Pulsed-Power Approach to Pair Production in Magnetic Fields below the Schwinger Limit

C. A. Williams [(1)] & D. H. Younis [(2)]
[(1)] Sandia National Laboratories (USA)
[(2)] U.S. Naval Research Laboratory (USA)

The Schwinger critical fields ($E_{crit} \equiv \frac{m^2c^3}{e\hbar} = 1.32 \times 10^{18}$ V/m and $B_{crit} \equiv \frac{E_{crit}}{c} = 4.41 \times 10^{9}$ T) typify the necessary field strengths for observing the non-linear nature of the vacuum [1]. Despite not being able to produce gigatesla fields in the laboratory, we propose an experimental scheme to produce relativistic electron-positron pairs by bombarding the azimuthal magnetic field of a current-carrying metal rod with a laser-driven electron beam. If the product of the electron Lorentz factor γ and static magnetic field B_ϕ (in the laboratory frame) approaches the Schwinger limit, pair production can be facilitated by both real and virtual photons via the Breit–Wheeler (BW) and Trident (Ψ) processes, respectively (the real photons in this case referring to the synchrotron emission) [2]. We report analytical calculations and numerical simulations (utilizing the QED-PIC codes EPOCH and TurboWAVE) that extract the dependencies of the pair yield on parameters characterizing the Z-pinch rod (current and stagnation radius), electron beam (electron momentum and beam charge), and geometry of the return-current can that surrounds the rod (the volume in which the electrons gyrate, and photons propagate) [3]. Additionally, we probe the dependence of the BW/Ψ pair production ratio on injection orientation, i.e., between beams injected axially (parallel to the rod) and those injected radially (perpendicular to the rod). Special focus is given to calculating the pair production rates that could potentially be produced at Sandia National Laboratories' Z Facility by firing the Z-Petawatt Laser (normalized vector potential $a_0 \approx 10$) to drive an electron beam onto a metal-rod Z-pinch imploded to $O(100\ \mu m)$ in radius by the nominal maximum current of the Z Machine (<30 MA), but currents up to 60 MA are explored as well, a mark which could be realized on next-generation pulsed-power facilities.

The production of electron-positron pairs in fields of magnetic type ($\mathcal{F} < 0, \mathcal{G} = 0$)[1] has never been observed in the laboratory. Magnetic pair production—in addition to its fundamental importance—is also of astrophysical significance; dense pair-plasmas are believed to form in the magnetospheres of pulsars through the interaction of synchrotron radiation with the ~10^8 T magnetic fields present there. This makes an experimental testbed of this process relevant to efforts attempting to down select between various magnetospheric models, as well as related phenomena such as fast radio bursts.

References:

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