Protection from Lightstrike in Lightweight Glass Beer Bottles

Carried out under the WRAP GlassRite Beer, Cider and Spirits project this study examines if the use of lightweighted bottles will have a significant impact on their ability to prevent lightstruck flavours occurring in beers. Previous work in this area is reviewed, and a practical laboratory study compares the light transmission properties of standard and lightweighted bottles of the three major glass colours. Findings suggest that lightstrike protection is not significantly compromised by lightweighting.
WRAP helps individuals, businesses and local authorities to reduce waste and recycle more, making better use of resources and helping to tackle climate change.

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Executive summary

Since the late 19th Century the impact of light on the flavour of beer has been well studied and documented. It is known that light at wavelengths between 350 and 520 nm cause a reaction in the sulphur containing amino acids to produce a compound known as 3-methyl-2-butene-1-thiol (MBT) which gives beer a flavour that is considered undesirable by most consumers.

Traditionally brewers have relied on amber bottles to filter out the harmful wavelengths of light and protect their product. However brand owners are now using both flint and green bottles, which offer lesser protection, as part of the marketing for certain beers. Additionally, more recently lightweighting initiatives have resulted in bottles with thinner walls. This study has been carried under the auspices of one such lightweighting initiative, the WRAP funded GlassRite Beer, Cider and Spirits project. Its aim was to identify whether or not moving to lightweighted bottle designs critically affects the light protection afforded to the beer by the bottle.

The study took six bottles representing lightweight (LW) and standard weight (SW) designs in amber, green and flint glass. Samples were removed from these bottles and the light transmission through these measured between 300 and 550 nm. The figure below highlights the results of this work.

![Graph showing light transmission through different bottle types](image)

It can be concluded from the results obtained that within experimental error there is very little difference in the protection offered by the two different glass thicknesses (bottle weights) for the amber and flint bottles; apparently marginally improved protection from the lightweight flint bottle, an anomalous result, is believed to be attributable to slight colour variation in the two flint samples. It is highlighted that the excellent protection offered by amber glass is maintained in the lightweight bottle.

For green bottles there is between 15 and 20% less protection offered by the lightweighted bottle, associated with an approximate 40% reduction in glass thickness. For lightweight green bottles the use of specially formulated glasses or light protective coatings may be required to compensate for this effect.

Additional tests gradually reduced the thickness of the glass samples by grinding and polishing to establish the relationship between thickness and light protection. Using this relationship it is possible to predict the level of light protection afforded to beer by green and flint glass, as a linear relationship exists between thickness and light transmission. A similar relationship can be expected for amber glass as predicted by the Beer Lambert Law however this is not evident from the experimental data collected during this project in the range of wavelengths.
tested. Experimental data for amber glass shows it to effectively block 100% of light below 500nm at all thicknesses tested suggesting that reducing thickness of amber glass is unlikely to ever have a detrimental impact on beer flavour.
1.0Introduction

The WRAP funded GlassRite Beer, Cider and Spirits project which ran January 2007 to March 2008 aimed to encourage and support the uptake of lightweight bottles in these sectors, in order to yield the environmental and business benefits available from such a move. Dialogue with organisations in the beer supply chain through this project identified the need to assess any impact on the light protection qualities of glass bottles resulting from lightweighting.

The ability of light to alter the flavour of certain foods and drinks has long been recognised and manufacturers control packaging and storage conditions in order to minimise these effects. Beer is one drink that is known to develop a “light struck” flavour even after brief exposure, with different beers suffering this effect to different extents dependent on the beer ingredients used. Lightstrike is also sometimes known as ‘skunking’ due to the distinctive aroma, and is associated with the chemical compound MBT, 3-methyl-2-butene-1-thiol. To minimise this effect beer has traditionally been bottled in amber glass which reduces the transmission of light at the wavelengths where the chemical reaction occurs. In addition to glass colour, transmission of light through the glass is also affected by thickness of the glass. With efforts to reduce the weight of bottles the thickness of glass used will inevitably decrease with a possible subsequent decrease in the protection provided to the contents by the container.

This study examines light transmission through glass of different colours and thicknesses to determine whether the use of lightweight bottles will decrease light protection afforded, and possibly increase the incidence of light struck flavours in beers. With brewer advice, the study deliberately did not consider lightstrike in specific beers, due to the variable propensity of different beers to suffer light strike.

Existing literature was reviewed to determine the current knowledge in this area. This was supported by an experimental study of the light transmission properties of a range of glass thicknesses (representative of different bottle weights), to empirically examine the affect of lightweighting initiatives on the light protection characteristics of bottles; this affect was examined for amber, green and flint bottles.

A parallel theoretical study carried out under the GlassRite Wine project concentrates on the theoretical aspects of light induced flavour changes in wine, and possible measures such as coatings to enhance bottle light protection; this work is separately reported. Comparatively this study provides experimental data on changes in the level of light protection provided by different weight beer bottles. However, the findings in this report will be beneficial to other food and drinks sectors that are considering the affect of lightweighting on product protection.
2.0 Review of Existing Literature

2.1 Methodology

Using the British Glass Information Service database, published literature on the affect of light on food and drink flavour and more specifically the affect on beer was identified and reviewed.

Additionally, previous work investigating the affect of wall thickness and glass colour on light transmission was reviewed. Alternative methods of reducing light transmission, other than glass thickness alone, such as applying coatings and sleeves to bottle, were briefly reviewed.

Where relevant studies considering flavour taint due to light in other foods and drinks are included in the following discussion. The impact of light on wine has been researched in more detail and is fully discussed and reported under the parallel GlassRite Wine project.

2.2 Findings

2.2.1 What is Light Struck Beer?

Light has been known to alter the flavour of beer for a long time, first being formally documented in 1875. Research into the causes and prevention of these flavour changes has been carried out since the early 20th century. The effect is known by many synonyms including: sunstruck, lightstruck, skunked, sunflavour, lichtgeschmack, sonnengeschmack and gout de lumier. The resulting flavour and aroma have been described as leek, onion, soy, wet wool, Marmite, fresh mint, honeycomb, cooked cabbage, corn nuts, wet dog/wool soy/marmite. All these flavours could be considered to be undesirable, however, some brewers state that the flavours are part of their beers character, and a patent exists for a procedure to artificially “ripen” beer by irradiation to produce this distinctive taste.

At a chemical level it was reported by De Clerck in 1934 and Gray in 1941 that lightstruck flavours coincide with a reduction in redox potential and/or low oxygen levels. Boggis reports that light coloured beers are most likely to exhibit lightstruck flavours whilst Brand offers the contradictory view that darker coloured beers are more susceptible than lighter ones. Several studies have suggested that artificially darkening beer using malt or caramel has reduced the incidence of flavour causing compounds however it is suggested that this is a result of the chemistry of the colouring compounds rather than the colour itself.

There are no known health effects from drinking lightstruck beer other than the nominally unpleasant odour, although Taylor and Poole make specific mention of care being required when handling prepared concentrated MBT (3-methyl-2-butene-1-thiol) the main flavour compound in lightstruck beer.

2.2.2 What Causes Light Struck Flavour in Beer?

The cause of the flavour and odour in lightstruck beer is generally accepted to be caused by the oxidation of lipids, and degradation of thiol (sulphur containing) amino acids in the beer. These substances occur naturally in the beer from its ingredients and as products of the brewing process.

This reaction is catalysed by riboflavin (vitamin B) found naturally in beer, in the presence of light. It is widely accepted that it is mainly light with a wavelength below 520nm, that causes the reaction in beer; Taylor and Poole record that it is light with a wavelength between 400 and 520nm that affects beer flavour. Taylor and Poole report that the extent of any photo-induced reaction is directly proportional to the amount of light absorbed at the wavelengths required for reaction. From this they conclude that lightstruck flavour will occur rapidly in sunlight due to its intensity. However the reactions will also occur more slowly under artificial light.

3 Boggis C., Don’t go into the light, Off Licence News 24 August 2007.
6 De Clerck J., J. Inst Brew. 4; 407, 1934.
7 Gray P., Stone I., and Rothschild H., Wallerstine lab Communications, 4:29, 1941.
because of the lower intensity of light at the relevant wavelengths. It is noted that for this reason care needs to be
given to display conditions at the point of sale. Moll noted that the rate of change is highest (measured by
decline in riboflavin) for the first 2 hours of exposure to light and that after 6 hours the beer was considered
too deteriorated to drink.

The major flavour source in lightstruck beer is recognised as 3-methyl-2-butene-1-thiol (MBT), also known as
prenyl mercaptan, with some contribution from methanethiol and methionol. MBT has been identified as a major
flavour source in roasted coffee and is also produced by skunks hence the use of the term “skunked” to describe
the character of beer that has undergone this reaction. Goldstein et al. identified small quantities of MBT (1-5
ng/l) in beer even before exposure to light and suggests it may be formed during part of the wort boiling process,
whilst Brand concluded that the flavour develops in compounds from the fermentation process not the hopped
wort. Templar et al. reported the flavour threshold in beer for MBT to be 4.4-35ng/l in beer whilst Goldstein
reports this to be 1.25-2.5ng/l and Kapp and Maitland suggest that concentrations as low as 1ng/l make beer
unpalatable.

2.2.3 The Chemistry of Lightstruck Beer
The reaction to produce MBT in beer, catalysed by riboflavin (Vitamin B2) naturally occurring in beer, is generally
thought only to occur when the beer is exposed to light. When the beer is returned to the dark no further
reaction occurs. Amino Acid (iso-alpha-acids, isohumulomnes) in particular methionine found naturally in the beer
breaks down in the presence of light to produce MBT. The reaction is, shown below.

\[
\text{Amino Acid (e.g. Methionine)} \xrightarrow{\text{Light}} \text{Riboflavin} \rightarrow \text{MBT + Ammonia + Carbon Dioxide}
\]

Riboflavin enters an excited state when exposed to light. When it reverts back to its unexcited state its energy is
passed to the amino acids causing their transformation to MBT. Photochemical reactions occur in the visible and
ultraviolet region of the spectrum between 200-800nm, however, it is generally light in the ultraviolet region
(200-400nm) that affects products contained in glass packaging.

2.2.4 The Prevention of Lightstruck Flavours.
Beer manufacturers have developed many ways of preventing or reducing the intensity of lightstruck flavours in
their products. These fall into three main categories:

- protective primary containers: packaging the product directly into a protective container;
- secondary packaging: packaging the primary container in a second layer of protective packaging; or,
- beer composition: modifying the beer itself to reduce its susceptibility to become light struck.

These different methods are considered in turn below.

2.2.4.1 Protective Primary Containers
If protection from light was the only consideration when choosing packaging for beer then it is likely that it would
all be packaged in metal cans rather than bottles as these offer 100% protection from light. However beer sold in
cans has a reputation amongst beer connoisseurs for tasting metallic and being inferior to beers sold in bottles.
For this reason marketers of premium beers favour glass bottles for packaging their products. Traditionally amber
is the colour of choice as this is recognised as offering the best protection, however, many brands see green and
clear bottles as more distinctive.
The British and US Pharmacopeia considered to be the authoritative source for standards relating to medicine regulation\textsuperscript{16,17} defines a light protective container as one that does not transmit more than 10% of light between 290-450nm at 2mm thickness. Several studies have been carried out to determine the light transmission of different colour glasses, details of which are outlined in table 1 (it is not obvious what thicknesses these results relate to, it is assumed that results have been normalised before conversion to a percentage). Pajean et al carried out work to look at light transmission related to colour and thickness of glass, and details of their findings are outlined in table 2. These results suggest that using an amber bottle of 3.5 mm provides total UV protection.

The light protective qualities of a glass bottle (or any material) are governed by the Beer Lambert Law which defines the relationship between the light absorption of a material and its thickness. This law is defined by the equation:

\[ A = e \cdot b \cdot c \]

Where:
- \( A \) is net absorbance;
- \( e \) is the molar absorptivity of the glass;
- \( b \) is the thickness of the glass; and,
- \( c \) is the concentration of the compound or compounds offering light protection in solution i.e. in the glass.

For a given glass composition the values of \( e \) and \( c \) will be constant so the protection offered by the bottle will be directly proportional to the thickness of the glass.

### Table 1: Comparison of different bottle colours and their light transmission.

<table>
<thead>
<tr>
<th>Glass Colour</th>
<th>Percentage light transmission at specified wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Easton\textsuperscript{18} (350-500nm)</td>
</tr>
<tr>
<td>Amber</td>
<td>2%</td>
</tr>
<tr>
<td>Dark green</td>
<td>37%</td>
</tr>
<tr>
<td>Dead leaf</td>
<td>-</td>
</tr>
<tr>
<td>Georgia green</td>
<td>-</td>
</tr>
<tr>
<td>Champagne green</td>
<td>-</td>
</tr>
<tr>
<td>Heineken green</td>
<td>-</td>
</tr>
<tr>
<td>Flint</td>
<td>90%</td>
</tr>
<tr>
<td>Half white</td>
<td>-</td>
</tr>
</tbody>
</table>

### Table 2: Comparison of different bottle colours and thicknesses and their light transmission Pajean et al

<table>
<thead>
<tr>
<th>Glass Colour</th>
<th>Thickness</th>
<th>Percentage light transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amber</td>
<td>3.5mm</td>
<td>0%</td>
</tr>
<tr>
<td>Amber</td>
<td>1.8mm</td>
<td>5%</td>
</tr>
<tr>
<td>UV absorbing green</td>
<td>4.2mm</td>
<td>7%</td>
</tr>
<tr>
<td>Green</td>
<td>3.5mm</td>
<td>46%</td>
</tr>
<tr>
<td>Flint</td>
<td>3.0mm</td>
<td>90%</td>
</tr>
</tbody>
</table>

Several groups of researchers have carried out studies on the composition of glass used to manufacture beverage containers in an effort to increase the light protection provided and several patents exist for such glasses; this subject is reviewed in more detail as part of the GlassRite Wine lightstrike study. Xu et al\textsuperscript{20} looked at the impact of altering the ratio of ceria and titania in glass on its colour and light absorption. They found that a decrease in the ratio of ceria to titania resulted in a more orange colour and shifted the absorption towards longer visible light.

\textsuperscript{16} http://www.usp.org/
\textsuperscript{17} British Pharmacopia August, Appendix XIX B A449, 2007.
\textsuperscript{18} Henfling D., Wine in glass bottles, PWV July/August, p.31-27, 1996.
\textsuperscript{19} Mastroballista G., Effect of light on extra virgin olive oils in different types of glass bottles, Italian Food and Beverage Technology, Vol. 111 March, 1964.
wavelengths, away from the critical protection band. Volf\textsuperscript{21} reports that a 5% ceria addition results in the absorption of UV light up to a wavelength of 352nm, and a 10% addition absorbs up to 362nm for a 1mm thick piece of glass. Iron, chromium, vanadium and manganese also influence the absorption characteristics of glass however these also affect the colour of the glass so have limited commercial use for clear glass.

The physical design of a bottle also has a notable affect on the light protective properties of a bottle. Taylor and Poole\textsuperscript{10} carried out extensive research on two amber bottles of similar thickness that were exhibiting very different protective characteristics. They found that the shoulder area had significant affect on the light transmission through the bottle. Designs with a longer steeper shoulder transmitted less light than a bottle with a shallower shorter shoulder, probably due to a more glancing angle of incidence. They also found that a stippled pattern around the neck improved the protection afforded to content slightly, possibly due to light scattering.

2.2.4.2 Secondary Packaging

Bottled beer is generally delivered to retailers either in cardboard boxes or film (UV protective) wrapped trays both of which effectively protect the content of bottles from the flavour altering wavelengths of light. Problems begin to arise when the trays or boxes are opened and the individual bottles are placed on display and taken to consumers' homes where even under fluorescent lighting, light can have an affect on the flavour of the beer\textsuperscript{9}.

It is possible to apply coatings directly to bottles, which protect the content of a bottle from ultraviolet light. Coatings tend to be classified as either organic or inorganic although work carried out by Mahltig et al.\textsuperscript{22} showed that a combination of organic and inorganic coatings provided the widest range of protection over the wavelengths causing lightstrike problems. They report that both silica and polymer coatings containing benztriazol or phenylacrylate offer a poor level of protection in the 350-400nm region. They found that a TiO$_2$ coating at thickness of 8nm reduces the transmission at 325-400nm to less than 10%. They propose using an organic UV absorber in a UV absorbing titania coating. Several companies offer coating products designed to filter out UV radiation and more detailed analysis of these can be found in the GlassRite wine project report.

2.2.4.3 Beer Composition

Several different studies have looked at methods to alter the composition of the beer to inhibit the development of lightstruck flavours. Gray et al.\textsuperscript{7} showed that copper additions at 2ppm and molecular oxygen reduced the tendency of beer to develop lightstruck flavour in beer. It has also been reported that beer brewed in copper vessels is less prone to exhibiting lightstruck flavours. The addition of zinc salts to the wort has also been reported in other studies\textsuperscript{1} to reduce the incidence of lightstrike and this is a widely adopted practise in the brewing industry although not specifically to reduce light strike. Increasing the dark colour of beer by adding colouring agents has been described by Templar et al\textsuperscript{1} to reduce the formation of lightstruck flavours. Their review also details several inorganic compounds, which could reduce the incidence of lightstrike, however these either have a detrimental affect on flavour or make the beer unsafe to drink. It is reported that red wine is less susceptible to light due to its higher tannin levels, however, this is likely to have undesirable results if added to beer\textsuperscript{2}.

Some brewers including the Miller Brewing Company use modified hop extracts called tetra-hop instead of using hop flowers to bitter their beers. These contain isomerised alpha-acids (amino acids) with a modified molecular structure, and are unaffected by exposure to light. The extract is reported to have added benefits by greatly increasing the foam retention of a beer, however it also alters the flavour of beer and increases the cost of the brewing process\textsuperscript{23}.

A controversial alternative view found on many beer related internet discussion sites is that many brewers particularly those brewed in Mexico disguise the lightstruck flavour of their beers by marketing their beers to be drunk with a slice of lime in the neck of the bottle to “disguise” the flavour\textsuperscript{24,25,26}.

\textsuperscript{23} http://www.evansale.com/skunked_beer.html.
\textsuperscript{25} http://www.bellaonline.com/articles/art15596.asp.
\textsuperscript{26} http://beeradvocate.com/articles/272.
2.2.5 Measuring the Light Protection Offered by Beer Containers.

The protection offered to beer by containers can be measured in several ways, either by measuring changes in the beer itself, using a substitute chemical mix to represent the beer or by measuring the transmission of light through the container.

Goldstein et al.\textsuperscript{12} extracted the MBT from beer by an analytical method that had been exposed to light. The quantity of MBT was then measured by gas chromatography using flame ionisation detection mass spectroscopy, a flame photometric detector and sulphur chemiluminescence methods of analysis. They conclude that while it is possible to measure MBT in this way, due to the low levels of detection required an experienced and competent operator is necessary and great care must be taken to avoid contamination.

Taylor and Poole\textsuperscript{10} simulated the reaction of beer in light using a solution of hexamethyl triamino triphrenylmethane in acetone. This solution changes colour when exposed to light in direct proportion to the amount of radiation received, and this can be measured spectrophotometrically. They also measured the pressure change caused by the breakdown of hydrogen peroxide in bottles exposed to light as a gauge of light transmission.

Moll\textsuperscript{11} used the reduction of riboflavin concentration as a measure of increasing light struck flavour in beer over time. Other studies have used the various methods to measure changes in the redox of beers as a measure of the light struck flavour\textsuperscript{6,7}.

Several papers exist detailing methods of measuring the transmission characteristics of containers and glass in particular. The relationship between light transmission at specified wavelengths and the reaction with beer to produce lightstruck flavours is well established enabling the protective qualities of different containers to be compared relatively simply without recourse to sophisticated instrumental or wet chemical techniques. Taylor and Poole\textsuperscript{10} use a method involving the removal of the bottom of the bottle and a table with a hole cut in it, into which the bottle sits. A light meter is placed below the table and the bottle is illuminated from above by a lamp and appropriate filter. In a different approach, the transmission of glass slides of different thicknesses and compositions can be measured using a spectrophotometer as detailed in the work of Xu et al\textsuperscript{20}.
3.0 Experimental Study

Whilst the review of literature has identified methodologies capable of measuring the impact of light on beer chemically, the literature identifies the transmission of light as the principal cause of lightstruck flavour. It therefore follows that by measuring the differences in light transmission between lightweighted and none lightweighted bottles it is possible to infer the effect on flavour.

For this study we took a range of lightweighted and non lightweighted bottles and measured the transmission of light at the wavelengths identified as impacting beer flavour in order to identify any detrimental affect caused by lightweight bottle design. Glass samples of different colours and thickness were prepared in order to determine the relationship between light transmission and glass thickness.

3.1 Methodology

3.1.1 Selection of Samples

Six bottles were chosen to represent the range of weights and colours available in lightweight and standard weight (non lightweight) traditional beer and cider bottles (light strike is not reported to affect cider, but these bottles represented the desired weight range). In Table 3, bottles A-C represent currently available and standard weight bottles whilst D-F are lightweighted bottles. The glass thickness at various points around the bottle was measured using a Hall Effect Thickness Gauge (Magna-Mike 8500) to identify the indicative range of glass thicknesses currently on the market. These are shown graphically in figure 1.

Table 3: Details of the bottles selected for use in the practical study.

<table>
<thead>
<tr>
<th>Bottle</th>
<th>Colour</th>
<th>Weight g</th>
<th>Volume ml</th>
<th>Shoulder</th>
<th>Sidewall</th>
<th>Heel</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Flint</td>
<td>402.8</td>
<td>500</td>
<td>1.99</td>
<td>2.20*</td>
<td>2.41</td>
<td>3.97</td>
</tr>
<tr>
<td>B</td>
<td>Amber</td>
<td>433.2</td>
<td>568</td>
<td>2.96</td>
<td>3.05</td>
<td>2.24</td>
<td>5.00</td>
</tr>
<tr>
<td>C</td>
<td>Green</td>
<td>469.1</td>
<td>500</td>
<td>2.45</td>
<td>3.27</td>
<td>2.58</td>
<td>5.04</td>
</tr>
<tr>
<td>D</td>
<td>Flint</td>
<td>323.3</td>
<td>550</td>
<td>2.15</td>
<td>2.11</td>
<td>3.32</td>
<td>5.61</td>
</tr>
<tr>
<td>E</td>
<td>Amber</td>
<td>301.8</td>
<td>500</td>
<td>1.66</td>
<td>2.10</td>
<td>2.02</td>
<td>4.28</td>
</tr>
<tr>
<td>F</td>
<td>Green</td>
<td>281.7</td>
<td>500</td>
<td>1.64</td>
<td>1.90</td>
<td>2.40</td>
<td>3.46</td>
</tr>
</tbody>
</table>

*A second sample of this design of bottle was measured at 4.10 mm.

Figure 1: Glass thickness at different points of bottles of selected standard and light-weighted bottles in mm.
3.1.2 Light Transmission of Samples
Sidewall samples were cut from bottles of the selected brands and ground and polished to produce slides of 8mm width for analysis in the UV spectrophotometer. The light transmission curves of the samples were established between wavelengths of 300-550 nm, this being the region of the spectrum highlighted by the literature review as most critical for triggering the lightstrike reaction. This assessment was carried out using a standard GTS procedure for measuring light transmission\(^{28}\). The sample thicknesses were measured and this information is recorded in table 4 along with each sample's dominant colour wavelength\(^{29}\).

3.1.3 Measuring the Relationship between Glass Thickness and Light Transmission
Samples of green, amber and flint glass were progressively ground down to reduce their thickness. These samples were then polished to give a smooth surface, similar to the original surface finish. At each thickness the transmission curve was measured using the same method as in section 3.1.2 above.

3.2 Results
The characteristics of the glass samples used to determine UV light transmission curves are detailed in table 4. Differences in thickness between the prepared samples (table 4) and the indicative design measurements in table 3 are due to glass distribution variations within individual bottles and also, as described in 3.1.2 above, the extraction of samples from different bottles, but of the same brand and design; such variations are evident from the weight distribution from weighing several bottles of nominally the same design, and visually from viewing glass distribution in bottle cross sections. The dominant colour wavelength denotes differences in colour tint.

The glass thickness in the lightweight samples is 45%, 42% and 41% thinner than the conventional containers for flint, amber and green glass examples respectively.

<table>
<thead>
<tr>
<th>Bottle</th>
<th>Thickness mm</th>
<th>Colour</th>
<th>Dominant Colour Wavelength nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.41</td>
<td>Flint</td>
<td>486.21</td>
</tr>
<tr>
<td>B</td>
<td>4.53</td>
<td>Amber</td>
<td>488.27</td>
</tr>
<tr>
<td>C</td>
<td>4.55</td>
<td>Green</td>
<td>520.10</td>
</tr>
<tr>
<td>D</td>
<td>2.42</td>
<td>Flint</td>
<td>487.00</td>
</tr>
<tr>
<td>E</td>
<td>2.63</td>
<td>Amber</td>
<td>529.23</td>
</tr>
<tr>
<td>F</td>
<td>2.41</td>
<td>Green</td>
<td>518.71</td>
</tr>
</tbody>
</table>

The percentage transmission curve of each sample was measured using the UV spectrophotometer, as shown in figure 2; SW represents the standard weight, whereas LW represents the lightweighted container.

Experimentally, the different colours of glass exhibit the behaviour identified in the literature where in transmission is greatest in flint glass, then green, with amber blocking the most light.

Both amber samples can be seen to effectively block the transmission of light in the critical wavelengths. Even in the lightweighted sample which shows a slight deterioration in protection, all light is blocked to 460nm and transmission is only 5% at 520 nm, compared to approximately 2% for the standard sample.

Comparatively the green samples, allow the transmission of a considerably greater level of light for both samples, the lightweighted had approximately 20% greater transmission at both 460nm and 520nm. The drop in transmission exhibited by the green samples at 384 nm and 450 nm are due to the absorption by iron and chromium respectively, these elements being added to the glass batch recipe to produce the green colour.

Relative to amber glass, a more notable increase in transmission is notable in the lightweight green sample, with an increase of 15-20% associated with the ~40% reduction in glass thickness.

\(^{28}\) GTS quality procedure 12 on the Camspec M350 Spectrophotometer.
\(^{29}\) The CIE Lab colour value, also often referred to as ‘colour coordinates’, is a technical measurement of colour, rather than the subjective visual assessment by a human observer. This value can be used to calculate a characteristic dominant colour wavelength for a given glass composition.
Both flint samples allow transmission of 80-90% of light in the critical range, with little difference between the two samples. The apparent anomaly in which the thinner sample marginally blocks more transmission than the thicker sample is believed to be associated with marginal glass chemistry and/or colour differences between the samples. However the dominant wavelengths of each are very similar. It is also possible that the anomaly is simply an experimental artefact caused by the preparation of the samples, for example the presence of slight curvature in one of the samples. In reality this is somewhat academic as from the results it is apparent that both flint samples provide little protection against light above 320 nm.

In order to determine the impacts of further reductions in thickness that might occur as a result of lightweighting, samples of glass were further progressively reduced in thickness by grinding and then polishing and the light transmission through each was measured. The results of this analysis (for 5 glass thicknesses between approximately 1.8 and 4.5mm) were plotted on the graphs shown in figure 3 and a simple linear regression carried out on the data in order to establish the relationship between thickness and light transmission.

The results of this analysis show that for flint and green glass a trend line with an $r^2$ value of greater than 0.99 can be fitted to the data for average wavelength suggesting that it is possible to calculate the indicative light protection offered by glass of a known thickness using the equation for the line with a high level of confidence. These results are consistent with the Beer Lambert Law wherein the thinner lightweight bottles have a higher percentage transmission i.e. they allow more light to pass through at a given wavelength, in this case between 350 and 550nm.

The amber glass samples had a transmission just below 100% at 500nm and as such the trend line for this graph does not fit the data well as the data does not represent a straight line across the measured range. It would be possible to produce a better fit for amber if the range of wavelengths measured was extended, however, for the purpose of this study this is not necessary as it can be assumed that any practical thickness of amber glass will provide sufficient protection to the beer from the wavelengths affecting flavour.

**Figure 2: Light transmission curves for selected bottle side walls for standard weight (SW) and lightweighted (LW) bottles.**
Figure 3: Light transmission at selected wavelengths for glasses of different colours and thicknesses.
Green

% transmission

Glass thickness mm

- 350 nm
- 400 nm
- 450 nm
- 500 nm
- 550 nm
- Average across wavelength
- Regression of average wavelength
Flint

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Regression of average wavelength
3.3 Conclusions from the Practical Study.

The results obtained from the practical element of the project confirm that the amber bottles provide the greatest level of protection against light in the region identified to cause lightstruck flavours. Both the flint and green bottles allow the transmission of over 15% and up to 75% of light in the critical wavelength.

In the case of amber and flint bottles it can be seen that reducing the thickness of glass in order to reduce the bottle weight does not significantly reduce the protection from light, albeit protection from flint glass is poor.

For the green samples there is a reduction in protection of approximately 15-20% between the lightweighted and standard weight bottles associated with an approximate 40% reduction in thickness. However, the protection provided by the lightweight bottles is significantly greater than either of the flint samples.

From the further thinning and regression work performed, it is possible to predict the level of light protection afforded to beer by green and flint glass, as a linear relationship exists between thickness and light transmission (figure 3). A similar relationship can be expected for amber glass as predicted by the Beer Lambert Law however this is not evident due to the range of wavelengths tested as part of this study. The data for amber glass shows it to effectively block close to 100% of light below 500nm at all thicknesses tested in this study suggesting that reducing thickness of amber glass within currently practicable limits is unlikely to ever have a detrimental impact on beer flavour.
4.0 Discussion – The Implications of Lightweighting on Lightstruck Flavour in Beer

A review of literature has identified that light with a wavelength of between 350 to 520nm causes a reaction between ingredients found in beer, resulting in a flavour that is considered to be unpleasant by many consumers.

To prevent this problem beer has traditionally been sold in amber bottles which have been shown by this investigation and previous workers to prevent light of the critical wavelength reaching the beer in sufficient quantity to cause a problem. However, more recently marketing and branding requirements have resulted in beers being bottled in flint bottles to entice consumers by making the beer itself visible, whilst continental beers and lagers tend to be bottled in green glasses. Analysis from this project and others has shown that bottles of these colours provide far less protection from light.

In addition to glass colour affecting the level of light protection provided there is a clear relationship between glass thickness and level of protection. The push towards lightweighting of bottles and the resultant reduction of glass thickness in bottles has the potential to result in an increase in the incidence of beers being spoiled by the light.

Experimental comparison of standard weight and lightweighted designs in this study shows that for the amber bottles both lightweight and conventional bottles prevented over 90% of light in the critical wavelength from reaching the beer, giving excellent light protection. Conversely, both the lightweighted and standard weight flint bottles prevented less than 20% of light in the critical range from reaching the beer offering minimal protection from the effects of light. The green bottles offer more protection than the flint bottles but still allow around 40% of light to reach the beer, these samples exhibited the greatest difference between lightweighted and non lightweighted bottle with approximately 15-20% more light reaching the beer in the lightweighted bottle, associated with an approximate 40% reduction in glass thickness.

The results obtained suggest that the use of lightweight bottles for beers currently packaged in standard weight flint and amber bottles will have no negative impact on beer flavour.

The situation is less apparent for beers packaged in green glass, because the protection offered by green glass unlike flint does offer a level of light protection so reducing the thickness does have a detrimental affect on performance. This may need to be taken into consideration when specifying a lighter weight green bottle. To increase the light protective qualities of the lightweighted green and flint bottles the use of UV protective coatings or glass compositions formulated to reduce the transmission of could be employed, however, the cost benefit analysis of such measures would need to be assessed on a brand by brand basis.

This study has only looked at the effect of reducing the thickness of the glass on the light protective qualities of lightweighted bottles. The process of lightweighting can also result in significant changes in bottle shape. Literature suggests that this too can impact on the protection from light offered to the contents. A useful additional piece of work would be a study to investigate the transmission of light through the whole bottle for both lightweight and standard bottles in order to identify whether or not bottle shape should be given higher priority when reducing the weight of future bottles.

Finally it should be noted that this study has examined variation with glass thickness of the light protective properties of glass against certain critical wavelengths. What cannot be predicted is how individual beers will behave when exposed to such light; this may be a significant issue for green glass where light transmission does notably change with glass thickness. It can however be concluded that the very high level of protection offered by amber glass is maintained in lightweight bottles, and that this protection will naturally be afforded irrespective of individual beer chemistries.