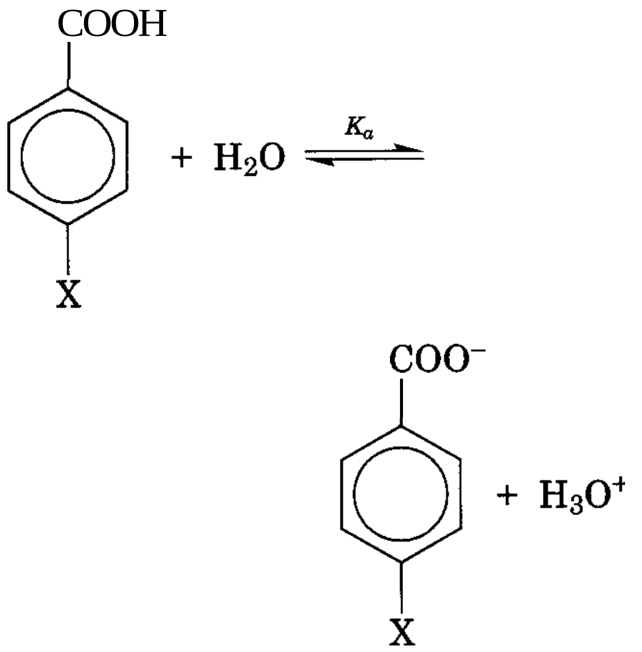
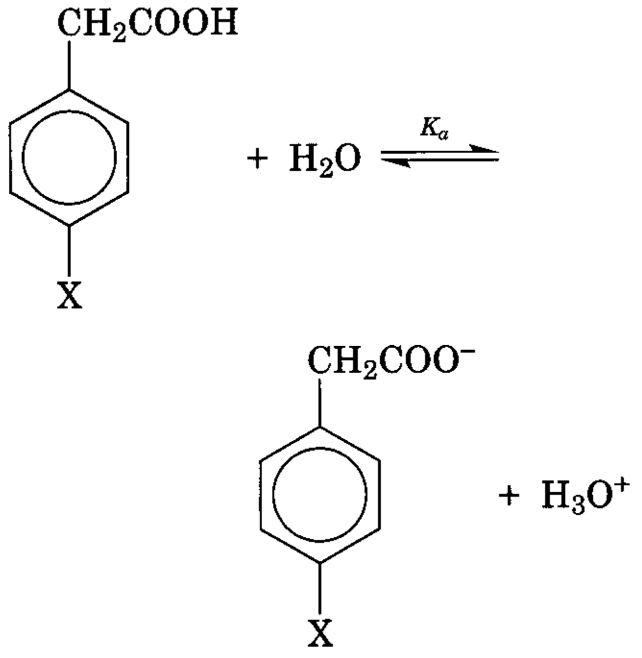


(1.28)

characterized by positive values, whereas electron-donating ones have negative values. In an extension of this approach, the ionization of substituted phenylacetic acids was measured.



(1.30)

The effect of the 4-Cl substituent on the ionization of **4-Cl** phenylacetic acid (PA) was found to be proportional to its effect on the ionization of 4-Cl benzoic acid (BA).

$$\log(K'_{\mathrm{Cl(PA)}}/K'_{\mathrm{H(PA)}}) \propto \log(K_{\mathrm{Cl(BA)}}/K_{\mathrm{H(BA)}})$$

Since $\log(K_{\mathrm{Cl(BA)}}/K_{\mathrm{H(BA)}}) = \sigma$,

$$\text{then } \log \frac{K'_{\mathrm{Cl}}}{K'_{\mathrm{H}}} = \rho \cdot \sigma \qquad (1.31)$$

ρ (rho) is defined as a proportionality or reaction constant, which is a measure of the susceptibility of a reaction to substituent effects. A positive rho value suggests that a reaction is aided by electron withdrawal from the reaction site, whereas a negative rho value implies that the reaction is assisted by electron donation at the reaction site. Hammett also drew attention to the fact that a plot of log K_A for benzoic acids versus log k for ester hydrolysis of a series of molecules is linear, which suggests that substituents exert a similar effect in dissimilar reactions.

$$\log \frac{k_X}{k_H} \propto \log \frac{K_X}{K_H} = \rho \cdot a \qquad (1.32)$$

Although this expression is empirical in nature, it has been validated by the sheer volume of positive results. It is remarkable because four different energy states must be related.

A correlation of this type is clearly meaningful; it suggests that changes in structure produce proportional changes in the activation energy AG* for such reactions. Hence, the derivation of the name for which the Hammett equation is universally known: linear free energy relationship (LFER). Equation 1.32 has become known as the Hammett equation and has been applied to thousands of reactions that take place at or near the benzene ring bearing substituents at the meta and para positions. Because of proximity and steric effects, ortho-substituted molecules do not always follow this maxim and are subject to different parameterizations. Thus, an expanded approach was established by **Charton** (79) and Fujita and Nishioka (80). **Charton** partitioned the **ortho** electronic effect into its inductive, resonance, and steric contributions; the factors a, β, and X are susceptibility or reaction constants and h is the intercept.

$$\text{Log k} = \alpha\sigma_I + \beta\sigma_R + Xr, + h \qquad (1.33)$$

Fujita and Nishioka used an integrated approach to deal with **ortho** substituents in data sets including meta and para substituents.

$$\text{Log k} = \rho a + \delta E_S^{\mathrm{ortho}} + fF_{\mathrm{ortho}} + C \qquad (1.34)$$

For **ortho** substituents, para sigma values