ω | o m e g a

Simulation of Radiation Calculation of Black Body by Using the Interpolation Method

Feli Cianda Adrin Burhendi[1,*], Rizky Dwi Siswanto[2], Wahyu Dian Laksanawati[1]

[1]*Physics Education Study Programme, Universitas Muhammadiyah Prof. DR. HAMKA*
Jl. Tanah Merdeka, Pasar Rebo, Jakarta 13830, Indonesia
[2]*Mathematics Education Study Programme, Universitas Muhammadiyah Prof. DR. HAMKA*
Jl. Tanah Merdeka, Pasar Rebo, Jakarta 13830, Indonesia

Abstract

Simulation of radiation calculation of black body by using the interpolation method is designed to facilitate the determination of radiation in black matter efficiency. Fortran programming languages are chosen for computational processes. The calculation program that has been designed is able to calculate the efficiency of black body radiation easily and quickly with a fairly small error rate of 0.5%. The light radiation spectrum of objects is around 1000, 1100, 1200, and 1300 °C. The x axis shows the wavelength, while the y axis shows the intensity or strength of light. If we pay attention to the curvature of 1000 °C, along with the increasing frequency of light, the intensity of light is also getting stronger aka more bright. But at certain light frequencies, the line reaches the peak, and after that the light intensity drops dramatically. At temperatures of 1200 °C and 1300 °C, even though the temperature rises, the outline of the line graph is similar to the line 1000 °C. This is in accordance with the existing theoretical and experimental results.

*Corresponding author. E-mail address: felicianda@uhamka.ac.id

Introduction

In Physics, black body is objects absorbs all light falling him, no light that went or reflected. The term black body was first introduced by gustav kirchoff in 1862. Light emitted by objects black called black body radiation. If objects is heated at high temperature emitting light waves looked in lenght, like metal, incandescence long time later there will candescant, and brings forth light [1].

Knowledge of the laws governing thermal radiation of bodies enables understanding and description of large number of phenomena in nature, and operation principles for a wide range of devices used in everyday life and scientific applications. As examples, it is worth mentioning cosmologic research, the greenhouse effect, heat transfer processes used in harvesting of energy from renewable resources, such as solar collectors or solar ponds, cooling of electronic systems, measurement of thermal properties of bodies, motion detectors used in alert and protection systems or thermal vision cameras [2].

In line with that, the conclusion of the mathematical model of the law of perfect black matter radiation made by Max Planck at the beginning of the 20th century was based on ideas and ideas,

which were considered contrary to the laws of classical physics [3].

Here we will take a closer look at the Maxwell field and then in particular its properties at finite temperature in the form of black-body radiation. It is characterized by a pressure p and an energy density ρ. In a spacetime with three spatial dimensions, these are related by $\rho = \rho/3$. This can be derived by purely kinematic arguments which are used in the following section to find the corresponding relation in a D-dimensional Minkowski spacetime. When the radiation is in thermal equilibrium at temperature T, we then get by thermodynamic arguments the generalization of the Stefan-Boltzmann law in the form $\rho \propto T^D$ [4].

The generalized statistical mechanics has successfully been applied to investigate physical systems which exhibit nonextensive features like stellar polytrops, Levy-like anomalous diffusions, two dimensional turbulence, cosmic background radiation, solar neutrino problem and many others. Within the framework of the nonextensive statistical mechanics, we have generalized the Planck's law for the black-body radiation. Earlier, an attempt was made to generalize the Planck's radiation law (known as the asymptotic approach) [5] for the explanation of the cosmic microwave background radiation [6] at a temperature of 2.725 K. Another attempt was made to generalize statistics of quantum and classical gases using the factorization approach [7]. There are some versions of generalized Planck's law available in the existing literature[8] in this regard. There are also recent attempts to generalize the Planck's radiation law using Kaniadakis approach [9, 10].

The total radiant intensity of all wavelengths is directly proportional to the temperature of a four-level T, so it can be written

$$\int_0^\infty R \, \mathrm{d}\lambda = \sigma T^4 \tag{1}$$

This equation is called the Stefan law and σ is known as the Stefan-Bolzman constant, the σ constant value is equal to

$$\sigma = 5.6703 \times 10^{-8} \frac{W}{m^2 K^4} \tag{2}$$

The wavelength where each curve reaches its maximum value, which is called λ_{maks} (although it is not a maximum wavelength), decreases if the transmitter temperature is increased, it is proportional to the increase in temperature, so $\lambda_{\mathrm{maks}} \propto 1T$ is found

$$\lambda_{\mathrm{maks}} T = 2.898 \times 10^{-3} mK \tag{3}$$

This result is known as the Wien shift law.

Classic calculations for radiant energy emitted for each wavelength now are divided into several calculation stages. Without the proof being presented, the following points out the important parts of the decline. First, the calculation of the amount of radiation for each wavelength, then the contribution of each wave to the total energy in the box, and finally the intensity of radians associated with that energy. The box contains electromagnetic standing waves. If all the walls of a box are metal, then the radiation is reflected back and forth with the nodes (electric nodes) found on each wall (the electric field must be zero in a conductor).

The number of standing waves with a wavelength between λ and $\lambda + \mathrm{d}\lambda$ is

$$N(\lambda) \, \mathrm{d}\lambda = \frac{8\pi v}{\lambda^4} \, \mathrm{d}\lambda \tag{4}$$

V is the volume of the box. For a one-dimensional standing wave, such as in a tension rope along L, the permissible wavelength is $\text{fÉ}= 2L/n, (n = 1, 2, 3, ...)$. The number of possible standing waves with a wavelength between $\text{fÉ}1$ and $\text{fÉ}2$ is so that in the interval between fÉ and $\text{fÉ} + \mathrm{d}\text{fÉ}$ there will be as many different waves.

Each wave gives a share of kT energy to radiation in the box. This result is obtained from classical thermodynamics. Radiation in the box is in a state of thermal equilibrium with the wall at temperature T. This radiation is reflected by the wall of the box because it is absorbed by the wall and then emitted immediately by wall atoms, which in this process vibrate at the radiation frequency. To obtain radiant intensity from energy density (energy per unit volume) multiply by $c/4$. These results were also obtained from the theory of electromagnets and classical thermodynamics.

By combining the elements above, the estimated radiant intensity is

$$R(\lambda) = \frac{8\pi}{\lambda^4} kT \frac{c}{4} \tag{5}$$

This is known as the Rayleigh-Jeans formula. The decline uses classical electromagnetic theory and thermodynamics, which is a maximum effort in applying classical physics to understand the problem of black matter radiation.

In Planck's theory, each oscillator can emit or absorb energy only in quantities that are multiples of integers of a basic energy

$$E = n\varepsilon, n = 1, 2, 3, ... \tag{6}$$

n denotes the number of quanta. Furthermore, the energy of each quanta is determined by frequency according to

$$\varepsilon = h\nu \tag{7}$$

h is an appeal constant known as the Planck constant. Based on this assumption, the spectrum of radiant intensity Planck calculates is

$$R(\lambda) = \left(\frac{c}{4}\right)\left(\frac{8\pi}{\lambda^4}\right)\left[\left(\frac{hc}{\lambda}\right)\frac{1}{e^{\frac{hc}{\lambda kT-1}}}\right] \qquad (8)$$

Methods

The are many methods that able us to measure more or less accurately Planck's constant. The most useful, for a college or high school physics laboratory, are based on aplication of the photoelectric effect or black body radiation. Those are not the most accurate, but are the easiest to implement under the above-mentioned conditions. The first method relies upon Einstein formula describing the energy of electrons emitted from an illuminated surface for different frequencies of incoming photons. This method is quite often used in introductory laboratories. The second method seems more interestingas its implementation requires more knowledge about basic of quantum and statistical physics [11]. While implementing the method of interpolation.

Interpolation calculations were carried out to obtain theoretical results, then computation was carried out with the fortran95 program to obtain experimental data.

Results

The graph of the black body radiation spectrum can be seen in Figure 1. The bottom curved line is the spectrum of light radiation from objects at around 1000 °C. The x axis shows the wavelength, while the y axis shows the intensity or strength of light. If we pay attention to the curvature of 1000 °C, along with the increasing frequency of light, the intensity of light is also getting stronger aka more bright. But at certain light frequencies, the line reaches the peak, and after that the light intensity drops dramatically. At temperatures of 1200 °C and 1300 °C, even though the temperature rises, the outline of the line graph is similar to the line 1000 °C. Only the difference, the peak point is higher and slightly shifted to the right (to a greater frequency of light). We can also see that the frequency of light at the highest intensity is directly proportional to the temperature of the object.
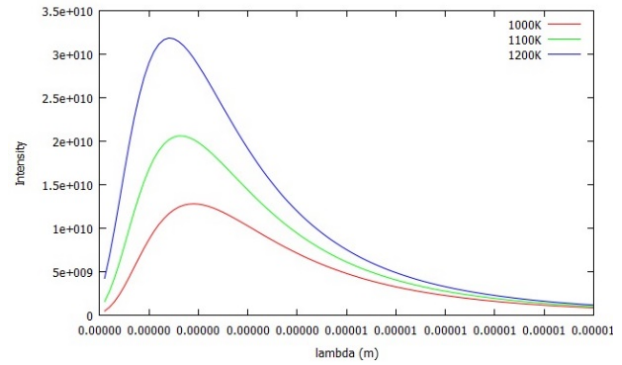

Figure 1: Graph of the black body radiation spectrum

Conclusion

The use of the interpolation method for calculating the efficiency of black body radiation can be used because it is in accordance with practical data or experiments that have been carried out by Wien and Max Planck. So this facilitates accurate data retrieval and forecasting data for different energy levels.

References

[1] Festiyed, Program perhitungan efisiensi energi radiasi benda hitam melalui metode Simpson dengan Borland Delphi 7, SAINSTEK **XI** (1), (2008).

[2] W. Poprawski, Z. Gnutek, E. B. Radojewska, and R. Poprawski, Investigation of black body radiation with the aid of a self-made pyroelectric infrared detector, Eur. J. Phys. **36** (6), 65025 (2015).

[3] M. A. Ramirez-Moreno, S. Gonzalez-Hernandez, and G. A. De Parga, A semiclassical approach to the matte black-body, Eur. J. Phys. **36** (6), 65039 (2015).

[4] H. Alnes, F. Ravndal, and I. K. Wehus, Black-body radiation with extra dimensions, J. Phys. A Math. Theor. **40** (47), 14309-14316 (2007).

[5] C. Tsallis, F. C. Sá Barreto, and E. D. Loh, Generalization of the Planck radiation law and application to cosmic microwave background radiation, Phys. Rev. E **52**, 1447 (1995).

[6] J. C. Mather, Measurment of the cosmic microwave background spectrum by the Cobe FIRAS instrument, Astrophys. J. **420** (2), 439-444 (1994).

[7] F. Büyükiliç, Doğan Demirhan, and A. Güleç, A statistical mechanical approach to generalized statistics of quantum and classical gases, Phys. Lett. A **197** (3), 209-220 (1995).

[8] U. Tirnakli, F. Büyükiliç, and D. Demirhan, Generalized distribution functions and an alternative approach to generalized Planck radiation law, Physica A **240** (3-4), 657-664 (1997).

[9] K. Ourabah and M. Tribeche, Planck radiation law and Einstein coefficients reexamined in Kaniadakis κ statistics, Phys. Rev. E **89**, 062130 (2014).

[10] I. Lourek and M. Tribeche, Thermodynamic properties of the blackbody radiation: a Kaniadakis approach, Phys. Lett. A **381** (5), 452-456 (2017).

[11] J. Dryzek and K. Ruebenbauer, Planck's constant determination from black?body radiation, Am. J. Phys. **60**, 251 (1992).