.
2. Order the unit.
3. Install and monitor operation.
4. Spend the next few weeks or months monitoring its performance.
5. Save all data and work.

027

1. Calculate latent heat, accurately.
2. Ensure condensers are of proper design
3. Recheck initial design.
4. Check current facility use.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

70. (024) When is solar loading *averaged*?
    a. In the morning.
    b. In the evening.
    c. Throughout the day.
    d. During the hottest part of the day.

71. (025) What is the *final step* of heat load calculations?
    a. Add sensible and latent loads.
    b. Gather building information.
    c. Review and trust your work.
    d. Speak with the customer.

72. (026) What is the *first step* in determining equipment sizing?
    a. Save data.
    b. Order the unit.
    c. Select the correct equipment.
    d. Install and monitor the equipment.

73. (026) After selecting the correct equipment, the *next step* is to
    a. save the data.
    b. order the unit.
    c. install the equipment.
    d. monitor the equipment in operation.

74. (027) If equipment cannot keep up with the load, what could be assumed about the system?
    a. It is oversized.
    b. It is undersized.
    c. The load is not enough.
    d. That there is no latent heat generated.

75. (027) What is the *final* step when finding mistakes with sizing?
    a. Calculate latent heat, accurately.
    b. Calculate building dimensions.
    c. Check current facility use.
    d. Recheck initial design.

Student Notes

Glossary of Abbreviations and Acronyms

A	airfoil
AC	alternating current
AC/R	air conditioning/refrigeration
ACCA	Air Conditioning Contractors of America
AFSC	Air Force specialty code
Ak	area factors
amp	ampere
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
BCE	Base Civil Engineering
Btu	British Thermal Unit
Btuh	British Thermal Unit per hour
CFC	chlorofluorocarbon
cfm	cubic feet per minute
CO^2	carbon dioxide
cu ft	cubic feet
DB	dry bulb
DC	direct current
DP	dew point
EPA	Environmental Protection Agency
fpm	feet per minute
fps	feet per second
ft wg	feet of water gauge
GM	grains of moisture
gpm	gallons-per-minute
HCFC	hydrochlorofluorocarbons
HTM	heat transfer multiplier
HVAC/R	heating, ventilation, air conditioning and refrigeration
IAQ	indoor air quality
ID	inside diameter
in. Hg	inches of mercury
in. wg	inch of water gauge
lb	pounds
LED	light-emitting diode
NPT	National PipeThread
O^2	oxygen
OA	outside air
OJT	on-the-job training
PM	pounds of moisture
psf	pounds per square foot
psi	pounds per square inch
psia	pounds per square inch absolute

psig	pounds per square inch gauge
RH	relative humidity
rpm	revolutions per minute
TP	total pressure
UV	ultraviolet
VAC	volts, alternating current
VAV	variable-air-volume
Vp	velocity pressure
WB	wet bulb
WOG	water, oil, gas
WSP	working steam pressure

Student Notes

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