Effect of Different Standard Light Sources on the Red Color of Rhodochrosite

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Abstract. Based on the uniform color space CIE1976L^*a^*b^* system, the color of rhodochrosite is characterized by three elements: lightness L^*, chroma C^* and hue angle h. On the basis of the color analysis of rhodochrosite, the standard D65 light source, A light source and CWF light source were used as experimental light sources to explore the influence of different light sources on the three color elements of rhodochrosite, and comprehensively analyze the influence of different light sources on rhodochrosite color. The conclusion is that A light source can improve the L^* value and C^* value of rhodochrosite to make it more bright and brilliant, which is suitable as the display light source of rhodochrosite; and CWF is not suitable as the illumination light source of rhodochrosite.

Introduction

Rhodochrosite is an important manganese ore, which as possible biogenic relics in Archean settings[1,2], mostly hydrothermal sediment[3,4] or metamorphic genesis. At present, there is no clear conclusion on its formation process. In the manganese deposit of the Datangpo Formation in South China, following their burial in organic-rich sediments, the Mn(IV) oxides and hydroxides are reduced, producing soluble Mn(II) via processes mediated by heterotrophic microbes under suboxic conditions, which in turn form the Mn-carbonates. Indicating that a two-step microbially mediated process of Mn ore formation might be common[5,6]. Besides, surprising formation of a rhodochrosite-like (MnCO_3) phase on Co-Zn-Mn sintered spinels upon storage at room temperature and ambient air[7].

In the mining and extraction of manganese ore, adding sodium hexa metaphosphate (SH) or linoleate hydroxamic acid (LHA) has a significant improvement on the flotation separation of rhodochrosite[8,9]; the leaching rate of Mn^{2+} can be improved by adding EDTA, citrate starch ester and other additives[10,11], which is beneficial to the extraction of manganese. In addition, low-grade manganese ore can be treated with heat to prepare nanomaterials for the removal of environmental pollutants[12].

Chromaticity is based on glassman's law and established by visual color matching experiment, under the standard formulated by the Committee of International Illumination (CIE). It mainly studies color measurement and evaluation[13], and it is used in many fields such as textile industry, printing industry[14], architecture, stomatology and gemology. The CIE L^*a^*b^* color space is a uniform color space recommended by the Committee of International Illumination in 1976. In 1987, GB792-87 released in China adopted the CIE L^*a^*b^* space as the national standard[15].

CIE 1976 L^*a^*b^* color space conforms to the subjective feature that the visual color difference scale of human eyes in the red and green direction is smaller than that in the yellow and blue direction[16]. Therefore, the red color of the rhodochrosite is studied on the basis of this color space. Select two standard illuminants by the International Commission on illumination (CIE)[17], a standard illuminant D65 (color temperature 6504 K) that simulates typical daylight, and an A-light source (color temperature 2856 K) for typical incandescent lamps for home or store lighting. And CWF light source (color temperature 4150 K)[18] used for cold white fluorescent light sources in commercial and office buildings in the United States, using these three common light sources as experimental light sources.
Factors that affect the color of a gem are light sources, gems, and observers. The A light source makes the red color of ruby and red tourmaline more vivid \cite{18,19}, but it is not conducive to the appearance of garnet color with less red tint, such as manganese aluminum garnet and calcium aluminum garnet, and there will be obvious color cast phenomenon \cite{20}. The effect of different light sources on the color of red gemstones such as ruby, red tourmaline and orange-red garnet has important reference significance for rhodochrosite which is also a red gem.

**Sample Selection and Experimental Design**

Rhodochrosite is divided into single crystal rhodochrosite and polycrystalline rhodochrosite, the latter is more common, and the two types of rhodochrosite are different in color tone, chroma, transparency and other properties, so the experiment only takes polycrystalline rhodochrosite as the research object.

In order to study the effect of different light sources on the color of rhodochrosite, a total of 41 samples of red to orange red and brown red with large difference in hue and continuous color gradation were tested. All samples are micro-transparent curved gemstones with good polishing and uniform color on the same sample, and the thickness is 3-6mm, which met the requirements of the reflection test mode of the color measurer, and eliminates the interference of other factors on the experimental results.

The experiment placed the polycrystalline rhodochrosite sample on a standard white background using an X-rite color i5 color measurer. The test conditions were reflection mode and the measurement method excluded specular reflection. The experiment uses D65 standard light source, 360-750nm measurement range, measuring time less than 2.5 seconds, voltage 240V, frequency 50-60Hz, wavelength interval 10nm.

Obtaining \(x, y, z\) tristimulus values, and calculating color parameters \(L^*, C^*, h_0\) through ICQ analysis software matched with the instrument; and the color parameters under the A light source and the D65 light source are simulated.

**Discussion of Results**

Based on the uniform color space CIE 1976 \(L^*a^*b^*\) system, standard D65 light source was used to measure and analyze the color parameters of the sample, including lightness \(L^*\), chroma \(C^*\) and hue angle \(h_0\). The color parameters of A light source and D65 light source were obtained by Color iControl simulation, and the influence of different light sources on the color of polycrystalline rhodochrosite was analyzed.

**Color Analysis of Rhodochrosite under D65 Standard Light Source**

**Color Parameter Analysis.** The overall range of brightness values of polycrystalline rhodochrosite samples is 33.34-66.24. All samples are of medium brightness, and most of them belong to the lower range of medium brightness value. Some samples with a color biased to orange were abnormally low in brightness, and it was speculated that the determination of brightness value was affected by the internal small cracks or cleavage surface of the sample through magnification examination.

The chroma \(C^*\) value is between 0-100%, the chroma \(C^*\) value of 0 means pure white, gray, and pure black; the chroma of single color light has a \(C^*\) value of 100\% \cite{21}. The sample chroma \(C^*\) value is between 11.49-36.56, which is low to medium chroma. So color of the polycrystalline rhodochrosite has a higher gray value and a lower purity.

The hue angle of the sample is concentrated at 19°-40° and the hue transitions from orange to red.

**Analysis of the Relationship between \(a^*\) and \(b^*\).** According to Figure 1, it can be seen that there is a good positive correlation between the chroma value \(a^*\) and \(b^*\) of the rhodochrosite, that is, as the value of sample \(a^*\) increases, \(b^*\) value also shows an increasing trend. And the \(a^*\) and \(b^*\) values of
the sample are both positive values, indicating that the yellow tone will also increase when the red tone of the sample increases.

Figure 1. Relationship between $a^*$ and $b^*$ of rhodochrosite.

Influence of Light Source on the Color of Rhodochrosite

The spectral power distribution of different light sources has different influence on the color of polycrystalline rhodochrosite. Because the rhodochrosite is medium brightness and chroma, the color tone is orange-red or brown red to red, so the light source has a great influence on its color.

The D65 light source simulating the sunlight in cloudy days has a relatively uniform energy distribution in all regions. The blue-green area with a range of 480~500nm has a relatively low radiation energy peak, that is, the color of the D65 light source is slightly bluish-green, and the display of rhodochrosite is close to the color seen by the naked eye under sunlight (Figure 2). CWF light source has the sharp edge of radiation energy at 540nm and 620nm. It is a yellowish-green light source, which has a some interference effect on the display of the red color of rhodochrosite, so it is not suitable as the illumination source of rhodochrosite (Figure 4). The relative spectral power distribution diagram of A light source approximates smooth curve, and the irradiation energy in the red area is the strongest, which has the superposition effect on the display of the dominant color of rhodochrosite, so it is the best light source for the color display of rhodochrosite (Figure 3).

Figure 2. Relative spectral power distribution of D65 light source.

Figure 3. Relative spectral power distribution of A light source.
Ten samples of rhodochrosite with large color difference were selected and simulated by color parameters (Table 1). It can be known that rhodochrosite under A light source has the most bright and brilliant color and is suitable to be used as illumination light source for rhodochrosite. Among the three light sources, rhodochrosite under D65 light source is closer to the color seen by naked eyes under sunlight. However, the color of rhodochrosite under CWF light source is the darkest among the three light sources, which can enhance the mixed hues except red of rhodochrosite and is not conducive to its color display.

Table 1. Rhodochrosite simulated color blocks under three different light sources.

|     | 8   | 3-1 | 2   | 12-4 | 23-1 | 30  | 10-2 | 36-1 | 41-1 | 27-1 |
|-----|-----|-----|-----|------|------|-----|------|------|------|------|
| D65 |     |     |     |      |      |     |      |      |      |      |
| A   |     |     |     |      |      |     |      |      |      |      |
| CWF |     |     |     |      |      |     |      |      |      |      |

Univariate Analysis of Variance

Influence of Different Light Sources on Red Brightness of Rhodochrosite. Figure 5 and table 2 show that different light sources have little influence on the brightness of rhodochrosite. The brightness value of rhodochrosite is the highest under A light source, and the brightness value of rhodochrosite under D65 light source and CWF light source is almost the same, which is $L^*_{A} > L^*_{D65} \approx L^*_{CWF}$.

| light source | $L^*$ average | N  | $L^*$ Standard deviation |
|--------------|---------------|----|--------------------------|
| D65          | 44.8864       | 83 | 5.86383                  |
| A            | 47.0892       | 83 | 6.20405                  |
| CWF          | 44.9763       | 83 | 5.87901                  |

Figure 5. Effect of different standard light sources on red brightness value of rhodochrosite.
The A light source has the strongest radiant energy in the red region, and is colored light that is biased toward orange-red. It has a superimposed effect on the brightness of the rhodochrosite, making it brighter. However, the brightness is the degree of light and darkness of the surface of the object, so the degree of increase in brightness is small.

**Influence of Different Light Sources on Red Chroma of Rhodochrosite.** It can be seen from Figure 6 and Table 3 that different standard light sources have a great influence on the chroma value of rhodochrosite. The chroma value of rhodochrosite is the highest under A light source, D65 light source is slightly higher than CWF light source. The effect of A light source on the chroma value of rhodochrosite is the most obvious, while the CWF light source has slight interference effect on the chroma. That is, $C^*_{A} > C^*_{D65} > C^*_{CWF}$.

![Figure 6. Effect of different standard light sources on red chroma value of rhodochrosite.](image)

**Table 3. Chroma values of rhodochrosite under three standard light sources.**

| light source | $C^*$ average | N  | $C^*$ Standard deviation |
|--------------|---------------|----|--------------------------|
| D65          | 19.4473       | 83 | 5.13681                  |
| A            | 25.1015       | 83 | 6.08987                  |
| CWF          | 18.8610       | 83 | 5.01981                  |

The chroma indicates the brightness and purity of the color. The spectral energy of A light source is mainly concentrated in the red region, which is the colored light of orange-red. As a red gemstone, rhodochrosite has a low chroma value. The orange-red light source has a superimposed effect on the red chroma value on the surface of the rhodochrosite, which greatly improves the chroma value of rhodochrosite and makes the red color more full and colorful. D65 light source is sunlight simulating cloudy day, and the energy distribution in each region of the spectrum is relatively uniform, which makes the chroma value of rhodochrosite more objective and accurate. CWF light source is a cold white store light source in the United States, which is biased towards yellow-green light and has certain interference to the chroma of rhodochrosite red, making its chroma value slightly lower than that of rhodochrosite under D65 light source.

Therefore, the A light source can better display the red color of the rhodochrosite, which is suitable for the display and sale of rhodochrosite; the rhodochrosite under the D65 light source is closer to its objective color than the other two light sources, and is suitable for the identification and evaluation of rhodochrosite. The CWF light source is not suitable as an illumination source for rhodochrosite.

**Influence of Different Light Sources on Red Hue Angle of Rhodochrosite.** As can be seen from Table 3 and Figure 7, different standard light sources have a certain influence on the hue angle of rhodochrosite. Among them, CWF light source has the largest hue angle, followed by D65 light source, and finally A light source. That is $h^0_A > h^0_{D65} > h^0_{CWF}$. 

![Diagram showing influence of different light sources on red hue angle of rhodochrosite.](image)
Figure 7. Effect of different standard light sources on red hue angle value of rhodochrosite.

Table 4. Hue angle values of rhodochrosite under three standard light sources.

| light source | $h_0$ average | N | $h_0$ Standard deviation |
|--------------|---------------|---|-------------------------|
| D65          | 19.4473       | 83 | 5.13681                |
| A            | 25.1015       | 83 | 6.08987                |
| CWF          | 18.8610       | 83 | 5.01981                |

In colorimetry, the hue angle ranges from 0 to 360 degrees, 50° represents large red (R), 110° is yellow (Y), 170° represents green (G), and the middle value represents some transition hue angle values.

CWF light source source has a higher energy distribution at the wavelength $\lambda \in (550,620)$. When superimposed on the surface of the rhodochrosite, it will enhance its yellow-green tone and increase its hue angle, which makes the rhodochrosite more orange-red and reduces its color saturation, which is consistent with the above conclusion that the CWF source makes the rhodochrosite chroma values reduction. So, the CWF source is not conducive to the red display of the rhodochrosite. The hue angle of rhodochrosite under A light source is not a single regular increase or decrease, most of which is a decrease in hue angle and a small increase, which is related to the different hue angle of rhodochrosite samples. The spectrum of A light source is a rising curve from the lowest energy in the purple region to the highest energy in the red region. The color of the light is orange-yellow, and the surface of the sample is irradiated to enhance the orange-red tone of the rhodochrosite sample. When the rhodochrosite sample is orange primary color tone, the hue angle of rhodochrosite is increased; when the sample is red main color, the $h_0$ value is biased toward a smaller red color ($50°$), and the hue angle is lowered. Therefore, the A source is suitable for the display of most rhodochrosite samples.

**Conclusion**

(1) Rhodochrosite color belongs to medium lightness, low to medium chroma, high gray level in color and lower purity. The hue angle changes from orange to red. There is a positive correlation between the red tone and the yellow tone in rhodochrosite, that is, the yellow tone will also increase when the red tone increases.

(2) The spectral energy of the light source A is higher in the yellow and red regions, and the color light tends to be orange-red. Therefore, it has the superposition enhancement effect on the brightness and chroma of rhodochrosite, and the enhancement effect on the chroma is more obvious. Therefore, the red of rhodochrosite under the light source A is more full and bright. A light source is suitable for rhodochrosite red display light source.

(3) CWF light source has sharp radiation energy front at 540nm and 620nm, and its color light is yellowish green, which weakens the chroma of rhodochrosite red and significantly increases its hue angle, making rhodochrosite red under CWF light source dim, which is not conducive to the display of rhodochrosite red. So CWF light source is not suitable for display light source of rhodochrosite.
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