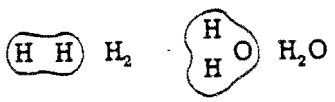
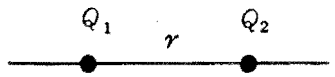
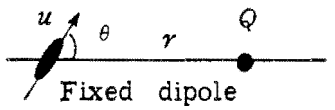
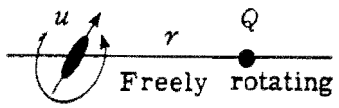
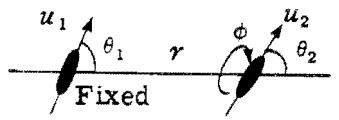
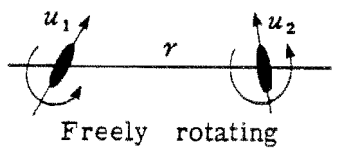
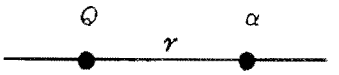
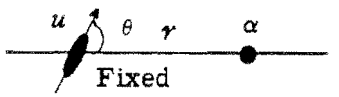
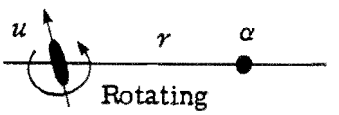
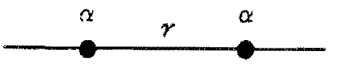
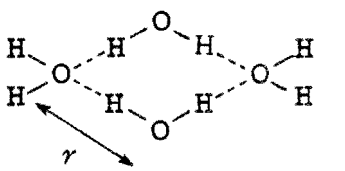
Type of interaction		Interaction energy $w(r)$
Covalent, metallic		Complicated, short range
Charge–charge		$Q_1Q_2/4\pi\varepsilon_0 r$ (Coulomb energy)
Charge–dipole		$-Qu\cos\theta/4\pi\varepsilon_0 r^2$
		$-Q^2u^2/6(4\pi\varepsilon_0)^2kTr^4$
Dipole–dipole		$-u_1u_2[2\cos\theta_1\cos\theta_2 - \sin\theta_1\sin\theta_2\cos\phi]/4\pi\varepsilon_0 r^3$
		$-u_1^2u_2^2/3(4\pi\varepsilon_0)^2kTr^6$ (Keesom energy)
Charge–non-polar		$-Q^2\alpha/2(4\pi\varepsilon_0)^2r^4$
Dipole–non-dipolar		$-u^2\alpha(1+3\cos^2\theta)/2(4\pi\varepsilon_0)^2r^6$
		$-u^2\alpha/(4\pi\varepsilon_0)^2r^6$ (Debye energy)
Two non-polar molecules		$-\frac{3}{4}\frac{h\nu\alpha^2}{(4\pi\varepsilon_0)^2r^6}$ (London dispersion energy)
Hydrogen bond		Complicated, short range, energy roughly proportional to $-1/r^2$

Fig. 2.2. Common types of interactions between atoms, ions and molecules in vacuum. $w(r)$ is the interaction free energy (in J); Q, electric charge (C); u, electric dipole moment (C m); α, electric polarizability ($C^2\,m^2\,J^{-1}$); r, distance between interacting atoms or molecules (m); k, Boltzmann constant (1.381×10^{-23} J K^{-1}); T, absolute temperature (K); h, Planck's constant (6.626×10^{-34} J s); ν, electronic absorption (ionization) frequency (s^{-1}); ε_0, dielectric permittivity of free space ($8.854 \times 10^{-12}\,C^2\,J^{-1}\,m^{-1}$). The force is obtained by differentiating the energy $w(r)$ with respect to distance r.