Blackbody Radiation Experimental Apparatus (Arabeta) to Support Physics Learning for Senior High School Students

I Safari¹, A B Susilo and C E Rustana
Physics Education Master Program, Universitas Negeri Jakarta
Jl. Rawamangun Muka, Jakarta 13220, Indonesia
Email: ⁱmansfr2@gmail.com, anggarabs@unj.ac.id, crustana@unj.ac.id

Abstract. As part of ongoing research to develop a tool for teaching thermal radiation, we have constructed an Experimental Apparatus of Blackbody Radiation (ARABETA). Some previous researches have been conducted to investigate students understanding of Modern Physics, but very little on the topic of Black-body radiation. Apart from being more abstract, the experimental apparatus on this topic are also almost difficult to find in school laboratories. A preliminary study that involved 53 physics teachers in Jakarta region confirmed that black body radiation is a concept that is difficult to visualize to students during learning. Therefore, we developed a simple apparatus that is capable of measuring the temperature and thermal radiation of the samples used. This research uses research and development model by following some steps of Borg and Gall. The results of this measurement are shown in a graph of intensity against the multiplication result of the Stefan-Boltzmann and the fourth power of its absolute temperature, so that the emissivity value of the sample can be obtained. Through this development, we may provide an alternative solution for the experimentation issue in the learning of blackbody radiation at senior high level.

1. Introduction

Physics is an empirical science, which is based on the phenomena that occur, can be observed and measured [1]. Therefore, in the study of physics subjects accompanied by observation of phenomena or experiments in the laboratory in which measurements are also carried out. In Putra's research, et al., 2018 it was obtained that work in the
laboratory is rarely done by high school teachers, thus allowing potential problems for students in understanding the subjects studied.

Blackbody radiation is one of the difficult and abstract physics learning materials for senior high school students. This data was obtained from preliminary studies to 53 high school physics teachers in Bekasi and Jakarta. According to 53 respondents, black matter radiation material is rarely observed and conducted experiments in the laboratory, due to the absence of real practicum tools for students.

Blackbody radiation experiment apparatus have actually been widely developed by experts such as experiments for the measurement of coefficients of emission of pine wood biomass pellets, rice husks and cypress wood by the method of multi-wave radiation thermometric [2], coefficient of emission of leaf revitalization conditioned in a greenhouse using an infrared thermometer and a thermocouple wire [3], measurement of blackbody emission in steel threads. Illuminated objects with infrared imaging radiometers and observed with Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy [4]. Experiments in measurement of black matter cavity radiation designed using monte carlo method [5-9], measurement of exhaust pipe emission by Monte Carlo method [10], measurement of radiation emissions of black material made of ceramic pipes with rolled heating wire [11], measurement of emissions of nickel and aluminum particle powder using Bragg fiber regeneration/RFBG lattice [12], development of normal spectral emissivity measuring instrument of solid material at high temperatures from 1073K to 1873K and wavelength from 2 μm to 25 μm [13], development of data logger-based thermal radiation practical device using the DHT11 Arduino temperature sensor[14] and the development of SNR V-1.4SL thermal radiation devices made of easily accessible and environmentally friendly materials and equipment [15].

Some experiments and practical device designed in addition to using expensive materials and tools, are also still too complicated compared to the achievement of competency standards formulated by Indonesia's national education curriculum in 2013 on quantum phenomena learning. This study aims to develop a blackbody radiation experiment apparatus (ARABETA) that is adapted to the achievement of competency standards of Indonesia's national education curriculum in 2013, namely to qualitatively analyze quantum phenomena that include the radiation properties of black matter, photoelectric effects, Compton effects, and X-rays in daily. This study developed a blackbody radiation experiment apparatus that can show quantum phenomena and use materials that are easily obtained in everyday life.

2. Method
The radiation intensity of black matter varies with the temperature indicated by the equation:

\[ I = \frac{P}{A} = \frac{e \sigma A T^4}{A} \text{ and } I = e \sigma T^4 \]  \hspace{1cm} (1)

With \( P \) is the power in watts that radiations at all wavelengths from the surface of an object.

\[ \sigma = 5.670 \times 10^{-8} \text{ W/m}^2\text{K}^4 \]  \hspace{1cm} (2)
is a Stefan–Boltzmann constant, A is the cross-sectional area of the object in m², e is the surface emissions of the object, T is the surface temperature in kelvin[16] This research uses research and development model by following some steps of Borg and Gall, they are; research and information collecting, planning, develop preliminary form of product, preliminary field testing, main product revision and final product revision.

The previous design, sample was not covered by box but only covered by quartz glass as shown as figure below:

![Figure 1. The previous design of blackbody radiation experiment apparatus. 1-Alumunium as sample (covered by quartz glass); 2-Supporting wall; 3-Termocouple; 4-Linshang Infrared Power meter; 5-Fuse; 6-Power supply; 7-Arduino board; 8-Laptop](image)

The result of this design shows that the temperature of quartz glass as cover and the noise intensity of radiation from environment are too high. The next design using heater filament connected to power supply with temperature controller. The heater was covered by sample (alumunium, copper and stainless Steel rod with 3cm of inner diameter and 2 mm of thickness). The temperature of sample was measured by termocouple Arduino which are connected to laptop. The experimental apparatus was covered by wooden box and the intensity of radiation emitted by sample was measured by using Linshang infrared intensity. The recorded intensity and the fourth power of absolute temperature of sample were plotted in a graph to find the gradient of graph as the coefficient emissivity of sample.

The experiment was applied with the similar duration, length and thickness of sample. Each sample was measured for 5 minutes every 50 kelvin of increasing temperature which started from 323 K and be limited to 823 K of heater temperature and recorded every second by using arduino platform. The intensity of radiation emits by sample was measured with Linshang infrared power meter and recorded by using smartphone. Both data (temperature of sample and intensity of radiation) were plotted into a graph. The design of experiment is shown by picture below;
3. Result and Discussion
The result of ARABETA using three sample rod (stainless steel, copper and alumunium) is presented by graph below;
**Graph a.** The experiment result using stainless steel rod as sample

\[ y = 0.0137x - 49.03 \]

**Graph b.** The experiment result using aluminium rod as sample

\[ y = 0.0161x - 26.128 \]

**Graph c.** The experiment result using copper rod as sample

\[ y = 0.0146x - 23.417 \]
All samples measurement starts from 300 K to 773 K of sample’s temperature (when the temperature of stainless steel was 668.4 K, Aluminium was 591.1 K and Copper was 609.4 K). Intensity or radiation emits by stainless steel start from 467.5 K of sample’s temperature, 398.15 K of aluminium rod’s temperature and 325.5 K of copper rod’s temperature.

According to data from three graphs above in the same temperature every sample emits different intensity of radiation. From the gradient of graph a known the coefficient emissivity of stainless steel rod is 0.0137, the gradient of graph b known the coefficient emissivity of aluminium rod is 0.0161 and the gradient of graph c known the coefficient emissivity of copper rod is 0.0146. According to literature, the coefficient emissivity of stainless steel polished is 0.075, coefficient emissivity of aluminium polished is 0.039-0.057 and the coefficient emissivity of copper polished is 0.023-0.052 [17]. For experiment from 0 to 2500 C, the coefficient emissivity of stainless steel polished is 0.1-0.15, coefficient emissivity of aluminium polished is 0.05-0.1 and the coefficient emissivity of copper polished is 0.1 [18].

The different result may be effect of radiation background of environment such as wood as the material of cover box, alumina and teflon material as supporting wall and also ceramic as connecting cover. The significance of infrared power meter may be also effects to the result.

The implication of this research are to use more significant infrared power meter and which is also connected to data logger in order to get more accurate data and to use slimmer designed cover box in order to reduce noise intensity of blackbody radiation by environment.

4. Conclusion
The developed experiment apparatus for blackbody radiation may show the blackbody radiation as simple quantum phenomena, eventhough the result of experiment is still farther than literature.

References
[1] I. Y. Putra, D. Dasmo, D. L. Saraswati, I. A. D. Astuti, N. Nurullaeli, Y. B. Bhakti and I. B. Rangka 2018 Developing of physics practical module based on scientific method for students (Jakarta: MSCEIS)
[2] S. Zheng, Y. Yang, X. Li, H. Liu, W. Yan, R. Sui and Q. Lu. Temperature and emissivity measurements from combustion of pine wood, rice husk and fir wood using flame emission spectrum, Fuel Processing Technology 204, pp. 1-7. 2020.
[3] Chen and Chiachung. Determining the Leaf Emissivity of Three Crops by Infrared Thermometry, Sensors, 15, 11387-11401; doi:10.3390/s150511387, pp. 11388-11401. 2015.
[4] M. Larciprete, Y. Gloy, R. L. Voti, G. Cesarini, G. Leahu, M. Bertolotti and C. Sibilia. Temperature dependent emissivity of different stainless steel textiles, International Journal of Thermal Sciences, 113, pp. 130-135. 2017.
[5] J. G. C. B. Yikun Zhao. Comparative Study on Radiation Properties of Blackbody Cavity Model Based on Monte Carlo Method, *International Journal of Thermophysics* 2020, pp. 1-11. 2020.

[6] J. D. Lucas and J. J. Segovia. Measurement and Analysis of the Temperature Gradient of Blackbody Cavities, for Use in Radiation Thermometry *Int J Thermophys*, pp. 39-57. 2018.

[7] P. Saunders. Optimising Blackbody Cavity Shape for Specially Uniform Integrated Emissivity, *International Journal of Thermophysics*, pp. 1-9. 2017.

[8] C. J. Donlon, W. Wimmer, I. Robinson, G. Flisher, M. Ferlet, T. Niightingale and B. Brass. A Second-Generation Blackbody System for the Calibration and Verification of Seagoing Infrared Radiometers, *Journal of Atmospheric and Oceanic Technology*, pp. 1104-11027. 2014.

[9] V. A. Arkhipov, V. D. Gol’din, I. K. Zharova and K. G. Perfilieva 2018 *Technique of measuring the emissivity coefficient* (Tomsk Rusia: in Thermophysics 2018)

[10] G. Mei, J. Zhang, S. Zhao and Z. Xie. Design and analysis on fume exhaust system of blackbody cavity sensor for continuously measuring molten steel temperature, *AIP ADVANCES*, 7, pp. 1-6. 2017.

[11] W. G. Z. R. E. B. P. R. Poprawski. Investigation of black body radiation with the aid of a self-made pyroelectric infrared detecto, *European Journal of Physics*, pp. 1-9. 2015.

[12] M. L. G. L. J. R. M. F. Z. S Grohmann 2019 *Characterisation of the activation and reaction behaviour and determination of the emissivity of reactive nickel-aluminium particles with regenerated fibre Bragg gratings* (Munich: in Materials Science and Engineering)

[13] D. Ren, H. Tan, Y. Xuan, Y. Han and Q. Li. Apparatus for Measuring Spectral Emissivity of Solid Materials at Elevated Temperatures, *Int J Thermophys*, pp. 1-20. 2016.

[14] B. H. I. H Permana 2018 *Development of Thermal Radiation Experiments Kit Based on Data Logger for Physics Learning Media* (Jakarta: in Materials Science and Engineering)

[15] A. Malik, R. Zakwandi, S. Nurfalah, N. Nurhayati, C. Rochman and D. Nasrudi 2018 *Measuring the coefficient of emissivity using thermal radiation equipment SNR V-1.4 SL* (Bandung: in 3rd Annual Applied Science and Engineering Conference (AASEC 2018))

[16] R. D. Knight 2007 *The emission and absorbtion of Light," in Physics for scientis and engineer* (San Fransisco: Pearson) pp. 1231-1233

[17] E. T. Box. "Emissivity Coefficient Materials," [Online]. Available: https://www.engineeringtoolbox.com/emissivity-coefficients-d_447.html. [Accessed 26 5 2021].

[18] Optotherm, "Emmisivity in the infrared" 2018 Optotherm, Inc., [Online]. Available: https://www.optotherm.com/emiss-table.htm. [Accessed 26 5 2021].