Oxygen may also be produced by the electrolysis of water. Passing electric current through water separates the oxygen from the hydrogen. One further method of producing gaseous oxygen is by separating the nitrogen and oxygen in the air through the use of a molecular sieve. This membrane filters out nitrogen and some of the other gases in air, leaving nearly pure oxygen for use. Onboard oxygen sieves, or oxygen concentrators as they are sometimes called, are used on some military aircraft. Their use in civil aviation is expected.

Another source of oxygen used frequently for emergency passenger oxygen on airline aircraft is chemical in nature. The chemical combination with oxygen when burning some materials causes a release of excess oxygen that can be captured and used. This unique production of oxygen is explained further below.

OXYGEN STORAGE

GASEOUS OXYGEN TANKS

Pure gaseous oxygen, or nearly pure gaseous oxygen, is stored and transported in high-pressure cylinders that are typically painted green. Technicians should be cautious to keep pure oxygen away from fuel, oil, and grease to prevent unwanted combustion. Not all oxygen in containers is the same. Aviator’s breathing oxygen is tested for the presence of water. This is done to avoid the possibility of it freezing in the small passage ways of valves and regulators. Ice could prevent delivery of the oxygen when needed. Aircraft often operate in subzero temperatures, increasing the possibility of icing. The water level should be a maximum of .02ml per liter of oxygen. The words "Aviator’s Breathing Oxygen" should be marked clearly on any cylinders containing oxygen for this purpose. (Figure 15-3)

Traditionally, the cylinders used to store high pressure oxygen have been heavy steel tanks rated for 1 800-1 850 psi of pressure and capable of maintaining pressure up to 2 400 psi. While these performed adequately, lighter weight tanks have been developed. Some newer cylinders are comprised of a lightweight aluminum shell wrapped by Kevlar™. These cylinders are capable of carrying the same amount of oxygen at the same pressure as steel tanks, but weigh much less.

Also available are heavy-walled all-aluminum cylinders. These units are common as carry-on portable oxygen used in light aircraft. Most oxygen storage cylinders are painted green, but yellow and other colors may be used as well. The tanks are typically certified to department of transportation (DOT) specifications in the country of manufacture. To ensure continued serviceability, cylinders must be hydrostatically tested periodically. In general, a hydrostatic test consists of filling the container with water and pressurizing it to 5/3 of its certified rating. It should not leak, rupture, or deform beyond an established limit. Figure 15-4 shows a hydrostatic cylinder testing apparatus.

Most cylinders also have a limited service life after which they can no longer be used. After a specified number of filling cycles or calendar age, the cylinders must be removed from service. The most common high-pressure steel oxygen cylinders used in aviation are the 3AA and the 3HT. They come in various sizes but are certified to the same specifications. Cylinders certified under U.S. DOT-E-8162 are popular for their extremely light weight. These cylinders typically have an aluminum core around which Kevlar™ is wrapped. The DOT-E-8162 approved cylinders are also approved
The placard must be covered with a coat of clear epoxy when additional information is added, such as a new hydrostatic test date.

Oxygen cylinders are considered empty when the pressure inside drops below 50 psi. This ensures that air containing water vapor has not entered the cylinder. Water vapor could cause corrosion inside the tank, as well as presenting the possibility of ice forming and clogging a narrow passageway in the cylinder valve or oxygen system. Any installed tank allowed to fall below this pressure should be removed from service.

**CHEMICAL OR SOLID OXYGEN**

Sodium chlorate has a unique characteristic. When ignited, it produces oxygen as it burns. This can be filtered and delivered through a hose to a mask that can be worn and breathed directly by the user. Solid oxygen candles, as they are called, are formed chunks of sodium chlorate wrapped inside insulated stainless steel housings to control the heat produced when activated. The chemical oxygen supply is often ignited by a spring-loaded firing pin that when pulled, releases a hammer that smashes a cap creating a spark to light the candle. Electric ignition via a current-induced hot wire also exists. Once lit, a sodium chlorate oxygen generator cannot be extinguished. It produces a steady flow of breathable oxygen until it burns out, typically generating 10-20 minutes of oxygen. (Figure 15-6)

Solid oxygen generators are primarily used as backup oxygen devices on pressurized aircraft. They are one third as heavy as gaseous oxygen systems that use heavy storage tanks for the same quantity of oxygen available. Sodium chlorate chemical oxygen generators also have a long shelf life, making them perfect as a standby form of oxygen. They are inert below 400 °F and can remain stored with little maintenance or inspection until needed, or until their expiration date is reached.

<table>
<thead>
<tr>
<th>Certification Type</th>
<th>Material</th>
<th>Rated Pressure (psi)</th>
<th>Required Hydrostatic Test</th>
<th>Service Life (years)</th>
<th>Service Life (fillings)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOT 3AA</td>
<td>Steel</td>
<td>1 800</td>
<td>5</td>
<td>Unlimited</td>
<td>N/A</td>
</tr>
<tr>
<td>DOT 3HT</td>
<td>Steel</td>
<td>1 850</td>
<td>3</td>
<td>24</td>
<td>4 380</td>
</tr>
<tr>
<td>DOT-E-8162</td>
<td>Composite</td>
<td>1 850</td>
<td>3</td>
<td>15</td>
<td>N/A</td>
</tr>
<tr>
<td>DOT-SP-8162</td>
<td>Composite</td>
<td>1 850</td>
<td>5</td>
<td>15</td>
<td>N/A</td>
</tr>
<tr>
<td>DOT 3AL</td>
<td>Aluminum</td>
<td>2 216</td>
<td>5</td>
<td>Unlimited</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Figure 15-5. Common cylinders used in aviation with some certification and testing specifications.
The feature of not extinguishing once lit limits the use of solid oxygen since it becomes an all-or-nothing source. The generators must be replaced if used, which can greatly increase the cost of using them as a source of oxygen for short periods of time. Moreover, chemical oxygen candles must be transported with extreme caution and as hazardous materials. They must be properly packed and their ignition devices deactivated.

**ONBOARD OXYGEN GENERATING SYSTEMS (OBOGS)**

The molecular sieve method of separating oxygen from the other gases in air has application in flight, as well as on the ground. The sieves are relatively light in weight and relieve the aviator of a need for ground support for the oxygen supply. Onboard oxygen generating systems on military aircraft pass bleed air from turbine engines through a sieve that separates the oxygen for breathing use. Some of the separated oxygen is also used to purge the sieve of the nitrogen and other gases that keep it fresh for use. Use of this type of oxygen production in civilian aircraft is anticipated. (Figure 15-7)

**LIQUID OXYGEN**

Liquid oxygen (LOX) is a pale blue, transparent liquid. Oxygen can be made liquid by lowering the temperature to below -183 °C or by placing gaseous oxygen under pressure. A combination of these is accomplished with a Dewar bottle. This special container is used to store and transport liquid oxygen. It uses an evacuated, double-walled insulation design to keep the liquid oxygen under pressure at a very low temperature. (Figure 15-8)
A controlled amount of oxygen is allowed to vaporize and is plumbed into a gaseous oxygen delivery system downstream of a converter that is part of the container assembly. A small quantity of LOX can be converted to an enormous amount of gaseous oxygen, resulting in the use of very little storage space compared to that needed for high-pressure gaseous oxygen cylinders. However, the difficulty of handling LOX, and the expense of doing so, has resulted in the container system used for gaseous oxygen to proliferate throughout civilian aviation. LOX is used nearly exclusively in military aviation.

**OXYGEN CHARGING**

Charging procedures for oxygen systems vary. Many general aviation aircraft are set up to simply replace an empty cylinder with one that is fully charged. This is also the case with a portable oxygen system. High performance and air transport category aircraft often have built-in oxygen systems that contain plumbing designed to refill gaseous oxygen cylinders while they are in place. A general discussion of the procedure to fill this type of installation follows.

Before charging any oxygen system, consult the aircraft manufacturer’s maintenance manual. The type of oxygen to be used, safety precautions, equipment to be used, and the procedures for filling and testing the system must be observed. Several general precautions should also be observed when servicing a gaseous oxygen system. Oxygen valves should be opened slowly and filling should proceed slowly to avoid overheating. The hose from the refill source to the oxygen fill valve on the aircraft should be purged of air before it is used to transfer oxygen into the system. Pressures should also be checked frequently while refilling.

Airline and fixed-base operator maintenance shops often use oxygen filler carts to service oxygen systems. These contain several large oxygen supply cylinders connected to the fill cart manifold. This manifold supplies a fill hose that attaches to the aircraft. Valves and pressure gauges allow awareness and control of the oxygen dispensing process. (*Figure 15-9*)

Be sure all cylinders on the cart are aviator’s breathing oxygen and that all cylinders contain at least 50 psi of oxygen pressure. Each cylinder should also be within its hydrostatic test date interval. After a cart cylinder has dispensed oxygen, the remaining pressure should be recorded. This is usually written on the outside of the cylinder with chalk or in a cylinder pressure log kept with the cart. As such, the technician can tell at a glance the status of each oxygen bottle. No pump or mechanical device is used to transfer oxygen from the fill cart manifold to the aircraft system. Objects under pressure flow from high pressure to low pressure. Thus, by connecting the cart to the aircraft and systematically opening oxygen cylinders with increasingly higher pressure, a slow increase in oxygen flow to the aircraft can be managed.

The following is a list of steps to safely fill an aircraft oxygen system from a typical oxygen refill cart.

1. Check hydrostatic dates on all cylinders, especially those that are to be filled on the aircraft. If a cylinder is out of date, remove and replace it with a specified unit that is serviceable.
2. Check pressures on all cylinders on the cart and in the aircraft. If pressure is below 50 psi, replace the cylinder(s). On the aircraft, this may require purging the system with oxygen when completed. Best practices dictate that any low-pressure or empty cylinder(s) on the cart should also be removed and replaced when discovered.
3. Take all oxygen handling precautions to ensure a safe environment around the aircraft.

*Figure 15-9. Typical oxygen servicing cart used to fill an aircraft system.*
4. Ground the refill cart to the aircraft.
5. Connect the cart hose from the cart manifold to the aircraft fill port. Purge the air from the refill hose with oxygen before opening the refill valve on the aircraft. Some hoses are equipped with purge valves to do this while the hose is securely attached to the aircraft. Others hoses need to be purged while attached to the refill fitting but not fully tightened.
6. Observe the pressure on the aircraft bottle to be filled. Open it. On the refill cart, open the cylinder with the closest pressure to the aircraft cylinder that exceeds it.
7. Open the aircraft oxygen system refill valve. Oxygen will flow from cart cylinder (manifold) into the aircraft cylinder.
8. When the cylinder pressures equalize, close the cylinder on the cart, and open the cart cylinder with the next highest pressure. Allow it to flow into the aircraft cylinder until the pressures equalize and flow ceases. Close the cart cylinder, and proceed to the cart cylinder with the next highest pressure.
9. Continue the procedure in step 8 until the desired pressure in the aircraft cylinder is achieved.
10. Close the aircraft refill valve, and close all cylinders on the cart.
11. The aircraft oxygen cylinder valve(s) should be left in the proper position for normal operations. Remotely mounted cylinders are usually left open.
12. Disconnect the refill line from the refill port on the aircraft. Cap or cover both.
13. Remove the grounding strap.

When filling cylinders on a cold day, compensation for temperature and pressure changes dictates that cylinders be filled to less than the maximum rated capacity to allow for pressure increases as temperature rises. Strict adherence to the temperature/pressure compensation chart values is mandatory to ensure safe storage of aircraft oxygen.

Note that some aircraft have temperature compensation features built into the refill valve. After setting the ambient temperature on the valve dial, the valve closes when the correct amount of oxygen pressure has been established in the aircraft cylinder. A chart can be used to ensure proper servicing.

Temperature has a significant effect on the pressure of gaseous oxygen. Manufacturers typically supply a fill chart or a placard at the aircraft oxygen refill station to guide technicians in compensating for temperature/pressure variations. Technicians should consult the chart and fill cylinders to the maximum pressure listed for the prevailing ambient temperature. (Figure 15-10)

When it is hot, oxygen cylinders are filled to a higher pressure than 1 800 psi or 1 850 psi, the standard maximum pressure ratings of most high-pressure aircraft oxygen cylinders. This is allowable because at altitude the temperature and pressure of the oxygen can decrease significantly. Filling cylinders to temperature-compensated pressure values ensures a full supply of oxygen is available when needed.
OXYGEN SYSTEMS AND SUPPLY REGULATION

The use of gaseous oxygen in aviation is common; however, applications vary. On a light aircraft, it may consist of a small carry-on portable cylinder with a single mask attached via a hose to a regulator on the bottle. Larger portable cylinders may be fitted with a regulator that divides the outlet flow for 2-4 people. Built-in oxygen systems on high performance and light twin-engine aircraft typically have a location where oxygen cylinders are installed to feed a distribution system via tubing and a regulator. The passenger compartment may have multiple breathing stations plumbed so that each passenger can individually plug in a hose and mask if oxygen is needed. A central regulator is normally controlled by the flight crew who may have their own separate regulator and oxygen cylinder. Transport category aircraft may use a more elaborate built-in gaseous oxygen system as a backup system to cabin pressurization. In all of these cases, oxygen is stored as a gas at atmospheric temperature in high-pressure cylinders. It is distributed through a system with various components that are described in this section.

The design of the various oxygen systems used depends largely on the type of aircraft, its operational requirements, and whether the aircraft has a pressurization system. Systems are often characterized by the type of regulator used to dispense the oxygen: continuous-flow and demand flow. In some aircraft, a continuous-flow oxygen system is installed for both passengers and crew. The pressure demand system is widely used as a crew system, especially on the larger transport aircraft. Many aircraft have a combination of both systems that may be augmented by portable equipment.

CONTINUOUS-FLOW SYSTEMS

In its simplest form, a continuous-flow oxygen system allows oxygen to exit the storage tank through a valve and passes it through a regulator/reducer attached to the top of the tank. The flow of high-pressure oxygen passes through a section of the regulator that reduces the pressure of the oxygen, which is then fed into a hose attached to a mask worn by the user. Once the valve is opened, the flow of oxygen is continuous. Even when the user is exhaling, or when the mask is not in use, a preset flow of oxygen continues until the tank valve is closed. On some systems, fine adjustment to the flow can be made with an adjustable flow indicator that is installed in the hose in line to the mask. A portable oxygen setup for a light aircraft exemplifies this type of continuous-flow system and is shown in Figure 15-11.

A more sophisticated continuous-flow oxygen system uses a regulator that is adjustable to provide varying amounts of oxygen flow to match increasing need as altitude increases. These regulators can be manual or automatic in design. Manual continuous-flow regulators are adjusted by the crew as altitude changes. Automatic continuous-flow regulators have a built-in aneroid. As the aneroid expands with altitude, a mechanism allows more oxygen to flow though the regulator to the users. (Figure 15-12)

SYSTEM LAYOUT: CABIN (CONTINUOUS FLOW)

Many continuous-flow systems include a fixed location for the oxygen cylinders with permanent delivery plumbing installed to all passenger and crew stations in the cabin. Fully integrated oxygen systems usually have separate, remotely mounted components to reduce