EduFisika Jurnal Pendidikan Fisika

Volume 8 Number 3, December 2023, pp. 336-343
P-ISSN:2477-7935
E-ISSN:2548-6225
DOI: 10.59052/edufisika.v8i3.29625

DETERMINATION OF THERMAL RADIATION EMISSION TO VARIOUS TYPES OF MATERIALS

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Article Info
Received: 25 Oct 2023
Revised: 20 Nov 2023
Accepted: 25 Nov 2023
OnlineVersion: 02 Dec 2023

Abstract :
The research aims to measure and compare the amount of thermal radiation emitted by various materials with different colors and textures and calculate each material's emissivity. Experiments were carried out using four surface variations of the cube. The results show that the black surface of the Leslie cube emitted the most thermal radiation, followed by the dull, shiny, and white surfaces. The average value of thermal radiation output for each surface was 3.4 mV for black material, 1.6 mV for white material, 2.4 mV for shiny-colored materials, and 2.8 mV for dull-colored materials. The power obtained for each surface was 1.9 x 10-8 Watts, 0.87 x 10-8 Watts, 1.3 x 10-8 Watts, and 1.6 x 10-8 Watts, respectively. The emissivity of each material, which is the ratio of the thermal radiation emitted by the material to that of a black body at the same temperature, was 1, 0.458, 0.684, and 0.842, respectively. Based on the sensor output value, it can be concluded that black cloth is the most effective material in transmitting thermal radiation energy compared to glass, cardboard, and styrofoam. The research also provides empirical data and calculations of different materials' thermal radiation and emissivity, which can be used for further analysis and applications. The research contributes to the literature on physics education and thermal radiation by demonstrating a practical and engaging way of teaching and learning the concept of thermal radiation using a Leslie cube.

Keywords: Black Body, Cube, Thermal Radiation

INTRODUCTION

Thermal radiation or heat radiation is heat that comes from radiation from objects that emit heat energy (Latifah et al., 2018; Zander et al., 2019; Chekini et al., 2020). According to Siegel & Howel (2001), Nakamura et al. (2022), and Souai et al. (2022), thermal radiation is a method of heat transfer that involves the transfer of heat from one object to another through the interaction of photons between these objects, any object involved can be solid, liquid, or gas. Meanwhile, a black body is defined as an object that absorbs all radiation that comes to it. An ideal black body is modeled by a black cavity with small holes. When the light beam enters the cavity through the hole. The light beam will be reflected many times on the cavity wall without having time to exit again through the hole. Light energy will be absorbed by the cavity walls every time a reflection occurs. This aligns with Rey's (2006) statements that radiation heat transfer plays an important role when high temperatures are reached. Black body radiation is electromagnetic radiation emitted by black bodies. The radiation spectrum of a black body at several temperatures (T) is shown in Figure 1 (Kenneth, 2011).

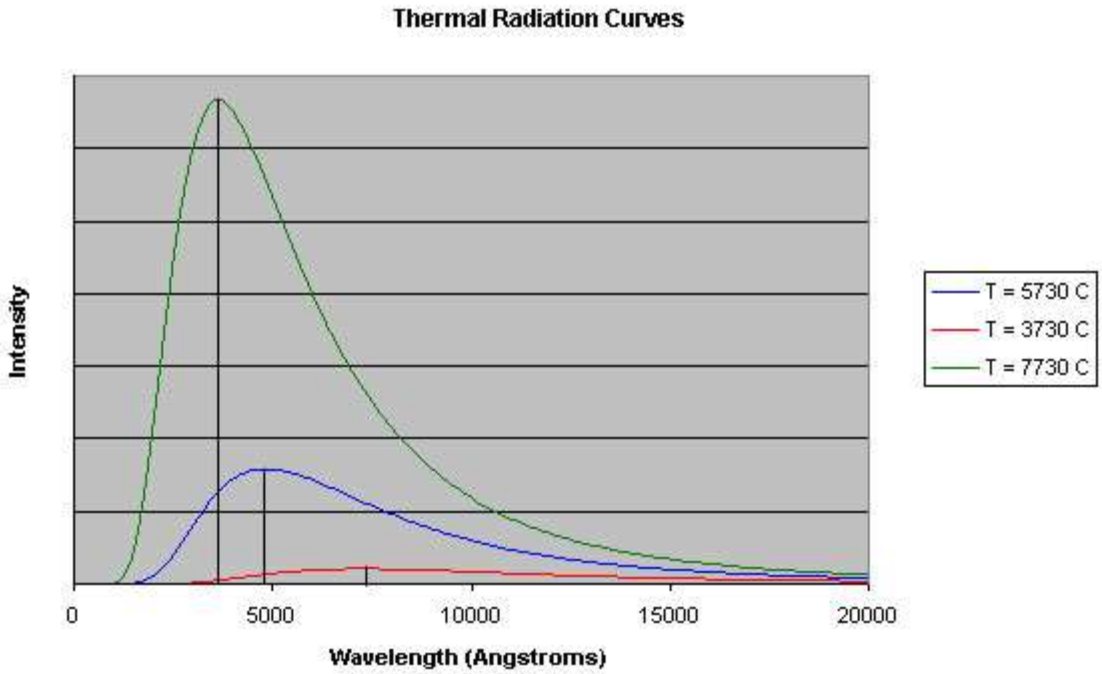

Figure 1: Thermal Radiation Spectrum Curve

In 1879 Stefan-Boltzmann conducted experiments to determine the universal character of black body radiation. They found that the total power per unit area (intensity) emitted at all frequencies by a hot black body is proportional to the fourth power of its absolute temperature, I = $e\sigma T^4$. The total radiant energy emitted is proportional to the area under the graph at a constant temperature, which is equal to E = $e\sigma T^4$ (Udoetok, 2016). It can be seen that the amount of radiation energy is proportional to the intensity produced; this equation is known as the Stefan-Boltzmann law.

Thermal radiation is electromagnetic radiation that includes continuous exposure to wavelengths, including radio waves, infrared radiation, light, ultraviolet radiation, and X-rays. The fundamental source of all electromagnetic radiation is accelerated moving electric charges. All objects emit electromagnetic radiation as a result of the thermal motion of their molecules. In line with what was stated by Latifah et al. (2018), thermal radiation or heat radiation is heat that comes from radiation from objects that emit heat energy. Every object has various properties ranging from being good at emitting and absorbing radiation to objects that are difficult to emit or absorb radiation. According to Sudiarta (2019) and Foltran et al. (2023), objects with a temperature higher than their environment will emit more thermal radiation than they absorb thermal radiation from the environment. A black body has an absorption and emissivity (emissivity) value equal to one (e = 1), meaning it absorbs all the energy it receives, and no energy comes out. This differs from white objects with an emissivity value of zero (e = 0), meaning that white objects reflect all radiant energy. Likewise, Z. Khan et al. (2013) examined thermal radiation in the energy equation. However, the use of heat transfer through thermal radiation plays a vital role in gas turbines, nuclear power plants, and thermal energy (Ahmad., Javed., & Ghaffari, 2015; Rami et al., 2017; Terpugov et al., 2021; Pal, & Das, 2022; Zhou et al., 2023). Thermal radiation is especially important in applications involving high temperatures because the radiation from an object depends on the fourth power of its absolute temperature multiplied by the Stefan-Boltzmann constant. Due to the scale of the Stefan-Boltzmann constant, the influence of radiation becomes significant at high absolute temperatures. Therefore, the effect of heat radiation is very high in furnaces, combustion chambers, fires, flames, and nuclear explosions (Udoetok, 2016; Chanakya & Kumar, 2022; Patil et al., 2023; Ymeli, 2023).

In this research, an experiment was carried out on thermal radiation (Leslie cube) to measure the level of thermal radiation on different surfaces and measure the amount of thermal radiation emitted from various objects around the room. Research on thermal radiation using Leslie cubes was previously carried out by Putra (2018), namely calculating the emissivity of various types of surfaces and the absorption and transmission of thermal radiation. The results obtained in thermal radiation experiments on the emissivity of various types of surfaces show that black surfaces have larger values than other surfaces. The surface quantities of the cubes are in order from largest, black, white, glossy, and dull. The surface of a black body has the best quality in emitting thermal radiation. This can be seen from the results where black has the highest sensor output value compared to other types of surfaces. In the second experiment regarding the absorption and transmission of thermal radiation (Patel, 2021; Vanhamel et al., 2021; Sullivan et al., 2021; Madhura et al., 2022). It was found that the plate type influences the process of transmitting thermal radiation, whereas glass and metal plates are effective in transmitting thermal radiation. The resistance has a constant value above room temperature.

The gap research of this study is that there is a lack of literature on the thermal radiation of different surfaces and objects using a Leslie cube. Most previous studies have focused on the theoretical aspects of thermal radiation, such as the Stefan-Boltzmann law, Planck's law, and Wien's displacement law. However, there is a need to explore the experimental aspects of thermal radiation, such as the measurement of thermal radiation on different surfaces and objects using a Leslie cube, which is a simple device that can demonstrate the variation of emissivity with surface color and texture. Using a Leslie cube, the thermal radiation of different surfaces and objects is important for understanding heat transfer and energy balance in various contexts, such as engineering, astronomy, and climate science.

The resistance to the radiation emitted is directly proportional, so if the resistance used is greater, the radiation emitted will also be greater. Research conducted by Siegel and Howell (1971) and Liu et al. (2019) revealed that thermal radiation is influenced by several factors such as surface shape, material properties, cross-sectional area, and material emissivity, which in their research has developed the SNR V-1.4SL thermal radiation equipment which can overcome equipment limitations laboratory. Thermal emissions are electromagnetic field radiation emitted from all objects with a temperature higher than absolute zero. Planck's law states that the thermal emission of a standard black body depends primarily on its temperature (Plank, 1901). In this case, thermal emissivity measurements become important to evaluate the thermal emission capabilities of an object. The emissivity of an object is expressed as the ratio of the energy emitted by the object and an ideal black body at the same temperature. The emissivity of an ideal black body is equal to 1, and the emissivity of other bodies lies between 0 and 1. Thermal emissivity measurements help to accurately characterize thermal emitters in the field of infrared thermal emission engineering for various applications, including personal thermal management (Bierman, 2016; Sathish et al., 2023), radiative cooling and heat preservation (Raman, 2014; Yan, 2020), infrared (Kats, 2013; Liu, 2021), and infrared encryption (Shahsafi, 2019; Wang et al., 2020).

Several things that differentiate the experiments in this research from previous research are variations in resistance, temperature, and the use of gain on the radiation sensor to produce data for varying thermal radiation output, power, and emissivity. The variations carried out in this research are novelties obtained.

RESEARCH METHOD

The tools and materials used in this research are a Thermal Radiation Cube, Radiation Sensor, 2 Multimeters, Precision Rails, Connecting Cables, and Types of Barriers shown in Figure 2.

Figure 2. Arrangement of experimental equipment

To determine the power which can be expressed by equation (1)

$$P = \frac{V^2}{R} \quad \dots (1)$$

The amount of emission in this experiment is calculated by equation (2)

$$E_{emisi} = \frac{P_x}{P_{hitam}} x\ 100\% \quad \dots (2)$$

This research consisted of 2 experimental parts, which measured radiation levels on different surfaces and the amount of thermal radiation emitted from various objects around the room.

The following are the working steps of the 2 parts of the experiment. Part 1. Measuring Thermal Radiation Levels on Different Surfaces. Connect the multimeter with the thermal radiation cube. Select the resistance measurement mode on the multimeter. Turn on the light on the thermal radiation cube to maximum intensity, ensuring that the temperature reaches approx 45 ℃. In the temperature conversion table, 45 ℃ is equal to 41,3 kΩ. If the resistance on the multimeter shows 41.3 kΩ, the temperature on the cube is 45℃. Connect the radiation sensor with a multimeter while waiting for the 41.3 kΩ resistance. Select DC voltage measurement mode on the multimeter. Place the radiation sensor on the precision rail at a distance of 5 cm from the cube during data collection. If the resistance shows 41.3 kΩ, turn on the radiation sensor. Then calculate the amount of thermal radiation that appears on the multimeter for each side of the cube using gain 1. Repeat the steps above using gain 2.

Part 2 Measuring the Amount of Thermal Radiation from Various Materials Around the Room. Use a trial step using gain 2. Place the sensor 5 cm away from the black surface cube, then place the glass between the sensor and the light. Remove the blocker from the radiation cube, then repeat step 2 with a blocker of a different material similarly.

RESULTS AND DISCUSSION

Measuring Thermal Radiation Levels on Different Surfaces

In the first part of the experiment, gain 1 and gain 2 were used on the radiation sensor. Gain produces the amount of power transmitted in the direction with maximum directivity. Various types of material surfaces are used to measure thermal radiation levels, as seen in Table 1.

Table 1. Measuring Thermal Radiation Levels on Different Types of Surfaces

Types of survace	Themperature (℃)	Thermal Radiation (mV)	R (Ω)	P (Watt)	ε
		Gain 1			
Black	45	0.9	41.3	0.000000019	1
	50	0.9	33.6	0.0000024	1

	55	1.6	27.5	0.000058	1
	45	0.6	41.3	0.0000000087	0.458
White	50	0.5	33.6	0.0000000074	0.031
	55	0.5	27.5	0.0000000090	0.000151
	45	0.8	41.3	0.00000015	7.894
Ligthning	50	0.8	33.6	0.00000019	0.080
	55	0.8	27.5	0.00000023	0.0040
	45	0.8	41.3	0.00000015	0.62
Dull	50	1.0	33.6	0.000000030	0.126
	55	1.0	27.5	0.000000036	0.0062
Gain 2					
	45	0.7	41.3	0.000000011	1
Black	50	0.9	33.6	0.0000024	1
	55	0.9	27.5	0.0000030	1
	45	1.7	41.3	0.000000070	6.363
White	50	1.7	33.6	0.000000086	0.035
	55	1.6	27.5	0.000000093	0.031
	45	0.5	41.3	0.0000006	54.545
Ligthing	50	0.9	33.6	0.0000024	1
	55	1.0	27.5	0.000000036	0.012
	45	1.6	41.3	0.000000061	5.545
Dull	50	1.1	33.6	0.000000036	0.015
	55	1.1	27.5	0.000000044	0.0147

Measuring the amount of thermal radiation emitted from various materials around the room

The second part, measuring the amount of thermal radiation, shows the thermal radiation emitted by black bodies and the types of objects used as barriers between the sensor and the cube. The objects used are glass, black cloth, cardboard, and styrofoam. To see the radiation emissions from various objects, see Table 2.

Table 2. Thermal radiation for various barrier type objects

Types of barriers	Thermal radiation (mV)
Glass	0 mV
Black cloth	1,7 mV
Paperboard	1,1 mV
Styrofoam	1,3 mV

Experiments regarding thermal radiation (Leslie cube) were carried out in two experiments. The first experiment measured thermal radiation levels on different surfaces. The second experiment was to measure the amount of thermal radiation emitted from various objects around the room. In the first experiment, which measured the level of thermal radiation on different surfaces, the thermal radiation produced on the cube's various surfaces resulted in the object's black surface having a greater absorption capacity than other colors. The quantity of the object surface emitted by thermal radiation, namely black surfaces, has a significant value compared to other surfaces. The surface quantities of the cubes are in order from largest: black, dull, flash, and white. The quality of each surface is different. The surface of a black body has the best quality in emitting thermal radiation. This can be seen from the results where black has the highest sensor output value compared to other types of surfaces. In this first experiment, the researchers also made variations to the gain on the radiation sensor, namely using gain 1 and gain 2. According to Shabrina and Samuel (2018), 17 gain is the amount of power transmitted in the direction with maximum directivity. The experimental results show that at gain 2, the thermal radiation produced is more significant than when using gain 1.

The second experiment measured the amount of thermal radiation emitted from various objects around the room. It was found that the thermal radiation emitted by black objects with the types of plates used as barriers between the sensor and the cube. The plates used are glass, black cloth, cardboard, and styrofoam. From the experiments carried out, it was found that the sensor output on black cloth had a more excellent value than glass, cardboard, and styrofoam barriers. Based on the sensor output value, black cloth effectively transmitted thermal radiation energy compared to glass, cardboard, and styrofoam. The plate-type variants' results vary (Hasanov et al., 2019; Li et al., 2020; Budiyanto & Shinoda, 2021; Patra et al., 2022; Acharya et al., 2023).

The novelty of this study is that it introduces a new experiment on thermal radiation using a Leslie cube to measure thermal radiation on different surfaces and objects. The study also provides empirical evidence of the variation of thermal radiation with surface color and texture and the emissivity of other materials. The study contributes to the literature on physics education and thermal radiation by demonstrating a simple and effective way of teaching and learning the concept of thermal radiation using a Leslie cube. The limitation of this study is that it only uses four surface variations and a limited number of objects to measure thermal radiation using a Leslie cube. The study also does not account for other factors that may affect thermal radiation, such as the temperature, the distance, and the angle of the sensor. Future research may extend the scope and duration of the study to include more surface variations and objects and to control for other variables that may influence thermal radiation.

The resistance, converted to temperature in thermal radiation, influences the amount of radiation obtained. Resistance is inversely proportional to the absorption capacity of thermal radiation, where the smaller the resistance, the greater the radiation absorption capacity. Temperature has an essential influence on thermal radiation; the higher the temperature, the greater the energy radiated.

CONCLUSION

Based on the experiments that have been carried out in this research, it can be concluded that: 1. Surfaces that are capable of emitting radiation from the best to the worst are black, dull, lightning, and white. 2. Black cloth effectively transmits thermal radiation energy compared to glass, cardboard, and styrofoam. 3. The resistance, which is then converted to temperature in thermal radiation, has an influence on the amount of radiation obtained.

ACKNOWLEDGMENTS

Thanks are addressed to the management of the Physics Laboratory for Mathematics and Natural Sciences Education at Jambi University, who have facilitated the experimental site. The creation is addressed to the teaching and education faculty at Jambi University, who have focused their attention on this research.

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