

nomena, such as stick-slip on the atomic scale or stick-slip in relation to phase transitions were discovered. Quantitative measurements under well-defined conditions were achieved and compared to theoretical models. Actually, it turned out that the computer simulations, especially the molecular dynamics calculations, were extremely useful for an understanding and visualization of the complex processes. The aim of this book is to provide an overview of tribology. Chapter I gives a brief overview of the history of tribology. Chapter II is an overview of instruments in tribology, where tribometers, surface force apparatus, quartz crystal microbalance and friction force microscopy experiments are described. Then, chapter III and IV will give an overview about the normal and lateral forces which are relevant for tribology. Chapter V will discuss the energy dissipation mechanisms. Chapter VI will give an overview of Nano-Rheology. Chapter VII gives some insights into the close relationship of friction and ultrasonics. The appendix gives some more details on the calibration procedure of friction force microscopy.

1.2 Short outline of the history of tribology

Friction is an every-day experience and almost everybody is aware of its existence. Thus, it is natural that, since a couple of centuries, many researchers tried to get a fundamental understanding. Already, the great pioneers of tribology found, that friction plays a special role in the field of physics and they found phenomenological friction laws, which seemed to be against intuition, e.g., the independence of friction of the contact area. Today, we still learn these three macroscopic laws of friction in school, which were established by Leonardo da Vinci, Guillaume Amontons and Charles Augustin Coulomb:

1. Independence of the area of contact

Friction is independent of the apparent area of contact.

2. Amonton's Law

Friction is proportional to the applied load. The ratio $\mu = F_L/F_N$ is called coefficient of friction. It is larger for static friction than for kinetic friction.

3. Coulomb's Law

Kinetic friction is independent of the velocity.

These three fundamental laws of friction, which are based upon macroscopic experiments, are still not fully understood in terms of more fundamental microscopic processes. In the following, a brief historical review will give a short insight into the work of tribological pioneers. For detailed informations see in the references¹.

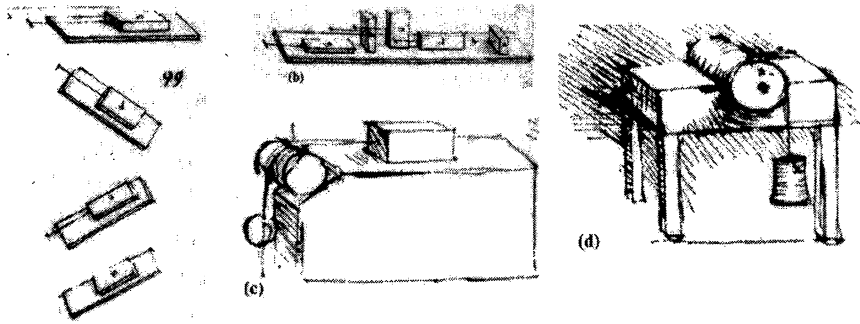
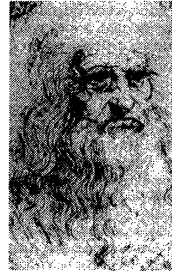


Figure 1.4: Schematics of the friction experiments by Leonardo. He measured the inclination angle of the plane when the block starts sliding. (From¹)

1.3 Leonardo da Vinci (1452-1519)

Leonardo da Vinci has the credit to be the first who made quantitative studies of the problem of friction. Leonardo's experimental setup for friction measurements was rather simple. He measured the angle α of an inclined plane, where a body, put on the plane, started sliding and the weight needed to make a block on a table moving (see Fig. 1.4). With his methods he was only able to measure static friction and most probably he wasn't aware of the difference between static and kinetic friction. Leonardo found the following two laws of friction, in which we essentially recover friction laws 1 and 2.



Leonardo da Vinci

1. The friction made by the same weight will be of equal resistance at the beginning of its movement although the contact may be of different breadths and lengths.
2. Friction produces double the amount of effort if the weight be doubled.

Leonardo defined a friction coefficient as the ratio of the friction divided by the mass of the slider. Experimentally, he found an universal friction coefficient of 0.25 independent of the material. This universal friction coefficient of 0.25 is called Bilfinger value. Many other friction scientists after Leonardo believed in the existence of an universal material independent friction coefficient. However, most of them found another value but all in the range 0.1 - 0.6. Amontons' sketch of his apparatus for friction experiments. The spring D measures the