Radiation reaction force dialog

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April 2026

Conversation on Radiation Reaction

Question 1

What is the best current theory for how radiation reaction modifies the trajectory of an accelerated charged particle?

Answer

The leading modern view is that radiation reaction is best described by the **Landau–Lifshitz (LL) equation**, a reduced and physically well-behaved form of the older Abraham–Lorentz–Dirac (ALD) equation. It avoids runaway and pre-acceleration solutions while remaining consistent with classical electrodynamics.

The LL equation is obtained by treating the ALD self-force term as a small correction and substituting the Lorentz-force acceleration back into it ("reduction of order"). This yields a causal, stable, and experimentally consistent equation of motion.

Question 2

Yes, please write out the LL equation explicitly.

Answer

The covariant Landau–Lifshitz equation for a particle of charge q and mass m is

$$m\,\frac{du^\mu}{d\tau} = qF^{\mu\nu}u_\nu + \frac{2q^3}{3m}\left(\partial_\alpha F^{\mu\nu}u^\alpha u_\nu + \frac{q}{m}\left[F^{\mu\nu}F_{\nu\beta}u^\beta - (F_{\alpha\beta}u^\beta)(F^{\alpha\gamma}u_\gamma)u^\mu\right]\right).$$

The first term is the Lorentz force, and the remaining terms encode radiation reaction. In the nonrelativistic limit, the LL equation reduces to

$$m\mathbf{a} = q(\mathbf{E} + \mathbf{v}\times\mathbf{B}) + \frac{2q^3}{3m}\Big(\dot{\mathbf{E}} + \mathbf{v}\times\dot{\mathbf{B}} + \frac{q}{m}\left[(\mathbf{E} + \mathbf{v}\times\mathbf{B})\times\mathbf{B} + (\mathbf{v}\cdot\mathbf{E})\mathbf{E} - \gamma^2(\mathbf{E} + \mathbf{v}\times\mathbf{B})^2\mathbf{v}\right].$$

Question 3

Is there any experimental test of the LL equation, like at a free-electron laser such as the LCLS?

Answer

Yes—the LL equation has been tested experimentally, but not at an X-ray free-electron laser such as LCLS. The strongest tests come from the CERN NA63 collaboration, which used aligned single crystals to generate extremely strong electromagnetic fields. Their measurements of radiation spectra agree with LL-based predictions (with modest quantum corrections).

LCLS does not naturally reach the classical strong-field regime where LL dominates, so it has not performed a direct LL test. Future experiments at facilities like FACET-II or ELI may probe both classical and quantum radiation reaction more deeply.

Question 4

Does the stochastic-quantum-corrected theory use random numbers to generate photon emissions guided by the classical angular and frequency distributions, and then use momentum conservation to change the particle's momentum after each photon is emitted?

Answer

Yes. In the quantum regime, radiation reaction is modeled as a **stochastic sequence of discrete photon emissions**. At each timestep:

1. The total emission probability is computed from strong-field QED rates.
2. A random number determines whether an emission occurs.
3. Additional random numbers sample the emitted photon's energy and angle from the QED spectrum.
4. The electron's momentum is updated via

$$p^\mu \to p^\mu - k^\mu,$$

enforcing exact energy–momentum conservation.

Between emissions, the electron follows the Lorentz-force equation. Averaged over many events, the stochastic model reduces to the LL equation in the classical limit.