Corrections for charge of secondary electrons, i.e. photoelectrons, Compton electrons and Auger electrons, during absolute measurement of air kerma and exposure by free air ionization chambers

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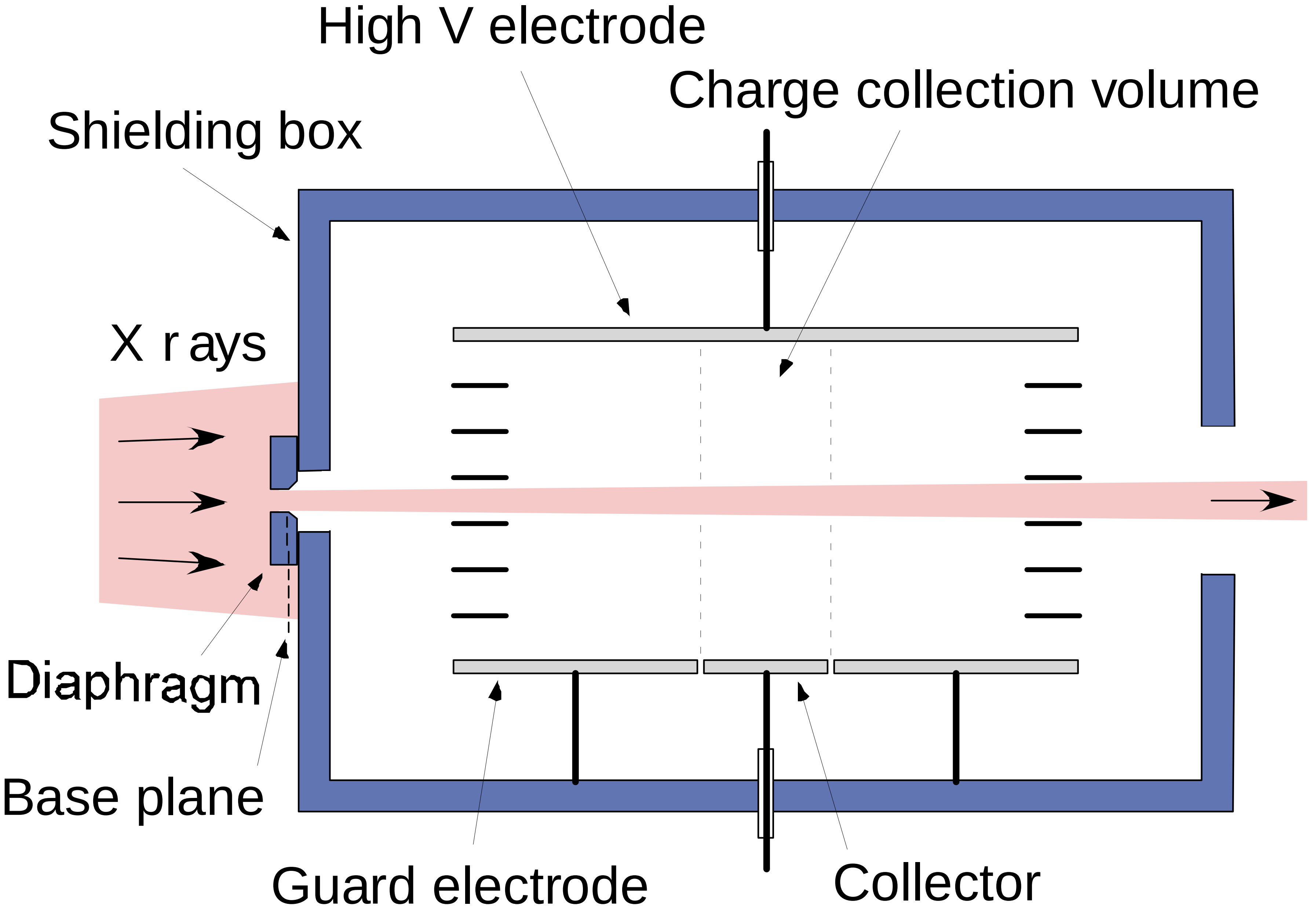
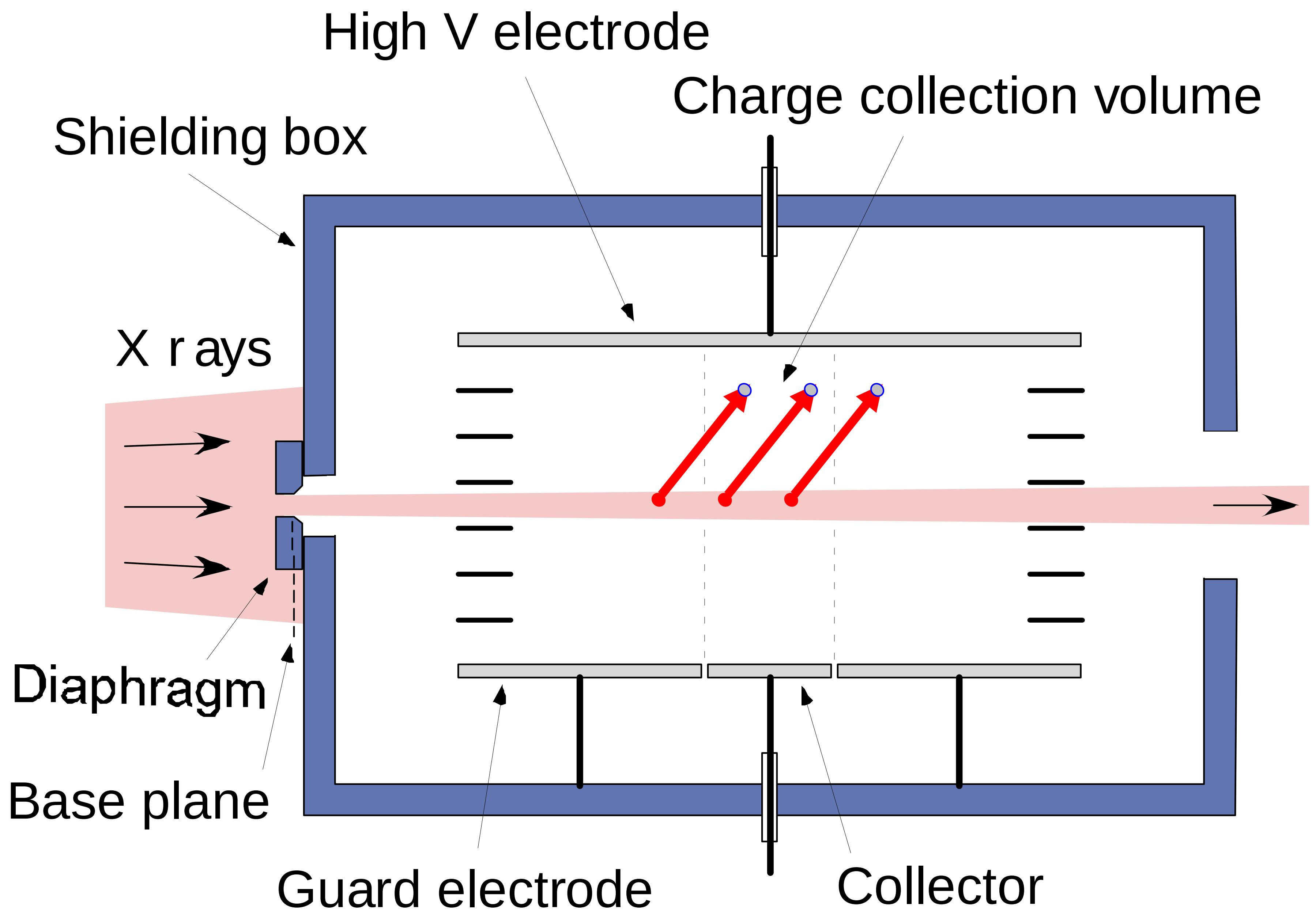
$$K_{\mathrm{air}} = \frac{\mathrm{d}E}{\mathrm{d}m} = \frac{X\,(W / e)}{1 - g}$$

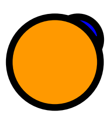
$$X = \frac{Q}{m}\Pi k_{\mathrm{i}}$$

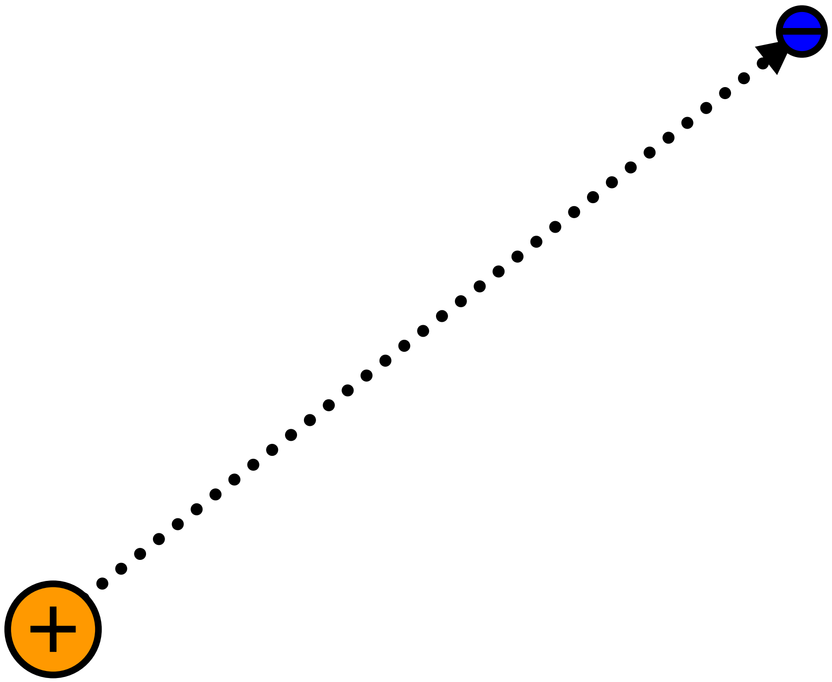
$$K_{\mathrm{air}} = \frac{Q(W / e)}{m(1 - g)}\Pi k_{\mathrm{i}}$$

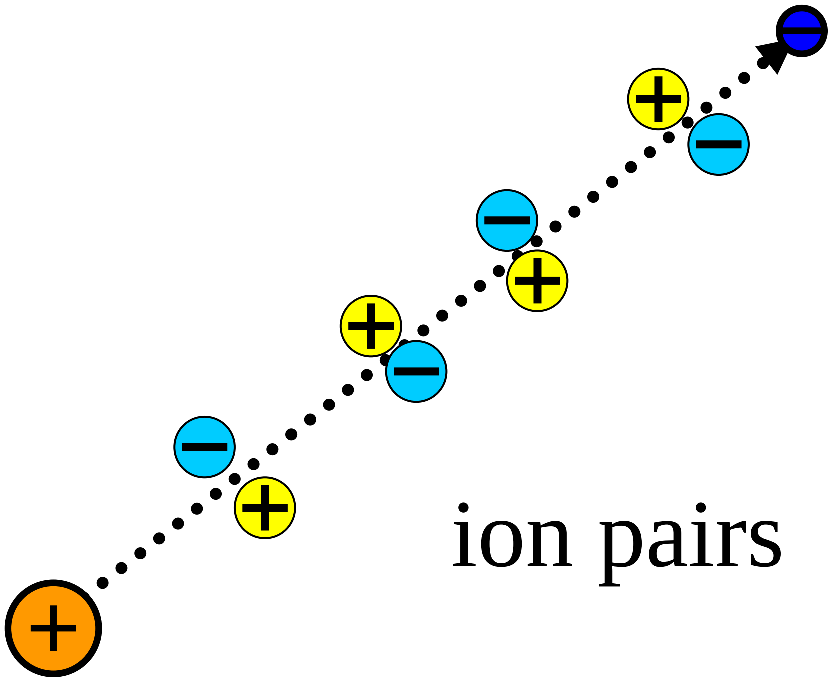

High V electrode
Charge collection volume
Shielding box
X rays
Diaphragm
Base plane
Guard electrode
Collector

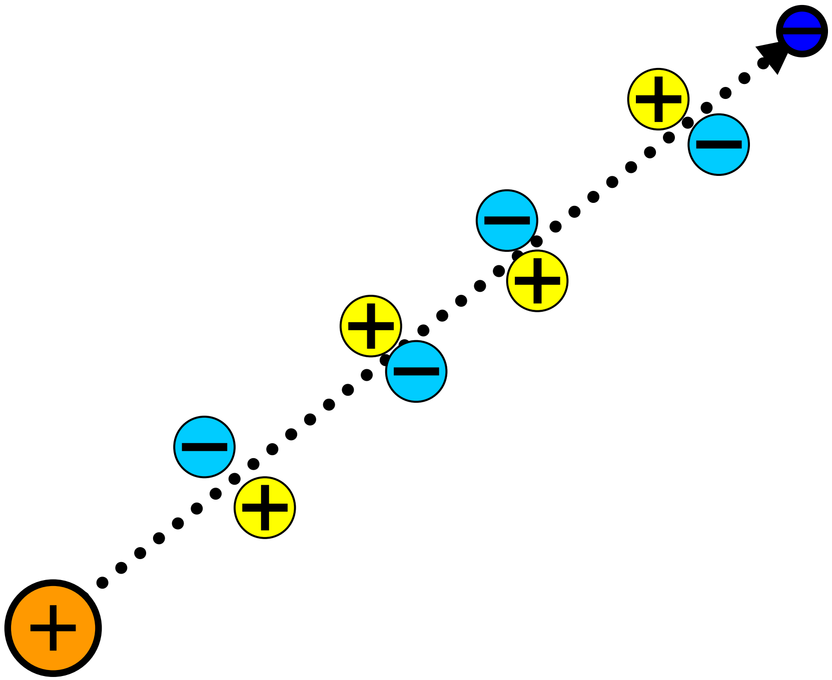


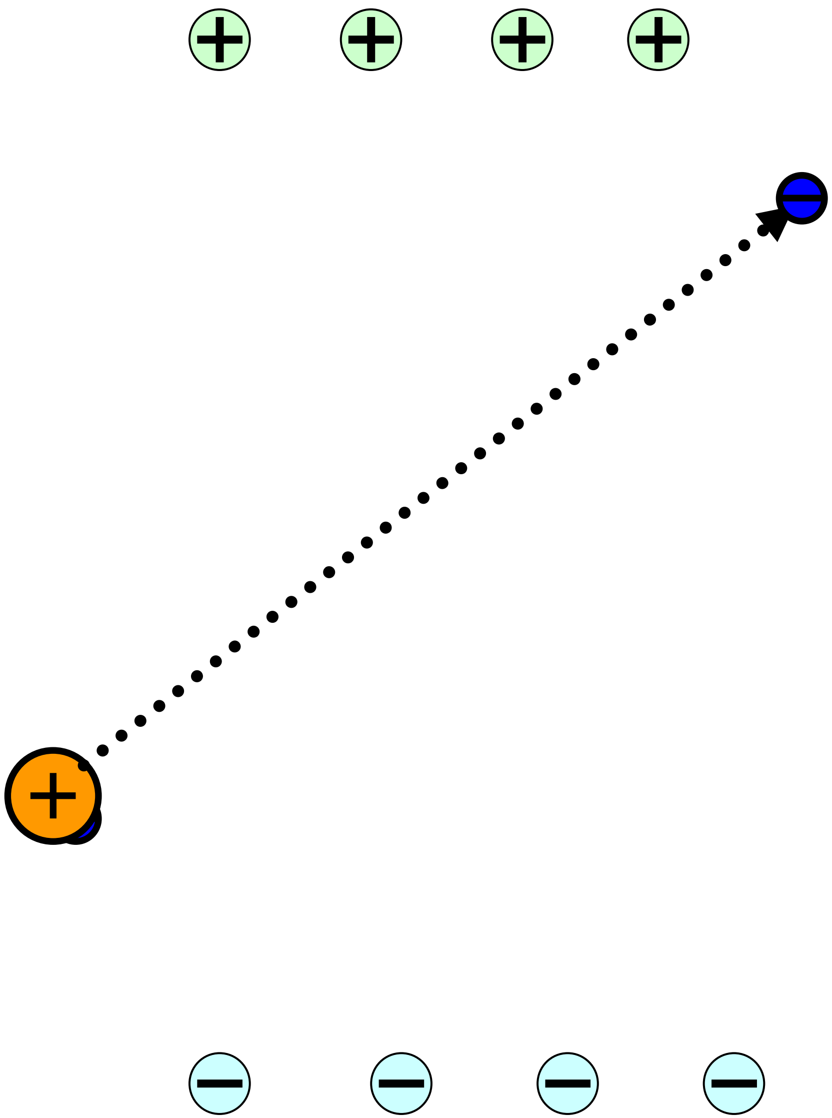
High V electrode
Charge collection volume
Shielding box
X rays
Diaphragm
Base plane
Guard electrode
Collector

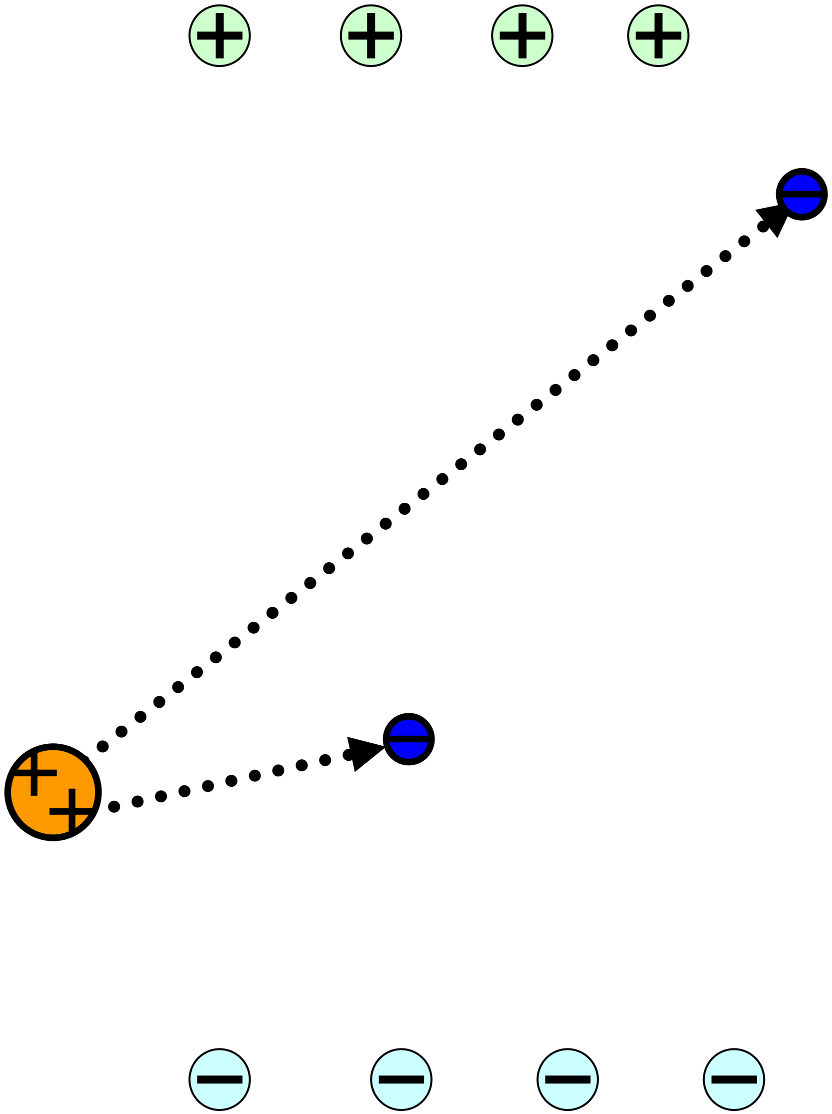


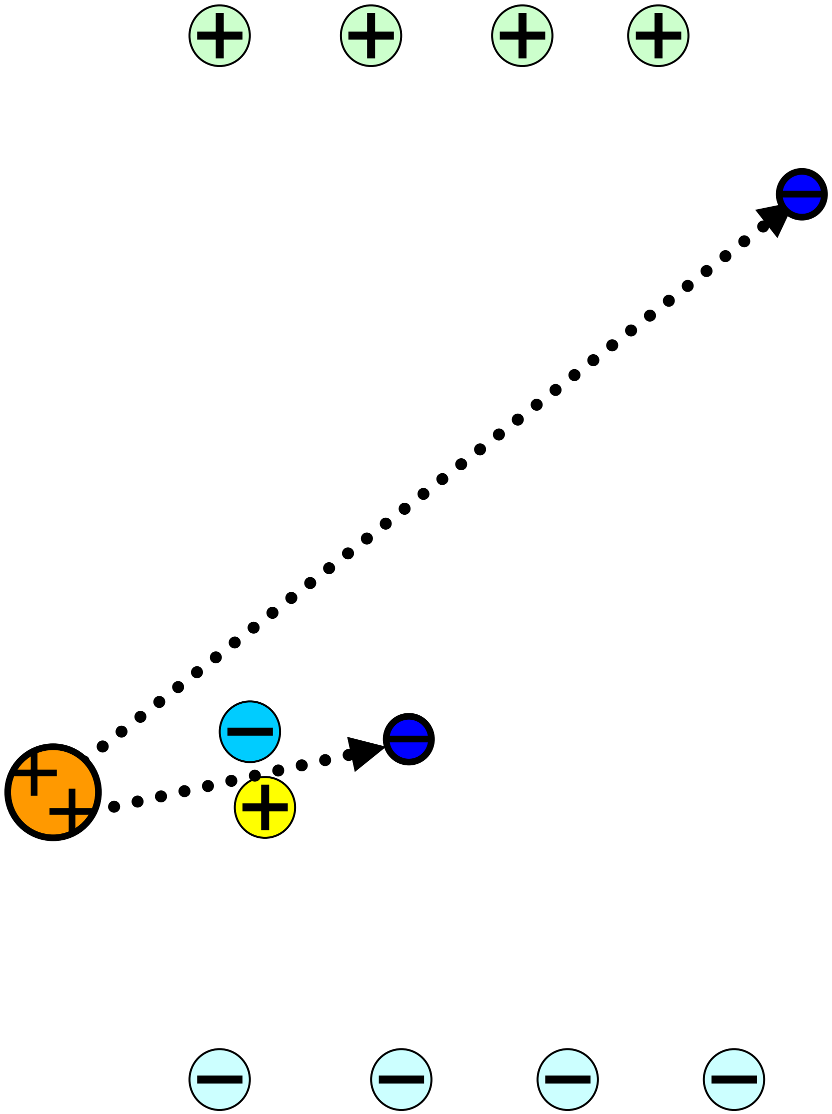


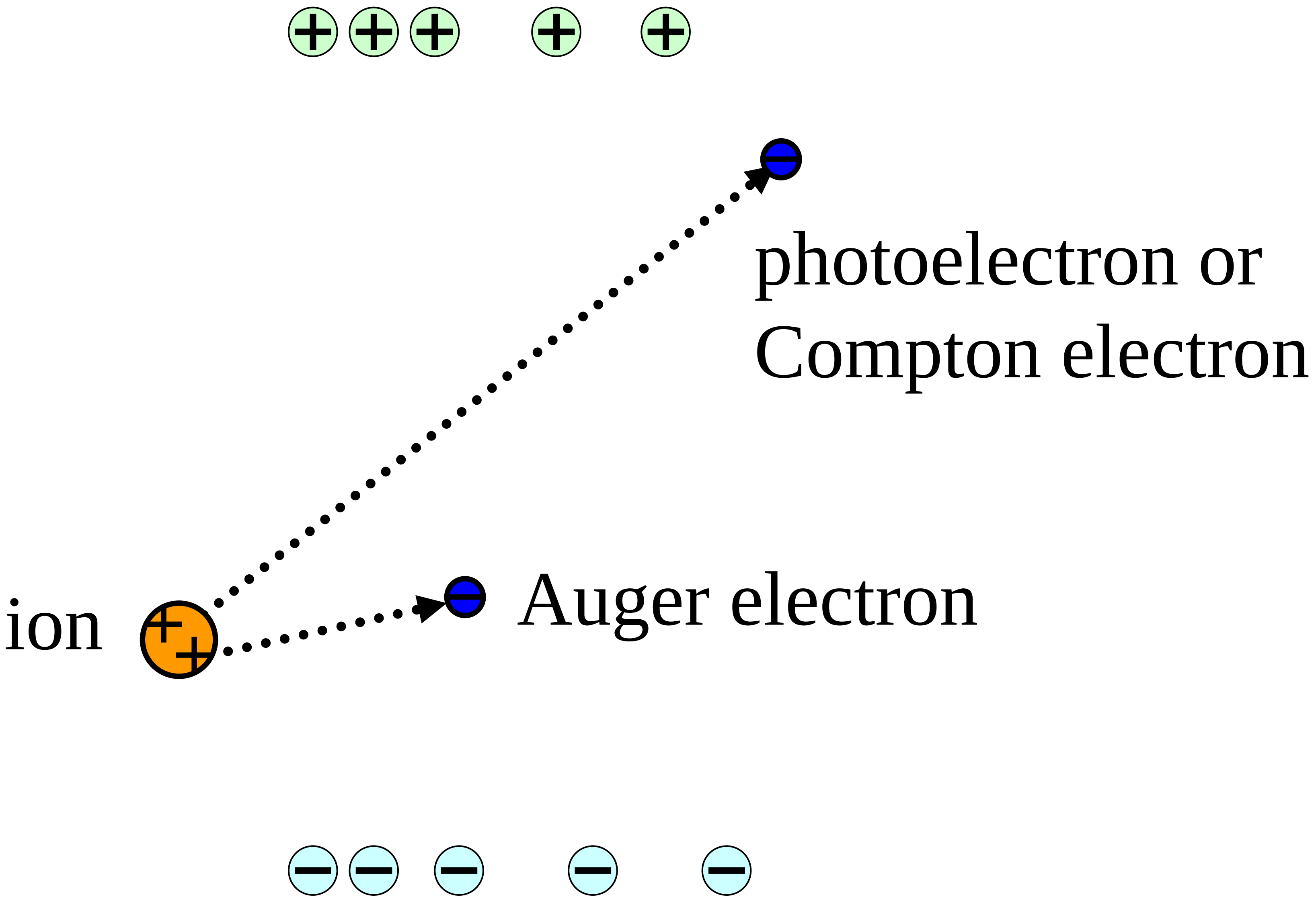

ion pairs

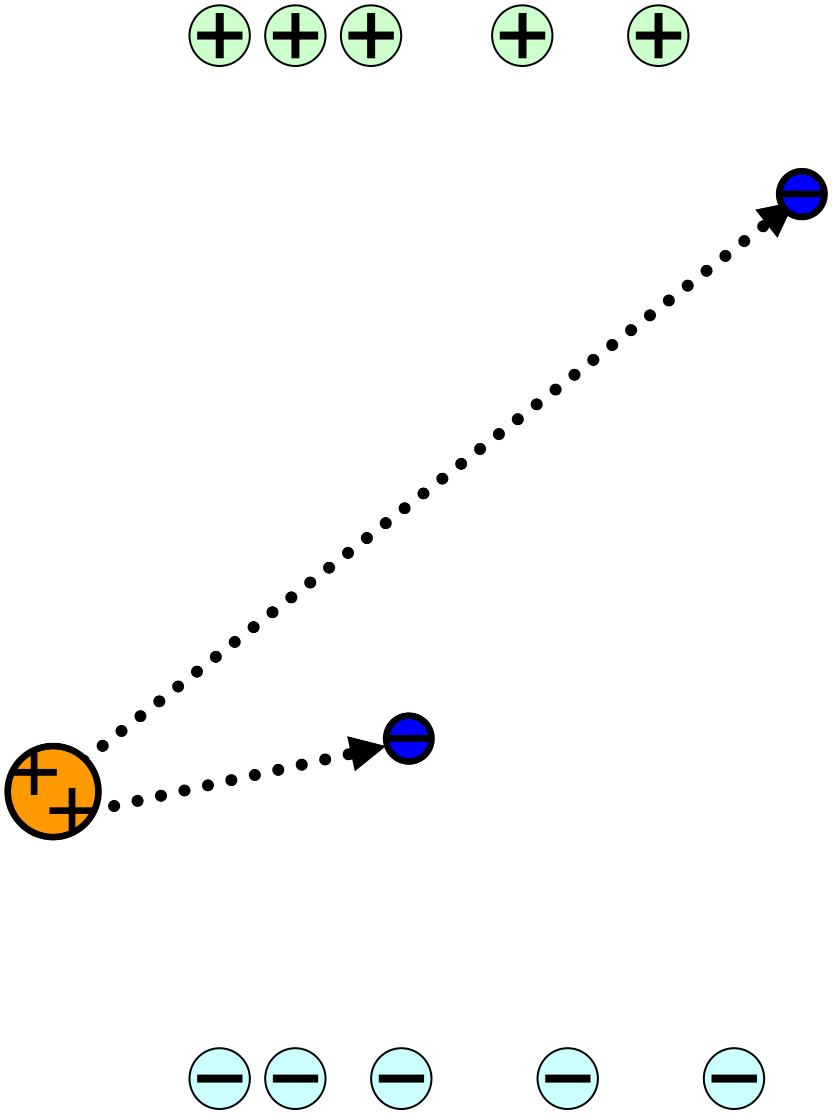


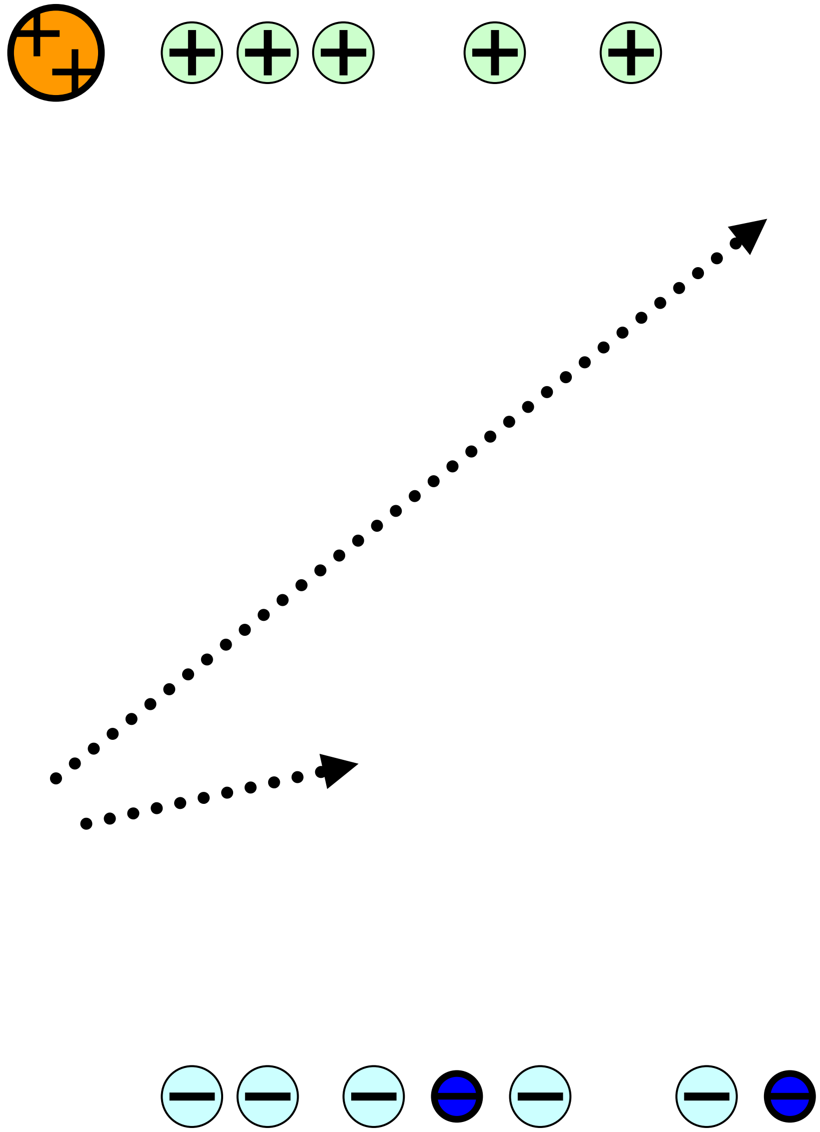


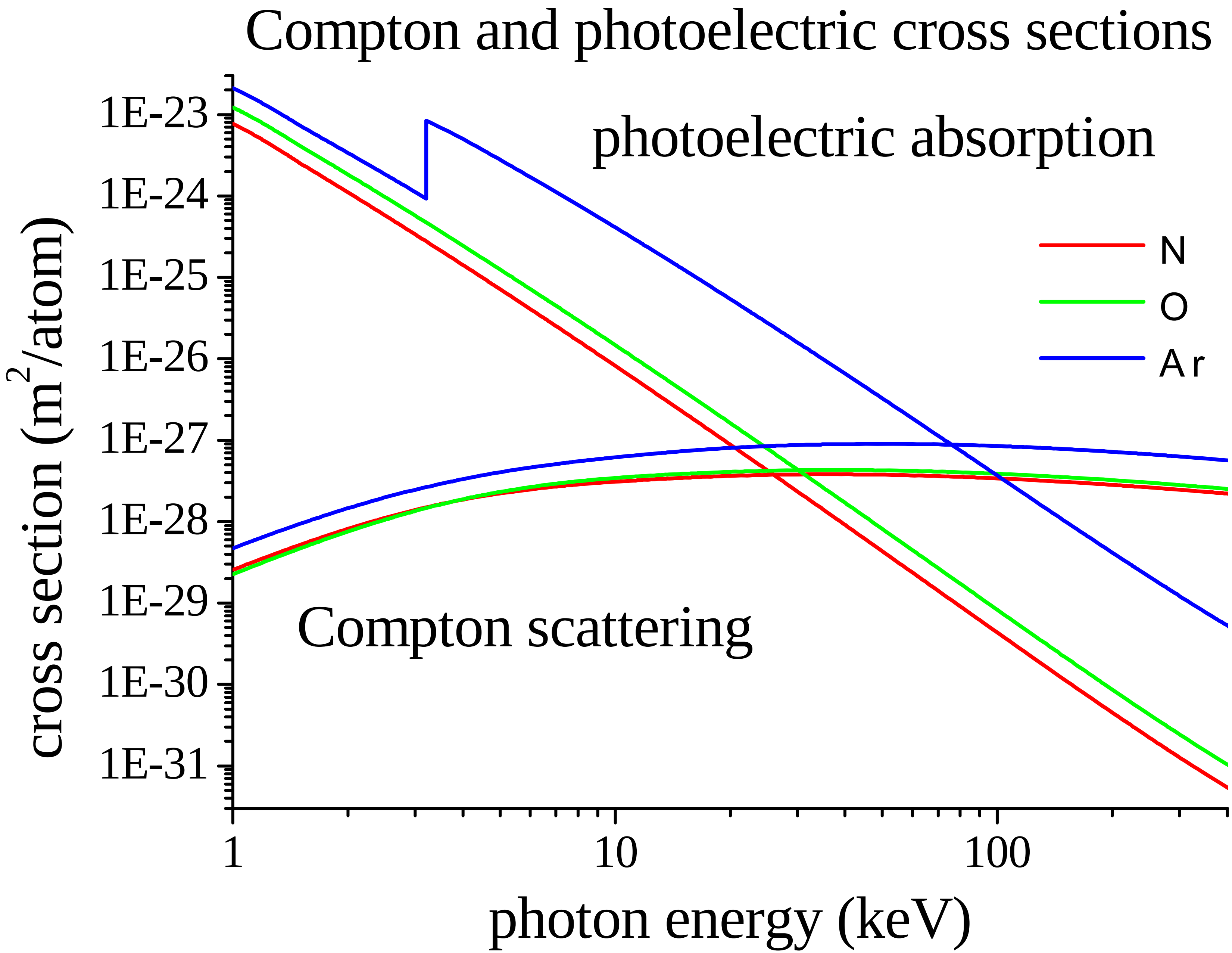


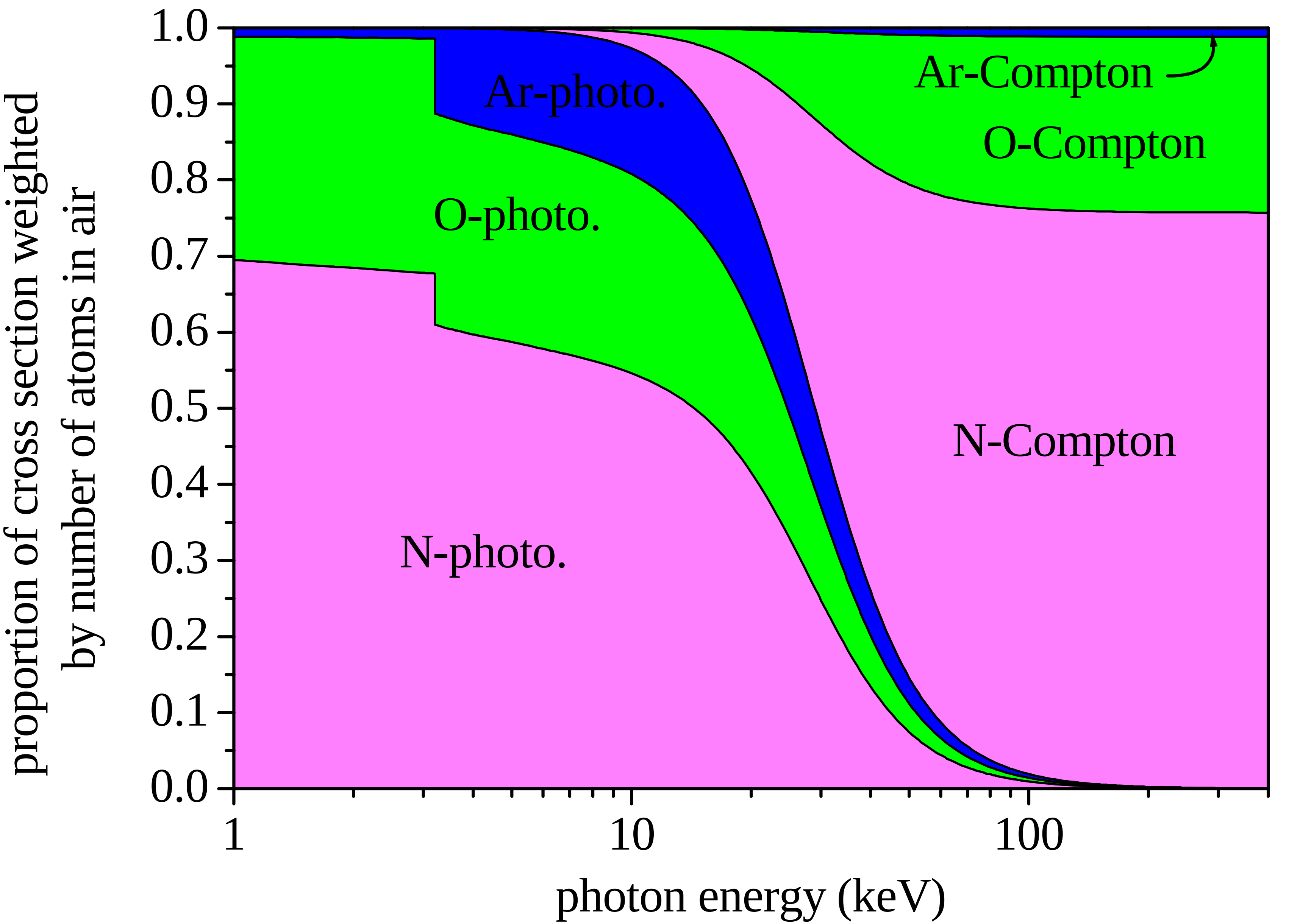



photoelectron or
Compton electron
Auger electron
ion

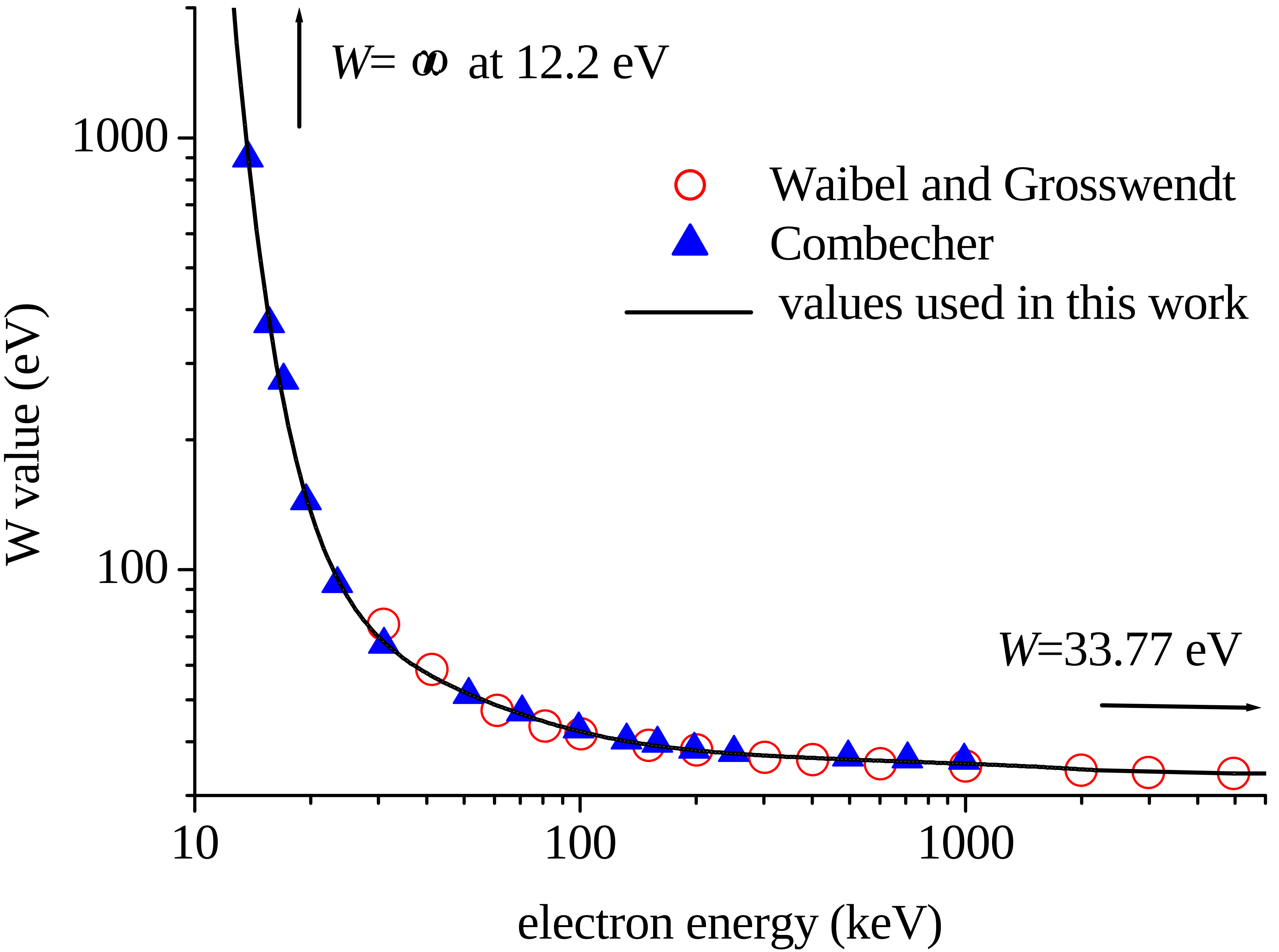





Compton and photoelectric cross sections
photoelectric absorption
Compton scattering
N
O
Ar
cross section (m^2/atom)
photon energy (keV)
1E-23
1E-24
1E-25
1E-26
1E-27
1E-28
1E-29
1E-30
1E-31
1
10
100



proportion of cross section weighted
by number of atoms in air
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
10
100
photon energy (keV)
Ar-photo.
O-photo.
N-photo.
Ar-Compton
O-Compton
N-Compton



W= ∞ at 12.2 eV
1000
100
Waibel and Grosswendt
Combecher
values used in this work
W value (eV)
W=33.77 eV
10
100
1000
electron energy (keV)

Photoelectron energy

= $h\nu$ - binding energy

Compton electron energy

= T - binding energy

Auger electron energy

= bind. energy1

– bind. energy2 – bind. energy3

Compton scattering cross section σ to transfer energy T to electrons

$$\frac{\mathrm{d_e}\sigma}{\mathrm{d}T} = \frac{\pi r_0^2}{\alpha^2 m_0 c^2}\left\{2 + \left(\frac{T}{h\nu - T}\right)^2\left[\frac{1}{\alpha^2} + \frac{h\nu - T}{h\nu} - \frac{2}{\alpha}\left(\frac{h\nu - T}{T}\right)\right]\right\}$$

$$T_{\max} = h\nu/(1 + 1/2\alpha)$$

$$\alpha = h\nu/(m_0 c^2)$$

$$r_0 = e^2/(m_0 c^2)$$

$m_0 c^2$: the electron rest mass energy

Binding energies of atomic shell (in eV)

Atomic species	K	L_1	$L_{2,3}$	M
N	409.9	37.3	14.5	
O	543.1	41.6	13.6	
Ar	3205.9	326.3	249.1	19.2

Average charge states after de-excitation of inner shell vacancy of atoms (+)

atomic species	K	L_1	$L_{2,3}$	M
N	2.00 (2.20)	1.00	1.00	
O	2.00 (2.20)	1.00	1.00	
Ar	4.20	3.00	2.00	1.00

K-shell vacancy of N and O atoms

Average charge state = 2+

$K\text{-}L_{2,3}L_{2,3}$ (2+)

Average charge state = 2.2+

20%: $K\text{-}L_1L_{2,3} \rightarrow L_1\text{-}L_{2,3}L_{2,3}$ (3+)

80%: $K\text{-}L_{2,3}L_{2,3}$ (2+)

Vacancies of Ar atoms

$L_{2,3}$: Average charge state = 2+

$L_{2,3}$-M,M (2+)

L_1: Average charge state = 3+

L_1-$L_{2,3}$ M → $L_{2,3}$-MM (3+)

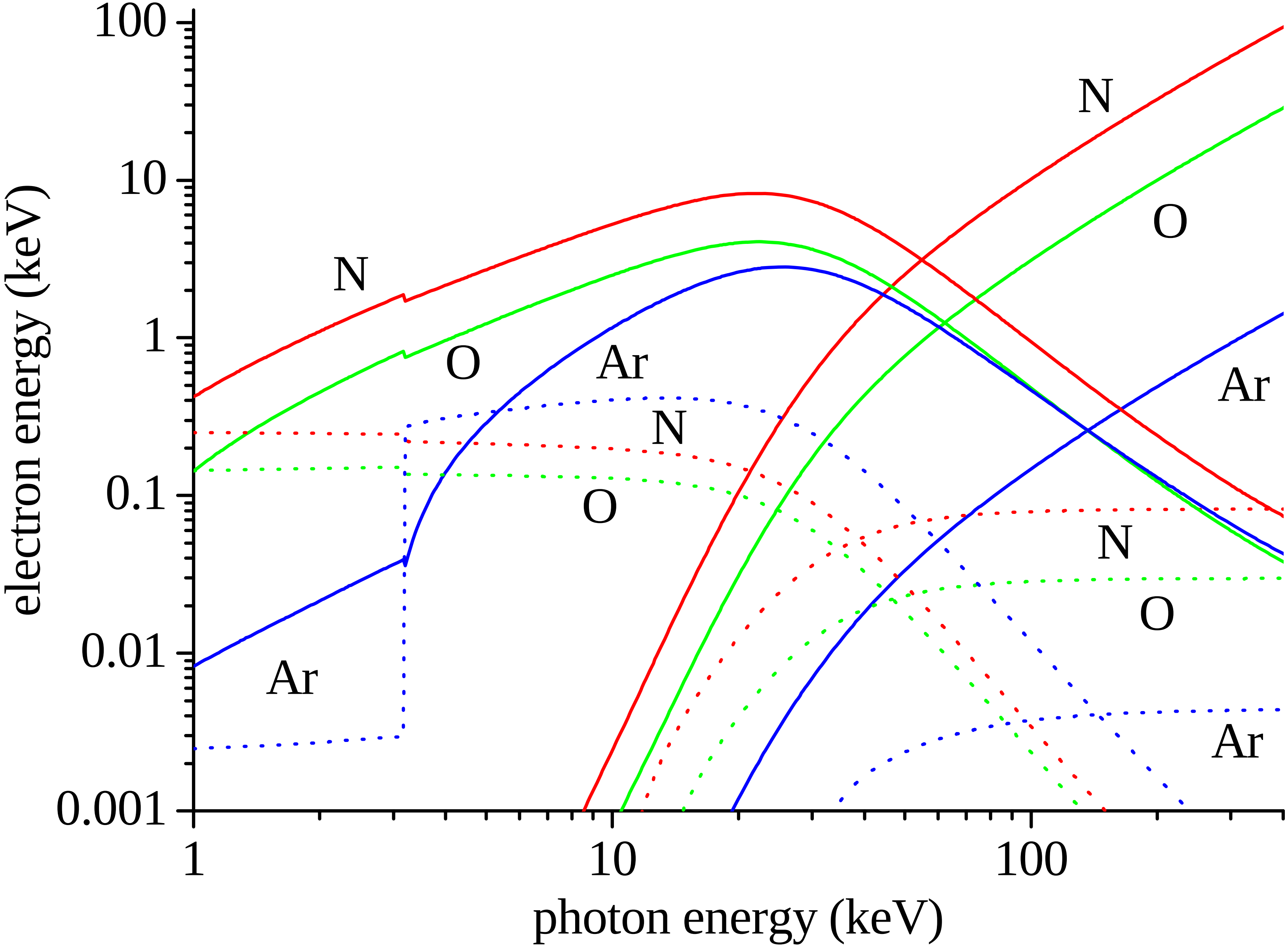
K: Average charge state = 4.2+

12%: K_α x ray → $L_{2,3}$-MM (2+)

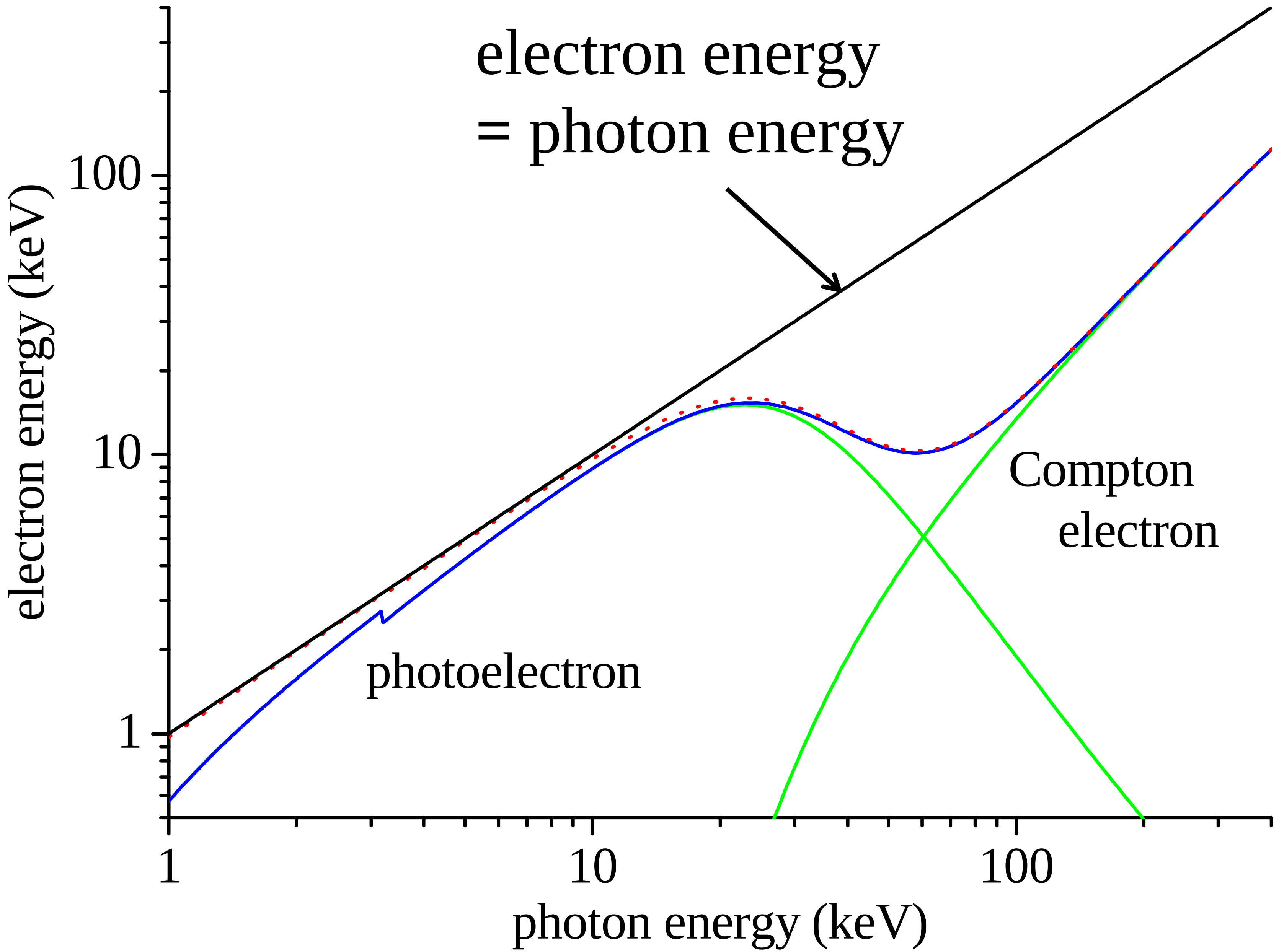
34%: K-$L_{2,3}L_{2,3}$ → 2$L_{2,3}$-MM (4+)

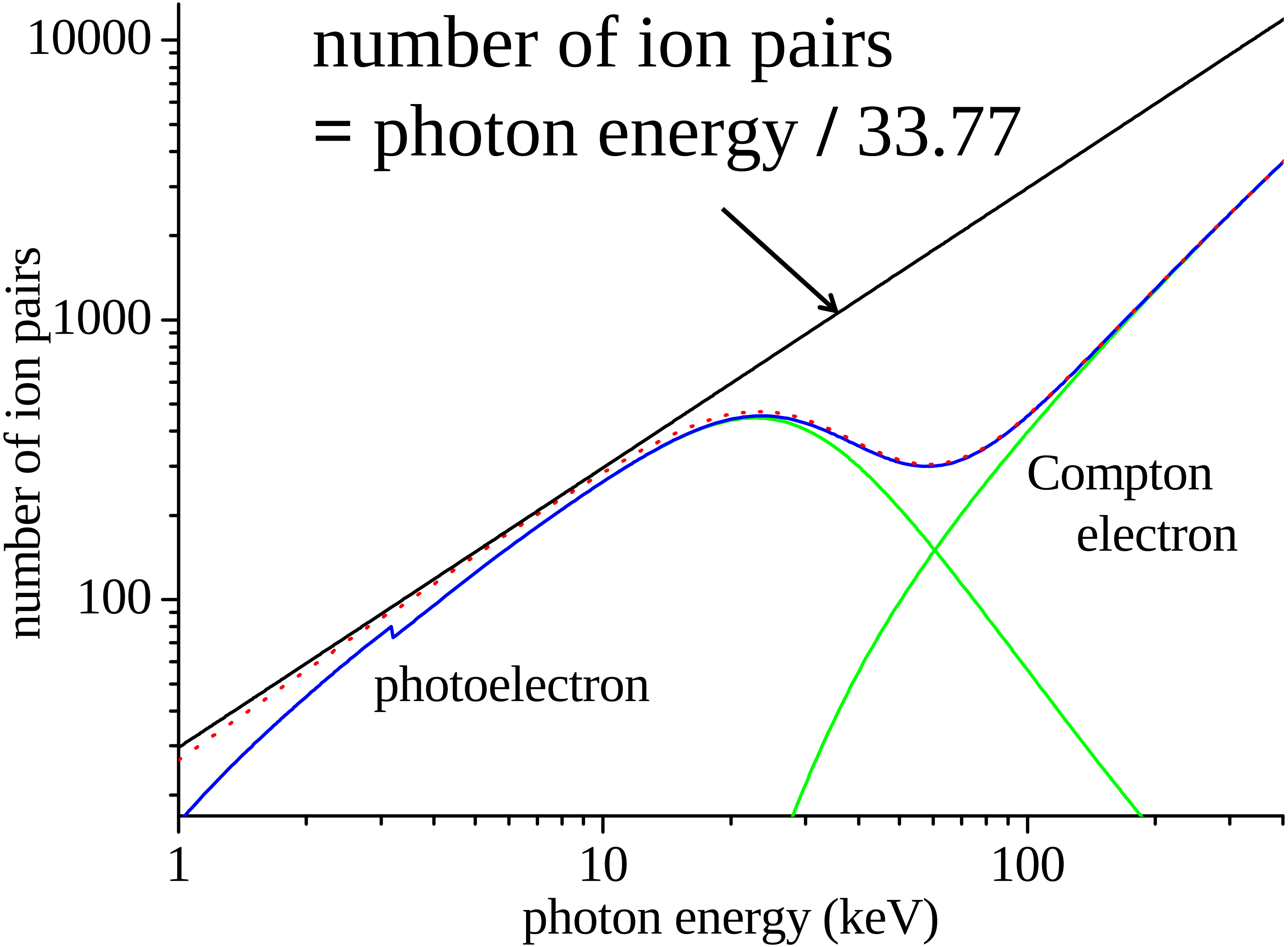
54%: K-$L_1L_{2,3}$ → L_1-$L_{2,3}$ M → $L_{2,3}$-MM

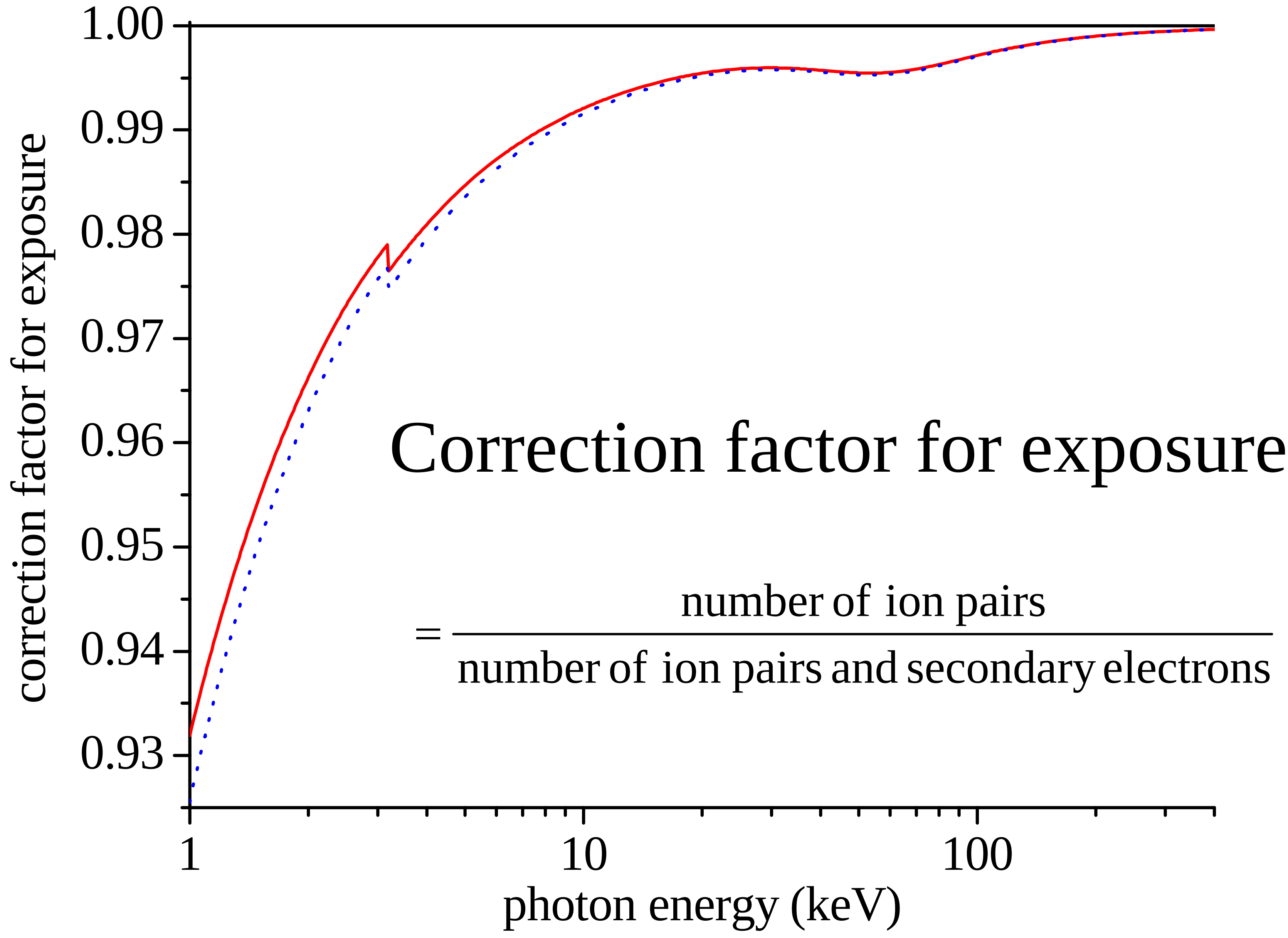
→ $L_{2,3}$-MM (5+)

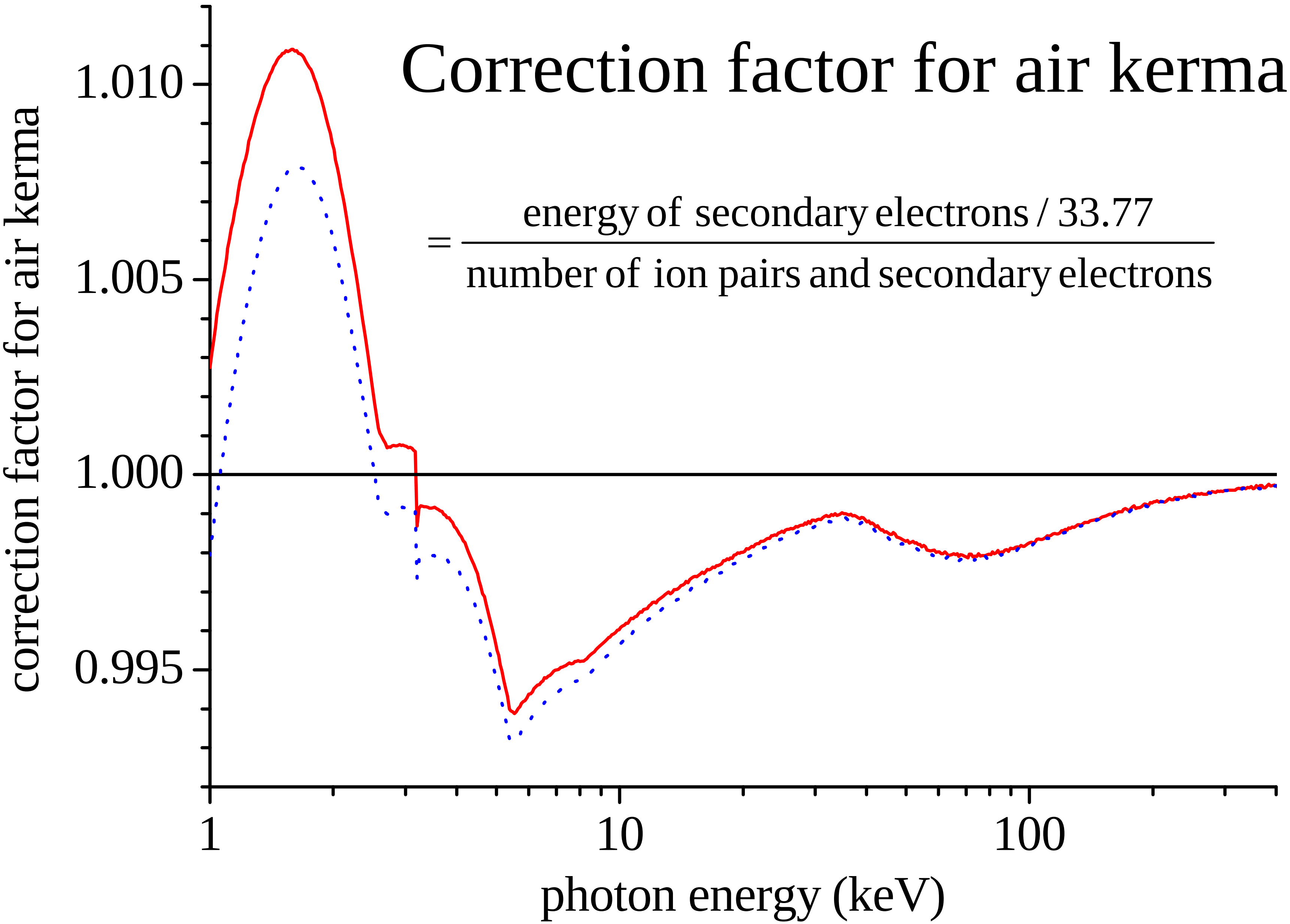


100
10
1
0.1
0.01
0.001
electron energy (keV)
1
10
100
photon energy (keV)
N
O
Ar
N
O
N
O
Ar
N
O
Ar
Ar

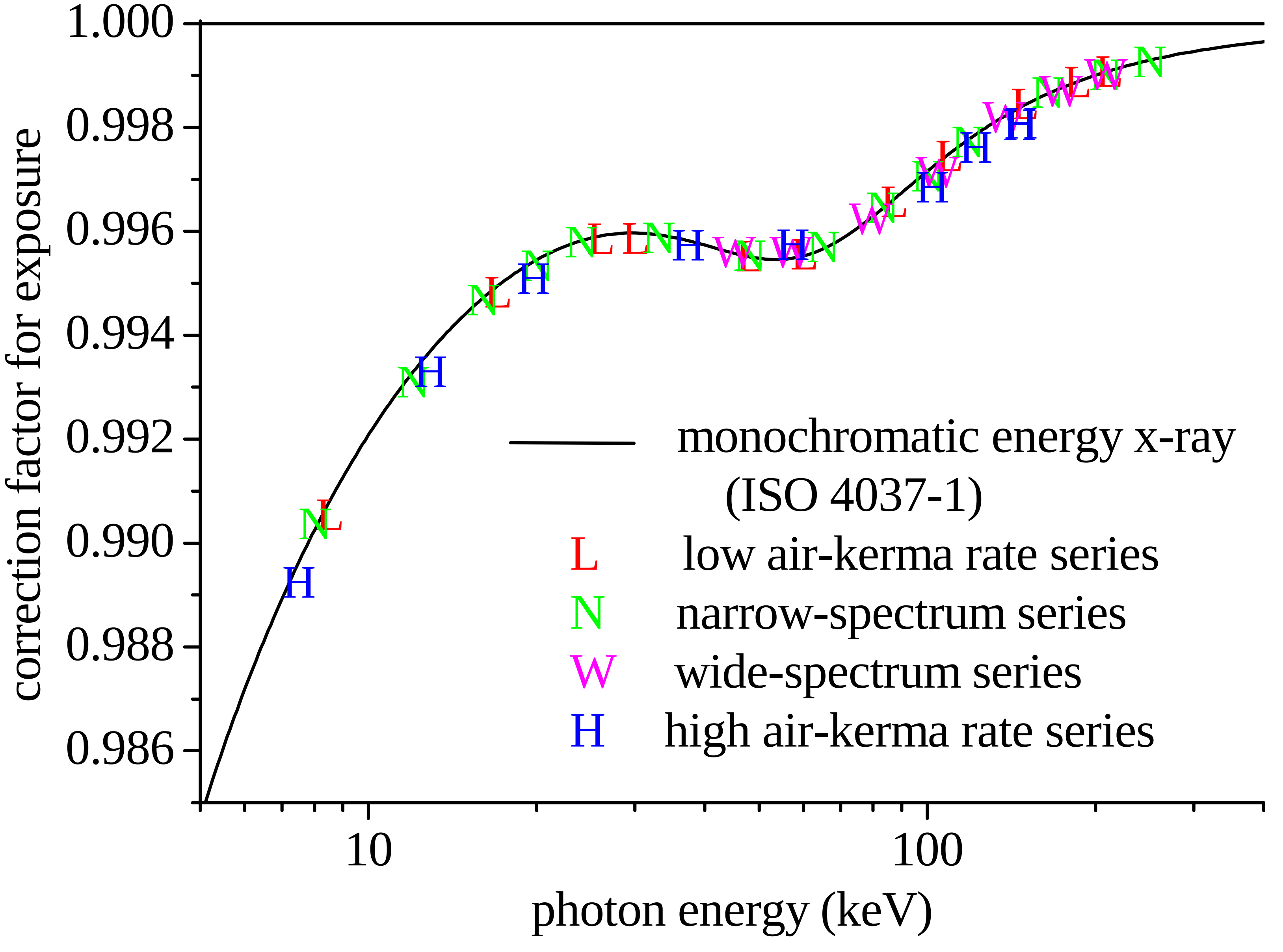

electron energy
= photon energy
Compton
electron
photoelectron
100
10
1
1
10
100
electron energy (keV)
photon energy (keV)


number of ion pairs
= photon energy / 33.77
Compton
electron
photoelectron
10000
1000
100
number of ion pairs
1
10
100
photon energy (keV)

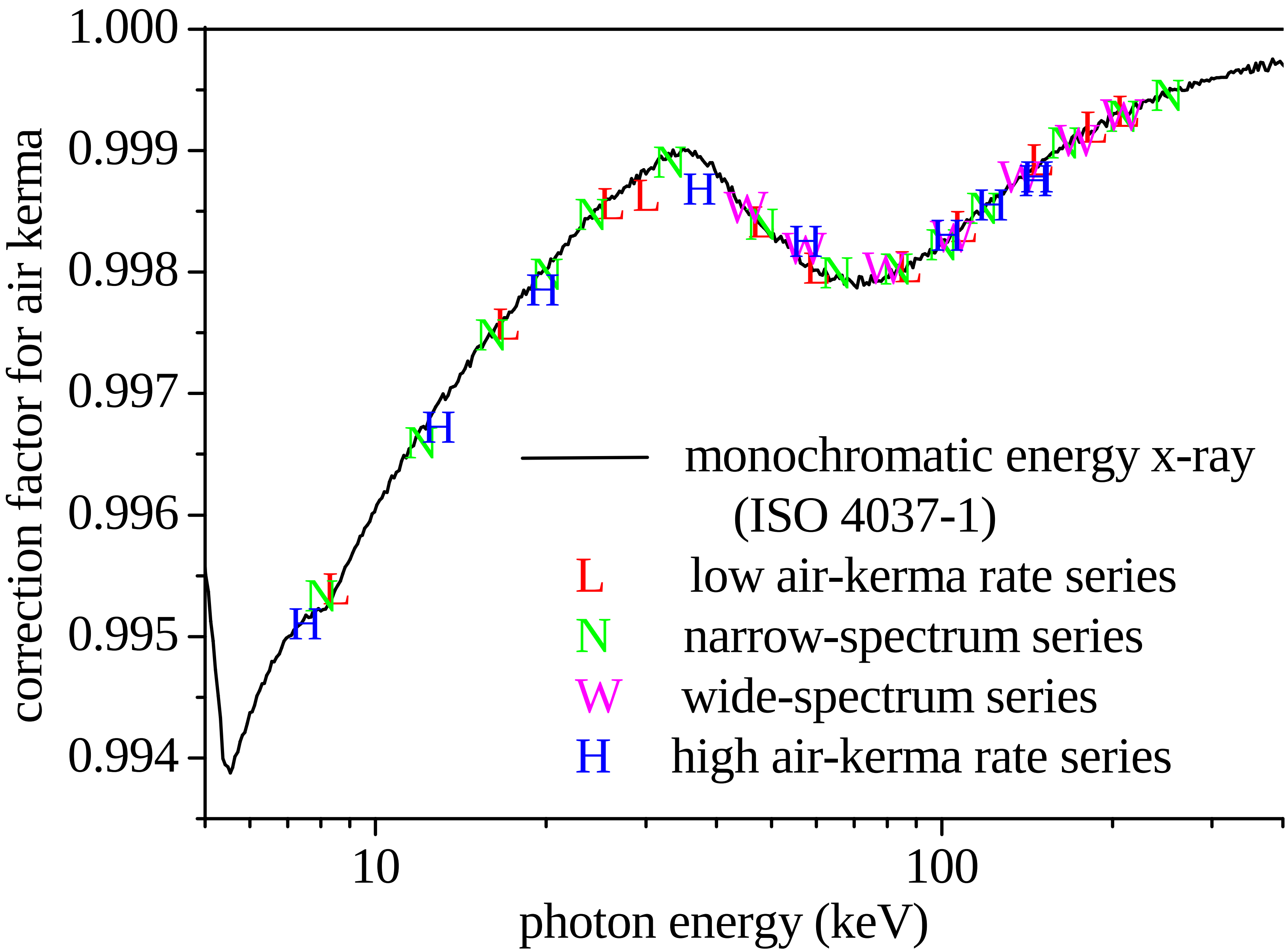

1.00
0.99
0.98
0.97
0.96
0.95
0.94
0.93
correction factor for exposure
1
10
100
photon energy (keV)
Correction factor for exposure
= number of ion pairs / number of ion pairs and secondary electrons



Correction factor for air kerma
= energy of secondary electrons / 33.77 / number of ion pairs and secondary electrons
correction factor for air kerma
1.010
1.005
1.000
0.995
1
10
100
photon energy (keV)



1.000
0.998
0.996
0.994
0.992
0.990
0.988
0.986
correction factor for exposure
10
100
photon energy (keV)
monochromatic energy x-ray
(ISO 4037-1)
L low air-kerma rate series
N narrow-spectrum series
W wide-spectrum series
H high air-kerma rate series


1.000
0.999
0.998
0.997
0.996
0.995
0.994
correction factor for air kerma
10
100
photon energy (keV)
monochromatic energy x-ray (ISO 4037-1)
L low air-kerma rate series
N narrow-spectrum series
W wide-spectrum series
H high air-kerma rate series

Conclusion

(1) Correction factors for air kerma and exposure for the charge of secondary electrons were obtained.

(2) We are lucky because correction is smaller for air kerma than for exposure.

(3) Nevertheless, an international agreement should be made regarding the values of the correction factors because the values are universal and independent of the type and size of free-air ionization chambers.

Thank you for attension