Effect of particle size, transparency and light intensity on the color of powder

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Abstract. In daily life, the color of matter will change in some cases. This paper mainly studies the factors that affect the color of powder. The effects of grinding particle size, transparency of grinding material and solvent medium on the colour of powder were investigated. The innovation of this paper lies in the quantitative measurement and analysis of the color of grinding powder by the method of measuring the wavelength and the light intensity with spectrometer.

1. Introduction

In our daily life, it isn’t difficult to find that after grinding colored materials into powder, the powder obtained may have a different color from the original material in some cases[1-2]. The optical properties of the powder first depend on the degree of light scattering[3]. The more obvious the light scattering phenomenon, the more scattering times, the brighter the powder color[4], as shown in Figure 1. In addition, the research shows that the browning index of light is the main index affecting the color of substances[5], and the browning index is related to the brightness, red and yellow intensity; the larger the browning index, the darker the color[6].

According to theory of Mie scattering[7], the saturation and brightness have a certain effect on color. However, the research results show that the brightness and saturation have little effect on the color of pigment[8]; some researchers suspect that the temperature difference will affect the color of powder, but the research shows that the effect of temperature on the color change is not obvious[9], and the most important factor affecting the color of powder is the particle size of powder and the light intensity.
intensity when observing the powder. In the field of atmospheric research, the difference of observed color is attributed to the size of atmospheric aerosol, its extinction coefficient and optical depth[10].

From the radiation theory, Melamed, N. T. deduced the diffuse reflection relationship through the light scattering equation and the light radiation equation[10], and the diffuse reflection diagram is shown in Figure 2, then they got the specific color change rule. Gueli, A. M. carried out depth research on adding solvents to the powder[11]. Some researchers also found that the higher the transparency of the powder, the brighter the color[12-14].

![Diffuse reflection of light](image_url)

Figure 2. Diffuse reflection of light.

In this paper, the factors that affect the color of powder are discussed, mainly including the influence of transparency, the particle size, the powder of different media, and the light intensity on the color of powder.

2. Theoretical analysis

2.1. Beer-Lambert law

Assuming that the ground powder is sufficiently thick and opaque. Referring to relevant literature[15-16], it is found that Beer-Lambert law can perfectly explain the phenomenon of powder discoloration.

It can be seen from Figure 3 that when a beam of parallel monochromatic light passes vertically through a uniform non scattering absorbing substance which can be solid, liquid or gas, its absorbance $A$ is directly proportional to the concentration $c$ of the absorbing substance and the thickness $b$ of the absorbing layer, and inversely proportional to the transmittance $T$.

![Reflection, absorption and refraction](image_url)

Figure 3. Reflection, absorption and refraction.

The mathematical expression of Beer-Lambert law is[7]:

$$A = \log\left(\frac{1}{T}\right) = Kbc$$  (1)

Where, $A$ and $T$ are the absorbance and the transmittance, and $K$ is the molar absorption coefficient, and $b$ is the thickness of absorption layer, and $c$ which unit is mol/L is the concentration of the light absorbing substance.
Through Beer-Lambert law, we can qualitatively analyze that: for the powder is grinded more fully, the concentration of its light absorbing substance is smaller, the absorbance is smaller, the reflected light intensity is bigger, and the color is brighter.

2.2. Diffuse reflection

When the light incidents the powder surface, the diffuse reflection must occur, and the coarser the surface, the minor the powder particles, the more obvious the diffuse reflection phenomenon.

![Figure 4. Diffuse reflection on the surface of the powder.](image)

It can be seen from Figure 4 that the rougher the surface, the more complicated the surface structure, and the more obvious the diffuse reflection phenomenon. Let the diffuse reflectance of the surface material be $R$, the average refractive index is $T$, the average value of the single surface reflection coefficient is $m_e$, and the coefficient of a part of the light rays appearing inside the particle is $x$; then the expression of the diffuse reflectance is\[9:\]

$$R = \frac{2xm_e + x(1-2xm_e)T(1-m_R)}{(1-m_R) - (1-x)(1-m_e)TR}$$

As can be seen from the formula (2), the diffuse reflectance $R$ is proportional to the average refractive index $T$, and the more sufficient the powder grinding, the larger the average refractive index, the larger the diffuse reflectance, and the darker the powder color.

3. Experiment

3.1. The effect of powder transparency on its color

The green chocolate, the yellow chalk, and the withered leaves were grinded into particles of different particle sizes using a mortar. For grinding the green chocolate, as shown in Figure 5, the diameter of No.1 is more than 10 mm, and the diameter of No.2 is less than 10 mm, and the diameter of No.3 is less than 5 mm, and the diameter of No.4 is less than 0.5 mm.

![Figure 5. The color of the green chocolate changes before and after grinding.](image)

As for grinding the yellow chalk, as shown in Figure 6, the diameter of No.1 is more than 9 mm, and the diameter of No.2 is less than 5 mm, and the diameter of No.3 is less than 2 mm, and the diameter of No.4 is less than 0.5 mm.
Figure 6. The color of the yellow chalk changes before and after grinding.

As for grinding the withered leaves, as shown in Figure 7, the diameter of No.1 is less than 5 mm, and the diameter of No.2 is less than 5 mm, and the diameter of No.3 is less than 2 mm, and the diameter of No.4 is less than 0.5 mm.

Figure 7. The color of the withered leaves changes before and after grinding.

Under the sunlight source, we take various degrees of grinding, and use the camera color processor to shoot 5 times for each powder. Then we get the average of the three primary colors ($R$, $G$, $B$) values, and the results are recorded in Table 1.

Table 1. The $R$, $G$, $B$ values of three grinding materials.

|                      | Grinding green chocolate | Grinding yellow chalk | Grinding withered leaves |
|----------------------|--------------------------|------------------------|--------------------------|
|                      | 1    | 2    | 3    | 4    | 1    | 2    | 3    | 4    | 1    | 2    | 3    | 4    |
| $R$                  | 137.0 | 154.5 | 187.0 | 213.7 | 211.0 | 210.0 | 206.0 | 200.0 | 140.0 | 101.5 | 86.5 | 73.5 |
| $G$                  | 109.7 | 153.0 | 182.5 | 208.0 | 200.0 | 192.0 | 187.0 | 180.0 | 110.0 | 75.0  | 50.0 | 46.0 |
| $B$                  | 36.2  | 50.2  | 79.7  | 136.5 | 86.0  | 73.0  | 52.0  | 30.6  | 80.0  | 51.0  | 27.0 | 23.0 |

According to the results recorded in Table 1, the average values of the three primary colors ($R$, $G$, $B$) values are visualized as shown in the following Figure 8:

Figure 8. Changes in the $R$, $G$, and $B$ values of the three materials (the green chocolate, the yellow chalk, and the withered leaves).

For Figure 8. Taking account into the different parameters of the front and back of the leaves, we take the average of the parameters of the front and back as compare objects. The black curve represents data for the green chocolate, and the red curve represents data for the yellow chalk, and the green curve represents data for the withered leaves.
It can be seen from Table 1 and Figure 8 that for the green chocolate with high transparency, when the chocolate particle size is smaller, the $R$, $G$, $B$ values of the powder tend to increase, and the $R$, $G$, $B$ values image of the powder showed an upward trend, while the color of the chocolate powder became shallow as the particle size decreased. However, for the yellow chalk and the withered leaves with low transparency, the $R$, $G$, $B$ values of the powder tend to decrease as the particle size is smaller, and the $R$, $G$, and $B$ values image of the powder showed downward trend, and the color of the powder became deeper as the particle size decreased.

### 3.2. Effect of the particle size on powder color

It can be seen from Table 1 and Figure 8 that the grinding particle size has the greatest influence on the $B$ value, and compared with the $R$ and $G$ values, due to the inherent transparency of the powder, the gradient of the $B$ value changes most during grinding.

### 3.3. Effect of adding different media on powder color

The independent variable we are studying here is the added solvent medium, and we still use the No. 4 yellow chalk powder of the section 3.1 as the research object. The mobile phone was fixed with a bracket to prevent the mobile phone from shaking, and was photographed under the solar light source, as shown in Figure 9.

![Figure 9. Effect of different media solvents on observed color.](image)

Here, no matter is added to the No. 1 control group, and 5 ml pure water was added dropwise to the powder as the second experimental group. 5 ml 75% of the ethanol was added dropwise to the powder as the third experimental group, and 5 ml absolute ethanol was added dropwise to the powder as the fourth experimental group.

| No. 4 yellow chalk with different solvents | 1 | 2 | 3 | 4 |
|--------------------------|---|---|---|---|
| $R$  | 237.0 | 228.0 | 222.0 | 205.0 |
| $G$  | 230.0 | 220.0 | 203.0 | 184.0 |
| $B$  | 114.0 | 48.0 | 21.0 | 3.0 |

The camera color processor is used to identify the three primary colors ($R$, $G$, $B$) values, and the average values of the three primary colors of each group are obtained as shown in Table 2 and Figure 10:
Figure 10. The variation of the three primary colors values after adding different solvent media. From Tables 2 and Figure 10, it can be obtained that the higher the degree of infiltration of the yellow chalk powder to the solvent medium, the less the amount of light refracted and the darker the color.

3.4. The effect of light intensity on the color of the powder

Using the yellow chalk of No.1, No.3, and No.4 of the section 3.1 under the illumination of the sun light source, the spectrogram obtained by irradiating the yellow chalk with different grinding degrees at a fixed angle (90°) and a fixed distance (25 cm) with a flame spectrometer is used to measure the three particle diameters multiple times. The best set of results is shown in Figure 11.

Figure 11. Spectrometer measurement frequency light intensity figure.

Looking at the spectrogram, we conclude that the degree of grinding does not cause the peak of the wave to move left or right. Only the intensity of the reflected light changes, and the more fully polished, the stronger the intensity of the reflected light. It is this change in light intensity that causes the observed color and darkness of the powder to change. Spectrograms of other materials and other conditions yield the same conclusions.

4. Conclusion

In order to explore the factors affecting the color of the powder, by controlling the experimental variables for research and experimental data analysis, we have the following conclusions:

- The more transparent the material, the lighter the powder color. The more opaque the ground material, the darker the powder color.
- The higher the degree of wetting of the solvent medium by the colored material abrasive material, the deeper the color of the colored material observed.
- The degree of grinding does not change the reflection wavelength of the color of the substance, but only change the intensity of the reflected light.
It is because of the diffuse reflection that the intensity of the reflected light changes; the more the grinding, the stronger the intensity of the reflected light, so that the color of the powder changes.

The results of this study indicate that the transparency of the powder, the size of the powder, the light intensity of the powder, and the nature of the solvent added are the most important factors affecting the color of the powder.

Acknowledgments
The authors would like to thank Hong Gu for fruitful discussions. This work was supported by the National Natural Science Foundation of China (No. 61904123), the Natural Science Foundation of Tianjin (No. 18JCQNJC71800), and the Scientific Research Project of Tianjin Educational Committee (No. 2018KJ220).

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