

on electronic structure, when we discuss the role of d-band filling in determining some of the physical properties of transition metals.

The final point to be made is that Chelikowsky (1979) has presented solubility plots in which the two coordinates are prompted by the semi-empirical theory of Miedema (Alonso and March, 1989). Since, however, electronic structure also enters this theory, we shall defer further discussion to Chap. 6.

### 1.12. *Friction Mechanisms*\*

The mechanisms of friction are discussed in early books on the subject (e.g. Bowden and Tabor, 1950). Here we refer to the subsequent account of Stoneham *et al.* (1993). These workers note the following mechanisms:

- (i) Adhesion: surfaces adhere and then work is done in separating them.
- (ii) Ploughing: one surface pulls away small amounts of the other and
- (iii) Anelasticity: here the assumption is that energy is dissipated by dislocation motion and plastic deformation in the material.

We shall, in later chapters, discuss friction on a mesoscopic scale as well as specific atomistic studies. As to the first of these, we shall see below that two main steps are involved. The first of these is the characterization of rough surfaces and their contact. The second step is to invoke some law of friction. In such a law, we want to stress here the central importance of atomic force microscope (AFM) data (see Appendix 2.5) and its interpretation.

Tribology, the study of surfaces in moving contact, is an important area for technology. In spite of this, friction, at the time of writing, is not well understood at an atomistic level. Persson (1994) has posed some fundamental questions as follows:

- (1) What is structure of sliding interface: both geometric and electronic?
- (2) Where does the sliding take place?
- (3) What is the physical origin of the sliding force?

Persson follows these somewhat general points with some more specific questions:

- (i) Why is the frictional force  $F$  usually proportional to the load  $N$ ?
- (ii) What is the microscopic origin of 'stick-and-slip' motion? (see following page).

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\*The reader who requires an advanced account should refer to the book *Physics of Sliding Friction*, Eds. B. N. J. Persson and E. Tosatti, NATO ASI series E: Applied Sciences, Vol 311 (1996): (Kluwer: Dordrecht).

Persson (1994) has discussed the theory of friction. He asserts that, during sliding of a metal block on a metal substrate (in the absence of any lubricant), the frictional force is due mainly to the shearing of cold-welded contact 'points' junctions (see also Bowden *et al.*, 1967). After a junction has been formed, it is first elastically deformed, a slow process if the sliding velocity  $v$  is small, followed by plastic deformation involving rapid motion of dislocations, and other fast, nonadiabatic, rearrangement processes. As the block slides across the substrate, junctions are continually 'broken' and 'formed' at a rate proportional to the sliding velocity  $v$ . Persson argues that this is the reason why the frictional force is velocity independent. He asserts that the fundamental problem in sliding friction is to understand the microscopic features of the above rapid processes and then to relate these to the macroscopic movement of the metal block over the metal substrate.

Landman (1995) emphasized the importance of atomic-scale simulation in this problem. Simulations often reveal that the physical behaviour of materials at interfaces can be very different from that in the bulk. For example, the traditional picture of stick-slip motion ascribed it to a negative slope in the friction-velocity function but subsequent work has put this in reverse: in many cases stick-slip behaviour is found to be the primary process — arising from successive freezing and melting transitions of the shearing film — and it is this which gives rise to the negative friction-velocity dependence.