

# **Theory: Interaction of electrons with matter**



# Periodensystem der Elemente



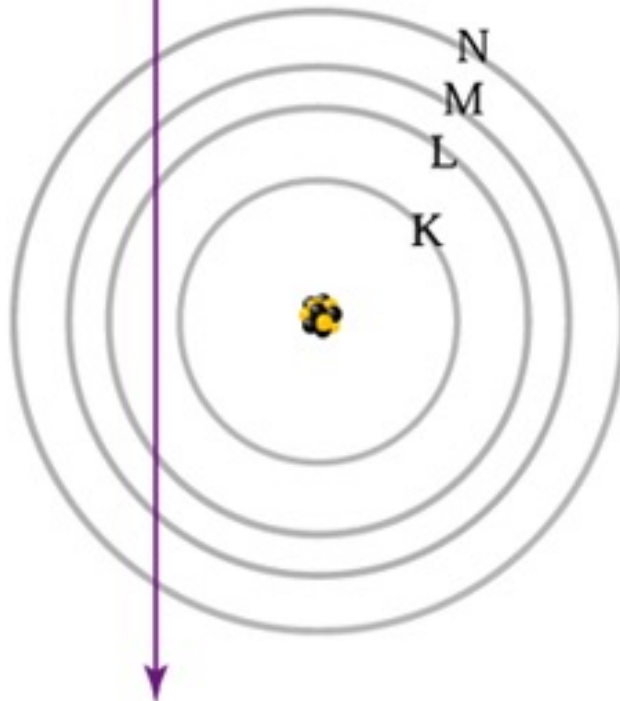
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1A 1																	18 2						
1 H Wasserstoff 1,0079																	2 He Helium 4,0026						
2 Li Lithium 6,941	2 Be Beryllium 9,0122																	13 B Bor 10,811	14 C Kohlenstoff 12,011	15 N Stickstoff 14,007	16 O Sauerstoff 15,999	17 F Fluor 18,998	18 Ne Neon 20,18
3 Na Natrium 22,99	4 Mg Magnesium 24,305																	13 Al Aluminium 26,982	14 Si Silicium 28,086	15 P Phosphor 30,974	16 S Schwefel 32,065	17 Cl Chlor 35,453	18 Ar Argon 39,948
4 K Kalium 39,098	4 Ca Calcium 40,078	3 Sc Scandium 44,956	4 Ti Titan 47,867	5 V Vanadium 50,942	6 Cr Chrom 51,996	7 Mn Mangan 54,938	8 Fe Eisen 55,845	9 Co Cobalt 58,933	10 Ni Nickel 58,693	11 Cu Kupfer 63,546	12 Zn Zink 65,38	13 Ga Gallium 69,723	14 Ge Germanium 72,64	15 As Arsen 74,922	16 Se Selen 78,96	17 Br Brom 79,904	18 Kr Krypton 83,798						
5 Rb Rubidium 85,468	5 Sr Strontium 87,62	5 Y Yttrium 88,906	6 Zr Zirkon 91,224	6 Nb Niobium 92,906	7 Mo Molybdän 95,96	8 Tc Technetium 97,901	9 Ru Ruthenium 101,07	10 Rh Rhodium 102,91	11 Pd Palladium 106,42	12 Ag Silber 107,87	13 Cd Cadmium 112,41	14 In Indium 114,82	15 Sn Zinn 118,71	16 Sb Antimon 121,76	17 Te Tellur 127,6	18 I Iod 126,9	18 Xe Xenon 131,29						
6 Cs Cäsium 132,91	6 Ba Barium 137,33	6 La - Lu Lanthanoide	7 Hf Hafnium 178,49	7 Ta Tantal 180,95	8 W Wolfram 183,84	9 Re Rhenium 186,21	10 Os Osmium 190,23	11 Ir Iridium 192,22	12 Pt Platin 195,08	13 Au Gold 196,97	14 Hg Quecksilber 200,59	15 Tl Thallium 204,38	16 Pb Blei 207,2	17 Bi Bismut 208,98	18 Po Polonium [209]	19 At Astat [209]	18 Rn Radon [222]						
7 Fr Francium [223]	7 Ra Radium [226]	7 Ac - Lr Actinoide	8 Rf Rutherfordium [261]	9 Db Dubnium [262]	10 Sg Seaborgium [263]	11 Bh Bohrium [264]	12 Hs Hassium [265]	13 Mt Meitnerium [266]	14 Ds Darmstadtium [271]	15 Rg Roentgenium [272]	16 Cn Copernicium [277]	17 Uut Ununtrium [284]	18 Fl Flerovium [289]	19 Uup Ununpentium [288]	20 Lv Livermorium [293]	21 Uus Ununseptium [292]	18 Uuo Ununoctium [294]						
		7 La Lanthan 138,91	8 Ce Cer 140,12	9 Pr Praseodym 140,91	10 Nd Neodym 144,24	11 Pm Promethium [144]	12 Sm Samarium 150,36	13 Eu Europium 151,96	14 Gd Gadolinium 157,25	15 Tb Terbium 158,93	16 Dy Dysprosium 162,5	17 Ho Holmium 164,93	18 Er Erbium 167,26	19 Tm Thulium 168,93	20 Yb Ytterbium 173,05	21 Lu Lutetium 174,97							
		8 Ac Actinium [227]	9 Th Thorium 232,04	10 Pa Protactinium 231,04	11 U Uran 238,03	12 Np Neptunium [237]	13 Pu Plutonium [244]	14 Am Americium [243]	15 Cm Curium [247]	16 Bk Berkelium [247]	17 Cf Californium [251]	18 Es Einsteinium [252]	19 Fm Fermium [257]	20 Md Mendelevium [258]	21 No Nobelium [259]	22 Lr Lawrencium [260]							

<http://www.dentilux.com/services/services.htm>

Primary beam

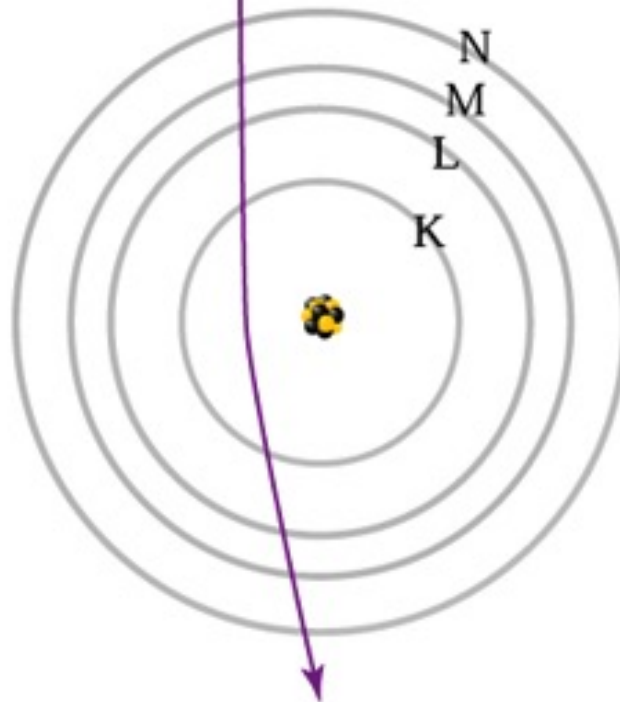
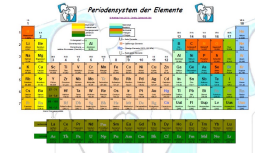
15 keV



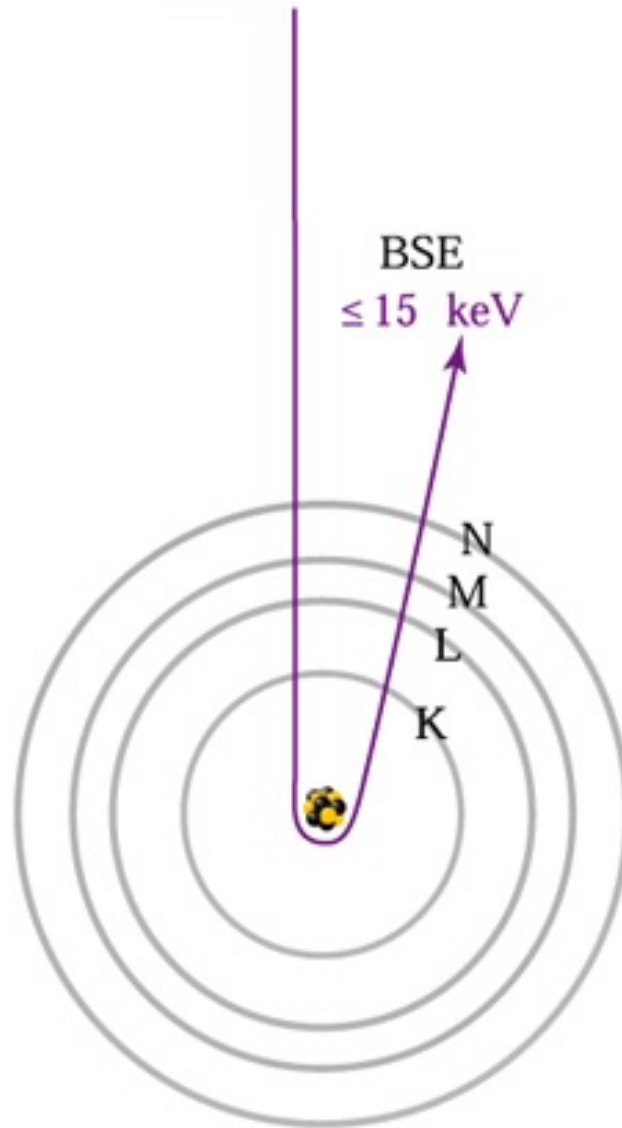
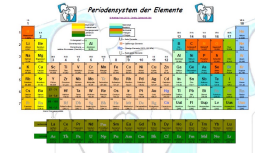
Periodensystem der Elemente

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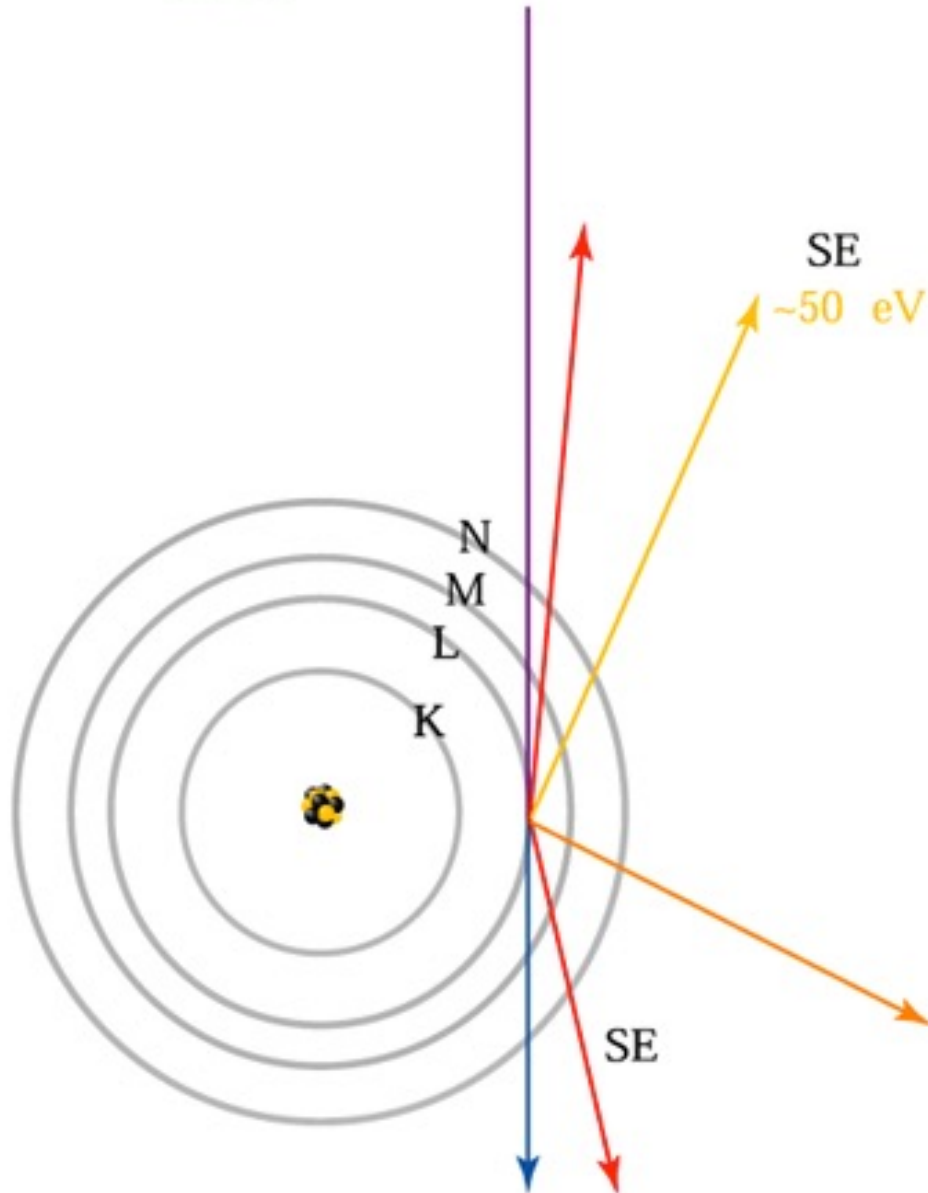
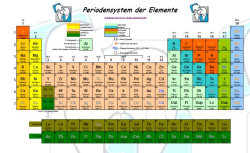
Primary beam  
15 keV



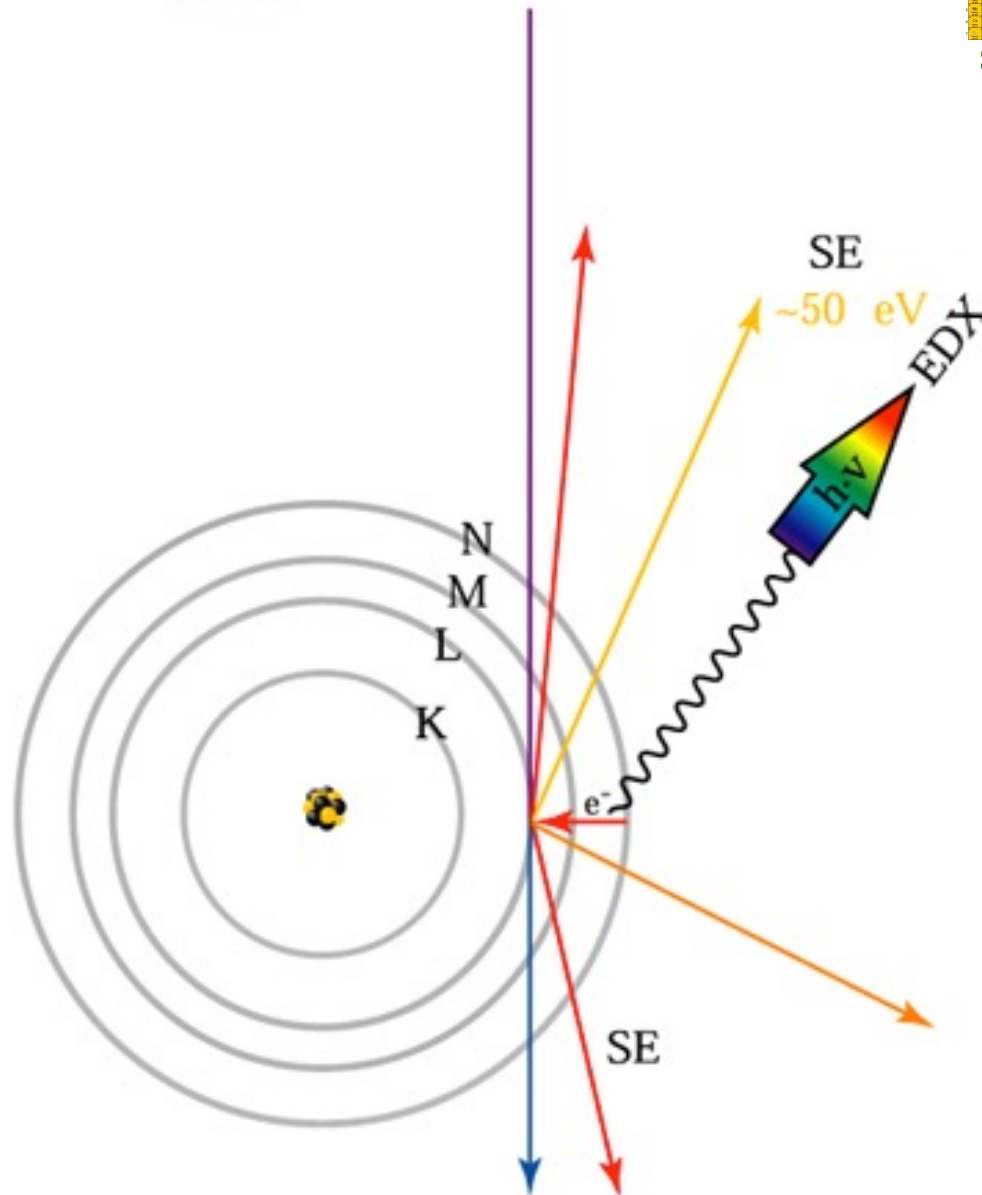
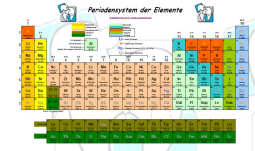
Primary beam  
15 keV



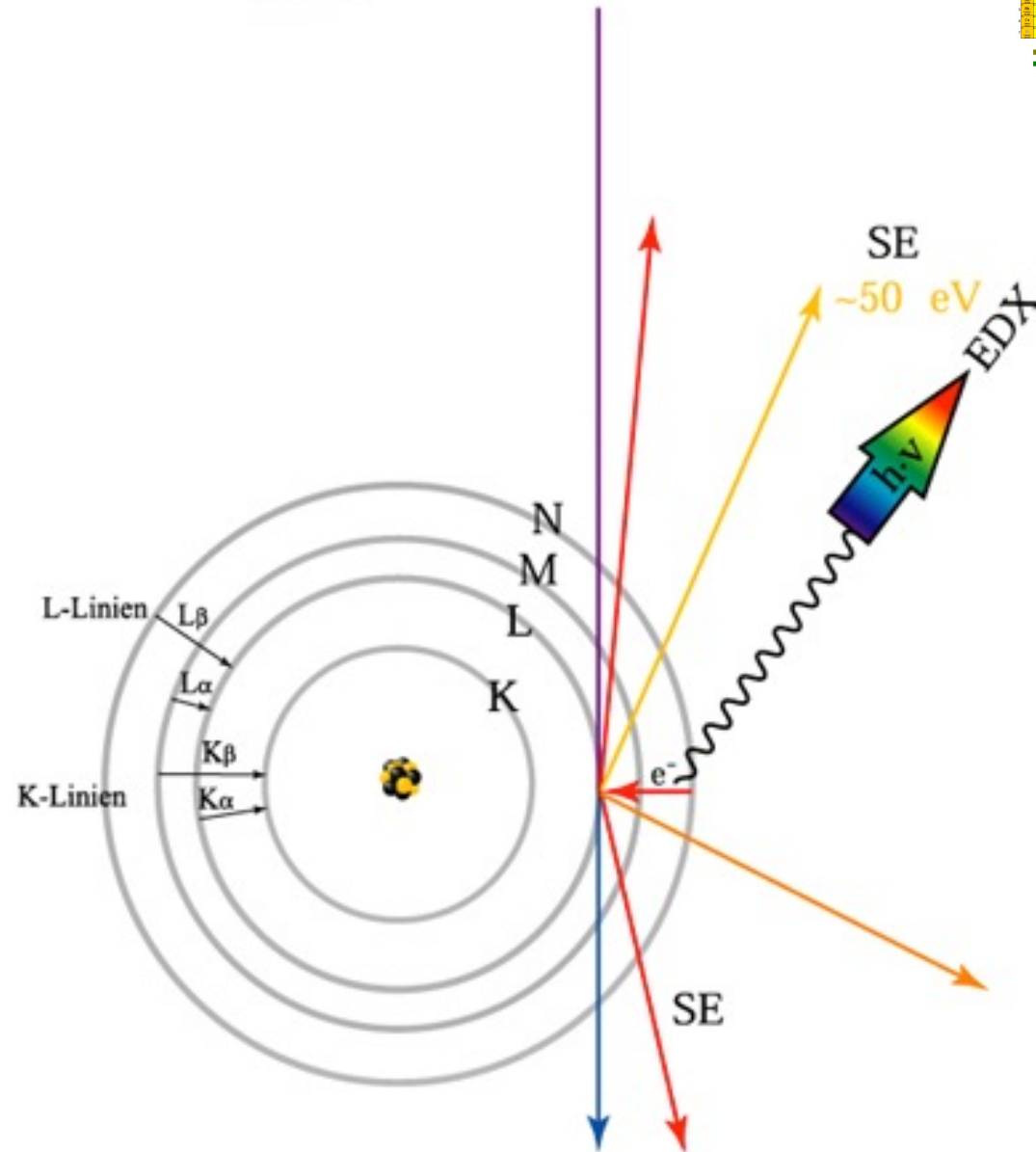
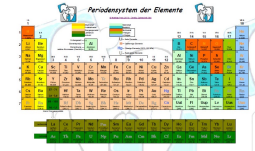
Primary beam  
15 keV



Primary beam  
15 keV

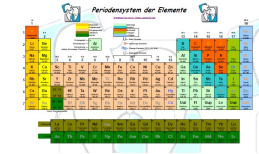


Primary beam  
15 keV





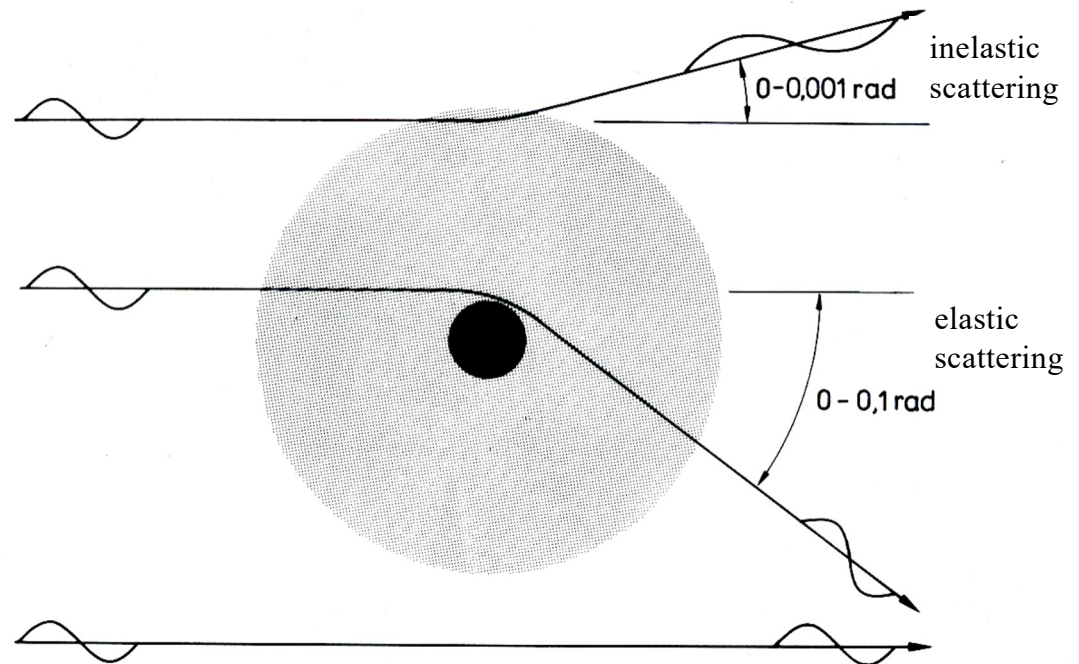
# Scattering: With or without energy loss

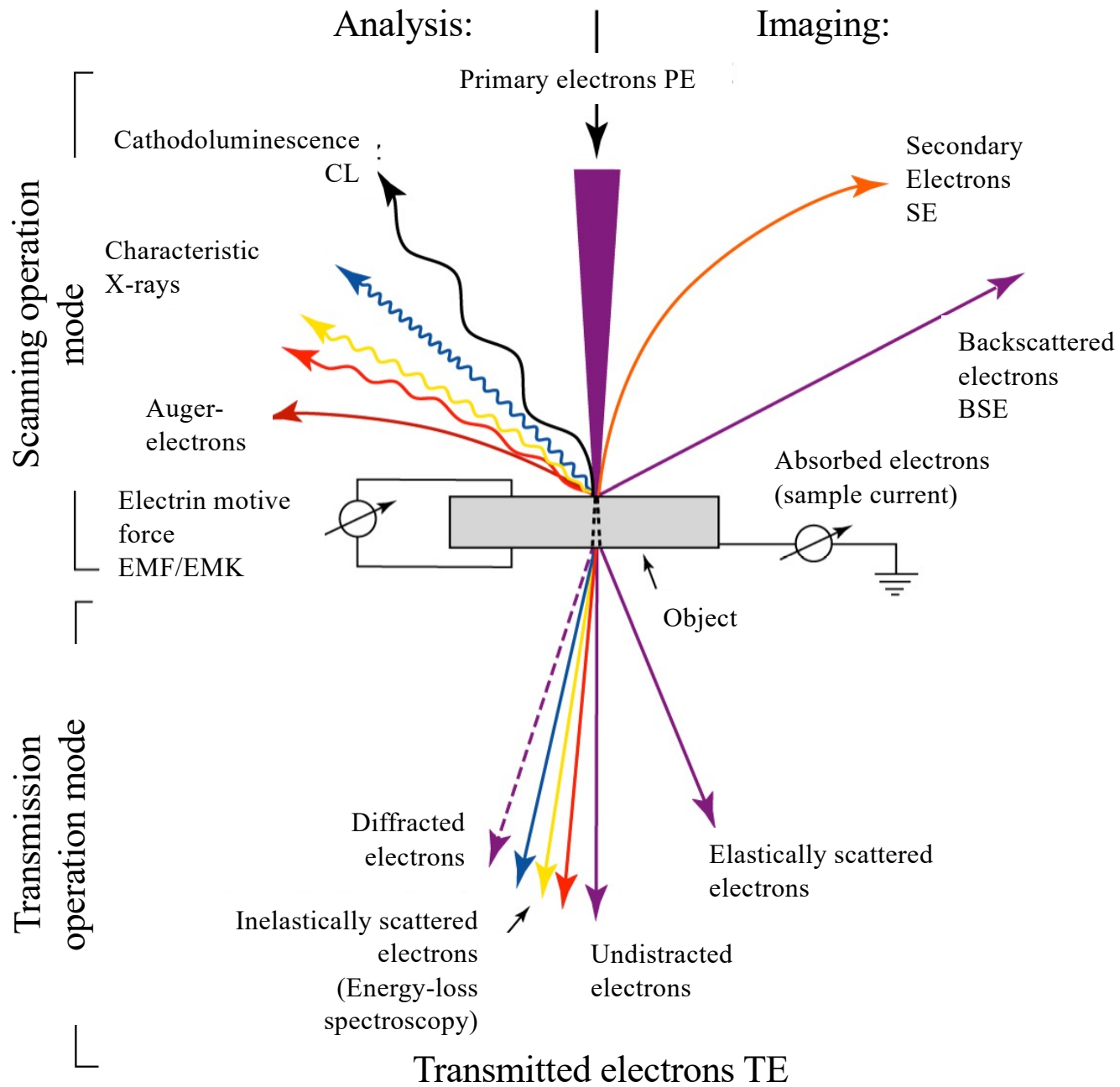


- Interaction of electrons with sample atoms

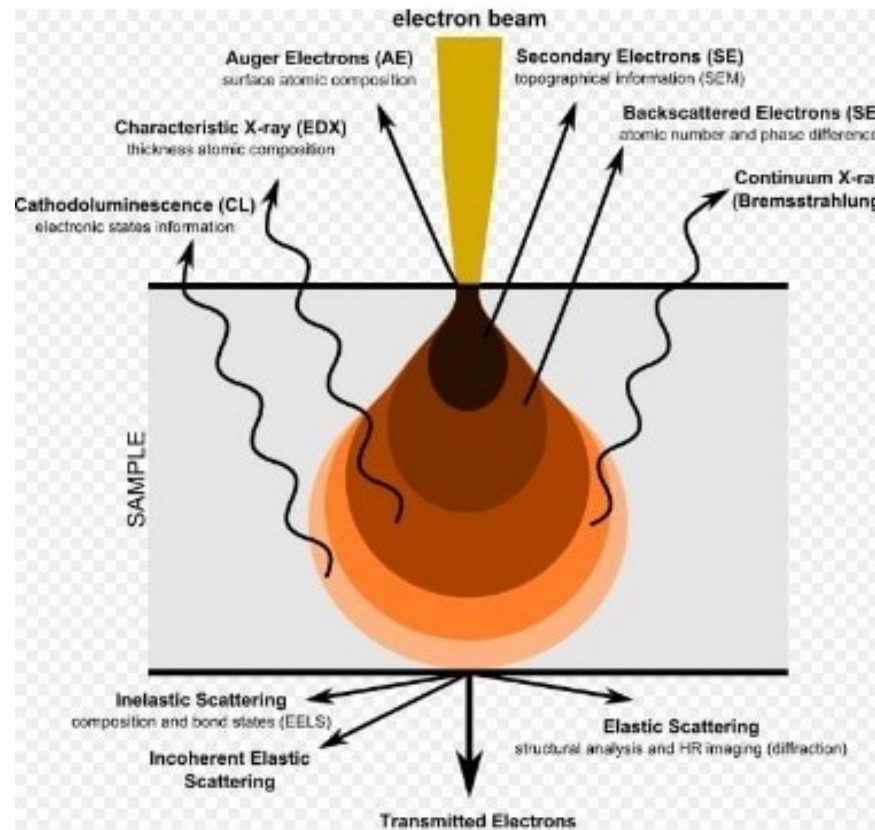
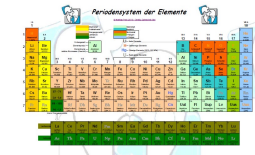
- elastic scattering  
(nucleus – electron)  
no energy exchange  
scattering angle  $> 10^{-1}$

- inelastic scattering  
(electron – electron)  
energy loss  
scattering angle very small :  $10^{-3} - 10^{-5}$



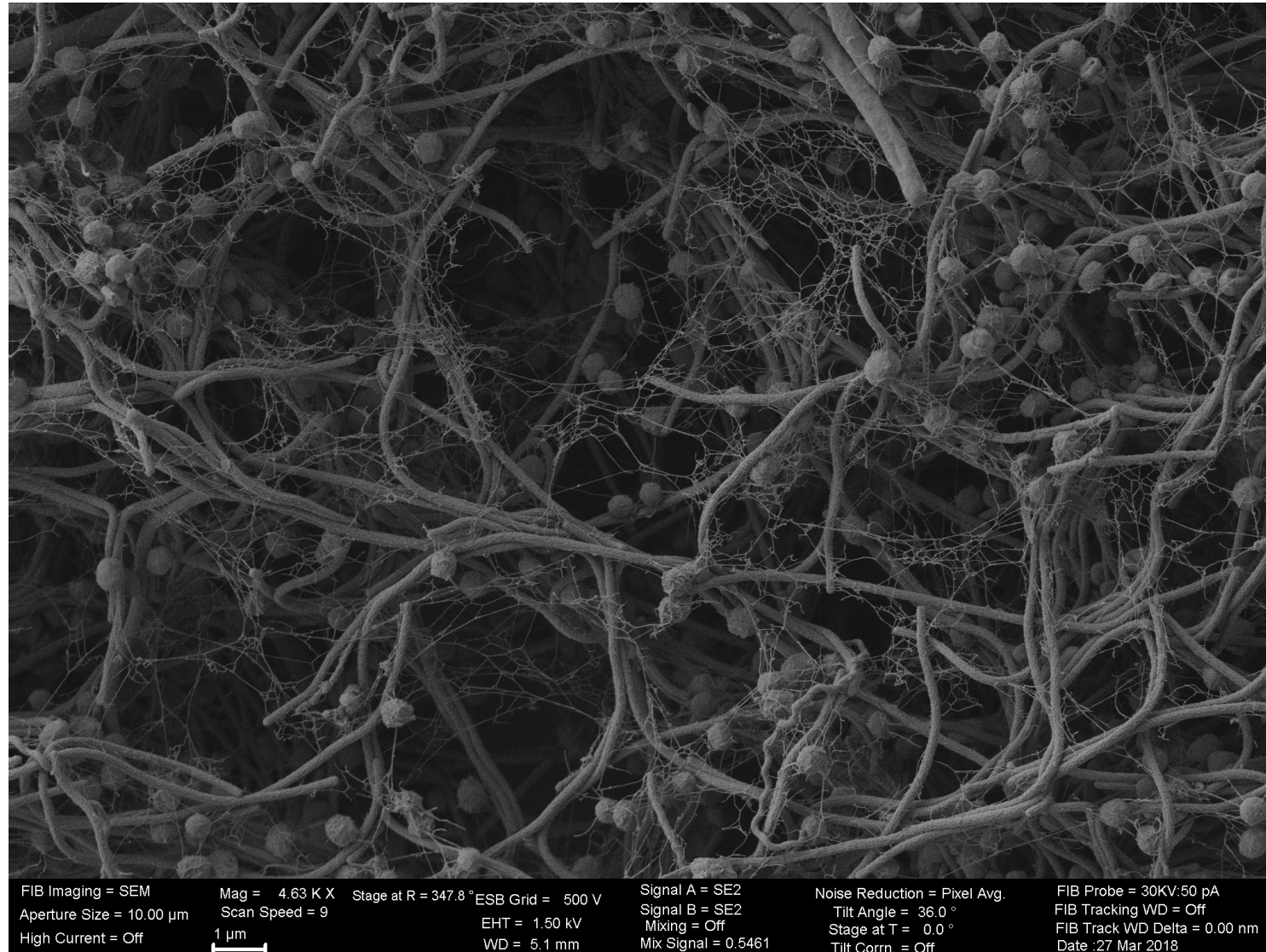
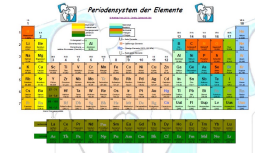


# Origin of signals in the SEM



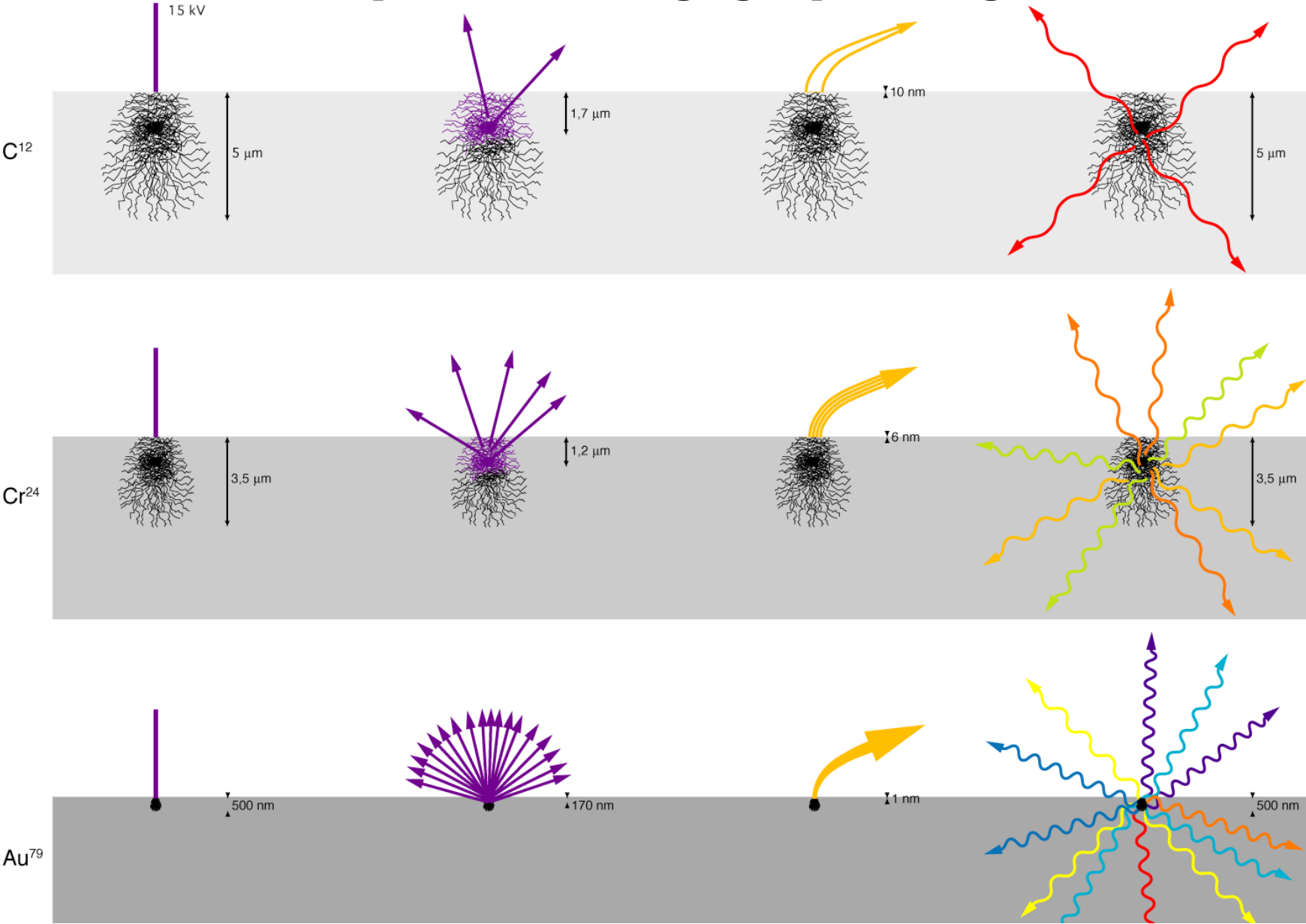
<https://www.thermofisher.com/blog/microscopy/wp-content/uploads/sites/12/2019/11/electron-matter-interaction-volume.jpeg>

# „Image formation“ in the SEM

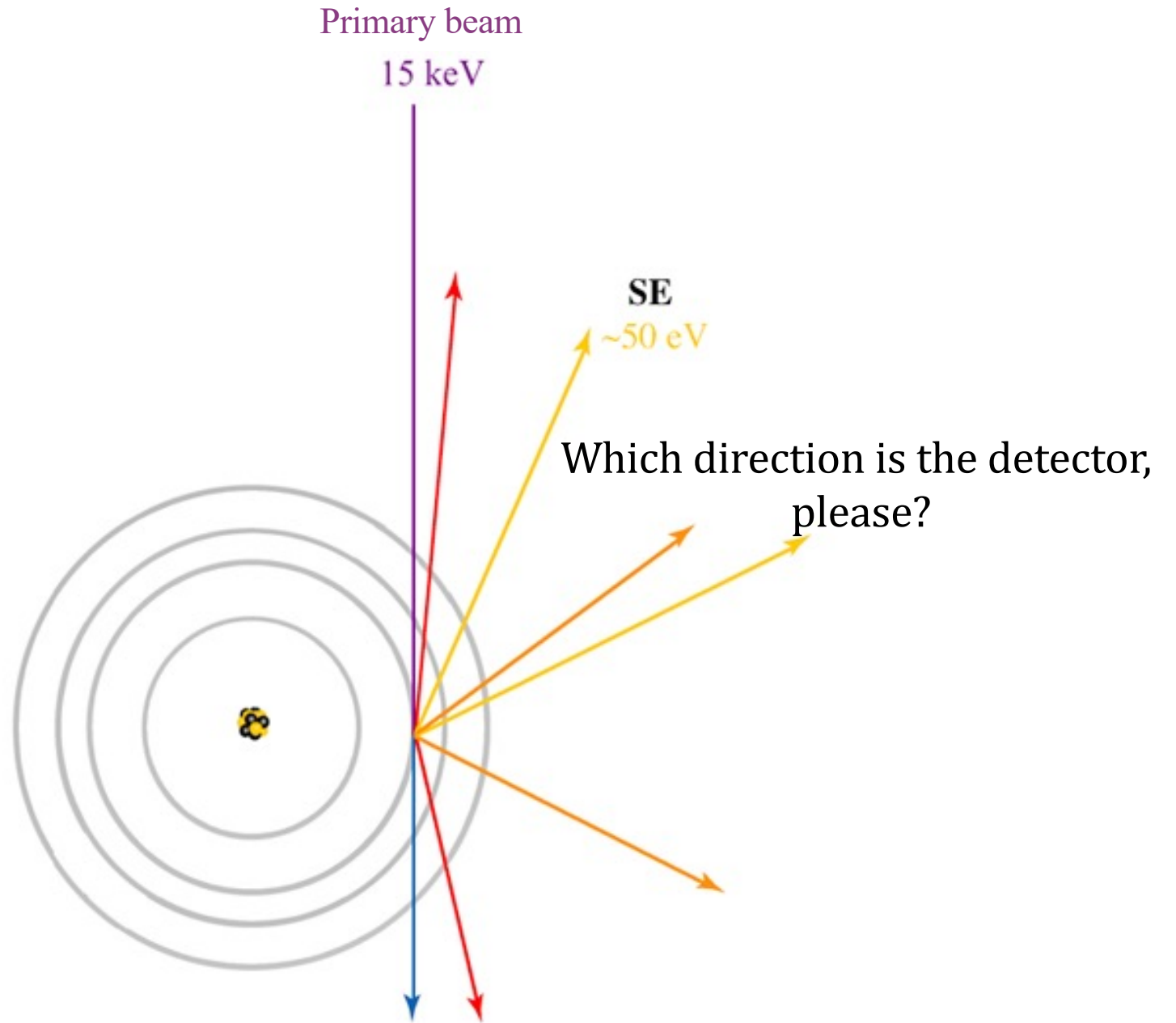




# Comparison of emerging depths of signals

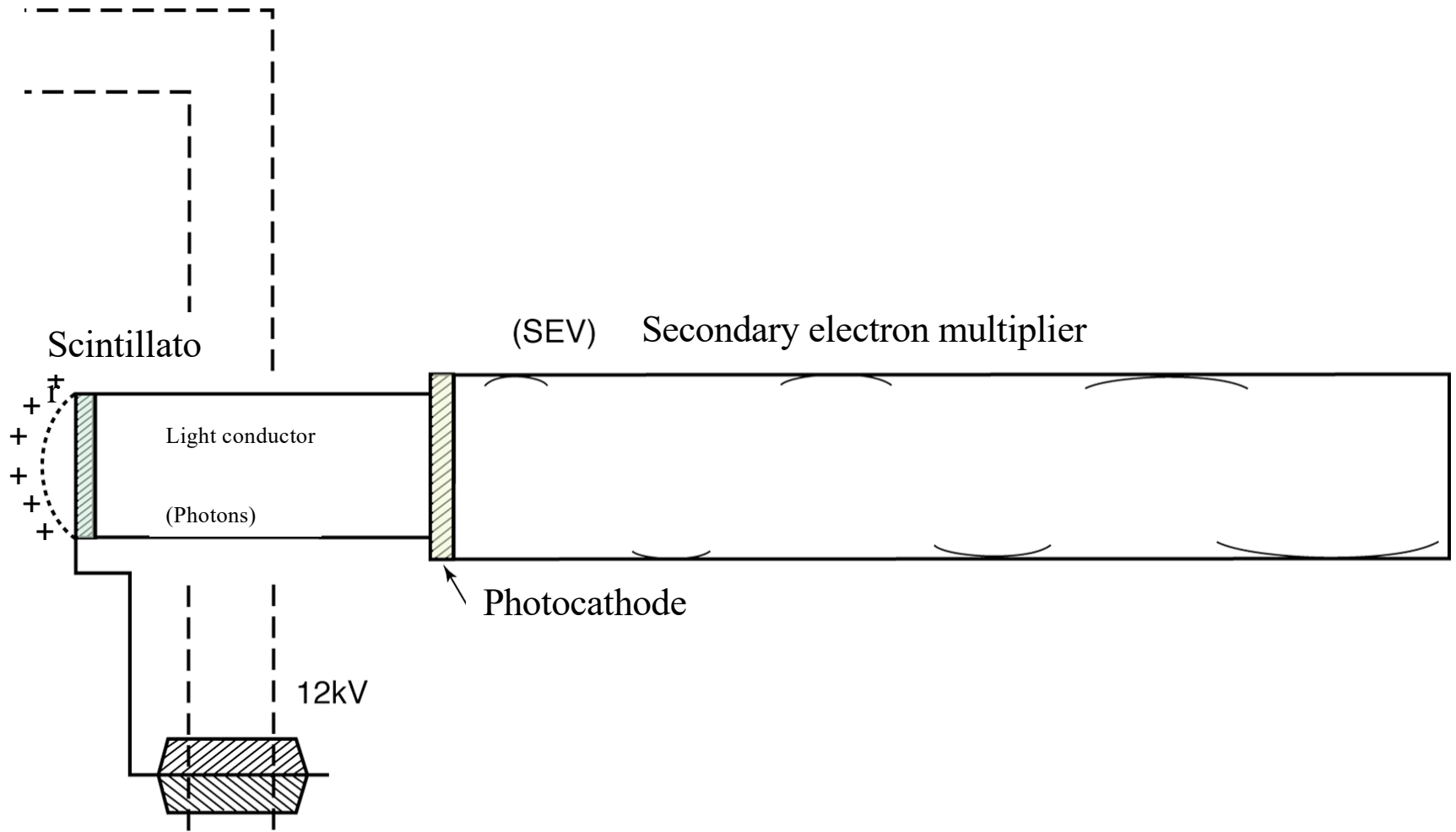


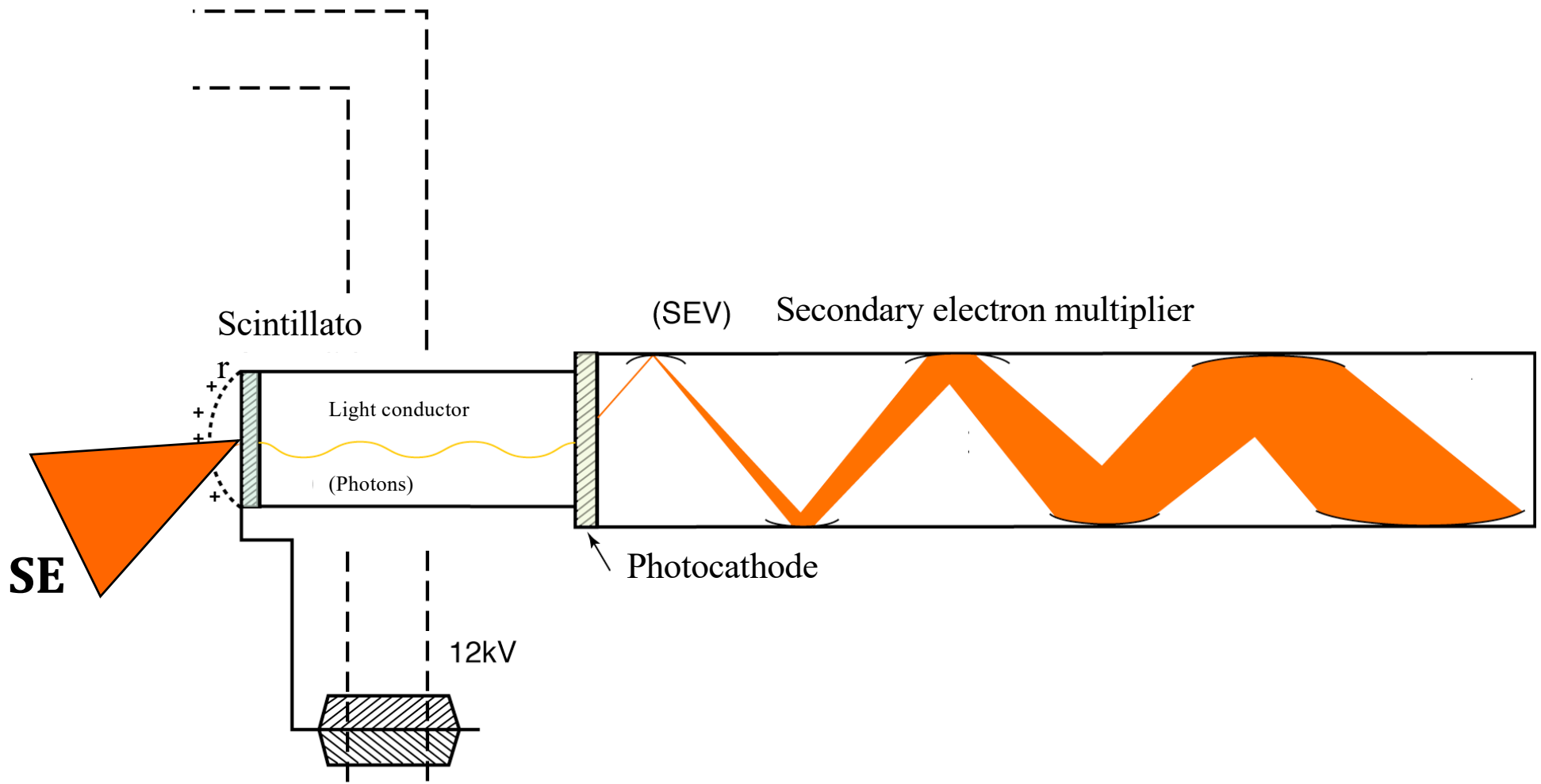
# **From the electron beam to the SE-image**



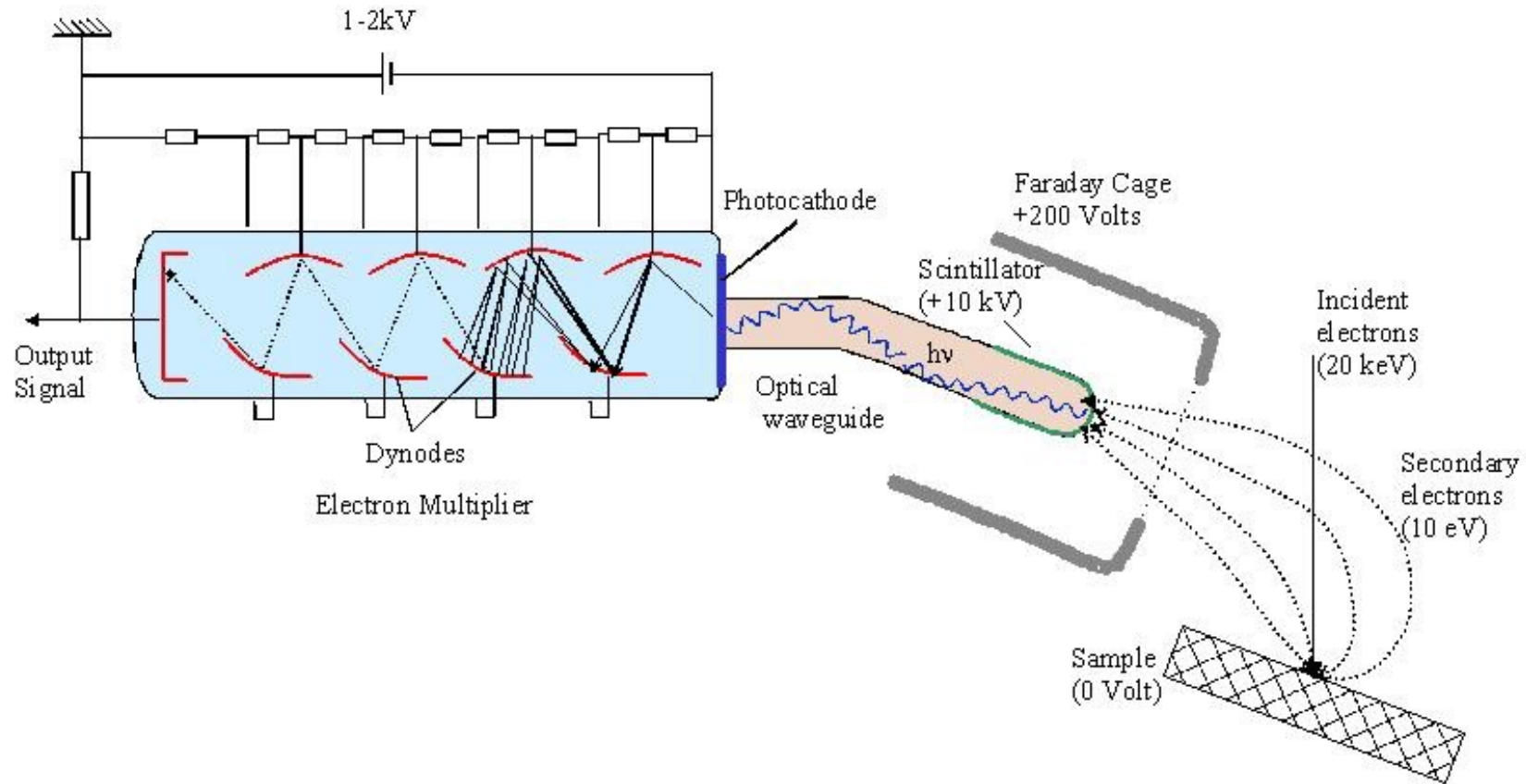
# Secondary electron detector



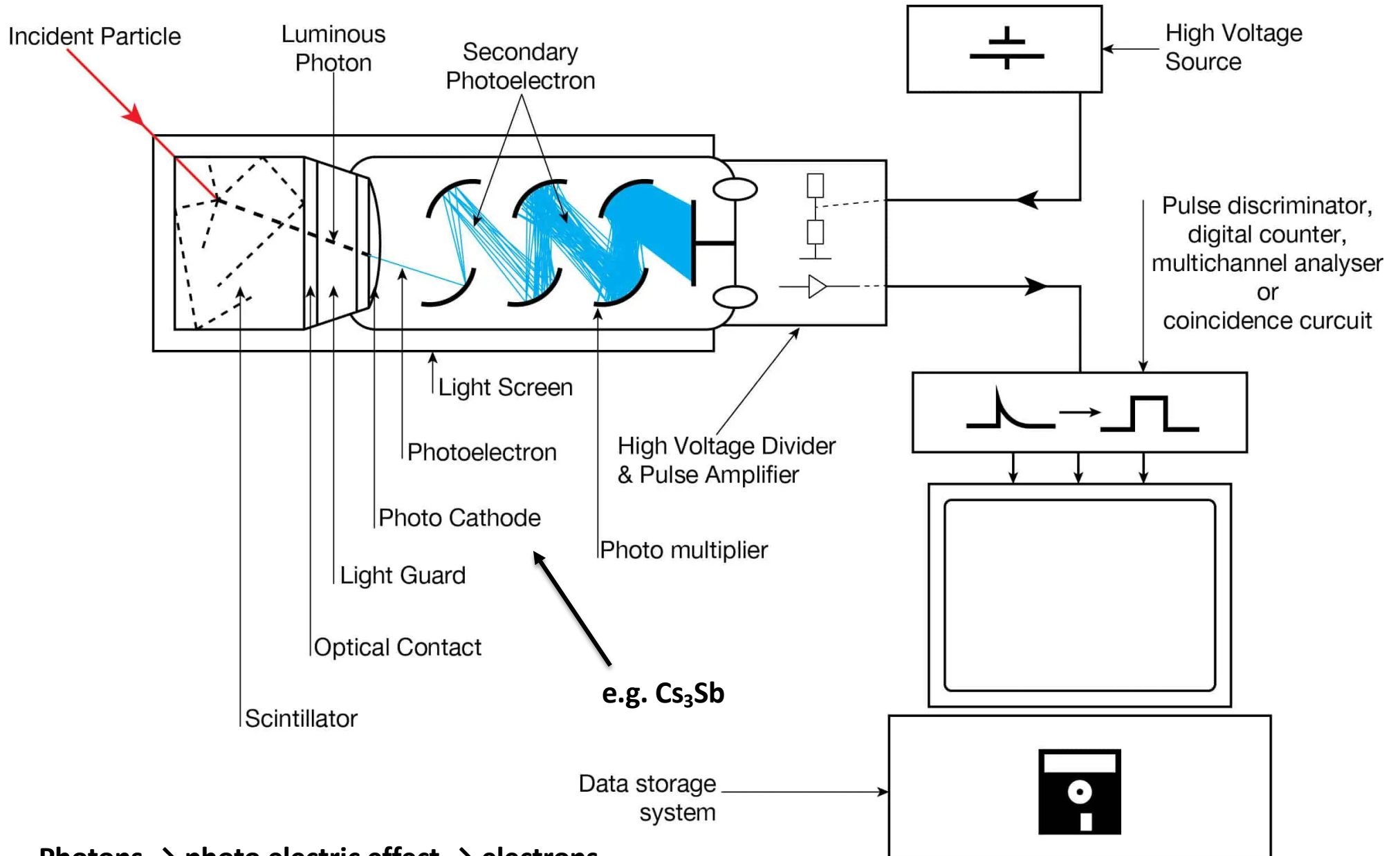




# Everhart-Thornley-detector

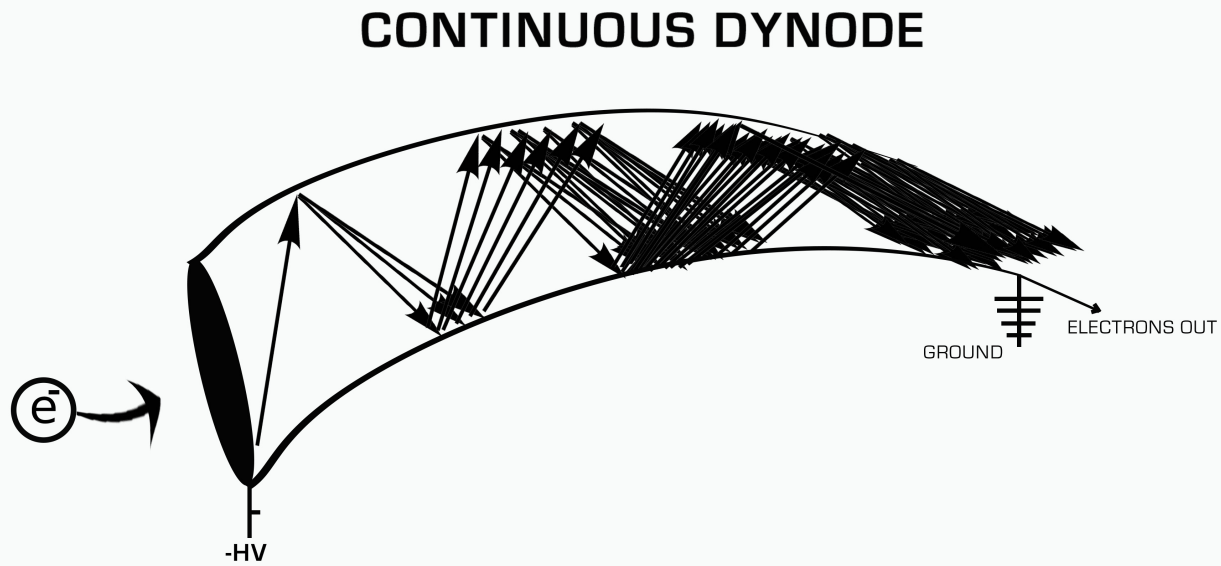
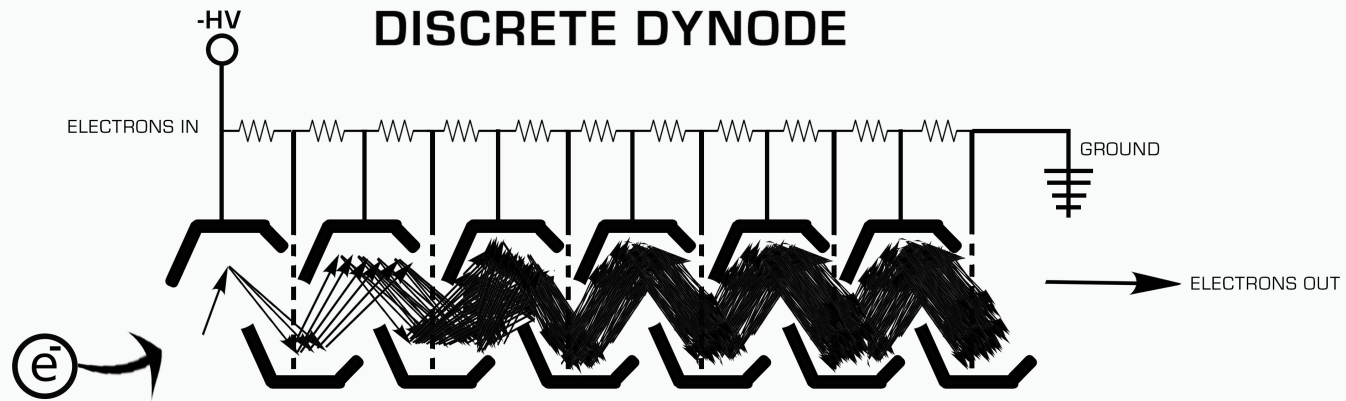


# SE-detector: photo cathode

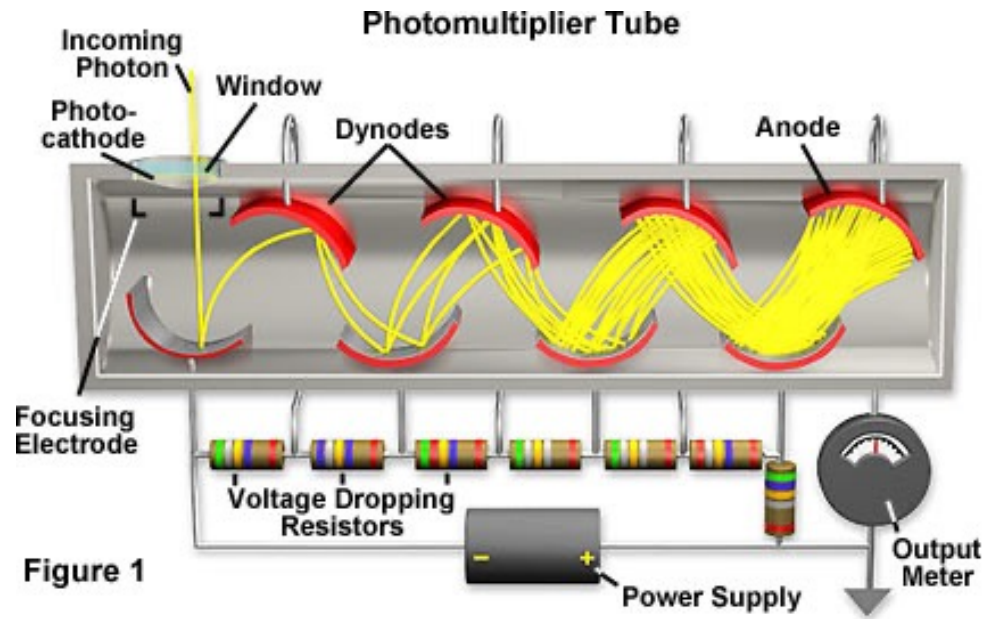


Photons → photo electric effect → electrons

# Dynodes



# Dynodes

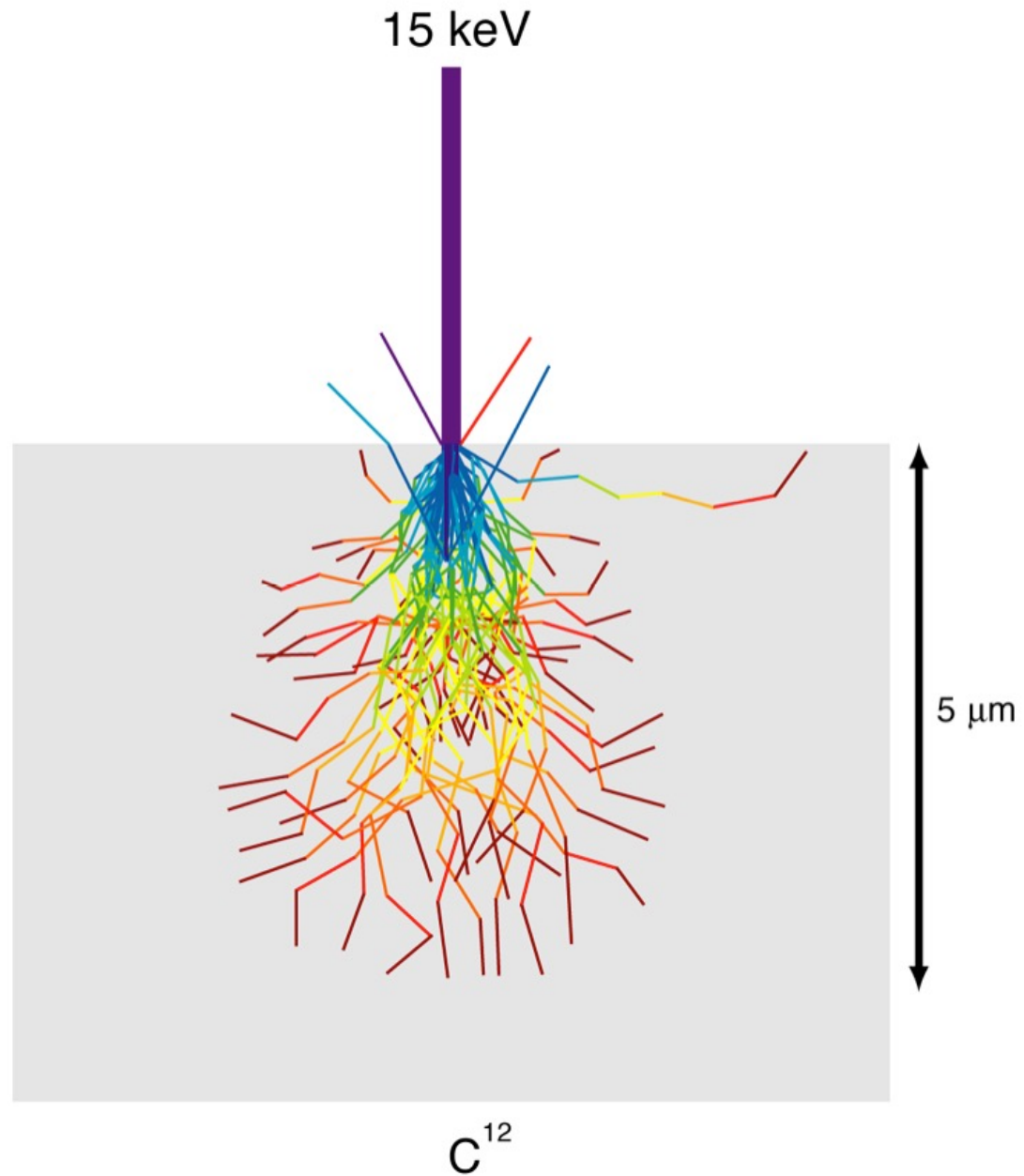


<https://www.olympus-lifescience.com/de/microscope-resource/primer/digitalimaging/concepts/photomultipliers/>

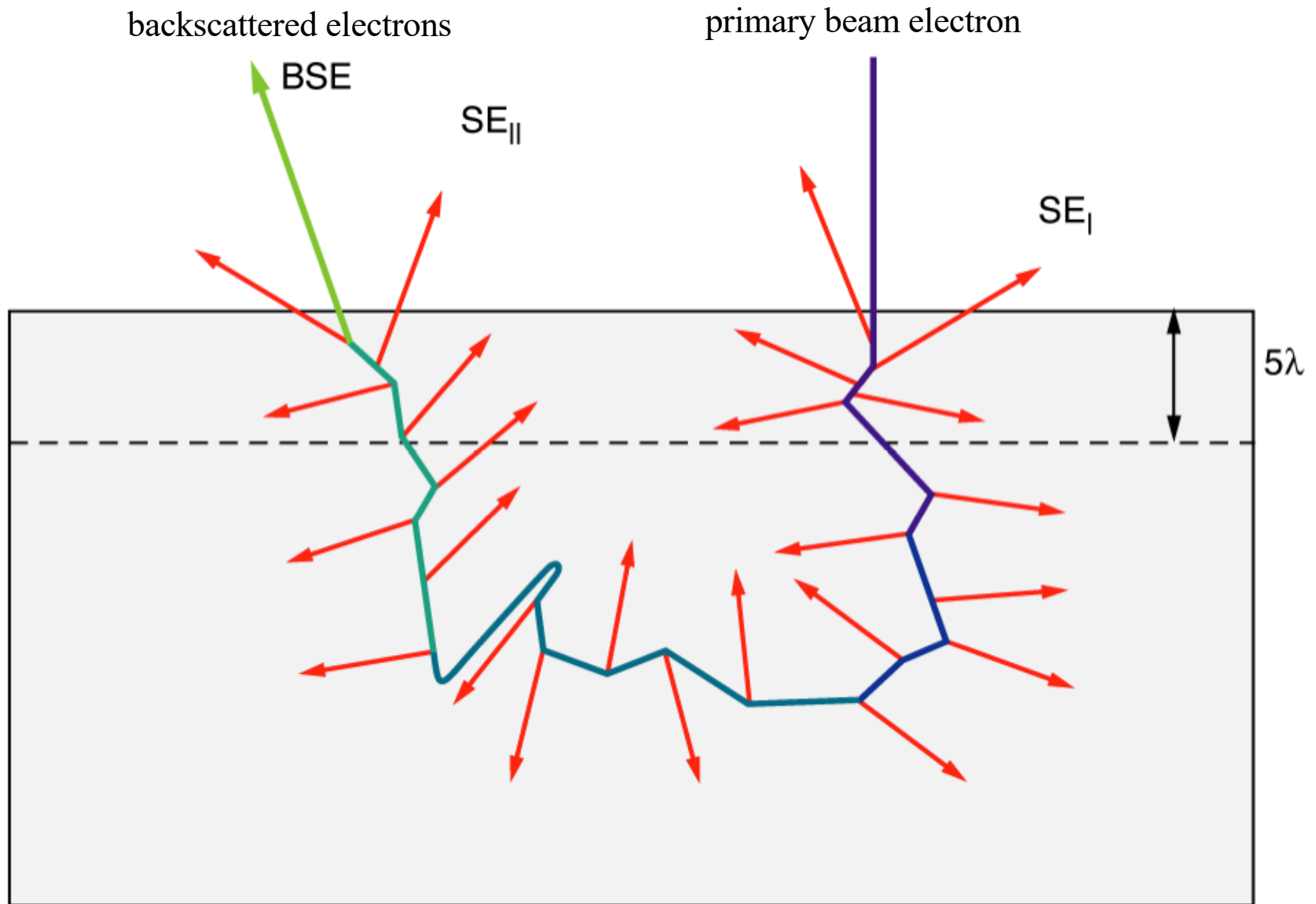


<https://de.wikipedia.org/wiki/Dynode>

# The path of primary/secondary electrons

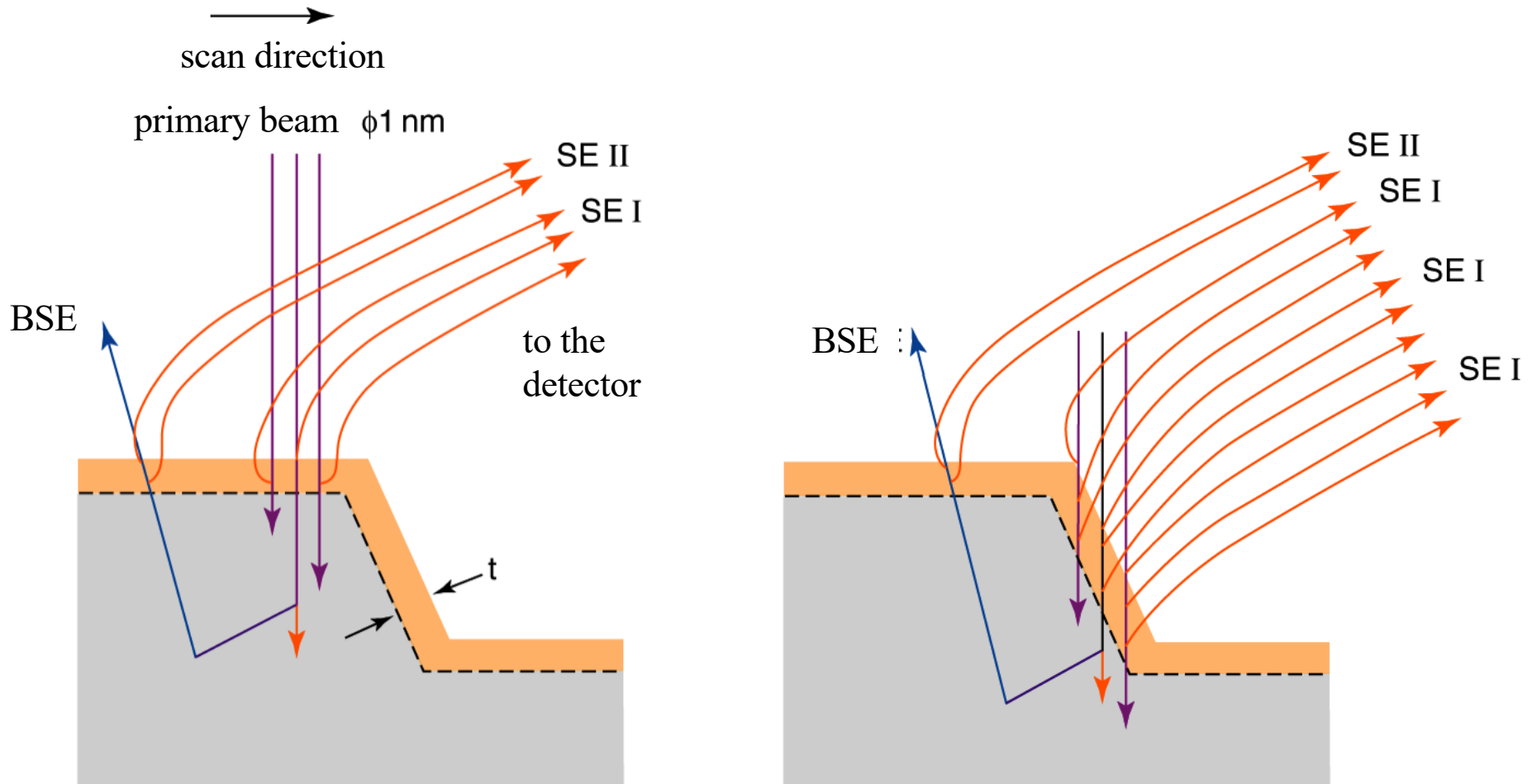


# SE I - SE II - BSE

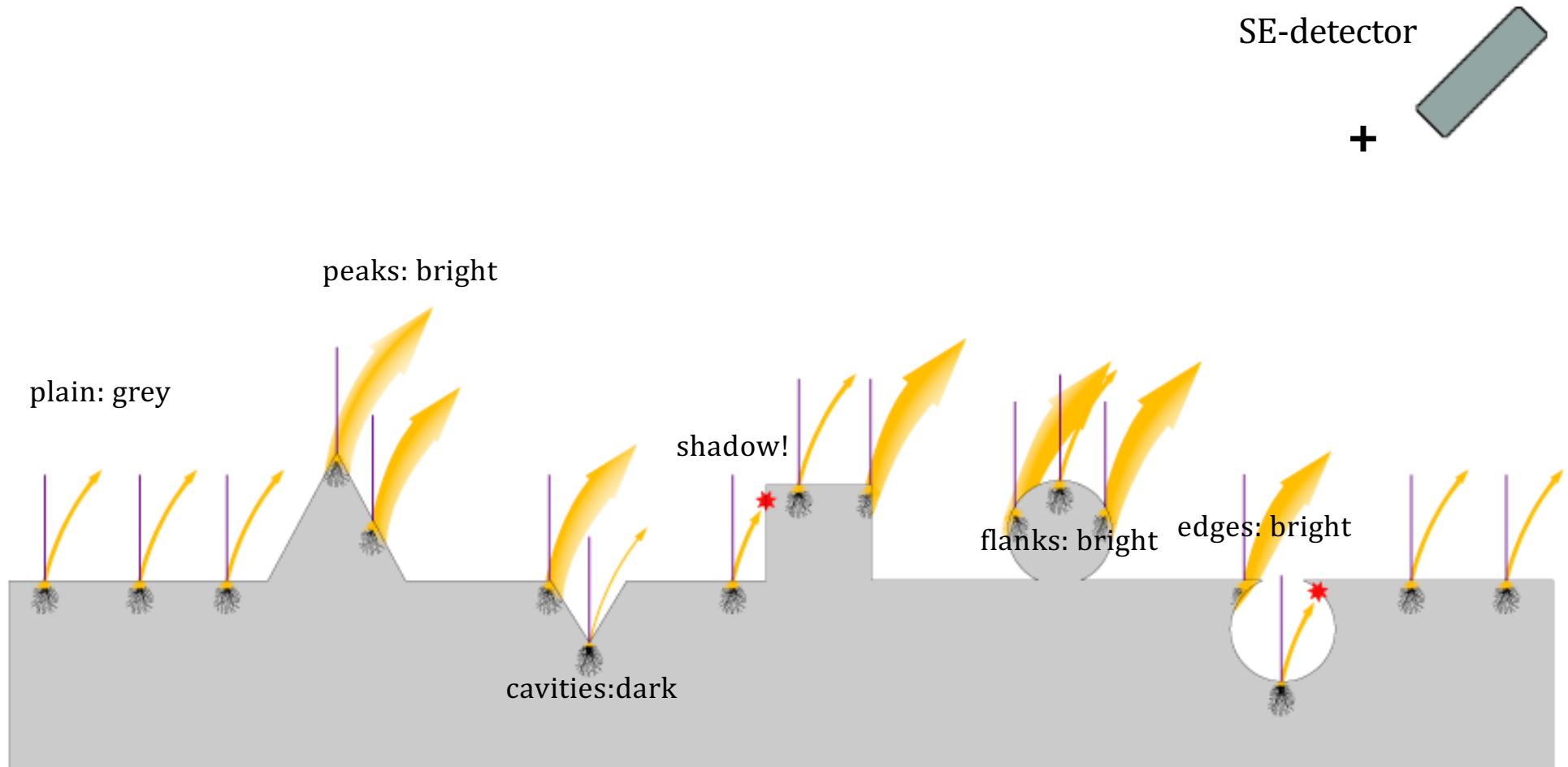




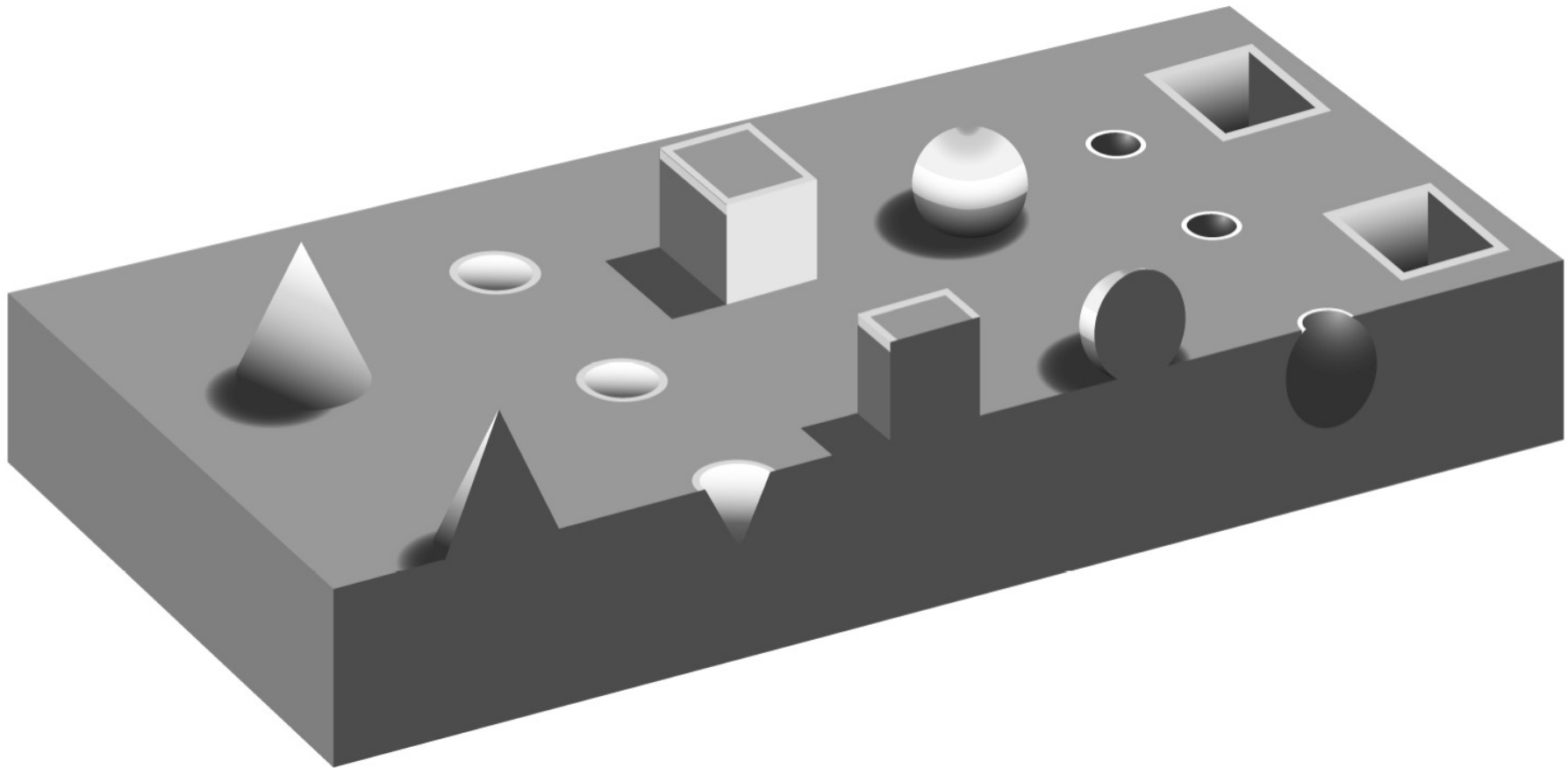
# SE: „from plain to incline“



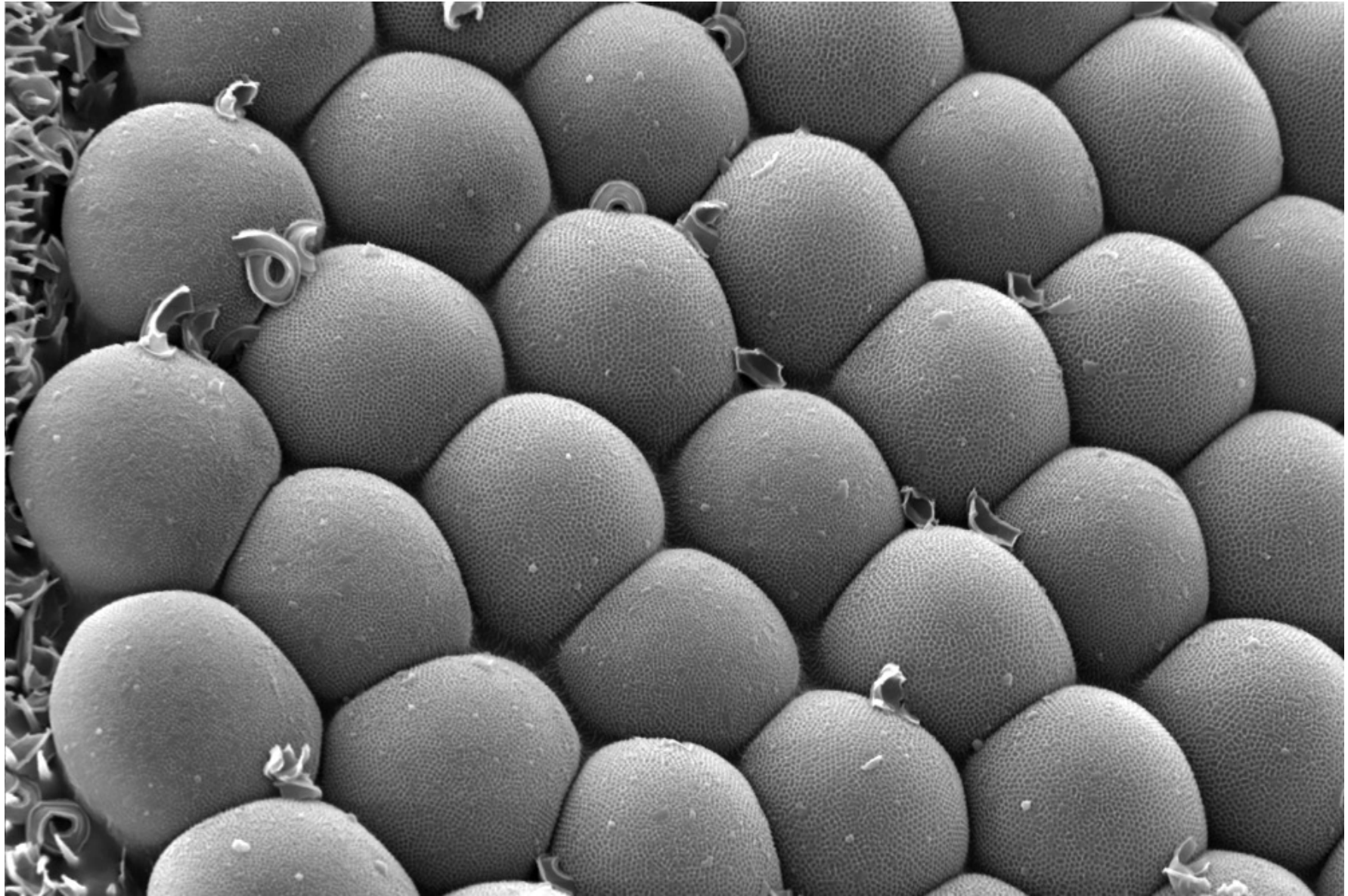
# Getting into the 3<sup>rd</sup> dimension using the “topography contrast”



# Topography contrast



## Topography contrast



## Resolution: why is the cathode type and beam diameter so important?



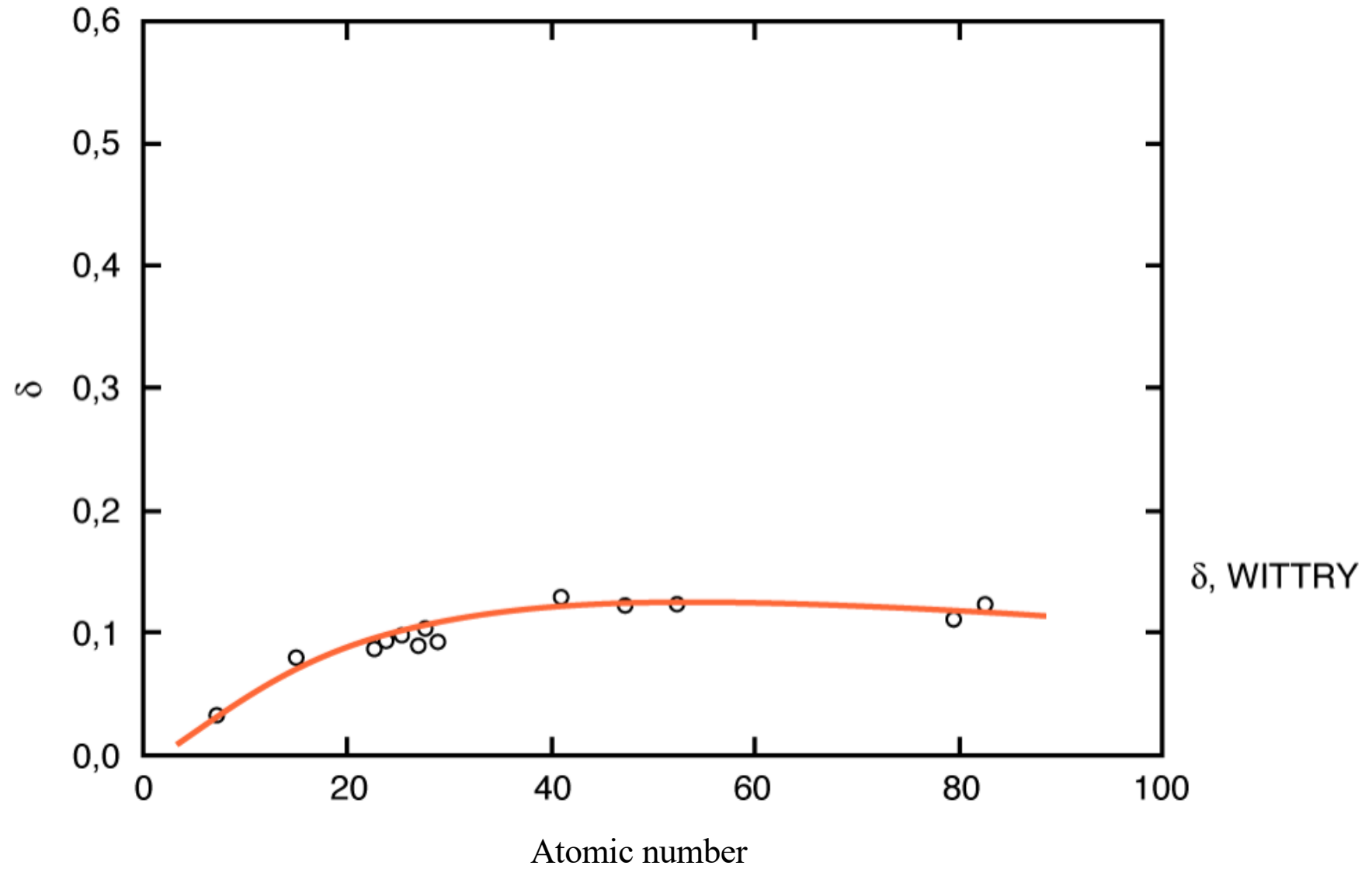
<https://i.weltbild.de/p/nagelbild-pin-art-071465579.jpg?tr=tr%3An-maxsize&iv=26>

## Resolution: why is the cathode type and beam diameter so important?



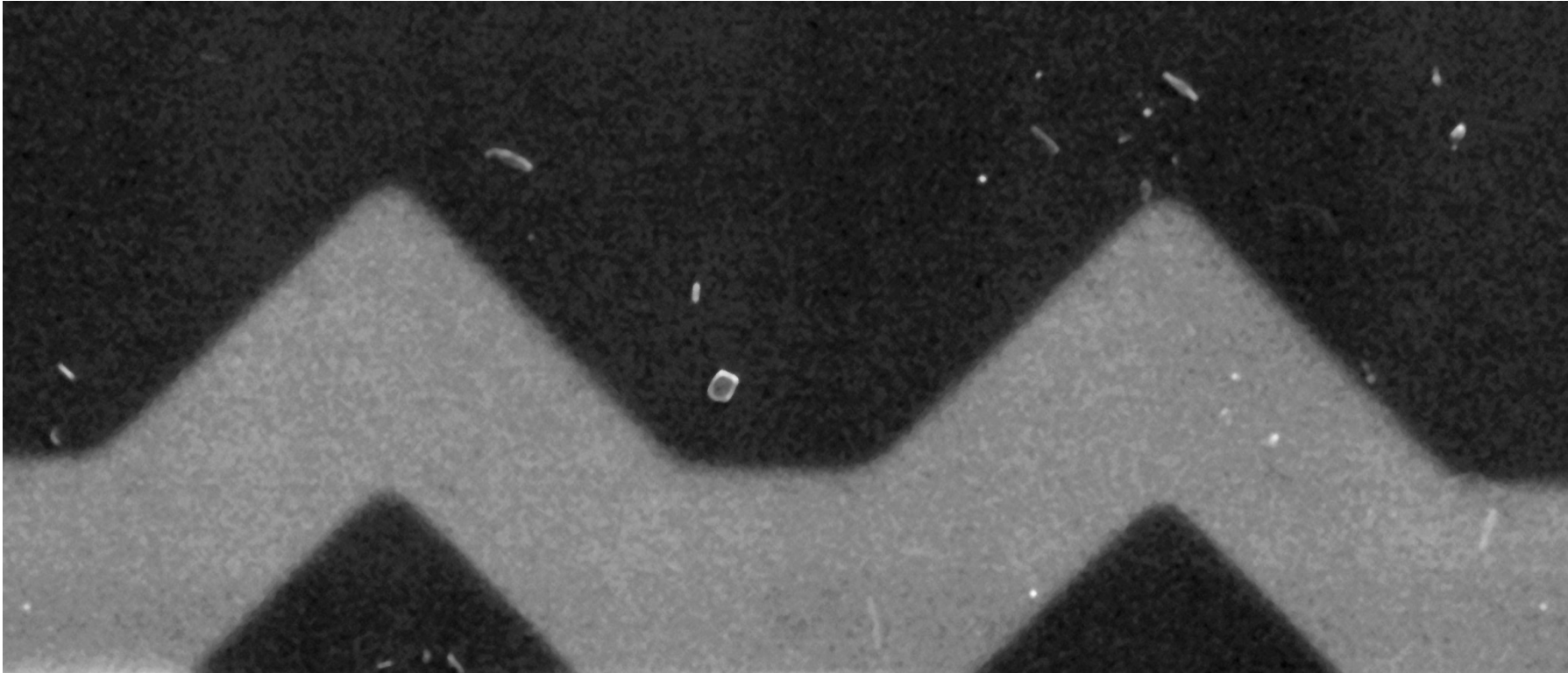
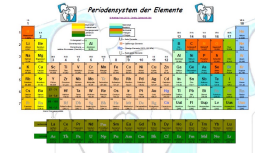
<https://i.weltbild.de/p/nagelbild-pin-art-071799810.jpg?tr=tr%3An-maxsize&iv=26>

# Atomic number and SE-yield





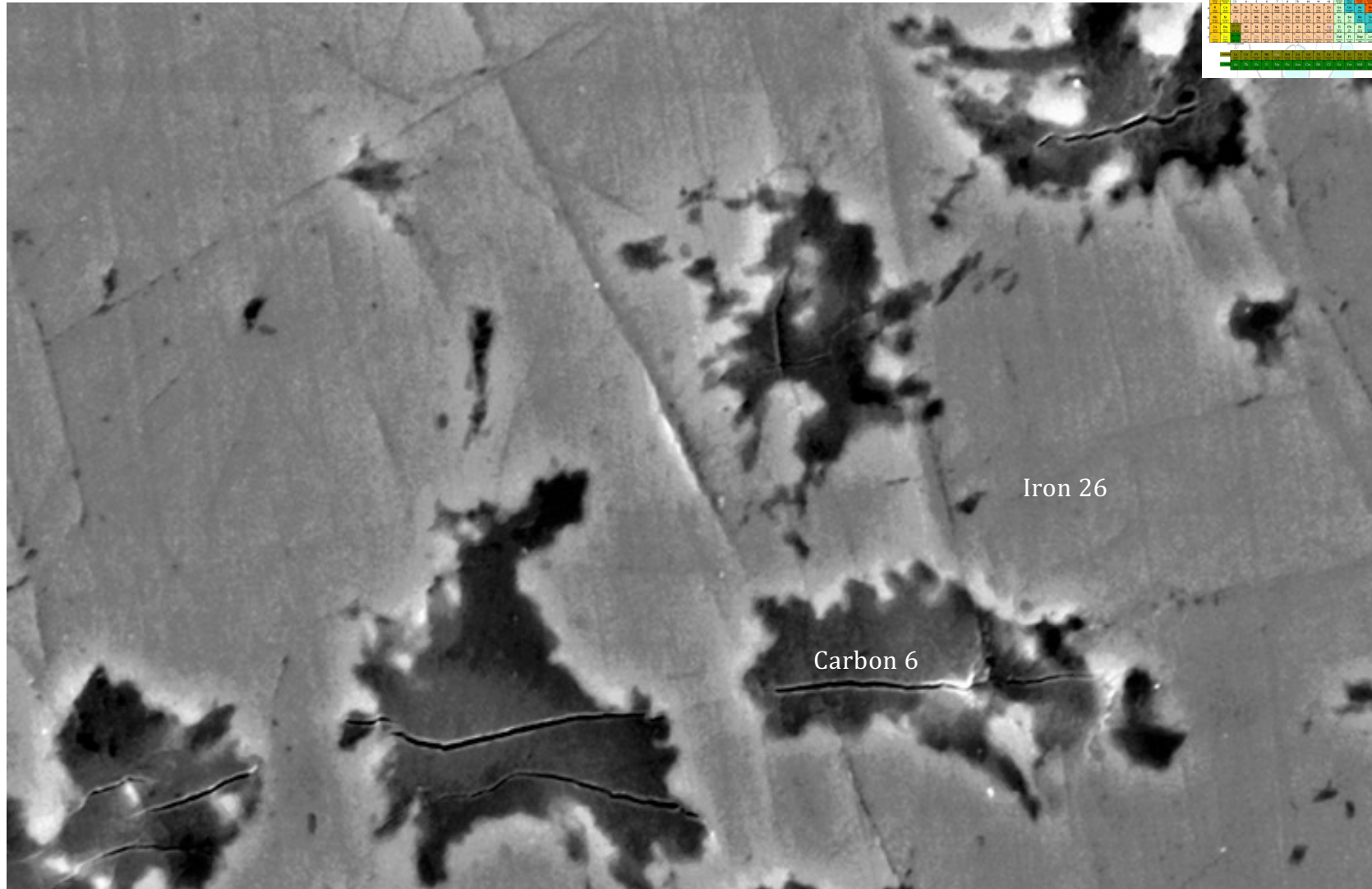
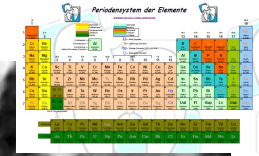
# Material contrast



SE-image (8 kV) smooth surface of a semiconductor

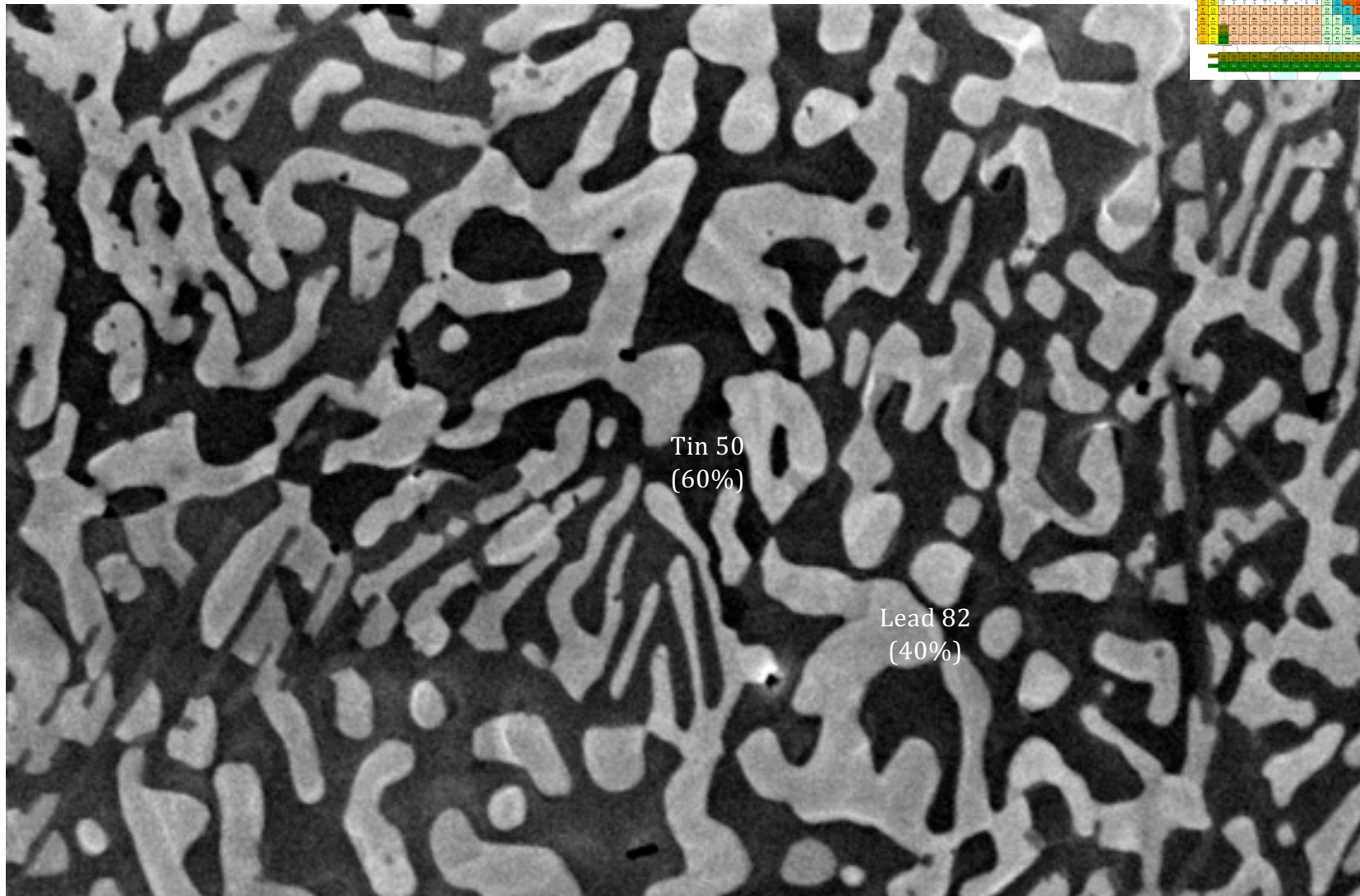
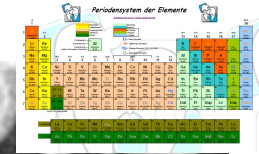


# Material contrast



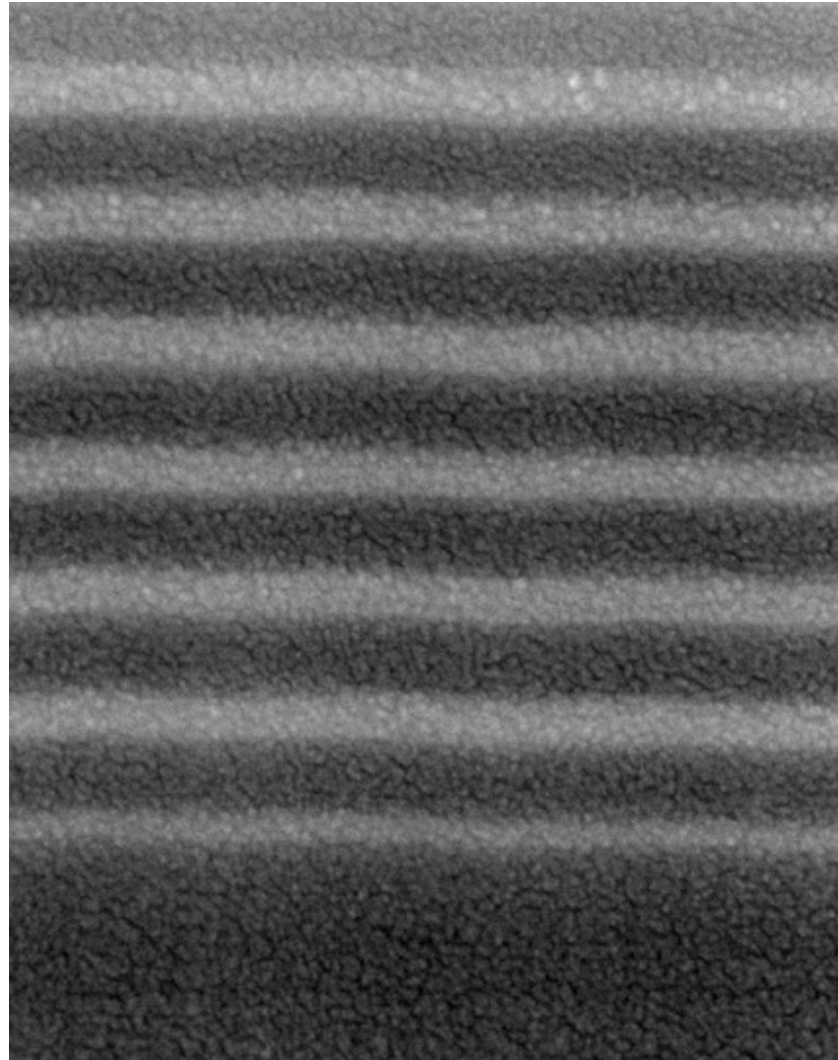
SE-image (10 kV) smooth surface of an old kitchen knife

# Material contrast



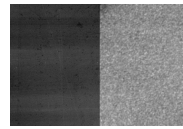
SE-image (8 kV) smooth surface of tin-solder/brazing solder

## Material contrast



SE-image (20 kV) fracture surface from glass with blooming in a layer sequence

# Material contrast or „micro roughness“



2 different materials?

