Student Worksheet

Light Extraction by Changing Composition of Material

Introduction:

"*Nothing can travel faster than the speed of light.*"
"*Light always travels at the same speed.*"

These two misleading statements are generally quoted as results of Einstein's Theory of Relativity. The fact of the matter is that the speed of light in a vacuum is always the same: 3.0×10^8m/s, and light travels the fastest in a vacuum. In any medium, the particles present in the medium scatter the light and the speed changes depending on the composition of the medium through which the light is traveling. Many waves behave the same way by slowing down in different media. This property of the material is called the *index of refraction* and is expressed as a ratio of the speed of light in a vacuum and the speed of light in the medium.

$$\text{index of refraction (n)} = \frac{\textit{speed of light in a vacuum } (c)}{\textit{speed of light in a medium } (v)}$$

Materials with increased index of refraction are needed in industry for anti-reflective coatings ~~and~~ in photonic devices~~,~~ such as light emitting diodes (LEDs) and image sensors. LEDs are a particular type of diode that convert electrical energy into light using semiconductors and electroluminescence. The light from the LEDs primary optic is too broad for most applications, lacking intensity over distance. The LED uses a small semiconductor crystal with reflectors and other parts to make the light brighter and focused into a single point. The wavelength of the light depends on the energy band gap of the semiconductors used.

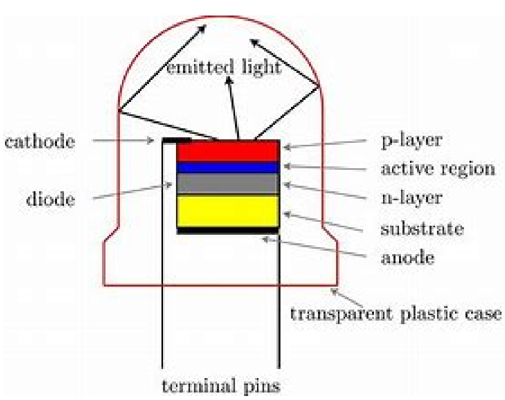

Figure 1. Diagram of a light emitting diode. https://commons.wikimedia.org/wiki/File:LED_Device.jpg

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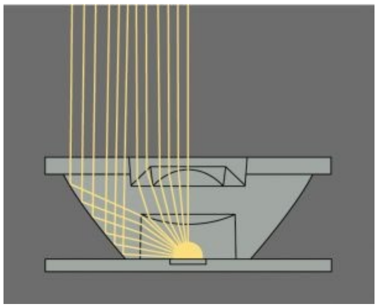

Figure 2. Diagram of the reflection from a LED reflector that uses a total internal reflection lens made from a polymer. galery/lighting-reflectors.html -

Since these materials have a high index of refraction, design features of the devices such as special optical coatings and die shape are required to efficiently emit light. LED research has led to the development of many high efficiency products but there is still a need for optical encapsulants with high refractive index to increase efficiency. The silicone materials used presently have a refractive index of 1.5, and scientists are in constant search for materials to increase this refractive index. Introduction of nanoparticles with higher refractive indices have the potential to increase the refractive index of the composite. High efficiency LEDs cannot be used without a protective encapsulant which decreases the brightness but also increases the optical size of the LED. The higher refractive index results in the bending of light at a higher angle into the encapsulant thus increasing the optical size. For a typical polymer, encapsulation decreases the brightness by a factor of about two[1].

Industrial and academic researchers have been trying to manufacture these products with low cost. Mixing a material that has a high refractive index into a medium is known to increase the index of refraction of that medium. LEDs are encapsulated in polymers or silicone (n = 1.5)[3]. Much research is occurring to increase the light extraction from LEDs by adding nanoparticles to these media. Nanoparticles (1-100 nm) don't have a noticeable effect on the transmission of the visible light because their size is smaller than visible light (380 nm-740 nm). Amorphous TiO_2 at 30% concentration showed light transmittance of 94% at 450 nm and refractive index of 1.63[4].

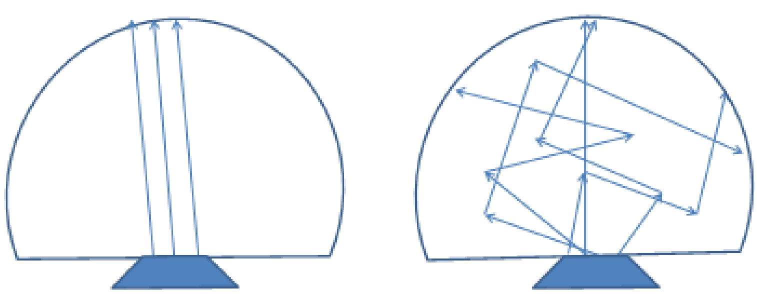

Figure 1: Role of nanoparticles in increasing the optical size of an LED

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Materials per group:

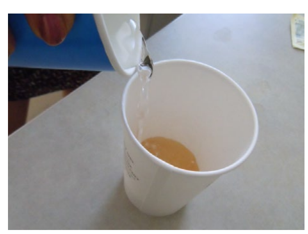
- styrofoam cup
- 1 pack of unflavored gelatin
- 1 cup water
- hot plate or kettle to boil water
- plastic spoon
- mini silicone half-sphere cake mold/baking pans
- different sizes/colors of glitter
- balance
- weighing boats
- craft stick/wood splints for mixing the glitter into the gelatin
- clock, watch, or stopwatch
- photodetector
- multimeter with leads
- set of alligator clips
- laser light pen
- graph paper
- metric ruler

Procedure:

- Your group of 3 will be assigned a different variable such as glitter color, particle size of the glitter, or the concentration of glitter particles. Glitter represents a macro-model of nanoparticles.
- You teacher will indicate how many groups will share one mold.

Day 1: Preparation of gelatin

1. Each group will have one control gel – no glitter added. Depending on the variable being tested, you will be instructed on a fixed amount to weigh out of the glitter for each gel using a balance and weighing boats. If you are testing type of glitter or particle size of glitter, all concentrations must be the same. If your group was assigned the concentration variable you will have 5 different concentrations assigned by you teacher. Record your glitter variables in your data table.



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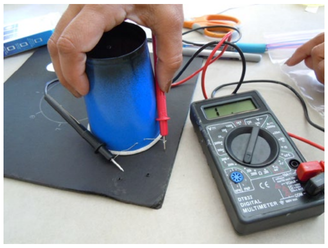
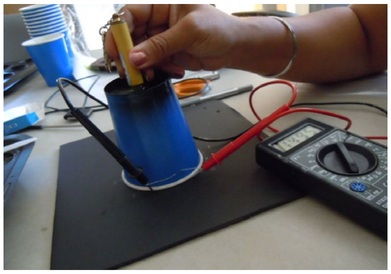
2. Dissolve one packet of gelatin in one cup of hot water in a styrofoam cup. Stir to remove all the lumps using a plastic spoon. This will make 6 half-spheres. One of the half spheres will be used as control without any glitter and others will have the glitter variables.
3. Pour the gelatin into the molds. Using a craft stick stir the gel in the molds every minute for 5 minutes. When the gel starts to set (begins to thicken) add the glitter particles to it.
4. Keep stirring to make sure the particles are evenly distributed.
5. Stop stirring once the gel seems to be firming and the particles are not moving to the bottom of the gel (not settling to the bottom), otherwise the gel will be lumpy. Label the mold with your group name and the variable. Leave the gel to set overnight in a refrigerator.
6. Clean up your lab stations. Put the styrofoam cup, plastic spoon, and craft stick in the trash.

Day 2: Measuring the light extraction



1. Now that the gels are set, remove them from the mold and invert one gel on the photodetector reading guide positioning it in the center.
2. Attach the multimeter probes to the photodetector wires and plug the other ends into the multimeter. The photodetector wires should not touch each other.
3. Set the multimeter to measure resistance (Ohms, Ω), and set the meter to 20 kΩ. The resistance will decrease as the illumination on the photodetector increases.
4. Measure and record the readings on the multimeter for ambient light (the light regularly in the classroom), with ambient light blocked by inverting the cup (make sure to cover the hole for the laser light), and with laser light shining directly on the photodetector. Record your readings on your Student Worksheet.



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5. Now invert the photodetector cup on the guide covering the gel with the photocell aligned with number 1 on the guide.
6. Set up the laser pointer to shine through the hole in the bottom of the cup (which is inverted, so the top of the cup).
7. Record the reading on the multimeter in the table on your Student Worksheets in the Record Your Observations section.
8. Rotate the cup so the photocell is aligned with number 2 and record the readings on the multimeter.
9. Repeat the procedure. Record readings for all the points.
10. Add the values together for each reading to give a final reading and record in the Total column of your table.
11. Repeat for all of your gel variables.

Cleanup

- Wipe the photodetector guide cards with wet towel.
- Dispose of all the gels in a regular trash can.
- Unplug the leads from the multimeter and store.

Record your observations:

Resistance for ambient light _________

Resistance with light blocked __________

Resistance with laser shining on photodetector________

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Table 1: Record the resistance for gels with different concentrations of glitter.

	Resistance At Different Angles (Ω								
Concentration g/gel	1	2	3	4	5	6	7	8	Total

Table 2 : Record the resistance for gels with different particle size of glitter.

	Resistance At Different Angles (Ω								
Particle size	1	2	3	4	5	6	7	8	Total

Table 3 : Record the resistance for gels containing diffèrent types/color of glitter

	Resistance At Different Angles (Ω								
Type of glitter	1	2	3	4	5	6	7	8	Total

Analyze the Results:

Plot a graph on your graph paper using the resistance value as a function of the variable tested. Make sure to use the independent variable on the X- axis. If you are testing different types of glitter, make a bar graph, and if you are testing different concentrations, make a scatter plot with a best-fit line.

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Draw Conclusions:

1. What is the relationship between the independent and dependent variable?

2. Why are nanoparticles used in materials to increase the index of refraction?

3. What other material can we use in this experiment to make the light transmission better?

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