BACKGROUND

The stratosphere absorbs much of the sun's damaging ultraviolet radiation through ozone. UV radiation is categorized into three bands: UVA (with wavelengths of 320 to 400 nm), UVB (280 to 320 nm), and UVC (200 to 280 nm). The shorter the wavelength is, the more dangerous the light. As sunlight passes through the atmosphere, all UVC and about 90% of UVB radiation is absorbed (by stratospheric ozone, carbon dioxide, etc.). UVA radiation is less affected by the atmosphere. Therefore, the UV radiation reaching the Earth's surface is largely composed of UVA with a small UVB component.

The world faces the environmental issue of stratospheric ozone thinning due to increased air pollution of chlorine- and bromine-containing substances. These substances — chlorofluorocarbons (CFC's), halons, methyl bromide, methyl chloroform, and carbon tetrachloride — exist in air conditioners, refrigerants, aerosol cans, pesticides, and industrial solvents; they catalyze ozone destruction. According to the National Center for Atmospheric Research, ozone levels over to Europe and North America have dropped about 10% from the 1970's to the 2000's. As stratospheric ozone continues to decrease, more UV components of sunlight are able to pass through the atmosphere and reach terrestrial light. UVB light is particularly efficient in causing photo damage in synthetic and naturally occurring materials, such as polymers (plastics, rubber, etc.) used in buildings and agriculture. Products using these materials may crack or disintegrate if they are not UV stable. The environmental problem is known as UV degradation. Continuous exposure is a more serious problem than intermittent exposure, since attack is dependent on the extent and degree of exposure.

The purpose of this experiment is to determine the effects of UV light on the elasticity of rubber bands. Elasticity is the property of solid materials to return to their original shape and size after the forces deforming them have been removed.

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1 Peter H Raven et al., Environment, 9th Edition (Wilev) . 2015.
4 Raven et al., Environment.
5 Ibid., 384.

No mention of the protocol to decrease the pollutants, makes it seem like the environmental issue is still growing. The context is laid out with references and creates the context for the research question. A clear research question and linked to the context.
RESEARCH QUESTION

How does UV light (UVA and UVB) exposure affect the elasticity of rubber bands?

HYPOTHESES

Main hypothesis:
The longer the rubber band is exposed to a smaller wavelength of UV light, the less elasticity the rubber band will have.

Three hypotheses will be stated for each light type:
1. If the rubber band is exposed to UVB light for a longer period of time, then the elasticity the rubber band will decrease.
2. If the rubber band is exposed to UVA light for a longer period of time, then the elasticity the rubber band will decrease, but not as much as the rubber band exposed to UVB light.
3. If the rubber band is exposed to LED light for a longer period of time, then the elasticity of the rubber band will not change.

MATERIALS

1. 1 UVA bulb
2. 1 UVB bulb
3. 1 LED bulb
4. 24 Rubber bands
5. 1 Meter stick
6. 1 12-inch ruler
7. 3 Reflector bases
8. 3 Chemistry stands
9. 1 Spring scale
10. 2 Sharpies (red and black)
11. 1 Vernier UV-VIS Spectrophotometer
Example 2: Annotated student work

VARIABLES

<table>
<thead>
<tr>
<th>Named variable and unit</th>
<th>Measurement/Control</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Independent</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Time rubber exposed to light (hours)</td>
<td>1. Standard clock 2. Vernier UV-VIS Spectrophotometer</td>
<td>1. Accurately measures the time rubber band is exposed 2. This device verifies that each light bulb emits appropriate wavelength of UV light</td>
</tr>
<tr>
<td>2. Type of light (nanometers)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dependent</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Length of rubber band pre- and post-exposure (centimeter)</td>
<td>1+2. Standard meter stick</td>
<td>1+2. Accurately measures length of rubber bands</td>
</tr>
<tr>
<td>2. Length rubber band stretches pre- and post-exposure (centimeter)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Controlled</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Height of Light (centimeter)</td>
<td>1. Standard ruler 2. UVA — 50W; UVB — 26W; LED — 8 W</td>
<td>1. Different heights of light affect amount of light rubber bands will receive 2. Although wattages are different, these light bulbs are best source of controlled light.</td>
</tr>
<tr>
<td>2. Source of light within trials (Watts)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

METHOD

Set up

1. Attach 3 reflector bases to 3 chemistry stands 25cm from work surface.
2. Fasten each light bulb (LED, UVA, and UVB) into the reflector base
3. Turn on each light
4. Measure the wavelength of each light 3 times with the Vernier UV-VIS Spectrophotometer (in order verify that the light wavelength corresponds to the UVA UVB wavelengths)

24-Hour Experiment

1. Obtain 3 rubber bands
2. Use red and black Sharpies to label each rubber band
3. Measure the initial length of each rubber band with no force applied
4. Attach the spring scale to the solid support (i.e. a coat hook)
5. Attach 1 rubber band to spring scale
6. Stretch rubber band 3 times with 20N of force on the spring scale while measuring the
   length the rubber band stretches each time with a standard meter stick
7. Measure the final length of each rubber band with no force applied
8. Repeat steps 3-7 for each of the 3 rubber bands
9. Place all 3 rubber bands underneath the light source (either UVA, UVB, or LED)
10. Repeat steps 1-9 for each light source (UVA, UVB, LED)
11. Leave rubber bands under the light source for 24-hours

**After 24-Hours**
1. Remove the 3 rubber bands from underneath light source
2. Wait 5-8 minutes for rubber bands to cool
3. Attach 1 rubber band to spring scale
4. Stretch rubber band 3 times with 20N of force on the spring scale while measuring the
   length the rubber band stretches each time with a standard meter stick
5. Measure the final length of each rubber band with no force applied
6. Dispose of rubber bands into the trash
7. Repeat steps 1-5 for the 3 rubber bands underneath each light source

**72-Hour Experiment**
1. Repeat steps 1-9 from the 24-Hour Experiment above
2. Leave rubber bands under the light source for 72-hours
3. Repeat step 1-2 for each light source (UVA, UVB, LED)

**After 72-Hours**
1. Repeat steps 1-7 from After 24-Hour above for the 3 rubber bands underneath each light source

**Note:** To ensure precise results, this method should be repeated 2 times.

**ETHICAL CONSIDERATIONS**
Disposal of rubber bands: I will not return the rubber bands into the bag as they are likely to be
chemically altered or stretched out. Therefore, the rubber bands will be disposed into the
garbage.
Safety of UVA and UVB light: As UVA and UVB light are dangerous for the eyes, the rays of
these light sources are protected from reaching other people's eyes by the reflector base.
Energy use of lights: It is recognized that through this experiment, the different lights will be using electrical energy; however, there is no alternative, but to consume this energy. An LED lightbulb was chosen because it is energy-efficient.

DATA COLLECTION

RAW DATA

The Vernier UV VIS Spectrophotometer was used to measure the wavelength of the UVA, UVB, and LED light in order verify that the light wavelength corresponds to the correct wavelengths.
Graph 2: Wavelength of UVB Light Bulb

Graph 3: Wavelength of LED Light Bulb
Example 2: Annotated student work

Chart 1: Change in Length Initial Rubber Band with No Exposure

Chart 2: 72 Hours of UVB Exposure

Chart 3: 72 Hours of UVA

Chart 4: 72 Hours of LED Exposure

Chart 5: 24 Hours of UVB Exposure

Chart 6: 24 Hours of UVA Exposure

Note: The data shown in this chart indicate that the rubber bands used in this experiment lose some elasticity before they are exposed to light as they are newly manufactured rubber bands. It is expected that some elasticity will be lost due to new use.

Note N/A in this chart signifies that the rubber band broke after applying 20 N of force.
Averages were calculated for each change in final length of the rubber (with no force applied) after being stretched 3 times pre-exposure and then the final length of the rubber band after being stretched 3 times post-exposure. Then, an average of each averaged trial were taken to calculate the total average change in length of the rubber band pre- and post-exposure.

10 Note the date is skewed for the Total Average Change in Length Post UVB and the Loss of Elasticity because the rubber band broke after applying 20 N of force, therefore, the length of the rubber band could not be measured.
Chart 12: Loss of Elasticity After 24-Hours of UVA Exposure

Chart 13: Loss of Elasticity After 24-Hours of LED Exposure

Averages of the change in length that each rubber band stretched to pre- and post-exposure were calculated.

Chart 14: Average Length of Each Trial Rubber Band Stretched Pre-Post 24 Hour Exposure
**Chart 15: Average Length of Each Trial Rubber Band Stretched Pre-Post 74 Hour Exposure**

<table>
<thead>
<tr>
<th>Light Type</th>
<th>Pre-Exposure</th>
<th>Post-Exposure</th>
<th>Pre-Exposure</th>
<th>Post-Exposure</th>
<th>Pre-Exposure</th>
<th>Post-Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVB</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>43.90</td>
<td>50.90</td>
<td>34.03</td>
<td>38.43</td>
<td>44.67</td>
<td>N/A</td>
</tr>
<tr>
<td>Trial 2</td>
<td>32.87</td>
<td>39.57</td>
<td>36.43</td>
<td>41.70</td>
<td>38.53</td>
<td>46.05</td>
</tr>
<tr>
<td>Total Avg.</td>
<td>38.36</td>
<td>45.23</td>
<td>35.23</td>
<td>40.07</td>
<td>41.60</td>
<td>46.05</td>
</tr>
<tr>
<td>UVA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>37.23</td>
<td>45.70</td>
<td>39.87</td>
<td>44.07</td>
<td>38.33</td>
<td>41.77</td>
</tr>
<tr>
<td>Trial 2</td>
<td>34.88</td>
<td>40.97</td>
<td>37.93</td>
<td>45.47</td>
<td>36.87</td>
<td>42.37</td>
</tr>
<tr>
<td>Total Avg.</td>
<td>36.01</td>
<td>43.33</td>
<td>38.90</td>
<td>44.77</td>
<td>37.60</td>
<td>42.07</td>
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<tr>
<td>LED</td>
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<td></td>
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<tr>
<td>Trial 1</td>
<td>37.23</td>
<td>45.70</td>
<td>35.27</td>
<td>39.83</td>
<td>38.33</td>
<td>41.77</td>
</tr>
<tr>
<td>Trial 2</td>
<td>34.88</td>
<td>40.97</td>
<td>36.47</td>
<td>43.35</td>
<td>36.87</td>
<td>42.37</td>
</tr>
<tr>
<td>Total Avg.</td>
<td>36.01</td>
<td>43.33</td>
<td>35.87</td>
<td>42.57</td>
<td>37.60</td>
<td>42.07</td>
</tr>
</tbody>
</table>

Note: The data is skewed for the total average length post-UVB Exposure of the tan rubber band since this rubber band broke after applying 20N of force; therefore, the length of the rubber band could not be measured.
Averages of the change in length that all rubber bands stretched to under each light source pre- and post-exposure were calculated.

**Chart 16: Average Length Rubber Band Stretched Pre-and Post Exposure**

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Pre-Exposure Length (cm)</th>
<th>Post-Exposure Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVB</td>
<td>35.74</td>
<td>42.76</td>
</tr>
<tr>
<td>UVA</td>
<td>35.67</td>
<td>41.92</td>
</tr>
<tr>
<td>LED</td>
<td>26.92</td>
<td>41.18</td>
</tr>
</tbody>
</table>

**Chart 17: Average Length Rubber Band Stretched Pre-and Post-72 Hour Exposure**

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Pre-Exposure Length (cm)</th>
<th>Post-Exposure Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UVB</strong></td>
<td>34.41</td>
<td>41.78</td>
</tr>
<tr>
<td>UVA</td>
<td>37.51</td>
<td>43.39</td>
</tr>
<tr>
<td>LED</td>
<td>36.50</td>
<td>42.32</td>
</tr>
</tbody>
</table>

**Graph 4: Type of Light vs. Loss of Elasticity vs. Exposure Time**

Total averages of the length that the rubber band stretches pre- and post-72 and -24 hour exposures were graphed. According to the graphs below, all rubber bands post-exposure

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Note: The data is skewed for UV Post-Exposed Length because the rubber band broke after applying 20N of force.
Stretched further than pre-exposure.

Graph 5: Average Length the Rubber Band Stretches Pre- and Post-72 Hour Exposure Type of Light vs. Loss of Elasticity vs. Exposure Time

Graph 6: Average Length the Rubber Band Stretches Pre- and Post-24 Hour Exposure

Note: The data is skewed for the Post-UVB Exposure bar since the two of the rubber bands broke and were not able to be measured.
Pictures of the stretched rubber bands were taken post-24 and 72 hour exposure. Clearly, there is UV-Degradation of the rubber band post-72 exposure.

Chart 18: Qualitative Data for Trial 1 — Rubber Bands post-24 and -72 Hour Exposure

<table>
<thead>
<tr>
<th></th>
<th>24 Hours</th>
<th>72 Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UVA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LED</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CONCLUSION
From the data collected, it can be concluded that the hypotheses of this experiment are supported. Twenty-four hours of UV light exposure does not affect the elasticity of rubber bands as much as seventy-two hours of UV light does. This conclusion is proven in Graph 4, where there is a clear value difference in results produced from 24-hours of exposure to 72-hours of exposure. The UVB light 72-hour trial caused the most UV degradation of the materials as seen in Graph 4 as well as the physical break down of the rubber band seen in Chart 18. The UVA 72-hour trial produces loss in elasticity, however, not as much as the UVB 72-hour trial and not as little at the LED 72-hour trial. Ultimately, the UVB light, the light with the smallest wavelength, produced the biggest loss of elasticity in both the 24-hour and 72-hour period trials as seen in Graph 4 produced from Chart B-13. The UVA light did not produce some loss of elasticity, but not as much as the UVB light. The LED produced smallest loss in elasticity, which is to be expected because the light does not contain a UV component.
Using this experiment as a representation of the effects of UV light on rubber bands, one can see that as the rubber bands are exposed to longer periods of time and smaller wavelengths of UV light (UVB), the more UV-degradation occurs. This experiment is based on artificial UVA and UVB light, not natural sunlight and it was carried out indoors. Despite these obstacles, this experiment holds merit in its broader implications. This experiment shows possible effects that UV light has on rubber bands, a material used for industrial and agricultural purposes. As the stratospheric ozone decreases due to air pollution, sunlight will have more UVB-component, causing more UV degradation in materials such as rubber bands. Their service life decreases, which leads to more of these resources being disposed and used.

EVALUATION

Although the data proves the hypotheses correct, the reliability of the data cannot be determined because standard deviation was not calculated. Standard deviation is hard to determine because change in length of the rubber band without force were calculated is an average calculated from other averages. Due to the mathematical processing of the data, it is impossible to calculate the standard deviation; therefore, the data should have been processed differently.

In hindsight, it would have been better to expose the rubber band for another trial and have them exposed for 120 hours rather than just 24 and 72 hours. It would be better to see how 75 hours compares to 120 hours of exposure. One limitation of the data is that these rubber bands were not necessarily intended to be used in an outdoor environment where they would be exposed to UV radiation.

The length the rubber bands stretched under 20N of force was measured by hand; therefore, are inaccurate due to human error. In order to eliminate this possible error, weights should be used to stretch the rubber bands to a certain length rather than with a certain force.

The rubber bands were placed next to each other, directly under the light. It would have been interesting to see if the results would change if placed in different areas under the light (i.e. near the edges of light).

Elasticity was measured by the change in length the rubber experienced from pre- to post exposure with no force. While this method is good method to measure the loss in elasticity, it would be more reliable if the elasticity was calculated through more mathematical-based method.
**SOLUTION**

One solution to cause a negative feedback system of decreasing air pollution and increase stratospheric ozone is to **promote and educate people about alternative products to chlorine and bromine-containing products, especially CFCs.** Regulating human activities avoids further environmental problems. For example, because the effect of releasing CFCs is a global issue, international protocols have been established in a cooperative effort for the planet’s future, such as the Montreal Protocol. Although the Montreal Protocol has been successful in decreasing the amount of CFC’s being used, they still exist and will continue to deplete stratospheric for at least 50 years.\(^{14}\) Alongside of this plan should be a general effort to use cleaner sources of energy to decrease the amount of air pollution the world produces.

The **Montreal Protocol has been successful in decreasing the use of CFC’s, but has increased the use of hydrofluorocarbons (HFC’s), a substitute potent greenhouse gas, contributing to the global warming issue.** This shows the complexity of solving environmental issues: as one problem is fixed, the effects of the process to fix it cause another problem in another area of the environment.

Word Count: 2021

\(^{14}\) Raven et al., *Environment*, 386,
Bibliography


