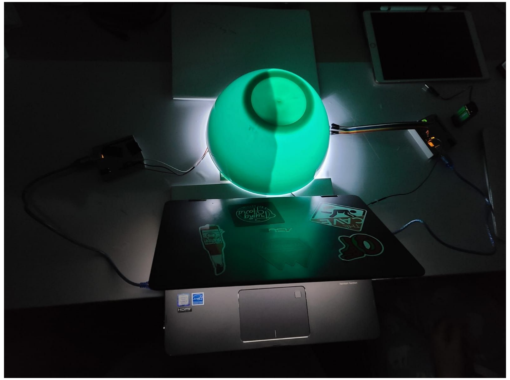
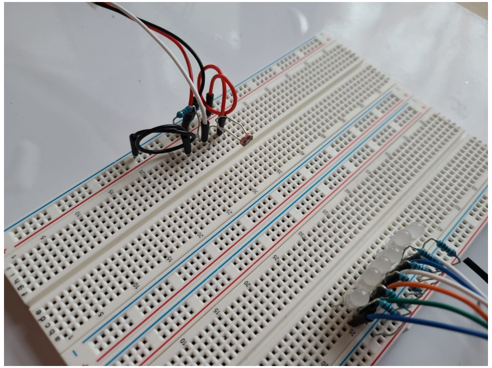
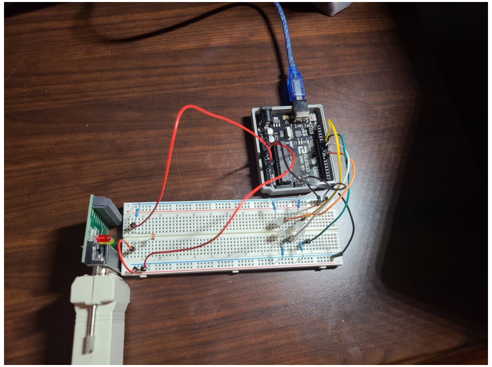
Determination of Light Attenuation of Various Materials







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Team Contribution

Aidan Sirbu: Lead Engineer; Lux Meter Calibration; Arduino Coder; Presenter

Katie Brown: Lead Researcher; Light Attenuation Data Collection; Presenter

Harold Smith-Perez: Data Analyst; Co-researcher; Experimental design

Lindsey Simpson: Spokesperson; Presentation format and design; Co-researcher

Bhapushon Thayalan: Oversaw experiment progress; Presentation format and design; Co-researcher

Background

Light Attenuation: *the reduction in light intensity as it travels through a medium as a result of the scattering and absorption of photons*

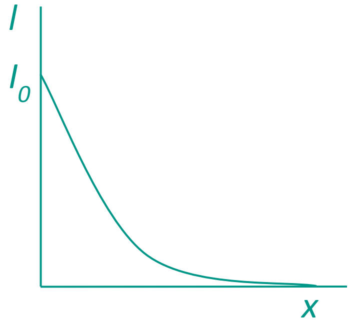
linear attenuation coefficient

length over which the attenuation takes place

Transmitted intensity

$$I = I_0 e^{-\mu x}$$

Incident intensity



Linear Attenuation Coefficient: *Quantifies the degree to which a volume of material can be penetrated by a wave or particle*

➔ *The greater the μ value, the more rapidly the intensity decreases as it travels through the medium.*

Photoresistor Calibration

Question

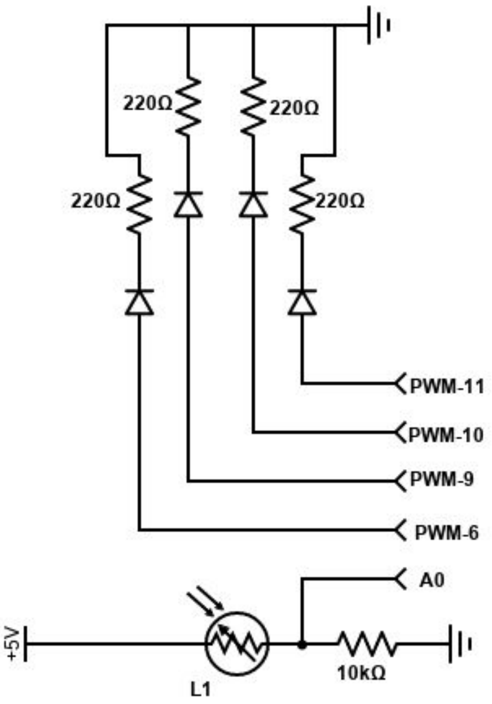
➔ *Which circuit variable should we measure?*

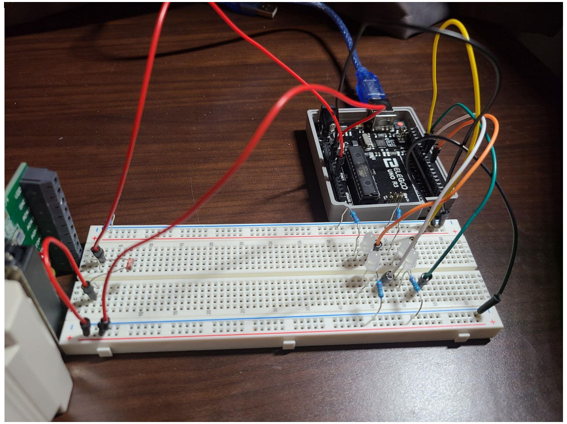
Relation

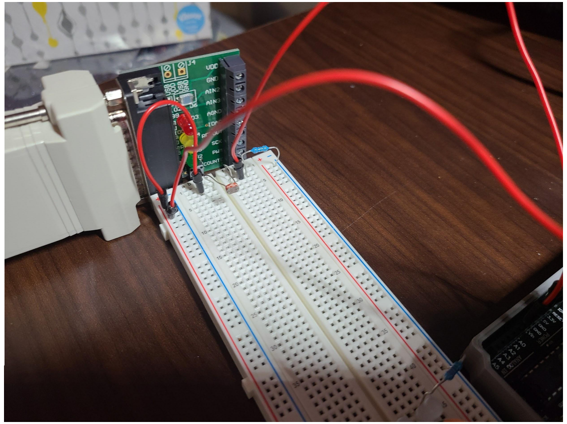
➔ *Lux expected to vary exponentially with resistance of photoresistor*

Limitation

➔ *Positioning of Lux meter*







Photoresistor Calibration

Circuit Variable Chosen

- ➔ *Voltage across 10kΩ resistor*

Challenges

- ➔ *Converting analog input to voltage*
  - ◆ ***Problem:** Produced truncation error*
  - ◆ ***Solution:** Took raw analog input instead*
- ➔ *Quickly varying analog input*
  - ◆ ***Problem:** Flooded serial monitor with large range of values*
  - ◆ ***Solution:** Took average over 100 iterations*

Experiment

- ➔ *Performed in dark room*
- ➔ *Bowl with white interior (good reflectivity) placed over circuit*

Photoresistor Calibration

Relation derivation

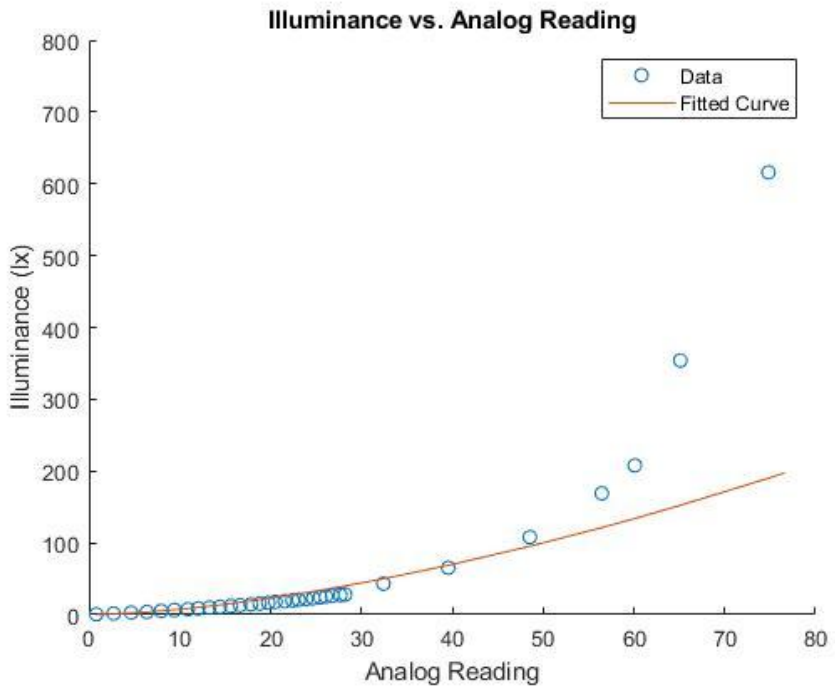
$$\ln(lux) = c_1 + c_2 \ln(input)$$

$$\ln(lux) = -1.6453 + 1.5974 \ln(input)$$

$$lux = e^{(-1.6453 + 1.5974 \ln(input))}$$

$$lux = e^{-1.6453} \times input^{1.5974}$$

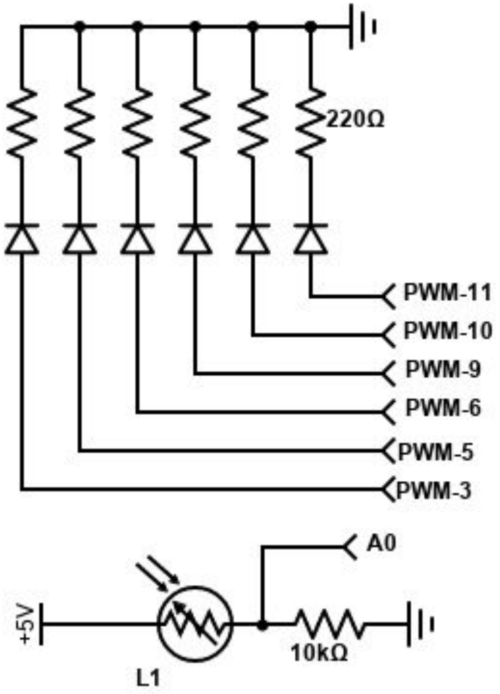
Plot of Data

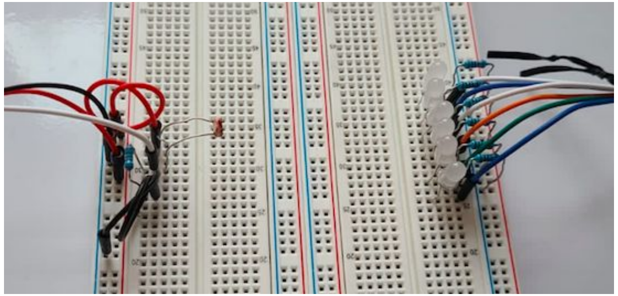


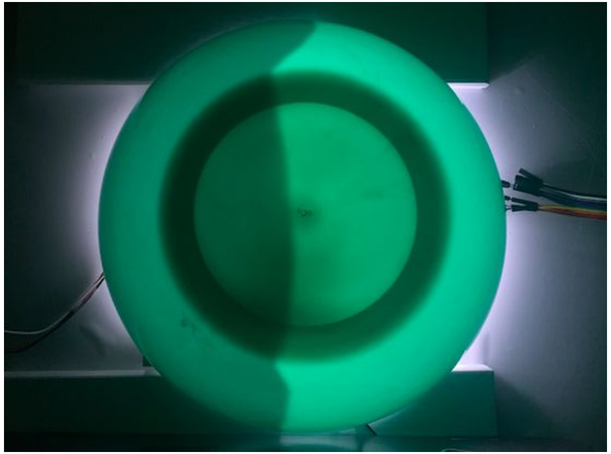
Attenuation Factor: Experiment

Experimental Design

- ➔ *Photoresistor calibrated to measure illuminance facing 6 LED’s*
- ➔ *Placed layers of material in between*
- ➔ *Measured the fraction of light that was transmitted through the material*
- ➔ *Repeated for printer paper, tissue paper and sheet protectors*





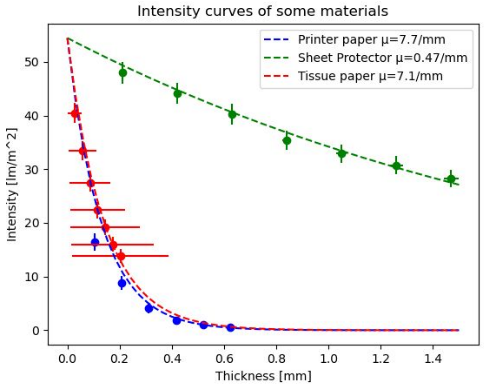


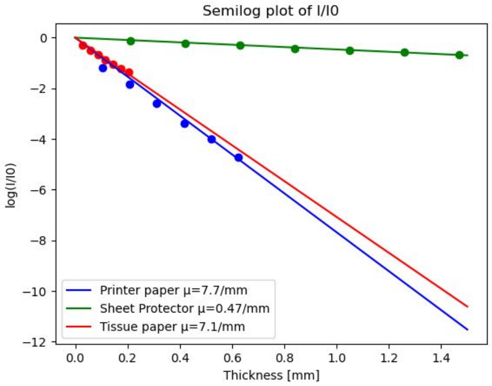
Attenuation Factor Results

Data Analysis

- ➔ *Measured illuminances were plotted against material thickness*
- ➔ *Python Scipy was used to optimize curve of best fit*
- ➔ *Semilog plot was generated in order to determine the attenuation factor, which is the slope*

Material	*Light Attenuation Factor*
Printer Paper	μ = 7860 m^{-1}
Sheet Protectors	μ = 7076 m^{-1}
Tissue Paper	μ = 465 m^{-1}



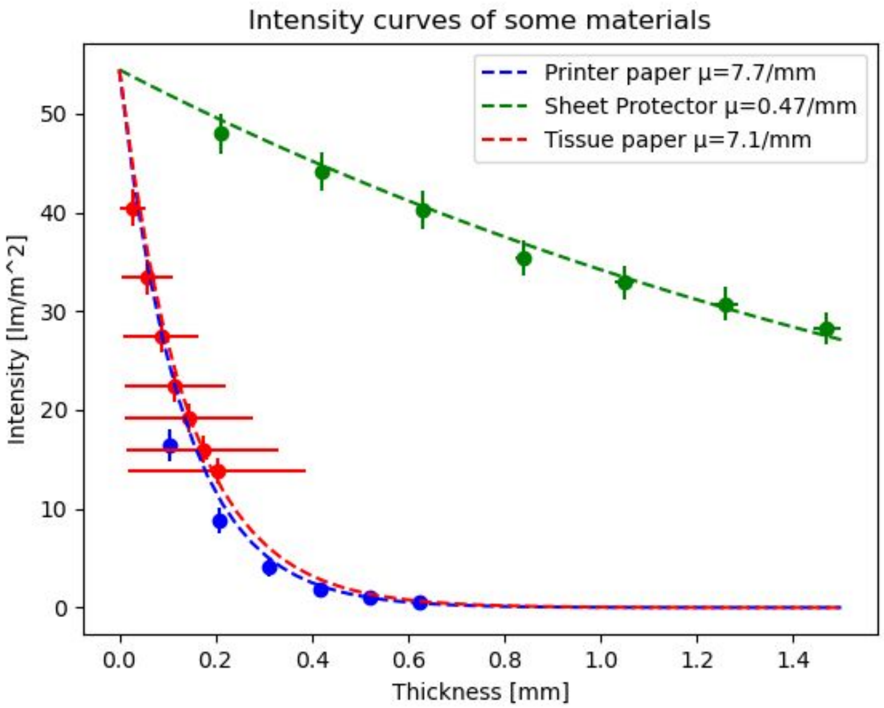


Attenuation Factor Results

Uncertainty Propagation in Illuminance

$$\begin{aligned}
\delta(input) &= 0.01 \\
\frac{\delta(input^{1.5974})}{(input^{1.5974})} &= 1.5974\frac{\delta(input)}{input} \\
\delta(input^{1.5974}) &= (input^{1.5974}) \cdot 1.5974\frac{0.01}{input} \\
\delta lux &= \delta(e^{-1.6453}(input)^{1.5974}) \\
\delta lux &= e^{-1.6453}(input^{1.5974}) \cdot \frac{1.5974 \times 10^{-2}}{input}
\end{aligned}$$

Conclusion & Key Takeaways



Applications of Light Attenuation

➔ *Sunlight decreasing with depth of water determines where photosynthetic algae can live*

➔ *Attenuation decreases strength of signals in fibre optic cables*

➔ *Seismic waves from Earthquakes are attenuated by the ground*

Appendices

Plot Code:

```
import numpy as np
import matplotlib.pyplot as plt
import scipy.optimize as scop

I0 = 54.44

def get_data(filename):
    df = np.loadtxt(filename, skiprows=2,dtype=float)
    thickness = df[:,1]; err_th = df[:,5]
    lux = df[:,2]; err_lx = df[:,4]
    return thickness, err_th, lux, err_lx


def fit_data(thickness, err_th, lux, err_lx):
    func2fit = lambda x, mu: -mu*x
    loglux = np.log(lux/I0)
    mu, err = scop.curve_fit(func2fit, thickness, loglux,sigma=err_lx)
    err = np.sqrt(np.diag(err))
    logerr = abs(np.log((lux+err)/I0) - loglux)
    return mu, err, loglux, logerr


x1, err_x1, I1, err_I1 = get_data('printer_pape.txt')
x2, err_x2, I2, err_I2 = get_data('sheet_pros.txt')
x3, err_x3, I3, err_I3 = get_data('tissue_pape.txt')

mu1, std1, logI1, err_logI1 = fit_data(x1, err_x1, I1, err_I1);print(mu1, std1)
mu2, std2, logI2, err_logI2 = fit_data(x2, err_x2, I2, err_I2);print(mu2, std2)
mu3, std3, logI3, err_logI3 = fit_data(x3, err_x3, I3, err_I3);print(mu3, std3)

plt.scatter(x1, I1, c='b')
plt.errorbar(x1, I1, yerr=err_I1, xerr=err_x1, ls='None', c='b')
plt.scatter(x2, I2,c='g')
plt.errorbar(x2, I2, yerr=err_I2, xerr=err_x2, ls='None',c='g')
plt.scatter(x3, I3,c='r')
plt.errorbar(x3, I3, yerr=err_I3, xerr=err_x3, ls='None',c='r')

x = np.linspace(0,0.0015)
plt.plot(x,I0*np.exp(-mu1*x),ls='--', label='Printer paper \u03BC=7.7/mm', c='b')
plt.plot(x,I0*np.exp(-mu2*x),ls='--', label='Sheet Protector \u03BC=0.47/mm',c='g')
plt.plot(x,I0*np.exp(-mu3*x),ls='--', label='Tissue paper \u03BC=7.1/mm',c='r')

plt.xlabel('Thickness [mm]')
tix = plt.xticks()[0][1:-1]
plt.xticks(ticks=tix,labels=[str(round(i,2)) for i in tix*1000])
plt.ylabel('Intensity [lm/m^2]')
plt.title('Intensity curves of some materials')

plt.legend()
plt.show()

plt.scatter(x1, logI1, c='b')
#plt.errorbar(x1, logI1,xerr=err_x1,yerr=err_logI1, ls='None',c='b')
plt.plot(x, -mu1*x,label='Printer paper \u03BC=7.7/mm',c='b')

plt.scatter(x2, logI2, c='g')
#plt.errorbar(x2, logI2,xerr=err_x2,yerr=err_logI2, ls='None',c='g')
plt.plot(x, -mu2*x,label='Sheet Protector \u03BC=0.47/mm',c='g')

plt.scatter(x3, logI3, c='r')
#plt.errorbar(x3, logI3,xerr=err_x3,yerr=err_logI3, ls='None',c='r')
plt.plot(x, -mu3*x,label='Tissue paper \u03BC=7.1/mm',c='r')

plt.title('Semilog plot of I/I0')
plt.xlabel('Thickness [mm]')
plt.ylabel('log(I/I0)')
tix = plt.xticks()[0][1:-1]
plt.xticks(ticks=tix,labels=[str(round(i,2)) for i in tix*1000])
plt.legend()
plt.show()
```

Error Code:

```
Experiment 1: Printer Paper
Sheets     Thickness (m)          Illuminance (lx)       Input      Error in Illuminance  Error in Thickness
1          0.000104   16.5        16.19882   1.6271002222.00E-06
2          0.000208   8.76        10.89786   1.2840342144.00E-06
3          0.000312   4.12        6.796004   0.9684055726.00E-06
4          0.000416   1.84        4.102966   0.7163638068.00E-06
5          0.00052    1           2.801027   0.5702907731.00E-05
6          0.000624   0.49        1.792152   0.43675213 1.20E-05
```

```
Experiment 2: Sheet Protectors
Sheets     Thickness (m)          Illuminance (lx)       Input      Error in Illuminance  Error in Thickness
1          0.00021    47.98       23.38731   2.02627238 4.17E-06
2          0.00042    44.16       22.20364   1.9643677098.33E-06
3          0.00063    40.23       20.94516   1.8970742441.25E-05
4          0.00084    35.35       19.3164    1.8075121621.67E-05
5          0.00105    32.89       18.46357   1.7594057862.08E-05
6          0.00126    30.71       17.68766   1.7148545622.50E-05
7          0.00147    28.26       16.79061   1.6623545352.92E-05
```

```
Experiment 3: Tissue Paper
Sheets     Thickness (m)          Illuminance (lx)       Input      Error in Illuminance  Error in Thickness
1          0.000029   40.46       21.02004   1.9011231542.63E-05
2          0.000058   33.42       18.64927   1.7699557865.26E-05
3          0.000087   27.49       16.50273   1.6452686627.89E-05
4          0.000116   22.37       14.50514   1.52321812 1.05E-04
5          0.000145   19.18       13.17325   1.4380485591.32E-04
6          0.000174   16.02       11.76921   1.34441486 1.58E-04
7          0.000203   13.82       10.72964   1.2721567931.84E-04
```