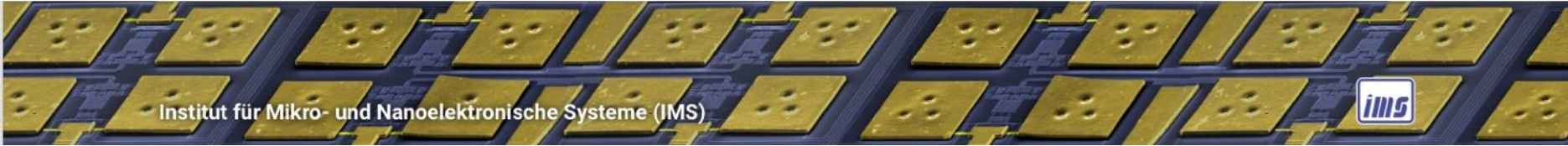
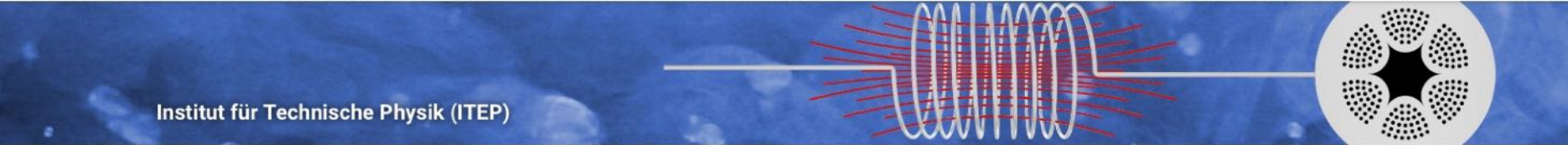


Superconductivity for Engineers

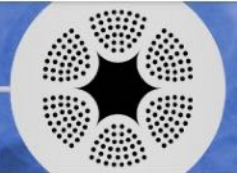
Prof. Dr. Sebastian Kempf, Prof. Dr. Bernhard Holzapfel
Summer term 2021



Institut für Mikro- und Nanoelektronische Systeme (IMS)



Institut für Technische Physik (ITEP)



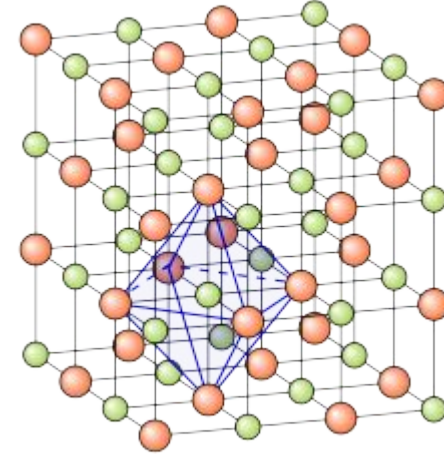
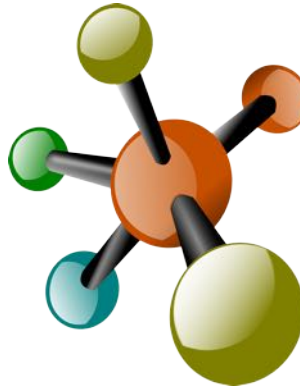
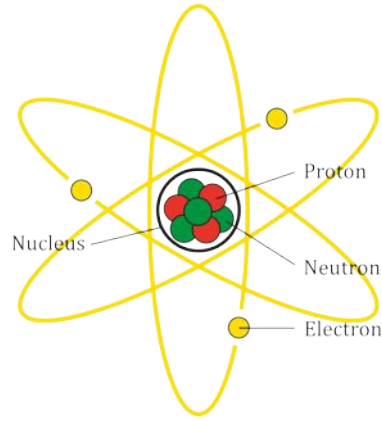
(Preliminary) Schedule

	Day	Date	Lecture / Tutorial	Day	Date	Lecture / Tutorial
1	Mon	21-04-12	Lecture 1 (SK)	Wed	21-04-14	
2	Mon	21-04-19	Lecture 2 (BH)	Wed	21-04-21	
3	Mon	21-04-26	Lecture 3 (SK)	Wed	21-04-28	Tutorial 1 (IMS)
4	Mon	21-05-03	Lecture 4 (SK)	Wed	21-05-05	
5	Mon	21-05-10	Lecture 5 (SK)	Wed	21-05-12	Tutorial 2 (IMS)
6	Mon	21-05-17	Lecture 6 (SK)	Wed	21-05-19	
7	Mon	21-05-24	---	Wed	21-05-26	
8	Mon	21-05-31	Lecture 7 (BH)	Wed	21-06-02	Tutorial 3 (IMS)
9	Mon	21-06-07	Lecture 8 (BH)	Wed	21-06-09	Tutorial 4 (ITEP)
10	Mon	21-06-14	Lecture 9 (BH)	Wed	21-06-16	
11	Mon	21-06-21	Lecture 10 (BH)	Wed	21-06-23	Tutorial 5 (ITEP)
12	Mon	21-06-28	Lecture 11 (BH)	Wed	21-06-30	
13	Mon	21-07-05	Lecture 12 (BH)	Wed	21-07-07	Tutorial 6 (ITEP)
14	Mon	21-07-12	Lecture 13 (SK)	Wed	21-07-14	
15	Mon	21-07-19	Lecture 14 (SK)	Wed	21-07-21	Tutorial 7 (IMS, ITEP)

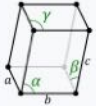
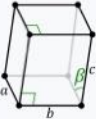
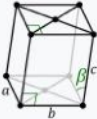
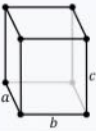
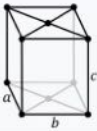
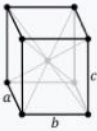
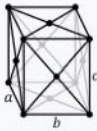
(Preliminary) Lecture content

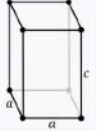
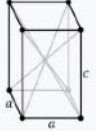
- Lecture 1: (SK) Introduction and overview
- Lecture 2: (BH) Superconductor applications
- Lecture 3: (SK) Normal metals and properties of the normal conducting state
- Lecture 4: (SK) Perfect conductor, ideal diamagnetism, Two-Fluid-Model, London theory
- Lecture 5: (SK) Disordered superconductors, Pippard theory, microwave properties
- Lecture 6: (SK) BCS theory
- Lecture 7: (BH) Ginzburg-Landau theory
- Lecture 8: (BH) Typ-I superconductors
- Lecture 9: (BH) Typ-II superconductors
- Lecture 10: (BH) Typ-II superconductors
- Lecture 11: (BH) Current transport, ac-losses, thermal aspects
- Lecture 12: (BH) Current transport, ac-losses, thermal aspects
- Lecture 13: (SK) Josephson junctions and SQUIDs
- Lecture 14: (SK) Josephson junctions and SQUIDs

Atoms, molecules and solids

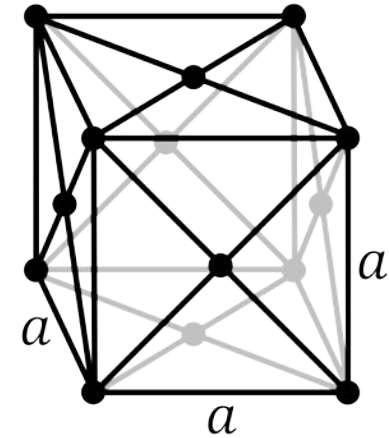
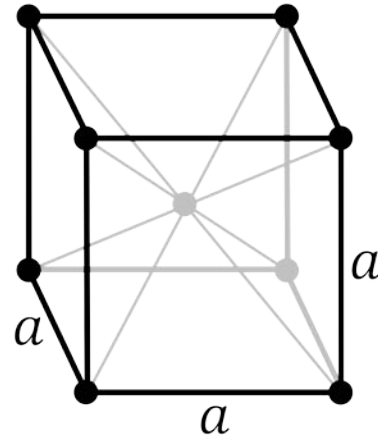
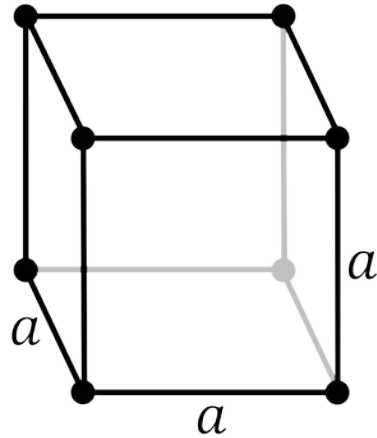


Crystal structure

Crystal family	Lattice system	Schönflies	14 Bravais Lattices			
			Primitive	Base-centered	Body-centered	Face-centered
triclinic		C_i				
monoclinic		C_{2h}				
orthorhombic		D_{2h}				

tetragonal		D_{4h}			
hexagonal	rhombohedral	D_{3d}			
	hexagonal	D_{6h}			
cubic		O_h	 Cubic, simple		

Cubic crystal structure



Valence electrons

Valence electrons

Group →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period ↓																		
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	* 71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	* 103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
			* 57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
			* 89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

Periodic table block	Periodic table group	Valence electrons
s	Group 1 (I) (alkali metals)	1
	Group 2 (II) (alkaline earth metals) and helium	2
f	Lanthanides and actinides	3–16 ^[a]
d	Groups 3–12 (transition metals)	3–12 ^[b]
p	Group 13 (III) (boron group)	3
	Group 14 (IV) (carbon group)	4
	Group 15 (V) (pnictogens or nitrogen group)	5
	Group 16 (VI) (chalcogens or oxygen group)	6
	Group 17 (VII) (halogens)	7
	Group 18 (VIII or 0) (noble gases) except helium	8

a. ^ Consists of ns, (n-2)f, and (n-1)d electrons.

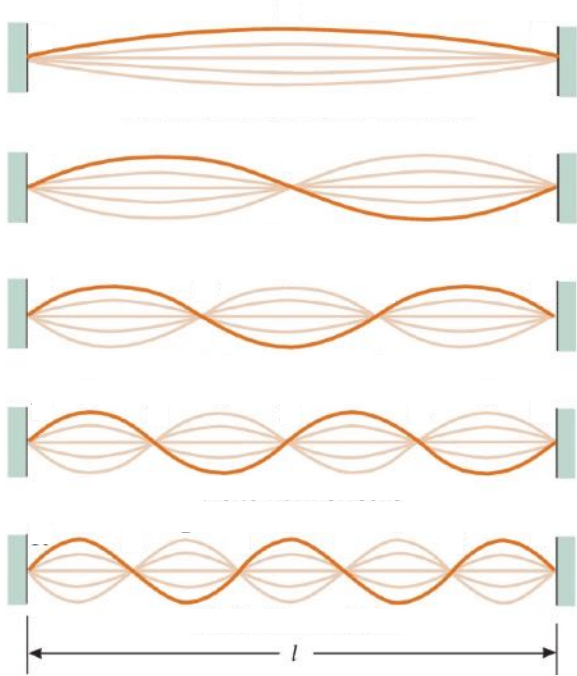
b. ^ Consists of ns, and (n-1)d electrons.

Metals

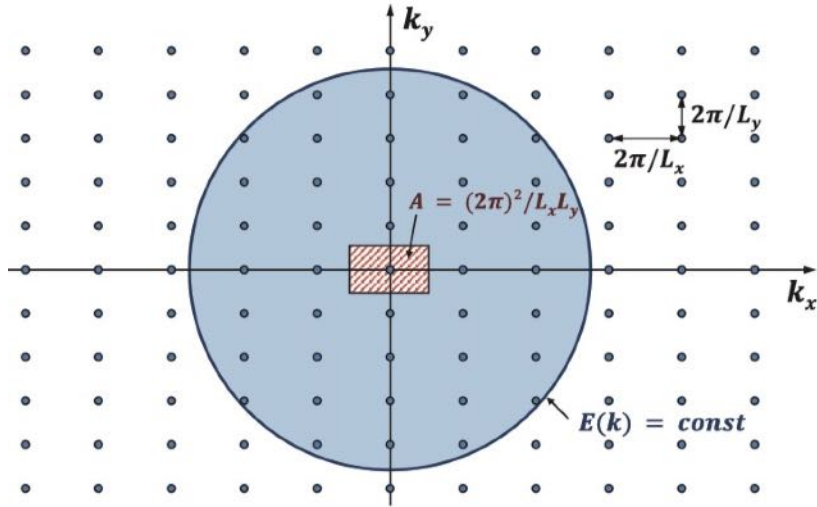
Metals

Electrons in metals

Confined quantum particles



Fermi sphere



Density of states

Density of states

Fermi-Dirac-Distribution

Fermi-Dirac-Distribution

Free - electron gas @ $T = 0 \text{ K}$

Free - electron gas @ $T = 0 \text{ K}$

Free - electron gas @ $T = 0\text{ K}$

Metall	n (10^{22} cm^{-3})	E_F (eV)	T_F (K)	k_F (10^8 cm^{-1})	v_F (10^8 cm/s)
Li	4.70	4.72	54 800	1.11	1.27
Na	2.54	3.16	36 700	0.91	1.05
Rb	1.15	1.85	21 500	0.69	0.79
Cu	8.45	7.00	81 200	1.35	1.55
Au	5.90	5.51	63 900	1.20	1.38
Ag	5.86	5.49	63 700	1.20	1.39
Be	24.2	14.14	164 100	1.92	2.21
Zn	13.10	9.39	109 000	1.56	1.79
Al	18.06	11.63	134 900	1.74	2.00
Pb	13.20	9.37	108 700	1.57	1.81

Free - electron gas @ $T > 0 \text{ K}$

Free - electron gas @ $T > 0 \text{ K}$

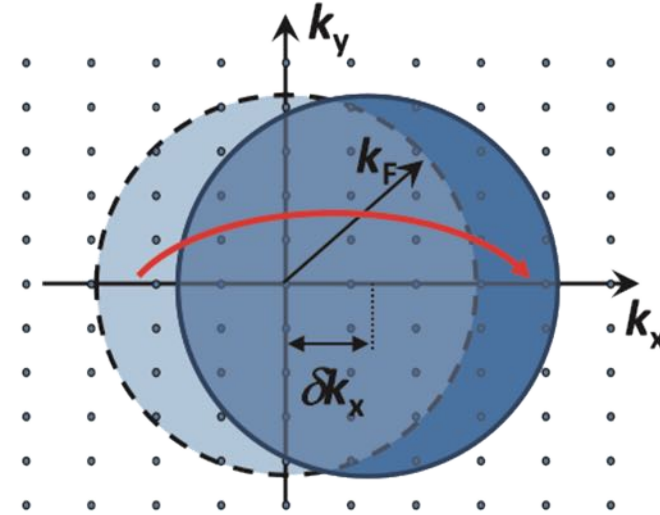
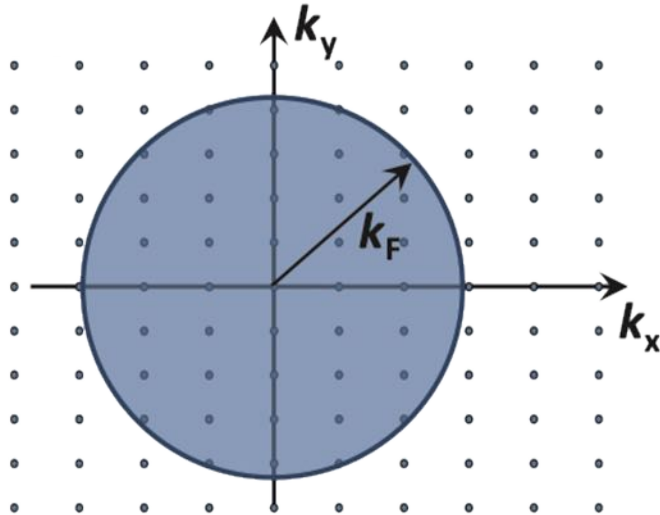
Specific heat

Drude model

Drude model

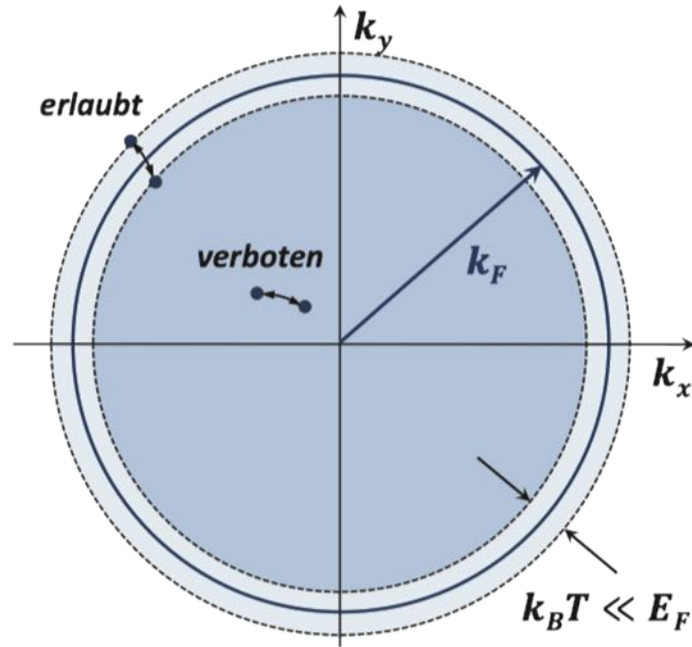
Sommerfeld model

Sommerfeld model



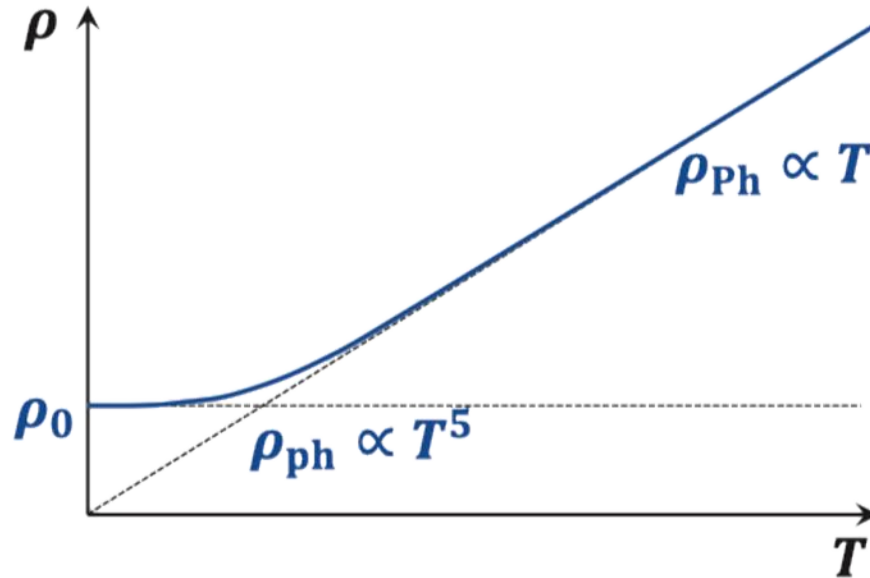
Sommerfeld model

Sommerfeld model

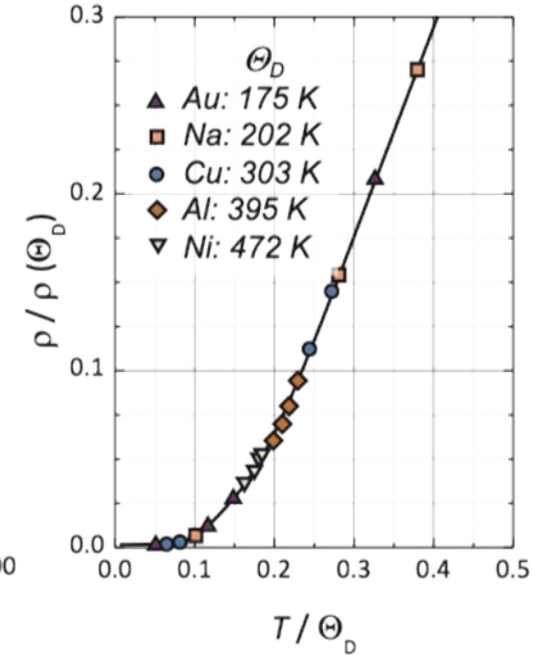
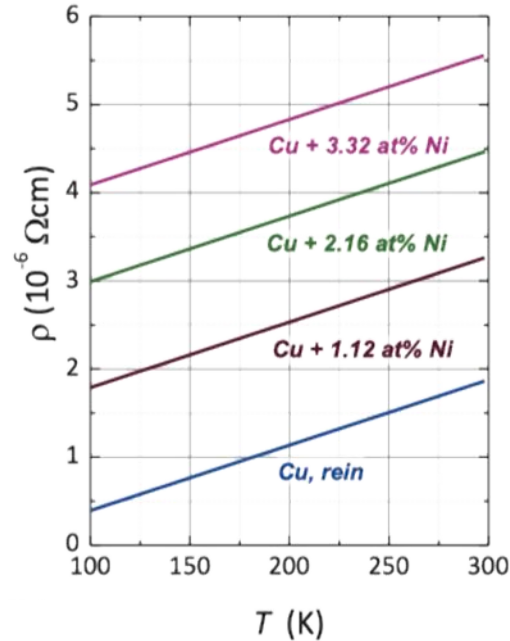
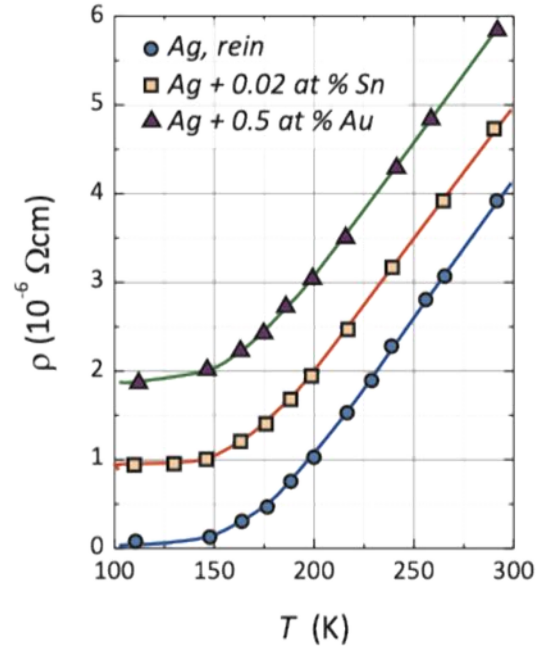


Scattering processes

Temperature dependence of electrical resistivity



Temperature dependence of electrical resistivity



Heat conductance

Wiedemann-Franz-Law

Electron screening

Electron screening