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**Theory of sawtooth oscillations and**

**fast particle effects on internal kink modes: a review**

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Sawtooth oscillation relaxations are a ubiquitous, complex phenomenon in tokamak plasmas. Sawteeth can take up many different aspects; thus, the challenge for any theoretical interpretation is to find the unifying aspects behind the various experimental manifestations of sawtooth oscillations and to be capable of making predictions while allowing for the observed variability of the phenomenon. This was the approach that led us [1] to develop a model for the sawtooth period and amplitude, which is still today the reference model for predicting the behavior of sawteeth in future tokamak experiments such as ITER. The essential aspects of this model are:

1) Sawtooth relaxations are always initiated by the instability of an internal kink mode with toroidal n=1 and dominant poloidal m=1 mode numbers.

2) Taking into account two-fluid effects such as resistivity, electron and ion diamagnetic frequency and ion-viscosity effects, a threshold condition for the instability of m=n=1 internal kink modes can be found, which allows for stable q-profiles with q0 (on-axis q) below unity; as a consequence, a criterion is given for the *trigger* of sawtooth relaxations when q0<1 based on linear stability considerations.

3) The nonlinear evolution of the internal kink mode can take different aspects and is not completely understood (see, e.g., [2]), but to the extent that this mode causes magnetic reconnection at the q=1 surface and that q>1 is not a necessary condition for stability, a phenomenological partial reconnection model was developed in [1], which generalizes Kadomtsev’s complete reconnection theory [3]. This model allows us to calculate the relaxed q and pressure profiles after the sawtooth crash.

4) In predictive numerical codes, the sawtooth period is the time it takes for the plasma profiles to evolve, according to the prevailing transport conditions, from the relaxed state to the state where the instability “trigger” condition is fulfilled [4].

5) Fast particles can affect significantly the sawtooth trigger condition. Therefore, a detailed discussion of fast particle effects on internal kink modes is reviewed, including the theory of fishbones [5] and fast ion stabilization of internal kinks [6].

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