



# SAFETY OF SELF-BALANCING SCOOTERS

AND UL 2272



## Overview

Self-balancing scooters (more commonly known as hoverboards) were one of the hottest selling items of the 2015 U.S. holiday shopping season.<sup>1</sup> But initial consumer enthusiasm evaporated in the wake of widespread reports of fires traced to the scooters' rechargeable lithium-ion batteries. The U.S. Consumer Product Safety Commission (CPSC) reports that, during the period from December 1, 2015 through February 17, 2016, the agency received notices from consumers of 52 separate fires directly related to self-balancing scooters, resulting in more than \$2 million (USD) in property damage.<sup>2</sup>

In response to the heightened risk associated with rechargeable battery systems used in self-balancing scooters, UL published UL 2272, *Outline of Investigation for Electrical Systems for Self-Balancing Scooters*. In contrast to standards that are applicable only to lithium-ion batteries themselves, UL 2272 takes a system-wide approach to the electrical safety of self-balancing scooters that incorporate drive systems using rechargeable lithium-ion batteries. Specifically, the standard details requirements related to the construction of scooters, and prescribes electrical, mechanical, and environmental testing to electrical safety.

This UL white paper discusses the fire-related safety issues associated with self-balancing scooters and presents a summary of the requirements found in UL 2272. Beginning with an overview of lithium-ion battery safety, the paper reviews the recent incidence of scooter fires as well as actions taken by some manufacturers and retailers to reduce consumer risks. The white paper then provides details on the requirements of UL 2272, and concludes with compliance guidelines for manufacturers and retailers.



## Background on Lithium-Ion Batteries

Over the past 25 years, rechargeable (also known as secondary) lithium-ion battery technologies have evolved, providing increasingly greater energy density and longer cycle life. Commercial lithium-ion batteries now power a wide range of consumer electrical and electronic devices, medical devices, industrial equipment and electric vehicles. The worldwide market for lithium batteries is projected to exceed \$13 billion (USD) in annual sales by 2020, with the market for rechargeable lithium-ion batteries representing nearly 90 percent of those sales (\$11.9 billion).<sup>3</sup>

However, as the use of lithium batteries grows globally, and with large numbers of batteries powering a wide range of products in a variety of usage environments, there have been reported incidents raising safety concerns. While the overall rate of failures associated with the use of lithium-ion batteries is low, the consequences of failure can be quite severe. Several publicized examples involving consumer products like laptop computers and electronic toys have led to numerous product safety recalls by manufacturers, the CPSC and others. Some of these cases have been linked to overheating of lithium-ion batteries, leading to fire or explosion.

A lithium-ion battery is an energy storage device in which lithium ions move through an electrolyte from the negative electrode (the “anode”) to the positive electrode (the “cathode”) during battery discharge and from the positive electrode to the negative electrode during charging. Electrochemically active materials in lithium-ion batteries typically include a lithium metal oxide for the cathode, and a lithiated carbon for the anode. The electrolytes are typically a liquid in most commercial designs, but some are a gel polymer or ceramic. For most lithium ion batteries, a thin (on the order of microns) micro-porous film called a separator provides electrical isolation between the cathode and anode, while still allowing for ionic conductivity.

Variations on the basic lithium chemistry exist to address various performance and safety issues. In general, however, the safety of lithium-ion cells is chiefly dependent on battery design and manufacturing quality control. First, the design of the battery cell needs to be sufficiently robust to withstand the anticipated use conditions of the device being powered. Second, manufacturing processes need to be tightly controlled to ensure that contaminants and other impurities from material sourcing and production processes do not make their way into the final product.



## Safety Issues with Self-Balancing Scooters

While fictional hoverboards date back to the 1989 movie *Back to the Future, Part II*, interest in real self-balancing scooters took off dramatically in mid-2015, fostered in part by social media posts from celebrities and athletes.<sup>4</sup> Despite some concerns about patent infringement,<sup>5</sup> demand for self-balancing scooters quickly peaked, with eBay reporting orders for nearly 7500 hoverboards on Cyber Monday (the Monday after the U.S. Thanksgiving holiday) alone.<sup>6</sup>

But just as quickly, numerous reports surfaced of incidents and injuries related to the operation of self-balancing scooters, primarily connected with falls and collisions involving moving scooters. To cite just one example, research by athenahealth found that, during the second half of 2015, 144 patients within its U.S. healthcare partner network of 55 million people included the word ‘hoverboard’ as a cause of a present illness.<sup>7</sup> Headaches, wrist fractures and concussions were among the most common injury and pain-related diagnoses identified with these incidents.

Of even greater concern during this period was the number of fires connected with self-balancing scooters. In some cases, the scooters caught fire or exploded while being charged. In other incidents, some scooters caught fire while in use, endangering riders and the general public. By mid-December 2015, the CPSC had received reports of at least 16 fires in 12 states related to self-balancing scooters. By mid-February 2016, the number of scooter-related fires reported to the CPSC had grown to 52. These statistics included a home in Nashville, TN valued at \$1 million that was completely destroyed by a scooter-related fire.<sup>8</sup>

The safety issues with self-balancing scooters have been exacerbated by the apparent use or misuse of safety marks that could mislead consumers regarding any safety testing that may have taken place. According to the CPSC, safety marks appearing on some scooters or product packaging may reflect testing and certification of individual components but not the entire electrical system – an important distinction. In certain instances, safety marks are actually counterfeit, leading consumers to believe that safety testing has been performed when it has not.<sup>9</sup>





### Recent Actions to Mitigate Safety Risks

Efforts to address the potential dangers associated with self-balancing scooters were swift and extensive. A number of sellers, including Amazon, Overstock and Target, removed self-balancing scooters from their websites and retail store shelves. Some retailers even offered refunds to customers who previously purchased scooters.

In addition, more than 60 separate airlines, including all major U.S. carriers, banned self-balancing scooters on their flights, both as carry-on and as checked items.<sup>10</sup> Complete or partial bans against scooters were also put in place at more than 20 colleges and universities across the U.S.<sup>11</sup> And, New York City's Metropolitan Transit Authority (MTA) banned scooters from all forms of public transportation in the city due to concerns about the risk of fire in enclosed spaces (i.e., subway trains and buses).<sup>12</sup>

Most important, the CPSC issued a Notice to manufacturers, importers and retailers of self-balancing scooters, urging them to comply with "currently applicable voluntary safety standards, including all referenced standards and requirements contained in UL 2272." In its Notice of February 18, 2016, the CPSC said that it "considers self-balancing scooters that do not meet (UL 2272) to be defective," and that the Agency may seek a recall of such products, or detain or seize non-compliant products at import.<sup>13</sup>

On July 18, 2016, there was a press release from CPSC Chairman Elliot F. Kaye announcing a CPSC recall of hoverboards that involved 10 different companies due to fire hazard concerns. There were over 500,000 scooters affected by this recall. Companies were either forced to refund, repair or replace the affected scooters with ones that were compliant to UL 2272.

### UL 2272—A System-Level Approach to Battery Safety in Self-Balancing Scooters

Safety testing of individual power system components used in self-balancing scooters, such as lithium-ion battery cells and battery packs, chargers and power supplies, has been available for several years. However, individual components that have been tested for safety may not perform as expected when combined with other components in a given application. This is especially true in cases of electrical systems, where individual components must be carefully matched to support the complete range of anticipated use conditions of the end product.

To address this gap, UL has published UL 2272, *Outline of Investigation for Electrical Systems for Self-Balancing Scooters*. Rather than assessing the safety of individual components, UL 2272 approaches the evaluation of self-balancing scooters from a system-level perspective, examining the entire electrical system from several vantage points to identify all potential electrical and fire-hazard safety risks. This system-level approach better anticipates the full range of safety conditions, allowing manufacturers to address them prior to their products reaching the market.

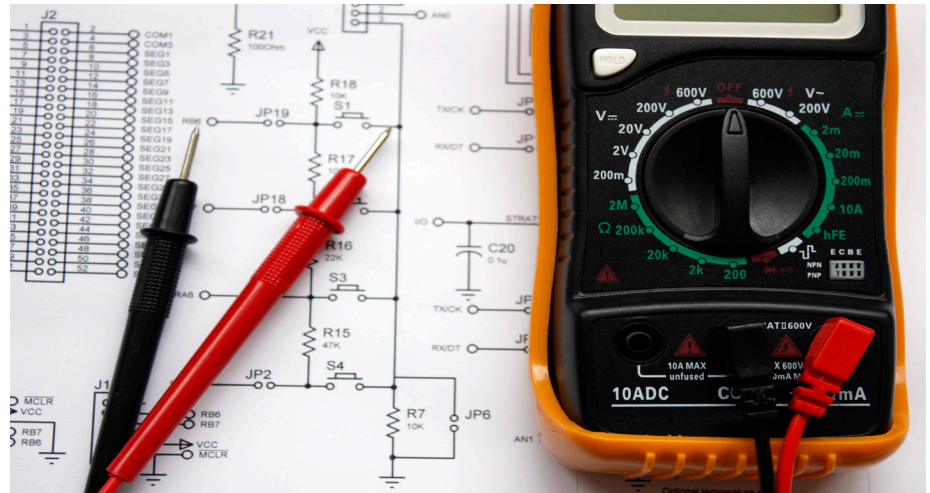
In general, testing under UL 2272 is conducted on samples of entire self-balancing electrical systems. Under most individual tests, sample systems are also subject to a charge/discharge cycle if the sample is operational after a given test has been completed. And compliance requirements are consistent, easing the assessment process.

Specific testing and other requirements contained in UL 2272 and applicable to self-balancing scooters are described in the following sections.

## Electrical Testing

Self-balancing scooters are subject to a number of different electrical tests. A number of these tests, including the overcharge, short circuit, overdischarge and imbalanced charging tests, consider single fault conditions in the protection circuitry that have not been previously evaluated for functionality or reliability. Specific electrical tests include:

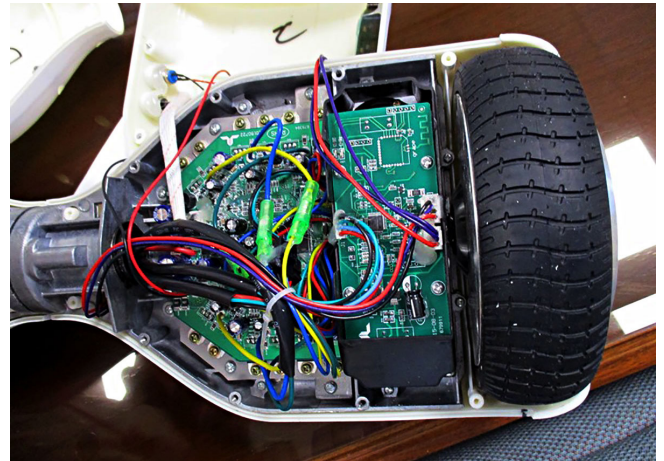
- **Overcharge**—The overcharge test evaluates the ability of a sample self-balancing scooter (the device under test, or DUT) to withstand an overcharge condition under a single fault condition without causing an explosion, fire or rupture of the battery. The voltage limits for charging are to be maintained.
- **Short circuit**—The short circuit test evaluates the ability of the scooter’s battery circuit to withstand a short circuit condition under a single fault condition in the discharge protection circuit, without causing an explosion, fire or rupture of the battery.
- **Overdischarge**—This test evaluates a DUT’s ability to withstand an overdischarge under a single fault condition in the discharge protection circuitry, without causing an explosion, fire or rupture of the battery. Voltages on cells are not to exceed their specified end of discharge condition.
- **Temperature**—Temperature testing determines whether or not component cells in a given sample are maintained within their specific operating current, voltage and temperature limits during maximum charging and discharging conditions. Temperature testing also determines whether temperature sensitive safety critical components and temperature sensitive materials remain within their temperature ratings. This test considers specified ambient temperatures for charging and operation when determining compliance.
- **Imbalance charging**—This test is conducted to determine whether a DUT with battery cells connected in series is able to maintain those cells within their specific operating parameters without causing an explosion, fire or rupture of the battery, even when a single cell becomes unbalanced.
- **Dielectric voltage withstand**—The dielectric voltage withstand test evaluates the electrical insulation including the electrical spacings for any hazardous voltage circuits (if applicable) within the DUT. This test is used to evaluate the electrical insulation after various tests in the standard.
- **Isolation resistance**—The final electrical test, the isolation resistance test, determines whether DUT insulation provides adequate isolation of hazardous voltage circuits from accessible conductive parts. This test may be used as an option to the dielectric voltage withstand test for evaluating the electrical insulation after various tests in the standard.



## Mechanical Testing

Under UL 2272, the assessment of the mechanical safety of self-balancing scooters includes the following tests:

- Vibration—The vibration test determines whether the electrical system of the hoverboard is robust enough to withstand effects of vibration during use without resulting in loose connections or parts that could create a hazardous condition. The test utilizes a random vibration profile.
- Shock—This test determines whether or not the DUT can withstand a mechanical shock, consisting of half-sinusoidal pulses, to which a device may be subject when in use without causing an explosion, fire or rupture of the battery.
- Crush—The crush test is conducted to determine the DUT's ability to withstand an anticipated crushing event due to specified weight limits being exceeded that could occur during use without causing an explosion or fire.
- Drop—This test evaluates whether a hazard is created when a DUT is inadvertently dropped during handling or lifting, and involves dropping the DUT three times from a height of approximately one meter on to a concrete surface.
- Mold stress relief—The mold stress relief test is a type of accelerated aging test that determines whether any shrinkage or distortion on a molded or formed thermoplastic enclosure that occurs due to internal stresses results in the exposure of hazardous parts or the reduction of electrical spacings.
- Strain relief—The final mechanical test actually consists of two strain relief tests, a strain relief pull test and a push-back test, designed to assess non-detachable exposed scooter cords and cables that may be subjected to pulling or pushing during anticipated use.



## Environmental Testing

Environmental testing of self-balancing scooters includes water exposure testing and thermal cycling.

- Water exposure testing includes an assessment in accordance with the requirements of IEC 60529, *Degrees of protection provided by enclosures (IP Code)* minimally for IPX4 for exposure to splashing water, as well as a partial immersion test intended to simulate exposure to puddles of water.
- Thermal cycling testing specified in UL 2272 is intended to determine the extent of a scooter's ability to withstand exposure to rapidly changing temperatures (such as when a scooter enters a heated environment after being outdoors) without evidence of damage that could lead to a hazardous event.

## Material and Component Testing

Material testing of self-balancing scooters includes testing for flame resistance of non-metallic materials. All materials used in scooter enclosures must comply with the enclosure requirements detailed in UL 746C, *Standard for Polymeric Materials – Use in Electrical Equipment Evaluations*. In addition, polymeric materials used in enclosures must have a minimum flame rating of V-1 as defined in UL 94, *Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances*. Flammability rating can also be assessed using the 20 mm end product flame test detailed in UL 746C.

There are also tests to evaluate the safety of the scooter motors under conditions of short circuit and overload to determine that there is no potential for overheating that could lead to a fire. The motor tests include an overload test that evaluates a motor's ability to safely withstand an overload condition and a locked rotor test to evaluate a motor's ability to safely withstand a locked rotor condition.

Adhesive labels that are applied to the scooter surface that have not been subjected to prior evaluation must be assessed for their permanence.

## Marking and Instruction Requirements

Finally, under UL 2272, self-balancing scooters must be marked with the manufacturer's name, model or part number, electrical ratings and the date of manufacture. Scooter must also be marked with charging instructions, and all terminal and connection points must be identified and, if applicable, include polarity markings. Scooters with hazardous voltage circuits must display a warning to that effect.

All scooters must also be marked to warn consumers to read the scooter instruction manual to reduce the risk of injury, and be accompanied by instructions for their proper use, including charging, operating, storage and disposal. UL 2272 also specifies instruction requirements for temperature limits, charger and weight limits, and replacement of user replaceable parts such as fuses and lightbulbs. For scooters equipped with removable battery packs intended for removal and charging outside of the scooter, additional instructions addressing the safe handling and charging must also be provided.



## The Future of UL 2272 and Other Scooter Standards

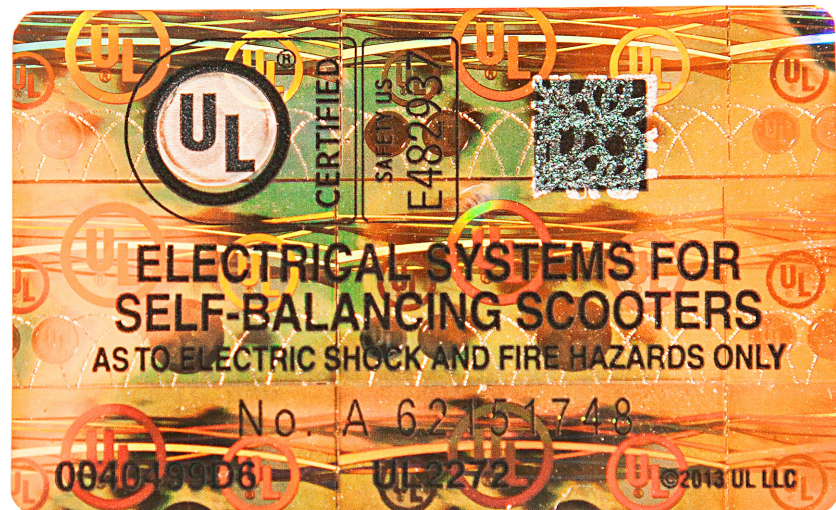
The publication of UL 2272 has been followed by continued research into safety issues related to self-balancing scooters. This research, along with reports based on actual field experience, are likely to serve as the basis for further revisions to UL 2272 intended to improve the mechanical and electrical safety of scooters.

UL 2272 is in the process of being adopted as an American National Standard by the American National Standards Institute (ANSI), as well as a National Standard by the Standards Council of Canada. As a bi-national standard, UL 2272 would define the de facto safety requirements for electrical systems of self-balancing scooters sold in most of the North American market. UL 2272 requirements are also expected to serve as the basis for further national and regional standards development efforts.

### Guidelines for Manufacturers and Retailers

In the meantime, manufacturers of self-balancing scooters are strongly advised to promptly seek UL 2272 testing and certification for their products. The CPSC's stated position regarding hoverboards means that non-conforming self-balancing scooters may be subject to recall, or may be detained or seized by customs and border officials at U.S. ports of entry. Such enforcement actions can have costly consequences for manufacturers, and compromise the integrity of their brand with consumers.

For manufacturers, evidence of UL 2272 certification is also expected to become a procurement requirement for both online sellers and traditional retailers as part of their overall effort to reduce potential product liability exposure. Retailers will likely require manufacturers of self-balancing scooters to supply documentation that supports their claims of product safety testing and certification, and can be expected to verify such claims against the records maintained by independent testing organizations to protect themselves and their customers from products bearing counterfeit safety marks.



UL and other safety testing organizations maintain online certification directories, providing both retailers and consumers with quick access to information about certified products. In addition, self-balancing scooters that have been tested and certified as compliant with the requirements of UL 2272 will bear a specialized holographic version of the UL Mark to help thwart the use of counterfeit safety marks. The holographic mark will enable retailers and consumers alike to visually verify that a self-balancing scooter has been appropriately evaluated and tested to the most rigorous safety requirements.



## Summary and Conclusion

The dramatic increase in electrical safety issues associated with self-balancing scooters has prompted quick action from regulators and retailers, and has also resulted in the development of UL 2272. Rather than evaluating a single component, UL 2272 takes a system-wide approach to the safety of electrical systems used in scooters to reduce the overall risk of fire, explosions and other electrical hazards. This makes testing and certification to UL 2272 essential for manufacturers of self-balancing scooters. For more information about the safety of self-balancing scooters, including UL's efforts to combat counterfeit safety marks, visit [www.ul.com/hoverboards](http://www.ul.com/hoverboards). For information about testing and certification to the requirements of UL 2272, email [HoverboardQuote@ul.com](mailto:HoverboardQuote@ul.com).

- <sup>1</sup> See “Cyber Monday Recap: Top Selling Items on eBay,” December 1, 2015. Web. 20 February 2016.  
<https://www.ebayinc.com/stories/news/cyber-monday-recap-top-selling-items-on-ebay/>
- <sup>2</sup> See letter from Robert J. Howell, acting director of the Office of Compliance and Field Operations, U.S. Consumer Product Safety Commission, to manufacturers, importers and retailers of self-balancing scooters, February 18, 2016. Web. 20 February 2016.  
<http://www.cpsc.gov/Global/Business-and-Manufacturing/Business-Education/SelfbalancingScooterLetter.pdf?epslanguage=en>
- <sup>3</sup> “Lithium Batteries: Markets and Materials,” BCC Research, Report FCB028G, January 2016. Web. 4 March 2016.  
<http://www.bccresearch.com/market-research/fuel-cell-and-battery-technologies/lithium-batteries-materials-report-fcb028g.html>.
- <sup>4</sup> “Hoverboard 101: What you need to know,” USA Today, December 2, 2015. Web. 4 March 2016.  
<http://www.usatoday.com/story/tech/nation-now/2015/12/02/hoverboard-holiday/76621864/>.
- <sup>5</sup> For an excellent summary of the patent battle over hoverboards, see “How ‘Hoverboards’ Epitomize Our Broken Patent System,” Wall Street Journal, December 20, 2015. Web. 4 March 2016.  
<http://www.wsj.com/articles/how-hoverboards-epitomize-our-broken-patent-system-1450674060>
- <sup>6</sup> “Cyber Monday Recap: Top Selling Items on eBay,” see Note #1 above.
- <sup>7</sup> “Roads? Where we’re going, we don’t need roads,” CloudView blog posting, December 15, 2015. Web. 4 March 2016.  
<http://www.athenahealth.com/blog/2015/12/15/roads-where-were-going-we-dont-need-roads>.
- <sup>8</sup> “Tennessee Warns of Hoverboard Dangers After 2 Nashville Home Fires,” Insurance Journal, February 12, 2016. Web. 6 March 2016.  
<http://www.insurancejournal.com/news/southeast/2016/02/12/398555.htm>.
- <sup>9</sup> “Statement of U.S. CPSC Chairman Elliot F. Kaye on the Safety of Hoverboards and the Status of the Investigation,” U.S. Consumer Product Safety Commission, January 20, 2016. Web. 6 March 2016.  
[http://www.cpsc.gov/en/Newsroom/Press-Statements/Statement-from-US-CPSC-Chairman-Elliot-F-Kaye-on-the-Safety-of-Hoverboards-and-the-Status-of-the-Investigation/?utm\\_source=rss&utm\\_medium=rss&utm\\_campaign=Press+Statements](http://www.cpsc.gov/en/Newsroom/Press-Statements/Statement-from-US-CPSC-Chairman-Elliot-F-Kaye-on-the-Safety-of-Hoverboards-and-the-Status-of-the-Investigation/?utm_source=rss&utm_medium=rss&utm_campaign=Press+Statements).
- <sup>10</sup> “Here are all the airlines that have banned hoverboards—and why,” posting on Fusion.net, December 29, 2015. Web. 6 March 2016.  
<http://fusion.net/story/250086/airplane-hoverboard-ban-list/>.
- <sup>11</sup> “Colleges Are Starting To Ban ‘Hoverboards,’” Huffington Post, January 7, 2016. Web. 6 March 2016.  
[http://www.huffingtonpost.com/entry/colleges-hoverboards\\_us\\_568ebd62e4b0a2b6fb6f3390](http://www.huffingtonpost.com/entry/colleges-hoverboards_us_568ebd62e4b0a2b6fb6f3390).
- <sup>12</sup> “Hoverboards are now banned from New York City subways, trains and buses,” posting on The Verge, January 27, 2016. Web. 6 March 2016.  
<http://www.theverge.com/2016/1/27/10842342/nyc-hoverboard-ban-mta-subways-buses>.
- <sup>13</sup> See Note #2 above.