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Fermi Acceleration – From Cosmic Rays to Discharge Heating

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Low pressure, radio frequency (rf) driven discharges are widely used for materials processing in the microelectronics industry. Electrons in these discharges can be heated "collisionlessly" by repeated interaction with the fields near the plasma skin. The physical description of this "collisionless" heating harks back to two seminal ideas originating over fifty years ago in the disparate fields of astrophysics and condensed matter physics. The motion of a ball bouncing between a fixed and an oscillating wall was originally proposed by E.Fermi [*Phys. Rev.* **75** 1169 (1949)] in April 1949 as a model for cosmic ray acceleration. Expectations that the ball could be heated to very high energies gave way to the realization that while the motion is chaotic at low energies, the phase space has an intricate fractal structure and there is an adiabatic limit to the heating. Also in April 1949, A.B. Pippard [*Physica* **15** 45 (1949)] proposed an explanation for the anomalous high frequency skin resistance of metals at low temperatures, in which he divided electrons into two classes that "interacted with" and "did not interact with" the skin layer fields. The application of these ideas to collisionless electron heating in discharges has been fruitful [M.A. Lieberman and V.A. Godyak, *IEEE Trans. Plasma Sci.* **26** 955 (1998); E. Kawamura, M.A. Lieberman, and A.J. Lichtenberg, *Phys. Plasmas* **13** 053506 (2006)]. In this talk, Fermi's proposal for the origin of cosmic rays is reviewed. The Fermi acceleration model is used to describe collisionless heating in radio frequency-driven discharges, with illustrations drawn from experiments, computer simulations and analysis. The re-discovery of Pippard's model of the anomalous skin effect in metals, in the context of collisionless heating in discharges, is described.