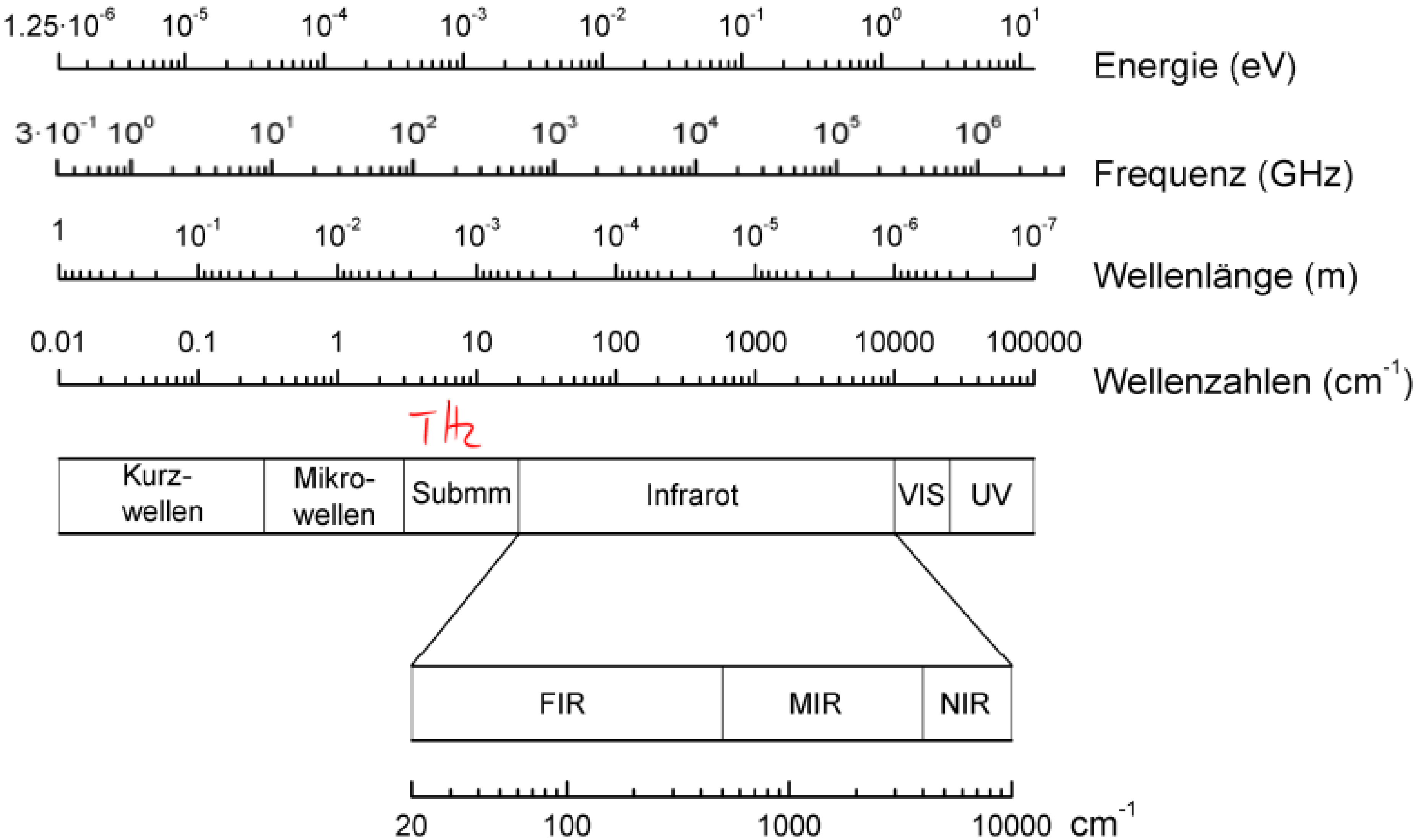
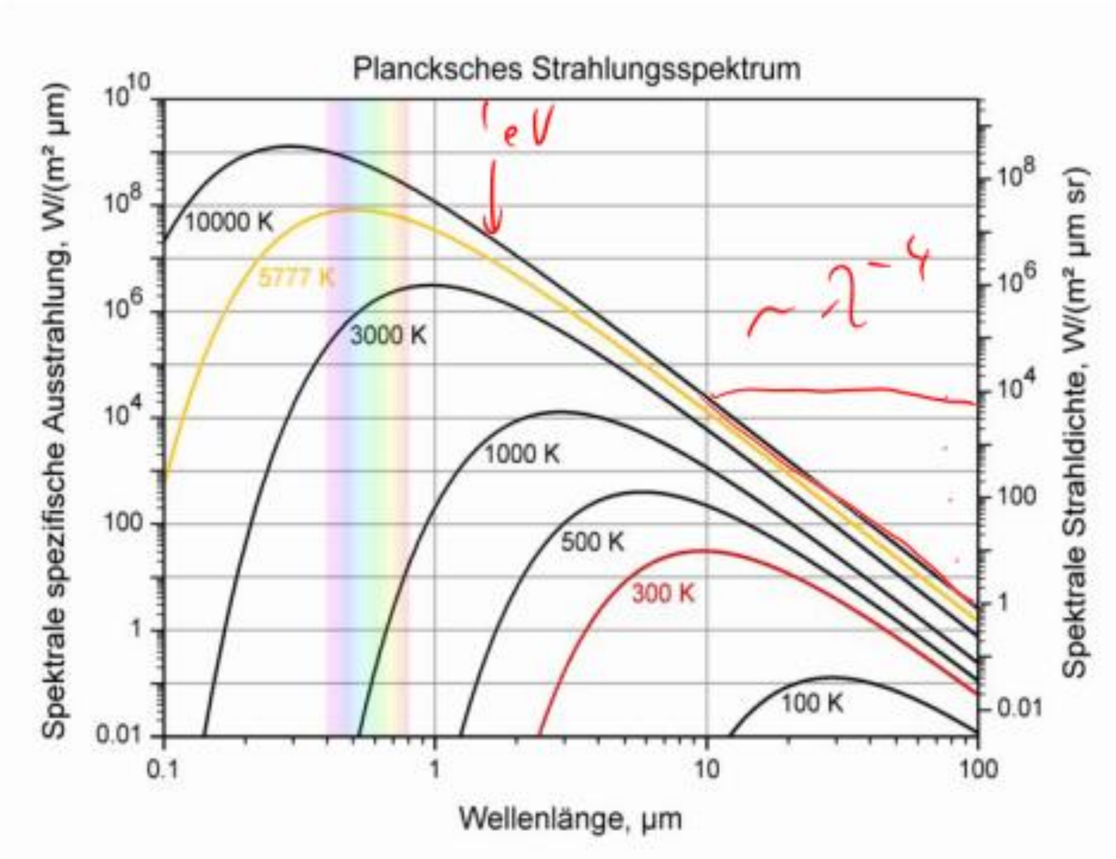
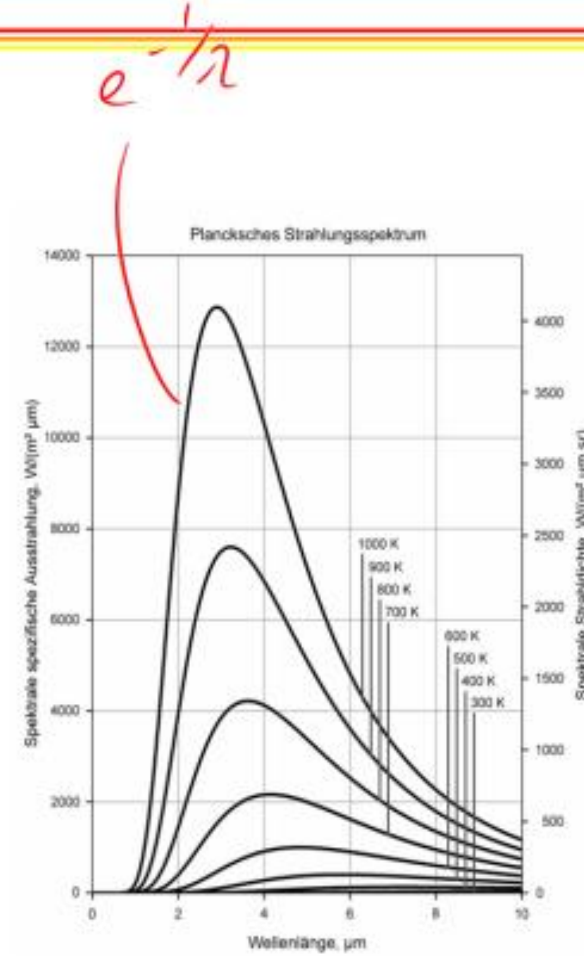
Spectral units

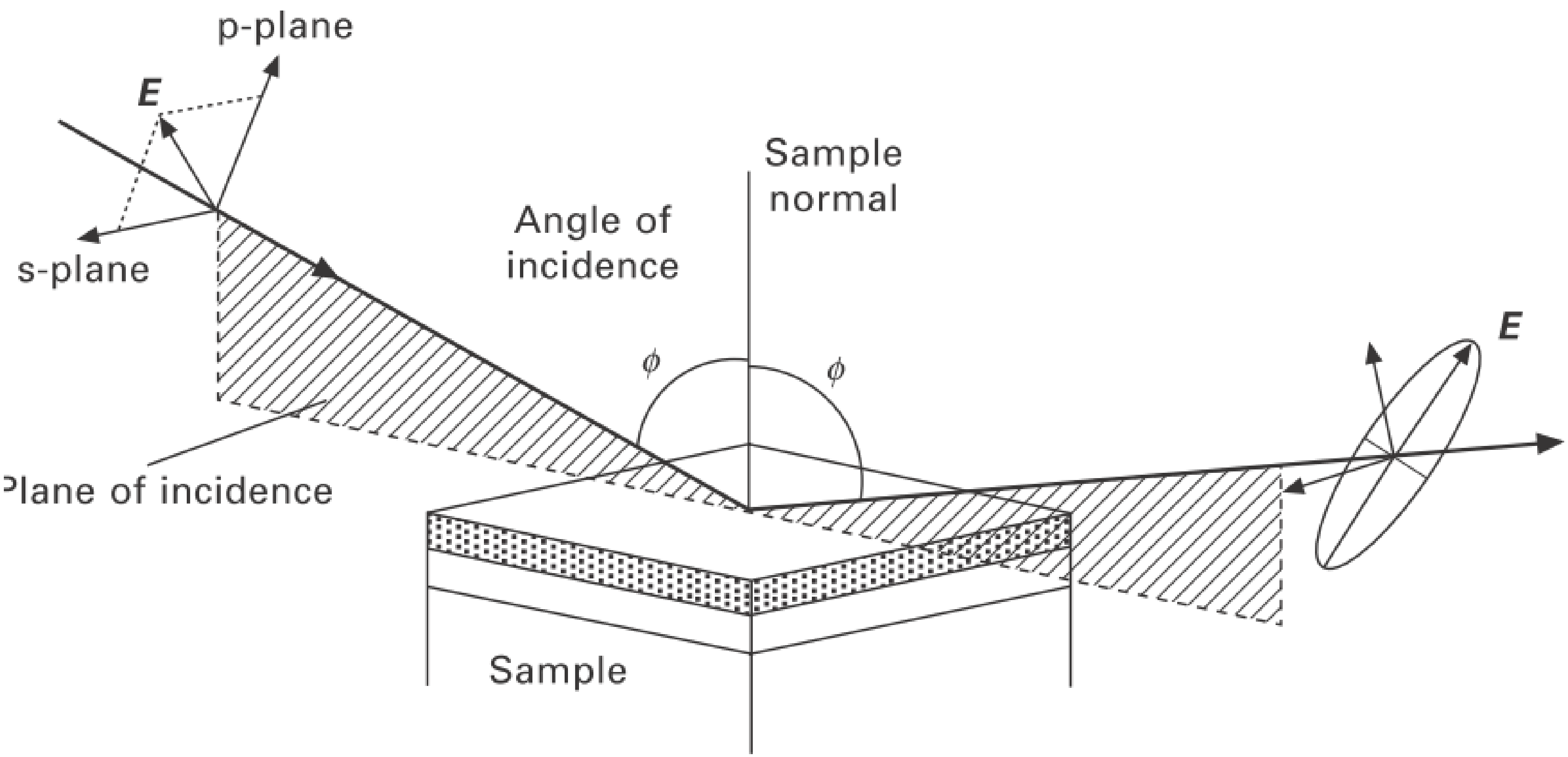


A black body's radiation



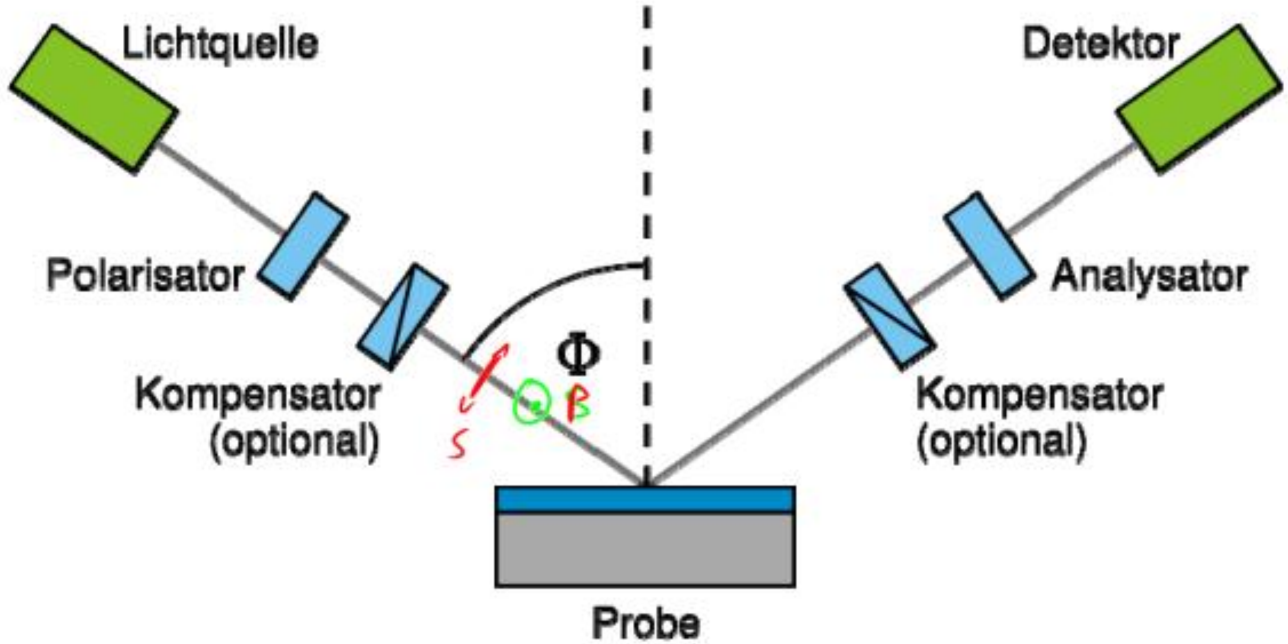


Ellipsometry



5.1 When linearly polarized incident light, consisting of p- and s- orthogonal polarization components, is reflected from a surface at oblique angle of incidence (ϕ) the result is often elliptical polarization. Ellipsometry measurements determine the change in polarization that occurs when light interacts with the sample.

Ellipsometry



$$\rho = \frac{R_p}{R_s} = \tan \Psi \exp(i\Delta)$$

→ n, k   ε′, ε″

Optical conductivity

- complex dielectric constant: $\epsilon = \epsilon_1 + i\epsilon_2$
- by definition: $\sqrt{\epsilon} = n + ik = \hat{n}$

$$\epsilon_1 = n^2 - k^2 \qquad \epsilon_2 = 2nk$$

- with complex conductivity: $\sigma = \sigma_1 + i\sigma_2$

  and $\epsilon = 1 + \frac{i\sigma}{\epsilon_0 \omega}$

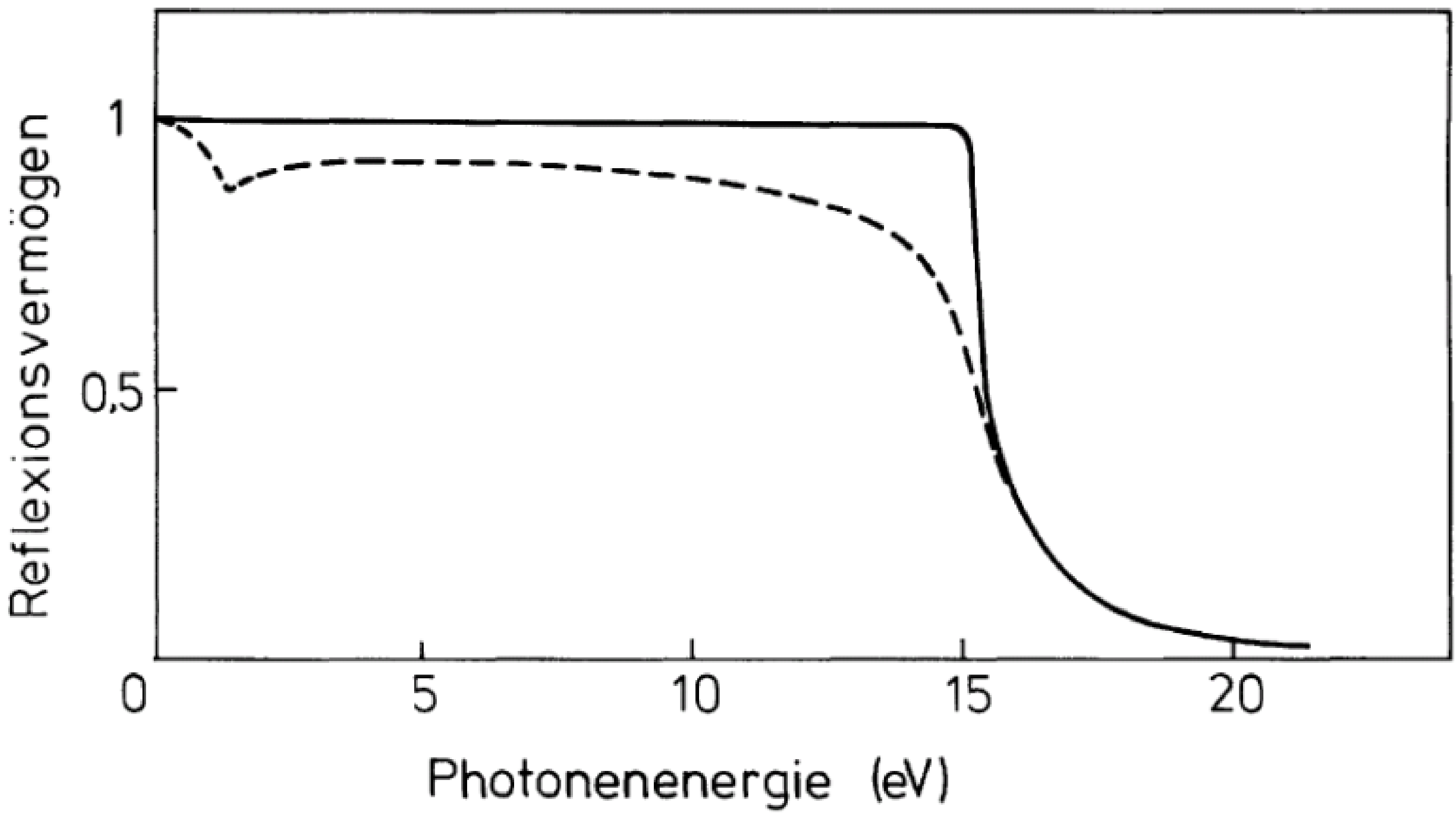
$$\sigma_1 = \epsilon_0 \epsilon_2 \omega \qquad \sigma_2 = \epsilon_0 (1 - \epsilon_1) \omega$$

	Dielectric constant $\hat{\epsilon}$	Conductivity $\hat{\sigma}$	Refractive index $\hat{N}$
$\hat{\epsilon}$	$\hat{\epsilon} = \epsilon_1 + \mathrm{i}\epsilon_2$	$\epsilon_1 = 1 - \frac{4\pi\sigma_2}{\omega}$ $\epsilon_2 = \frac{4\pi\sigma_1}{\omega}$	$\epsilon_1 = \frac{n^2-k^2}{\mu_1}$ $\epsilon_2 = \frac{2nk}{\mu_1}$
$\hat{\sigma}$	$\sigma_1 = \frac{\omega\epsilon_2}{4\pi}$ $\sigma_2 = (1-\epsilon_1)\frac{\omega}{4\pi}$	$\hat{\sigma} = \sigma_1 + \mathrm{i}\sigma_2$	$\sigma_1 = \frac{nk\omega}{2\pi\mu_1}$ $\sigma_2 = \left(1 - \frac{n^2-k^2}{\mu_1}\right)\frac{\omega}{4\pi}$
$\hat{N}$	$n = \left\{\frac{\mu_1}{2}\left[\epsilon_1^2 + \epsilon_2^2\right]^{1/2} + \frac{\epsilon_1\mu_1}{2}\right\}^{1/2}$ $k = \left\{\frac{\mu_1}{2}\left[\epsilon_1^2 + \epsilon_2^2\right]^{1/2} - \frac{\epsilon_1\mu_1}{2}\right\}^{1/2}$	$n = \left\{\frac{\mu_1}{2}\left[\left(1 - \frac{4\pi\sigma_2}{\omega}\right)^2 + \left(\frac{4\pi\sigma_1}{\omega}\right)^2\right]^{1/2} + \frac{\mu_1}{2} - \frac{2\pi\mu_1\sigma_2}{\omega}\right\}^{1/2}$ $k = \left\{\frac{\mu_1}{2}\left[\left(1 - \frac{4\pi\sigma_2}{\omega}\right)^2 + \left(\frac{4\pi\sigma_1}{\omega}\right)^2\right]^{1/2} - \frac{\mu_1}{2} + \frac{2\pi\mu_1\sigma_2}{\omega}\right\}^{1/2}$	$\hat{N} = n + \mathrm{i}k$

Table 7.1 Free electron density and plasma properties of some metals. The figures are for room temperature unless stated otherwise. The electron densities are based on data taken from Wyckoff (1963). The plasma frequency ω_p is calculated from eqn 7.6, and λ_p is the wavelength corresponding to this frequency.

Metal	Valency	N ($10^{28}\,\mathrm{m}^{-3}$)	$\omega_p/2\pi$ (10^{15} Hz)	λ_p (nm)
Li (77 K)	1	4.70	1.95	154
Na (5 K)	1	2.65	1.46	205
K (5 K)	1	1.40	1.06	282
Rb (5 K)	1	1.15	0.96	312
Cs (5 K)	1	0.91	0.86	350
Cu	1	8.47	2.61	115
Ag	1	5.86	2.17	138
Au	1	5.90	2.18	138
Be	2	24.7	4.46	67
Mg	2	8.61	2.63	114
Ca	2	4.61	1.93	156
Al	3	18.1	3.82	79

Experimentelles Beispiel: Aluminium



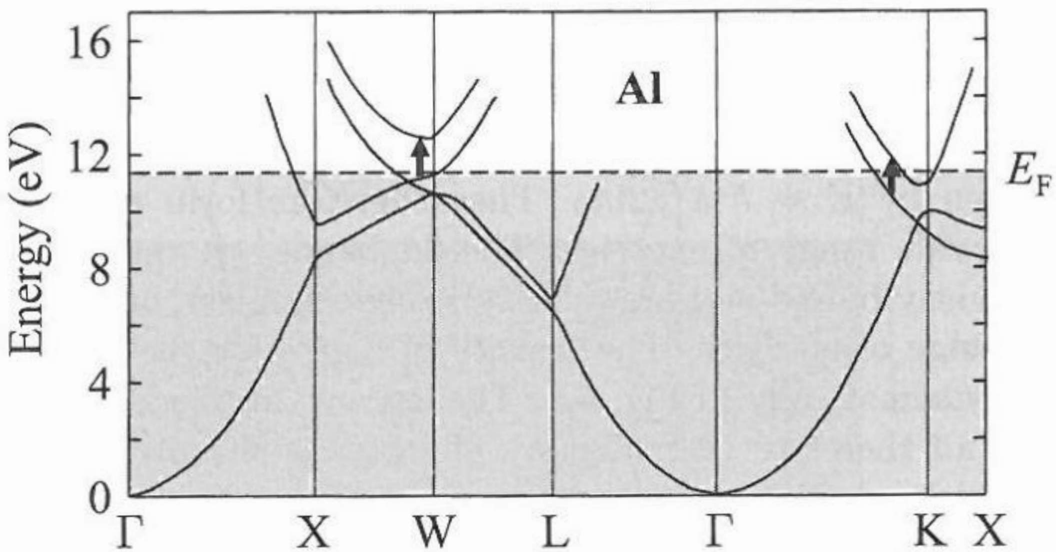


Fig. 7.3 Band diagram of aluminium. The transitions at the W and K points that are responsible for the reflectivity dip at 1.5 eV are labelled. After Segall (1961), © American Physical Society, reprinted with permission.

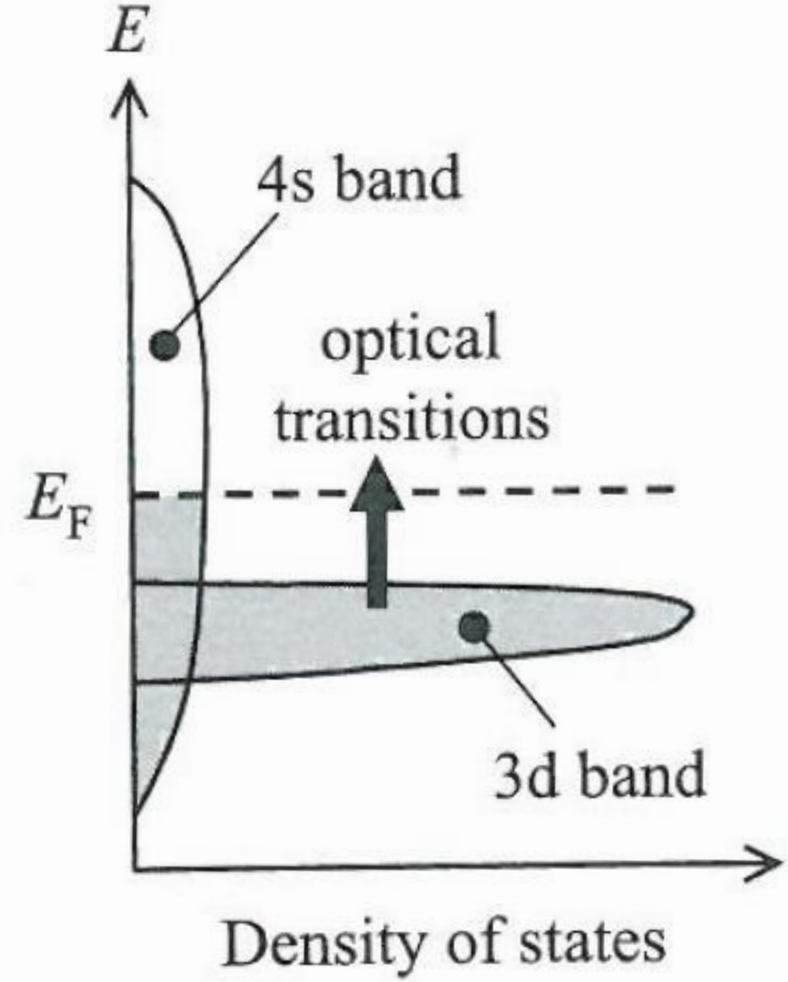


Fig. 7.4 Schematic density of states for the 3d and 4s bands of a transition metal such as copper.

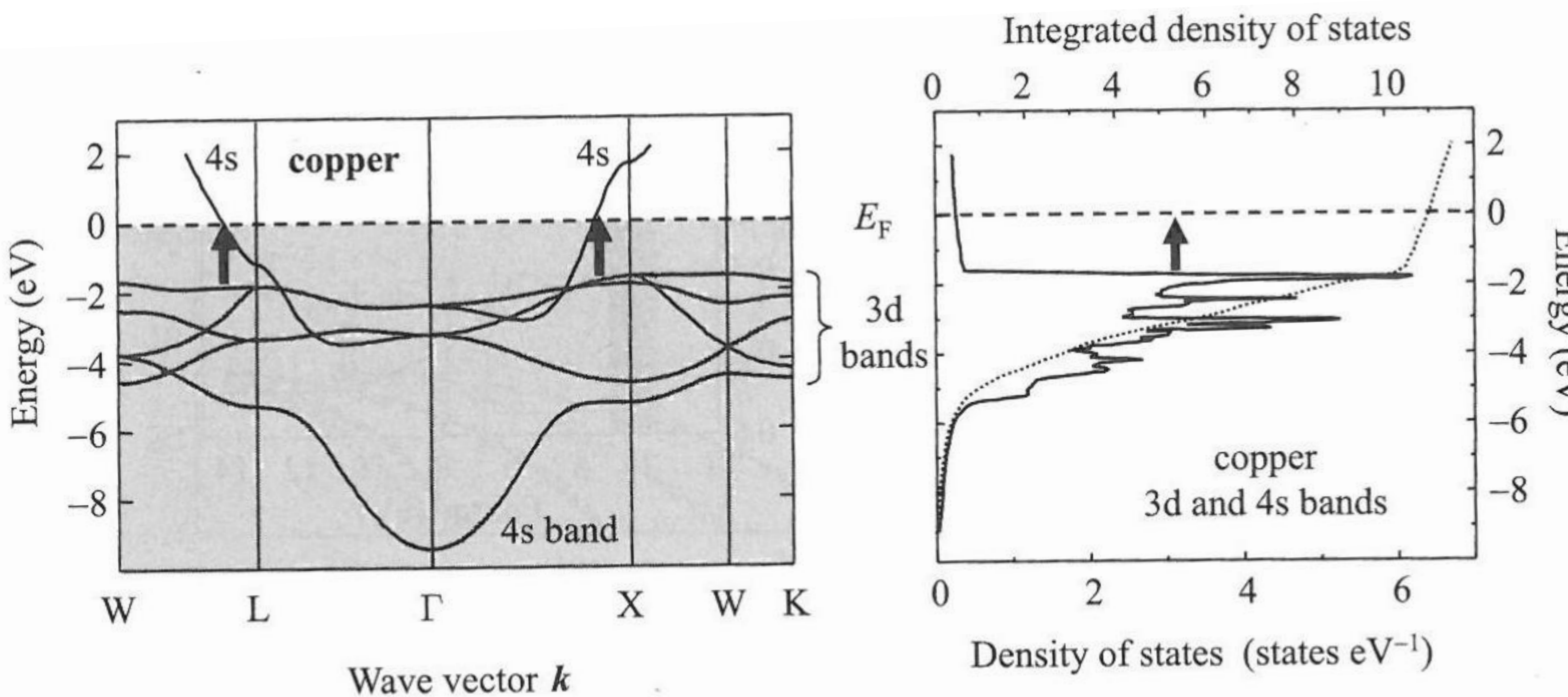
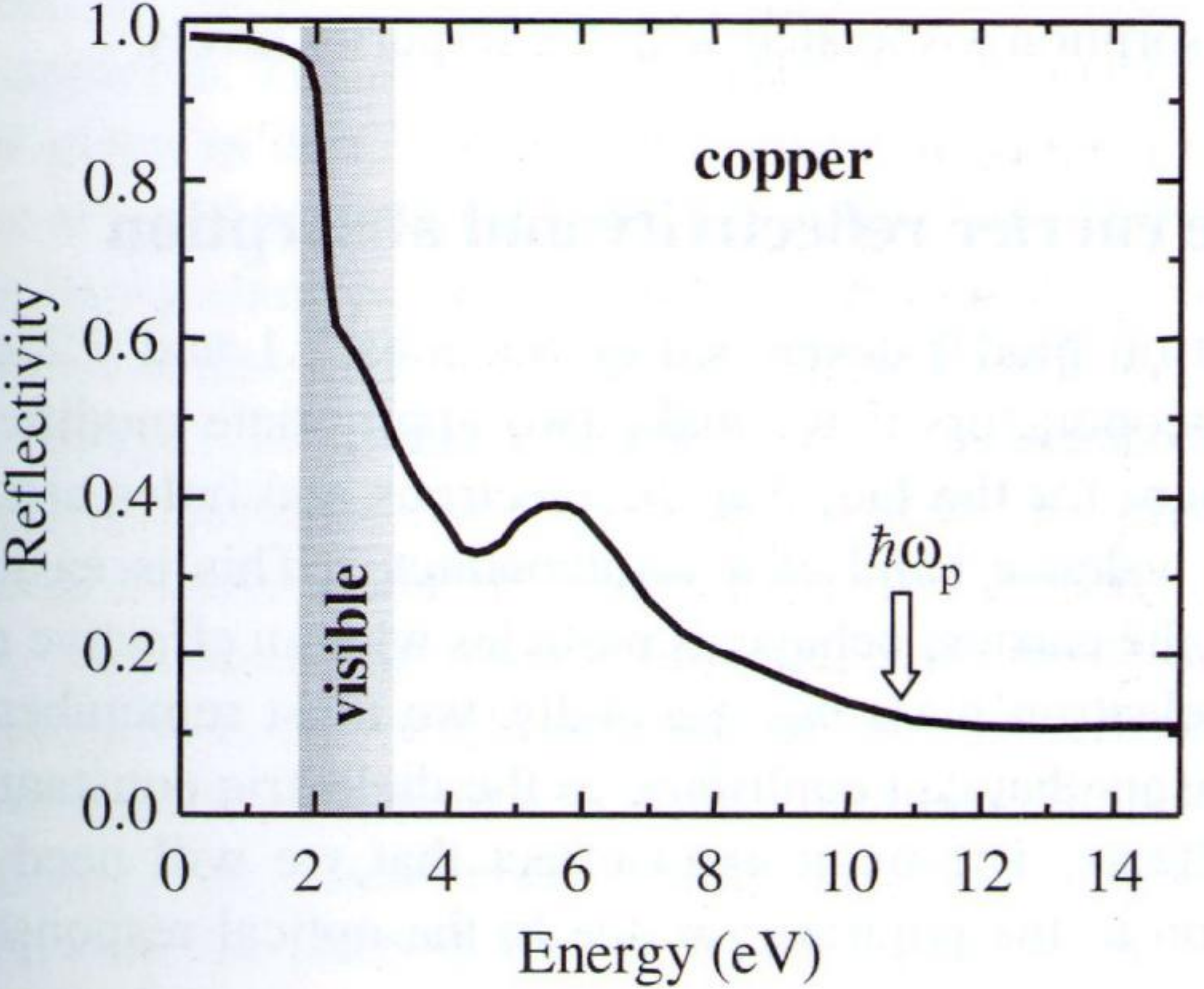
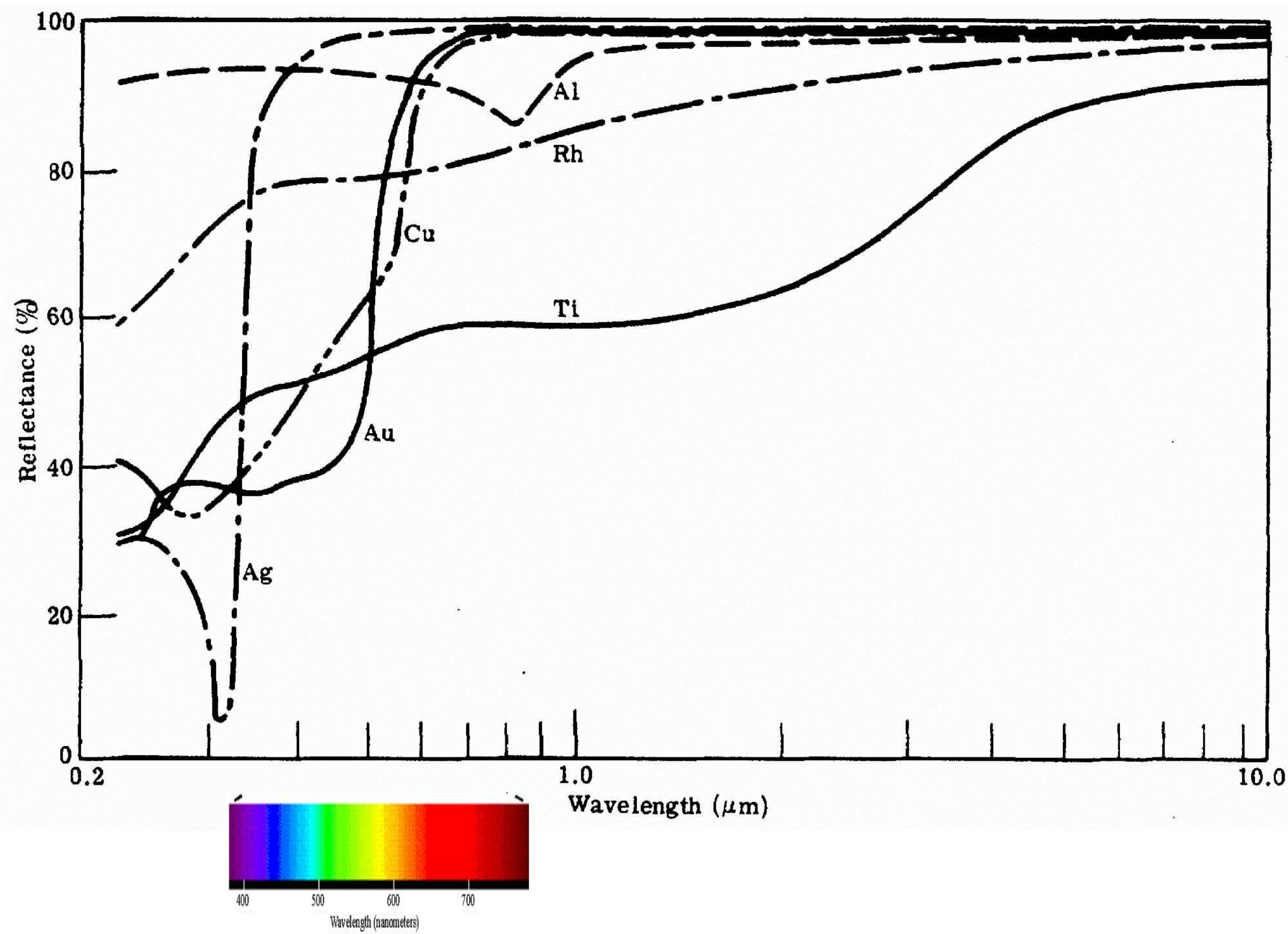


Fig. 7.5 Calculated band structure of copper. The transitions from the 3d bands responsible for the interband transit around 2 eV are identified. The right-hand side of the figure shows the density of states calculated from the band structure. strongly peaked features between about −2 eV and −5 eV are due to the 3d bands. The dotted line is the integrated densit states. The Fermi level (defined here as $E = 0$) corresponds to the energy at which the integrated density of states is equa 11. After Moruzzi et al. (1978).

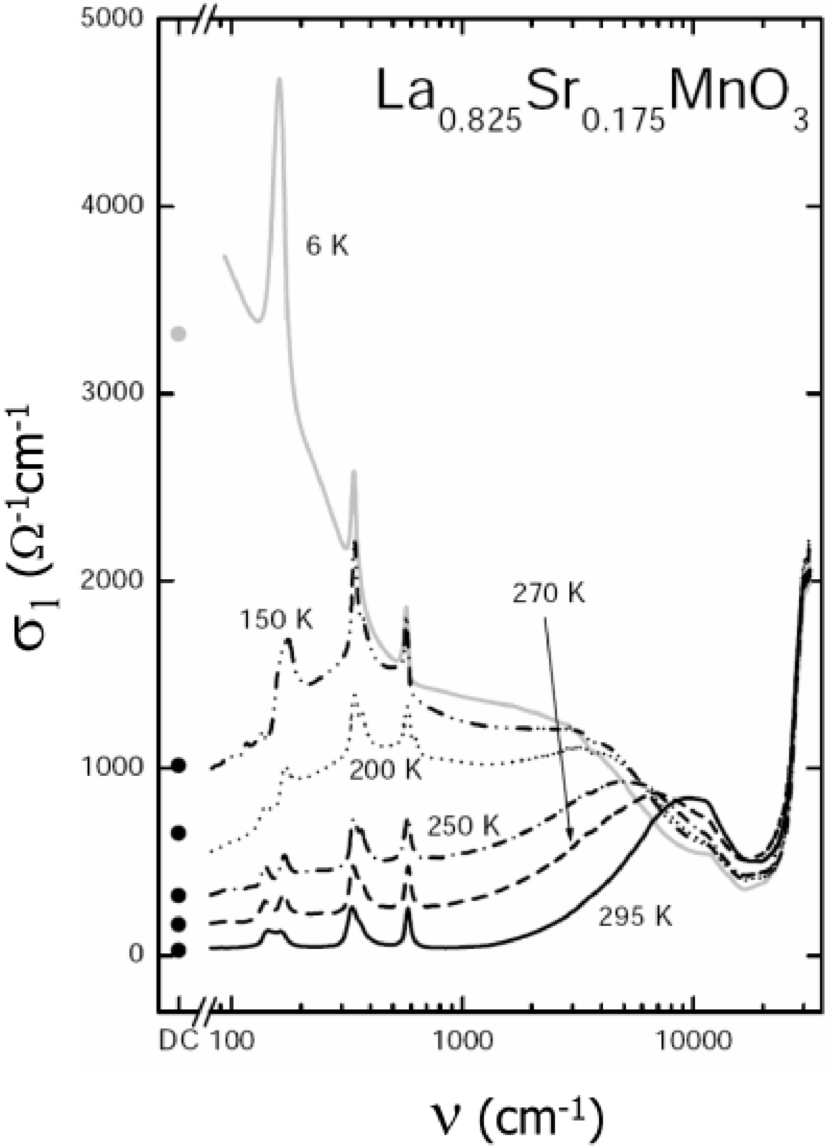


copper
visible
Reflectivity
Energy (eV)
$\hbar\omega_p$
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
14

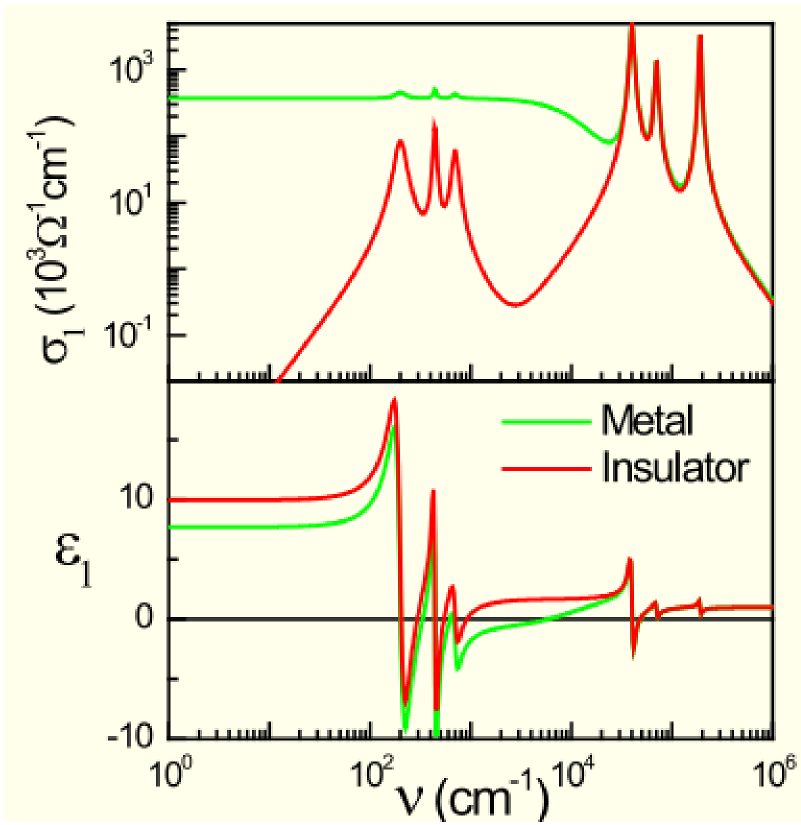


100
80
60
40
20
0
Reflectance (%)
0.2
1.0
10.0
Wavelength (μm)
Al
Rh
Cu
Ti
Au
Ag
400
500
600
700
Wavelength (nanometers)

Experimentelles Beispiel: Isolator-Metall-Phasenübergang in Manganaten



Modell



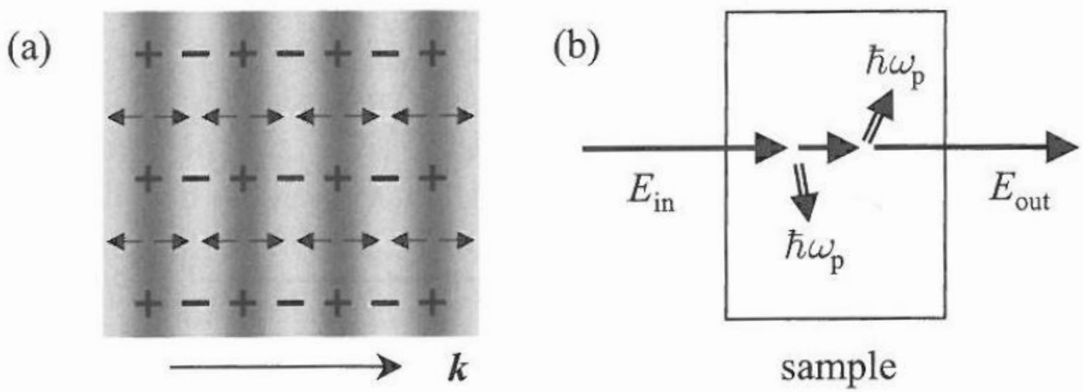
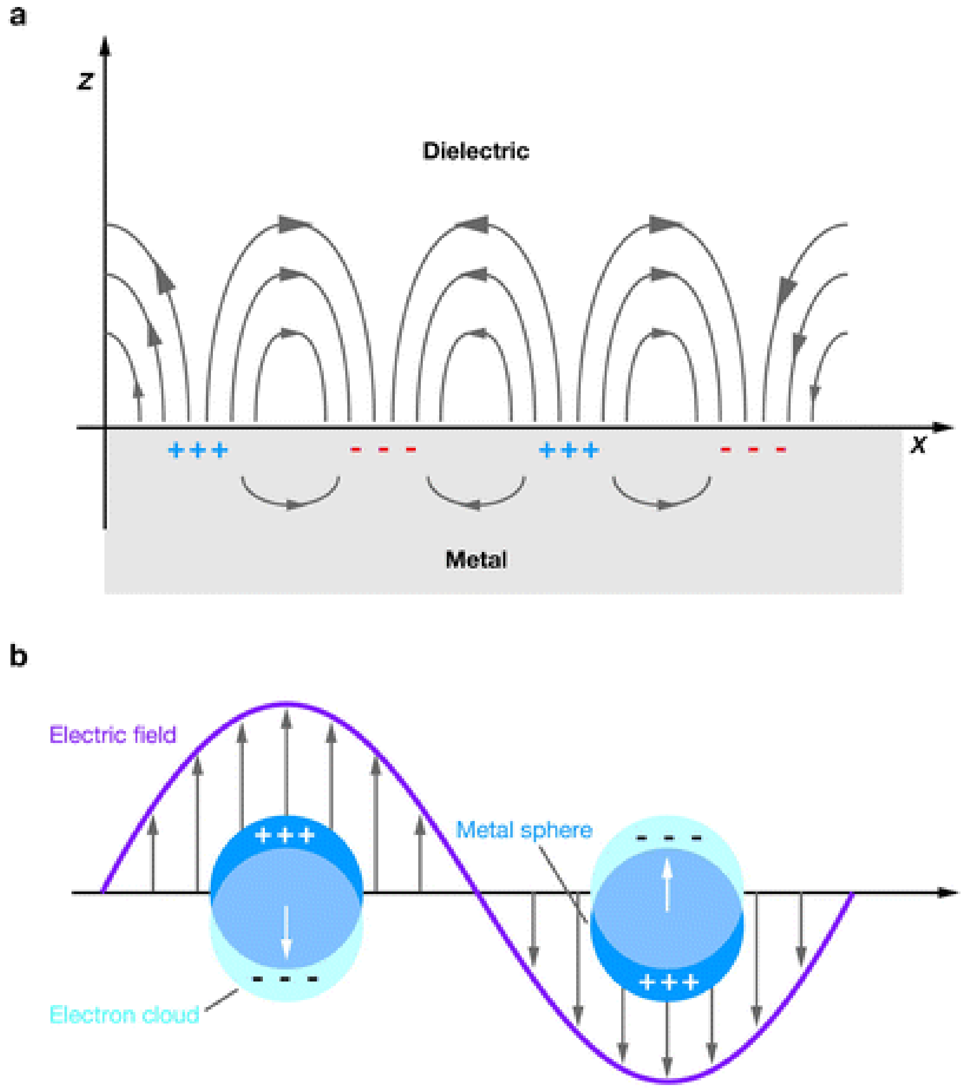
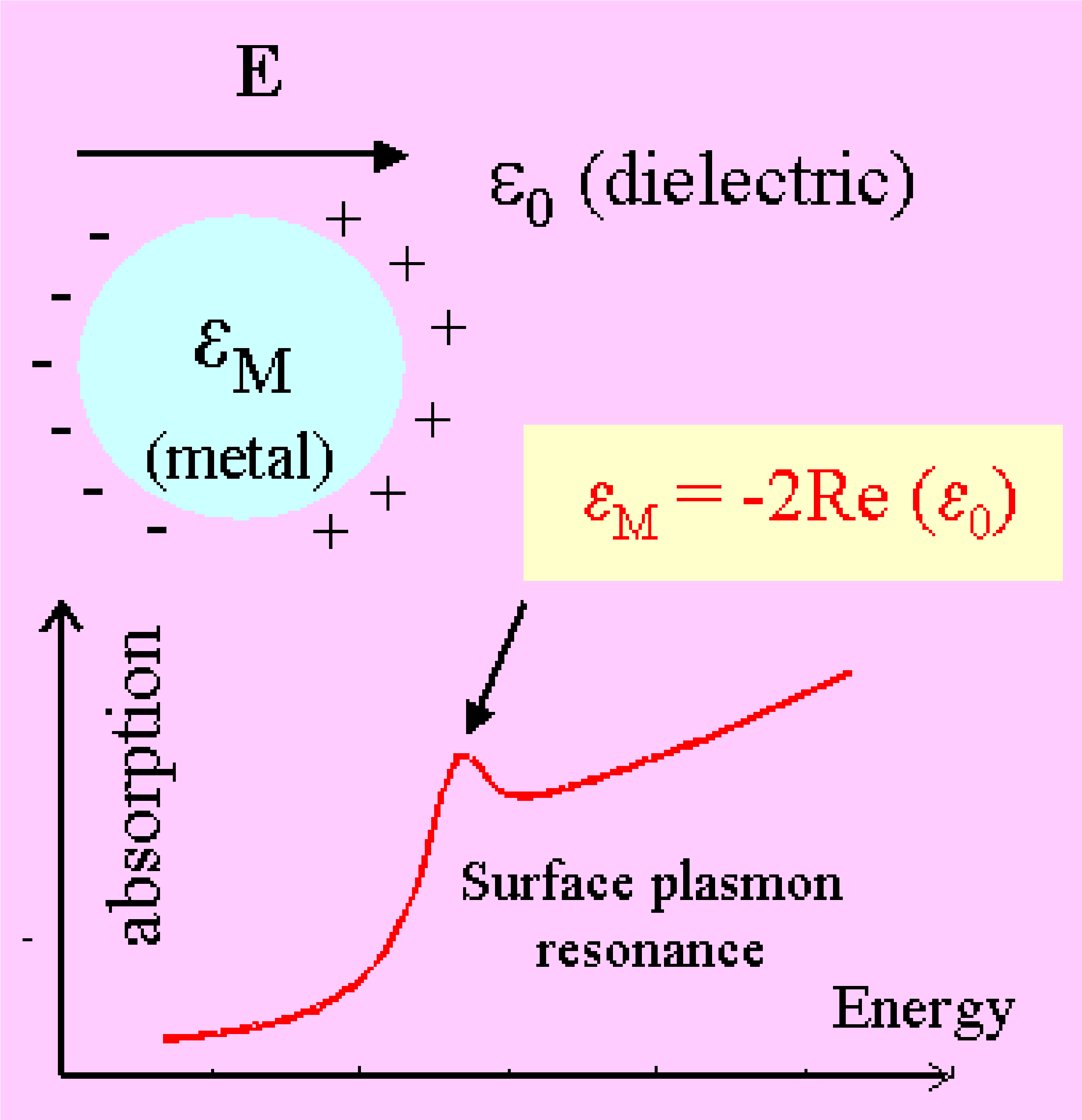


Fig. 7.12 (a) Charge fluctuations in a free carrier plasma oscillation. The lighter regions denote areas with excess electron densities. The small arrows indicate the direction of the electric fields, which are parallel to the direction of propagation of the wave, as indicated by its wave vector $\boldsymbol{k}$. (b) Excitation of plasmons by inelastic scattering of particles. The case in which two plasmons are excited is shown. For metals, electrons with keV energies are used, but for doped semiconductors, optical frequency photons have sufficient energy.

Surface plasmon, localized surface plasmon



Willets KA, Van Duyne RP. 2007.
Annu. Rev. Phys. Chem. 58:267–97


E
ε_0 (dielectric)
ε_M
(metal)
$\varepsilon_M = -2\mathrm{Re}\,(\varepsilon_0)$
absorption
Surface plasmon
resonance
Energy

Surface plasmon resonance