Physics 12 IB Group4 **Paper Density and Light Intensity**

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1 Problem Statement

To determine if there exists a relationship between the density of a specific kind of paper and the percent loss of light Γ.

2 Theoretical Introduction

2.1 Background

It is already a known fact that a certain percentage of light is lost when light passes through any object. In this experiment, the relation between these percentages are to be recorded and compared for translucent objects of roughly the same material and composition. In order to conduct this comparison, it was decided to use sheets of paper as the translucent material. Light will thus be shone through up to 8 sheets of 6 different types of paper to experimentally determine whether or not such a relationship exists.

Notes

1. The density of a material is the mass of material per unit volume.
2. The value Γ is the percent loss of light when passed through a translucent material.
3. Candela (abbreviated *cd*) – A unit of luminous intensity equal to $\frac{1}{60}$ of the luminous intensity per square centimeter of a blackbody radiating at the temperature of solidification of platinum (2,046). Also called candle.

There is an exponential relationship between the intensity I of light that is allowed to pass through paper, and the relative thickness t (in μm) of that paper. This relationship can be described mathematically:

$$I = I_0 k^t \tag{1}$$

where I_0 is the intensity of a normal beam of light, and k is the paper constant. The paper constant k is related to the percent loss of light Γ per micrometer unit of paper thickness t by:

$$\Gamma = (1 - k) \times 100\% \tag{2}$$

2.2 Hypothesis

We believe there is a relationship between the density of paper and the amount of light that is lost when passed through it. When the density d of the paper increases, the molecules within the paper are more closely spaced and so more light would be obstructed and thus the percent loss Γ would be high.

On the contrary, paper with highly spaced-out molecules have a much lower density. This creates gaps between the molecules through which light can pass, and so the percent loss Γ would be small.

We hypothesize that there will be a linear relationship between the two variables d (paper density) and Γ (percent loss of light). Qualitatively speaking, if the density of the sheet of the paper were to double, twice as much light would be obstructed. Similarly, if we were to halve the density of paper used, the percent loss of light Γ would also halve. In other words, halving the paper density would mean twice as much light would be allowed to pass through the paper.

2.3 Investigation Methodology

The investigation methodology outlines the theoretical reasons for why we chose this method to conduct the investigation.

We chose this method for this investigation because we felt it was the most reliable and the most effective in terms of time and cost. By using several different types of paper, we would be able to compare each result-set and find a common relation, if there existed one. We chose to use several sheets of each type of paper as this will enable us to find discrepancies (if any) and lead us to a more reliable conclusion. The choice to use bulbs of varying wattages was motivated in order to verify if the sheets of paper blocked out the same percentage of light, no matter how much light is shone through.

3 Variables

Independent

- Bulb wattage
- Type of paper (and therefore density)
- Paper stack thickness t

Dependent

- The intensity of light I that passes through paper

Controlled

- Distances between set-up materials
- Size of opening of slit mask
- Bulb wattage

3.1 List of Symbols

I = Light intensity passing through paper
I_0 = Relative intensity measured without any paper
k = Paper constant
t = Thickness of paper stack
d = Density of paper
Γ = Percent loss of light

4 Materials Required

1. 6 different kinds of paper of varying thickness and composition (8 sheets of each kind)
2. Light bulbs (40W and 60W) and socket
3. Micrometer screw gauge
4. High precision electronic weighing scale
5. DataStudio light intensity sensor and software
6. Meter stick
7. Cardboard box

5 Procedure

1. Set-up the equipment (see diagram on poster) and make note of the distances between the light-bulb, the paper stack and the sensor.
2. Connect the DataStudio intensity measuring sensor to the USB port of the computer. Initialize the software and prepare the device for data harvesting.
3. Record the light intensity of the surroundings while the light bulb is off (if significant).
4. Turn on the light bulb, and place the hole-punched cardboard box over it.
5. Making sure the sensor is lined up with the hole in the cardboard box, record the initial intensity I_0 with no obstructing paper.
6. Take one sheet of one type of paper (of the 5 types) and hold it tight against the box so that it covers the hole. Record the light intensity once the graph has stabilized.
7. Repeat the previous step with 2, 3 and up to 8 sheets of paper.
8. Follow the same procedure for all 5 types of paper.
9. Switch the bulb to a different wattage, and repeat steps 5 through 8.

10. Construct a thickness vs. intensity graph and calculate the paper constant k for each type of paper (and possibly for each bulb).
11. Determine the density d of each type of paper by taking appropriate measurements.
12. Graph a density vs. paper-constant graph and determine the relationship between the two variables.

6 Data Collection

Attached

7 Data Analysis

	Density	Γ_{40}	Γ_{60}
1	0.429	71.534	65.485
2	0.772	63.928	55.689
3	0.773	65.259	57.881
4	0.794	75.400	69.643
5	0.840	58.112	55.729

Table 1: Density vs. Percent Loss

See also attached graph

8 Evaluation

8.1 Conclusion

By analyzing the graph that shows the variation of the percent loss of light Γ with the corresponding density, it seems that there is absolutely no relationship between the two variables. Although the results seem to be totally random, we cannot discard the experiment easily and come to a fallacious judgement that there is absolutely no constant relationship between a paper's density d and the percentage of light it blocks when light is shone through it.

There are a few reasons as to why it was difficult to deduce useful results from this experiment. Most importantly, we did not have enough data points to come to a valid conclusion. This makes it impossible to say with certainty whether the results form a random distribution or whether there really exists a mathematical pattern to it. Moreover, the data points that we did obtain were too erroneous to use to formulate patters, and thus couldn't be used as proof to support our "paper constant" theory. Secondly, even minor errors in our procedures, measurements and calculations were magnified in the order of thousands because of the exponential operations conducted on our data. For example, while trying to use a micrometer gauge to measure the thickness of a piece of paper, the relative error involved out-shadowed the difference in thickness between any two pieces of paper, even if they were of the same kind.

Nonetheless, the lab was successful in revealing an important relationship between the bulb wattage W that was used as the light source and the percent loss of light Γ. A complete ratiocination of this relationship is beyond the scope of the experiment; however, the relationship may be informally summarized as follows:

The percent loss of light Γ is proportional to the initial intensity I_o that is shone without any obstructing paper.

In other words, increasing the initial intensity I_o of light that is shone through, which in our case is the bulb wattage, increases the percentage of light that is lost as a result of obstruction. *This relationship is independent of the type or kind of paper used.* We proceed to generalize that this relationship between the relative light intensity I_o and the percent loss of light Γ holds true for any kind of translucent substance, such as glass, diamond or even plastic. We infer this conclusion by observing that the two curves in the attached graph are simply functional transformations of one another.

8.2 Limitations

There were a number of limitations that had to be overcome while trying to conduct this lab, both in terms of the materials used as well as the procedures followed. Using a micrometer screw gauge to measure the thickness of a sheet of paper, for example, wasn't always the best idea, as the screw gauge works best for firm, solid and fixed-volume objects. Also, even though we used the same type of paper to record the intensity of light that passed through it, we were highly uncertain if each sheet of paper had exactly the same thickness. These were some of the experimental limitations with respect to our materials and procedures.

8.3 Experimental Refinements

If we were to redesign this lab from scratch, we would take into consideration the following points:

1. Use another material other than plain paper.
2. Establish a *control* variable to compare results to.
3. Use a more appropriate (but equally precise) device to measure thickness.
4. Base findings on a third property of the substance used.
5. Take larger readings so that *relative* errors remain small and insignificant.

9 Technical Details

The availability of scientific instruments in high schools is usually limited; ergo, it is of no doubt that real scientists, having advanced technology at their disposal, may wish to repeat our experiment and obtain more practical results. In conducting our experiment, we used five different kinds of paper; however, two of the types were almost exactly the same. The rest were normal sheets of paper (except paper no. 2). Scientists would have in their inventory a much larger variety of paper that could satisfy this experiment. It is our belief that the difference between the papers chosen was partly why this part of the experiment was unsuccessful. Furthermore, scientists would have bulbs of different wattages, enabling them to repeat the part of our experiment that yielded useful results. In order to verify these conclusions experimentally, we would need several wattages of light bulbs, some of which we did not have access to. There is thus tremendous room to extend this lab and conduct further analysis into the mysteries of our “paper constant” theory.
