EXTENDED ESSAY

-Chemistry-

Investigation of the Effect of UVC Light on Vitamin C Concentration

« How does the duration of the UVC exposure of 15.0, 30.0, 60.0, 90.0, 120.0, and 180.0 minutes applied by a UVC lamb of 240 nm affects the vitamin C concentration in vitamin C tablets, containing 1000 mg of L-Ascorbic Acid, measured by 0.005 $mol.dm^{-3}$ iodine titration? »

Word Count: 3816

Table of Contents

1. INTRODUCTION

1.1 BACKGROUND INFORMATION

1.1.1 UVC Light

Ultraviolet light is a form of electromagnetic radiation which has a higher frequency and less wavelength than visible light. UV radiation is observed in four groups (increasing in energy and frequency): UVA (315-400 nm), UVB (280-315 nm), UVC (200-280 nm), Vacuum UV (100-200 nm), (image 1). UVC comes from the Sun and when coming to the World, it reacts with ozone in the atmosphere and can not be able to reach the surface of the world. The main reason for that is it has higher energy. International Agency for Research on Cancer, which is an intergovernmental agency forming part of the World Health Organization, made it clear that all types of UV light is carcinogenic. When a UVC light reaches to the skin, most of it is reflected. However, 4-7% of the light is absorbed by the first 2 micrometers of the stratum corneum, the outer layer of epidermis, skin. Other effects of UVC light are erythema, which is the rash skin caused by injured blood capillaries, and photokeratitis, which is a painful eye condition in the cornea.

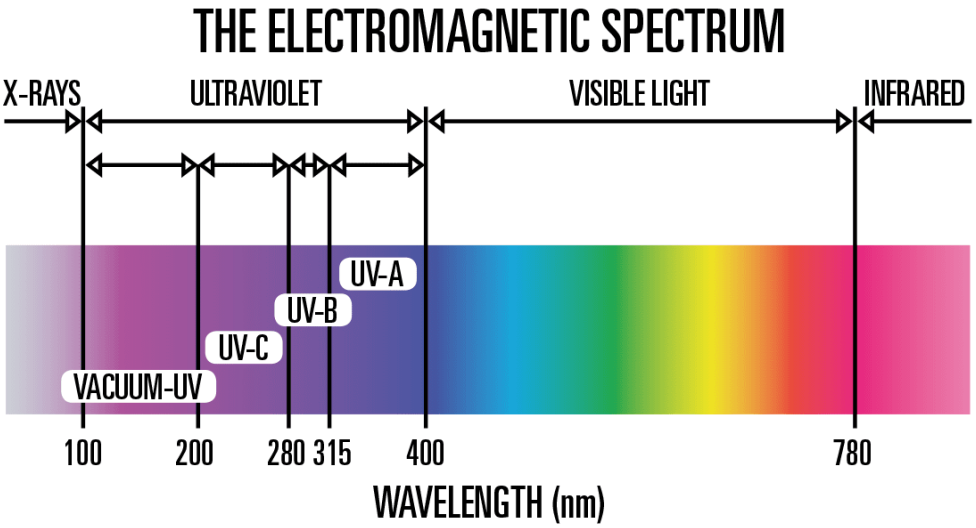


Figure 1: The electromagnetic spectrum [1]

[1] (Henley-On-Thames), Breathe Creative. "How Does Ultraviolet Light (UV-B and UV-C) Disinfect?" *Berson, Hanovia & Aquionics UV*, 28 Dec. 2020, https://www.weuvcare.com/how-does-ultraviolet-light-disinfection/.

1.1.2 UVC and Its Antiseptic Property

UVC light is absorbed the easiest in UV radiation by DNA, RNA, and proteins. One property of UVC light is that it is an antiseptic, in other words, it tends to inactivate bacteria and viruses; in addition, this property depends on the absorption of a photon by DNA and RNA molecules. The most antiseptic effect is seen between 205-280 nm and the susceptibility of microorganisms is the highest at 265 nm. Photochemical reactions prevent microorganisms' ability to reproduce by harming the bonds of DNA and RNA. UV-GI, ultraviolet germicidal irradiation, is a disinfection method by which UVC light is used to inactivate microorganisms by destroying nucleic acids and making it impossible to perform their cellular functions. UVC radiation was first applied for the disinfection of drinking water and was found to be effective against many human pathogens, viruses, bacteria, yeasts, and protozoa.[2] [3] [4] These positive outcomes encouraged research on the UV applications for food processing and preservation.[5] [6] [7] [8]

1.1.3 Effect of UVC Light on DNA

DNA is made up of units called nucleotides and they are composed of deoxyribose, phosphate, and four nitrogenous bases; which are thymine, adenine, cytosine, and guanine. Cytosine and thymine are single-ring structures called pyrimidines, adenine and guanine are double-ring structures called purines. Thymine and adenine pairs by forming two hydrogen bonds, cytosine, and guanine pairs by forming three hydrogen bonds. (image 2) Viruses contain either DNA or RNA but they never contain both of them. During UV irradiation, the most sensitive target of microorganisms is the DNA or RNA of the viruses, the DNA of bacteria, and the DNA of fungi. UVC radiation inactivates microorganisms

[2] Masschelein, W. J. (2002). Ultraviolet light in water and wastewater sanitation. Boca Raton: CRC Press.
[3] Chevrefils, G., Caron, E., Wright, H., Sakamoto, G., Payment, P., Barbeau, B., & Cairns, B. (2006). UV dose required to achieve incremental log inactivation of bacteria, protozoa and viruses. IUVA News, 8(1), 38–45.
[4] Bolton, J. R. (2010). Ultraviolet applications handbook. Edmonton: ICC Lifelong Learn Inc.
[5] López-Malo, A., & Palou, E. (2005). Ultraviolet light and food pres- ervation. In G. Barbosa-Cánovas, M. S. Tapia, & M. P. Cano (Eds.), Novel food processing technologies (pp. 405–422). Boca Raton: CRC Press.
[6] Koutchma, T., & Orlowska, M. (2012). UV light for processing fruits and fruit products. In S. Rodrigues, & F. A. N. Fernandes (Eds.) Advances in fruit processing technologies. CRC Press Inc., ISBN 13: 9781439851524 (in press).
[7] Koutchma, T. N., Forney, L. J., & Moraru, C. I. (2009). Ultraviolet light in food technology. Principles and applications. Boca Raton: CRC Press.
[8] Gómez-López, V. M., Koutchma, T., & Linden, K. (2012). Ultraviolet and pulsed light processing of fluid foods. In P. J. Cullen, B. K. Tiwari, & V. P. Valdramidis (Eds.), Novel thermal and non-thermal technologies for fluid foods (pp. 185–223). Elsevier Inc., ISBN: 978-0-12-381470-8 (in press).

by causing a crosslink between two thymine bases; in other words, the formation of chemical bonds of DNA is changed, which is more stable than a hydrogen bond. This is called denaturation and the crosslink leads to cell death or mutations and also inhibits the cell to reproduce effectively.

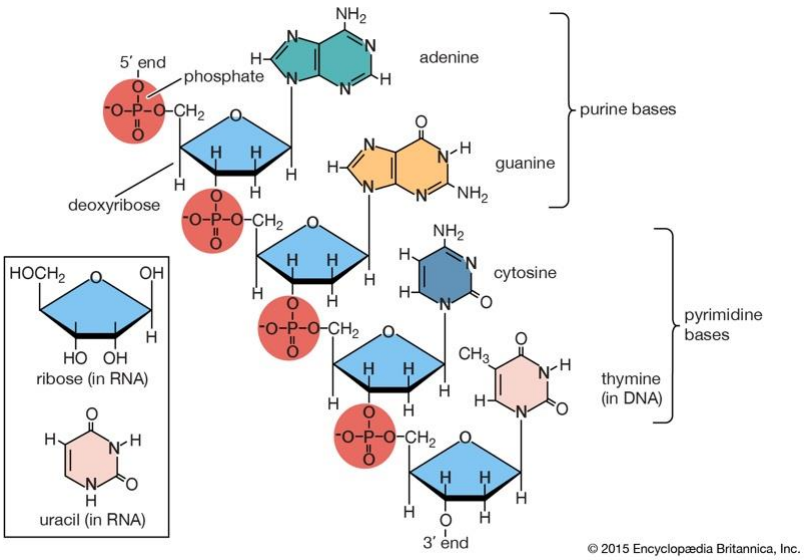


Figure 2: Polynucleotide chain of deoxyribonucleic acid (DNA) [9]

1.1.4 UV Technology on Food Products

Ultraviolet technology gained much of the interest with the breakout of the coronavirus as an alternative solution for sterilization.[10] Food products include numerous compounds, such as vitamins, carbohydrates, lipids, and proteins. Those compounds which form a complex system of a food product might be sensitive to light. That being the case, higher UV fluences can lead to formation of undesirable components, quality deterioration, and nutritional loss. The application of UVC radiation on food results in increased shelf life and hygienic food consumption, since it destroys the pathogenic microorganisms.[11] However, when UVC treatment is applied on a nutrient, rich in vitamin C, vitamin C concentration decreases, antioxidants and proteins might be harmed. Vitamin C is a water-soluble

[9] "DNA." *Encyclopædia Britannica*, Encyclopædia Britannica, Inc., https://www.britannica.com/science/DNA.
[10] Center for Devices and Radiological Health. "UV Lights and Lamps: Ultraviolet-C Radiation, Disinfection, and Corona." *U.S. Food and Drug Administration*, FDA, https://www.fda.gov/medical-devices/coronavirus-covid-19-and-medical-devices/uv-lights-and-lamps-ultraviolet-c-radiation-disinfection-and-coronavirus.
[11] Csapó, J., et al. "Effect of UV light on food quality and safety." *Acta Univ. Sapientiae* 12 (2019): 21-41.

vitamin and is sensitive to UV irradiation and the maximum absorption of vitamin C under UVC is at about 260 nm. In an experiment, the concentration of vitamin C in apple juice was examined before and after UV treatment (254 nm and 25W), the result was that the UV treatment with an average fluence rate of 14.5 mW/cm^2 for 5.2 s caused 50% of the vitamin C content to decompose at the slowest flow rate. In a similar experiment, this time done with a carrot juice, 18-25% of the vitamin C concentration was decreased and the applied irradiation dose was 1450 J/s. [12]

1.1.5 Vitamin C

Vitamin C is the biologically active form of ascorbic acid and is a water-soluble antioxidant that is found in vegetables and fruits. It is essential for the human body since human body is not able to synthesize vitamin C endogenously. Vitamin C contributes to the assimilation of iron, healing of wounds, building collagen, and defense against viral infection and bacteria. Also, it is required for biosynthesis of collagen fibers which is responsible for forming tendons, skin, and blood vessels. Furthermore, protein metabolism, reduction of plasma cholesterol level, some neurotransmitters, absorption of inorganic iron, and inhibition of nitrosamine formation require vitamin C.[13] In case of vitamin C deficiency in human body, there will be a risk of cardiovascular diseases, scurvy, hemorrhaging in skin, loosening of teeth, joint pains, exhaustion, connective tissue weakness and capillary fragility. [14] To prevent the common cold, intake of 1-3 g of vitamin C is suggested since it has a protective property. During the pandemic of Covid-19 started in 2019, vitamin C is used as a nonspecific treatment for respiratory tract infections and immune system. Some of the sources of vitamin C are lemon which contains approximately 77 mg/100 g of vitamin C and broccoli which contains 84.5 mg/100 g fresh weight.[15] Pure form of vitamin C is known as L-Ascorbic Acid.

[12] Orlowska, M., Koutchma, T., Grapperhaus, M. *et al*. Continuous and Pulsed Ultraviolet Light for Nonthermal Treatment of Liquid Foods. Part 1: Effects on Quality of Fructose Solution, Apple Juice, and Milk. *Food Bioprocess Technol* 6, 1580–1592 (2013). https://doi.org/10.1007/s11947-012-0779-8

[13] Getoff, N. (2013). "Vitamin C: electron emission, free radicals and biological versatility," In Vivo 27: 565-70.

[14] Rickman J.C., Bruhn, C.M. and Barrett, D.M. (2007). "Nutritional comparison of fresh, frozen, and canned fruits and vegetables II. Vitamin A and carotenoids, vitamin E, minerals and fiber," J Sci Food Agric 87: 1185-1196.

[15] Hill, Caroline. "20 Foods That Are High in Vitamin C." *Healthline*, Healthline Media, 5 June 2018, https://www.healthline.com/nutrition/vitamin-c-foods#TOC_TITLE_HDR_16.

1.1.6 Vitamin C and Iodine Titration

In this investigation, effect of the duration of UVC radiation on vitamin C concentration in vitamin C tablets is measured by iodine titration. As the iodine is added during the titration, the ascorbic acid is oxidized to dehydroascorbic acid, while the iodine is reduced to iodide ions. The reactions that take place are:

(1) $KIO_3(aq) + 6\ H^+(aq) + 5\ I^-(aq) \rightarrow 3\ I_2(aq) + 3\ H_2O(l) + K^+(aq)$

(2) $C_6H_8O_6(aq) + I_2(aq) \rightarrow C_6H_6O_6(aq) + 2\ I^-(aq) + 2\ H^+(aq)$

Reaction (1) shows the generation of I_2 and the reaction (2) shows the oxidation of vitamin C. During reaction (1) dissolved iodide ions (I^-) are needed so solid KI is added. In reaction (2) ascorbic acid ($C_6H_8O_6$) is converted to dehydroascorbic acid ($C_6H_6O_6$). In this titration, as an indicator starch solution is used, which is prepared with soluble starch and the oxidizing agent is iodine. The end-point of the reaction is when I_2 and starch indicator solution come across and form a blue-black color complex.[16]

1.2 RESEARCH QUESTION

How does the duration of the UVC exposure of 15.0, 30.0, 60.0, 90.0, 120.0, and 180.0 minutes applied by a UVC lamb of 240 nm affects the vitamin C concentration in vitamin C tablets, containing 1000 mg of L-Ascorbic Acid, measured by 0.005 $mol.dm^{-3}$ iodine titration?

1.3 HYPOTHESIS

The concentration of vitamin C in vitamin C solution prepared with tablets will decrease as the duration of the UVC light exposure increases.

[16] *CHL 212 – Quantitative Analysis - La Salle University*. http://www1.lasalle.edu/~prushan/Experiment8-redox%20titration.pdf.

2. VARIABLES

2.1 INDEPENDENT VARIABLE

Variable	How it will be changed
Duration of UVC light treatment	A UVC lamp with an exposure of 240 nm will be applied on standard vitamin C solutions, which is prepared with vitamin C tablet containing 1000 mg of ascorbic acid and 200 mL of distilled water, for durations of 15.0, 30.0, 60.0, 90.0, 120.0, 180.0 minutes of UVC radiation.

Table 1: Independent variable of experiment

2.2 DEPENDENT VARIABLE

Variable	How the change will be measured
Amount of iodine used in mL	After applying UVC treatment, the concentration of vitamin C will be measured by 0.005 $mol.dm^{-3}$ iodine titration.

Table 2: Dependent variable of experiment

2.3 CONTROLLED VARIABLE

Variable	Effect on experiment	How it will be controlled
Nanometer of the UVC lamp being 240	If the power or the nm of the UVC lamp differed, it wouldn't be possible to know what affected the vitamin C concentration, the duration or the power of the lamp since the independent variable is duration.	The same UVC lamp will be used in all trials.

Vitamin C source	If different vitamin C sources were used, the concentrations would be different and it would not be possible to record the data after the UVC treatment.	Vitamin C tablets with the same concentrations will be used. One tablet contains 1000 mg of L-ascorbic acid.
Concentration of the indicator (starch indicator)	If the concentrations of the indicators were different, then the duration till the color change would change.	Starch solution of %1 is used in all trials and also to avoid any precipitation, the solution is mixed with fish and rod before each trial.
Concentration of iodine solution prepared	Since vitamin C calculations are conducted with the molarity of iodine solution, there would be changes or random errors while calculating the vitamin C concentration.	For most trials, iodine solutions with the same concentration which is 0.005 molar, are used. However, because of lack of materials and chemicals and to prevent excessive usage of them, different molars of iodine solutions are used, which is not a problem for the calculation.
Size of measurement tools	If the size of the measurement tools were changed, the uncertainties would have changed and it would be more possible to make a mistake.	Same size of measurement tools such as beakers, conical flasks and Erlenmeyer flasks are used.

Table 3: Controlled variables of experiment

3. METHODOLOGY

3.1 MATERIALS

In this investigation, standard vitamin C concentrations prepared with vitamin C tablets were applied UVC radiation for the durations of 15.0, 30.0, 60.0, 90.0, 120.0 and 180.0 minutes with a UVC lamp of 240 nm.

3.1.1 Apparatus (Equipment)

Equipment	Quantity	Uncertainty
20 mL pipette	1	± 0.5
Measuring cylinders	1 × 10 mL 1 × 100 mL	± 0.5 ± 0.5
Burette and stand	1	± 0.05
A chronometer	1	± 0.1

Table 4: Equiments that will be used for measuring, their quantity and uncertainty

Lab coats, safety glasses

UVC lamp with an exposure of 240 nm

Stir bar and stir plate

250 mL Erlenmeyer (conical) flasks (× 7)

100 mL or 200 mL volumetric flask

3.1.2 Chemicals and Solutions

Iodine (0.005 $mol.dm^{-3}$)

Vitamin C tablets

Distilled water

1% Starch Indicator Solution (soluble starch)

Potassium iodide solution

3.2 DESIGNING THE EXPERIMENT

I had to redesign the experiment and create a titration station because of lack of materials. There was no ring stand with a fixed burette attached to it available so I used a stirring motor and a burette with pomp. Iodine is vacuumed to the burette with pomp from the Erlenmeyer flask. While the vitamin C solution which starch indicator has dropped into, is being stirred with the stir bar and the stir plate, iodine is dropped until the blue color stays constant.

Figure 3: Vitamin C solutions prepared with a vitamin C tablet and 200 mL distilled water.

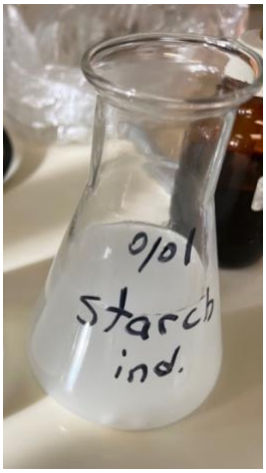


Figure 4: Starch indicator solution

Figure 5: Weighing the soluble starch to prepare 1% starch indicator solution.

Figure 6: The settings screen of the UVC lamp.

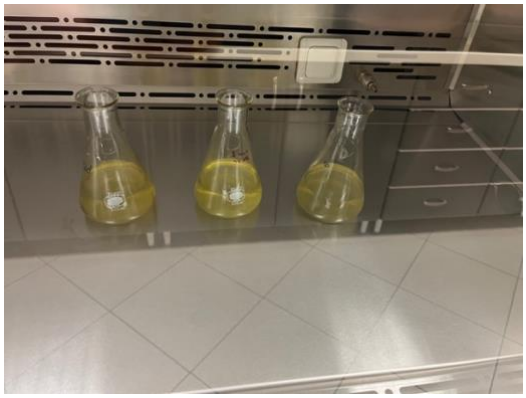


Figure 7: Vitamin C solutions in the UVC Lamp

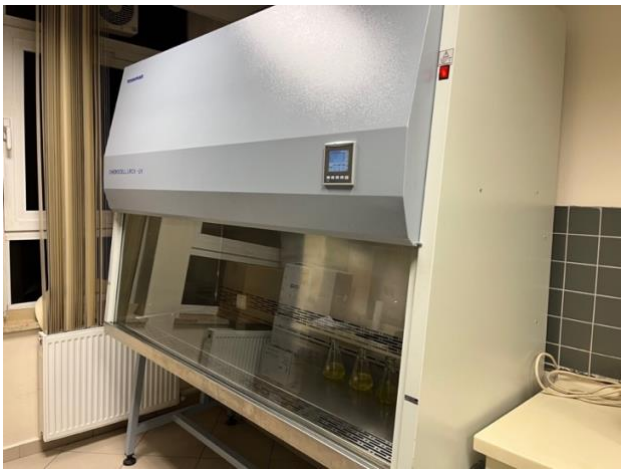


Figure 8: UVC lamp

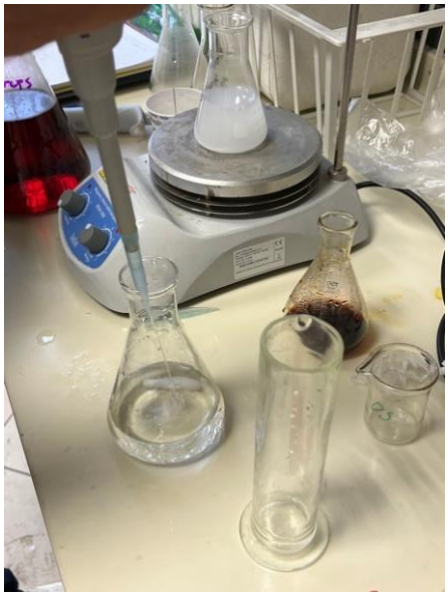


Figure 9: Dropping starch indicator to the analyte.

Figure 10: Dropping iodine from the burette to the analyte.

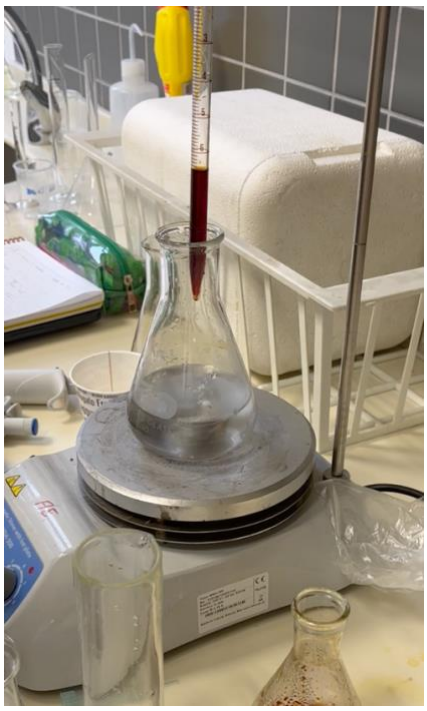


Figure 11: Instant color changes during titration

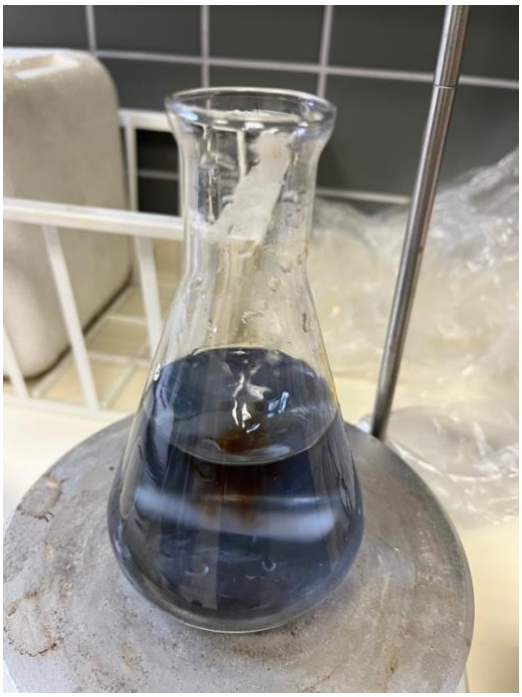


Figure 12: Reaching the end point of the titration.

Figure 13: After the end point, where no more color change is observed.

3.3 PROCEDURE AND PREPARATION OF SOLUTIONS

1. Prepare a standard solution of vitamin C by dissolving one tablet of vitamin C, which contains 1000 mg of L-Ascorbic Acid, in 200.0 mL of distilled water. Prepare from this solution in separate seven Erlenmeyer flasks.
2. Prepare a safe environment for UVC treatment and put those seven Erlenmeyer flasks with standard vitamin C solutions inside the UVC lamp.
3. Start the UVC lamp carefully and before taking any of the Erlenmeyer flasks when their time is over, first turn off the lamp to decrease any contact with the UV light. Also, put a caution sign at the door indicating that UVC lamp is turned on.
4. Use a chronometer and treat the vitamin C solutions with UVC light for durations of 15.0, 30.0, 60.0, 90.0, 120.0, and 180.0 minutes with the UVC lamp of 240 nm.
5. After the UVC treatment, turn off the UVC lamp and ventilate the room.
6. Weigh 2.0 g of potassium iodide and 1.3 g of iodine to prepare 0.005 mol L^{-1} of iodine solution. Add those two substances to a 100 mL beaker and add a few mL distilled water. Swirl the solution until the iodine is dissolved. Transfer iodine solution to a 1 L volumetric flask making the solution up to the 1L mark and rinse all traces of solution into the volumetric flask using distilled water.
7. Prepare starch indicator solution (1% or 0.5%) in a conical flask by weighing 0.25 g of soluble starch and adding it to 50 mL near-boiling water.
8. Pipette 20 mL of the sample of standard vitamin C solution into a 250 mL conical flask and add about 150 mL of distilled water. The mL of standard vitamin C solution and distilled water can be changed without changing the proportion of standard vitamin C solution and distilled water. As it can be seen at the “Content of the Solution” column of the Table 5 because of lack of chemicals and substances, 10 mL of standard vitamin C solution and 75 mL of distilled water are used.

9. Then add 1 mL starch indicator prepared at step 7 and mix the solution carefully so that the starch indicator mixes homogeneously.
10. Titrate the sample with 0.005 mol.dm^{-3} of iodine solution. The endpoint of the titration is when all the ascorbic acid has been oxidized and the excess iodine is free to react with the starch indicator, which will form a blue-black starch-iodine complex. Record the final volume of iodine used at the endpoint.
11. Repeat the titration at least for 5 times for different durations of UVC treatment.
12. Make the necessary calculations.[17] [18]

3.4 SAFETY AND ENVIRONMENTAL PRECAUTIONS

For safety, it is important to use protective equipment and to wear gloves, goggles, and lab coats. 1 M or more iodine solution can cause harm when in contact with the eye and skin and if inhaled even less than 1M can stain the skin.[19] If iodine spills on the skin, the area in contact must be washed immediately a few times. If any material spills around the experiment site, it should be cleaned up properly for environmental reasons. Furthermore, used chemicals and materials must be discarded, and beakers and other equipment must be cleaned before each trial.

Other than iodine, the usage of UV lamp is risky either. UV radiation is harmful to both eyes and skin and the symptoms usually occur after 4 to 24 hours. UV radiation can have two types of injury to the skin which are acute, such as erythema, and chronic, such as accelerated skin aging and skin cancer. Outer layers of the eye absorb UV light and cause photokeratitis and cataracts. One property of UV light is to convert oxygen to ozone so proper ventilation must be used since ozone can irritate the user. Furthermore, when turning on and off the lamp, the user should be protected

[17] *Determination of vitamin C concentration by titration*. (n.d.). Retrieved October 3, 2021, from https://www.canterbury.ac.nz/media/documents/science-outreach/vitaminc_iodine.pdf.
[18] Helmenstine, Anne Marie, Ph.D. "Vitamin C Determination by Iodine Titration." ThoughtCo, Aug. 27, 2020, thoughtco.com/vitamin-c-determination-by-iodine-titration-606322.
[19] *Student Safety Sheets 56 Iodine - CLEAPSS Science Home*. http://science.cleapss.org.uk/resource/SSS056-Iodine.pdf.

from electrical connections. UV lamp should not be used in a high-traffic area of a lab, there must be a separate room for the lamp. Moreover, there should be warning signs at the door to restrict access and to indicate the presence of potential UV hazards. Lab coats, goggles, gloves, and face shields should be used.[20]

4. DATA

4.1 RAW DATA

Duration of UVC radiation $\pm$ 0.1	**Content of the solution**	**Molarity of the Iodine (mol.dm^{-3})**	**Initial burette reading ±0.05**	**Final Burette Reading ±0.05**
0.0 minutes (no UV exposure)	20 ml of vitamin C solution diluted with 150 ml of distilled water	0.05 mol.dm^{-3}	0 0 0 0 0	40.2 39.1 39.6 36.8 42.1
15.0 minutes	10 ml of vitamin C solution diluted with 75 ml of distilled water	0.005 mol.dm^{-3}	0 6.5 12.9 19.6 26	6.5 13.8 19.3 26.3 32.4
30.0 minutes	10 ml of vitamin C solution diluted with 75 ml of distilled water	0.005 mol.dm^{-3}	0 6 12.3 18.4 24.3	6 12.5 18.4 24.1 30.6

[20] *Safety Tips for Using UV Lamps - Berkeley Lab*. https://www2.lbl.gov/ehs/safety/nir/assets/docs/uv/UV%20lamps%20safety%20tips.pdf.

60.0 minutes	10 ml of vitamin C solution diluted with 75 ml of distilled water	0.005 $mol.dm^{-3}$	5 10.8 16.6 22.2 28.4	10.8 16.6 22.2 28.4 33.9
90.0 minutes	10 ml of vitamin C solution diluted with 75 ml of distilled water	0.005 $mol.dm^{-3}$	4.8 10.4 15.6 21 26.7	10.4 15.6 21 26.7 31.8
120.0 minutes	10 ml of vitamin C solution diluted with 75 ml of distilled water	0.005 $mol.dm^{-3}$	0 5.2 9.9 15.2 20.8	5.2 9.9 15.2 20.8 25.9
180.0 minutes	20 ml of vitamin C solution diluted with 150 ml of distilled water	0.005 $mol.dm^{-3}$	2.5 13.6 27.2 0 11.8	13.6 27.2 41.7 11.8 25.1

Table 5: Raw data table of the titration results and the initial and final burette readings

4.2 DATA PROCESSING

Duration of UVC radiation ($\pm$ 0.1)	**Difference (mL)**	**Average mL of I_2 used ±0.01**	**Mean Uncertainty**
0.0 minutes (no UV exposure)	40.2 39.1 39.6 36.8 42.1	39.56	± 5.93
15.0 minutes	6.5 7.3 6.4 6.7 6.4	6.66	± 1.01
30.0 minutes	6 6.5 6.1 5.7 6.3	6.12	± 0.89
60.0 minutes	5.8 5.8 5.6 6.2 5.5	5.78	± 0.78

90.0 minutes	5.6 5.2 5.4 5.7 5.1	5.4	± 0.67
120.0 minutes	5.2 4.7 5.3 5.6 5.1	5.18	± 1.01
180.0 minutes	10.3 10.6 8.8 11.5 10.3	10.3	± 3.02

Table 6: Calculated average iodine used in mL and the mean uncertainties

All of the sample calculations are made for 0.0 minutes of UV exposure.

4.2.1 Sample Calculation of Average Volume of Titrant

5 trials for each duration of UVC exposure were made. To find the average volume of titrant for no UVC exposure, the following calculation is made:

$$\frac{40.2 + 39.1 + 39.6 + 36.8 + 42.1}{5} = 39.56\ mL$$

4.2.2 Sample Calculation of Mean Uncertainty of Average Volume of Titrant

The uncertainties for initial and final burette reading and average volume of titrant is found by dividing the smallest division of the burette by two. To find the mean uncertainty of mean titrant for each duration of UVC radiation, the following process is followed:

$$(\text{the highest titrant value} - \text{the smallest titrant value}) \div 2\sqrt{5}$$

If this process is applied for no UV exposure, the following equation occurs:

$$(42.1 - 36.8) \div 2\sqrt{5} = 5.93$$

This method is applied for each duration and the results are shown at Table 6.

4.2.3 Sample Calculation of Uncertainty of Average Vitamin C Concentration

The formula for the calculation of percentage uncertainty is as followed,

$$\text{Percentage Uncertainty} = (\text{Absolute uncertainty} \div \text{value (mean)}) \times 100$$

The mean certainties calculated at Table 1 are absolute uncertainties so first, they are turned to percentage uncertainty.

Average volume of titrant for no UVC exposure is 39.56 ± 5.93 as it is seen at Table 1. The absolute uncertainty is turned to percentage uncertainty.

$$\text{Percentage Uncertainty} = (5.93 \div 39.56) \times 100 = 14.99\ \%$$

When calculating the vitamin C concentration after applying UVC for different durations, molarity is calculated by dividing moles to 0.17 liters whose uncertainty is ± 0.01 or by 0.085 liters whose uncertainty is ± 0.001. Therefore, the percentage uncertainty of the volume is calculated:

$$\text{Percentage Uncertainty} = (0.01 \div 0.17) \times 100 = 5.88\%$$

Percentage Uncertainty = (0.001 ÷ 0.085) × 100 = 1.18%

To calculate the uncertainty of average vitamin C concentraiton, those two uncertainties are added:

14.99 % + 5.88% = 20.87%

This method is applied for all durations and the results are shown at Table 8.

4.2.4 Sample Calculation of Standard Deviation and Standard Error for the Volume of Titrant

Standard deviation is calculated for volume of iodine used during the titration since the vitamin C concentration is calculated with the values of volume of titrant, which is shown at Table 10. The formula of standard deviation is $\sqrt{\frac{\sum(X-\mu)^2}{n-1}}$, where n is the number of values and μ is the mean of the datas. Standard error is $\frac{\sigma}{\sqrt{n}}$, where σ is standard deviation and n is the number of values.

$$\sigma = \sqrt{\frac{(40.2-39.56)^2+(39.1-39.56)^2+(39.6-39.56)^2+(36.8-39.56)^2+(42.1-39.56)^2}{4}}$$

$$\sigma = 1.92$$

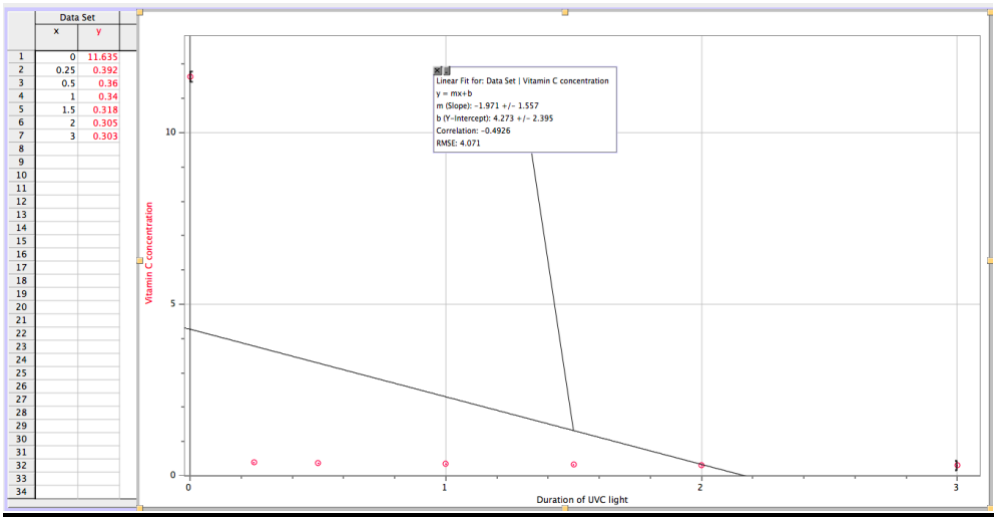
$$\sigma\bar{x} = \frac{\sigma}{\sqrt{n}}$$

$$\sigma\bar{x} = \frac{1.92}{\sqrt{5}} = 0.86$$

When the calculations with those formulas are done for all durations, the values at Table 7 are found.

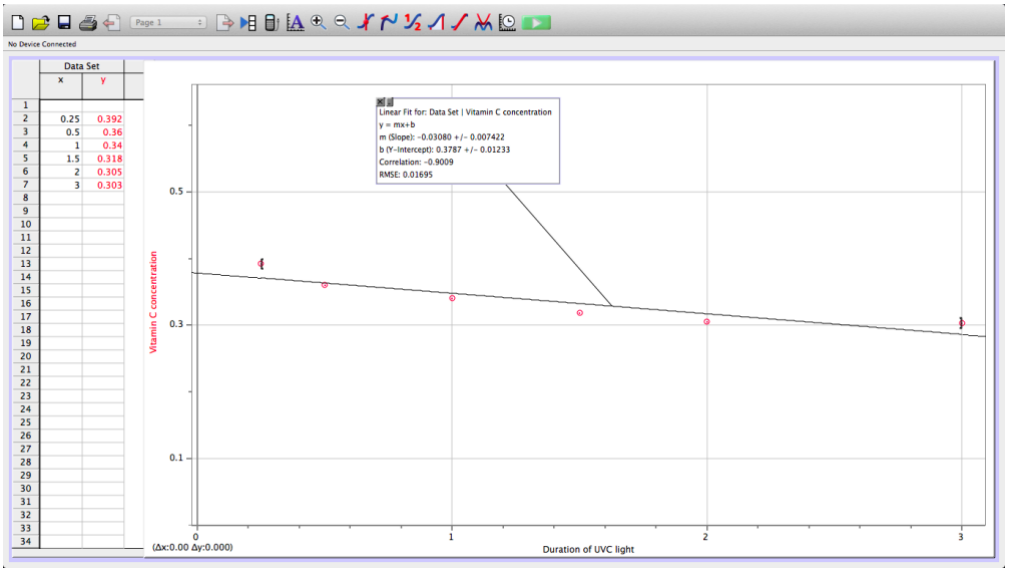
Durations of UV Exposure $\pm$ 0.1	**Average Volume of Iodine (mL)**	**Standard Deviation**	**Standard Error**
0.0 minutes (no UV exposure)	39.56 $\pm$ 5.93	1.92	0.86
15.0 minutes	6.66 $\pm$ 1.01	0.38	0.17
30.0 minutes	6.12 $\pm$ 0.89	0.30	0.14
60.0 minutes	5.78 $\pm$ 0.78	0.27	0.12
90.0 minutes	5.4 $\pm$ 0.67	0.25	0.11
120.0 minutes	5.18 $\pm$ 1.01	0.33	0.15
180.0 minutes	10.3 $\pm$ 3.02	0.97	0.43

Table 7: Calculated Standard Deviation and Standard Error Values of Volume of Iodine



Graph 1: Processed data graph of vitamin C concentration and duration of UVC radiation in hours

After processing data, two graphs are drawed at LoggerPro. As it can be observed from Graph 1, the results obtained are not linear and this is because there is a slight decrease in vitamin C concentration as the duration of UVC radiation increase. There is a big gap between 0.0 minutes of and 15.0 minutes of radiation. Therefore, when the vitamin C concentration at 0.0 minutes is not graphed, the linear decrease is clear.



Graph 2: Processed data graph of vitamin C concentration and duration of UVC radition (without graphing the data of no UVC radiation applied)

Graph 2 shows the linear decrease in vitamin C concentration as the duration of UVC radiation increases. At graph 1, the initial vitamin C concentration, which UVC radiation was not applied, was in the graph too so the linear graph did not fit. Therefore, Graph 2 is more accurate.

4.3 ANALYSIS

4.3.1 Qualitative Analysis

The standard vitamin C solution prepared with a vitamin C tablet and 200 mL of distilled water had a yellow-orange color. Before the titration, addition of starch indicator did not cause any change in the color of the solution. When the aliquots were titrated with iodine which had a brown-red color and dropped from the burette, color change of the sample from its original color to blue-black color complex occured. However, after swirling the solution it disappeared. When the color of the sample turned to blue permanently, the end point was reached.

4.3.2 Sample Calculation of the Vitamin C Concentration After 0.0 Minutes of UV Radiation

$C_6H_8O_6(aq) + I_2(aq) \rightarrow C_6H_6O_6(aq) + 2\ I\text{-}\ (aq) + 2\ H^+(aq)$

$V_{average}$: 39.56 mL

The mol.dm^{-3} of I_2 used in the titration is 5×10^{-2}.

The equation of molarity is $m = \frac{n}{v}$, where n is the moles of solute and v is litres of solution.

$$\text{Therefore } 5 \times 10^{-2} = \frac{n}{39.56 \times 10^{-3}}$$

$$n = 1.978 \times 10^{-3} \text{ moles}$$

Since the molarity of I_2 will be equal to the molarity of $C_6H_8O_6$, molarity (mol.dm^{-3}) of the ascorbic acid is calculated:

$$M = \frac{1.978 \times 10^{-3}}{0.17}$$

$$M = 11.635 \times 10^{-3} \text{ mol.dm}^{-3}$$

In this equation V is 0.17 L since 20 mL of vitamin C standard solution is diluted with 150 mL of distilled water. Also, since 1 L equals to 1 dm^3, there is no need to transform units.

This calculation method is applied for all durations of UVC radiation and is found in Appendix. Vitamin C concentration values are found at Table 8.

4.3.3 Quantitative Analysis

Duration of UVC radiation ($\pm$ 0.1)	**Average vitamin C concentration (mol.dm^{-3})**	**Uncertainty**
0.0 (no UV exposure)	11.635×10^{-3}	± 20.87 %
15.0 minutes	0.392×10^{-3}	± 16.34 %
30.0 minutes	0.360×10^{-3}	± 15.72 %
60.0 minutes	0.340×10^{-3}	± 14.67 %
90.0 minutes	0.318×10^{-3}	± 13.58 %
120.0 minutes	0.305×10^{-3}	± 1.37 %
180.0 minutes	0.303×10^{-3}	± 44.31 %

Table 8: Molarity (mol.dm^{-3}) of vitamin C concentrations at different durations

5. CONCLUSION

UVC light and its effects have been researched since it is used for disinfection. Even though it has been useful for the health sector and especially during the pandemic, there are so many risks due to the usage of UVC light. It causes mutations and harm when in contact with skin so it should be used under the guidance and its sales should be monitored. Application of UVC radiation on

food products has become prevalent because there are some researches indicating that UVC light increases the shelf life of products; however, there is also a fact that UVC light decreases the vitamin C concentration, which is the result we obtained from this investigation.[21] The usage of UVC light should not be underestimated regarding its effect on human beings and food products and the effects of UVC light need further investigation to come to a conclusion about the general usage of UVC light. In this investigation, we worked on the effect of UVC light on vitamin C, which is rich and important nutrition, and found out that as the duration of UVC radiation increases, vitamin C concentration decreases.

6. EVALUATION

6.1 STRENGTHS AND LIMITATIONS

Strengths	Reason it's believed to be a strength
The mean uncertainties of average volume of titrant are less than 1.	The values obtained for the volume of titrant are close to each other which shows that there was slight error or no error.
The methodology is easy to repeat.	Since the methodology is easy to repeat, in case of any mistakes, the trials can be repeated without concern, which decreases the random error.
The values obtained are close to the values found at other experiments	When the values found at other resources like lab reports and the values obtained at this investigation are compared, there is just a slight difference between them. This shows that there is little percentage error.

Table 9: Strengths of the experiments

[21] LSUagcenter. "Ultraviolet Light Could Extend Shelf Life of Food and Reduce Waste." *YouTube*, YouTube, 10 Dec. 2018, https://www.youtube.com/watch?v=GjHSJT90Omw.

Limitation	**Effect of Limitation on the Result of the Investigation**	**Suggested Improvement and Why it will improve the investigation**
Determination of color change (random error)	The end point of each trial of titration is determined according to color change and the volume of iodine needed for the color change is noted. However, since the tone of the color observed is unlikely to be same, there can be a random error.	After the titration is done, a black-blue starch iodine complex is formed, this solution could be kept and compared with the result of the color of the next titration so that the colors where the end point occurs and volume of titrant is recorded are the same.
Inaccurate reading of levels and volume in the beakers (systematic error)	There is a probability that the reading of the values was made from different angles, which could result in inaccurate measurements.	A fixed angle should be determined to read the measurements.
Leaving the samples to stand (systematic error)	Since it is not possible to perform multiple trials at the same time, the samples wait and the vitamin C concentration can change a little bit but not in a way that would create a big difference.	Since the duration of UVC radiation is the independent variable, the titration trials of the shorter duration will be done the first. Therefore the titrations can be done repeatedly.

Table 10: Limitations of the experiment

6.2 SOURCES OF ERROR AND CALCULATED UNCERTAINTY

The errors in this experiment and their comparison with the uncertainties suggest that there is systemic error present. The systemic error occurs due to high number of calculations and measurements. There can be random error too but it is reduced by 5 trials for each duration. The main sources of systematic error are the possible inaccurate reading of measurements and the samples left standing while the titration is being repeated. Standing samples is a cause of systematic error since the Sun is a UV source and the sunlight comes from the window. One source of random error is the wrong determination of color change since all trials may not have the same tone of blue.

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8. APPENDIX

Calculating vitamin C concentrations for all durations

No UV exposure:

$V_{average}$: 39.56 mL

$$5 \times 10^{-2} = \frac{n}{39.56 \times 10^{-3}}$$

$$n = 1.978 \times 10^{-3}$$

$$M = \frac{1.978 \times 10^{-3}}{0.17}$$

$$M = 11.635 \times 10^{-3}$$

15 minutes:

$V_{average}$: 6.66 mL

$$5 \times 10^{-3} = \frac{n}{6.66 \times 10^{-3}}$$

$$n = 0.0333 \times 10^{-3}$$

$$M = \frac{0.0333 \times 10^{-3}}{0.085}$$

$$M = 0.392 \times 10^{-3}$$

30 minutes:

$V_{average}$: 6.12 mL

$$5 \times 10^{-3} = \frac{n}{6.12 \times 10^{-3}}$$

$$n = 0.0306 \times 10^{-3}$$

$$M = \frac{0.0306 \times 10^{-3}}{0.085}$$

$$M = 0.36 \times 10^{-3}$$

60 minutes:

$V_{average}$: 5.78 mL

$$5 \times 10^{-3} = \frac{n}{5.78 \times 10^{-3}}$$

$$n = 0.0289 \times 10^{-3}$$

$$M = \frac{0.0289 \times 10^{-3}}{0.085}$$

$$M = 0.34 \times 10^{-3}$$

90 minutes:

$V_{average}$: 5.4 mL

$$5 \times 10^{-3} = \frac{n}{5.4 \times 10^{-3}}$$

$$n = 0.027 \times 10^{-3}$$

$$M = \frac{0.027 \times 10^{-3}}{0.085}$$

$$M = 0.318 \times 10^{-3}$$

120 minutes:

$V_{average}$: 5.18 mL

$$5 \times 10^{-3} = \frac{n}{5.18 \times 10^{-3}}$$

$$n = 0.0259 \times 10^{-3}$$

$$M = \frac{0.0259 \times 10^{-3}}{0.085}$$

$$M = 0.305 \times 10^{-3}$$

180 minutes:

$V_{average}$: 10.3 mL

$$5 \times 10^{-3} = \frac{n}{10.3 \times 10^{-3}}$$

$$n = 0.052 \times 10^{-3}$$

$$M = \frac{0.052 \times 10^{-3}}{0.17}$$

$$M = 0.303 \times 10^{-3}$$