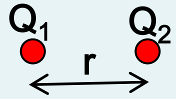
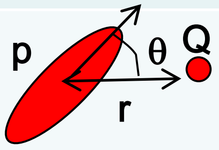
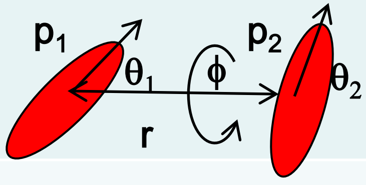
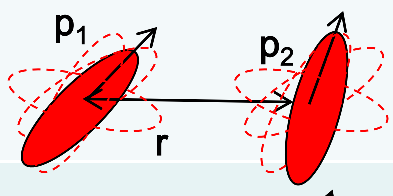
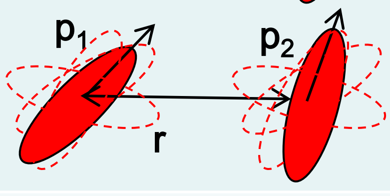
Lecture 6
Interaction forces II –

Tip-sample interaction forces

Ron Reifenberger
Birck Nanotechnology Center
Purdue University

Summary of last lecture

	Type of interaction
	Ion-ion electrostatic $$U(r) = \frac{Q_1 Q_2}{4\pi\varepsilon\varepsilon_0 r}$$
	Dipole-charge electrostatic $$U(r) = -\frac{Qp\cos(\theta)}{4\pi\varepsilon\varepsilon_0 r^2}$$
	Dipole-dipole electrostatic $$U(r) = -\frac{p_1 p_2 \left[2\cos(\theta_1)\cos(\theta_2) - \sin(\theta_1)\sin(\theta_2)\cos(\phi)\right]}{4\pi\varepsilon\varepsilon_0 r^3}$$
	Angle-averaged electrostatic (Keesom force) $$U_{Keesom}(r) = -\frac{p_1^{\,2} p_2^{\,2}}{3\left(4\pi\varepsilon\varepsilon_0\right)^2 k_B T}\frac{1}{r^6}$$
	Angle-averaged induced polarization force (Debye force) $$U_{Debye}(r) = -\frac{p_1^2\alpha_{02} + p_2^2\alpha_{01}}{(4\pi\varepsilon_0\varepsilon)^2}\frac{1}{r^6}$$
	Dispersion forces act between any two molecules or atoms (London force) $$U_{London}(r) = -\frac{3}{2}\frac{\alpha_{01}\alpha_{02}}{(4\pi\varepsilon_0\varepsilon)^2}\frac{(I_1)(I_2)}{I_1 + I_2}\frac{1}{r^6}$$

Adapted from J. Israelachvili, "Intermolecular and surface forces".

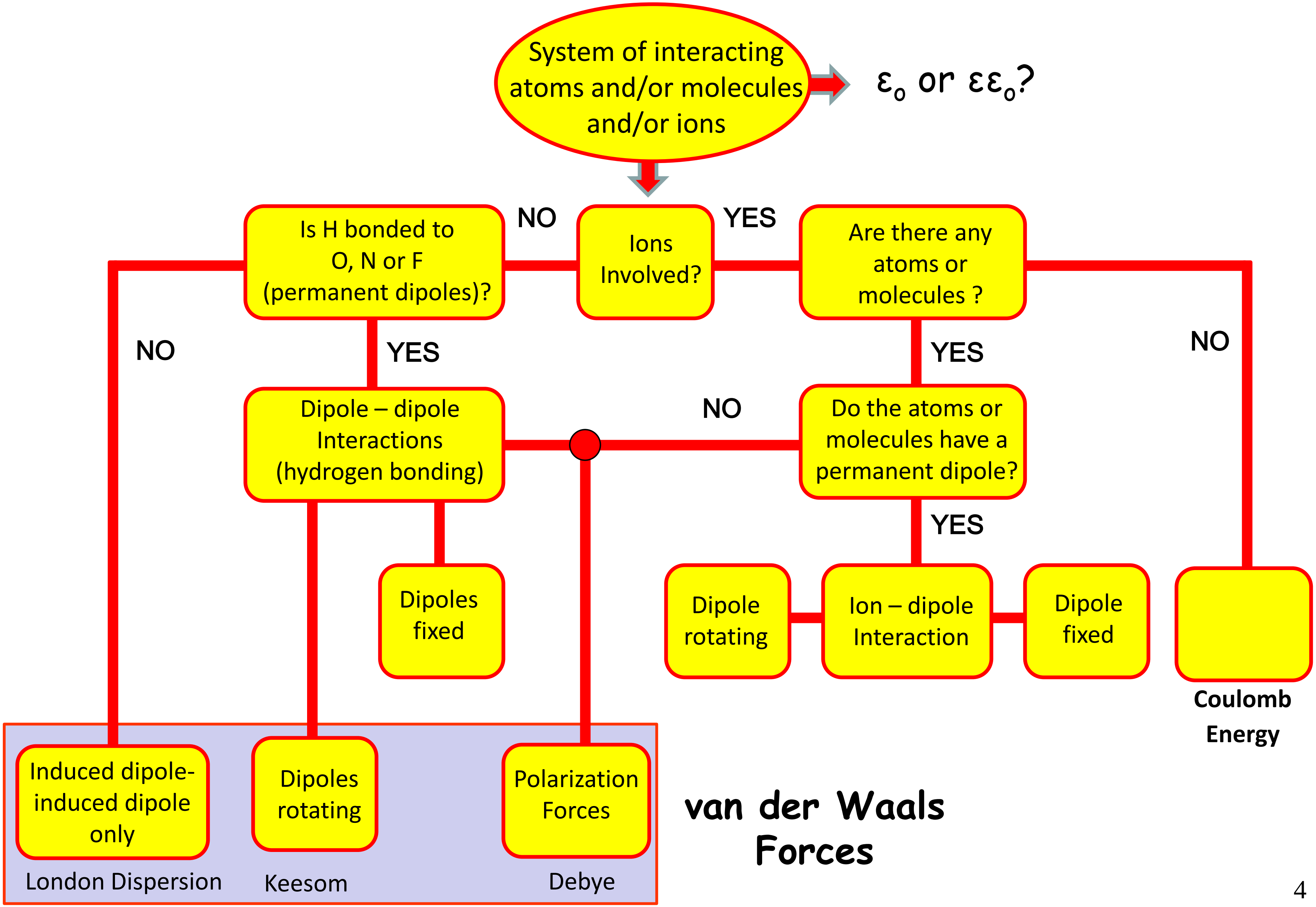
Relative values of Van der Waals force components are presented in **Table 1** [3].

Substance	$\chi, m^3 \times 10^{18}$	d, D	I, eV	C_{Keesom} $\times 10^{79}$ J·m^6	C_{Debye} $\times 10^{79}$ J·m^6	C_{London} $\times 10^{79}$ J·m^6
H	0.667	0	13.6	0	0	6.3
O_2	1.57	0	13.6	0	0	41.3
N_2	1.74	0	15.8	0	0	59.3
Ar	1.6	0	15.8	0	0	48
He	0.2	0	24.7	0	0	1.2
CO	1.99	0.12	14.3	0.0034	0.057	67.5
HCl	2.63	1.03	13.7	18.6	5.4	105
H_2O	1.48	1.84	18.0	197	10	48.8
NH_3	2.24	1.5	11.7	87	10	72.6

Table 1. Magnitudes of polarizability, dipole moment, ionization potential and energies of different weak interactions between various atoms and molecules.

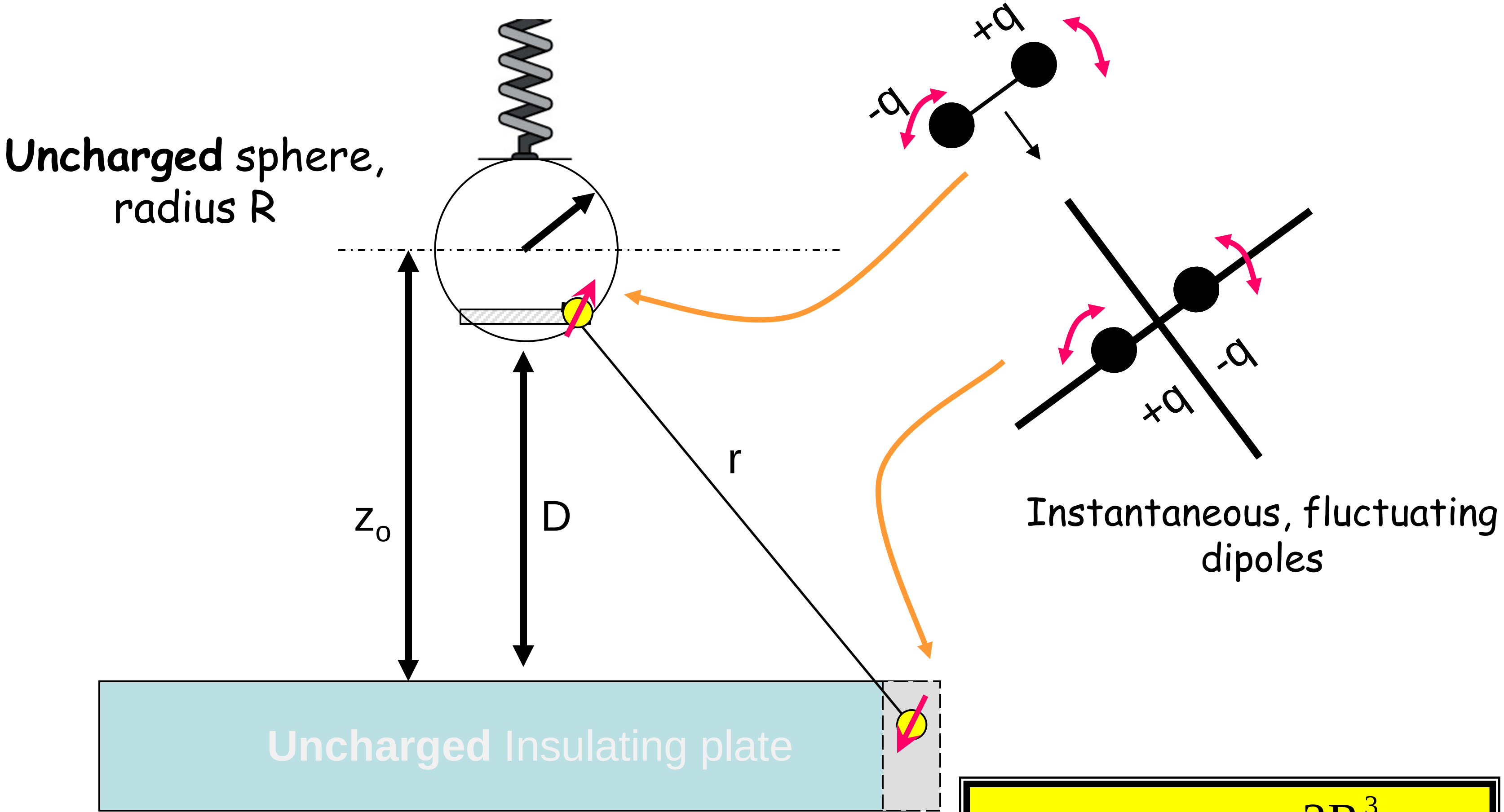
Source: http://www.ntmdt.com/spm-basics/view/intermolecular-vdv-force

Summary of Coulombic Intermolecular Forces



Interaction between electrically NEUTRAL objects!

Dispersive or van der Waals Force



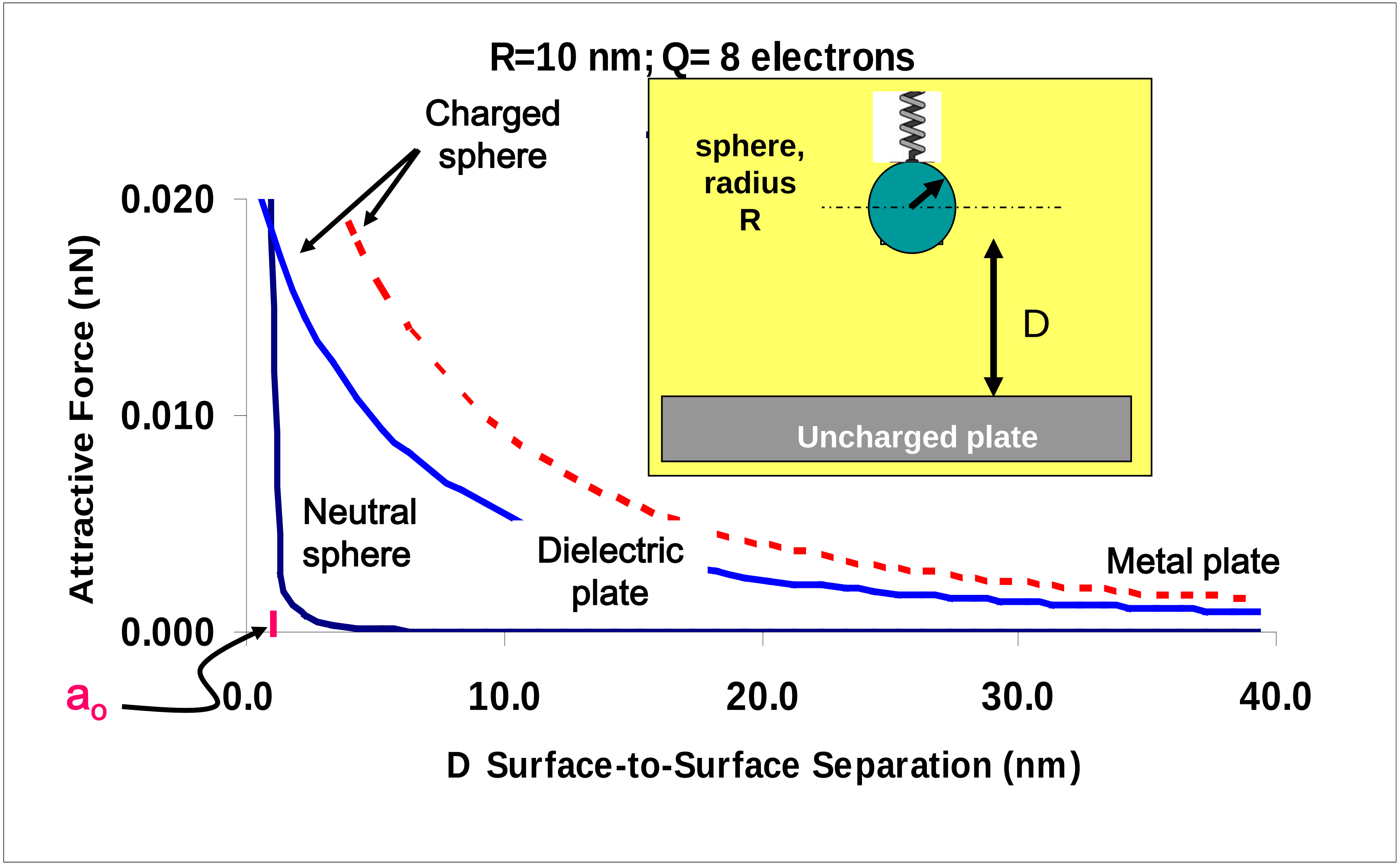
an Electrodynamic effect!

$$F(D) = -A\frac{2R^3}{3D^2(2R+D)^2}$$

A=Hamaker's constant

1 click

Putting in some numbers



Implications for AFM

- In AFM the tip usually has native oxide on the tip within which small trapped charges or permanent dipoles can exist. As debris accumulates more permanent dipoles and charges accumulate on tip
- Dispersion potential U(r) scales as r^{-6} while electrostatics scales as

  r^{-1} (ion-ion), or

  r^{-2} (ion-dipole), or

  r^{-3} (dipole-dipole)
- In reality attractive forces are due to combination of vdW and short range electrostatics (i.e. covalent forces)