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STUDY THE SCATTERING DYNAMIC OF ELECTRON - YUKAWA POTENTIAL IN PRESENCE OF BICHROMATIC LASER FIELDS

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Abstract: Scattering is one of the most powerful tools for studying the dynamics of particle interactions in the presence of external fields such as laser or magnetic fields. The objective of this work is to investigate the scattering dynamics of an electron interacting with the Yukawa potential in the presence of bichromatic polarized laser fields. For this purpose, the Kroll–Watson approximation, the Volkov wave equation, and the Yukawa potential are used . The **result** shows that the DCS is highly sensitive to the screening parameter, momentum transfer, separation distance, and scattering angle. Distinct peaks emerge for different screening strengths, with their positions and intensities varying systematically with changes in the scattering angle and screening effect. The developed theoretical model provides new insights into multiphoton processes and resonance mechanisms in laser-assisted scattering.

Introduction: The screened Coulomb (Yukawa) potential is widely used to model interactions between charged particles in plasmas, colloids, and similar systems. This work presents an analytical method (supported by numerical results) to obtain the momentum-transfer cross section for collisions under the attractive Yukawa potential. We focus on the regime of strong interactions, where scattering occurs mainly at large angles—opposite to the standard Coulomb scattering theory(Khrapak et al., 2003). A theoretical study of high-energy hadron interactions is conducted using the eikonal approach with a Yukawa-type relativistic quasipotential, applying unitarity and analytic continuation to analyze the scattering amplitude in the impact-parameter plane(Abdulvahabova & Afandiyeva, 2025)

Methods and Materials

Theoretical Part: These methods and materials are used to determine DCS. For our system, we consider the equation to describe conduction-band electron dynamics in the (x,y) plane (Liu et al., 2009; Maurer & Keller, 2021).

$$X(r,t) = \frac{1}{(2\pi)^{\frac{3}{2}}} \exp\left\{ i\frac{p}{\hbar}.\left(r + \frac{e}{m}\int A(t)dt \right) - i\frac{E}{\hbar}t - i\frac{e^2}{2m\hbar}\int A^2(t)dt \right\} \quad (1)$$

The potential for bichromatic laser is (Barna & Varró, 2016)

$$A(t) = \epsilon_1\left(\frac{\varepsilon_1}{\omega}\right)\cos(\omega t) + \epsilon_m\left(\frac{\varepsilon_m}{m\omega}\right)\cos(m\omega t + \phi) \quad (2)$$

. Now putting value of A(t) form (2) in (1) and solving as

$$X(r,t) = \frac{1}{(2\pi)^{\frac{3}{2}}} \exp\left\{ i\frac{p}{\hbar}.\left(r + \frac{e}{m}\int \left(\epsilon_1\left(\frac{\varepsilon_1}{\omega}\right)\cos(\omega t) + \epsilon_m\left(\frac{\varepsilon_m}{m\omega}\right)\cos(m\omega t + \phi) \right) dt \right) - i\frac{E}{\hbar}t - i\frac{e^2}{2m\hbar}\int \left(\epsilon_1\left(\frac{\varepsilon_1}{\omega}\right)\cos(\omega t) + \epsilon_m\left(\frac{\varepsilon_m}{m\omega}\right)\cos(m\omega t + \phi) \right)^2 dt \right\} \quad (3)$$

For elliptical polarized the S-matrix is (Kroll and Watson, 1973)

$$S_{fi}^E = \delta_{fi} - \frac{i}{\hbar}\int_{-\infty}^{\infty} \langle \psi_f^E(r,t) | V(r) | \psi_i^E(r,t) \rangle \, dt \quad (4)$$

In equation (4) δ_{fi} is Kronecker delta, $V(r)$ is the potential, $\psi_i^E(r,t)$ is the incident wave function & $\psi_f^E(r,t)$ is the scattered or final wave function.

Yukawa proposed potential in 1935 as effective non-relativistic potential which described the strong interactions between nucleons (citation) as

$$V(r) = -\frac{Ae^{-\mu r}}{r} \quad (5)$$

From the relation of DCS and T-matrix is (Kavazović et al., 2021) we have,

$$\frac{d\sigma}{d\Omega} = \frac{p_f}{p_i}\left|T_{fi}\right|^2 \quad (6)$$

In equation (6) $\frac{d\sigma}{d\Omega}$ is differential cross-section, k_f is final momentum & k_i is initial momentum. Similar methodology was developed by (Kurmi et al., 2025).

$$\frac{d\sigma}{d\Omega} = \frac{p_f}{p_i}\left| -\frac{(exp\,(i\Delta p cos\theta r \;- \mu r) \times J_n(dn_1) \times J_n(dn_2)\exp(in\phi)\,A)}{4\pi^2\,(i\Delta p cos\theta - \mu) \times i\Delta p} \right|^2 \quad (7)$$

Computational Detial: Where Δp is change in momentum the computational parameters include incident momentum (1–3 eV), final momentum (0-1 eV), potential strength $V_0=2.7\times10^{-10}$ a.u., scattering angle (0–57°), field strength (0.1), photon energy (1.17 eV), separation distance (1–7 Å), Bessel order (0), photon phase (45°), and screening (0.01–1). Equation (7) analyzes DCS variations.

Result and Discussion:

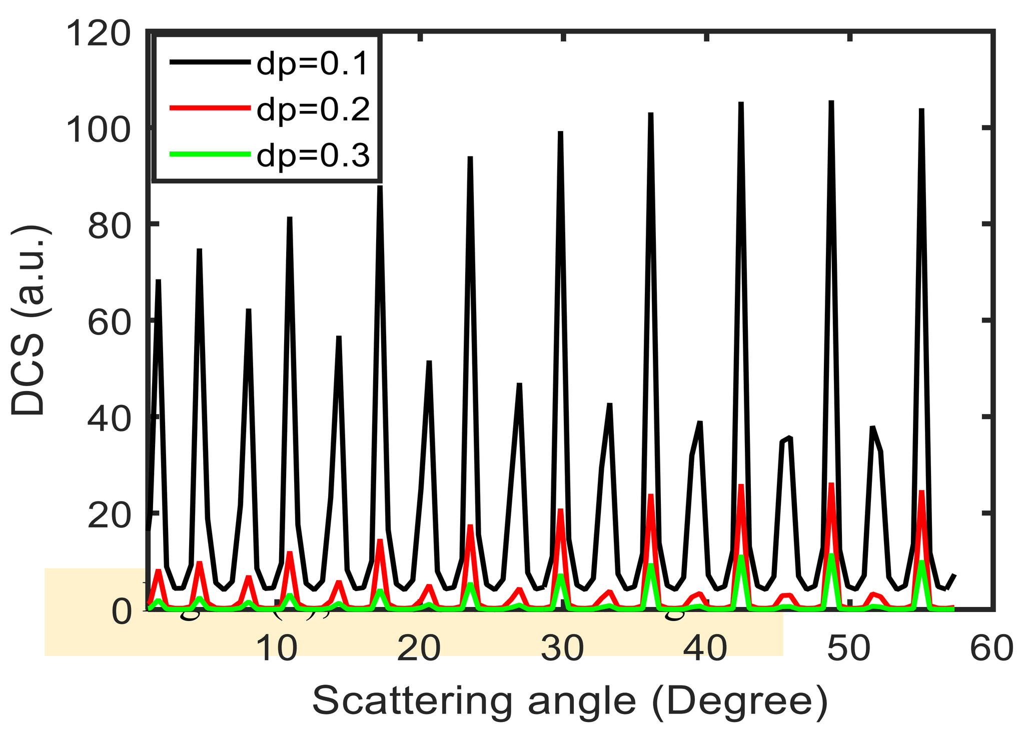

Figure (1) illustrates the variation of the differential cross section (DCS) with scattering angle (degree) in the presence of a laser field.

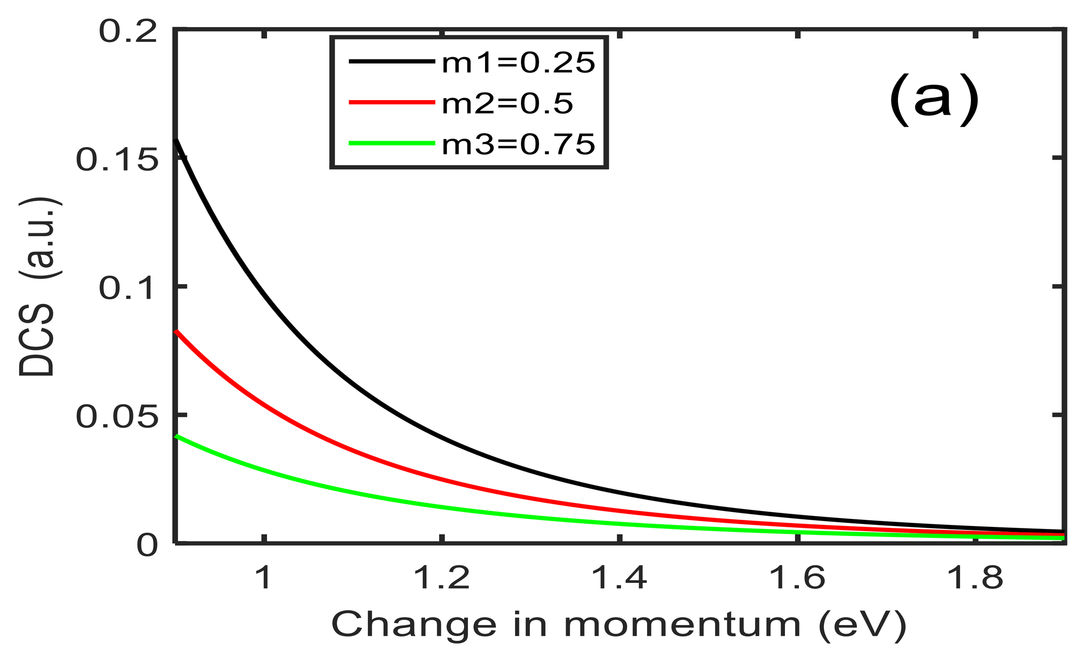

Figure (2) illustrates the variation of the differential cross section (DCS) with Change in momentum (eV) in the presence of a laser field.

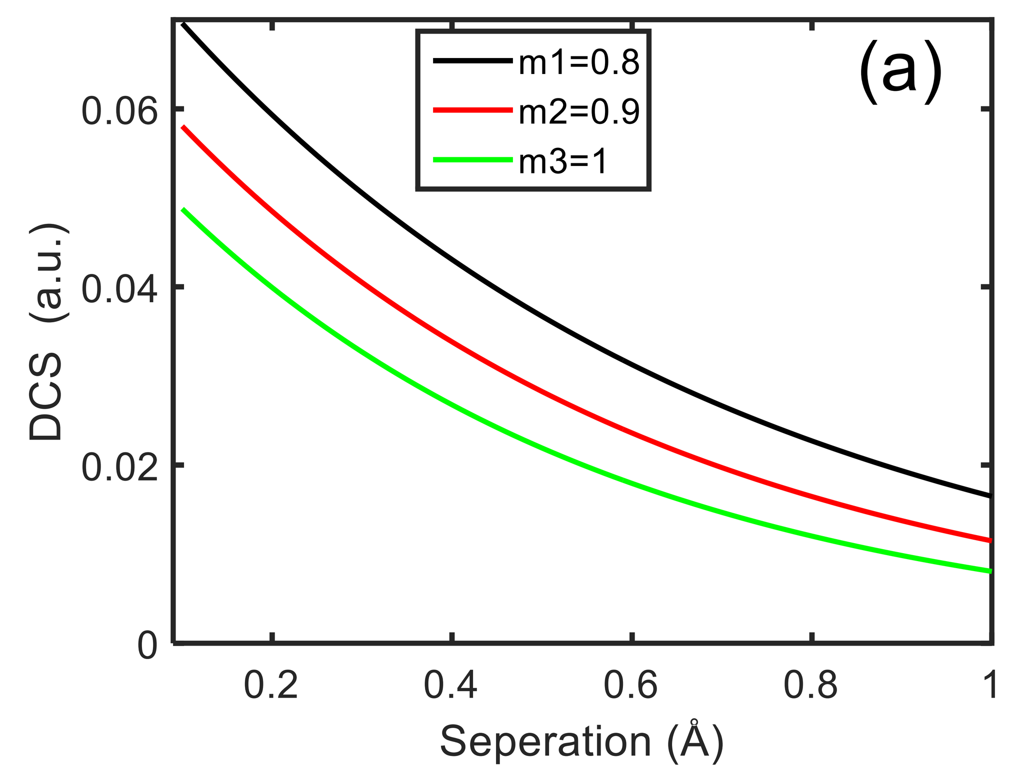

Figure (3) illustrates the variation of the differential cross section (DCS) with separation(Å) in the presence of a laser field.

Conclusion The overall study demonstrates that the DCS is strongly influenced by momentum transfer, scattering angle, screening effect, and separation distance under the presence of a laser field with Yukawa potential. The analysis shows that screening modifies both the depth and position of DCS maxima and minima. Additionally, the variation of DCS with separation distance, change in momentum and screening parameters indicates the interaction strength between the incident and scattered electrons, further confirming the dominant role of screening in electron–electron interactions. These findings provide valuable insight into photon–particle scattering dynamics.

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