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Wheels within wheels: Hamiltonian dynamics as a hierarchy of action variables

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In Hamiltonian systems where one coordinate oscillates, the remaining coordinates may undergo a net displacement during one period of the oscillating coordinate. The archetypal example from plasma physics is charged particle motion in a magnetic field where the particle's position across field lines increases with every gyration, resulting in the well known guiding center drifts. We show that the net displacements of the non-periodic coordinates can be obtained by appropriate partial differentiation of the action integral associated with the periodic coordinate. This result is then used to demonstrate that the action integral acts as a Hamiltonian for the other coordinates providing time is scaled to the period, or "tick-time," of the oscillating coordinate. This generalizes the concept of guiding center drifts to a broad range of Hamiltonian systems and allows one to compute such drifts in regimes where the guiding center approximation fails. As an example, we derive the guiding center formulas for the grad-B drift and magnetic mirror force by taking partial derivatives of the first adiabatic invariant mu. Other examples, including a relativistic coupling effect and a mechanical analog of magnetic mirroring, are supplied to illustrate the varied application of these results.