Current Reviews for Nurse Anesthetists

Electrical Safety in the Operating Room

LESSON 3
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LESSON OBJECTIVES
Upon completion of this lesson, the reader should be able to:
1. Define basic principles of electricity including amperage, voltage and resistance.
2. List factors that contribute to the risk of electrical injury in the OR.
3. Define macroshock and microshock.
4. Discuss various ways “grounding” is used in the OR.
5. Explain why every device in the OR should be grounded.
6. List safety features in the OR that serve to prevent macroshock.
7. Explain how an isolated power system works and why a ground fault circuit interrupter would not be appropriate in the OR.
8. Discuss the purpose of the line isolation monitor and steps to take when it alarms.
9. List steps you can take to minimize the risk of microshock.
10. Describe risks of the electrosurgical unit and how its risks can be minimized.

Introduction
The operating room (OR) is a hazardous environment. Patients are exposed to many potential sources of injury, including the risk of burns and arrhythmias from electrical devices. Although electrical injury is rare in the OR, it can still occur and it is vital that anesthesia providers understand the sources of potential electrical injury and how these injuries can be minimized. Because the anesthesia provider is charged with ensuring the safety of the patient, it is vital that we understand electrical devices and their safety features. In addition, we should understand how electrical power is supplied to the OR so that we can respond effectively and knowledgeably if an alarm sounds.

The purpose of this lesson is to outline the basic principles of electricity, upon which a description of electrical injury will be added. In addition, the unique power supply of the OR will be described plus safety features of individual electrical devices. Questions that will be addressed include:
- What is the relationship between voltage, resistance, and amperage?
- What is the difference between microshock and macroshock?
- Why is grounding of electrical devices in the OR important?
- What is an isolated power system?
- What is the function of the line isolation monitor?
- What are the risks of the electrosurgical unit (ESU)?

Basic Principles of Electricity
Electric current is, by definition, the flow of electrons. One amp (I) is defined as the current flow of one coulomb past a given point for one second. A coulomb is equal to $6.241 \times 10^{18}$ electrons. Voltage is defined as electromotive force, which is the potential difference in charge that causes the flow of electrons. For current to flow, there must be a voltage difference from one end of a conductor (such as a wire) to the other. Resistance is the force opposing the flow of electrons in the circuit such that 1 volt will push 1 amp of current through 1 ohm of resistance. These factors are related by Ohm’s law: $V = IR$ or $I = V/R$. 

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Other basic principles include current density, which is the amount of current flowing per unit area. A small amount of current can cause burns or arrhythmias if it is delivered to a small amount of tissue. Unintended charge storage in a device is called “stray capacitance”. This concept will become important later when we discuss microshock, because stray capacitance can be a source of very small amounts of current delivered directly to the heart (Table 1).

As shown in Figures 1 and 2, electrical current comes from the power generating plant. It is supplied to the home or hospital in a hot wire and a neutral wire with a potential difference between these wires of 120 volts. This is the electromotive force, which drives current through the system. If a patient or a caregiver comes into contact with the hot wire and ground simultaneously, or more likely, if they come into contact with the electrified case of an electrical device with a short circuit, they can complete the circuit and be electrocuted.

**Hazards of Electrical Devices in the Operating Room**

Electrical devices can cause burns, arrhythmias, and shocks, including macroshock and microshock. Factors that contribute to patient risk include the following (Table 2):

- The patient is frequently wet and immobilized. As will be discussed below, wet skin greatly lowers resistance and dramatically increases the risk of current flowing through the patient. Because they are immobilized, patients cannot withdraw from the pain of the electric current. The patient is also unclothed and, therefore, losses any resistance to electrical current provided by clothing.
- There are numerous electrical devices in the OR. These include the ESU, external warming devices, IV fluid warmers, ECG machines, cardio-pulmonary bypass machines, and fluid-filled catheters that are inserted into the heart and attached to electrical monitoring equipment. In addition, the patient may come into direct contact with the OR table with its metal frame and electric motor.
- ORs invariably have many power cords strewn about on the floor. These power cords are subject to damage from heavy usage, including carts and anesthesia machines rolling over them.
- The floors in ORs are frequently wet from blood, bodily fluids and irrigation fluids used during surgery.

In other words, electricity must be able to both enter into and exit out of the patient. **When a shock occurs, muscle contraction, respiratory paralysis, dysrhythmias and burns can result.** Macroshock is defined as shock that is external and perceived. Macroshock can cause burns and dysrhythmias in addition to significant internal damage as the current passes through tissues. If the current passes through the thorax, the risk of ventricular fibrillation is much greater. When patients come into contact with a faulty piece of equipment, the amount of current that could pass through them is determined by the wetness or dryness of their skin. For instance, dry skin provides about 50,000 ohms of resistance. With 120 volts, which is the voltage supplied by the power company in the United States, this would result in a current less than 3 milliamps (mA). This is enough to cause a burn at the site of contact but not enough to cause ventricular fibrillation, which requires somewhere between 80-100 mA.

<table>
<thead>
<tr>
<th>Electric current</th>
<th>The flow of electrons</th>
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<tbody>
<tr>
<td><strong>Amperage (I)</strong></td>
<td>The amount of current flow</td>
</tr>
<tr>
<td><strong>Voltage (V)</strong></td>
<td>Electromotive force that causes the flow of electrons; the potential difference in charge between two sides of a circuit</td>
</tr>
<tr>
<td><strong>Resistance (R)</strong></td>
<td>The force opposing the flow of electrons</td>
</tr>
<tr>
<td><strong>Ohm’s law</strong></td>
<td>V = IR</td>
</tr>
<tr>
<td><strong>Current density</strong></td>
<td>The amount of current flowing per unit area</td>
</tr>
<tr>
<td><strong>Stray capacitance</strong></td>
<td>Unintended charge storage in a device</td>
</tr>
<tr>
<td><strong>Macroshock</strong></td>
<td>Shock that is external and perceived</td>
</tr>
<tr>
<td><strong>Microshock</strong></td>
<td>Shock that is internal and delivered directly to the heart</td>
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</table>
In contrast, wet skin has a resistance of only about 500 ohms. With wet skin contacting an electrical source, current flow would be nearly 300 mA, which is more than enough to cause ventricular fibrillation. Microshock is current delivered internally, directly to the myocardium and electrical system of the heart. It is not perceived externally but can cause ventricular fibrillation with much lower current. As little as 100 microamps (µA) can cause ventricular fibrillation. Microshock will be discussed more fully below.

Figure 1. A shock can occur when a person becomes part of the electrical circuit, such as touching the hot and neutral wires of the circuit.

Figure 2. A shock can occur when a person touches the electrified case of a device with a short circuit. The current flows through the device and the person to ground, completing the circuit.
The Importance of Grounding

In the context of electrical safety, grounding is an extremely important concept. Unfortunately, this word is used in several ways in the OR, contributing to confusion (Table 3). There are at least three ways grounding is used in the OR.

1. **The electrical power supply to the hospital (or to your house) is grounded.** This means that one of the electrical supply wires is connected to the earth. Typically, the electrical wire is attached to a water pipe that goes down into the ground. This provides a low resistance pathway “to ground” for electrical charges that build up during an electrical storm or from other sources.

2. **Individual pieces of electrical equipment in the OR should be grounded.** This means that the device has a third wire (and third prong in the electrical outlet) that provides a low resistance pathway from the case (or chassis) of the equipment back to the power grid. In older homes, electrical outlets may be of the two slot or two prong variety. In contrast, all electrical outlets in the OR should be heavy duty and include the slot for the third prong. Again, this is a safety feature for the user. If there is an electric fault in the device, the electricity will preferentially flow down the third wire, through a fuse box to ground (Figure 3).

3. **The third way that we use “ground” in the OR is the electrosurgical unit (ESU).** We often refer to the return pad on the ESU, which is placed somewhere on the patient, as “the ground”. As will be explained below, this is not a ground but is a safety feature that allows electricity to return to the ESU generator.

Touching the neutral side of a circuit will not electrocute the individual or patient because it is connected to ground and you cannot complete the circuit back to the hot wire. Therefore, it is touching the hot side and ground at the same time that will complete a circuit and lead to electrical injury. Again, a more likely scenario is touching the metal case of an electrical device that contains a short circuit.

To prevent macroshock in the OR, a number of considerations are important.

- The equipment used in the OR is “hospital grade” meaning that it is very sturdy and is designed to protect the hot wire from exposure to people or the metal case of the device. The wall outlets in the OR are also hospital grade and should be serviced periodically by the facilities department.
- Every device in the OR should be grounded, meaning that it has a third prong.
- Individuals should not bring personal devices into the OR such as radios or lamps, especially if they only have two prongs.

Table 3

<table>
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<tr>
<th>Definitions of “Grounding” in the OR and the Hospital</th>
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<tbody>
<tr>
<td>- Electrical power to the hospital is grounded = electrical supply line is connected to earth at the point where it enters the building</td>
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<tr>
<td>- Individual pieces of equipment are grounded = a third wire is attached to the metal case of the device and exits the circuit via the third prong on the power cord</td>
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<tr>
<td>- The return pad on the electrosurgical unit (ESU) is incorrectly referred to as “the ground”</td>
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</table>
there's no ground; there is no pathway for current to flow through a patient. Therefore, the electrical circuit cannot be completed and no injury can occur. As shown in Figure 4, an isolated (or floating) power system is created with an isolation transformer. Outside each OR with an isolated power system, there is an isolation transformer. The transformer takes power from the power company and transforms it into a second power system that supplies the OR. This is done by placing coils adjacent to each other in the isolation transformer.

The isolated power system, unlike the power supplied to the hospital and to our homes, is not grounded. Therefore, the two power lines in the system are not designated as hot and neutral but rather are called line 1 and line 2. There is still a voltage potential between the two lines that will drive current through the circuit, but there is no connection of the circuit to the ground. Therefore, even if the patient came in contact with one of the lines or with a faulty electrical device, they cannot complete the circuit because the isolated power system is not grounded.

It is noteworthy that isolated power systems are expensive and, therefore, only used in locations such as an OR where there is the need for reliable and continuous power but also the high risk of electrical injury.

The line isolation monitor (LIM) is a device that rapidly alternates between each side of the isolated circuit (line 1 vs. line 2) looking for a short between either side and ground. Said another way, the LIM confirms the integrity of the system. If a short is detected that could result in a current of 5 mA (if a second fault was present), the LIM will alarm. When the alarm sounds, the most likely explanation is that a device just plugged into the OR circuit has a fault, or there are too many devices plugged into the circuit. As noted above, due to stray capacitance, all electrical devices have a small amount of current leakage. When the leakage from one device, or a total leakage of all the devices reach 5 mA, the LIM will alarm. If the LIM alarm sounds, the appropriate next step is to start unplugging non-essential devices in the reverse order they were plugged in.

Figure 3. With an intact third wire from a grounded device case, electricity preferentially passes out the third prong and away from the person.
When a faulty piece of equipment is plugged into an isolated circuit, this in effect converts the system back into a conventional system. Current would flow through line 1, through the device and out the ground wire of the device. The faulty device would continue to work, which could be vital for patient safety, but the LIM alarm will sound, alerting the OR staff that a faulty device has been plugged into the circuit.

Some may ask, “Why not use the safety device that is used in the wet areas of a home to protect patients in the OR?” This is known as a ground fault circuit interrupter (GFCI). The GFCI provides protection from macroshock in a grounded environment. This inexpensive device, which is required in our homes in wet areas such as the kitchen, bathroom, garage or outdoor areas, monitors current flow in the hot and neutral wires. If it detects an imbalance, the device assumes that there is a short circuit and it immediately interrupts current flow in the circuit. The GFCI effectively provides protection by limiting the duration of a shock. In the OR, the GFCI could also protect patients and caregivers from electrical injury but it would simultaneously shut off the device in question. If, for instance, there was a short circuit in the cardiopulmonary bypass or anesthesia machine, the GFCI would shut the device off. This would obviously have serious ramifications for the patient. In contrast, the isolated power system would not shut the device off but would alarm, alerting the OR staff that an electrical fault was present. Again, in an isolated circuit, the risk of electrical injury is extremely small because the system is not grounded. Even if a faulty device is plugged into the circuit, the current cannot flow through the patient to ground, so no electrical injury will occur. The only way for electrical injury to occur in an isolated circuit is for there to be two faults in the system, which is extremely unlikely.

**Microshock**

As noted above, current delivered directly to the myocardium is called microshock. This comes from intracardiac electrodes, such as pacemaker wires, or catheters such as saline- or blood-filled central venous catheters or pulmonary artery catheters. By regulation, current leakage for catheters near the heart must be less than 10 μA. About 100 μA is needed to cause fibrillation when applied directly to the heart. The circuit consists of current that flows from an electrode or catheter through the myocardium and back to the source.

> **It is important to note that the LIM warns of macroshock, not microshock which requires a much lower current to cause ventricular fibrillation.**

<table>
<thead>
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<th>Table 4</th>
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<tbody>
<tr>
<td><strong>Key Features of an Isolated Power System</strong></td>
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<tr>
<td>■ Eliminates ground, so current cannot flow through the patient and complete the circuit. No current flow to ground = no injury.</td>
</tr>
<tr>
<td>■ Isolation transformer outside each OR transforms power from the power company into a second power system that is ungrounded.</td>
</tr>
<tr>
<td>■ The lines in the isolated system have potential with respect to each other (but not ground), and are labeled line 1 and line 2.</td>
</tr>
<tr>
<td>■ The line isolation monitor (LIM) is a device that rapidly alternates between each side of the isolated circuit (line 1 vs. line 2) looking for a short between either side and ground.</td>
</tr>
<tr>
<td>■ When the LIM alarm sounds, a total leakage of 5 mA of current has been detected; devices should be unplugged in the reverse order they were plugged in.</td>
</tr>
<tr>
<td>■ The LIM warns of macroshock, not microshock risk.</td>
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Only a very small amount of voltage is required to generate the current necessary to cause microshock. If we assume that wet skin has a resistance to current flow of 500 ohms, and the resistance of a CVP catheter is around 25,000 ohms, the voltage necessary to cause microshock is only about 250 mV (V = 100 μA x 25,500 ohms).

Where could this small amount of voltage come from in the OR to drive current through the heart? As noted above, stray capacitance can build up in the case of a device with enough charge to cause ventricular fibrillation via a central line or pacemaker wire, if the grounding wire of the device is not intact. This would include the OR table, EKG machine and warming devices.

Further protection from microshock is provided by monitoring devices like the ECG. High impedance between the power supply of the device and the connection to the patient is designed in these devices. This makes conduction of any current, including small amounts from stray capacitance, very unlikely while still allowing recording of physiologic data.

As noted above, the LIM is not designed to warn of microshock hazard. The voltage requirements for microshock are far below the levels detected by the LIM. Furthermore, the LIM does not detect leakage...
in individual devices. The LIM provides information on the status of the entire system.

Anesthesia providers can take several steps to prevent microshock (Table 5). This includes never simultaneously touching an external device and a catheter, wearing rubber gloves when touching a catheter, and not allowing an external current source (such as the nerve stimulator) to touch a catheter that is placed in the heart.

**The Electrosurgical Unit**

The electrosurgical unit (ESU) is another source of injury in the OR. It provides energy to cut, coagulate or burn tissue. The energy transferred at the tip of the ESU is a function of current density. At the tip of the ESU, the current density is very high, whereas at the dispersal pad (incorrectly called the grounding pad), the current density is very low. The electrical current goes from the site where the surgeon is coagulating through the patient and out the return pad. At the return pad, the current density is low and should not burn the patient unless the return pad is placed over metal such as a total hip arthroplasty or if the return pad is not applied smoothly to the skin. If the gel on the return pad is dried out, it may not distribute the electrical energy evenly and could cause a burn at the exit site. Typically, the ESU return pad is placed on a large muscle mass with high blood flow and the ability to dissipate heat, such as the thigh.

The ESU has a very high frequency of current, anywhere from 50,000 to 2 million Hz. This frequency is too high to interact with the cardiac conducting system and cause ventricular fibrillation, even if the current passes through the chest.

Depending on the type of surgery and surgeon preference, monopolar or bipolar electrosurgical tips are used. A monopolar ESU functions with a single

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**Table 5**

<table>
<thead>
<tr>
<th>Steps to Prevent Microshock</th>
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<tbody>
<tr>
<td>Never simultaneously touch an external electrical device and central venous catheter or pacemaker wire</td>
</tr>
<tr>
<td>Wear rubber gloves when handling centrally inserted catheters and wires</td>
</tr>
<tr>
<td>Do not allow an external current source (e.g., the nerve stimulator) to touch the central venous or other catheter</td>
</tr>
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</table>

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tip and a dispersal pad remote from the site of the surgery. In bipolar, the electrical current flows from one prong to the other so that the pathway of current flow is very short and localized. This is commonly used in neurosurgery to prevent electrical energy passing through the brain and nerves.

As an additional safety feature, the modern ESU has its own LIM to ensure it is isolated from the patient. However, a burn could result from a broken ESU wire if an old-styled ECG machine was being used, with one of its electrodes being used as a ground. However, with modern ECG units, there is no grounding of the patient, essentially eliminating the risk of a burn at one of the ECG electrode sites.

There are miscellaneous risks associated with the ESU. If excess power settings are used, a local burn could occur. The surgeon or other caregiver could unintentionally activate the device and cause a burn. Finally, use of the ESU around flammable agents such as alcohol or an oxygen source could cause a fire (Table 6).

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**Table 6**

<table>
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<tr>
<th>Electrosurgical Unit Considerations</th>
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<tbody>
<tr>
<td>- The ESU return pad must be applied smoothly at the skin to avoid burns</td>
</tr>
<tr>
<td>- The current from the ESU is at a very high frequency and will not interfere with the cardiac conducting system</td>
</tr>
<tr>
<td>- A local burn can occur with excess ESU settings or accidental activation</td>
</tr>
<tr>
<td>- ESU use around flammable agents or oxygen sources can cause a fire</td>
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</table>

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**The most important safeguard against microshock is an intact ground wire on every device that is in contact with the patient.**

**Summary**

In the modern OR, electrical injury is rare. Nonetheless, the environment presents significant risks for the patient and caregivers because of multiple electrical devices that are being used, the wetness of the environment, and the fact that these devices are attached to the patient. The ESU is also a source of potential injury to the patient.

Electrical safety is about making it difficult for current to pass through people. The patient should be isolated from ground as much as possible. This is accomplished in large measure by the isolated circuit, which is monitored by the LIM. The ground wire (third prong) in the equipment is also a key feature. This provides a low resistance pathway for short circuits to prevent macroshock, and to dissipate leakage currents from stray capacitance to minimize microshock risk.

As always, knowledgeable, vigilant anesthesia providers can make a significant contribution to electrical safety.

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**References**


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Tips for your Clinical Practice: Key Points

- **Burns, arrhythmias and shock** may result in patients who are wet (decreased skin resistance); immobilized (cannot move away from the shock); and have attached electrical devices (such as ESU, IV fluid warmers, ECG machines, central venous and pulmonary artery catheters, and pacemaker wires), all of which predispose to electrical current entering and exiting the body.

- OR electrical equipment should have a **ground wire** and all electrical outlets should have a third prong that provides a **low resistance path** from the electrical equipment to the power grid.

- **Isolated power systems** have voltage and current flow but are not connected to ground; therefore current flow through the patient to ground cannot occur (thus minimizing electrical injury).

- An **LIM** will sound an alarm if a current leak of at least 5 mA (a short) occurs from the circuit to ground. Should this happen, non-essential devices should be disconnected in reverse order from which they were connected.

- **Microshock-induced ventricular fibrillation**, resulting from stray capacitance and a faulty ground wire, occurs if a 100 μA current flows from the device to the heart and back. LIMs **do not** detect microshock.

- Burns can result during **monopolar ESU** use if the dispersion pad is not evenly applied, the gel is dried, or the pad overlies a superficial metal implant device rather than a large muscle mass. ESU use around flammable agents (alcohol) or in an oxygen-rich environment can result in fire.

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POST-STUDY QUESTIONS

1. According to Ohm’s law, which of the following correctly defines the relationship between Voltage (V), Amperage (I) and Resistance (R):
   □ A. V = I/R
   □ B. I = V/R
   □ C. R = IV
   □ D. I = R/V

2. In the OR, which of the following is an incorrect use of the term “ground”:
   □ A. The electrical power supply to the hospital is “grounded.”
   □ B. Individual pieces of equipment in the OR should be “grounded.”
   □ C. The return pad from the electrosurgical unit (ESU) “grounds” the patient.
   □ D. The isolated power system provides power in the OR that is not “grounded.”

3. Which of the following factors contribute to electrical injury risk in the OR:
   □ A. The patient is wet.
   □ B. There are numerous electrical devices in the OR.
   □ C. The patient is unclothed and immobilized.
   □ D. All of the above.

4. Macroshock is:
   □ A. Shock that is external and perceived.
   □ B. Any shock over 500 mA.
   □ C. Shock applied directly to the heart.
   □ D. Shock that always causes ventricular fibrillation.

5. Microshock is:
   □ A. Shock too small to cause ventricular fibrillation.
   □ B. Shock applied internally, directly to the myocardium.
   □ C. Clinically important only when the amperage is > 1 amp.
   □ D. None of the above.

6. The third prong on a power cord:
   □ A. Diverts electricity directly from the hot wire to the neutral wire.
   □ B. Can drive current from the power company through the patient.
   □ C. Is only effective against macroshock.
   □ D. Provides a low resistance pathway from the device case to ground.

7. The purpose of an isolated power system in the OR is to:
   □ A. Reduce cost relative to the ground fault circuit interrupter.
   □ B. Eliminate the need for the third prong on power cords.
   □ C. Provide an ungrounded electrical system in the OR.
   □ D. Prevent microshock.

8. An isolated power system is used in the OR instead of a ground fault circuit interrupter (GFCI) because:
   □ A. The GFCI could cut off power to critical equipment at a critical moment.
   □ B. The isolated system is cheaper.
   □ C. Macroshock can NEVER happen with an isolated power system.
   □ D. Only an isolated power system will work in a wet environment.

9. The line isolation monitor (LIM):
   □ A. Continually alternates between the hot and neutral lines, looking for a short.
   □ B. Alarms when the leakage from a single device or a total from all the devices reaches 10 mA.
   □ C. Warns of macroshock risk.
   □ D. Warns of microshock risk.

10. Risks of the electrosurgical unit (ESU) include all of the following EXCEPT:
    □ A. Burns due to accidental activation.
    □ B. Interaction with the cardiac conduction system.
    □ C. Ignition of flammable liquids.
    □ D. Fire due to ignition of a substance in an area of high oxygen concentration.

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