JoVE: Science Education

Measuring Tropospheric Ozone

--Manuscript Draft--

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PI: Kimberly Frye and Margaret Workman, DePaul University

Environmental Science Education Title: Measuring Tropospheric Ozone

Overview: Ozone is a form of elemental oxygen (O_3), a molecule of three oxygen atoms bonded in a structure that is highly reactive as an oxidizing agent. Ozone occurs in both the stratosphere and the troposphere levels of the atmosphere. When in the stratosphere (located approximately 10-50 km from earth's surface), ozone molecules form to the ozone layer and help prevent harmful UV rays from reaching Earth's surface. In lower altitudes of the troposphere (surface - approximately 17 km), ozone is harmful to human health and is considered an air pollutant contributing to photochemical smog (figure 1). Ozone molecules can cause damage directly by harming respiratory tissue when inhaled, or indirectly by harming plant tissues (figure 2) and softer materials (figure 3) including tires on automobiles.

Outdoor tropospheric ozone is formed at ground level when nitrogen oxides (NO_x) and volatile organic compounds (VOCs) from automobile emissions are exposed to sunlight. Consequently, health concerns over ozone concentrations escalate in sunny conditions or when and where automobile use is increased.

Indoor tropospheric ozone is formed when electrical discharges from equipment using high voltages (e.g. ionic air purifiers, laser printers, photocopiers) break down the chemical bonds of the atmospheric oxygen (O_2) in the air surrounding the equipment:

$$O_2 \rightarrow 2O$$

The free radicals of oxygen in and around electrical discharge recombine to create ozone (O_3).

$$2O + 2O_2 \rightarrow 2O_3$$

Principles: Tropospheric ozone can be monitored by using a mixture of starch, potassium iodide, and water spread on filter paper. Once dried, the paper, called Schönbein paper, changes color when ozone is present.

The method is based on the oxidation capability of ozone. Ozone in the air will oxidize the potassium iodide on the test paper to produce iodine:

$2KI + O_3 + H_2O \text{--> } 2KOH + O_2 + I_2$

The iodine then reacts with the starch, staining the paper a shade of violet. The intensity of the color depends on the amount of ozone present in the air. The darker the color, the more ozone is present:

I_2 + starch → violet color

Ozone concentration is sampled at different sites of higher risk including parking lots, garages, parkways, and corners of heavily trafficked streets. Indoor sites include room and spaces with equipment involving ink printing such as copiers.

Procedure:

1. **Schönbein Paper Preparation**

    1.1. Place 100 ml of distilled water in a 250 ml beaker.

    1.2. Add 1 1/4 teaspoon of cornstarch.

    1.3. Place a stir bar in the beaker and place the beaker on a hot/stir plate. Heat and stir the mixture slowly until it gels. The mixture is gelled when it thickens and becomes somewhat translucent.

    1.4. Remove the beaker from the heat source, add 1/4 teaspoon of potassium iodide, and stir well.

    1.5. Cool the solution before applying to the filter paper.

    1.6. Lay a piece of filter paper on a glass plate, or hold it in the air, and carefully brush the paste onto the filter paper. Turn the filter paper over and do the same on the other side. Try to apply the paste as uniformly as possible.

    1.7. Set the paper out overnight and away from sunlight or place in a low temperature (20° C) drying oven to dry.

    1.8. Once paper is dry, use scissors to cut the filter paper into 1-inch wide strips. If storing the paper for later use, place the strips in a sealable plastic bag or glass jar out of direct sunlight.

2. **Measuring Ozone**

2.1. Spray a strip of test paper with distilled water and hang it at a data collection site out of direct sunlight. Ensure the strip hangs freely and unobstructed.

2.2. Expose the paper for approximately eight hours. Note where each strip was hung.

2.3. After exposure, seal the strip in an airtight container if the results will not be recorded immediately.

2.4. To observe and record test results, spray the paper with distilled water.

2.5. Observe the color by comparing it to the provided color scale and recording the corresponding Schönbein number.

Representative Results

Use the Schönbein number scale (figure 4) for quantitative analysis of ozone. The chart is used to compare with sample papers after 8 hours of exposure at sample locations. Score increases with increasing color intensity, with the darkest violet on the right side of the scale. Results should vary based on where collection site was (figure 5).

Applications: Tropospheric ozone exposure is harmful to human health, known to cause chest pain, coughing, throat irritation, and congestion. Ozone also interferes with lung function, exacerbating symptoms of bronchitis, emphysema, and asthma, and can permanently damage lung tissue.

Outdoor locations of increased amounts of sunlight and urban areas experience higher levels of tropospheric ozone due to increased amount and density of nitrate emissions. Indoor locations where copy machines and ink printers are used are also high-risk areas for ozone exposure.

Legend:
Figure 1: Golden Gate Bridge panorama
Characteristic coloration for smog in California in the beige cloud bank behind the Golden Gate Bridge. The brown coloration is due to the NOx in the photochemical smog.
By Aaron Logan - http://www.lightmatter.net/gallery/Travel/ggb

Figure 2: Plants damaged by ozone. Top row is normal, bottom row has been exposed to ozone.

Figure 3: Ozone cracks in natural rubber tubing.

Figure 4: Schönbein Number Scale

Figure 5. Graph of sample ozone concentrations.
Outdoor and indoor tropospheric ozone concentrations shown by site and Schönbein score.

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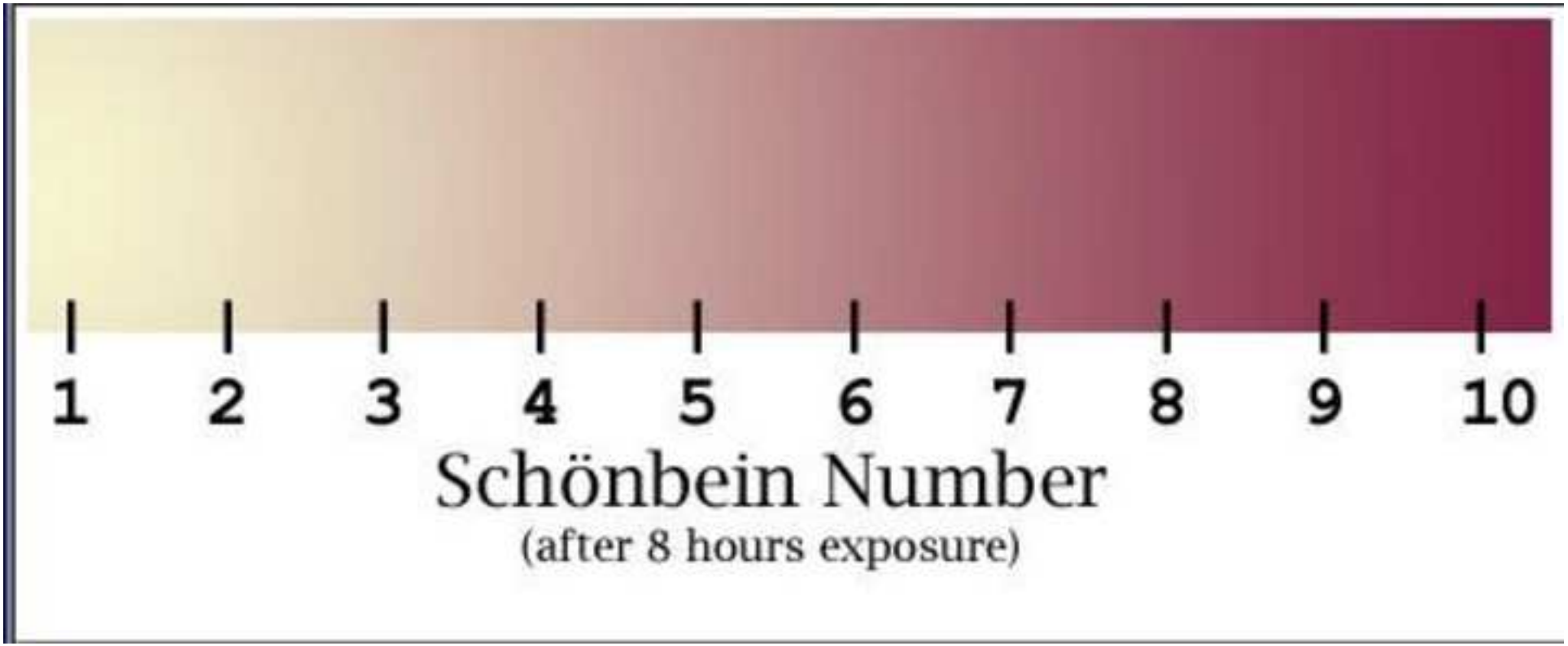

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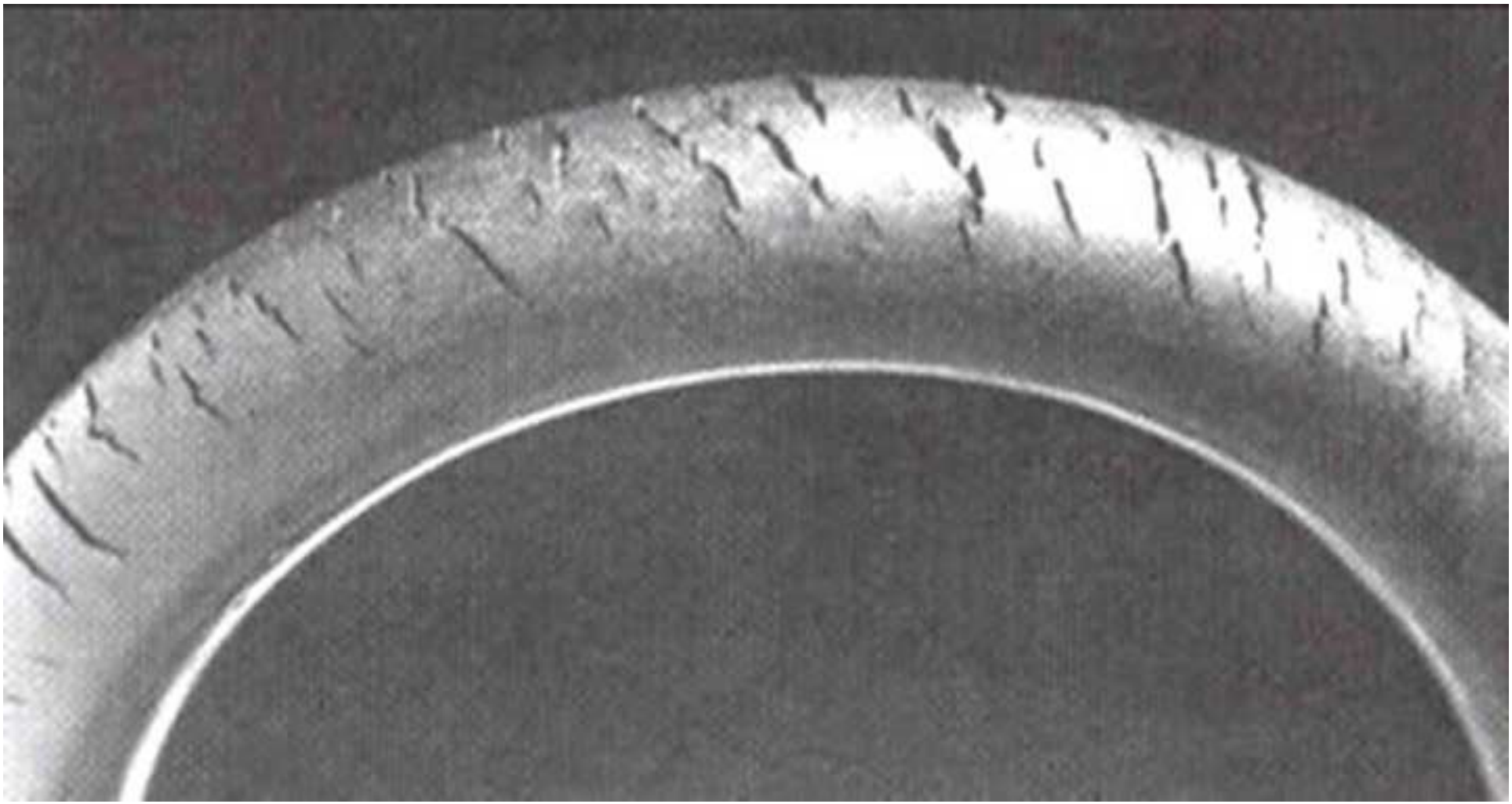

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Outdoor tropospheric ozone is formed at ground level when nitrogen oxides (NO_x) and volatile organic compounds (VOCs) from automobile emissions are exposed to sunlight. Consequently, health concerns over ozone concentrations escalate in sunny conditions or when and where automobile use is increased.

Comment [1]: Is there a generic reaction(s) we can give for this process, or is it too complex?

Reaction 1: NO2 + VOC + sunlight → NO + O

Reaction 2: O + O2 → O3

Indoor tropospheric ozone is formed when electrical discharges from equipment using high voltages (e.g. ionic air purifiers, laser printers, photocopiers) break down the chemical bonds of the atmospheric oxygen (O_2) in the air surrounding the equipment:

$$O_2 \rightarrow 2O$$

The free radicals of oxygen in and around electrical discharge recombine to create ozone (O_3).

$$2O + 2O_2 \rightarrow 2O_3$$

Principles: Tropospheric ozone can be monitored by using a mixture of starch, potassium iodide, and water spread on filter paper. Once dried, the paper, called Schönbein paper, changes color when ozone is present.

The method is based on the oxidation capability of ozone. Ozone in the air will oxidize the potassium iodide on the test paper to produce iodine:

$$2KI + O_3 + H_2O \rightarrow 2KOH + O_2 + I_2$$

The iodine then reacts with the starch, staining the paper a shade of violet. The intensity of the color depends on the amount of ozone present in the air. The darker the color, the more ozone is present:

$$I_3^- + \text{starch} \rightarrow \text{violet color}$$

Ozone concentration is sampled at different sites of higher risk including parking lots, garages, parkways, and corners of heavily trafficked streets. Indoor sites include room and spaces with equipment involving ink printing, such as copiers.

Procedure:

1. **Schönbein Paper Preparation**

1.1. Place 100 ml of distilled water in a 250 ml beaker.

1.2. Add 1 1/4 teaspoon of cornstarch.

1.3. Place a stir bar in the beaker, and place the beaker on a hot/stir plate. Heat on a medium to high setting, and stir the mixture slowly until it gels near approximately 90° C. The mixture is gelled when it thickens and becomes somewhat translucent.

Comment [2]: Can you give a range of temperate and time until it gels?

1.4. Remove the beaker from the heat source, add 1/4 teaspoon of potassium iodide, and stir well.

1.5. Cool the solution before applying to the filter paper.

1.6. Lay a piece of filter paper on a glass plate or hold it in the air, and using a small paint brush, carefully brush the paste onto the filter paper. Turn the filter paper over and do the same on the other side. Try to apply the paste as uniformly as possible.

Comment [3]: What do you use to do this? Stirring rod?

1.7. Set the paper out overnight and away from sunlight, or place in a low temperature (20° C) drying oven to dry.

1.8. Once the paper is dry, use scissors to cut the filter paper into 1-inch wide strips. If storing the paper for later use, place the strips in a sealable plastic bag or glass jar, out of direct sunlight.

2. Measuring Ozone

2.1. Spray ~~a~~ strips of test paper with distilled water and hang a minimum of~~a~~ three strips ~~it~~ at each~~a~~ data collection site out of direct sunlight. Hang~~ing can be~~ by securely taping or tacking one end of the strip to a structure (e.g. wall, parking blocks, light poles). Strips can also be hung using wire with one ~~s~~end driven into the ground and the other end secured to the strip. Ensure the strips hang ~~freely and~~ unobstructed.

2.2. Expose the paper for approximately eight hours. Note where each strip was hung, and use weather data to record relative humidity location during paper exposure. Alternatively, a psychrometer can be used to measure relative humidity of each site.~~.~~

2.3. If the results will not be recorded immediately, seal the strip in an airtight container after exposure.

2.4. To observe and record test results, spray the paper with distilled water.

2.5. Observe the color by comparing it to the provided color scale and recording the corresponding Schönbein number. Calculate the average Schönbein number for each site.

~~2.5.~~**2.6.** Use the relative humidity data for each site and the Relative Humidity Schönbein Number Chart to convert Schönbein site averages to ozone concentration (ppb).

Representative Results: Use the Schönbein number scale (Figure 4) for quantitative analysis of ozone. The chart is used to compare with sample papers after 8 hours of exposure at sample locations. Use the Relative Humidity Schönbein Number Chart to convert Schönbein scores to ozone concentration (ppb) (Figure 5).

Score increases with increasing color intensity, with the darkest violet on the right side of the scale. Results should vary based on the location of the collection site (Figure 6~~5~~).

Applications: Tropospheric ozone exposure is harmful to human health, known to cause chest pain, coughing, throat irritation, and congestion. Ozone also interferes with lung function, exacerbating symptoms of bronchitis, emphysema, and asthma, and can permanently damage lung tissue.

Comment [4]: Is there a certain stip/m2 value you use? Is there a minimum number to hang?

Comment [5]: Can the Schinbein number be converted to an absolute concentration?

Comment [6]: Yes, humidity data is required for the conversion so I added a procedural step for that. Also requires another chart (I don't have rights to it though it's widely distributed in classrooms for use).

Outdoor locations of increased amounts of sunlight and urban areas experience higher levels of tropospheric ozone due to increased amount and density of nitrate emissions. Indoor locations where copy machines and ink printers are used are also high-risk areas for ozone exposure. Current US thresholds for ozone, set by the Office of Safety and Health, is 0.1 ppm with health risks including headache, irritation to eyes, nose and throat, brain and nervous system damage, lung damage, chronic respiratory disease, pulmonary congestion, edema, and hemorrhage.

Legend:
Figure 1: Golden Gate Bridge panorama
Characteristic coloration for smog in California in the beige cloud bank behind the Golden Gate Bridge. The brown coloration is due to the NOx in the photochemical smog.
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Figure 2: Plants damaged by ozone. Top row is normal, bottom row has been exposed to ozone.

Figure 3: Ozone cracks in natural rubber tubing.

Figure 4: Schönbein Number Scale

Figure 5. Relative Humidity Schönbein Number Chart

Figure 6~~5~~. Graph of sample ozone concentrations.
Outdoor and indoor tropospheric ozone concentrations shown by site and Schönbein score.

Comment [7]: I'm not sure what specifically to add here to address the feedback asking for more detail on the difference between outdoor/indoor levels. There are no differences between outdoor/indoor levels. In both cases it's a presence/absence test and any presence of ozone is considered harmful to human health.

The only real difference is that the indoor sites would need less test strips (replicates) because they're enclosed spaces whereas outdoor sampling sites would geographically be larger. Another way to state this would be that indoor areas are always higher concern because of less ventilation...

Is this the kind of more detail needed?

Comment [8]: We found an OSHA threshold limit https://www.osha.gov/dts/chemicalsampling/data/CH_259300.html

There is no distinction between indoor and outdoor threshold limits or health effects.

Comment [JR9]: Author says she was unable to find public domain images for Figure 4 and 5. Is it possible for us to recreate these?

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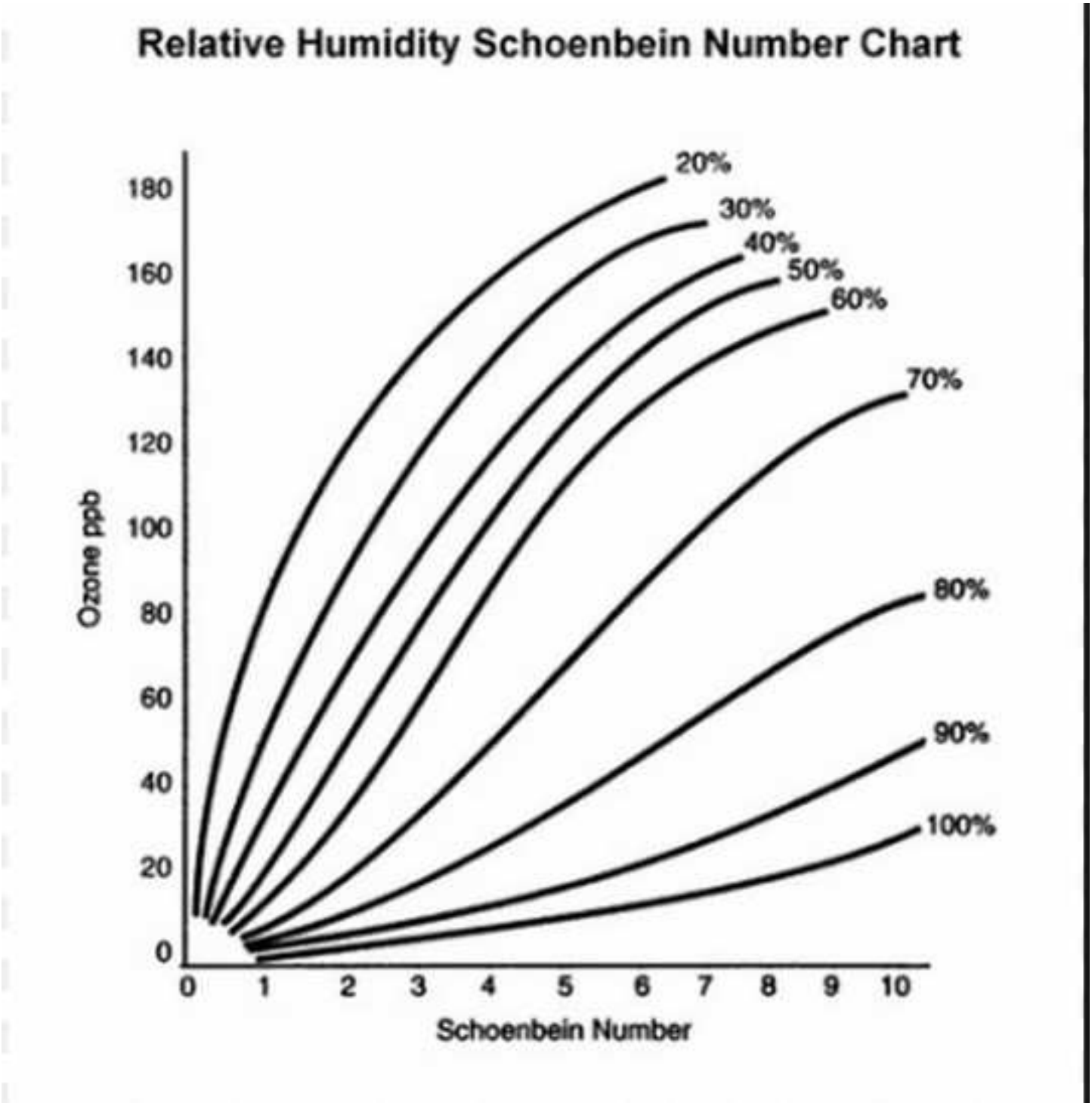

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