HARVARD
Campus Services
ENVIRONMENTAL HEALTH & SAFETY

LABORATORY SAFETY GUIDELINE
Peroxide-Forming Chemicals

Inorganic and organic peroxides, because of their exceptional reactivity and oxidative capacity are widely used in research laboratories. This review provides users of peroxide formers a general overview of the hazards, conditions of formation, types, storage, common problems, testing and disposal policies/requirements of peroxide-forming chemicals. All researchers working with these chemicals will be **required** to follow these general guidelines for all peroxide-forming chemicals and are strongly encouraged to reference available chemical specific guidelines, maintain a standard operating procedure (SOP) for their process, as well as contact their EHS Laboratory Safety Advisor and department safety officer if they have questions before beginning work.

What is a Peroxide-former?

Peroxide formers are chemicals that have the **ability to form shock-sensitive explosive peroxide crystals/liquid over time**. Note: Peroxide-forming chemicals may have other hazards associated with them when initially supplied by their manufacturers. Many of the organic solvents commonly used in laboratories are peroxide formers.

Typical classes of compounds that form peroxides include:

- Ethers, acetals, and ketals, especially cyclic ethers and/or ethers where the oxygen atom of the ether functional group is bound to primary or secondary alkyl group(s);
- Aldehydes, including acetaldehyde and benzaldehyde; and
- Compounds containing hydrogen atoms that can be heterolytically cleaved to form stable radicals, including hydrogen atoms bound to benzylic, allylic, and tertiary carbon atoms.

If the chemical does not contain an inhibitor or stabilizer (e.g., butylated hydroxytoluene or BHT), it can form peroxides more quickly.

How are Peroxides formed?

Certain conditions are required for a peroxide former to produce peroxides:

Oxygen	Exposure of peroxide-forming compounds to oxygen **always** enhances peroxide formation.
Time	Autoxidation generally refers to the slow reaction between organic chemicals and elemental oxygen under mild conditions. Over time, and in the presence of oxygen, chemicals will typically form peroxides. Peroxide-forming chemicals will usually have manufacturer listed expiration dates and institutional storage guidance.
Heat / Concentration	The likelihood of autoxidation increases with concentration or the application of heat. Chemicals that have already formed detectable peroxides should not be heated or concentrated.
Light	Ultraviolet light, including sunlight, promotes both autoxidation and depletion of the inhibitor. Although ultraviolet light catalyzes autoxidation, the reaction cannot proceed in the absence of oxygen.

Consequences

Improper storage or usage of a peroxide-former can result in devastating consequences:

Peroxide explosion – UC Berkeley
ehs.berkeley.edu/lessons-learned/lesson-learned-peroxide-explosion-injures-campus-researcher

Peroxide explosion – University of Minnesota
dehs.umn.edu/sites/dehs.umn.edu/files/safety_alert_-_thompson_explosion_aug19.pdf

Classes of Peroxide Formers

Peroxide formers are divided into classes according to the conditions required for peroxide formation. Please see Appendix A for a list of common chemicals in these peroxide classes.

Class A Peroxide Formers – Severe Peroxide Hazard

These compounds spontaneously decompose and become explosive when exposed to air, with or without any other peroxide-forming factors. These are the most hazardous of peroxide formers.

Solid Class A Peroxide Formers

Solid peroxide formers present little problem except when finely divided, since the reaction, if any, will occur only at the surface.

Class B & C Peroxide Formers – Form Peroxides from Concentration and Autopolymerization

Class B compounds can form explosive levels of peroxides, but usually become hazardous only if the peroxides are concentrated by evaporation, distillation, etc.

Class C includes examples of vinyl monomers that are usually not particularly hazardous. However, their decomposition may initiate the explosive polymerization of the bulk monomer.

Proper Storage of Peroxides

Proper storage of peroxide formers according to the peroxide class and EHS Policy is as follows. Consider any container as open if you are uncertain. **In all cases, EHS requires prompt disposal of any peroxide-forming chemicals that are past the manufacturer's expiration date.**

Class A

- Unopened Container: Manufacturer's expiration date, if the chemical is stored appropriately, unused, and frequently visually inspected for peroxide formation (refer below for guidance on visual signs of peroxide formation).
- Opened Container: **3 months**, or up to the manufacturer's expiration date if it is tested every three months and peroxide free.
- Solid Chemical: Manufacturer's expiration date, if the chemical is stored appropriately, and frequently visually inspected for peroxide formation (refer below for guidance on visual signs).

Class B & C

- Unopened Container: Manufacturer's expiration date, if the chemical is stored appropriately, unused, and frequently visually inspected for peroxide formation (refer below for guidance on visual signs).
- Opened Container: **6 months**, or up to the manufacturer's expiration date if it is tested every three months and peroxide free. **Exception**: If a Class C chemical is uninhibited, disposed within 24 hours after the container is opened.

Other Storage Requirements

- Purchase peroxide-forming chemicals that have an added inhibitor or stabilizer and that are stored under an inert gas.
- Label potential peroxide formers with EHS-provided peroxide former tag – including date received, date opened, and date tested (if applicable). This tag is provided by EHS. Please see Appendix B.
- Protect from heat and light. Store peroxide formers in air-tight containers (preferably the container furnished by the supplier) in cool, dry, dark locations preferably in a dark amber glass with a tight-fitting cap.
- **Do Not** store peroxidizable chemicals in open, partially empty, or transparent containers.
- **Do Not** allow open flames, other sources of heat or sparks, friction, grinding or forms of impact near peroxides.
- **Do Not** use secondary glass containers with screw-cap lids or glass stoppers for extended storage. Use polyethylene containers, with screw caps or stoppers.
- **Do Not** store large quantities.
- Because distillation of a stabilized solvent will remove the stabilizer, the distillate must be stored with care and closely monitored for peroxide formation.
- It is also good practice for researchers to store these chemicals under inert gas, if possible, i.e., flow some inert gas into the container head space before putting the container away.

Contamination

Some contaminants such as heavy metals, metal oxide salts, alkaline materials (e.g., amines), strong acids, and many varieties of dust and dirt can cause the uncontrolled decomposition of peroxides. This condition can lead to pressure build up, explosions, and/or fire. In order to prevent accidental contamination, **never return a peroxide former to its original storage container once withdrawn**.

Temperature

- Peroxide accumulation may be enhanced by refrigeration because the rate of peroxide degradation is slowed more than the rate of peroxide formation.
- Excess cooling where you are approaching the freezing point of the chemical, however, may also cause the precipitation of peroxides from solution.
- If refrigeration is necessary, only completely spark-proof refrigerators should be used to store ignitable peroxide formers.

Visual Signs of Peroxide Formation

Visual inspection can help you determine if your compound has begun to form peroxides. A non-hazardous light source like a flashlight can be used to provide backlight or side light to the bottle to make indicators visible.

- Clear liquid containing suspended wisp-like structures
- Precipitated crystal formation appearing as chips, ice-like structures, solid mass
- Appearance of cloudiness
- Gross contamination
- White crystal under the rim of the cap
- Visible discoloration

Solid Chemicals (potassium metal, potassium and sodium amide):

- Discoloration and/or formation of a surface crust (for example, potassium metal forms a yellow or orange superoxide at the surface)

Note: Evaluation of alkali metals and their amides is based on visual criteria only. These substances react violently with water and oxygen, so standard peroxide tests should not be used.

If any of these indicators are observed, avoid additional testing or handling and contact EH&S immediately.

Do not move or disturb any container if there is any question regarding the presence of peroxides.

Testing for Peroxides

If you are unwilling or unable to test your chemicals for peroxides, then they must be discarded according to the prescribed disposal guidelines on the next page.

Any detected level of peroxide concentration is considered unsafe. If your chemical/compound tests positive for peroxide formers it is considered contaminated and must be disposed of, irrespective of peroxide concentration.

Please use peroxide testing strips to determine peroxide presence. These can be found at VWR.com. Please follow the manufacturer's storage guidelines for these testing strips, which have a limited shelf life.

PRECAUTIONS

Before starting work:

- Ensure that a written experimental protocol including safety information is available.
- Always read the Safety Data Sheet (SDS) for the specific chemical. Review Sections 2.3 (Hazards not otherwise classified), 7 (Handling & Storage) and 10 (Stability & Reactivity) of the SDS for incompatible chemicals.
- Make sure you are familiar with general University emergency procedures in the EHS Lab Emergency Response Guide.
- Identify the location of the nearest eyewash and shower and verify that they are accessible.
- Visually inspect the container for crystallization prior to opening/handling the container.
- If you are performing a distillation or evaporation it is important to test for peroxides **prior** to performing the experiments. Also, it is important to never distill to dryness.
- Most commonly sold peroxide formers come with inhibiting chemicals and are shipped under nitrogen or another inert gas within their supplied containers. Verify that the product that you are ordering contains both of these safety precautions unless the stock chemical that you need for your experiments cannot contain an inhibitor.

During work:

- When removing the peroxide-former from the septum cap, make sure that the syringe is completely depressed as to not introduce any air into the bottle, which could promote peroxide formation.
- Use only the minimum quantity required.
- Conduct all procedures inside a fume hood or behind a protective shield.
- **Do Not** return unused peroxide-forming chemicals to the stock container.
- As a reminder: Do not use volatile solvents that contain peroxides.
- It is important to not use any metal-containing utensils for weighing or working with peroxide formers.

Disposal:

- All peroxide-forming waste must go out as a hazardous waste.
- Please refer to the individual chemical hazard information sources or guidelines for specific disposal guidance or contact EH&S.
- Follow all safe handling storage requirements listed in the above section.
- If a container is thought to contain peroxides, contact EH&S immediately. **Do not** place the material in the satellite accumulation area (SAA) for pick up and disposal.
- Be sure to leave the peroxide-former tag on the bottle with recent testing dates when disposing.
- Never pour peroxides down the drain.

EMERGENCY PROCEDURES

Spill Response

OUTSIDE FUME HOOD OR VENTILATED ENCLOSURE

- Alert others evacuate to a safe distance and prevent entry into the lab.
- Contact the University Operations Center at (617) 49**5-5560** [HMS/HSDM (617) 43**2-1901**]
- Remain in a safe location until EH&S or other response personnel arrive.

INSIDE FUME HOOD OR VENTILATED ENCLOSURE (< 500 ml)

- If trained and confident, you may assist in the clean-up effort of small amounts, wearing PPE described above and using appropriate spill supplies.
    - Absorb spilled peroxides on vermiculite as soon as possible.
    - Let sit until completely absorbed, then sweep up material with a broom and dustpan located in the chemical spill kit.
    - Collect debris in appropriate container and move to your Satellite Accumulation Area. Label with appropriately completed hazardous waste tag and request a waste pickup.
- If not trained, close the fume hood sash and await support.
- Contact the University Operations Center at (617) 49**5-5560** [HMS/HSDM (617) 43**2-1901**] if you need support or technical assistance.

SOLID PEROXIDE-FORMING CHEMICALS

- Contact EH&S immediately
- Evacuate the lab
- Contact the University Operations Center at (617) 49**5-5560** [HMS/HSDM (617) 432-1901]

REMINDERS:

1. Review this entire guidance document prior to starting work with any peroxide forming chemicals
2. Evaluate the potential hazards that could arise from use of peroxide formers, ensure that you and anyone else working on the procedure understand the safe processes to follow, is using the proper PPE, and is familiar with area emergency equipment and procedures.
3. Never work alone while handling possible peroxide forming chemicals

4. Ensure that peroxide forming chemicals are stored and labeled properly with the Harvard peroxide former tag (see Appendix B), to track the date the material was received and will expire.
5. Inspect peroxide formers for visual signs of crystallization prior to handling, Test with an appropriate test strip prior to starting work.
6. Notify Harvard EH&S if material tests positive so that EH&S can arrange for safe disposal of the chemical.
7. Properly collect any chemical waste following chemical waste collection and labeling procedures.

REFERENCES

1. Prudent Practices in the Laboratory, National Research Council, Updated Version (2011) https://www.nap.edu/catalog/12654/prudent-practices-in-the-laboratory-handling-and-management-of-chemical
2. Peroxides and Peroxide Forming Compounds, Donald E. Clark, Ph.D., FAIC, BSP – Chemical and Biological Safety Officer Texas A&M University 2000
3. Recognition and Handling of Peroxidizable Compounds, National Safety Council Data Sheet I-655 Rev. 87
4. Review of Safety Guidelines for Peroxidizable Organic Chemicals, Richard J. Kelly, Chemical Health & Safety, September/October 1996
5. Harvard Department of Chemistry and Chemical Biology - Chemical Hygiene Plan – January 2012
6. Weill Cornell Medicine – EHS – Peroxide-Forming Chemicals https://ehs.weill.cornell.edu/sites/default/files/peroxide_formers.pdf
7. Chemicals That Form Peroxides: Handling and Storage – Ohio State University Department of Chemistry and Biochemistry https://chemistry.osu.edu/sites/chemistry.osu.edu/files/Peroxide%20Forming%20Chemicals%20Handling%20and%20Storage.pdf
8. Chemical Hygiene Plan (Chapter 6) - University of Nevada, Reno https://www.unr.edu/ehs/policies-manuals/chemical-hygiene-plan/chapter-6

Appendix A

These lists are not all-inclusive – these are some of the most common peroxide formers of these classes – if you have questions contact EH&S.

Class A Peroxide Formers – Severe Peroxide Hazard

Butadiene (liquid monomer) (106-99-0)	Divinyl acetylene (821-08-9)	Tetrafluoroethylene (liquid monomer) (116-14-3)
Chloroprene [or Chlorobutadiene] (liquid monomer) (126-99-8)	Isopropyl ether (108-20-3)	Vinylidene chloride (75-35-4)

Note: Potassium metal, Potassium amide & Sodium amide [or Sodamide] are also on this list. These peroxide formers are solid chemicals and cannot be tested with a peroxide testing strip so they must be stored appropriately (away from light) and monitored/checked with the required testing frequency. Please refer to the storage requirements in this document for guidance.

Class B Peroxide Formers – Significant Hazards upon Concentration (e.g., Evaporation or Distillation)

Acetal (105-57-7)	Cumene [or Isopropylbenzene] (98-82-8)	Diacetylene [1,3-Butadiyne] (460-12-8)	Furan (110-00-9)	4-Penten-1-ol (821-09-0)
Acetaldehyde (75-07-0)	Cyclohexanol (108-93-0)	Diethyl ether (60-29-7)	Methyl acetylene (74-99-7)	1-Phenylethanol (98-85-1)
Benzyl alcohol (100-51-6)	2-Cyclohexen-1-ol (822-67-3)	1,3-Dioxane (505-22-6)	Methylcyclopentane (96-37-7)	2-Phenylethanol (60-12-8)

Benzaldehyde (100-52-7)	Cyclohexene (110-83-8)	1,4-Dioxane (123-91-1)	MIBK (108-10-1)	2-Propanol [or Isopropanol] (67-63-0)
2-Butanol (78-92-2)	Decahydronaphthalene (91-17-8)	Ethylene glycol dimethyl ether [or Glyme] (110-71-4)	2-Pentanol (6032-29-7)	Tetrahydrofuran (109-99-9)

Class C Peroxide Formers – Significant Hazards from Autopolymerization

Acrylic acid (79-10-7)	Chloroprene (126-99-8)	Styrene (100-42-5)	Vinyl acetylene (689-97-4)	Vinylidene chloride (75-35-4)
Acrylonitrile (107-13-1)	Chlorotrifluoroethylene (79-38-9)	Tetrafluoroethylene (116-14-3)	Vinyl chloride (75-01-4)	
Butadiene (gas) (106-99-0)	Methyl methacrylate (80-62-6)	Vinyl acetate (108-05-4)	2-Vinyl pyridine (100-69-6) 3-Vinyl pyridine (1337-81-1) 4-Vinyl pyridine (100-43-6)	

Note: Chemical Abstract Service (CAS) numbers provided after chemical name [or common synonym] above

Appendix B

The following peroxide former tag must be filled out and attached to all containers of peroxide-forming chemicals.

Please contact EHS to request these labels.

PEROXIDE FORMER

RECEIVED: _____/_____/_____ month/day/year

OPENED: _____/_____/_____

EXPIRATION: _____/_____/_____ (date to dispose)

DATE TESTED	PEROXIDE CONCENTRATION

NOTE: If you are unwilling or unable to test the chemical for peroxides, then it must be disposed as hazardous waste.

ehs.harvard.edu/node/7689

Check off Applicable Class/State and Follow Storage Guidelines Below

Peroxide Former	Once Opened, Keep No Longer Than:
☐ Class A	**3 Months** or manufacturer's expiration date if no peroxides detected when: ☐ **Liquid** tested every 3 months ☐ **Solid** checked visually every 3 months
☐ Class B or C	**6 Months** or manufacturer's expiration date if tested every 3 months & no peroxides detected