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Effective compton cross section in non-degenerate high-temperature media

F. Shekh-Momeni*, J. Samimi

Department of Physics, Sharif University of Technology, Tehran, P.O. Box 11365-9161, Iran

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Abstract

The effective compton cross section in a non-degenerate plasma ($n \ll \{((kT/c)^2 + 2mkT)/h^2\}^{3/2}$) is investigated in a wide range of temperatures. The results show a decreasing behavior with temperatures especially for $kT \gg m_e c^2$. The results may be important in phenomena like accretion discs or ultra-relativistic blast waves in GRB models, where the emitted radiation has to pass through a medium containing high-energy electrons.

Keywords: Compton scattering; High-energy physics; Gamma-ray bursts; Accretion

1. Introduction

Compton scattering is one of the most important phenomena in astrophysics that affects the received flux from celestial objects. In a non-degenerate low-temperature plasma in which $n^{2/3}h^2/2\pi m_e \ll kT \ll m_e c^2$ [1], the free electrons can be considered effectively at rest, provided that the photon energy $E = h\nu$ is much greater than kT. In such a situation the Klein–Nishina formula for Compton scattering accurately works. The Klein–Nishina formula is only dependent on the

*Corresponding author.
E-mail addresses: fmomeni@mehr.sharif.edu (F. Shekh-Momeni), samimi@sharif.edu (J. Samimi).

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energy of the incoming photon as measured in the rest frame of the electron [2,3]

$$\sigma_c = \sigma_T \frac{3}{4}\left\{\frac{1+\varepsilon}{\varepsilon^2}\left[\frac{2(1+\varepsilon)}{1+2\varepsilon} - \frac{1}{\varepsilon}\ln(1+2\varepsilon)\right] + \frac{1}{2\varepsilon}\ln(1+2\varepsilon) - \frac{1+3\varepsilon}{(1+2\varepsilon)^2}\right\}, \tag{1}$$

in which ε is the ratio of the photon energy E to the electron rest energy $m_e c^2$ (Fig. 1). But at high temperatures where the electron mean energy is greater than or comparable to $m_e c^2$, the energy of the photon is highly different compared to different individual electrons. So, since the total Compton cross section is a function of the photon energy in the rest frame of the electrons, one would expect an effective cross section due to the thermal distribution of electrons. The aim of this paper is to obtain an effective cross section for Compton scattering in a wide range of plasma temperatures and photon energies. In Section 2, the averaging method is introduced. In Section 3, the momentum distribution of electrons in a wide range of temperatures is discussed and the normalization constant of the distribution is evaluated as a function of plasma temperature, and then, a numerically computable form for the effective cross section of Compton scattering is obtained. The results are presented in Section 4, as well as a discussion on their importance in GRBs.

2. Averaging formalism

Consider a monochromatic photon beam with energy $E = h\nu$ passing through a plasma that its temperature T and its electron number density n_e satisfy the non-degeneracy condition $n \ll \{((kT/c)^2 + 2mkT)/h^2\}^{3/2}$. Now, we define the effective cross section in Compton scattering $\sigma_{C,\text{eff}}$ as

$$\frac{dN}{N} = \sigma_{C,\text{eff}} \cdot n_e \, dl, \tag{2}$$

where dN/N denotes the fraction of photons scattered in a distance dl. Now, let us consider the fraction of electrons $\delta n_e/n_e$ that move in the solid angle $d\Omega$ and have a momentum magnitude

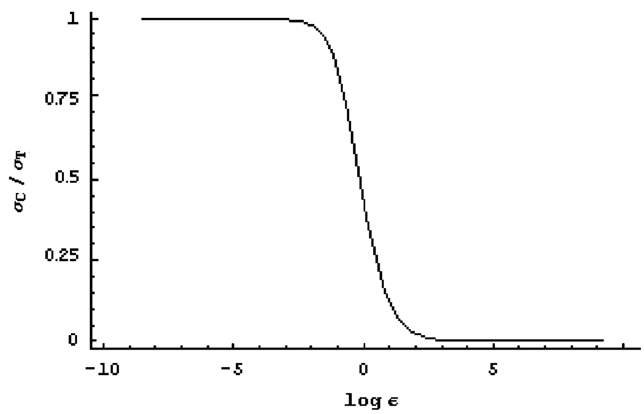

Fig. 1. The cross section in Compton scattering evaluated using Eq. (1).