

## Beer Experiment Report: How Does UV Exposure Affect Beer Taste?

Zabby Abbas, Amanda Beck, Matt Dinowitz, Ari Frankel, Coleen Tran, Orion Keifer

### Introduction

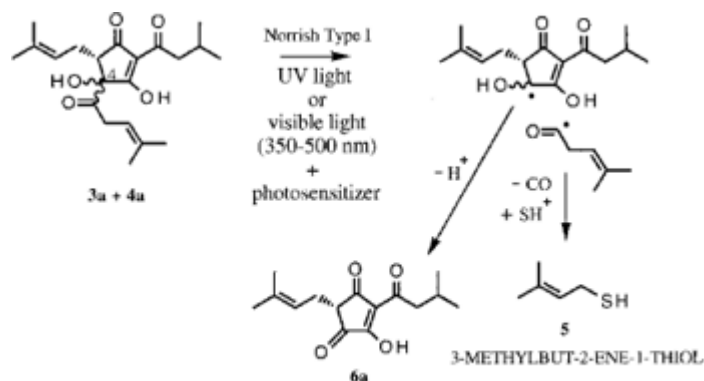
“Skunked” and “light struck” are common names given to beer that has taken on an unpleasant taste and odor after prolonged exposure to sunlight. The term “skunked” comes from the altered beer’s potent odor, which is similar to the odor given off by skunks. *Aleheads* identifies “skunked” flavors and odors as being those associated with cooked vegetables, chopped onions, burnt matches, rotten eggs, sewage/stink bombs, skunks, and cats.<sup>[i]</sup> Skunking can also be associated with a tingling sensation in the nose when sniffing the beer.<sup>[ii]</sup> Sulfuric odors or flavors are not always signs of skunking. They are in fact vital to many varieties of beer. Sulfuric odors and flavors may be imparted into beer from the water used in brewing. Many lagers that were developed in regions with high concentrations of sulfur in the water have a characteristic sulfuric note in their flavor and aroma. Importantly corona light, which was used in this experiment, also has noticeable sulfur notes in its flavor and aroma profile.

Improvements in technology have enabled brewers and interested chemists to understand the underlying chemistry of “skunking.” Among the many sources of flavor in beer are hops, which include  $\alpha$ -acids from the lupulin glands of the female hop cones. During the brewing process these  $\alpha$ -acids are heated and isomerized into iso-  $\alpha$ -acids. Exposure to sunlight can cause the iso- $\alpha$ -acid humulone to break down and form methylbut-2-ene-1-thiol-3.<sup>[iii]</sup> Methylbut-2-ene-1-thiol-3 is the main chemical associated with the odor and flavor of “skunking.” The “thiol” in the name indicates that there is sulphur present. The sulphur is what gives off the offensive odor and taste properties. Figure 1 illustrates the photolytic breakdown of iso- $\alpha$ -acids and the formation of methylbut-2-ene-1-thiol-3. Much research is devoted to understanding this mechanism and identifying other sources of “skunked” flavor.

Methods for preventing “skunking” involve limiting beer’s exposure to UV light. *Beeradvocate.com* recommends storing beer in a dark place. Bottlers often protect beer from UV light by using dark colored glass, mainly brown and green. Cans are more effective at limiting exposure to UV light.<sup>[iv]</sup> An alternative method of protecting beer from “skunking” is wrapping beers in tin foil. This method of protection is deployed in this research project.

This research project is intended to contribute to the body of evidence associating exposure to UV light with “skunking.” Much of the research on this subject is concerned with identifying the mechanism of “skunking.” Many researchers are working to better understand the formation of methylbut-2-ene-1-thiol-3 and to identify other compounds that may be involved with “skunking.” This research project does not aim to explore the chemical mechanism of “skunking.” We examine the impact on taste and odor of a typical degree of “skunking” that an average consumer might expect to encounter drinking Corona lights on the beach. On the Earth’s surface we experience

sunlight at an average wave length of 483 nm<sup>[v]</sup>. In this experiment 40 minutes of exposure to light with wavelength 365 nm was used to induce “skunking” in Corona light. 40 minutes at 365 nm is roughly equivalent to 53 minutes of exposure to sunlight. This research is concerned with whether this impact is perceptible to average beer consumers. If this exposure to UV light does cause “skunking” in beer, then exposing beer to UV lamp light for 40 minutes should induce flavor and aroma changes consistent with “skunking.” Further support for this hypothesis would validate the aforementioned methods for preventing “skunking” and inform further research concerning the prevention of “skunking.” This could lead to insights to improving bottling, packaging and handling practices.



*Scheme 4. Formation of the lightstruck flavour in beer.*

**Figure 1.** The photolytic breakdown of iso-α-acids and the formation of methylbut-2-ene-1-thiol–3.

## Materials and Methods

Participants were all members of the B.R.E.W.E.R.S. class and were of legal drinking age. The study was designed as a class activity and consequently the study is tremendously under-powered limit generalizability. The results are presented solely for a discussion of the chemistry behind UV light’s effect on beer as well as the class’s observations on the effect on taste and smell. We consulted the Emory IRB and determined the study did not require formal approval to proceed.

In order to determine what effects ultraviolet light had on beer, we placed four bottles of Corona Light on a UVP Benchtop UV Transilluminator in a fume hood in an Introductory Biology lab at Emory University. Two bottles were covered with aluminum foil to prevent UV penetration and acted as controls (Figure 2b). Two experimental bottles were left uncovered to completely expose them to UV radiation (Figure 2b). As another control, we also left two bottles in a cooler alongside the Benchtop UV Transilluminator, but these beers were not exposed to the UV light (Figure 2a).

We removed the four bottles after 40 minutes from the UV Transilluminator and placed all of the bottles in the cooler. Based on previous findings, UV rays can affect beer taste after only five minutes of exposure. The UV Transilluminator could only be on for about 40 minutes in order to prevent the light bulb from burning out. Two days later, we chilled the bottles on ice for approximately one hour before serving the samples to participants. Each participant received three samples: (1) unexposed Corona Light left in the cooler, (2) aluminum-covered Corona Light placed on the UV Transilluminator for 40 minutes, and (3) uncovered, exposed Corona Light. Each participant received a survey where they scored their perception of sulfuric aroma, tingling sensation in the nose, sulfuric flavor, and overall enjoyment of the beers on a scale from 1 to 10, with 1 being “not at all” and 10 being “overwhelmingly”. Participants were shown pictures of common foods and items that contained sulfuric flavors and aromas to use as reference as they scored each beer sample. These images were of cooked vegetables, chopped onions, burnt matches, rotten eggs, sewage/stink bombs, a skunk, and a cat. Participants were also instructed on how to properly smell and taste the beer to maintain consistency as much as possible. Lastly, participants marked whether they were male or female on his or her survey in order to determine whether or not gender had an effect on scoring.

**Materials:**

- Six Bottles of Corona Light
- UVP Benchtop UV Transilluminator
- Aluminum foil
- Cooler
- Sampling Cups
- Scoring Sheets for Each Beer Sample

a.



b.



**Figure 2.** (a) Beer 1-Unexposed; (b) Beer 2-Aluminum Covered and Beer 3-Exposed

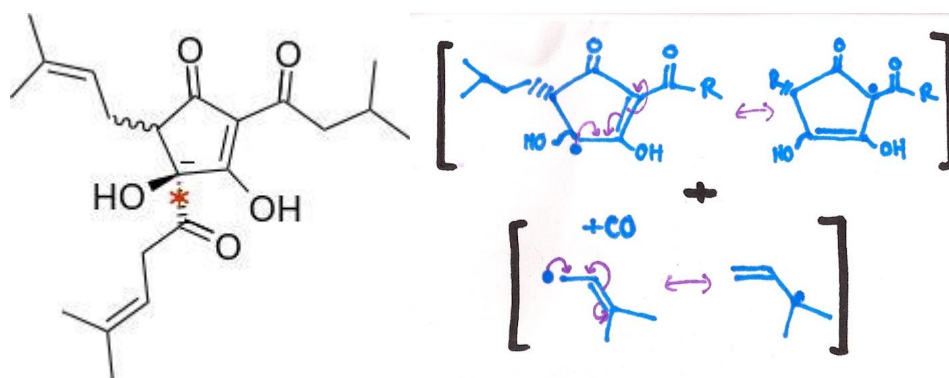
## First Principles

Beer skunking results from beer exposure to UV light. This phenomenon is marked by the breakdown of the alpha acid compound humulone via a photo-degradation process. In order to understand this mechanism, it is essential to outline two fundamental properties- the photon energy of UV light and radical chemical reactions. In this way, we can understand the reaction between UV light and humulone and how the formation of MBT (the skunking product) is initiated.

Ultraviolet light (UV) is a type of electromagnetic radiation that carries energy. It exists in the wavelength range of 10-400 nm and due to Planck's law,  $E=h/\lambda$ , corresponds to a photon energy of 3 to 124 eV. UV light can facilitate chemical reactions because it is comprised of energy that can be absorbed by bonding electrons in particles. The clashing of photon energy from UV light and bonding electrons can result in vibration and breaking of bonds— which leads to a change in a molecules chemical structure. This reaction can only occur if the energy of the UV light is greater than that of the bond strength (energy) within compounds. As the bonds within a compound splits, the formation of a new molecule can take place.

Typically UV light promotes radical-chemical reactions that yield free radicals. Free radicals are compounds that have unpaired valence electrons. Free radicals form when the dissociation of electrons form relatively stable intermediates that will further react into more stable compounds with fully paired electron shells—this is referred to as a free radical reaction. The photodegradation of the alpha-acid isohumulone is one of many naturally occurring processes involving a free-radical mechanism.

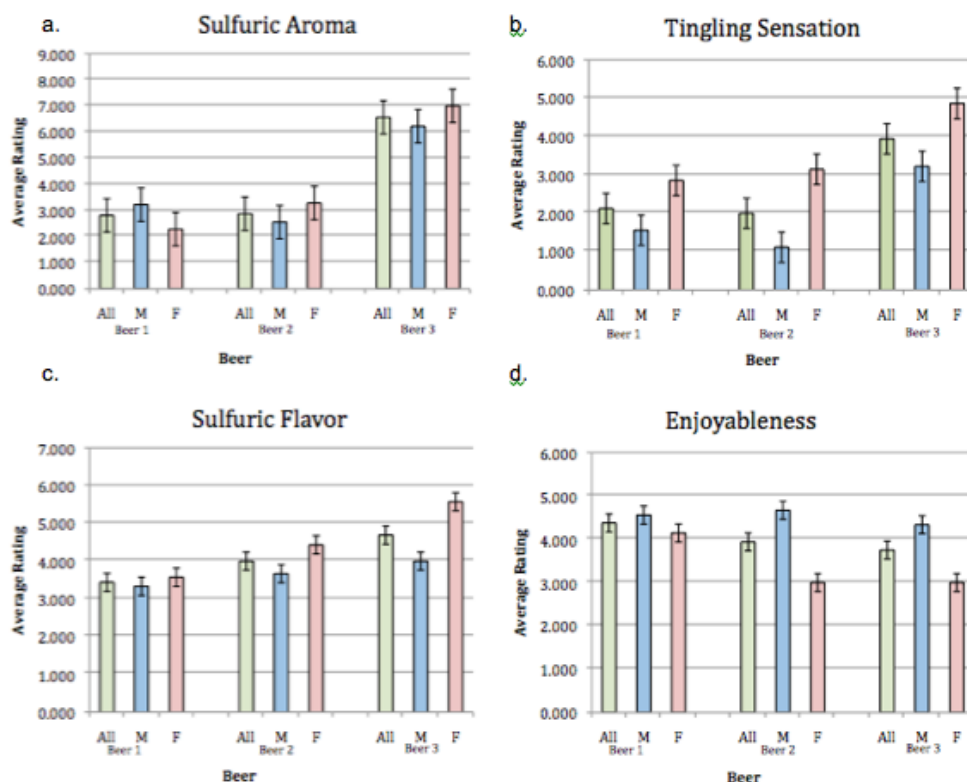
Isohumulone, an isomer of humulone, is commonly produced during the boiling phase of brewing because humulone isomerizes under high temperature conditions. Although isohumulone imparts bitterness to beer, it has the potential to skunk beer if it undergoes a photodegradation process through the presence of UV light. To understand this mechanism it is necessary to outline the chemical structure of isohumulone:



Isohumulone can readily form into radical intermediates under UV light conditions because the chemical structures of the intermediates allow for delocalization and thus stability (shown above). The radical intermediates are 3-methylbut-2-enyl and a five-

membered ring ketyl radical (the position of the bond that undergoes homolytic cleavage is labeled with an asterisk above). It is crucial, however, to consider the competing energies carried by UV light and the bond strengths in isohumulone. Through this, we can understand the progress of the reaction above: The energy in the exocyclic carbon-carbon bond is similar to that of a typical carbon-carbon bond, ranging in bond strength from 3.60 to 3.90 eV. UV light, on the other hand, is photosensitized by riboflavin and strikes isohumulone with 3.11 to 4.14 eV. This provides enough energy to be absorbed by isohumulone, resulting in electron dissociation within the exocyclic carbon-carbon bond. These steps initiate the formation of the final product methylbut-2-ene-1-thiol-3. By referring to figure 1, we can understand why: the thiol group is responsible for the skunking properties of methylbut-2-ene-1-thiol-3. Sulfhydryl (-SH) derives from the sulfur containing amino acid cystine, which can be found in most water sources and malts used in brewing. A sulfhydryl radical forms through photo-oxidation of cysteine. Upon this formation, the sulfhydryl radical reacts with the 3-methylbut-2-enyl radical to produce methylbut-2-ene-1-thiol-3.

## Results



**Figure 3.** Average score of participants' perception of the beers' (a) sulfuric aroma, (b) tingling sensation in the nose, and (c) sulfuric flavor, and (d) the enjoyableness of each beer. Green bars-all participants; blue-males only; pink bars-females only.

To determine the effects of UV light on beer, participants scored Beers 1, 2, and 3 on four criteria associated with beer “skunking”: sulfuric aroma, tingling sensation in the nose, sulfuric taste, and enjoyableness. Each criteria was scored from a 1 to 10 scale, with 1 being “not at all” to 10 being “overwhelmingly” or very much. For example, a score of 10 for enjoyableness would mean the participant very much enjoyed the beer, and a score of 10 for sulfuric aroma corresponds to an overwhelmingly noticeable sulfuric aroma. Average scores for each category were computed for all participants, male participants, and female participants per beer sampled. ANOVAs were performed to compare the mean differences between the three beers. Participants rated sulfuric aromas for Beers 1 and 2 significantly lower than Beer 3 (Fig. 2a). Tingling sensation in the nose also had lower scores for Beers 1 and 2 compared to Beer 3 ( $p < 0.05$ ; Fig. 2b). Post Hoc Tukey analyses from sulfuric aroma and tingling sensation showed significant differences when comparing Beers 1 and 3 (for aroma,  $p = 0.000$ ; for tingling sensation,  $p = 0.042$ ) and Beers 2 and 3 (for aroma,  $p = 0.000$ ; for tingling sensation,  $p = 0.027$ ), but not Beers 1 and 2. Participants did not perceive sulfuric taste among the three beers differently and did not enjoy one beer over the others (Fig. 2c & 2d).

Male and female scores were compared using independent t-tests. To account for possible errors due to multiple comparisons, a Bonferroni-corrected significance level of 0.00417 was calculated. The independent t-tests revealed no statistical significance between gender scoring across all categories and beer samples ( $p > 0.00417$ ), except for tingling sensation in the nose for Beer 2 ( $p = 0.003$ ; Fig. 2b).

## Discussion

Based on the experimental data, we found that participants noticed a difference in sulfuric aromas and tingling sensation in the nose between the three samples—(1) unexposed Corona Light left in the cooler, (2) aluminum-covered Corona Light placed on the UV Transilluminator for 40 minutes, and (3) uncovered, exposed Corona Light. However, participants did not notice a difference in taste and enjoyableness between the three beers. When the difference was quantitatively expressed in the results, it showed that participants smelled an increased sulfuric aroma with skunked beer (3) compared to un-skunked beer (1 & 2). Our results partially supported our hypothesis that if UV light causes “skunking” in beer, then exposing beer to a UV lamp light for forty minutes should induce flavor and aroma changes consistent with “skunking.” While our results supported our hypothesis in terms of aroma, it did not support the idea of changes in tastes.

Biologically, this is consistent with the idea that the human tongue can perceive five different tastes—sweet, salty, sour, bitter, and umami. On the other hand, the human nose contains thousands of distinct olfactory receptors. The sulfuric taste may not have been as distinct as its aroma because of the narrow range of flavors that can be

detected by the human tongue. The many olfactory receptors in the human nose could have caused the participants to be more responsive to the variation in aromas between samples making it easier to target the sulfuric aroma caused by skunking. This may have been the reason why our participants were more sensitive to the sulfuric aromas compared to sulfuric tastes.

Beer that is exposed to UV light can convert iso-alpha-acids into 3-methylbut-2-ene-1-thiol that causes beer to become skunked. Since our research further supports the correlation between UV light and “skunked” flavor in beer, methods in preventing beer from being exposed to UV light should be considered. Many beer companies have already considered some of these methods. Glass bottles tinted brown or amber provide a protective barrier for beer from ultraviolet electromagnetic radiation which can either cause photochemical reactions or advance radical reactions including the breakdown of compounds that make beer skunked. This research helps support the known effect of ultraviolet light, by showing that participants indicate a noticeable sulfuric aroma in beer exposed to UV light for forty minutes.

There were factors that were not taken into consideration when conducting this study. The participant’s responses could have been influenced by personal opinions and preferences that were not accounted for when collecting data. The results did not indicate any significant differences in scoring between genders, which could have been due to the small amount of participants used in the study.

The research conducted in this study provides a platform in which further studies can derive their information to investigate more aspects regarding the impact of UV light on beer aroma and taste. Other studies can examine the correlation of how dark the bottle’s tint must be and yet withstand UV light exposure before becoming “skunked.” Also, one could further investigate how long different shades of bottles can be exposed to UV light before becoming “skunked.” By examining the results of this experiment, a better understanding of the effect of UV light on taste and aroma of beer can evolve and steps to prevent beer from becoming “skunked” can become more prevalent. Future studies could also examine the harm or benefit of 3-methylbut-2-ene-1-thiol to the human body. By determining its health effect, one can direct the importance of exposing beer to UV light to people and beer companies.

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[i] <http://beersensoryscience.wordpress.com/category/aroma-2/>

[ii] <http://beeradvocate.com/articles/527>

[iii] Burns, Colin S., Arne Heyerick, Denis De Keukeleire, and Forbes D. E. Malcom.

"Mechanism for Formation of the Lightstruck Flavor in Beer Revealed by Time-Resolved Electron Paramagnetic Resonance." *Chemistry - A European Journal* 7.21 (2001): 4553-561. *Wiley Online Library*. Web. 24 Apr. 2013.

[iv] <http://beeradvocate.com/articles/527>

[5] Beichner, Robert & Serway, Raymond *Physics for Scientists And Engineers with Modern Physics Fifth Edition*. Orlando, FL: Saunders College Publishing, 2000.