

Apparently, it has yet been established whether normal contact or touching, as opposite to rubbing, can introduce the charge transfer by ions.

Back-transfer of ionic charge is also a topic of interest if the ions transfer is believed to be the charge transfer mechanism during contact, considering whether the ions can transfer back when the surfaces are separated. It is suggested by Ruckdeschel and Hunter (1977) that the tunnelling of ions is unlikely to be significant due to their large mass, though ions might cross from one surface to another by thermionic emission. However, it is rather too complicated to discuss this phenomenon in great detail, as it is still far from conclusive.

### *c) Electrons Transfer*

For many insulators, the charge density after contact with a metal has been found to depend on the work function of the contacting metal. A substantial number of important experimental evidence has shown that the contact charge is determined by the difference in energy between the metal Fermi level,  $E_F$ , and some energy level characteristic of the insulator,  $E_0$ , (Davies, 1967; Davies, 1969; Inculet, 1967; Garton, 1976). Such a finding implies that, if the contact charge on the insulator is correlated with the metal work function, it is very probable that charge transfer is due to electrons (Davies, 1967; Duke and Fabish, 1978; Rose-Innes, 1980).

Some insulators may acquire positive charge when they are contacted by metal, and others may acquire negative charge, depending on whether the work function of the contacting metal is small or large. It appears likely that the insulator can lose electrons to the metal in case it is charged positively, and that there is electrons transferring to the insulator from the metal if the insulator is charged negatively. Nevertheless, being known as the poor conductors of electricity, it seems improbable that the insulators do have those bearings while they are in contact with the metals. This skepticism has been attemptedly explained by the solid state physics. It is pointed out that, in an insulator, there is a large forbidden gap in the spectrum of allowed electron energies; a valence 'band' of states fully occupied by electrons lying several electron volts below a conduction 'band' of unoccupied states (Figure 1.6)

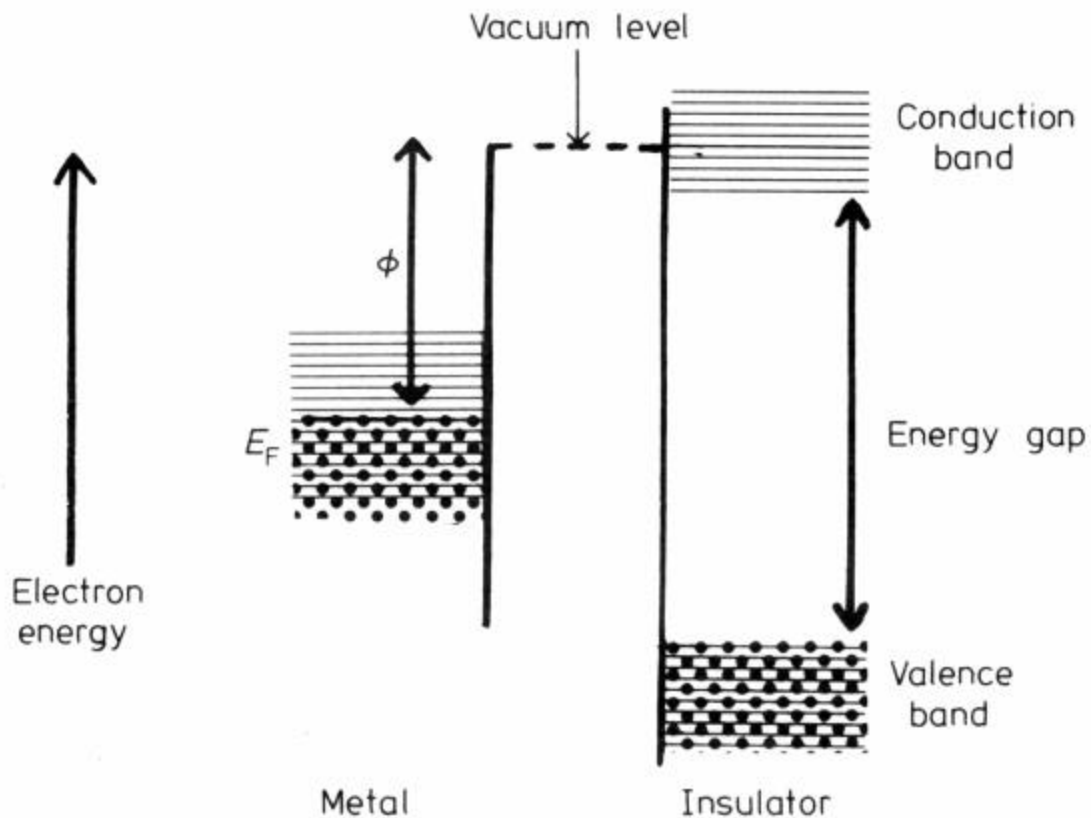
(Rose-Innes, 1980). In other words, the insulator must contain empty states that can accept electrons from the metal, and full ones that can donate electrons to the metal as well. The energy of both kinds of electron states must be close to the Fermi level of the metals. It is possible that there are many electron states at the same energy  $E_0$ , but some of them are empty and some occupied. Moreover, electron states may be distributed over a wide range of energy, in such a way that the states below a certain energy,  $E_0^*$ , being full and those above empty.

Insulator states may be of several kinds, namely: the Bloch states of the conduction and valence bands, localized states due to impurities, and localized states intrinsic to the surface; or in case of polymers, the states can be associated with side groups. Those states identify the nature of the bands, which depends on the kind of insulator. For instance, in a polymer or disordered weakly bonded material, the bands will consist of states that are partly localized, whereas in a crystalline or strongly bonded material, the bands will comprise of non-localized states distributing throughout the sample. These insulator states are believed to play a crucial role and can be used to explain the charging mechanism in the contact electrification of metal-insulator.

The amount of the charge transferred, when a metal and an insulator are brought into contact, has generally been determined by two approaches. Most commonly, the insulator and the metal are assumed to come into thermodynamic equilibrium and that the charge transfer is such as to bring the 'Fermi level' of the insulator and the Fermi level of the contacting metal into coincidence. Alternatively, the tunnelling of electrons into localized states near to the surface of the insulator has been proposed to be the charging mechanism. In this case, the total amount of charge transferred may be limited by the distance that the electrons can tunnel.

In attempting to satisfactorily explain why and how charges are transferred between insulators and the contacting metals, much effort, both experimental and theoretical, has been disbursed. Recently, it has been acknowledged that in most insulators, the bottom of the conduction band lies close (approximately within an eV) to the vacuum level. The finding then cannot contribute significantly to explain the contact charging of the insulators by the metals, since the electrons should not be able to

pass from the metal into insulator whereas the Fermi level of most metals lies in the energy gap of the insulator. (Considering that the work function of metals usually has a value between 3 and 6 eV and the Fermi level of metals is typically 4 or 5 eV below the vacuum level.) Therefore, the contact charging of such insulators should be impossible, according to this information.



**Figure 1.6.** Metal and Insulator. (after Rose-Innes, 1980)