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Physical and Luminescence Studies of Natural Fluorescent Material (Stone)

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Abstract

This study investigates the physical properties (volume and density) and optical behavior of a natural fluorescent stone under ultra-violet (UV) and green/red laser light. The stone exhibits fluorescence, emitting a blue-white glow when exposed to 365 nm UV light, suggesting the presence of minerals like fluorite (CaF_2), scheelite ($CaWO_4$), and calcite ($CaCO_3$). Under 532 nm green laser excitation, the stone displays internal scattering and a green glow, further supporting the presence of fluorite (CaF_2). Also, on excitation by red (650nm) strong fluorescence was observed. The stone's translucency and strong luminescence make it suitable for optical crystal analysis.

INTRODUCTION

Natural fluorescent is a mineral that emits visible light when exposed to ultraviolet (UV) light or other form of electromagnetic radiation depending upon its nature. This glowing effect caused by stone's unique chemical composition, which has made them popular in both scientific & various decorative purposes.[1] Common example is fluorite and calcite mineral which exhibit bright, vibrant colors under UV illumination.

Natural stones are solid mineral materials formed over millions of years through geological processes and quarried from the earth for construction and decoration due to their durability, unique mineralogical patterns, color, and strength, exhibit long-term structural resilience in a range of climates and remain popular for both functional and aesthetic applications. [2–4]

The phenomenon associated with these materials is luminescence, which refers to the emission of light by a substance without heating it. It arises when electrons within a material are excited through various energy inputs, such as light, electricity, chemical reactions, or radiation and then release light as they relax to lower energy states. [5–9]

Luminescence classification in widely accepted categories is mentioned here:

1. *Photoluminescence:* Light emission after absorption of photons (encompasses fluorescence and phosphorescence).
2. *Electroluminescence:* Light generated in response to an electric current or field (e.g., LEDs).
3. *Chemiluminescence:* Light produced via chemical reactions (e.g., glow sticks).
4. *Bioluminescence:* A specific form of chemiluminescence occurring in living organisms (e.g., fireflies).
5. *Cathodoluminescence:* Light emitted when electrons bombard a material (common in cathode-ray imaging).
6. *Radioluminescence:* Light produced by exposure to ionizing radiation, such as X-rays or radioactive decay.

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Luminescence materials exhibit property of luminescence, when excited by different sources of energy, it is seen that semiconductor materials have tendency to illuminate light in visible spectra [10–13].

UV Excitation: UV excitation is the process where uv light energizes a material, causing its electrons to jump to higher energy levels. When they return to their normal state, they release visible light-this is fluorescence. It's commonly used to make natural fluorescent stones glow under UV light. [1, 14, 15]

Excitation by Green Laser: A green laser is a type of laser that emits visible green light of wavelength of 532 nanometers (nm). The energy associated with it excites the electrons to higher energy state. When the electron returns to their ground state, they emit light of longer wavelength. This is a common technique which is used in various fields, such as fluorescence microscopy and spectroscopy. [16, 17].

Excitation by Red Laser: It refers to the in process in which a red laser beam of wavelength 650 nm is use to excite electron.

A fluorescent stone is a mineral that emits visible light when exposed to illumination. It may be due to the fact that trace impurities or intrinsic activators absorb the corresponding energy and re-emit it, producing characteristic glow of colors. [18]

Various types of fluorescent stone with example
Igneous
- *Fluorite (CaF_2):* Named after its fluorescence behavior, it glows blue under uv due to the presence of activators like Eu^{2+} or other rare earth ions.

Metamorphic
- *Scheelite ($CaWO_4$):* Intrinsically fluoresces a bright blue under uv; molybdenum impurities can shift it toward white yellow, while iron can quench it.
- *Calcite ($CaCO_3$):* Fluoresces in shades ranging from red/orange to green/yellow depending on impurity activators like Mn^{2+}, Pb, Ce; while pure calcite generally does not fluoresce.

Sedimentary
- *Aragonite ($CaCO_3$ polymorph):* Often fluoresces yellow white under uv, commonly with greenish or white phosphorescence; driven by trace activators.
- Some other types of calcite specimens in sedimentary form (e.g. in limestone, travertine) also fluoresce depending on its impurity content.

In the present work, we have done two separate studies on natural fluorescent stone. In the first part of our study, we calculated its volume and density based on the very basic Archimedes principle. According to this principle, the volume of water displaced by a submerged object is equal to the volume of the object. It is very useful for the volume measurement for objects which are not regular in shape. In the second part of our work fluorescent stone was excited with three sources namely natural white light, ultra-violet (UV) light, and green laser light, and its effect was recorded and analyzed.

EXPERIMENTAL SECTION

Determination of Volume and Density of Natural Stone

Although several other techniques such as Stokes' law, Mohr–Westphal balance, and similar methods are available for density determination, each has its own advantages and limitations depending on the nature and form of the sample. However, Archimedes' principle remains the most reliable and accurate method for irregularly shaped solids, as it provides a direct and precise measurement of volume through fluid displacement, thereby yielding a more accurate determination of density for natural stones and minerals.

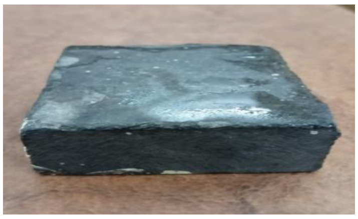

Figure 1. Regular cuboid stone.

Figure 2. Beaker of 500 ml filled with 200 ml distilled water

To determine volume and density of natural luminescent stone, Archimedes principle was used here. First, we determined the volume and density for regular cuboid stone to confirm the process, whether it is right or wrong.

Volume of Regular Cuboid Stone

We have taken cuboid stone as shown in Figure 1 having dimensions of, length (l) = 5 cm, breath (b) = 5.5 cm, height (h) = 2.2 cm.

We know the volume of cuboid is $V_{c1} = 5 \times 5.5 \times 2.2 = 60.5\ cm^3$

Again, Volume of Same Regular Cuboid Stone by Archimedes Principle

Let us take distilled water of 200 ml in beaker of capacity 500 ml as shown in Figure 2. The inner radius of beaker is measured, which is 3.6 cm. height of water column is 3.7 cm.

Now we have to put cuboid stone in the beaker (refer Figure 3) and observed increment in water column (h_{ci}) by 1.5 cm. This increased volume of water will be the volume of cuboid stone as proposed in Archimedes principle.

i.e. volume of displaced water by cuboid stone = volume of cuboid stone

$$V_{c2} = \pi r^2 h_{ci} = 3.14 \times 3.6^2 \times 1.5 = 61.04\ cm^3$$

Thus, the volume estimated through Archimedes principle is almost matching with geometrical calculation confirming that our process is correct.

Figure 3. Regular cuboid stone immersed in 200 ml distilled water.

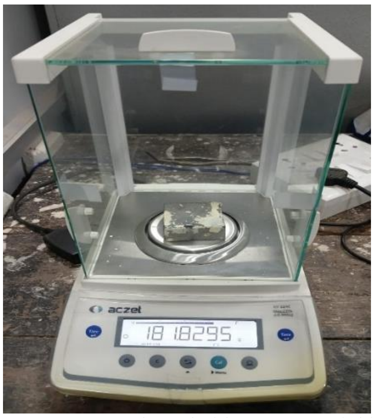

Figure 4. Regular cuboid stone on weighing machine

Density of Regular Cuboid Stone

In order to calculate the density of cuboid stone, we have to first measure its mass. The measurement is shown in the Figure 4 and its value is come out to be 181.8295 g.

1. Density of cuboid stone when its volume is calculated geometrically:

$D_{c1} = M_c/V_{c1} = 181.83g/60.5cm^3 = 3.00g/cm^3 = 3005.45\ kg/m^3$.

2. Density of cuboid when its volume is calculated using Archimedes principle:

$D_{c2} = M_c/V_{c2} = 181.83g/61.04cm^3 = 2.97g/cm^3 = 2978.87kg/m^3$.

Now, we have determined the volume and density of natural fluorescent stone used in our study.

Volume of Natural Luminescent Stone by Archimedes Principle

Volume of displaced water (refer Figure 5) by unknown stone will give its volume V_s

$V_s = \pi r^2 h_{si} = 3.14 \times 3.6^2 \times 0.5 = 20.35cm^3$

Figure 5. Natural Luminescent stone when immersed in 200 ml distilled water.

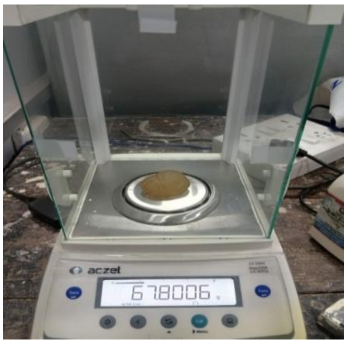

Figure 6. Natural Luminescent stone on weighing machine.

Table ?

Type of stone	**Initial Volume of water**	**Initial height of water column (h_1)**	**Final height of water column, when stone was immersed in water (h_2)**	**Increase in height of water column h= ($h_1 - h_2$)**	**Volume of apparently Increased water (V) V= π R²h**	**Real mass of stone using weighing machine (M)**	**Density of stone (Mass/ Volume)**
Regular Cuboid stone	200ml	3.7 cm	5.2 cm	1.5 cm	*61.04 cm^3	181.83 g	2.79 g/cm^3 or 2878.87 kg/m^3
Natural luminescent stone.	200ml	3.8 cm	4.2 cm	0.5 cm	20.35 cm^3	67.80g	3.33 g/cm^3 or 3331.1kg/m^3

**Volume of regular cuboid stone using geometry = L × B × H* =5 × 5.5 × 2.2 = 60.5 cm^3

Density of Natural Luminescent Stone

To calculate the density, we have to measure its mass which come out to be 67.80 g as shown in Figure 6.

Therefore, the density of Natural Luminescent stone is
$D_s = M_s/V_s = 67.80g/20.35cm^3 = 3.33g/cm^3 = 3331.70kg/m^3$

Table 1 shows observed volume, mass and density of regular cuboid stone and natural luminescent stone.

LUMINESCENCE STUDY

The experiment was performed under different excitation of photon energy and change in optical behavior was recorded.

Under Natural White Light

The stone is placed under natural light (shown in Figure 7). It appears to be a yellowish or tan, rounded stone or mineral. Texture was smooth but not polished, with visible surface cracks or patterns.

Figure 7. Natural Luminescent stone under natural light.

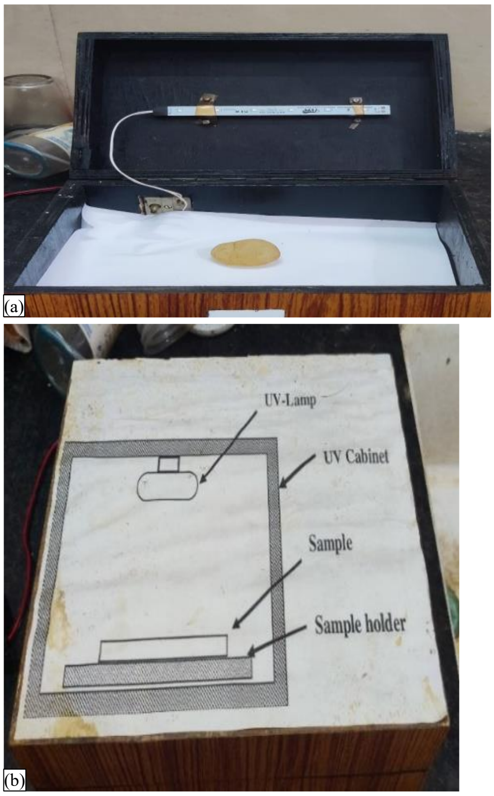

Figure 8. (a) Natural Luminescent stone in UV excitation chamber; (b) Schematic diagram of UV excitation chamber

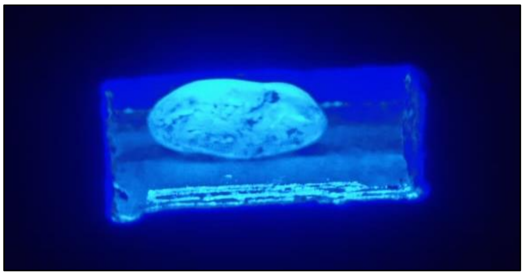

Figure 9. Natural Luminescent stone under UV light of wavelength 365nm.

Figure 10. Natural Luminescent stone under green laser light of wavelength 532nm.

Figure 11. Natural Luminescent stone under Red Laser light of wavelength 650 nm.

Under Ultra-Violet (UV) light

When the stone is placed in uv excitation chamber of dimension 0.75F × 1F (shown in Figure 8). The uv excitation wavelength was 365 nm with operating voltage 24 volt. Under uv light it glowed blue in color (shown in Figure 9).

Under Green laser light

When stone is placed under the green laser light of wavelength 532 nm with operating voltage of 3.7 volt. It strongly glowed green in color (shown in Figure 10).

Under Red Laser Light

When stone is placed under the red laser light of wavelength 650 nm with operating voltage of 220 volt. It strongly glowed red in color (shown in Figure 11).

Table 2 shows observation and remarks of sample stone under different sources of excitation.

Table ?

Type excitation source	Observation	Remarks about crystal
Normal illumination	Yellowish or tan, smooth but not polished, with some crakes and patten	Fluorite or calcite
UV Photon of wavelength 365 nm	Glowed blue	Fluorite, calcite or scheelite
Green Photon of wavelength 532 nm	Glowed bright green	Fluorite
Red photon of wavelength 650 nm	Strong Red fluorescence	Calcite or Quartz

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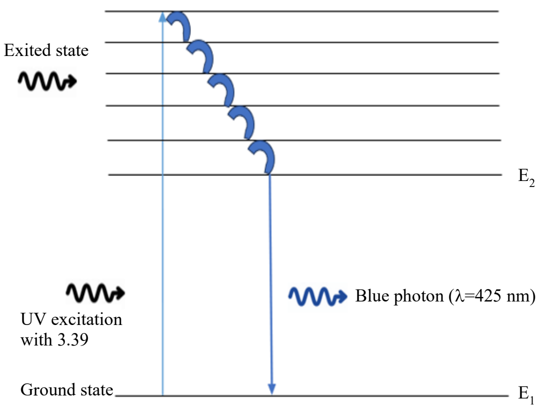

Figure 11. Energy Transition diagram for blue photon emission.

RESULT AND DISCUSSIONS

We have calculated the volume and density of the natural luminescent stone using Archimedes principle. These parameters come out to be $20.35cm^{3}$ and $3331.70kg/m^3$ respectively. In order to verify our results first we have tested the Archimedes principle on regular cuboid stone. It is found that theoretical calculations based on the geometrical formula of cuboid body is almost consistent with the experimental results based on the Archimedes principle.

However slight discrepancy ($\approx 1\%$) is there between two calculations which is obvious in any physics experiment when compared with the standard theoretical calculations.

On the other hand, under natural light, a raw mineral specimen possibly fluorite, calcite, or a type of quartz [19-20] and under uv light blue fluorescence was observed, which suggests the mineral has fluorescent properties. It may be due to the presence of fluorite, calcite, scheelite. [21–27]. Moreover, under green laser light stone glowed green in color. This indicates translucency and internal crystalline structure, allowing it to scatter the laser light internally. Under red laser light stone glowed red in color. This again indicates translucency and internal scattering. It confirms fluorite. [28–31]

MECHANISM OF LIGHT EMITTING

The stone is glowed under uv and laser source due to the presence of fluorescence. As discussed earlier, fluorescence is a type of photoluminescence, where a substance absorbs energy from light which excites the electron causing them to jump to higher energy level. These excited electrons are unstable and tent to return to their original, lower energy levels. When electrons return to their ground state (lower energy level), they release the excess energy in the form of visible light. Fluorescence is instantaneous process which means the glow appears when light is present and disappears when it's removed.[6, 8]

Fluorescence occurs when fluorophore (a molecule) absorbs light of lower wavelength (higher energy) and causes electron to jump from ground state(E_1) to exited state (E_2). The exited electron then loses some of its energy by nonradiative relaxation (internal conversion). Finally, the still exited electron return back to its ground state ($E_2 \rightarrow E_1$) and hence loses the excess energy in the form of light. The light emitted from this is of longer wavelength (lower energy). [6,8,32-34] This process referred to as fluorescence. Moreover, the electron spin direction does not change during fluorescence.

CONCLUSION

The stone's properties suggest it is a natural mineral or gemstone, likely fluorite or calcite, given it exhibits fluorescence under various photon excitation. Its translucency and internal light scattering, observed under laser illumination, further supports this identification. Physical property measurements using Archimedes' principle, a valuable technique for irregularly shaped samples, were employed to characterize the stone. This study demonstrates the utility of simple yet effective methods for mineral identification, suitable for undergraduate research projects.

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