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Unraveling collisional energy loss of a heavy quark in quark-gluon plasma

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At leading order in QCD coupling constant, we compute the energy loss per traveling distance of a heavy quark dE/dz from elastic scattering off thermal quarks and gluons at a temperature T, including the thermal perturbative description of soft scatterings ($-t < -t^*$) and a perturbative QCD-based calculation for hard collisions ($-t > -t^*$). Within this soft-hard factorization model, we find that the full results of dE/dz show a mild sensitivity to the intermediate cutoff t^*, supporting the validity of the soft-hard approach within the temperature region of interest. We re-derive the analytic formula for dE/dz in the high-energy approximation, $E_1 \gg m_1^2/T$, where E_1 is the injected heavy quark energy and m_1 is its mass. It is realized that the soft logarithmic contribution, $dE/dz \propto ln(-t^*/m_D^2)$, arises from the t-channel scattering off thermal partons, while the hard logarithmic term, $dE/dz \propto ln[E_1T/(-t^*)]$, stems from the t-channel scattering off thermal partons, and the one $dE/dz \propto ln(E_1T/m_1^2)$ comes from the s- and u-channel scattering off gluons. The sum of these contributions cancels the t^*-dependence as observed in the full result. The mass hierarchy is observed as $dE/dz(charm) > dE/dz(bottom)$.
Our full results are crucial for a better description of heavy quark transport in QCD medium, in particular at low and moderate energy. We also calculate the energy loss by imposing Einstein's relationship. The related results appear to be systematically larger than that without imposing Einstein's relationship.

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